Joint Defra / Environment Agency Flood and Coastal Erosion Risk Management R&D Programme

Saltmarsh management manual

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Environment Agency

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Science at the Environment Agency

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- **Carrying out science**, by undertaking research – either by contracting it out to research organisations and consultancies or by doing it ourselves;
- **Delivering information, advice, tools and techniques**, by making appropriate products available to our policy and operations staff.

Steve Killeen
Head of Science

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1 Introduction

1.1 Purpose of the Manual

Saltmarsh has a value that is related to its flood and coastal defence function and ecosystem and conservation importance, as well as its role in pollution control, waste disposal and the maintenance of water quality, fisheries, agriculture, recreation and tourism. This value is based on the interaction of its basic components (soil, water, flora and fauna), their physical shape (including channels and saltmarsh surfaces) and the assemblage of plants and animals they hold. It is, therefore, important to develop an understanding of both the requirements of saltmarsh and when and how to intervene to manage it.

In the context of the wider estuary environment, saltmarsh maintenance, restoration or enhancement is increasingly being considered as a means of managing flood risk. It also has the advantage of enhancing the conservation importance of a ‘natural’ as well as a frequently designated, priority and Biodiversity Action Plan habitat.

Lapwing (*Vanellus vanellus*) © Chris Gibson, English Nature

The Saltmarsh Management Manual describes what it is that needs to be managed and aims to help develop an understanding of how to evaluate the need for management intervention and the form that intervention might take. The Manual includes details of a number of techniques that can be applied for maintaining, restoring, enhancing or creating saltmarsh. The focus of the Manual is on managing existing saltmarsh environments. Although creation is not strictly related to the management of ‘existing’ saltmarsh, it is also considered because it represents an important option for the future management of the coast/estuaries and a lot of information pertinent to the creation of a new habitat can apply to the restoration or enhancement of an existing resource that is declining.

Guidance is provided in this Manual on determining the most appropriate option and/or technique for saltmarsh management based on the requirements of the site in question.

That is, the Manual is aimed at assisting coastal and estuarine managers in the identification of the problems that a saltmarsh may have (if any) and the determination of an appropriate management response (i.e. the selection of a solution or range of potential solutions).

As a general rule, management will not be required where the saltmarsh remains in a constant, healthy, functioning state and, consequently, can respond to change (such as sea level rise) and adapt to most physical changes. Conversely, if change is particularly rapid, the saltmarsh is becoming degraded (including becoming more juvenile in its plant assemblages) or is physically eroding, then a programme of remedial work is more likely to be required. Saltmarshes can degenerate for a number of reasons, including sea level rise, changes in drainage patterns, disruption to the estuarine processes and changes in land use on or adjacent to the marsh. Saltmarshes also go through natural cycles of development and decline as an ephemeral feature on many coastlines over the long term.

To determine the best approach to management, it is important to understand why such change is occurring and to identify those changes that are the result of a local impact and those where it is part of a wider scale of change. This, in turn, will influence the choice of the most appropriate management technique (if management is appropriate at all); by identifying the nature of the problem the solution is more likely to present itself.

1.2 Project objectives

This ‘2005’ version of the Saltmarsh Management Manual has been developed from and updates the Saltmarsh Management Guide produced in 1995 by the (then) National Rivers Authority (NRA). The project was funded by the Defra / Environment Agency Joint Flood and Coastal Erosion Risk Management R&D Programme (as project SCO30220 under the Engineering Theme). Under this programme, the objectives for the project were

1. To synthesise advances in underlying science and good practice, and produce an updated Saltmarsh Management Manual, based on a thorough revision of the NRA/Environment Agency’s existing Saltmarsh Management Guide, and taking account of current knowledge and experience as well as recent research.
2. To encourage the dissemination of the Manual and the uptake of its recommendations by making the Manual available online in electronic format.

The key tasks in achieving these objectives were defined by Defra and the Agency as being:

Task 1 Review the structure and content of the original Saltmarsh Management Guide, as well as the additional chapters appended to the original Guide.

Task 2 Review recent experience in saltmarsh management and advances in scientific understanding or management practice since the publication of the original Guide.

Task 3 Establish a revised structure for the updated Saltmarsh Management Manual (including consideration of an alternative ‘interactive document’ format) and prepare a contents list.

Task 4 Edit and update the original Manual content and incorporate new sections, as appropriate.

Task 5 Prepare an updated Saltmarsh Management Manual.

Task 6 Publish a final version in an electronic format.

The original Manual was created from a series of papers reflecting the topics addressed through a co-ordinated and considered National (Saltmarsh) R&D programme. The original papers were supplemented by further work and re-issued in 2001. Following a review of the original Manual by the Environment Agency, it was determined that it needed to be updated in some areas and, more importantly, drawn together as a more coherent and structured guidance document.

Another important issue identified by the review was the need to improve the ease of use of / navigation through the information in the Manual, and hence access to it, through restructuring and electronic dissemination of the output.

1.3 Structure of the manual

The Manual is structured to firstly help the reader develop a general understanding of saltmarshes and how they function, to understand why it is worth intervening (when it is worth intervening) and then to provide a more in-depth understanding of what aspects of these environments might need to be managed through understanding why they might change. This is followed by a detailed discussed of what courses of action might be taken to manage saltmarsh and how saltmarshes might be monitored.

This aims to be a logical journey through the wealth of information available but also provides a structure that more experienced coastal and estuarine managers can dip into at appropriate points, or point less experienced managers to for reference, training and development.

The following describes the content of each section in a little more detail. In general, Chapters 2 to 4 provide the background and contextual information whilst Chapters 5 and 6 present potential management and monitoring techniques.

Chapter 2 - WHAT IS THE SALTMARSH THAT WE MIGHT MANAGE? - addresses the morphology and processes associated with estuaries and bays (in general terms) and with their intertidal sub-systems (mudflats and saltmarshes), as well as saltmarsh ecology. This is supported by further detail provided in Appendices A1 (Saltmarsh Processes and Morphology) and A2 (Saltmarsh Ecology). Understanding the form and function of the estuarine or coastal system in question is critical to establishing the baseline against which options for saltmarsh management can be assessed.

Chapter 3 - WHY IS SALTMARSH WORTH MANAGING? - briefly examines the ‘value’ of saltmarsh, with particular reference to those areas that are of key importance to coastal managers, namely ecosystem and conservation importance and flood and coastal defence (with further detail provided in Appendix B1). A summary of the concepts surrounding the economic value of these functions is also provided.

The potential use of project appraisal techniques in assessing the economic as well as other potential values of saltmarsh is considered in Appendix B2; and Appendix B3 considers approaches to decision making based on the number of impact categories that can be expressed (or not) in monetary terms.

Chapter 4 - FACTORS LEADING TO SALTMARSH CHANGE - explores the human and natural factors that may affect saltmarsh habitat and lead to both morphological and ecological change (and further detail is provided in Appendix C). Both past uses that have influenced the development of saltmarshes (e.g. land claim) and current activities that could affect the condition and distribution of saltmarsh (e.g. 'saltmarsh squeeze') are described. Determining the nature of change and the causes and processes driving it are fundamental for saltmarsh management.

Chapter 5 - SALTMARSH MANAGEMENT - presents the main focus of the Manual. It includes details of a range of techniques that are available for maintaining, restoring or enhancing saltmarshes. It also provides references for saltmarsh creation techniques that can be used in areas where there is no existing saltmarsh.

Section 5.2 is intended to help coastal managers decide whether or not it is appropriate to undertake saltmarsh maintenance and/or enhancement. Basic guidance on the steps to be taken in determining the most appropriate management option is also provided. Section 5.3 then outlines the techniques that can be used for saltmarsh management based on a number of different requirements. Appendix D supports this section by providing a series of case study examples. Potential environmental effects are discussed and the effectiveness of the various techniques at maintaining and enhancing saltmarsh habitat is reviewed.

Chapter 6 - SURVEY AND MONITORING OF SALTMARSH - An essential component of the development of a management scheme to address saltmarsh loss, improve coastal defence value and/or enhance ecological status is to monitor the state of the physical and biological systems that the scheme is dealing with. This Chapter, therefore, describes the general components of a saltmarsh monitoring programme.

1.4 Contributors to the manual

The project was managed on behalf of Defra and the Environment Agency by **Michael Owen** and overseen by a **Steering Group** constituting:

Defra	Mark Dixon (seconded to Defra from the Environment Agency)
	Paul Murby
Environment Agency	Jane Rawson, replaced by Karen Thomas
	Nick Stevens
	Helen Young
English Nature	Dr Susan Watt, replaced by Sue Rees

In addition, specialist input to the Manual was provided by Dr Pat Doody, Prof. Kenneth Pye, John Ash and Teresa Fenn (Risk & Policy Analysts). Additional contributions and

support from a broad group of individuals and organisations who were consulted on matters ranging from the type of output to matters of technical detail are also acknowledged and appreciated by the Steering Group and Royal Haskoning in producing this manual, namely:

ABPmer	Natalie Frost
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Chichester Harbour Conservancy	Ann de Poitier
	Philip Couchman
Countryside Council for Wales	Peter Rhind
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English Heritage	Peter Murphy
English Nature	Carol Reid, Janette Gazzard, Sue Burton, Chris Gibson,
	Ian Black, Kate Jennings, Roger Morris
Environment Agency	Lyn Jenkins, Phil Griffiths, James Burke,
	Helen Orme, Gemma Costin, Trazar Astley
Essex Wildlife Trust	Dave Smart
National Trust	Grant Lohoar
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RSPB Scotland	Neil Cowie
Scottish Natural Heritage	Stuart Angus

Within Royal Haskoning, the drafting of the Manual was led by: Dr Richard Cottle supported by Chris Adnitt, Dr David Brew, Dr Nicola Meakins, Sean McNulty, Matt Hardwick and Robert Staniland. The section on Palaeoecology and Archaeology was prepared by Peter Murphy of English Heritage. The final document was edited by Sian John and Daniel Leggett and the electronic platform was prepared by Martin Pride.

2 What is the saltmarsh that we might manage?

2.1 Introduction

To effectively manage saltmarshes requires an understanding of what they are, how they are formed and how they function. Saltmarshes form part of estuary, coastal bay and often barrier beach systems. In order to develop and survive, they depend on processes and inputs from these larger systems. Saltmarshes are generally composed of mud or fine sand that settles out of suspension. For this to occur, the suspending water must move relatively slowly, with only low levels of turbulence. Once settled on the bed, the sediment can only accumulate and saltmarsh develop if the particles are not re-suspended by wave or current action. The necessary low energy conditions for saltmarsh development are normally encountered within the shelter of coastal bays, such as Poole Harbour or The Wash, behind barrier islands such as Scolt Head Island, or in estuaries such as the Solway, Dee or Blackwater (Figure 2.1). In each case, the location of the saltmarsh is primarily determined by the shelter afforded by the large scale coastal morphology. However, within each of these environments, a wide range of energy levels can be found and thus the distribution and morphology of saltmarshes is determined not only by these coastal forms, but also by more local factors such as the tidal dynamics, sediment transport pathways, locally generated waves and the presence or absence of vegetation.

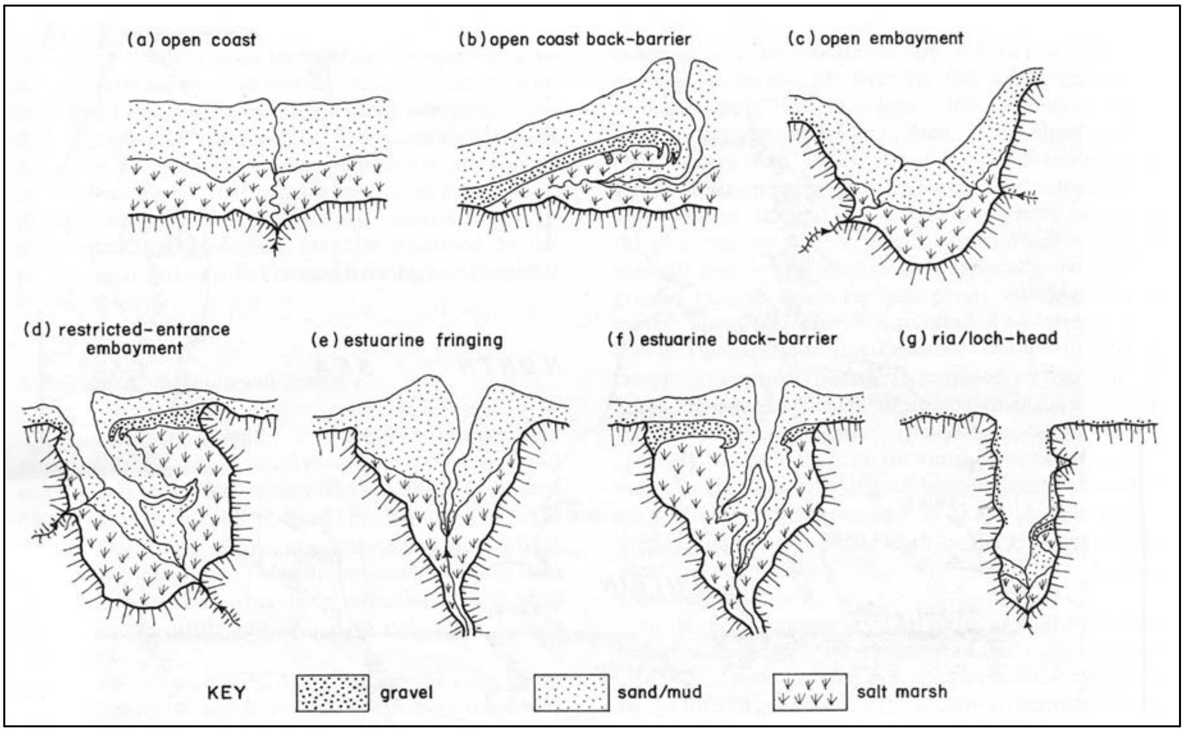


Figure 2.1 A geomorphological classification of saltmarshes (from Allen, 2000)

This chapter deals with the morphology and processes associated with estuaries and bays (Sections 2.2.1 and 2.2.3), and more specifically with their intertidal sub-systems (mudflats and saltmarshes; Sections 2.2.2 and 2.2.4), as well as saltmarsh ecology (Section 2.3).

Understanding the form and function of the estuarine or coastal system in question is critical as a baseline against which the options for saltmarsh management can be assessed.

2.2 Morphology and processes

2.2.1 Estuary and bay morphology

Saltmarshes and mudflats can be considered simply as the banks of an estuary or bay. The overall shape of an estuary or bay determines where these banks will be and, therefore, the location and extent of the saltmarsh depends on the morphodynamics of the system in which it is formed. Any broad scale change in the systems hydrodynamics will be reflected in the position of the banks, so that the mudflats and saltmarshes can be expected to erode or accrete accordingly. The corollary is that any changes imposed on the extent of a saltmarsh are also likely to have an effect on the estuary/bay as a whole. For example, enclosure of a section of saltmarsh due to land-claim will reduce the tidal prism and may have effects on processes throughout an entire estuary system. It is in this context that an understanding of estuary/bay morphology and processes is necessary for the development of a saltmarsh management strategy. Further details are provided in Appendix A1.

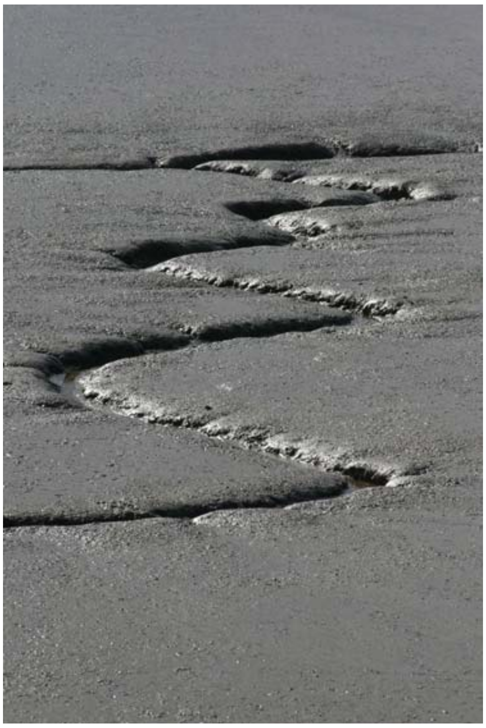
2.2.2 Mudflat and saltmarsh morphology

Saltmarshes are best understood as part of a hierarchy of landforms. The largest scale features, estuaries or bays, are made up of a number of landforms which may include composite mudflat/saltmarsh shorelines. This type of composite shore is not a random association, because saltmarshes depend on mudflats (or sandflats) and vice versa, so that the two are often found together. Within this composite unit another set of smaller scale morphological features can be defined, including saltmarsh creeks or mudflat channels. Each of these features has evolved to fit into the hierarchy and each has evolved a shape and a set of processes which tends to give it long term stability even though, in many cases, short term variations in shape may occur due, for example, to storms or other infrequent events. Further details are provided below and in Appendix A1.2.

Mudflats

There is great diversity in the morphology of mudflats that relates to the changing balance of physical, sedimentological and biological forces on the sediment. Mudflats merge landward with the zone where saltmarsh vegetation grows and they extend seaward to the low water line, where they may be bounded by lower-lying intertidal sandflats. In general terms, the width of a mudflat can be greater in areas characterised by a high tidal range than in areas with a small tidal range, but there are considerable deviations that indicate that there are other controls.

Mudflats undergo cycles of erosion and deposition. It has been suggested that a mudflat undergoing erosion has a low and concave upward profile, while one experiencing deposition has a high and convex upward profile (Figure 2.2). Change in the profile causes change in the duration of wave attack and tidal energy, altering the rates of erosion and deposition; so there may be a gradual progression to a new equilibrium.



Mudflat creek on different stages of the tidal cycle © Chris Gibson, English Nature

Hamford Water Mud mounds © Chris Gibson, English Nature

The mean level of concave upward (eroding) mudflats is below the mean tide level and the maximum slope is towards the top of the profile (Figure 2.2). There may also be a small scarp at the junction with the saltmarsh due to wave erosion during the extended period of high water. Convex upward (accreting) mudflats have a maximum slope closer to the low water mark. Accretion occurs due to the landward transport of sediment given the enhanced settling lag associated with the suspended sediment as it travels over the mudflat (see Section 2.2.4).

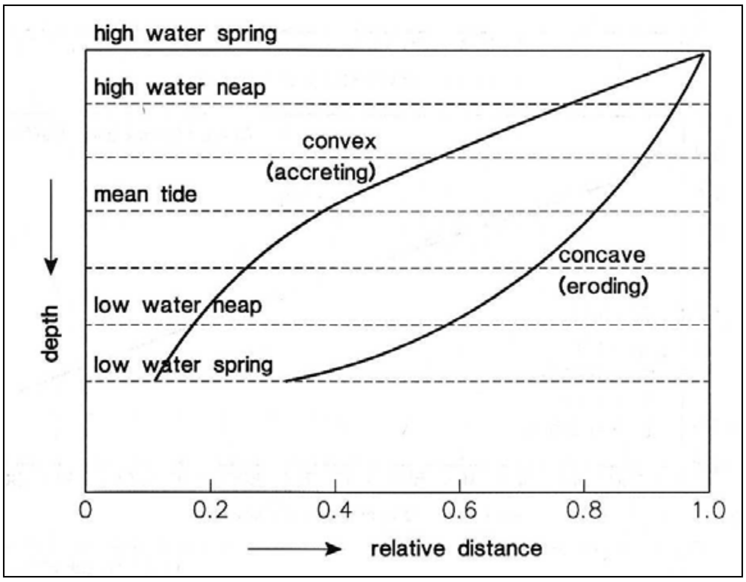


Figure 2.2 **Schematic diagram showing morphology of concave and convex mudflats relative to tide levels and relative shore-normal distance (after Van Rijn, 1998)**

Saltmarshes

Saltmarshes consist of two main geomorphological elements. First, a convex upward, planar or concave upward vegetated platform high in the tidal frame that is flooded by the tide and, second, generally unconnected networks of tidal creeks that branch and diminish landward towards the interior of the saltmarsh from its seaward edge. Additionally, some saltmarshes have pronounced areas of higher ground (levees) along the banks of the creeks, varying densities of water-filled depressions (salt pans) or bare areas of mud (mud basins) which are connected to the creek system and which drain at low tide.

Seven main types of saltmarsh are recognised (Figure 2.1):

- Open-coast marshes - typically sandy systems with relatively exposed sandflats to seaward;
- Open-coast back-barrier marshes - sandy-muddy systems found on the sheltered, landward side of coastal barriers;
- Open-embayment marshes - marshes which fringe the edges of large tidal embayments with unobstructed entrances and tend to be sandy;
- Restricted-entrance embayment marshes - typically mixed sandy-muddy systems, with the embayment partially closed off at the mouth by one or more spits or promontories;
- Estuary-fringing marshes - most commonly muddy and found in estuaries with little obstruction at the mouth;
- Estuary back-barrier marshes - found in estuaries behind barriers or spits at the mouth, often composed of mud overlying sand; and

- Ria/Loch head marshes - marshes restricted to the drowned river valleys of the south west, where pioneer to upper marsh occurs with transitions to woodland.

The two prime functions of the networks of saltmarsh creeks are to transport new sediment into the saltmarsh and to drain tidal water from the marsh surface on the ebb tide. They serve to distribute tidal water and suspended sediment over the saltmarsh platform during the flood tide. Bifurcating channel networks develop initially on mudflats and sand flats, but their form becomes modified once vegetation is established and a marsh surface starts to rise in the tidal frame (Steel and Pye, 1997). Marsh tidal creek systems act in the same way as a main estuary channel, acting as a focus for bi-directional flow.

The plan and cross-sectional form of the tidal creek network, like that of an estuary as a whole, reflects a balance between flood and ebb tidal forces. On a flooding tide, the creeks act to damp tidal energy by frictional drag of the water on their bed and banks. The greater the channel length and area of the banks and bed, the greater is the frictional drag on the flood tidal flow. In marshes with very intricate bifurcating channel networks, flood current velocity may be reduced effectively to zero near the head of the marsh. Therefore, there may be serious implications if a creek system is 'beheaded' by embankment construction, since the reduced channel system may be unable to fully dissipate the energy of the flood tide, resulting in relatively high current velocities and scour of the bed and banks close to the new sea wall. On many saltmarshes, truncated creeks can be seen to re-develop along the line of defence.

Hamford Water, Little Oakley saltings on a surge tide © Chris Gibson, English Nature

Sediment enters a marsh in two main ways, via the creek system and across the marsh front at high stages of the tide. In the case of wide marsh systems, sediment supply via its creeks is normally most important. Since sediment falls out of suspension quite quickly once water leaves the creeks, due both to reduced current velocities/turbulence and trapping effects of vegetation, sedimentation rates tend to fall off quite quickly with distance from the creek (Reed et al., 1999). Much of the sand and coarse-silt sized sediment is deposited within a few metres of the creek bank, leading to the formation of levees in systems where the suspended sediment contains a wide range of grain sizes. If the suspended sediment consists largely of medium and fine silt, deposition is more uniform and a 'flatter' marsh surface is likely to develop. If the density of creeks is relatively low, some areas of the marsh surface are likely to receive insufficient sediment to maintain vertical marsh growth. Such areas may become waterlogged leading, in extreme cases, to death of the marsh vegetation, ponding or the development of mud basins.

If the tidal energy (both flood and ebb) is high enough the creek system may self-adjust through headward erosion until a state of dynamic-equilibrium is achieved. However, if tidal energy is low, concentrations of suspended sediment too low or the particle size distribution strongly skewed, self-adjustment may be limited and a healthy, relatively flat and uniformly vegetated marsh surface may never be attained.

The density of creek spacing is controlled by vegetation density, suspended sediment concentrations and tidal stage variations. The importance of the creek system to saltmarsh viability means that any interference with the natural system should be avoided if possible. If modifications are necessary, they should be carried out with extreme care. Increases or decreases in creek length, width or number can alter the sensitive balance of tidal absorption to sediment transport capacity and result in rapid saltmarsh deterioration.

2.2.3 Estuary and bay processes

Estuaries and bays can be divided into muddy systems, dominated by a suspended sediment load comprised mainly of silts and clays (less than 63μm in diameter), and sandy systems dominated by bed load comprised of sands and gravels (> 63μm). The largest areas of mudflats in England and Wales are found in Essex, Kent, Humberside, Norfolk, Lincolnshire, Hampshire and Gloucestershire / Gwent; reflecting the generally muddy character of the upper intertidal flats in the estuaries of eastern and southern England. The intertidal flats of north-west and north-east England are mainly sandy, with mud generally restricted to the highest intertidal zone and the inner parts of estuaries. Extensive sandflats occur in the lower intertidal zones of most east coast estuaries, including the Humber, The Wash and Outer Thames Estuary. Relatively little sediment enters the estuaries of England and Wales from fluvial sources in present times.

If conditions are suitable, sediments transported into estuaries via fluvial processes can also form large deposits called deltas. Where the coast is dominated by tides, with little wave activity, the delta is likely to be typified by shoals (small islands) surrounded by water. Deltas are constantly changing owing to their constant sediment input and its rearrangement by local currents.

Saltmarshes within estuaries and bays are ultimately dependent on the energy provided by the tides and waves capable of transporting coastal sediments and changing the shape of the landforms. This change in shape may mean that the landforms gradually adjust to the applied forces in order to absorb the imposed energy without further morphological changes taking place; achieving so-called morphodynamic equilibrium.

The processes of sediment erosion and deposition are controlled by the relationship between the size of particles and the strength of the currents imposed upon them. When the velocity of the water flowing over a surface becomes fast enough, the sediment particles on that surface will be eroded and transported, to be deposited when the flow velocity decreases (i.e. the capacity of the flow to move sediments reduces). The initiation of transportation, and the type of transportation (suspended or bedload) that follows, will depend to a large extent on the particle size and the shear stress applied to the sediment by the flow. Deposition occurs when the force of gravity acting on the particles is sufficient to overcome the fluid forces causing movement. Further details are provided in Appendix A1.3.

2.2.4 Mudflat and saltmarsh processes

The tide is the central feature around which intertidal mudflats and saltmarshes function, through erosion/accretion and the development and maintenance of tidal creek networks. The tide also sets the maximum height to which saltmarshes can accrete vertically. Seawater enters the tidal creeks on the flood tide, gradually filling them as the tide rises until the water spills over and floods the adjacent intertidal mudflats and saltmarsh. Following high tide slack water, the water drains back off the saltmarsh and mudflats, initially over the leading edge of the saltmarsh and then through the creeks until the entire intertidal area is exposed once more.

Further details relating to mudflat and saltmarsh processes are provided in Appendix A1.4 and the key points are summarised below.

Mudflats

The sediments deposited on mudflats are characteristically sand-dominated at their seaward edge and mud-dominated at the landward end. The lower intertidal flats are submerged for most of the tidal cycle and are subjected to strong tidal currents and wave action. Consequently, muds are kept in suspension and sands are deposited only from the bed load. Higher intertidal flats are submerged only at high tide, when current speeds fall to zero. No bed load transport takes place but, during slack water, mud settles out of suspension. However, settlement of silt and clay particles out of the water column, to form mudflats, takes many hours even under laboratory conditions where there is no current. This process alone is too slow to account for the development of the extensive mudflats around the coasts of England and Wales. Settlement of fine sediment is, therefore, facilitated by flocculation; the process of individual grains grouping together (see Appendix A1.3.4).

A high suspended sediment concentration of relatively large particles or flocculants will result in rapid sedimentation; deposition rates of several centimetres on a single tide have been recorded and several tens of centimetres over a spring / neap tidal cycle. However, the average rate of sedimentation for a mudflat, as measured over a period of years, may not be greater than 1cm/annum, reflecting a balance between erosion and deposition over a tidal cycle as well as (over longer periods) the influence of storm events and sea level rise.

Saltmarshes

Saltmarshes are, in effect, vegetated mudflats; although the morphology and the processes which act upon them are distinct in several respects. Saltmarsh surfaces are higher than mudflat surfaces and so they are flooded less frequently. The tidal currents that normally flow over saltmarshes have much lower velocities than those flowing over mudflats (and this allows initial vegetation colonisation of the surface). This is because, as the tide floods the highest parts of the intertidal area, current velocities gradually decrease to zero towards the limit of high tide. The presence of vegetation on the saltmarsh also generally increases the attenuation of both tidal currents and waves as they pass over the vegetated area.

As the upper mudflats grow higher through the vertical accretion of sediment, the number and duration of tidal inundations decrease. At a critical point in this upward growth, the mudflat becomes exposed long enough for vegetation to become established (Figure 2.3). The elevation at which vegetation can colonise a mudflat depends on several factors, one of the most important being the availability of plant species able to survive within this environment (see Section 2.3).

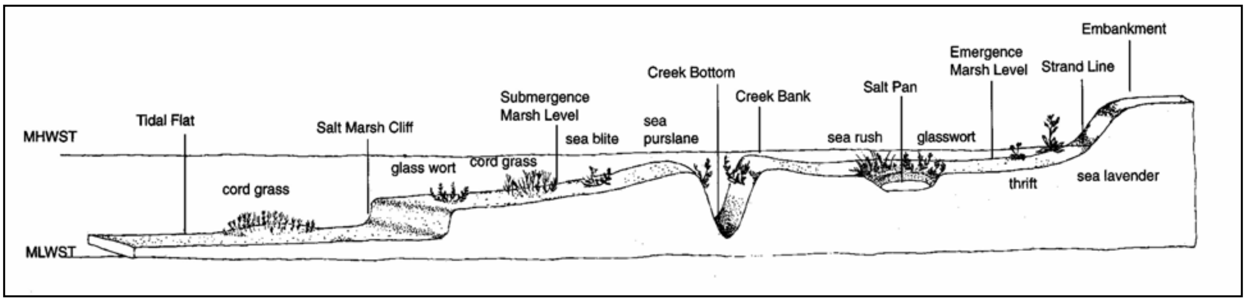


Figure 2.3 **Schematic diagram showing the profile of a saltmarsh and mudflat and their main physiographical features (www.abdn.ac.uk/geospatial)**

Spartina and *Salicornia* are the two most common UK pioneering salt-tolerant plants. The presence of these plants helps to reduce flow, in many cases, encouraging further deposition of mud. This is the process by which a forming saltmarsh can accrete sediment more rapidly than mudflats and help facilitate change in elevation across the intertidal profile. Care is needed, however, in applying the general assumption. Small swards of *Spartina*, for example, may suppress accretion rates compared to surrounding mudflats. Clumps of *Spartina* less than 2m in diameter have been shown to (in effect) raise the flow up above the bed (Pethick *et al.*, 1990). This leaves a zone of near zero velocity in the plant stems but high shearing velocity above them. As sedimentation is proportional to the depth of water this effectively “cuts off” the sediment laden water above the vegetation, thus reducing sedimentation compared to the open mudflat. Where this process occurs, *Spartina* can be found in water logged depressions within an accreting mudflat. Once the sward is wider than 2m, turbulence breaks down this separation. Care is also needed in simply considering vegetation as a sediment trap where energy levels (waves or tides) are increasing from historic levels. If energy levels increase, then vegetation can enhance erosion rates by being rotated and physically scouring the surface.

Numerous factors dictate the height at which a particular mudflat surface will start to *be colonised by vegetation. The most important factor is that suitable plant species* have to be available for colonisation; different plants are able to colonise at lower levels than others (see Section 2.3.2; and Box 2.3). Other factors include tidal current velocity and its ability to remove plant seeds, the availability of light for growth of plants and the salinity of the water. Once a saltmarsh is established, biological activity and sedimentation at a particular level on a saltmarsh depend on the pattern and extent of tidal inundation at that level. A youthful saltmarsh may be submerged by around half the tides in an average year, whereas a mature saltmarsh may be drowned on just a few tens of occasions.

Mudflat/saltmarsh process relationship

The development of most saltmarshes is dependent on the existence of a tidal flat which is capable of reducing wave and tidal energy sufficiently to allow sedimentation and vegetation to colonise at the landward extremity. The relationship between mudflat and saltmarsh is more complex than this, however, and involves morphological and sedimentological feedbacks. Three major interactions are relevant:

- the saltmarsh provides a form of 'insurance' for the mudflat during periods of storm wave attack. If the mudflat fails to dissipate all of the wave energy, then waves pass into the saltmarsh vegetation where the increased frictional drag is capable of damping all but the highest waves;
- the saltmarsh acts as a reservoir of sediment, capable of feeding the mudflat during extreme storm events when an overall widening and flattening of the intertidal zone is necessary; and
- the saltmarsh provides an area of the intertidal zone into which the mudflat can extend during storms.

The interdependency of the saltmarsh and mudflat means that each one has a much better chance of survival if the other is present. Mudflats do exist without saltmarshes, but they are prone to erosion, especially on their upper levels and where waves are reflected from hard defences or natural cliffs. Saltmarshes can also exist without mudflats, but these are usually protected by some other form of defence, natural or artificial. If no protection is available at the seaward edge, then a marsh cliff will tend to form and may recede slowly landwards. The combined saltmarsh/mudflat landform is efficient and should be considered as one unit by coastal managers.

2.2.5 Wave attenuation over the saltmarsh

There is a long history of the use of engineered works for coastal flood and erosion protection in the UK and around the world. It has long been assumed that saltmarsh has the beneficial effect of attenuating wave energy and, thereby, contributes to this protection. Interest in quantifying the ability of saltmarsh to attenuate wave energy has been further stimulated by concern over future accelerated sea level rise and the associated increases in the cost of strengthening and raising flood protection structures (should this be viable). Widespread loss of saltmarsh from UK estuaries may be further reducing shoreline protection.

Research in the UK has shown that saltmarsh areas attenuate significantly more wave energy than unvegetated intertidal areas (Figure 2.4). Studies into the attenuation of waves over saltmarsh have consistently demonstrated greater wave height and energy reduction over saltmarsh compared to unvegetated sand or mudflats, but the extent and nature of the attenuation is highly variable. Further details are provided in Appendix A1.5.

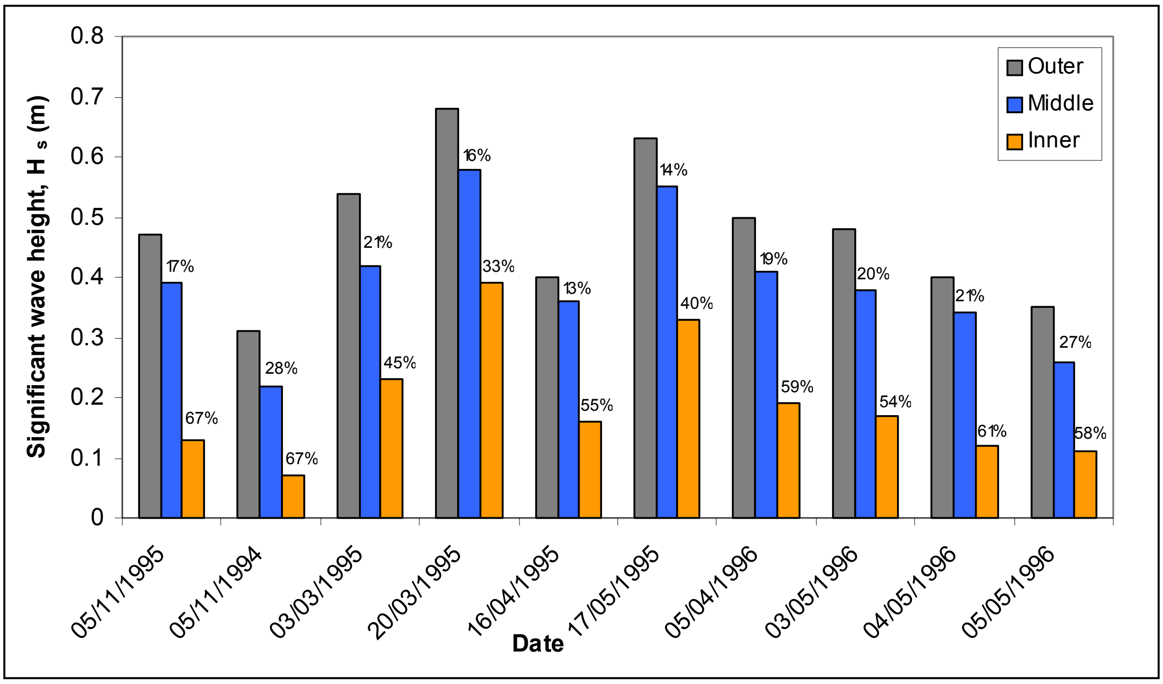


Figure 2.4 **Reduction of significant wave height between sandflat (outer), the saltmarsh edge (middle) and saltmarsh (inner) stations (from Möller *et al.* (1999))**

2.2.6 Important information

This section of the manual provides a checklist of essential process information the coastal manager needs to understand in order to implement an appropriate saltmarsh management strategy. It covers both saltmarsh specific and estuary/bay-wide processes. The management of saltmarshes cannot be divorced from the wider understanding of the functioning of the estuary or bay within which they sit.

The key information required on estuary and bay processes is summarised below and set out in detail in Box 2.1. That is:

- Tidal prism/cross-sectional area;
- Tidal levels;
- Sub-tidal channel geometry;
- Wave climate;
- Sea level change; and
- Sediment budget.

The key information required on the saltmarsh itself relates to (also see Box 2.2):

- The condition of saltmarsh/mudflat boundary;
- Saltmarsh and floodplain elevation;
- Saltmarsh surface accretion;
- Suspended sediment concentration;
- Saltmarsh vegetation; and
- Saltmarsh creek systems.

Box 2.1 Estuary and bay-wide processes information for saltmarsh management
Tidal prism/cross-sectional area The relationship between the tidal prism and cross-sectional area controls the velocity of flow through an estuary. An increase in velocity caused by an increase in the tidal prism may initiate erosion at critical points and a reduction in deposition. An understanding of this relationship is, therefore, important in the development of a management strategy. Tidal prism can be calculated from topographic survey data across transects in an estuary and water levels, extrapolated to a volume.
Tidal levels Tidal levels are fundamental to the development of saltmarshes. A relatively small tidal range decreases the residence time at high water and reduces net accretion. If no appropriate tidal level data is available, water levels should be recorded using an automatic tide gauge suitable for sea bed mounting. As a minimum, these operations should be able to record spring neap tidal variations, with a record of levels ideally covering a 4 week period (to cover a full lunar cycle).
Subtidal channel geometry The dimensions of the subtidal channel and its position within the estuary will determine the location and extent of mudflats and saltmarshes adjacent to it. Channel morphology also controls flood- or ebb-dominance which may vary at different positions in an estuary system, providing a simple method of predicting the future development of the estuary and the depositional regime within it. The movement of the channel to reach its current position can be analysed using historic charts and maps.
Wave climate Measurement of wave climate in an estuary or bay is essential for understanding the erosional processes which may act on its mudflats and saltmarshes. Estuarine sediment budgets are partly controlled by the re-entrainment of sediments by waves, and the location and temporal periodicity of the saltmarsh/mudflat edge can be a response to wave energy inputs. It may be possible to obtain high quality predicted wave information from the Meteorological Office for offshore points. Nearshore conditions can be calculated from this offshore data using a numerical transformation model. Waves generated locally within an estuary can be predicted from a knowledge of wind speed, fetch length and water depth, using standard formulae. Alternatively, site-specific measurements can be taken using of wave recording instrumentation. Joint probabilities of waves and tides should also be calculated as a basic tool for any saltmarsh management plan.
Sea level change The recent history of changes in relative sea level is fundamental to the future development of mudflats and saltmarshes in an estuary or bay. Long term tide gauge records covering at least a 20 year period should be used to determine this, after correcting for periodic perturbations such as the 18.6 year nodal tide. Present rates (1950-2004) of relative sea level change around most of the UK coast are below 5mm per year and may not present a problem to mid to upper saltmarsh vertical growth. They do, however, pose considerable problems for the horizontal development of saltmarshes and sea level rise should be regarded as critical in the initiation of coastal squeeze effects (see Section 4.2.3).
Sediment budget Sediment supply for saltmarsh development is rarely a limiting factor in English and Welsh estuaries, although it may be a critical factor in the response of the estuary system as a whole to sea level rise. Measurements of suspended sediment are so variable in space and time that they do not provide a good indicator of these large scale sediment budgets. Instead, volumetric analysis of the long term development of an estuary or bay, using charts and other historic morphological data sources, should be undertaken.

Box 2.2 Saltmarsh information required for saltmarsh management
Condition of saltmarsh/mudflat boundary The location and condition of the saltmarsh edge is controlled by wave and tidal energy and represents a balance between mudflat morphology and hydrodynamic inputs. Increasing the wave absorption capabilities of the fronting mudflat may allow saltmarsh progradation, but only if this is achieved without interrupting sediment movements over the intertidal zone. The periodic erosion of the saltmarsh edge in exposed estuarine locations must be regarded as a natural response to joint wave and tidal probabilities. Interference with this periodic process can inhibit saltmarsh or mudflat development. Field survey in combination with aerial photographic interpretation will provide an appreciation of the state of the saltmarsh edge.
Saltmarsh and floodplain elevation The elevation of the saltmarsh (or the floodplain behind an embankment) within the tidal frame is important because it is the primary factor that determines the number of tidal inundations that are experienced. Elevation data is now routinely collected using LiDAR (Airborne Laser Induced Direction and Range), which ‘scans’ the ground surface taking up to 10,000 observations per square kilometre. These observations are then converted to a local co-ordinate and elevation datum.
Saltmarsh surface accretion The vertical accretion on a saltmarsh is a response to the protection afforded by its vegetation against sediment re-entrainment after deposition. Dense vegetation may actually inhibit deposition. Vertical accretion rates decrease as the surface rises, unless there is a rise in relative sea level. Thus, the future development of the saltmarsh surface can be predicted by the form of the time/accretion rate curve; a decreasing rate suggests that sea level rise is balanced by vertical accretion. Accretion rates can be measured using a variety of simple techniques, including deployment of filter papers or metal accretion plates on/within the saltmarsh surface.
Suspended sediment concentration Field measurements of suspended sediment concentrations are important in the analysis of morphological change in mudflat and saltmarsh environments. Measurements can be made using turbidity meters along a transect from the mudflat, along the main creek through to the head of the saltmarsh. A temporal concentration profile for each station along the transect can be constructed and the patterns of sediment concentration in the water recorded throughout the tide. Long term monitoring will reveal overall patterns of suspended sediment concentration in relation to particular events.
Saltmarsh vegetation Vegetation assemblages on saltmarshes are important in terms of both the trapping / fixing of sediment and wave attenuation. Information about vegetation communities on 'mature' saltmarshes, i.e. those in equilibrium with the tidal frame, can be obtained from previously published surveys (e.g. Burd, 1989; Hemphill & Whittle, 2002; Stark *et al*., 2002) but, on immature marshes, vegetation succession can be rapid. Therefore, it is often necessary to undertake specific surveys. These can be done at a large scale based on aerial photograph interpretation or at a more local scale using ground (quadrat) surveys.
Saltmarsh creek systems Creeks have two major roles in saltmarsh development. First, they absorb tidal energy as the wave passes into the saltmarsh. The efficiency of this process depends on creek width, length and bifurcation ratios. Second, the delivery of sediment to the saltmarsh surface is achieved by flows over the saltmarsh/sea edge and by flows through the creek system. Sediment transport is severely limited by saltmarsh vegetation so that creek penetration of the saltmarsh surface is essential. The density of creek spacing is controlled by vegetation density, suspended sediment concentrations and tidal stage variations. Field survey in combination with aerial photographic interpretation would provide an appreciation of the geometry of the creek network.

2.3 Saltmarsh ecology

2.3.1 Saltmarsh

Pre-marsh processes

The development of saltmarshes depends fundamentally on a range of otherwise harsh physical and chemical conditions becoming sufficiently benign to allow (flowering) plants to colonise intertidal mudflats. These conditions are controlled by, but not necessarily directly related to, tidal inundation and other process factors. Colonisation by flowering plants is thus an indication that physical and particularly hydrodynamic forces are suitable, at least temporarily, for saltmarsh growth. The seaward limit of the colonists is conventionally regarded as the lower edge of the saltmarsh. However, the processes leading to saltmarsh development, including biological processes, are likely to have started on the mudflats seaward of the vegetation (see Appendix A2.2.1).

In several estuaries, particularly on more sandy substrates, there appears to be no absolute preconditions for the growth of colonising vascular plants and the subsequent development of saltmarsh, other than the amelioration of the hazardous physical and chemical forces associated with tidal submergence.

Most saltmarsh plants are essentially terrestrial organisms variously adapted to, or tolerant of, a semi-marine environment. At a minimum, they require sunlight and an atmosphere for photosynthesis and growth and, to acquire nutrients, their roots must be bathed in non-toxic solutions of ionic concentrations low enough to enable absorption by osmosis. All of these basic conditions are violated at some time by the act of tidal submergence. Saltmarsh plants have evolved various ways of coping with this factor and, in fact, very few (if any) British saltmarsh species require seawater at all in order to survive. Salt-tolerant plants are 'halophytes', therefore, it can be said that there are no saltmarsh obligate halophytes. On the contrary, provided that they are kept free of weeds, most saltmarsh plants can flourish in ordinary garden soils. In tolerating saline conditions, saltmarsh plants can out-compete other terrestrial vegetation.

The question therefore arises; what range of physical and chemical factors associated with tidal submergence act to limit the seaward extension of saltmarsh plants? The most obvious ones include the mechanical effects of moving water, possible burial by accreting sediments, the loss or reduction of light by silt-laden water, the waterlogging of the sediments and the bathing of the plant in saline solution.

Zonation and succession

A striking feature of saltmarsh vegetation is the zonation of different communities with increasing elevation. This zonation is generally displayed as bands of characteristic species assemblages that run more or less parallel to the shoreline, although in many sites this is more complex due to the presence of creeks which have a subset of zonation patterns along creek sides. The distinctions between zones are often blurred since the pattern is generated by different, but usually overlapping, vertical distributions of individual species. A typical example of the different vertical range of plants and how it produces zonation is shown in Figure 2.5.

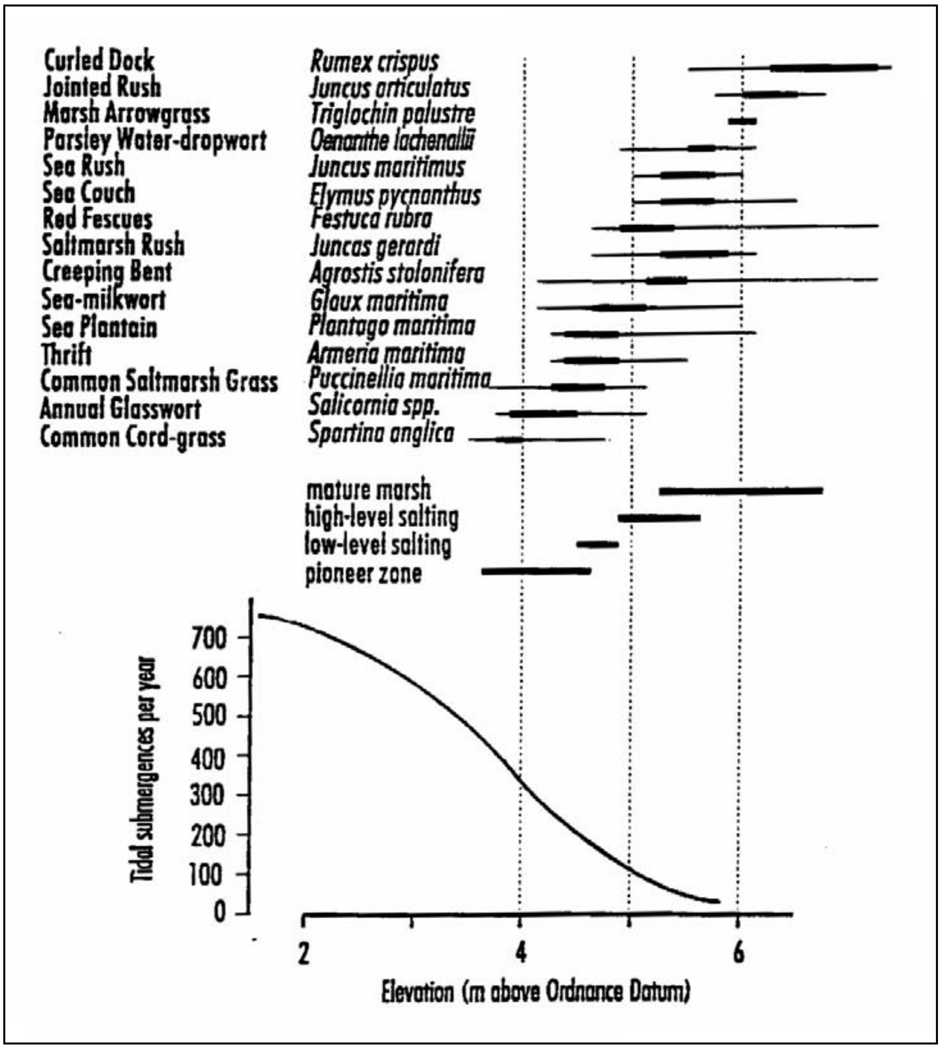


Figure 2.5 **Elevation ranges of some widespread saltmarsh species around Morecambe Bay; the thicker parts of the lines represent the range where a species is most frequent (after Gray & Scott, 1977)**

Although there is variation around the UK in which species are likely to occur in each zone, the species which typify each zone are remarkably constant from marsh to marsh. It has, therefore, been possible to describe distinct 'communities' or assemblages of characteristic species.

The causes of zonation are connected with the gradient of changing conditions related to decreasing tidal submergence as marsh elevation increases, as well as differences in the efficacy of the tolerance mechanisms of the different species. The interplay of these factors determines the vertical distribution, and hence zonation, of individual species. To understand zonation, however, a third element is required, the biotic interactions between individuals. The two most important of these are competition and facilitation. Further details are provided in Appendix A2.2.3.

Essex skipper, Thymelicus lineola, on Limonium © Chris Gibson, English Nature

Various studies have demonstrated the importance of elevation and of biotic interactions in determining both broad zonation and local distribution patterns among saltmarsh plants. The manipulation of these variables provides a useful potential means of managing saltmarsh vegetation. For example, repeated clipping or mowing of *Spartina* marsh will, at appropriate elevations, convert that marsh into one dominated by common saltmarsh grasses. This occurred in only three years in experimental plots on the Ribble estuary near Southport, when *Spartina* grass was harvested by cutting it to ground level each September. There is also, clearly, the potential to change the species composition of saltmarshes by altering marsh topography or drainage. Similarly, successional changes may be initiated by sowing a facilitating pioneer species into saltmarsh sites. However, it is important to note that if conditions are not right (e.g. elevation and gradient) planting may not be a viable option or success will be short-lived. Seed sowing and planting experiments were tried at Tollesbury, Essex with mixed results. In the short term, the use of turfs of vegetation proved to be more effective than planting with small plants or sowing seed, which had relatively poor success in all but the highest areas (Boorman, 2003). In contrast, no planting was undertaken in the Trimley Marshes managed realignment site on the Orwell Estuary, Suffolk, however, within 6 months significant areas of the site had been colonised by *Salicornia* spp. (Posford Haskoning, 2003) (Appendix D provides further details).

On the whole, saltmarshes do not tend to conform to the general picture of a successional and increasingly complex community developing under the driving forces of sediment accretion, increasing elevation and drainage and decreasing tidal submergence. On the contrary, the vast majority of saltmarshes south of a line from (approximately) Suffolk to South Wales, although often displaying successional changes in the upper marshes, appear to be in decline. Far from being replaced by low marsh species, the pioneer zones of these marshes are often either eroding or absent. Reasons for this include the extensive die-back of *Spartina* marsh and the combination of rising relative sea levels causing submergence and coastal squeeze (see Section 4.2).

Further details relating to saltmarsh development in general are provided in Appendix A2.2.

2.3.2 Saltmarsh types

Key species and communities

Four main general types of saltmarsh are recognised: pioneer marsh, low marsh, upper or high marsh and driftline or transitional marsh. The main species and vegetation types found in these marshes in England and Wales are briefly described below, beginning with the pioneer marshes and thereafter in the order in which they might be encountered progressing from a mudflat to a seawall (see also Appendix A2.3.1).

Salicornia spp **marsh © Chris Gibson, English Nature**

Pioneer marsh

The three commonest types of pioneer vegetation are *Spartina*, annual glasswort (*Salicornia*) and sea aster (*Aster tripolium*). Spartina marshes, which are often extensive and frequently comprise dense stands of the grass without any other species, are discussed in more detail in the next section. Annual glasswort (made up of various species of *Salicornia* and known in some areas as Samphire) and sometimes annual sea-blite (*Suaeda maritima*) form pioneer communities on open mudflats seaward of perennial vegetation. Theirs is essentially an avoidance strategy, germinating and reproducing between the spring and autumn equinoctial tides. In fact, the autumn tides are major dispersal agents, distributing glasswort and sea-blite seeds throughout the saltmarsh. These plants can, therefore, be found as seedlings at any level of the marsh and can survive to reproduce in depressions or pans in the upper marsh.

Sea aster pioneer zones are mainly confined to south east England and largely form dense, pure stands of the rayless form of aster (lacking the lilac ray florets common in asters on the upper marsh). There is some evidence that the rayless form may have arisen relatively recently and that it is genetically different from the rayed form in several ways (other than lacking rays) which have enabled it to spread in the pioneer and low zones of muddy south east saltmarshes.

Several other species may also act as pioneers. Common saltmarsh grass *(Puccinelia maritima)* is a frequent pioneer on the grazed, sandy marshes of the north west of England and is also found in many estuaries on the edge of marshes fringing their upstream reaches. In the latter instance the marsh is usually brackish marsh and almost any species from the upper levels of the more seaward marshes may colonise the mud at the estuary / tidal river / creek edge. However, the most common are sea club-rush (*Scirpus maritimus*), various species of orache (*Atriplex* species) and, in the more freshwater areas, common reed (*Phragmites australis*) or creeping bent-grass (where the zonation is often reversed, with more salt-tolerant species growing on the upper marsh).

Low marsh

Two species dominate the low marsh in England and Wales; common saltmarsh grass and sea purslane *(Atriplex portulacoides)*. In some saltmarshes vast areas may be covered by these species with only scattered plants of other species, such as aster, glasswort or sea-blite, being present. A study undertaken in the early 1970s in The Wash estimated that around 2500 hectares, more than half of the total area of saltmarsh, was dominated by one or both of these species. More recent surveys have revealed that sea purslane has declined in abundance; possibly because of its sensitivity to frost (the species reaches its northern geographical limit in southern Scotland). Common saltmarsh grass is more abundant on grazed saltmarsh, sea purslane being absent from all but a few isolated ungrazed marshes in the north west of England, north of the River Wyre.

From the higher parts of the low marsh, and especially above Mean High Water, other species begin to be more common. Among the first are common sea lavender (*Limonium vulgare*), greater sea-spurrey (*Spergularia media*), common scurvy-grass (*Cochlearia officinalis*) and sea thrift (*Armeria maritima*). Together with species already encountered on the low marsh, and with species such as sea plantain (*Plantago maritima*), sea arrow-grass (*Triglochin maritima*) and sea milkwort (*Glaux maritima*), these saltmarsh plants can form herb-rich communities (largely free of grasses) over much of the upper marsh. Various combinations of such species have been referred to in the past as the 'general saltmarsh' or GSM; a concept of little real use.

Upper marsh

The presence of red fescue *(Festuca rubra)* and/or saltmarsh rush (*Juncus gerardii*) is a reliable indicator of upper saltmarsh. Both may form quite large pure stands and red fescue, together with other grasses such as creeping bent-grass (*Agrostis stolonifera*) and hard-grass (*Parapholis strigosa*), is the major component of the higher level of the grazing marshes in the west and north of England. Frequent land claim in the south and east has made such species relatively uncommon or, at least, largely confined to a narrow band close to (or even on the) seawalls and embankments. More commonly, the higher parts of the upper marsh in the south and east are occupied by sea couchgrass. This grass, which is replaced in similar habitats in Scotland by its close relative the common couchgrass (*Elytrigia repens*), is unpopular when it is dominant. It is coarse and unpalatable and invades areas of grazing marsh occupied by fescue and bent-grass; it forms a tall loose sward on seawalls, rooting within the litter layer, weakening the bank surface and harbouring burrowing animals; and it prevents or delays succession to species-rich upper marsh and transitional communities and invades grazing marshes used by wildfowl.

Transitional marsh

The plant communities around the level of the highest astronomical tide and in transitions to freshwater marsh, grazing marsh, sand dunes or shingle, can often be floristically diverse and, especially in the south and east, can contain several ecologically specialised and, consequently, relatively scarce species. One group of annual maritime grasses, such as annual beard-grass (*Polypogon monspeliensis*), Borrer's saltmarsh grass (*Puccinellia fasciculata*), stiff saltmarsh grass (*Puccinellia rupestris*) and sea barley (*Hordeum marinum*), require open ground, and hence frequent disturbance, to survive. The best places to look for such species are not in the saltmarsh but on the landward side of seawalls in vehicle tracks on the berm, on the edges of recently cleared ditches and on the edges of seasonally drawn-down, cattle-poached ponds. Other scarce saltmarsh plants found at these higher elevations, often on muddy shingle or transitions to sand dune, include two species of sea lavender, matted sea lavender (*Limonium bellidifolium*) and rock sea lavender (*Limonium binervosum*), the sea heath (*Frankenia laevis*) and the bushy perennial shrubby seablite (*Suaeda vera*).

More widespread communities around the highest tide level include those dominated by rushes and reeds; such as sea club-rush (*Scirpus maritimus*), sea rush (*Juncus maritimus*) and, in the less saline areas, common reed. All of these species extend further seaward in the upper reaches of estuaries and in the north west of England as well as western Scotland (where higher rainfall creates fresher conditions on the upper marsh). Again, such communities have a characteristic list of associated plants (and animals). Two of the commonest and most easily identified are parsley water-dropwort (*Oenanthe lachenalii*) and brookweed (*Samolus valerandi*).

Examples of classifications of saltmarsh communities in the British Isles are provided in Appendix A2.3.

Box 2.3	**Elevations of different marsh habitats in The Wash**
In The Wash, pioneer saltmarsh vegetation (mainly *Salicornia* spp and *Spartina anglica*) first becomes established at elevations around 2.3 to 2.4m OD. *Salicornia* spp, *Aster tripolium*, *Suaeda maritima* and *Puccinellia maritima* dominate lower marsh vegetation (2.4 to 2.8m OD). Middle marsh communities (2.8 to 3.4m OD) are dominated by *Atriplex portulacoides* and *Puccinellia maritima*, whereas *Puccinellia maritima*, *Plantago maritima*, *Festuca rubra*, *Atriplex portulacoides*, *Agropyron pungens* and *Artemisia maritima* are all commonly found as upper marsh vegetation (above 3.4m OD). The oldest active saltmarshes in The Wash reach elevations of up to 4m OD (Pye, 1995). Note: these levels all relate to local tidal range and therefore actual levels vary at other locations.	

Spartina marsh

An important change in British (and many other temperate-zone) saltmarshes during the last century was caused by the evolution, spread and subsequent partial decline of the English cord grass *Spartina anglica*. The spread of the grass from its site of origin (Southampton Water), at first naturally along the south coast as far as Poole Harbour in the west and Rye in the east, but later by deliberate introductions all around the coast, is well documented. The main reason for planting was to improve the rate of colonisation and stabilise mudflats, either as a precursor to land claim for agriculture or for coastal protection (see also Appendix A2.3.3).

Smooth Cord grass, *Spartina anglica* © Chris Gibson, English Nature

In the late 1980s, *Spartina* dominated 6,950ha of tidal flats, 16% of the British saltmarsh habitat and 2% of the estuarine intertidal zone (Way, 1990). More recently, Gray *et al.* (1997) suggested that there were more than 10,000ha of *Spartina* in the 44,000ha of saltmarsh around the British coast. Nearly all of which was thought to be the fertile polyploid, although small pockets of the sterile hybrid do occur, notably on the south coast. Gray *et al.* (1997) also report that *Spartina* grass continues to spread on the west coast, with around 20 new sites and a 40% increase in area since 1965. However, on the east and south coasts the *Spartina* marshes have reduced in area since then, by around 44% and 11% respectively (Gray *et al*., 1997).

This regression of *Spartina* marsh ('die-back') was first noticed in the 1920s in the longer-established swards of south coast estuaries. The conditions under which it degenerated were characteristically badly drained, highly anaerobic soils with a high proportion of fine particles and high sulphide content. That is, by causing the rapid accretion of poorly drained sediment and often creating marshes with a concave profile, the *Spartina* itself was the cause of the deterioration. It has also been shown that a fungus (*Claviceps purpurea*) can contribute to die-back by significantly reducing seed production through the infection of embryonic tissues (Gray *et al*., 1991).

The invasion of *Spartina* on the northern and western coasts of England, where it has encroached onto amenity beaches (e.g. at Southport), colonised mudflats that are bird-feeding areas (e.g. at Lindisfarne) or threatened the floristic diversity of nearby saltmarsh (e.g. at Alnmouth), has prompted attempts to control further spread using a variety of physical and chemical methods. However, in other areas *Spartina* marsh is being encouraged, protected or even planted, in an attempt to limit the loss of saltmarsh. Appropriate management of this key species is likely to require consideration of the entire local saltmarsh and mudflat system, including the sediment supply.

2.3.3 Distribution of saltmarshes

Saltmarshes are located all around the UK coastline but vary considerably in extent and character between those that inhabit lowland areas and those which inhabit upland areas. Table 2.1 and Figure 2.6 show the distribution of saltmarsh sites in the UK, in the former case by size (see also Appendix A2.3.2). Lowland marshes, by definition, inhabit low lying geographic areas and account for the majority of saltmarsh habitat in the UK. Examples of lowland marshes include those of the Wash, Morecambe Bay, Liverpool Bay and the Solway Firth. In contrast, upland areas do not form continuous swards of saltmarsh habitat but, instead, support a more scattered distribution of mainly small, isolated marshes, either associated with minor estuaries, as is the case in England and Wales, or at the head of Scottish sea lochs where there is shelter from wave action.

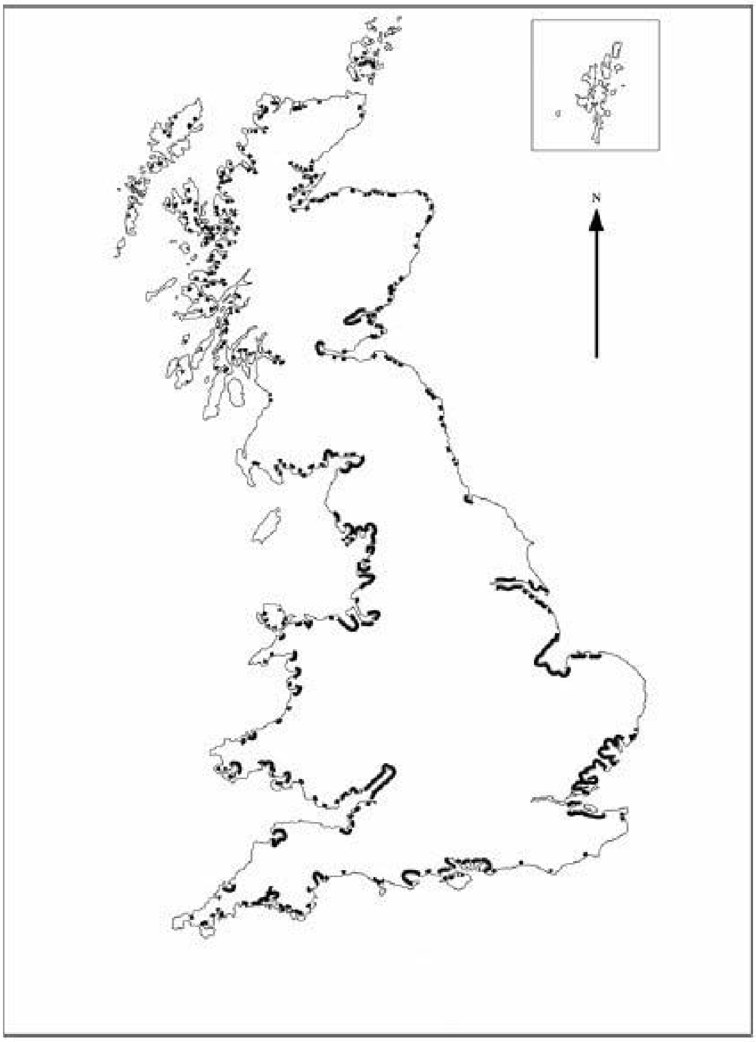


Figure 2.6 Distribution of saltmarshes in the United Kingdom (from Boorman, 2003)

Table 2.1 indicates that England accounts for over 70% of saltmarsh habitat present in the UK, with over 45% of that total occurring between Lincolnshire and Kent. Of the estimated 6,000ha of saltmarsh in Wales, nearly half (2,876ha) can be found in Llanelli and West Glamorgan; while of the 380 saltmarsh sites that are present in Scotland, over 70% are less than 10ha in extent, with Nithsdale on the west coast accounting for over 1000ha of habitat.

Table 2.1 Distribution of saltmarsh sites in the United Kingdom, showing distribution of sites by size (cited in Boorman, 2003)

Region	Area (ha)	Sites > 100ha	Sites < 10ha	All Sites	Av. area (ha)
England	32,500	59	16	120	270.8
Scotland	6,748	14	280	380	17.8
Wales	6,089	8	15	57	106.8
N. Ireland*	239	0	6	15	15.9
Total	**45,337**	**81**	**304**	**577**	**78.6**

* Refers to designated saltmarsh sites only

2.3.4 Saltmarsh as ecosystems

Saltmarsh productivity

Saltmarshes are believed to be highly productive environments, exporting large quantities of available carbon and energy (mostly in the form of detritus) into the water column and thus forming the basis of a rich estuarine ecosystem (examples are provided in Appendix A2.4.1). This view stems largely from studies undertaken in the early 1960s on the east coast of the USA on the growth and production of smooth cord grass marshes. However, although it is possible to demonstrate the high productivity of individual plant species and communities, in fact there is relatively little work to support either the idea of a consistent net export of materials by saltmarshes or of an intimately interconnected saltmarsh-estuarine ecosystem.

Not enough is known about the interrelationship between primary productivity in saltmarshes and their overall contribution to estuarine productivity. A range of technical difficulties exist in measuring aspects of the system such as decomposition, productivity, transport and consumption. Notwithstanding this, it is known that the primary production of saltmarshes can be very high. The primary producers, which convert solar energy to chemical energy through photosynthesis, include both vascular plants and algae; where the contribution of the latter to total productivity is difficult to measure and is largely unknown, but may be as high as 50%.

Invertebrates

Saltmarshes are not normally recognised for their rich and varied invertebrate fauna. They present difficult environments for colonisation by invertebrates due to the changes in salinity and humidity caused by periodic tidal immersion. However, far from being restricted in the diversity of invertebrates (see Appendix A2.4.2), saltmarshes are likely to have both a diverse and abundant fauna. The fauna is a mixture of marine, freshwater and terrestrial species which are adapted in various ways to the environment. Marine species tend to occur lower down the marsh and often burrow to avoid desiccation. Terrestrial and freshwater species occur mostly in the upper marsh and in transition zones, and have adapted to, or avoid, immersion in saline water.

Doody (1992) reports that, in Britain, terrestrial invertebrates inhabiting saltmarshes number some 293 resident species, of which 148 are found exclusively in saltmarshes. Marine species that occur in and under the marsh surface are varied and abundant, ranging in size from the smallest mud-dwelling mollusc to quite large burrowing crabs. In the higher and drier areas of the mudflat/saltmarsh interface the marine invertebrate fauna is largely limited to detrivores, such as the amphipod *Corophium* and the gastropod *Hydrobia*. Such studies as exist also suggest that, where it survives, the upper sections of marsh may be very diverse.

Differences in the distribution of species have been observed in relation to the plant communities. The presence of individual species is often closely associated with the type of vegetation that occurs.

Cream-spot Tiger Moth, *Arctia villica*, a nocturnal moth most frequently found on the coast
© Chris Gibson, English Nature

Birds

Saltmarshes are an extremely important habitat for a number of bird species which use them for a variety of purposes, including roosting, feeding, moulting and breeding (see Appendix A2.4.2). Throughout the seasons bird numbers fluctuate markedly, with greater densities occurring during the winter months. Successful breeding by a variety of birds occurs on the upper levels of open saltmarshes following the high spring tides in April and May. Of the seven or so species of birds which breed on saltmarshes, only the Redshank (*Tringa tetanus*) occurs in significant numbers. Approximately 50% of the UK's breeding population of redshank, which represents about 15% of the total breeding population of NW Europe, is supported by saltmarsh habitat (Norris, 2000). Of this around 1.5% occurs on the Wash, making this site internationally important for breeding redshank (Norris, 2000). In addition, transitional reedbeds and other marginal vegetation can be particularly valuable for rare species such as bearded tit and Savi's warbler. The structural diversity of the marsh is of crucial importance to some species, such as redshank, and high population numbers may be present in the best habitats.

Estuaries are particularly important for wintering wildfowl and waders, as they frequently support nationally and internationally important numbers of several species, most notably pink-footed goose (*Anser brachyrhyncus*), barnacle goose (*Branta leucopsis*), brent goose (*Branta bernicla*) and wigeon (*Anas Penelope*). These birds feed on a variety of intertidal vegetation, ranging from common saltmarsh grass (*Puccinellia maritime*) to eel grass (*Zostera spp.*), as well as agricultural grasslands and arable crops. Pioneer and low marsh vegetation, such as *Salicornia* and *Aster tripolium*, also provide an important feeding habitat for twite (*Carduelis flavirostris*), which consumes the numerous seeds produced by these plants.

Redshank, *Tringa tetanus* © Chris Gibson, English Nature

Of the wading birds, only redshank and snipe use saltmarsh in preference to the exposed tidal flat, probably because they like to be sheltered from view by the cover of vegetation. For these species, the saltmarsh represents the primary feeding location throughout most of the tidal cycle.

Other species, mainly grazing ducks and geese, use the saltmarsh itself as a source of food. The geese seek out open areas with close cropped or low vegetation and, even here, there are distinct preferences; while the brent goose preferentially feeds on eel grass (*Zostera* spp.) in the low marsh, the stronger grey-lag goose feeds on the tougher grasses of the marsh itself. Of the ducks, the wigeon feeds on both low and high marsh, normally at the water’s edge. For most of these species, the more palatable grasses favoured under high stocking densities of cattle and sheep are important to the continued use of the saltmarsh as a food resource.

Saltmarshes are also often particularly important for the smaller passerines, such as skylark, twite, reed bunting, rock pipit and Lapland bunting; some of which are winter visitors.

Curlew*, Numenius arquata*, © Chris Gibson, English Nature

Fish

Information regarding the extent to which fish communities use UK saltmarshes is limited due to the difficult sampling methods required to collect the data. However, a detailed study in Mont Saint Michel Bay, France, has shown that sea bass fry colonise the marsh creeks during the flooding spring tides and return to coastal waters on the following ebb tide (Laffaille *et al*., 2001 in Stevenson, 2002). This duration of 1-2 hours allow the juvenile fish to consume, on average, a minimum of 8% of their body weight, feeding on the numerous invertebrate fauna that colonise the marsh creeks. It should also be noted that a number of fish benefit indirectly from marshes by feeding on invertebrates which inhabit the adjacent mudflats and estuarine waters, which themselves feed on organic matter exported from the saltmarshes. The use of saltmarshes by fish (both as nursery and, potentially, breeding areas) is also supported by monitoring of managed realignment sites in Essex undertaken by the Environment Agency (Colclough et al, 2004).

Shellfisheries are not directly dependent on the saltmarsh although, historically, oyster beds are placed in creek bottoms, and pits and pools in the upper marsh are used for their over-wintering. However, the relationship between saltmarsh productivity and its wider role in providing a source of food and a nursery for fish and shellfish is unclear and, possibly, more important than studies have yet revealed.

Amphibians

Of the six native species of amphibians in the UK, the most threatened (the natterjack toad) is found in close association with saltmarshes. Of the 49 extant colonies of natterjacks in the UK, 16 are found on saltmarshes on the Irish sea coast of north west England and south west Scotland. Features of saltmarsh important to natterjacks include heavy grazing by livestock, the presence of ephemeral pools which desiccate rapidly and a pattern of tidal inundation which permits low salinity holding pools to develop in early summer, coinciding with the natterjack breeding season.

Mammals

Smaller mammals, such as voles and shrews, may be abundant on the upper marsh and provide an important source of food for birds such as short-eared owl and kestrel. However, saltmarshes are not known for rare mammal populations, although the otter may be attracted to larger sites because of the relative lack of disturbance. In areas where adjacent land is intensively cultivated or urbanised, these saltmarshes may provide the only "natural" land for some of the commonest creatures. Thus the occasional fox, rabbit, hare, badger and other typically terrestrial mammals are also present.

For marine mammals, the use of the edges of the marsh and saltmarsh creeks can be important and in some sites, such as the Wash, common seals use these regularly. Breeding colonies occur on many east coast and a few west coast estuaries, where they common seals may pup on tidal banks or saltmarsh creeks.

3 Why is saltmarsh worth managing?

3.1 Introduction

Saltmarshes have a *value* to humans that is based upon processes resulting from the interaction of their basic components; soil, water, flora and fauna. These processes generate the products, services and attributes that are valued by us (Stuip *et al*., 2002). English Nature (2002), for example, classifies the wide range of functions and services of saltmarshes into four main groups (see Appendix B1):

- Appreciation: enjoyment of nature for health, spiritual enrichment, the provision of better living environment, cultural context and artistic inspiration;
- Knowledge: a resource for general education, scientific and historic discovery and environmental monitoring;
- Products: sustainably harvested products, such as food, fuel, medicines and construction materials; and
- Ecosystem services: provision of basic life-supporting structures, including the maintenance of air, soils and climate and the mitigation of flooding and pollution.

http://www.englishnature.gov.uk/pubs/publication/PDF/valueofnat.pdf

However value is established, it is important to appreciate the link between the ecological processes taking place in a saltmarsh and the worth that it provides to people. This means that (Stuip *et al*., 2002):

- the values a saltmarsh provides depend upon its characteristics and processes; and
- the worth of values that a saltmarsh can provide is dependent on the way that it is managed.

The following sections briefly examine and discuss the value of saltmarsh, with particular reference to those areas that are of key importance to coastal managers, namely flood and coastal defence; ecosystem and conservation importance; and palaeoecology and archaeology. A summary of the concepts surrounding the economic value of these functions and services is provided in Section 3.4.

3.2 Ecosystem function and value

At the system level, saltmarsh habitat (and associated intertidal mudflats) can be considered to have a "natural" function as well as functions of anthropogenic value. The so-called natural ecosystem function of the habitat is complicated by the fact that its functional, ecological roles cannot be considered in isolation from the dynamic outcomes of the interactions between a wide range of processes (i.e. without some reference to human activity or value).

However, in the context of the management of saltmarsh habitat and its intrinsic nature conservation value, the following ecological functions are considered to be of most significance:

- Flood and erosion control (through wave attenuation);
- Pollution control and water quality (nutrient cycling and sediment retention);
- Waste decomposition and disposal (micro-organism processes and scavenging); and
- Habitat provision (spawning grounds for commercially exploited fish, habitats for plants, animals, insects, etc.).

3.2.1 Flood and coastal defence

Flood defences on low-lying open coasts and along estuaries are often fronted by mudflats and saltmarshes which form a first line of defence against wave attack. Wave energy dissipation (also described as wave attenuation) is reflected in a reduction in the wave heights experienced at landward sea defence structures (see Section 2.2.5). The presence of fronting marshes thus reduces the risk of overtopping as well as the structural undermining of defence structures and, ultimately, reduces costs for maintaining these defence lines.

Colne estuary, Langenhow, Open stone asphalt wall © Chris Gibson, English Nature

The profile of the role natural processes play in contributing to flood defence management has improved in line with increasing costs for sea wall maintenance and repair and due to the influence of sea level rise in accentuating existing problems along low-lying coasts. To this end, the value of saltmarsh (and fronting mudflat) as a functional, natural and potentially sustainable (i.e. self-repairing) wave break has been acknowledged although they may have lesser effect in attenuating extreme water level/wave conditions. The recognition that habitats form an integral part of coastal management has led to alternative and, potentially, more cost-effective and sustainable options for coast protection being developed and implemented (Möller et al., 2001). These include beach nourishment, foreshore recharge and, in the context of saltmarsh management most importantly, managed realignment of flood defences.

The effective attenuation of wave energy by saltmarsh confirms its potential for contributing to shoreline protection. Möller et al. (2001) investigated the likely attenuation and overtopping frequencies for a range of event return periods. This work, determined the effectiveness of saltmarshes in protecting backshore defences, when compared with unvegetated intertidal flat. This study showed that the occurrence of high overtopping discharges (i.e. those that are most likely to cause damage to the defences) is significantly lower when protection structures are fronted by saltmarsh. The main cost savings that can result relate to the lower acceptable specification of the sea wall.

Based on the assumption that a seawall without saltmarsh protection costs £5000/m then Figure 3.1 shows that savings of up to £4600/m could be made with an 80m wide saltmarsh. These values were derived several years ago and, therefore, have to be considered as comparative costs only. It should also be noted that the presence of marsh (and the cost savings obtained) should not be used to justify a sea defence scheme, i.e. this should be economically justifiable in its own right.

3.2.2 Pollution control and water quality

Several studies have demonstrated that saltmarsh can act as a sink for a number of compounds that are considered as pollutants, including herbicides, pesticides, organochlorines, polychlorinated biphenyls and heavy metals. This is likely to be of increasing significance under the Water Framework Directive and be an important driver for future saltmarsh management. The presence of these pollutants within estuarine and coastal waters can be largely attributed to human activity and their continued persistence in water and sediments can pose an environmental risk (e.g. contamination of shellfish stocks in estuaries). A significant proportion of these pollutants are adsorbed onto sediment particles, which become deposited on saltmarsh surfaces and thus are ‘removed’ from, albeit temporarily, aquatic systems. The combination of adsorption and the burial of pollutants under accreting sediment effectively in-activates these substances, making them unavailable, over time, to organisms and thus reducing the potentially toxic effects of bioaccumulation. As an example, tributyl tin (TBT) has a half-life period in the order of tens of years and burial of sediment contaminated with this substance over this time period can reduce loadings within estuary systems.

However, although these contaminants may be tied up in saltmarsh sediments for relatively long periods of time, shifts in the dynamics of processes can lead to the remobilisation of sediments. Cyclical patterns of erosion and accretion may, therefore, lead to the release and re-deposition of pollutants within a system until (and if) the material is deposited in longer term and system-removed sediment sinks (e.g. marine basins). Nevertheless, it should be stressed that deposition within estuarine systems, of which saltmarsh represents one of main depositional sinks, provides one of the key mechanisms for the removal and natural remediation of potentially harmful substances on a human timescale.

Nutrient cycling within saltmarshes can also have a significant effect on coastal and estuarine water quality. In this respect, healthy, functional saltmarsh habitat may have an important role to play in the control of nutrients which are important in determining water quality and, ultimately, human health. Saltmarshes within estuarine and open coast systems contribute to the cycling and availability of several key elements that are crucial in regulating biological productivity. For example, studies in France, England and The Netherlands, have shown a net export of dissolved nitrogen out of the saltmarshes (Boorman et al., 1994). The same study also showed net exports of phosphorous, albeit in much lower concentrations than nitrogen.

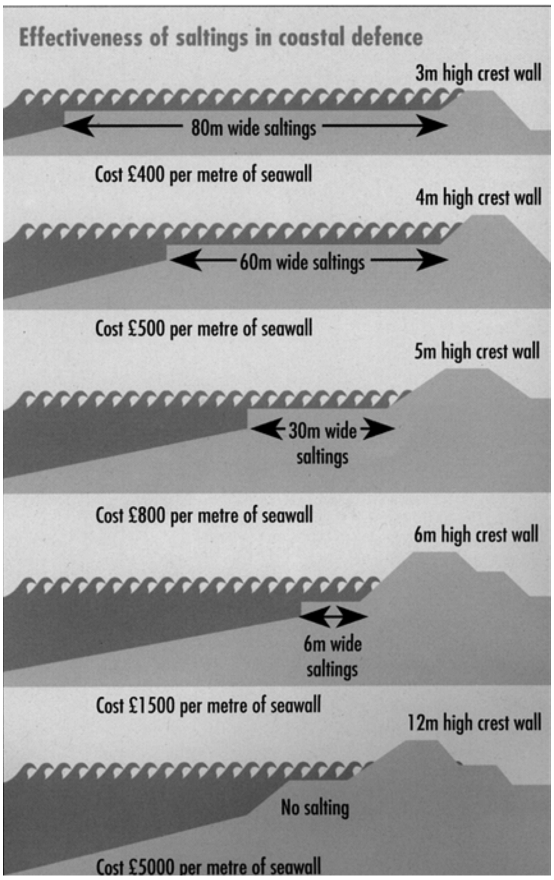


Figure 3.1 **Comparative cost benefits associated with the construction of sea defences in relation to extent of fronting saltmarsh**

Generally, the release of nitrogen and phosphorous from the saltmarsh occurs during the processes of the decomposition of organic matter, although direct losses by the leaching of nutrients from live plant tissues can also occur. The amounts released are high enough to account for significant increases in the activity of the estuarine plankton community and are thus of potential significance for many other estuarine communities (Boorman, 2000).

3.2.3 Biodiversity and conservation importance

The traditional view of saltmarsh habitat centres on specialist and geographically restricted salt tolerant plant communities. The rigours of the environment, notably caused by tidal inundation, restrict the range of plants able to tolerate the changes in salinity, desiccation and mechanical abrasion. However, despite this, in suitable conditions extensive areas of vegetation can sometimes develop, particularly where there is abundant sediment and shelter to allow the settlement of suspended particles from the water column onto the tidal flats. The resulting habitat is rare (with over 44,000ha in the United Kingdom) by comparison with peatland (1,300,000ha) or ancient semi-natural woodland (350,000ha) for example, and more comparable in size to other rare habitats such as calcareous grassland (43,500ha) and sand dunes (56,000ha).

Thrift, ***Armeria maritima*** **© Chris Gibson, English Nature**

Common sea lavender, *Limonium vulgare* © Chris Gibson, English Nature

In addition to the underlying interest of the specialist vegetation, saltmarshes support large numbers of both rare and abundant invertebrates and provide feeding and roosting areas for a large number of migrant and wintering wildfowl and waders. They also form one element in the mosaic of interrelated habitats which make up one of the most productive ecosystems in the world (estuaries).

The plant community mosaics that develop are obviously of interest; however, from a nature conservation perspective, their geographical range is also significant. Saltmarshes in the UK vary in composition from north to south, providing a floristic link between the saltmarshes of the Mediterranean and the Arctic. In addition, there are east/west gradients, which together provide a further contribution to the diversity of the plant interest.

Understanding these natural distribution patterns is also important in determining the significance of the changes to saltmarshes brought about by human activities (discussed in Section 4).

Evaluation of conservation importance of saltmarsh habitat

The value of a saltmarsh and its evaluation for nature conservation interests has traditionally involved the identification of important vegetation types, their sequence across an individual marsh and regional variation saltmarsh types. However, in recent years there has been greater consideration of the importance of saltmarsh-estuarine sites as ecosystems and the emphasis for determining value has shifted based on the interaction between processes and the resulting habitat complex. Thus, aspects such as geomorphology and the maintenance of processes have become of critical importance in assessing and evaluating the overall value of saltmarsh habitat from a biodiversity and nature conservation perspective.

Saltmarsh as a habitat

Saltmarshes support a wide range of plants and animals, many of which are specially adapted to the rigours of an environment where they are regularly covered by the tide. Consequently, many of the species present are found nowhere else. Because of the tendency of marshes to accrete and to develop in zones roughly parallel with the shore and related tidal regime, they represent one of the few examples of so-called primary succession (see Section 2.3.2). Furthermore, many of the larger estuarine saltmarshes represent some of the most extensive areas of natural and semi-natural habitat in an intensively used landscape. As such, they are important wildlife areas, because they are extensive, diverse, rare, ‘natural’ and vulnerable.

Geographical range of variation

Superimposed on the value the saltmarsh provides based on its associated plant and animal communities, is an interest which stems from the differences that characterise the geographical range and variation in the plant communities. Thus, the marshes of the south and east of England provide a link with those of the warmer south, including the Mediterranean, while those in the north which are more restricted, show affinities with those of the Arctic. The saltmarsh gradient in Britain is marked by a discontinuity between the Solway in the west and the Firth of Forth in the east. North of this line, species such as sea lavender, sea purslane and cord grass, which are dominant in the south, cease to be a major component of the vegetation.

Relationship with other habitats

The saltmarsh forms only one part in the complex sequence of habitats that make up the estuarine ecosystem. In the same way that the various components of the saltmarsh interact to support the wide range of plants and animals that live there, they are, in turn, important to the physical functioning of the whole system (see Section 2.2). At the same time, many saltmarshes only develop because they are sheltered from the extremes of tides and storms. Scolt Head Island in Norfolk, a barrier island characterised by shingle spits and sands dunes that enclose some of the most important examples of saltmarsh vegetation in Europe, clearly indicates the way in which one habitat is dependent on the morphology of another.

Interaction also occurs with mobile species where (at the level of an individual plant) an invertebrate species may feed on one part of the plant, rest on another and lay its eggs on yet another. At an even wider scale, wintering waterfowl tend to move between estuaries when they migrate and during the winter, and may nest in the uplands of Britain (Dunlin) or in the Arctic tundra (Knot).

There is no obvious physical link between saltmarshes in one estuary and another. However, many species travel between the marshes on individual estuaries and, for some of sea mammals and birds, between continents. The overall importance of the many links in the chain for the survival of much of the nature conservation interest of an individual estuary and its saltmarsh cannot be overemphasised. Thus, managing an individual marsh for nature conservation not only protects the plants and animals that occur there, but also contributes to the conservation of the estuarine ecosystem and, ultimately, the migrating birds which move between estuaries. Thus, whatever the individual situation on a saltmarsh, the large wheeling masses of wintering flocks of wildfowl and waders are a visual manifestation of a complex and rich environment.

Recognition of nature conservation value

The ecological value and importance of saltmarsh as a habitat is recognised through the designation of significant areas of habitat under a number of differing pieces of legislation and schemes (see Appendix B1.2). These designations variously reflect the intrinsic nature of the habitat, its function and the rarity value of some of the flora and fauna that it supports. In the vast majority of sites, saltmarsh forms a component of large site complexes (i.e. estuaries or open coastal sections) where its interaction with other habitats (e.g. mudflat or transitional terrestrial vegetation) and processes is of critical importance; and it is this habitat function that effectively being recognised by the designation(s).

3.3 Historical importance

3.3.1 Palaeoecology

Modern saltmarshes have developed on sediment sequences which commonly have been deposited over thousands of years. Saltmarsh sediments usually consist of mainly grey anoxic silts/clays, but peat units are also frequently present. At the base of the sediment sequence a palaeosol (buried soil) formed on the basal land surface, pre-dating the local postglacial marine transgression, can often be seen. Reconstruction of the environmental history of the site (‘palaeoecology’) can be achieved by analysis of microfossils (e.g. diatoms, foraminifers, pollen) and macrofossils (e.g. seeds, mollusc shells and insects) from samples of sediments. These proxy indicators give a picture of changing local environmental conditions during sediment deposition. Generally most clays and silts were deposited in intertidal environments, whereas peats formed in fresh to brackish water conditions. At some sites, the peat units include remains of *in situ* root systems and fallen trunks of ancient floodplain woodlands. Successive peat and clay units can be dated by radiocarbon, luminescence or palaeomagnetism, and the absolute levels of the contacts between these units can be determined in relation to OD. From this information, the environmental history of the locality can be established. That is, the date at which the basal land surface was influenced by rising sea-level and later successive phases of marine transgression or regression (see Box 3.1 for example). The data can also contribute to an understanding of wider sea-level changes.

Consequently, saltmarsh sediment sequences are of considerable scientific significance, and their conservation is an important component of saltmarsh management.

Box 3.1 Palaeocology case study: South Woodham Ferrers, Essex

Erosion by the River Crouch at the edge of the modern saltmarsh has exposed a section through a sediment sequence. Blocks of eroded sediment litter can be seen in the foreground of the photograph below. The 'bench' at the base of the section is a wood peat dated by radiocarbon to between 2900-2300 BC, overlying a palaeosol. Rising relative sea-level resulted in waterlogging of soils in the perimarine zone, suppression of microbial activity in increasingly anoxic conditions and the preservation of plant material as peat. As the marine transgression proceeded, the peat layer was overlapped by intertidal conditions and became covered by clays and silts. Further up the sequence a second peat layer (an 'intercalated peat') can be seen in the section as a horizontal line. This is a *Phragmites* peat, formed in a fresh to slightly brackish water environment between 380 – 680 AD. Some unknown factor, possibly the development of a barrier at the estuary mouth, resulted in restriction of tidal range and the development of freshwater habitats at this time. Renewed development of estuarine conditions led to this intercalated peat being sealed beneath clay and silt sediments (partly obscured in this photograph by *Halimione* plants). The basal palaeosol includes flints of the Mesolithic period and the intercalated peat includes a wooden trackway dated by radiocarbon to 567-664 AD.

Historical sediment sequence exposed through erosion © Peter Murphy, English Heritage

3.3.2 Archaeology

As noted in Section 3.3.1, saltmarsh sediment sequences often overlie a surface that was dry land before rising sea-level led to its submergence and, eventually, burial under silts, clays and peats. Buried soils ('palaeosols') frequently include artefacts dating to the early post-glacial, around 10,000 years ago, and at some locations well-preserved prehistoric occupation sites occur. Later sites and artefacts related to transportation, fisheries, salt production and other coastal activities can also be preserved within the sediments overlying this land surface (see Box 3.2). Organic materials, particularly wood for example, are well-preserved in anoxic saltmarsh sediments.

As illustrated by the examples provided in Box 3.2, erosion exposes sites that would otherwise remain unknown, however, it can eventually result in site destruction. English Heritage is, therefore, currently commissioning a series of *Rapid Coastal Zone Assessment Surveys*, intended to record eroding sites and to provide information that can be fed directly into the development of Shoreline and Estuary Management Plans, coastal strategies and coastal management schemes. The survey data are being incorporated into Local Authority *Historic Environment Records* (HER) and English Heritage's *National Monuments Record* (NMR). Both are GIS data-bases which can be accessed by members of the public and shoreline managers. However, any survey simply provides a 'snap shot' of what was visible at a particular time, and it is impossible to maintain a monitoring programme everywhere. Reports of sites newly exposed by erosion are, therefore, very welcome. Managers of coastal reserves and other sites are particularly well-placed to observe and report new finds. In almost all cases, recording eroding sites will involve minimal intervention and will entail drawing and photographing naturally-eroded sections and collecting artefacts and small sediment samples for dating or palaeoecological analysis.

Sites can also be damaged or destroyed by shoreline management schemes, such as managed realignment. Any ground-works, including excavation of borrow-dykes for new sea-walls or for the re-instatement of former creeks within realigned areas, can be damaging. However, it may be possible to preserve sites *in situ* by relocating proposed works. For example, Late Iron Age or Roman salt-producing sites ('Red Hills') were known to be present in the realigned area at the Essex Wildlife Trust Reserve at Abbot's Hall, Great Wigborough. Damage to these sites was avoided by slightly relocating planned drainage channels. In other cases preservation may not be possible, but full recording before sites are destroyed is usually considered to be acceptable mitigation.

For more information on archaeology and saltmarshes the reader is refered to Flemming (2004) and Fulford *et. al*. (1997).

For further information see www.english-heritage.org.uk under Public Policy>Coastal Policy. For advice, or to report a newly-exposed site, contact the appropriate County Archaeologist (usually located in the County Council Planning Department), the English Heritage Regional Office or Peter Murphy, Coastal Strategy Officer, Maritime Team, English Heritage, Fort Cumberland, Eastney, Portsmouth PO4 9LD peter.murphy@english-heritage.org.uk.

Box 3.2 **Examples of archaeological finds on Essex saltmarshes exposed by erosion**

The Stumble, Blackwater Estuary, Essex. Severe erosion has resulted in almost total loss of former saltmarsh sediments (except for a few small residual islands that can be seen in the left of the picture below). The old land surface is exposed over most of this modern mudflat and it is littered with Neolithic flints and pottery, representing long-term occupation from around 3700 – 2500 BC. The site is being monitored and recorded, but will eventually be destroyed by erosion.

© Peter Murphy, English Heritage

Purfleet, Essex. Flint and Cornish Greenstone Neolithic axes from a palaeosol exposed on the Thames foreshore are illustrated here.

© Peter Murphy, English Heritage

Box 3.2 **Examples of archaeological finds on Essex saltmarshes exposed by erosion (cont'd)**

Canewdon, Essex. A Bronze Age wooden paddle, dated by radiocarbon to 1225-998 BC, found in stratified saltmarsh sediments is shown in this photograph. At this time vessels were crossing the English Channel with cargoes of metalwork and other materials, which were traded along the coast and up estuaries.

© Peter Murphy, English Heritage

South Woodham Ferrers, Essex. A partly-excavated Bronze Age salt-evaporating hearth (1412 – 1130 BC), exposed by saltmarsh erosion, can be seen in the photograph below. Salt production is one of the most ancient estuarine industries. There were many Iron Age, Roman and Medieval salterns around the English coast, and the industry still continues today, for example at Maldon where the "curious crystals of unusual purity" are still produced.

© Peter Murphy, English Heritage

Box 3.2	Examples of archaeological finds on Essex saltmarshes exposed by erosion (cont'd)

The Stumble, Blackwater Estuary, Essex. Part of an Iron Age hurdle bridge across an ancient, now in-filled, creek (516 -390 BC), exposed by saltmarsh erosion, is illustrated below.

© Peter Murphy, English Heritage

Packing Marsh Island, Essex. Remains of the 19th to 20th century oyster fishery, including rectangular oyster storage pits, foundations of buildings and the hulk of a timber sailing barge (black outline near the middle of the image), used to transport the catch to London, can be seen in this aerial photograph.

© David Strachan, Essex County Council

3.4 The economic benefits of saltmarsh

Saltmarsh offers a wide range of different functions and services that are of value to people (see Section 3.1 above and Appendix B1) and, therefore, have a worth. This can be measured in a number of different ways. The easiest of which to understand is the concept of values having an economic worth that can be expressed in monetary terms. However, values can also be expressed in non-monetary terms, although such values are often more difficult to define.

According to Stuip *et al.* (2002) a number of different values can be defined according to the way that humans interact and benefit from the saltmarsh. That is:

- Use values are realised through human interaction -

    - Direct use values relate to the products and benefits that can be derived from the use of a saltmarsh, such as food, materials and recreational use;
    - Indirect use values arise from the benefits provided to existing activities or resources through their occurrence and can be thought of as services, for example, flood control; and
    - Potential future use value arises where there is uncertainty over the future demand for a product or service and/or its availability in a saltmarsh in the future. The potential future use value reflects the need to estimate, for example, the benefit of conservation of the saltmarsh.

- Non-use values relate to the essential nature of a wetland and the worth that is placed on it by particular groups - examples of non-use values include biodiversity or heritage.

Table 3.1 summarises the main types of saltmarsh value and the categories that they fall into. Notionally, consideration of all of the value types will give an indication of the Total Economic Value of a saltmarsh.

The concept of economic worth and definition of the functions of the feature (in this case saltmarsh) form the basis of economic appraisal. However, not all of the functions proposed for use in economic appraisal can be directly measured in monetary terms. Therefore, it may be necessary to identify ways in which impacts can be expressed as money values or to consider descriptive methods of valuation. There are a range of economic techniques available for placing a money value on impacts where a direct (e.g. market-value based) value is not available (see Appendix B2.6).

More generically, project appraisal can be used at a variety of different levels for the assessment of management options, from identifying where impacts may occur through to their full monetary valuation. The aim of any project appraisal is to provide a decision-maker with clear information on the choices that have to be made. This does not necessarily make the choices any easier, however.

The amount of detail required for a project appraisal will depend upon the type of decision that has to be made. In many cases, it will be sufficient to describe potential (or realised) impacts to saltmarsh habitat, for example, in qualitative terms or to report impacts and proposed mitigation measures in their natural unit of measurement (e.g. number of hectares of a particular habitat type created or restored). In other cases, particularly where it is necessary to justify expenditure or to obtain funding, it may be necessary to report benefits in monetary terms (see Appendix B2.5). For example, the inclusion of managed realignment as part of a flood defence strategy will require full project appraisal, where appropriate, including monetary valuation.

Table 3.1 Total economic value for wetlands

Use Values			**Non-Use Values**
Direct Use Values	**Indirect Use Values**	**(Potential) Future Use Values**	**Existence Value**
Saltmarsh products	Flood control	Potential future uses (as per direct and indirect uses)	Biodiversity
Recreation and tourism	Groundwater recharge	Future value of information	Cultural and heritage value
Transport	Shoreline stabilisation and storm protection		Bequest values (value for future generations)
Agriculture	Water quality improvement		
Peat/energy	(Micro)climate change mitigation		

Source: based on Barbier *et al.* (1996)

The potential use of project appraisal techniques in assessing the economic as well as other potential values of saltmarsh, using Appraisal Summary Tables (ASTs), is presented in Appendix B2.3.

Hamford Water © Chris Gibson, English Nature

4 Factors leading to saltmarsh change

4.1 Introduction

This section of the Manual explores the human and natural factors that may affect saltmarsh habitat and lead to both morphological and ecological change. Determining the nature of change and the causes and processes driving it are fundamental for saltmarsh management (should this be determined to be necessary); Section 5.2 provides further information. The issues discussed in this section, therefore, are intended to provide the basis (with the background information provided in Section 2 on saltmarsh morphology and ecology) for assessment of the nature of change or the potential outcome of change.

The first part of this section discusses physical process change and its potential effects on saltmarsh habitat; providing the background for a description of historical change in saltmarsh extent, linked to both natural changes in coastal and estuarine processes and morphological change brought about by human intervention. This historical context and discussion of forcing factors provides a platform from which existing or potential human activity can be assessed. Both past uses that have influenced the development of saltmarshes and current activities that could affect the condition and distribution of saltmarsh are described.

Table 4.1 illustrates the key impacts and pressures on saltmarsh habitat and these are then discussed further in this section.

Table 4.1 Key impacts and pressures leading to change in saltmarsh habitat (from Doody, 2001)

ENCLOSURE, including: Saltmarsh loss (primary land claim); The creation of grazing marsh; Intensive agriculture (secondary land claim). **GRAZING**: Ungrazed marsh; Low-moderate grazing; High levels of grazing; Formerly grazed marsh. **OTHER USES**: Turf-cutting; Hay-making; Reed cutting; Samphire gathering; *Spartina* planting or control; Sediment extraction. **SPORT AND RECREATION**: Bird-watching; Walking;	Wildfowling; Boating/mooring; Leisure fishing; Power boating and jet skiing; Sailing; Wind surfing; Horse riding. **ENGINEERING**: Maintaining sea walls. **POLLUTION**: Oil and chemical spills; Sewage; Litter. **SEA-LEVEL CHANGE**: Coastal squeeze; Flooding.

4.2 Physical and ecological processes: Change in saltmarsh extent and form

Saltmarshes are dynamic features which naturally experience change in extent (area), elevation, internal morphology and floristic composition over time. Some of the marshes currently in existence are very old features, having been established up to several thousand years ago (e.g. in the Holocene), while other are very young features, only a few decades old. In general, marshes older than about 100 years have attained (a degree of) equilibrium relative to the local tidal frame (which is related to mean sea level), but younger marshes are still in the process of moving towards an 'equilibrium' elevation.

Changes affecting saltmarshes take place on variety of temporal and spatial scales, partly as a result of the dynamic nature of saltmarsh processes and partly due to changes in external forcing factors, such as sea level, tidal range, wave climate, sediment supply and human activities (see Sections 2.2 and 4.3). It is, therefore, important to identify the scale of natural fluctuation, as distinct from any net directional change, before any intervention measures are considered and implemented (i.e. management measures, see Section 5). If net directional change is confirmed, it is then important to establish the causes of that change.

Hamford Water, Beaumont Creek © Chris Gibson, English Nature

There are five major types of change associated with saltmarsh habitat, details for which are provided in Appendix C (C.1). That is, change in:

- Lateral extent (area);
- Elevation (due to accretion or erosion);

- Creek density and morphology (caused by creek lengthening, new development or truncation) and/or change in the ratio of vegetated to unvegetated area;
- Floristic composition (plant species change due to their temporal position in succession processes, grazing and changes in sea level relative to the vertical sedimentation rate); and
- Vegetation vigour.

Eroding marsh, Copperas Bay, Stour Estuary © Chris Gibson/English Nature

Understanding and determining the nature of all of the above types of change is important, both with respect to maintaining the intrinsic ecological (conservation) value and the flood-defence importance of saltmarsh (see Section 3.2). The best standard of defence is provided by a wide, high saltmarsh, with low creek density, so that the saltmarsh acts as a solid berm colonised by tall and dense vegetation (Brampton, 1992; Pye and French, 1993). A reduction in marsh width, due to erosion or reclamation, will reduce its capacity to absorb (and partially reflect) wave energy. Similarly, vertical erosion, internal dissection and heavy grazing (which greatly reduce vegetation height) will reduce the capacity of the marsh to reduce wave energy and potential overtopping of sea defences behind. A reduction in plant vigour, such as the dieback of *Spartina* in southern England, may also have a potentially deleterious impact on the efficiency of wave and current dissipation across a saltmarsh.

Physical factors that may contribute to saltmarsh erosion include (further details are provided in Appendix C.2):

- Sea-level rise;
- An increase in the tidal range;
- Tidal asymmetry;
- Increased storminess; and
- Channel migration.

An increase in saltmarsh area most commonly occurs when vegetation progressively colonises adjoining areas of mudflat or sandflat, resulting in seaward progradation of the marsh or if a new natural barrier (offshore bar or barrier beach) develops. However, in some circumstances, an increase in area may also occur if the landward boundary of the marsh moves further inland. This can occur on (so-called) natural coasts when sea level rises and there is a low-lying or gently rising hinterland with no natural or artificial barrier to prevent landward extension. In the latter case, the seaward limit of the marsh may also move landwards or, if sediment supply is sufficiently large, remain static or even prograde. Of these scenarios, landwards translation of the entire marsh zone is most likely. If however, movement of the landward boundary of the marsh is prevented by steeply rising ground or an artificial defence, 'coastal squeeze' occurs and there is likely to be a reduction in marsh area (see Section 4.3.3).

4.3 Historical change in saltmarsh area

4.3.1 Introduction

Box 4.1 sets out the information relating to historical saltmarsh change that should be obtained in assessing the form and function of a marsh system, in order to undertake and understand the likely consequences of management.

Box 4.1	**Information required on historical change in order to assess the form and function of a saltmarsh system**
•	Age of the marsh in question (determined from OS maps, Admiralty Charts or published geological / environmental literature).
•	Recent historical rates of marsh edge retreat/advance (from air photos, maps, ground surveys).
•	Information about marsh elevation and local tidal levels (to establish the likely stage of 'maturity' of the marsh).
•	Information on the general nature of the marsh stratigraphy and lithology (from shallow borings).
•	Information about current and recent vertical accretion rates (from short term monitoring and analysis of sediment cores).
•	Information about temporal changes in local environmental forcing factors (sea level, tidal range and the wind / wave regime).
•	Data on human activities which have or are likely to be affecting the marsh (e.g. navigation, dredging, revetment construction, training wall construction, mud digging, grazing practices etc.)

The sections provided below on land claim and coastal squeeze summarise two of the key human influences on saltmarsh extent historically (and more recently). Further details are provided in Appendix C.

4.3.2 Land claim

The embanking and reclamation of many estuaries throughout the UK for agricultural and industrial purposes has had significant effects on saltmarsh morphology and ecology. A history of land claim in the British Isles, which began in several areas in Roman times, is provided in Appendix C (C.3.1 and C.3.2) and Figure 4.1 provides examples of land claim undertaken in The Wash and the Ribble Estuary.

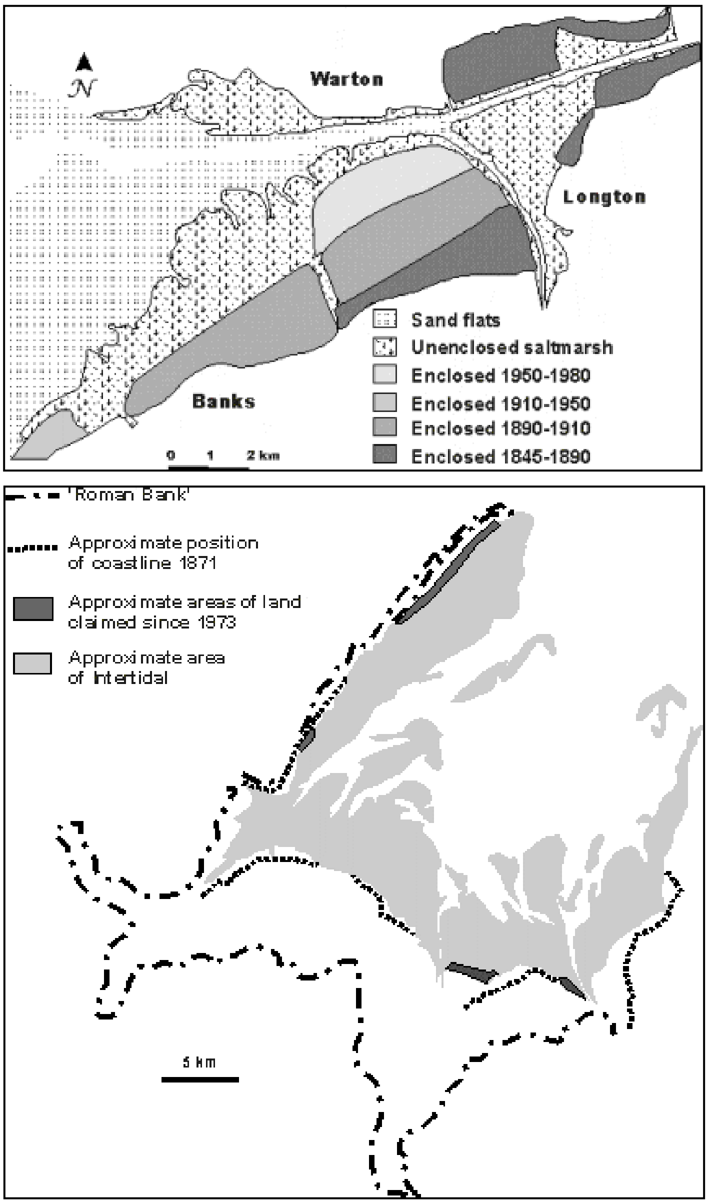


Figure 4.1 **Saltmarsh enclosure for agricultural use in the Ribble Estuary (from Doody, 2001) and The Wash (from Living with the Sea, 2003)**

Decreases in intertidal areas occur as land is reclaimed and embanked, affecting the progression of the tidal wave and tidal prism. Two main responses to embankment and reclamation occur: (a) enhanced intertidal accretion due to reduction of the tidal prism, as velocities are reduced and sediment can accumulate more readily, and (b) enhanced erosion outside the sea wall due to the concentration of excess tidal energy. In the second case, remaining saltmarshes on the outside of a sea embankment are likely to experience erosion due to lowering of the intertidal flats, retreat of the marsh edge and internal dissection as marsh creeks undergo deepening, widening and headward extension (Pye, 2000). The main channel may try and reach a new equilibrium through re-deposition of sediment but, in areas of ebb-dominance, a high proportion of the sediment may be exported to the open sea (van der Wal and Pye, 2004).

From an ecological perspective, sea walls built to exclude the tide are normally positioned on the upper, most diverse zone of the marsh, because enclosure has usually only been undertaken when saltmarsh is successionally advanced. This has resulted in the loss of the more mature saltmarsh, together with its associated fauna, as well as the truncation of the sequence of transitions to more terrestrial or freshwater/brackish habitat, thereby affecting other species that use the upper marsh for part or all of their life cycle.

Parts of southeast England also demonstrate more complex patterns of reclamation where, during the 19th and 20th centuries, some areas of reclaimed marsh were abandoned to the sea as economic conditions deteriorated and the maintenance of sea walls was scaled down. Following abandonment, new saltmarshes became established on those parts of the re-flooded land that were high enough in the tidal frame to allow plant colonization. New creek systems became established, eventually re-establishing a more natural pattern in equilibrium with hydraulic conditions (Crooks and Pye, 2000).

At the present time, the saltmarshes and associated areas of agricultural land along the coasts of much of eastern and southern England, as well as within the Severn Estuary, form a patchwork of semi-natural and higher, un-natural marsh landscapes. These landscapes reflect a complex history and the (often) partial adjustment of the saltmarsh to the process conditions and environmental forcing factors that now operate.

4.3.3 Coastal squeeze

In the 1980's concern was raised about the extent and apparent acceleration of the rate of saltmarsh loss on many parts of southeast and southern England. A study by Burd (1992), utilizing air photographs of different dates, concluded that significant saltmarsh area loss had indeed occurred in the estuaries of Essex, Suffolk and north Kent (see Table 4.2). The conclusions of this study were largely confirmed by a wider study of marshes in England and Wales (Pye and French, 1993), although this study also demonstrated that in some parts of the country, most notably the estuaries of northwest England, significant increases in saltmarsh area have occurred in recent decades. Net saltmarsh loss at most sites in southeast England was also confirmed by Cooper *et al.* (2000).

This documented loss of saltmarsh habitat has been attributed (at least partially) to the process of “coastal squeeze” (or is this context “saltmarsh squeeze”), which represents the result of interaction between the reclamation of former saltmarsh habitat and sea-level rise (see Figure 4.2).

The Essex and North Kent saltmarshes provide an illustration of the process. The saltmarshes in these areas have been enclosed by embankments for many years, with the creation of considerable areas of low quality agricultural land. At the same time there has been a relative rise in sea-level, resulting from a rise in mean sea level and the isostatic adjustment which is taking place in southeast England. Because the upper limit of the saltmarsh is constrained by a sea wall, the intertidal habitat is squeezed between it and the rising sea level. If the rate of sea level rise increases as a result of climate change, then the saltmarsh zone could ultimately disappear, as it has already done in some localities in Essex.

Table 4.2 Loss of saltmarsh in the estuaries of Essex and Kent 1973-1988

	Original area (ha)	Total area lost (ha)	Loss (ha) to reclamation	Loss (ha) to erosion	% of original area eroded
Orwell	99.5	39.9	7.5	32.4	32.6
Stour	264.2	129.5	13.3	116.2	44.0
Hamford Water	876.1	170.6	1.2	169.4	19.3
Colne	791.5	97.7	5.2	92.5	11.7
Blackwater	880.2	200.2	-	200.2	22.7
Dengie	473.8	46.7	-	46.7	9.9
Crouch	467.1	146.1	22.1	124.0	26.5
Thames (Essex)	365.9	105.6	22.3	83.3	22.8
Thames (Kent)	77.8	17.5	3.2	14.3	18.4
Medway	843.8	198.3	18.2	180.1	21.3
Swale	377.0	61.6	3.4	58.2	15.4

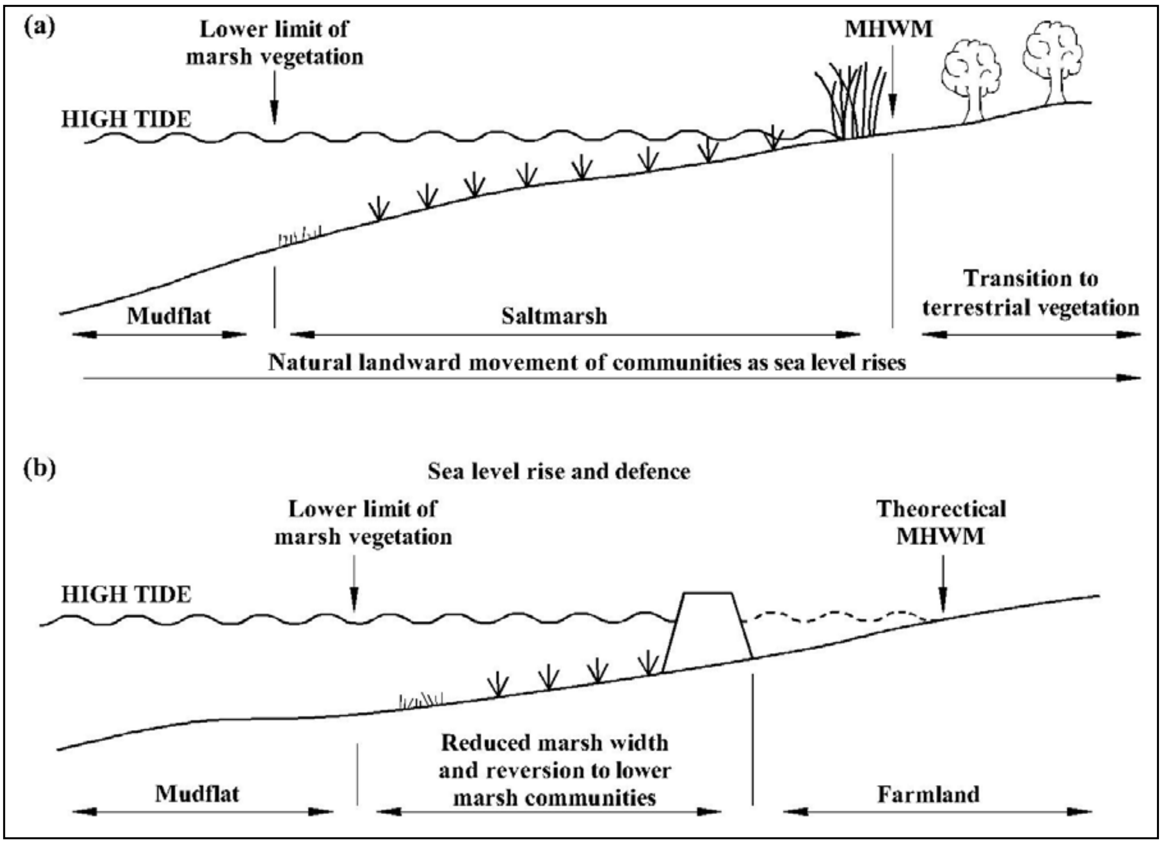


Figure 4.2 Illustration of the concept of Coastal Squeeze (a) before construction of Sea Wall and (b) after construction (from French, 1997)

4.4 Other human influences on saltmarsh management

4.4.1 Grazing

Grazing probably has a longer history of influence on saltmarsh in the UK than enclosure (the management of grazing is therefore addressed in Section 5.3.1). Its significance for the development of nature conservation interest is very important, as it modifies the vegetation and results in a major shift in the balance of flora and fauna. By comparison, other uses of the marsh tend to have a less obvious effect.

Orwell Estuary © Chris Gibson, English Nature

Grazing occurs extensively on marshes in Britain, especially in the west and north, and has a major effect on the structure and species composition of a marsh (e.g. through the grazing process itself and also soil compaction by grazing animals). The resulting nature conservation interest is markedly different between those areas that have traditionally been ungrazed, or subject to a low level grazing regime, and those which are heavily grazed (see Appendix C.4). In general, as grazing intensity increases, there is a loss of structural diversity as the standing crop is removed. At the same time, grazing sensitive species are removed from the sward, reducing species diversity. As the sward becomes shorter and dominated by grazing sensitive species, such as small grasses (e.g. saltmarsh grass and sheep's fescue), it is increasingly favoured by grazing ducks and geese. Therefore, the loss of structural diversity also adversely affects the saltmarsh invertebrate and breeding bird populations.

4.4.2 Alternative uses

A number of other human activities and practices have had, or continue to influence, saltmarsh processes, habitat and function. These are discussed in Appendix C.5, but include:

- Dredging, navigation and revetment construction;
- Sediment extraction;
- Turf cutting;
- Hay-making;
- Reed cutting;
- Samphire gathering; and
- The introduction of *Spartina*.

Hamford Water Sea Wall © Chris Gibson, English Nature

4.4.3 Access and amenity

Generally speaking, access to saltmarshes for normal recreational purposes does not represent a major problem. For the majority of people they are considered dangerous and inhospitable places which, even if they are appreciated, can be seen from the adjacent land.

Up until recently, the main value attached to saltmarshes was for its limited agricultural use or as important areas for wildlife, mainly of interest to bird watchers or as quarry for wildfowlers. Although the more general "wilderness" quality of the larger areas is increasingly being appreciated, saltmarshes are still considered as having low recreational potential. The range of recreational activities for which saltmarshes are used is described in more detail in Appendix C.6. Overall, however, recreational pressures are not very great.

4.4.4 Pollution

Saltmarshes are often exposed to a variety of pollutants, which may be derived from agricultural production on adjacent land or the contamination of water courses and sediments by industry (heavy metals), sewage disposal, landfill leachate and oil and litter that is transported into the system. All these forms of pollution are likely to have some impact on the saltmarsh, although there is insufficient information available to determine if they are a major threat to the ecological integrity of these systems. In general, saltmarshes are thought to be significant sinks for pollutants, which may be incorporated into the marsh through the sediments that accumulate or taken up directly by saltmarsh plants (see Section 3.2.2).

Most of the studies upon which the above information is based are at least 10 years old and from the USA. Further work undertaken at Imperial College, London shows that there are elevated levels of heavy metals in Essex saltmarsh sediments (demonstrating the locking-up of pollutants) and that there is some accumulation in the vegetation (Meakins et al., 1995 and Fletcher et al. 1995). However, this is not considered to be the primary cause of saltmarsh degeneration, although localised effects may be seen at outfalls where “shock loadings” of pollutants (and potentially their associated de-flocculants) exist (Leggett *et al*., 1995). The results of further studies on the effects of the use of agricultural herbicides on saltmarsh are included in a brief review of the main pollution sources provided in Appendix C.7.

4.4.5 Coastal defence and maintenance

The implications of continuing to maintain the current line of flood defences in estuary systems has already been considered in relation to the discussion of coastal squeeze (Section 4.3.3). In those areas where sea level is rising relative to the land, it would appear that a loss of saltmarsh is inevitable. The losses experienced in Essex and north Kent (see Table 4.1) provide an indication of what might happen elsewhere, particularly if the current scenarios associated with an increase in the rate of sea level rise due to global warming are realised.

The extent to which the maintenance of defences (i.e. holding the line) reduces the ability of the tidal zone to accommodate changes in sea level, the influence of storms and alterations in the tidal regime or the configuration of the estuary channels is potentially significant. The management response to these changes requires both consideration of the need to protect the saltmarsh and to maintain the flood defences in each case and each location. These issues are considered in a recent report published by CIRIA. The report, entitled ‘Coastal and estuarine managed realignment - design issues’ (Leggett *et al*., 2004), provides guidance on when ‘holding the line’ may be a viable economic or environmental option and when ‘retreating’ would better meet management objectives (see Section 5.3.9).

The direct effect of works to maintain sea walls can have implications for saltmarsh habitat both during construction and operational activities. Construction works can have an impact on the habitat due to a requirement for access across the marsh or works to the toe of the sea wall. Certain species that may be rarely distributed or sensitive to damage could be particularly at risk. Furthermore, works that stabilise the eroding edge of a saltmarsh may have long term effects on the development of the marsh which should be considered against the (potentially) short term gains associated with the works (see Section 5.3.7).

5 Saltmarsh management

5.1 Introduction – why and when to manage?

To achieve sustainable development of the coastal zone it is important to recognise the role played by natural and semi-natural habitats and to maintain and enhance these as part of coastal defence management. Within this, it is important to develop an understanding of the requirements of these habitats and how and when to intervene to enhance them for either to provide a coastal defence function or for their biodiversity value.

In the context of the wider estuary environment, saltmarsh maintenance or enhancement is increasingly being considered as a means of providing a long term and more sustainable approach to coastal defence (see Section 3.2). It also has the added advantage of enhancing the conservation importance of a natural habitat. Initiatives such as those undertaken by the 'Living with the Sea' LIFE Nature project (http://www.english-nature.org.uk/livingwiththesea/) address the issues of saltmarsh change. The seven pilot Coastal Habitat Management Plans (CHaMPs) make a key contribution to the development of coastal management policy, providing a better understanding of the impacts of coastal change over the next 30 to 100 years on the habitats and birds of European importance.

Blackwater Estuary, Salting restoration © Chris Gibson, English Nature

The Good Practice Guide to Coastal Habitat Restoration, produced as part of the Living with the Sea project, is a useful information resource for coastal managers. Based on case studies and experience from the UK and overseas, and by linking to other sources of information, it provides a ‘route to restoration’ for eight UK coastal habitats, including saltmarsh. Building on this, and other work, this section of the Saltmarsh Management Manual presents details of a range of techniques that are available for maintaining, restoring or enhancing saltmarshes. It also provides references for saltmarsh creation techniques that can be used in areas where there is no existing saltmarsh (see Sections 5.3.9 and 5.3.10). Although these techniques are not strictly related to the management of existing saltmarsh, they are considered here because they represent an important option for the future management of the coast and estuaries in those situations where the existing marsh is significantly threatened by erosive process (see Section 5.2.4).

At the broadest level, a scheme to maintain, restore or enhance a saltmarsh should be set within the broader context of an overall management plan for the coastline. Such an overall management approach should involve:

- Gathering data on the present-day status of the saltmarsh and on its recent changes (see Boxes 2.2 and 4.1);
- Identifying any problems and their causes (especially those that affect flood defences);
- Assessing the consequences of not intervening (in financial, social and environmental terms (see Appendix B2));
- Identifying suitable management options and assessing their likely efficiency and costs; and
- Further gathering of data to monitor the effectiveness of any scheme.

In general, if the physical processes within an estuary are suitable for saltmarsh formation, the saltmarsh will be self-sustaining. However, saltmarshes can degenerate for a number of reasons, including sea level rise, changes in drainage patterns, disruption to the estuarine processes and changes in land use on or adjacent to the marsh (see Section 4). It is important to understand where such change is the result of a localised impact and where it is part of a wider scale of change. For example, an estuary might change its shape in relation to a change in incident energy but the overall area of saltmarsh in the estuary may remain unchanged.

Where a saltmarsh is suffering from local erosion, some form of active management may be required to alter the environment and to achieve a more appropriate regime. Saltmarsh management in this context largely takes the form of the restoration of degraded marshes, as opposed to regeneration or re-creation (which can involve the establishment of marsh on areas where they have been entirely lost to land claim). Protecting or restoring saltmarshes by preventing erosion or promoting accretion (including seawards of the saltmarsh) is now less favoured, especially in areas where relative sea level is rising (Living with the Sea, 2003). In such circumstances, it may be more appropriate to adopt a strategy which accepts a landward movement of the saltmarsh to a more sustainable position in relation to physical change.

There have been considerable developments in the area of saltmarsh creation over the past two decades (especially in the USA and UK), as a result of which there are several comprehensive references available relating to creation and regeneration techniques (see Section 5.3.9). This section does not, therefore, concentrate on saltmarsh creation or regeneration techniques; rather it concentrates on the management of existing saltmarshes.

As a general rule, management is not required where the saltmarsh remains in a healthy, functioning state and, consequently, can respond and adapt to most changes. Conversely, if change is particularly rapid or (potentially as a result of such change) the saltmarsh has become degraded or is eroding, then a programme of remedial work may be required. In the latter case and if sufficient space is available to allow the saltmarsh to move landwards, then a natural process or roll-over may occur that retains both the flood management and biodiversity value of the saltmarsh (see Sections 4.2 and 4.3). There should be a presumption against interference in the landward retreat of saltmarsh, unless important assets are at risk.

Section 5.2 below is intended to help coastal managers decide whether or not it is appropriate to conduct saltmarsh maintenance and/or enhancement. Considerations include:

- the likely cause of saltmarsh loss or deterioration;
- the rate of loss;
- the cost-benefit of installing and maintaining the scheme; and,
- the potential environmental impact.

Basic guidance on the steps to be undertaken in determining the most appropriate course of management is also provided.

Section 5.3 then outlines the techniques that can be used for saltmarsh management based on a number of different requirements and Appendix D provides a series of case study examples. The potential environmental effects are also discussed and the effectiveness of the various techniques at maintaining and enhancing saltmarsh habitat is reviewed. In broad terms, the financial implications of different management techniques are considered in Section 5.4.

Routine monitoring of saltmarsh is also an important aspect of saltmarsh management. Without it, the first recognition of saltmarsh deterioration could be loss of a habitat or wave damage/increased overtopping to flood embankments and consequent damage to land-based assets. If intervention is left too late, then the damage to the saltmarsh could be too severe to respond with maintenance and enhancement schemes and major intervention may be required. Leaving things too late will also tend to reduce the options for management and to drive the solution towards landward movement of the defence line. Section 6, therefore, describes the general components of a saltmarsh monitoring programme, discusses the various techniques available for monitoring saltmarsh parameters and makes recommendations for monitoring programmes.

5.2 Guidance on the selection of suitable management plans

5.2.1 Introduction

The initial step in determining the appropriate level of management for a particular saltmarsh is the derivation of a clear set of objectives addressing what is to be achieved (e.g. a coastal defence function and/or to maintain/enhance biodiversity). A number of objectives could be assigned to any given scheme and these should be defined and agreed at the start of the process.

The selection of the most appropriate management measure(s) should be informed by a robust, but simple, analytical process (or appraisal) which enables the issues and the consequences of management to be fully understood. This is particularly important within the dynamic coastal and estuarine environments in which saltmarsh occurs, as physical and biological processes in one location may have consequences elsewhere within the system (which in turn may be of an adverse nature) (see Section 2). The following appraisal process is suggested to help ensure that a good understanding of the situation is developed and an informed process of selection is undertaken.

5.2.2 Appraisal of available options

The amount of detail required to undertake a structured appraisal will depend upon the type of decision that has to be made; project appraisal can be used at a variety of different levels. Technical management decisions may require a relatively simple appraisal (see below) while the inclusion of managed realignment as part of a flood defence strategy (see Section 5.3.9) would be likely to require a more comprehensive and detailed appraisal. Figure 5.1 provides an overview of the level of detail that may be required for different types of decision, relating to different management options. The figure provides an indication only of the appropriate level of detail required, but there may be occasions where more (or less) detail is required. It also provides an indication of the point at which project appraisal could be undertaken according to the type of decision to be taken.

In most cases, it is likely that the simple qualitative (and, where relevant, quantitative) consideration of the types of functions and services that would be impacted by the management activities proposed (i.e. described in words) will be sufficient to ensure that the 'best' decision is being taken. Other cases, however, such as in circumstances where compensatory habitat may need to be provided, are likely to require more detailed appraisal of impacts at the functional level to ensure that the right sort of outcome is achieved. This may require monetary valuation of the impacts, where this would build upon a description of the impacts in qualitative (words) and quantitative (numbers) terms. Appendix B3 provides further explanation of how decision making can be undertaken for each decision level.

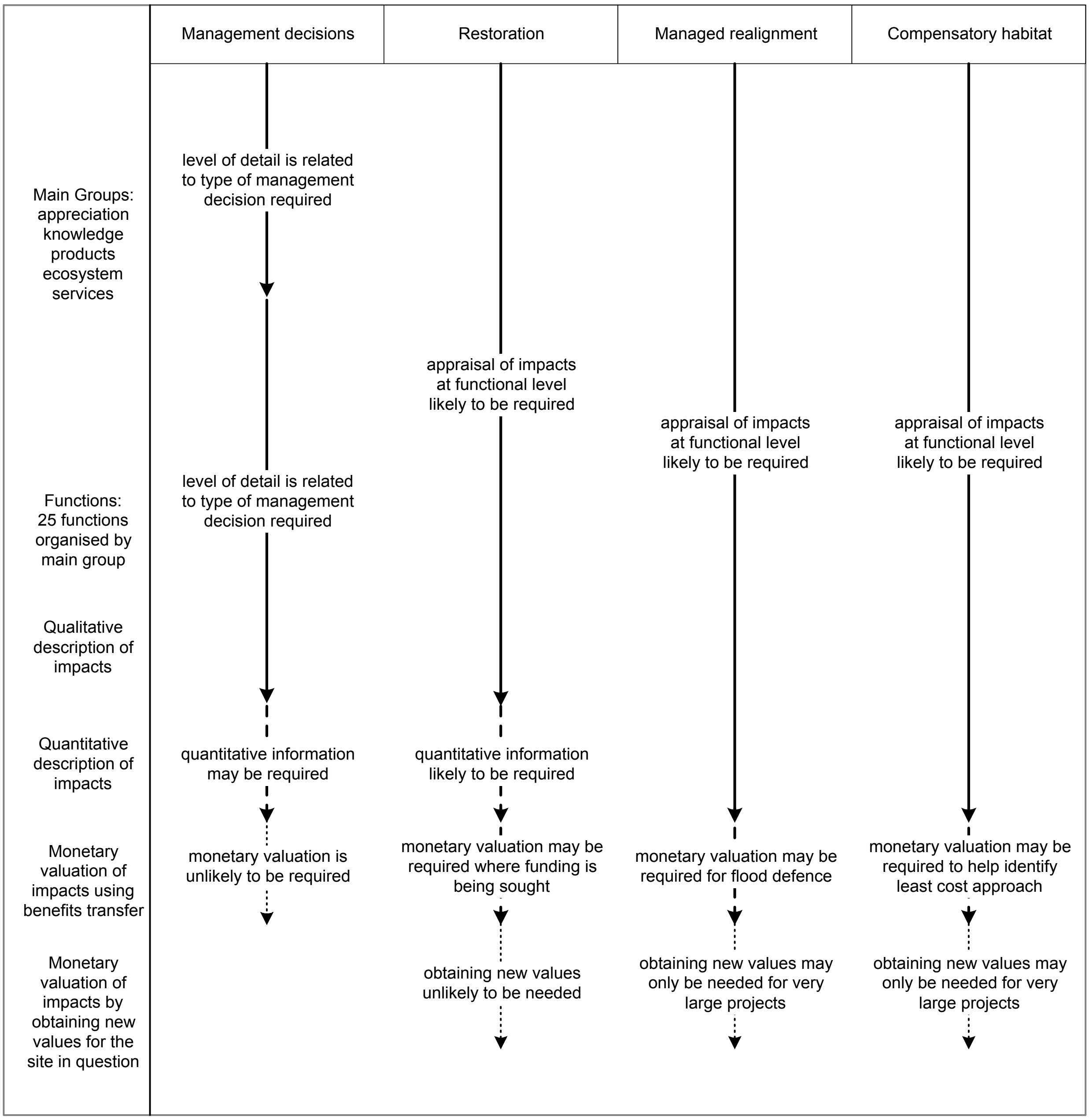


Figure 5.1 Overview of the level of detail needed for the appraisal of different management options; 'main groups' and 'functions' are described in Appendix B1

A method presently being used to compare management options is the Appraisal Summary Table (AST); see Appendix B2. This provides a mechanism for recording all of the predicted impacts (qualitative, quantitative and monetary estimates) associated with different options side-by-side, such that the appraisal process is transparent and auditable, and it is easier to make comparisons. An AST also provides a useful vehicle for presentation of information to, and discussion with, stakeholders when identifying and selecting a preferred option or course of action.

Different decision-making processes are proposed for the different types of decision that are likely to be required but, in all cases, the general approach is the same. The starting point is always to identify the objectives of the proposed actions, to define the baseline environment, to compare the alternative actions against the baseline and then select the action that will provide the greatest benefit, preferably at the least cost (see Box 5.1).

Box 5.1	**Steps in appraising and selecting a preferred management option**
Step 1	Define clear management objectives
Step 2	Describe the baseline environment (including the cause of the problem)
Step 3	Assess the implications of the alternative management options for the baseline environment
Step 4	Define the extent of any predicted impacts and actions (in environmental, social and financial terms)
Step 5	Select the option that will best achieve the management objectives (including do-nothing), provide the greatest benefit and the best value for money
Step 6	Design and implement a monitoring programme

5.2.3 Baseline data collection and analysis

This should involve a survey of the study area to determine the nature of the saltmarsh vegetation present, its condition and the general state of key parameters that may influence the success of management (i.e. distinct changes in saltmarsh width, erosion/accretion or the type/orientation of coastal defences). Box 5.2 describes the main tasks that should be undertaken as part of such a survey.

Box 5.2 Baseline survey tasks
Measure (or estimate) and record vegetated width
Look for signs of erosion
Estimate whether the rate of erosion is slight, moderate or rapid
Look for signs of accretion
Estimate whether the accretion is slight, moderate or rapid
Where available, analyse historic maps and aerial photographs to determine rate and nature of change in saltmarsh extent and distribution

The presence and extent of desirable conditions for successful saltmarsh development should also be established, as far as this is possible (see Table 5.1). In many cases this will need to be estimated from observations made of the site during the survey, however, there may be more detailed information available from other studies (e.g. research studies, coastal defence strategies, Shoreline Management Plans, CHaMPs and data from other schemes conducted in the area).

5.2.4 Saltmarsh classification

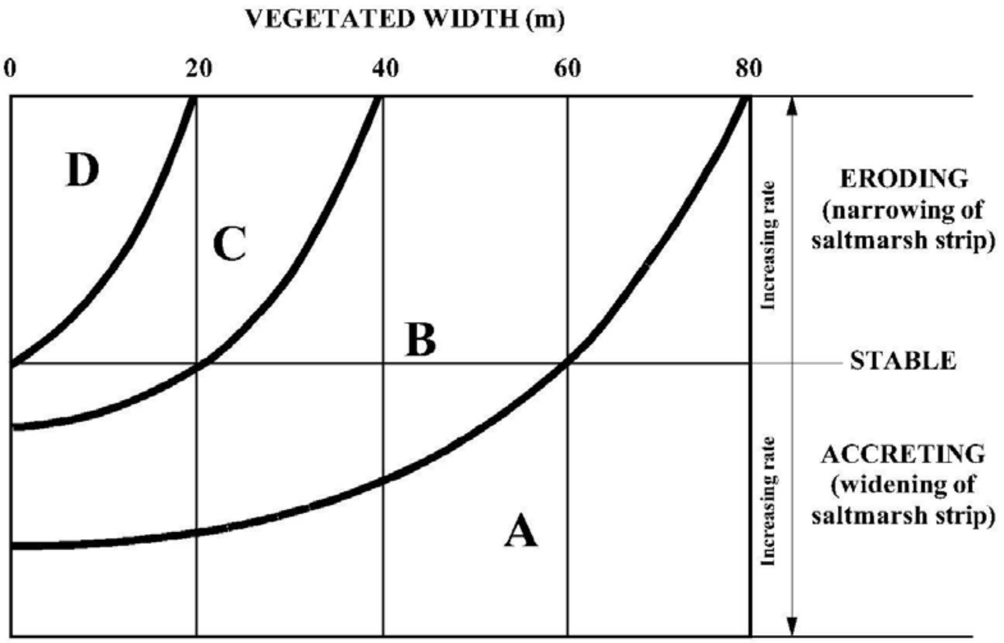
For each distinct section of coastline, the information obtained through baseline data collection can be used to define the 'status' of the saltmarsh based on a system of Saltmarsh Classification (see Figure 5.2). This type of classification uses the plan form of the saltmarsh to help to indicate the urgency of action (in terms of flood management) and the appropriate level of action required.

Table 5.1 Desirable physical and chemical conditions for successful saltmarsh development

Characteristic	Constraints
Exposure to waves and currents	Saltmarsh species will not establish or survive in exposed sites; protection against waves and strong currents will almost always be required at such sites (i.e. with a fetch greater than 2000m, sometimes less); a breakwater, for example, may be needed to "trip" waves moving inshore in order to prevent undercutting/slumping (see Section 5.3.5)
Tidal prism	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 to transport fine sediment (sand and mud) onto the saltmarsh surface
Elevation relative to the tide	Mean sea level to extreme high water level will generally provide suitable elevations for many saltmarsh species (precise needs vary according to the species); elevation which is too low or too high will inhibit species establishment, survival and community diversity/development
Slope and drainage	Steep slopes drain well but do not attenuate wave energy; poor drainage causing standing water can kill off existing species or prevent species from establishing; the best slopes are generally 3-5% downwards from landward to seaward; inadequate tidal flushing may lead to ponded water and the accumulation of toxins, or cause hypersaline salt pans
Sedimentation regime	Most saltmarsh species withstand sedimentation rates of 3 to 10mm per annum; in excess of 25mm/year may smother some (especially pioneer) plants; rapid sedimentation will cause the evolution from low or mid zone saltmarsh to high zone saltmarsh
Sediment grain size and depth; compaction	Plant establishment can be easier and more successful in well oxygenated sandy sediments with a firmer foundation (although note that planting is not a widely used technique; see Section 5.3.2); sandy soils may require higher energy to erode; although many low zone species can be found in much finer grained sediments. Shallow sediment depth can restrict vegetation growth; compacted soil will inhibit root growth (so it is recommended to use low ground pressure equipment when undertaking work)
Nutrient levels	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	Some seeds and young seedlings may be sensitive to full strength salinity; conversely, undesirable species such as alga may establish if salinity is too low. A number of saltmarsh species are semi-halophytic, that is they require fresh water to survive, and may show signs of stress or die in prolonged dry weather (lack of fresh water input) or where empounded (sea or brackish) water evaporates, such as in pans or saline lagoons.

Classification might equally use the saltmarsh vegetation succession to consider if, over time, the vegetation is:

- Generally tending towards more pioneer species - thus suffering greater inundation and becoming relatively lower in the tidal frame (and hence can be considered to be 'eroding');
- Remaining consistent in its assemblages - thus not developing to the next successional stage but keeping pace with change (and hence can be considered to be 'stable'); and
- Generally tending to more mature species - thus the saltmarsh in developing through a normal succession (and hence 'accretion' can be considered to be on-going).



Key:
A - No immediate risk to sea defences; monitor only
B - Investigate causes of change; consider implementing low cost maintenance and enhancement solutions; increase monitoring effort
C - Urgent need for study and (probably) intervening action
D - May not be possible to re-establish/maintain saltmarsh without major works or realignment

Figure 5.2 Saltmarsh Classification Diagram

5.2.5 Identify the possible cause of change

In order to design an effective maintenance or enhancement scheme, it is essential to determine the cause of the problem (that is, the installation of a wave break will not stop erosion due to plant death as a result of oil pollution). Moreover, if the saltmarsh does not face an imminent threat (i.e. it falls within categories A or B above), then there should be time to monitor and fully define the causes of erosion (see Section 6), and thereby the most appropriate management action, before intervention <u>needs</u> to occur.

It is normally possible to identify the cause of a localised erosion problem. For example, erosion adjacent to a sluice could be due to increasing drainage flows or contamination; erosion in close proximity to dredging (e.g. to create new berths) may be due to slumping or a change in wave/flow conditions; erosion on one side of a channel, coupled with accretion on the other, may indicate channel migration; while plant death adjacent to an outfall may be due to pollution or changes in freshwater discharge causing variable stress on plants. In cases where such localised erosion threatens coastal defences or causes the degradation of an important site for wildlife, it may be appropriate to consider correspondingly local schemes to stabilise or re-establish the saltmarsh.

In contrast, the cause of widespread erosion is often not obvious and there is likely to be more than one causal factor. Box 5.3 identifies types of saltmarsh change and possible causes.

Box 5.3	**Types of saltmarsh change and possible causes**
Reduction in saltmarsh width	
-	change in the shape of the tidal curve reducing the period available for sediment accretion to occur
-	increase in wave energy / increase in current speeds causing direct erosion through greater shear stress
-	boat/ship wash causing direct erosion
-	berth and channel deepening, leading to lowering of the intertidal area due to slumping (an increase in inshore water depth can also increase wave height in the intertidal zone)
-	channel meandering in the estuary as a result of changes to tidal or fluvial flow
-	change in the position of deep water channels or banks offshore, altering the pattern of waves and tidal currents
Creek lengthening and widening	
-	relative sea level rise (increasing the tidal prism)
-	change in the shape of the tidal curve
Change in the floral community	
-	relative sea level rise leading to a change in inundation patterns
-	grazing, potentially reducing diversity through alteration of conditions (including compaction and selective grazing; see Section 5.3.1)
-	change in freshwater/seawater input
Loss of plant vigour	
-	increase in wave/tidal energy causing rotation of plants, loosening roots and general demise
-	undesirable sediment chemistry (lack of nutrients, highly reduced environment etc.)
-	pollution (as a result of spillage or from terrestrial runoff including herbicides and pesticides)
-	disease (some species may be prone to diseases such as Wheat Rust)

5.2.6 Management option selection

As stated at the beginning of this section, the selection of the most appropriate management option should be informed by a robust and ideally simple appraisal, which enables the issues surrounding and the consequences of the management technique implemented to be fully understood. In most cases, it is likely that the simple qualitative/quantitative consideration of the types of functions and services that would be impacted will be sufficient to ensure that the 'best' decision is taken; while other cases are likely to require a more detailed appraisal of impacts to ensure that the right sort of outcome is achieved.

Table 5.2 provides an indication of the range of possible techniques or solutions available to combat ‘saltmarsh erosion’ (as opposed to a change in the floral community or plant vigour), where it is determined that intervention is appropriate. The Table includes situations where a saltmarsh may not be in immediate threat, Category A in Section 5.2.4 above, but where the technique could enhance or extend saltmarsh area. The circumstances in which different techniques should be used is indicated, based on the ‘state’ of the saltmarsh (i.e. classifications B to D; see Figure 5.2), along with the cause(s) of saltmarsh loss that can be addressed in each case. These techniques are discussed in more detail in Section 5.3 and Appendix D, along with techniques to improve ecological characteristics.

Table 5.2 Aid to scheme selection: saltmarsh erosion

Management option	**Saltmarsh categories for which the option may be appropriate**	**Notes**
Vegetation planting and/or Sedimentation fences (see Sections 5.3.2 and 5.3.3)	A, possibly B (i.e. consider the viability of implementing low cost maintenance and enhancement solutions)	Not suitable for areas suffering from wave erosion; More suited to aiding naturally recovering saltmarshes by enhancing accretion
Recharge (with mud) (see Section 5.3.4)	A, B, possibly C	Needs repeated application to maintain mudflat levels on an eroding shore (i.e. erosion will not resolved by a single application); Does not mitigate the causes of erosion, but can stop further recession if the rate of recharge equals erosion (therefore probably not suitable for C and D)
Recharge (with gravel/sand) (see Section 5.3.4)	A, B, C, possibly D (may not be sufficient in the latter case)	Banks of sand/gravel can be used to form artificial cheniers which may protect eroding marshes from wave and current erosion
Creative use of firm dredged spoil (see Section 5.3.4)	A, B, C, possibly D	Can combat undercutting and collapse of the saltmarsh edge and current induced erosion; Care must be taken not to degrade the integrity/quality of important nature conservation sites (i.e. through the introduction of clay onto mud)
Nearshore rock sills/breakwaters (see Section 5.3.5)	A, B, C, D	Can combat wave action; However, if not carefully designed, linear wave-breaks may exacerbate current induced erosion by channelling flows
Offshore wave breaks (see Section 5.3.5)	A, B, C, D	Can combat wave induced erosion
Armouring saltmarsh cliff edge(see Section 5.3.7)	C,D	Combats boat-wash, currents and waves
Managed realignment (or regulated tidal exchange) (see Sections 5.3.9 and 10)	A, B (consider as part of a long term strategy (i.e. 50 to 100 years) for coastal management), C, D	May be the only economically viable solutions in cases where it is not possible to re-establish or maintain the marsh (D)

It should be noted that it is normally not practical to attempt to combat saltmarsh loss caused by the widening and lengthening of creeks. Creeks lengthen in response to water flow from the marsh surface into the creek following tides that overtop the marsh and in response to changes in tidal prism. If vertical accretion lags behind sea level rise, the frequency of inundation will increase and, hence, creek length. Similarly, if the tidal prism increases the creek may lengthen in response. Possible management action includes the application of silt directly onto the saltmarsh surface to reduce inundation/prism and/or the erection of silt trapping structures. It may also be possible to armour creek banks (to below present sediment surface level) so that the response is to deepen the creek rather than widen it. However, these methods typically will be prohibitively expensive, except on a very local scale.

In all cases, but particularly in the case of 'hard' intervention (i.e. the use of clay, nearshore or offshore breakwaters and armouring the saltmarsh edge), care must be taken to ensure both the continued functioning of the wider coastal or estuarine system and that the 'integrity' of any important nature conservation sites is not damaged (e.g. the bird feeding value of a Special Protection Area (SPA) is not reduced by reducing the area of available mudflat). It is because of both the costs and the implications of hard engineering solutions for the wider functioning of coastal ecosystems, that soft solutions are now favoured and hard solutions rarely pursued (see Section 5.3).

Stour Estuary, Wrabness
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Hamford Water Nature Reserve © Chris Gibson, English Nature

As mentioned in Section 5.2.2, a method being used to compare management options where the decision-making process is more complex is the Appraisal Summary Table; further details are provided in Appendix B2. In this context, and for each option, a monetary value, as well as a quantitative assessment and qualitative description, can be placed on each potential impact (where this includes beneficial impacts). The approach taken to decision-making in this case is likely to vary according to the number of impact categories/criteria that are being considered (which will be dependent on the complexity of the decision being made) and that can be expressed in monetary rather than non-monetary terms (where it is most likely to be necessary to compare both). A full description of the various approaches available is provided in Appendix B3.

5.3 Saltmarsh management techniques

There are essentially three main approaches to managing saltmarsh, these involve:

- techniques to maintain or restore nature conservation interest;
- techniques that aim to manage erosion/accretion; and
- techniques to create new saltmarsh habitat (usually landward).

These are summarised in Box 5.4 and full details are provided below. Case study examples are also provided, and cross-referenced in the discussion of each technique as appropriate, in Appendix D. Further case study examples (including information on scheme design, materials and installation methods) are provided in Environment Agency R&D Note 473, *Maintenance and Enhancement of Saltmarshes* (Carpenter and Brampton, 1996) and ABP (1998) *Review of coastal habitat creation, restoration and recharge schemes* (www.estuary-guide.net).

Box 5.4 Techniques for managing saltmarsh
Techniques to improve ecological characteristics or to restore the marsh (where, for example, pollution or disease has occurred): • Grazing management • Vegetation planting • Source control and management of pollution events • Management of freshwater input/drainage • Management of access
Techniques for managing erosion/accretion: • Sedimentation fields • Intertidal recharge • Breakwaters • Vegetation planting • Source control • Other, less frequently used, hard-engineering techniques • Other erosion management techniques
Techniques for landward saltmarsh creation: • Managed realignment • Regulated tidal exchange systems

At a local level, techniques that improve the characteristics of or restore the saltmarsh (for example, grazing management or the control of drainage onto the marsh) are the most commonly adopted management measures. Where the problem is potentially more challenging and the saltmarsh is eroding, there has been a general shift in the approach taken to management away from techniques that aim to prevent erosion and promote accretion towards techniques that allow the landward migration. Traditional hard engineering techniques that have been used in the past have fallen out of favour due to their influence on the nature conservation value and 'functioning' of coastal and estuarine systems, particularly in areas adjacent to or within European designated sites (SACs or SPAs). Soft engineering techniques that do not permanently modify the landscape but rather work with natural processes are now preferred.

However, although traditional hard engineered techniques are now less favoured, they can be used in combination with several other techniques on a smaller scale. Therefore, the discussion of techniques that follows includes both hard and soft engineering approaches as, ultimately, they are potential techniques that could be applied in the right circumstances.

In order to assist in the selection of an appropriate management option, Table 5.3 (below) provides (by way of an example) a list of the possible causes of saltmarsh loss or degradation, the likely consequential effect and possible management solutions. However, <u>it is essential that these are defined on a case by case basis</u>, dependant on the objectives for the intervention, the nature (and quality) of the baseline environment and the cause of the change.

Table 5.3 Examples of possible management solutions based on the cause and effect of change

Cause	Effect	Potential Management Solution
Grazing pressure	Change in floral diversity	**Change the grazing regime** (see Section 5.3.1). **Monitor** species diversity; particularly if any rare or scarce species are believed to be present (see Section 6). Fence off any areas of particular sensitivity.
Grazing pressure	Localised erosion, generally in the upper/mid marsh	**Fence off eroded areas**, as once erosion starts it could increase rapidly if not managed. **Allow for natural recolonisation** but ensure that relief is suitable for vegetation establishment, particularly on creek edges. If planting is necessary, only plant species that are present in the adjacent area.
Change in tidal flows due to coastal development	Increase in scour and erosion	**Sedimentation fences** (potentially in conjunction with intertidal recharge) could be used to reduce the flow of water reaching the saltmarsh edge (see Section 5.3.3). In some cases, **planting** could be adopted. However, only native species should be used and ensure that they are used within the correct tidal zone. Note that it is only worth planting if there is enough sediment available to feed the saltmarsh (see Section

Cause	Effect	Potential Management Solution
		5.3.2).
Channel dredging	Slumping of intertidal area fronting saltmarsh	**Sediment recharge** into the estuarine system or onto intertidal area (see Section 5.3.4). Use of this technique, and the type of material to be used, will depend on the nature conservation/fisheries interest of the site and the ability of the system to 'hold' the sediment once it is placed. In some cases, this may require planting of saltmarsh vegetation, but only species already present on the site should be used, to ensure the sites' ecological integrity, and the marsh should be sufficiently stable to allow for growth of the leading edge. This will depend on the extent and rate of slumping. Some form of stabilisation may also be necessary, such as **sedimentation fences**. **Revetments** (see Section 5.3.7) should only be used as a last resort, as they will prevent the movement of material to the site and not allow for the colonisation of saltmarsh vegetation.
Loss of natural wave break offshore (e.g. removal of sandbank due to natural movement or dredging; change in the orientation of a tidal inlet)	Increased wave exposure causing erosion of the seaward edge of the marsh	**Nearshore rock sill/offshore breakwater**; dependent on the nature of the receiving environment and the objective of the saltmarsh management (e.g. if the erosion is occurring within an estuary that is important for shellfish or as a fish nursery, it is essential to determine the effect of placing a sill/breakwater both on the species concerned an on the water exchange rates and movement of sediment) (see Section 5.3.5); need to ensure that sediment is still available to feed the saltmarsh.
Sea level rise	Creek lengthening and widening Decrease in species diversity as saltmarsh squeeze occurs (see Section 4.2.3)	If allowing the natural roll back of the saltmarsh is not a viable option, then it is likely that the only option is to accept the loss of the saltmarsh. **Recharge** of sediment to raise saltmarsh levels may provide some additional time and reinstate diversity. **Managed realignment** should be investigated as an option to allow the creation of saltmarsh or allow natural roll back (see Section 5.3.9 and CIRIA, 2004).
Ship wash	Erosion of the seaward edge of saltmarsh and creek walls	**Reduce the speed of vessels** to a speed that reduces the wash caused by the vessel. If possible, change direction of approach of the vessel, to alter wave direction. In extreme cases, the use of **sedimentation**

Cause	Effect	Potential Management Solution
		fences can reduce the flow of water reaching the saltmarsh.
Recreational pressure	Change in floral diversity	**Prevent pressure** through interpretation boards. Restrict and/or control access through the use of boardwalks over the saltmarsh. In some cases **planting** could be used to recolonise degraded areas, in order to prevent further erosion. However, only use species present in marsh already to maintain biodiversity
	Localised erosion, generally in the upper marsh	
Change in freshwater/seawater input	Change in floral diversity	Dependent on the management objective of the site, manage the freshwater input to the site via **sluices** (see Section 5.3.6). In some instances changes to salinity could increase diversity within the overall site. Large scale changes (e.g. due to an increase in freshwater input), however, could lead to the loss of saltmarsh vegetation as halophytic plants are displaced from the site.
		Potential for **improvement of drainage** to facilitate flushing of water (see Section 5.3.6).
Pollution	Change in floral diversity	Preventative measures are necessary to stop pollution from entering the site (**source control**) (see Section 5.3.6).
		Extreme events, such as oil spills, should be dealt with on a case-by-case basis, but oil should generally be left to degrade naturally.
	Loss in plant vigour	Potential for **improvement of drainage** to facilitate the flushing of water. This is dependent on the nature of the pollutant and the period of exposure.
Disease	Loss in plant vigour	Potential for **improvement of drainage** to facilitate flushing of water. However, this will be dependent on the nature of the disease. Also potential for **planting**, but ensure that chemical conditions are suitable prior to planting as certain diseases can render the soil conditions unsuitable for colonization. Certain plant diseases may be species specific, so consider the use of alternative species within areas subject to die-back due to disease.
	Localised erosion	

5.3.1 Grazing

Summary

Grazing management is by far the most common form of saltmarsh management undertaken in the UK. However, its use is restricted to improving the nature conservation interest of a marsh rather than performing any specific saltmarsh protection function. Marshes that have not been previously intensively grazed are usually more diverse than those which have experienced it in the past. However, such sites are uncommon and most marshes in the UK have experienced some form of grazing pressure for mainly agricultural purposes.

Continued grazing of such marshes is generally preferred as, once disturbed, formerly grazed marshes do not regenerate into the previously rich and diverse marsh community that existed prior to grazing. Rather, they develop into a sward dominated by a few grazing/trampling tolerant species, the growth of which can be mutually exclusive to other plants, such that recolinisation by other saltmarsh species at any stage in the succession is prevented.

Description

The use of grazing animals as a tool for managing the nature conservation interest of a saltmarsh is well documented (Chatters, 2004; Paterson & Burrows, 1998). In terms of grazing management, three types of saltmarsh are generally recognised; ungrazed saltmarsh, grazed saltmarsh and formerly grazed saltmarsh (recognising that marshes that have experienced livestock grazing in the recent past are generally encouraged to maintain a degree of grazing rather than grazing being abandoned altogether). For a more detailed discussion on the effects of these approaches the reader is referred to Appendix C.4.

The adoption of a particular grazing regime will be dependant on the nature conservation objectives for the marsh, as different species of plant, invertebrates or birds will favour specific saltmarsh assemblages over others. Once these objectives are defined the selection of a suitable grazing regime will normally fall into one of three categories:

Lightly grazed

Grazing by native herbivores, such as ducks or geese, and/or low levels of intermittent grazing by livestock (typically at a ratio of 2 to 3 sheep or 0.7 to 1.0 young cattle per hectare, between April and October (Beeftink, 1977)). This level of grazing is probably replicates most closely the ‘natural’ ungrazed system, typically proving good structural diversity and a wide range of species of plants and invertebrates, plus grazing intolerant species.

Moderately grazed

Livestock grazing at typical densities of 5 to 6 sheep or 1 to 1.5 young cattle per hectare between April and October (Beeftink, 1977). This level of grazing produces an ‘intermediate’ conservation value and the communities that result are very dependant on the type of grazers used (e.g. cattle tend to produce a more structurally diverse vegetation than sheep).

Heavily grazed

In terms of nature conservation, this is the least preferred option. Grazing levels are typically 9 to 10 sheep or 2 to 2.5 young cattle per hectare, again, between April and October (Beeftink, 1977). These stocking densities really only apply to the agricultural sector rather than saltmarsh management, as the botanical and invertebrate biodiversity achieved is low. In addition, breeding birds nests can be affected through trampling.

An ideal situation would be to aim for a range of grazing pressures, and thus sward heights, across a site. This would enable a range of species adapted to specific niches to co-exist along with other species suited to a different level of grazing pressure (Lambert, 2000). However, in practice, this is very difficult to achieve as most sites experience a conflict of management requirements. Fortunately, there is a natural tendency for a range of sward types to develop, as grazing can be quite localised, e.g. at access or watering points. There then should be a reduction in grazing pressure away from these areas towards the periphery of the marsh, with a corresponding change in sward heights. However, this is easier to achieve on large rather than small sites and on more deeply dissected marshes than on ones with few drainage channels (Lambert, 2000).

Another method of grazing management involves the *rotation* of livestock across the saltmarsh and/or adjoining areas and throughout the year. A grazing regime in a specific area for a specific length of time promotes localised disturbance and allows plants with high growth rates and low growth forms to colonise. After grazing has ceased for the year (e.g. cattle mainly graze April to October), or has moved on to another area, the saltmarsh has time to regenerate, potentially increasing sward height which, in turn, can lead to an increase in sediment accretion.

Constraints

The above stocking densities are indicative only, as each site will vary in terms of existing environmental conditions and historical grazing regimes. Furthermore, determining stock densities may be difficult if the livestock have access to other areas, e.g. adjacent farmland.

Grazing across a marsh can be very localised, decreasing significantly from the sea wall, where pressure is greatest, to the pioneer zone which may be largely unaffected (Patterson & Burrows, 1998).

Potential effects

A range of impacts can be associated with grazing, some of which are dealt with in Appendix C.4. The main effects are (summarised from Chatters, 2004):

- The process of sedimentation is reduced;
- With high stocking rates, species richness can decrease;
- Species and plant communities of the lower saltmarsh can spread into the higher saltmarsh;
- Different vegetation patterns develop, especially in association with low stocking density;

- Litter production and population density of detritus-feeding invertebrates and their predators decrease;
- Immigration of invertebrates from higher saltmarshes into lower saltmarshes is reduced;
- The invertebrate community of lower saltmarshes spreads into higher saltmarshes;
- The number of plant-feeding insect species can decreases as a result of the destruction of the higher vegetation canopy;
- The surface roughness of marshes can reduce and, hence, their sea defence value; and
- Improved habitat for grazing wildfowl, such as Wigeon, can be created.

Monitoring

Monitoring requirements will depend on the purpose of the grazing regime. If the purpose is to improve habitat for breeding birds or overwintering wildfowl, then bird counts before and after using British Trust for Ornithology (BTO) survey methods will need to be carried out. Similarly, if the purpose is to increase terrestrial invertebrate diversity and/or plant diversity then post and pre-grazing surveys using established techniques (e.g. NVC surveys) should be undertaken.

If the desired objectives are not being met, then some consideration should be given to changing the stocking density.

Locations

Grazing management is undertaken at various locations in the North West (e.g. Morecambe Bay and associated Estuaries), on the Humber Estuary and at Orford Ness (by the National Trust). Case study examples are provided in Appendix D.

Further information
Beeftink, W.G. (1977). Saltmarshes. In: *The Coastline*, Barnes (ed.), R.S.K. John Wiley & Sons, Chichester, 93-122.
Chatters, C. (2004). Grazing domestic animals on British saltmarshes. *British Wildlife*. Vol. 15 No.6 pp392 -400.
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Packham, J.R. & Willis, A.J. (1997). *Ecology of Dunes, Saltmarsh and Shingle*. Chapman & Hall, London. 335pp
Patterson, I. & Burrows, A. (1998). Grazing the Wash. *Enact* 6 Vol. 1. pp 15-17.

5.3.2 Vegetation planting

Summary

Vegetation planting can be used in a variety of situations as an exclusive technique or, more commonly, in combination with other restoration or habitat creation methods. Through deliberate planting, particularly using *Spartina* species, erosive tidal flows can be dissipated by the plant stems, with the resultant effects of a decrease in current velocity, increased sediment deposition and an increase in the level of the mudflats and marshes.

Saltmarsh vegetation can only be established successfully, however, if the physical as well as biological conditions are satisfactory. Natural colonisation should, therefore, be considered as the preferred option for saltmarsh vegetation establishment rather than artificial transplantation; although planting or seeding initiatives nonetheless may 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.

Description

Saltmarsh vegetation will establish in areas of suitable elevation with sufficient protection from high energy tides and waves (see Section A2.2.2). Rather than waiting for natural colonisation to occur, increased sediment stability and wave attention may be achieved by artificially encouraging the growth of saltmarsh plants.

However, there are a number of considerations that need to be taken into account in determining the suitability of vegetation planting as a saltmarsh management technique and the types of plants that should be used. In summary, the following should be considered:

- Is there a history of saltmarsh growth? This will mean that it can grow in the area, but will also provide a seed supply for marsh succession and development;
- Is the coastline experiencing rapid erosion? If so, a planted marsh may not survive long and landward realignment may be a better option;
- Is the mudflat to be planted at a suitable elevation? Existing marshes will help determine the elevation at which pioneer vegetation will first appear;
- Is the mudflat slope suitable for marsh succession?; and
- Is the salinity, hydrology and substrate suitable for vegetation?

Wave action and the influence of tidal range are the most important components in determining the type of plants that should be used (if any). Exposed shorelines with high wave energy, which are not afforded additional protection from wave breaks, may experience plant wash-out or low survival rates for species/individuals unable to tolerate wave stress. The elevation of the planted surface and the relationship with tidal range, which will influence potential survival rates, should be used to determine the species selected. This requires careful consideration, as inappropriate times and durations of submergence will cause plant mortality. The combination of elevation and shore morphology with a particular set of wave conditions can also greatly influence the stress placed on plants. Similarly, the salinity of the water and the substrate is important in determining species survival rates, since some species are better able to tolerate highly saline conditions than others.

The ability of *Spartina* spp to survive under a wide range of conditions and to propagate by rhizhome has led to its widespread use in the UK for planting. *Spartina* has demonstrated the ability to colonise in different locations and in different parts of the intertidal in relation to the tidal frame. It has, however, also died-back in places, remained moribund in others, and smothered other indigenous species elsewhere (see Section 2.3.2).

Constraints

As far as possible, species selected for planting should represent the natural species assemblage for the area, in order to avoid the introduction of exotic species and problems with species competition; thereby maintaining the biodiversity of the site. Ideally, transplants should be taken from sources as close as possible to the intended planting site, since minor genetic differences may alter a plants ability to withstand particular environmental conditions.

Under UK and European Legislation, the consent of the relevant countryside agency (e.g. English Nature, the Countryside Council for Wales and Scottish Natural Heritage) is required for the introduction of any species into designated sites. It is, therefore, advised that the relevant agency is consulted at an early stage.

Potential negative effects

Establishing saltmarsh on mudflats can reduce the area available to feeding birds and, where mudflat is a designated feature, this could be considered to represent a significant impact.

Monitoring

Measurement of the existing environment prior to selection of this technique, or the identification of suitable species, should include the following:

- Topographic contour mapping of the foreshore (marsh and mudflat) related to Ordnance Datum. The accuracy of topographic measurement should be better than ± 10mm and the contour map should include 100mm contour intervals;
- Measurement of the wave climate and tidal regime over a range of timescales, related to the elevation of proposed surface, with an indication of the number of inundations per year and duration of submergence;
- Recording of the elevation of plants on surrounding marsh surfaces, to enable plantings to be made at the correct height for the geographic location;
- Vegetation mapping of adjacent marshes, with a full species list, or the nearest marsh habitats (noting their distance away). This allows species suitable to the area to be selected;
- Measurement of the salinity of the flooding water and proposed planting substrate, including seasonal variations;
- Recording adjacent land uses which may cause disturbance to planted marshes, e.g. through flushing by pollutants or stock grazing; and
- Measurement of the levels of pollutants and nutrients in the water and the proposed planting substrate to allow an assessment of potential mortality and/or the requirement for additional fertiliser or other soil amendments.

The future monitoring programme should be designed to assess the survival of the plantings, the need for further plantings and recommended changes to species types. It should also be possible to use the information gained from each scheme to plan and design future schemes. The information collected should, therefore, include:

- Percent survival rates of plants, plant vigour and vegetation cover, potentially using aerial photographs to assess spread of vegetation.
- Repeat vegetation mapping to assess change in diversity and to determine whether succession is occurring.
- Topographic contour mapping of the marsh and mudflat, related to Ordnance Datum, and vertical accretion measurements to assess whether the new marsh is accreting sediment.

Vegetation composition changes annually and, even if it is relatively stable, height and vigour can be highly variable from year to year. Measurements should, therefore, be repeated each year until a stable vegetation sward is established.

Locations

- Planting and sowing experiments, Tollesbury, Essex;
- *Spartina anglica* planting at Bosham, Chichester Harbour, West Sussex;
- *Spartina anglica* planting at Wytch Farm Gathering Station, Dorset;
- *Spartina anglica* planting using turfs at Cleaval Point, Poole Harbour, Dorset;
- Experimental realignment site at Abbotts Hall, Essex;
- Saltmarsh restoration programme for pollution control and Spartina anglica transplanting, Southampton Water; and
- *Spartina anglica* planting Humber Estuary Yorkshire.

Case study examples are provided in Appendix D.

Further information
For a more detailed assessment of vegetation planting the reader is referred to an Environment Agency study entitled “The restoration of vegetation on saltmarshes” (full reference provided below). The study considers seeding and planting issues, drawing upon experience both in the UK and abroad.
Brooke, J., Landin, M., Meakins, N. and Adnitt, C. (2000). *The Restoration of Vegetation on Saltmarshes*. Environment Agency R&D Technical Report W208.
Burd, F (1989a) *The Saltmarsh Survey of Great Britain*. NCC Research & Survey in Nature Conservation No. 17.

5.3.3 Sedimentation fences

Summary

The practice of using sedimentation fences was originally pioneered in Holland and Germany and was first applied in the UK in the late eighties/early nineties. It was originally applied in areas where ongoing intertidal erosion was a problem, particularly in southeast England. Following several experimental studies, the sedimentation field technique is believed only to be successful if the local sedimentary trend is towards accretion. In areas where the trend is towards erosion, the fields have proved ineffectual (Environment Agency, Anglian Region internal monitoring reports). Consequently, its use in recent years has declined and it is now used only in combination with a number of other techniques on a small scale, rather than as an exclusive, stand alone technique.

Description

Sedimentation fences are structures designed to slow the passage of water, thereby facilitating the deposition of sediment in suspension. Essentially there are two types; brushwood groynes and brushwood sediment fields or 'polders'.

Brushwood groynes

Brushwood groynes generally consist of two parallel rows of wooden stakes, spaced approximately 300mm apart at 600mm intervals, driven deep into the mud. Different orientations of the fences have been employed but, in general, the best orientation is shore normal (i.e. at right angles to the foreshore). A variety of materials can be used as infill between the stakes, including willow brushwood, geotextile claddings and straw. Overall, however, brushwood has been found to be the most durable. The groynes minimise wave action, slow currents, promote sedimentation and, to some extent, delay the departure of the ebb tide. Tidal velocities are reduced by the ponding effect and the erosive effects of wave and tide-generated shear stress are diminished, thus allowing the fine-grained fraction of the sediment to settle out (Colenutt, 2001). As a result, the sedimentation of suspended matter is enhanced, both behind the groynes and in front of the saltmarsh edge.

Sedimentation polders

Sedimentation polders enclose a width of mature upper marsh together with a similar width of mudflat seaward of the marsh, by the construction of a perimeter fence. Ditches are dug in a regular pattern across the polder to collect deposited sediment which is cleared and piled on the banks between the ditches. The fields can be up to 400m square, although many of the experimental sites constructed in the UK have been smaller, varying between simple groynes 30-50m apart and larger, more complex fields 100-150m square. Gaps in the fencing along the seaward line of each enclosure allow the tide to flow into a series of channels within the area. These are maintained to control the flow and sediment deposition. The main ditches are dug perpendicular to the coast while other trenches (or grips) are dug parallel to it. The main ditches direct the waters of the flooding tide onto the upper areas of the marsh sufficiently rapidly for them to carry the sediment towards the shore, instead of depositing it further offshore (Colenutt, 2001). This approach also involves re-excavating the ditches and grips and placing this sediment in the intervening space thus, over time, the general level is raised (as the ditches in-fill and create a new surface) until the process is no longer required. The pattern of gripping can be seen clearly in some eroding saltmarshes and, in the erosional phase, can provide preferential erosion lines.

Constraints

Ongoing maintenance is essential, as the fences tend to loose the infill material which is swept away by the tide and deposited on adjacent areas of saltmarsh, potentially causing vegetation mortality if not removed immediately. As the infill and damaged stakes are lost, the fences become less effective and erosion of the accreted material occurs. The grips must also be constantly re-dug to maintain their effectiveness and prevent the sediment from being washed out of the ditches.

Potential negative effects

The construction of the fences can have a major impact on the environment through trampling and disturbance during construction and maintenance. The infill material can be washed out of the fences and deposited on the marsh, with potentially significant deleterious effects on the vegetation (and in extreme cases to navigation). The structures themselves can have a local impact by increasing scour immediately adjacent to the fences. There is also a visual intrusion into the estuarine landscape at low tide and, potentially, a hazard to boat traffic at high tide. Rapid accretion of sediment can cause swamping of benthic intertidal invertebrates and, thus, may reduce the overall food resource available to birds (at least in the short term). Rapidly deposited sediment can also be unstable and erode away again on higher tides.

Monitoring

Pre-scheme monitoring should try to assess the accretion/erosion status of the mudflat/saltmarsh system. This can be achieved by analysing historic O.S. maps and/or aerial photographs. For a more detailed assessment, topographic surveys could be carried out to assess changes in elevation. Note that the technique is believed only to be successful if the local sedimentary trend is towards accretion.

Locations

Several sedimentation fences experiments were trialled in the late eighties/early nineties at various locations in the UK, particularly in Essex (see Holder & Burd, 1990); although monitoring of these sites suggested that their effectiveness was limited. Examples include Cudmore Grove and various sites along the Dengie peninsula and Appendix D details a sedimentation fence technique implemented on the Strood Channel, Essex.

Further information
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Holder, C.L. & Burd, F. (1990). *Overview of Saltmarsh Restoration Sites in Essex: an Interim Report.* Nature Conservancy Council.
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5.3.4 Intertidal recharge

Summary

Intertidal recharge aims to mitigate deficits in estuarine sediment by restoring the functioning of mudflats and saltmarshes through the introduction of sediment onto or adjacent to intertidal areas. In most cases this is considered to be a sacrificial sediment supply but can be an important response to critical conditions. It can provide a sustainable solution in some circumstances and provide additional time to investigate the sustainable options in others. Most schemes utilise sediment derived from the navigational dredging of ports and harbours and, in doing so, provide a 'beneficial' use for this material, but other sediment sources have also been considered.

Description

Coarse material derived from capital dredging is more typically suited to protective recharge schemes than finer material (which may be used to raise saltmarsh levels or provide material landward of the coarse sediment). The behaviour of sand and shingle, once deposited, is more predictable than fine sediment. In contrast, the finer cohesive material derived from maintenance dredging is less likely to remain at the disposal site unless protected in some way or placed in very quiescent conditions. The former may be achieved by sand and shingle placed as recharge material or through other constructed bunds (see Appendix D). Placing material in quiescent conditions is often practically difficult in terms of the access/costs for appropriate vessels/plant/machinery to handle the material. There is also a much greater potential for indirect ecological effects (e.g. through sediment re-suspension) which may be a particular issue for shellfish or where sediment loads may smother adjacent saltmarsh. The beneficial placement of maintenance dredged material within the UK, to date, has been relatively small-scale.

Water column recharge © Harwich Haven Authority

There are four ways in which dredged material can be used in this context. These are:

1. Recharge of reclaimed land to raise its elevation prior to managed realignment.
2. Direct recharge of existing saltmarsh to raise elevations for plant colonisation.
3. Sub-tidal placement of sediment or 'water column recharge' to reduce the tendency for erosion of adjacent intertidal margins.
4. Foreshore placement to increase the dissipation of wave energy, reduce erosion and/or trickle feed sediment back into the wider estuarine system.

Of all these applications, water column recharge and foreshore placement are the most widely used, with the latter receiving the most attention.

<u>Water column recharge</u>

Rather than relying on tidal currents to lift the material from the sea bed, water column recharge involves introducing dilute material directly into suspension. The key issue with this approach is that the sediment must be introduced gradually in order that it does not drop immediately to the sea bed and to increase the sediment concentration over a wide area by a modest amount.

There are different methods possible of sediment release; that is, pumping it back down the dredging pipe or by 'rainbowing' it into the air over the water. If the sediment is added too quickly, the density between the added sediment-water mixture and the ambient water will be too large, causing the sediment to descend quickly to the sea bed in a dense plume. As much initial dilution as possible must be achieved by introducing water as the sediment is released (if possible) and by releasing the sediment from a moving dredger.

The tidal currents in the estuary have a limited capacity to carry sediment, as energy must be extracted from the turbulence in the flow to act against the force of gravity causing the sediment to settle towards the bed. This is another reason for requiring adequate dilution. Fine muddy sediment settles relatively slowly, with typical settling velocities of $0.2\text{-}2.0 mm.s^{-1}$ in estuaries. Therefore, if the flow cannot carry the sediment, it will take some time to settle to the bed and may still be transported a reasonable distance before depositing.

<u>Foreshore placement: Direct placement of dredged material (pumping)</u>

The most rapid way to recharge a foreshore is by pumping material ashore. Two approaches can be used:

- Spraying from a dredger (rainbow discharging) moored close inshore, to cover the whole foreshore. This method is used most effectively along coastlines with low tidal ranges and low wave energy. The requirement for a shallow draughted vessel limits the amount of material that can be discharged. Consequently, this method is often restricted to small recharge schemes; and
- Pumping via a pipeline which runs up the beach from a dredger moored off the coast, potentially over the dredge site. Large volumes of sediment can be pumped onto the foreshore over relatively short time periods, thus making this technique more suitable for large recharge schemes. On a much smaller scale, the direct placement of marina dredged material via pipeline discharge over relatively short distances may be a potentially cost-effective option, involving no re-handling costs, storage of material or transportation to site by vessel (Colenutt, 2001). However, pumping distances and the potential disruption to navigation may restrict this option. Also, to sustainably replenish the entire intertidal and saltmarsh profile, pipelines would need to be permanently laid within the saltmarsh system or repeatedly mobilised and removed (Colenutt, 2001).

In many cases, depending on the nature of the material, some form of retaining structure (bund), either permanent or temporary, may be required to prevent the sediments from moving away from the site in which they were placed. This can be of particular concern when dealing with fine grained material which is delivered in a relatively fluid form on sloping ground, as the material may be lost due to gravitational forces. In important habitats (such as European designated sites), permanent structures are unlikely to be favoured.

Foreshore placement: Indirect placement of dredged material (‘trickle charging’)

Trickle charging is a process which involves the slow recharging of foreshores by placing sediment either at a single point, or at a series of points, on a beach, mudflat or in the subtidal and allowing either longshore or onshore currents (depending on location of sediment placement) to move and distribute sediment across the foreshore. Determining where to place the material will require a detailed understanding of longshore and onshore currents in the affected area. The advantage of this approach is that the resulting foreshore profile forms naturally and so should become an integral part of the mudflat/saltmarsh system. The major disadvantage is that the recharge process is slow when compared to direct pumping.

Constraints

The main constraints associated with sediment recharge, in particular from dredged sources, include:

- The use of finer sediments derived from maintenance dredgings may be limited. Cohesive muds require time to consolidate and dewater before becoming stable enough to support engineering structures or mature plant and animal communities. The timescale required for such processes might be outside the timescale for habitat creation or restoration schemes;
- Finding suitable sources of dredge material may not be easy. Disposal sites may be restricted by coastal development, the location of intake and outfall pipes, navigation channels, land ownership and the proximity of fisheries, in addition to the presence of sensitive animal and plant communities;
- Disposing of dredged material on land generally takes longer to plan, find resources, obtain permits and undertake, than disposal at sea (although beneficial uses have to be sought as part of the application process for a Food and Environment Protection Act (FEPA) license to dispose of dredged arisings offshore); and
- Disposal on land can provide further difficulties as many regulatory bodies may have to be consulted, including the Environment Agency under the Waste Management Licensing Regulations, 1994 (as amended).

However, the economic benefits of (and strong regulatory incentives for) reducing the amount of material to be disposed of at sea, can provide an incentive to encourage beneficial use schemes associated with development (or maintenance) in ports and harbours.

Potential effects

Although the use of fine sediment for intertidal recharge is more suited to the natural system, without management, it could cause smothering of shellfisheries in adjacent areas and may cause a navigation hazard to small craft in inshore waters. Conversely, the placement of sands and gravels on muddy foreshores can reduce the area available to feeding birds (and potentially introduce a 'foreign' material into the system, or one that has not been apparent for some time). There is also a potential risk of material being lost from the recharge site and the redistribution of sediments could cause an increase in suspended sediments.

Bolam and Whomersley (2003) present the results of a sampling program investigating invertebrate (macrofaunal) recovery rates following a beneficial use scheme involving the placement of fine-grained dredged material on a saltmarsh at Westwick Marina in the Crouch Estuary. Results indicated a rapid recolonisation of the fauna typical of the surrounding saltmarsh, with evidence to suggest that post-juvenile immigration was the predominant recovery mechanism at the recharge stations.

Potential beneficial effects include:

- Increased wave attenuation and coastal protection;
- Increased protection for marsh edge;
- Facilitation of future marsh development;
- Increased habitat for conservation interests;
- Increased wildlife potential for estuaries; and
- Useful employment of dredged arisings.

Monitoring

It is important that the processes operating in the coastal or estuarine environment are sufficiently well understood to allow an appropriate sediment recharge technique to be selected and an assessment of the overall suitability of the scheme. The minimum data requirements prior to carrying out intertidal recharge are, therefore:

- Historic analysis of maps and aerial photographs to determine the rate of saltmarsh retreat and changes in the high and low water marks;
- Topographic contour mapping of the foreshore (mudflat and saltmarsh), corrected to Ordnance Datum, to give an actual elevation that may be related to tidal inundation;
- Measurement of the wave environment and tidal regime;
- Analysis of existing sediment properties and grading curves;
- Analysis of sediment properties and grading curves of the recharge sediment;
- Modelling of wave climate, currents and sediment transport regime;
- Analysis of marine invertebrate communities; and
- Analysis of any existing pollutants in the foreshore and the recharge material.

Significant changes may be expected in the short term following recharge. Therefore, monitoring should be intensive in the early stages, reducing in frequency over time, with provision made for changes in the scheme based on the results of monitoring.

Locations

This approach has been implemented at various locations in the southeast of England, including: Hamford Water, the Blackwater Estuary, the Colne Estuary and the Orwell Estuary. Case study examples are provided in Appendix D.

Further information
For further information regarding the ecological effects of sediment recharge, the reader is referred to the DECODE (Determination of the Ecological Consequences of Dredged-material replacement) website maintained and hosted by CEFAS. DECODE is an umbrella group consisting of several organisations, each with their own field of expertise regarding the beneficial use of maintenance dredged material. The site can be viewed at: www.cefas.co.uk/decode.
Additional information on alternative uses of primary aggregates published by CIRIA, including brief case studies, can be downloaded at: www.ciria.org.uk/acatalog/c590.pdf
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5.3.5 Breakwaters

Summary

As for 'sedimentation fences', the use of breakwaters as an exclusive technique to prevent saltmarsh erosion has declined in recent years. Difficulties in obtaining planning permission and the move towards soft engineering approaches has led to the decline of this technique. It is now typically used only in combination with a number of other techniques on a small scale, rather than as an exclusive stand alone technique.

Description

Offshore and nearshore breakwaters can encourage the development of a stable saltmarsh/mudflat profile through a reduction in wave energy. Several types of breakwater have been used for general shoreline protection, which largely take the form of submerged rocky reefs offshore, using a shore-parallel line of individual islands. An alternative, cheaper option to rock breakwaters is geotextile tubes. They are long tubes made from strong geotextiles, which are filled in-situ to form breakwaters, groynes or levees. They can be used in water up to a metre deep and do not present the same difficulties in equipment access that rock or concrete structures face, with costs approximately a third cheaper (Living with the Sea, 2003).

In some cases a breakwater may be combined with brushwood fences, which connect the breakwater to the shore to act as a large-scale polder. The use of this technique in high energy wave climates, however, means that fences, if used, can be subject to severe damage. Breakwaters may also be combined with foreshore recharge and vegetation planting to enhance their overall effect.

They are usually positioned at or near low water to encompass as much of the intertidal profile as possible and provide protection for most of the tidal cycle. This has the advantage of allowing the circulation of sediment between the marsh and mudflat and the intertidal profile to respond to short term changes in wave energy. Where breakwaters are used without shore-connecting structures, there is also less disruption of longshore sediment transport processes.

Breakwaters, once installed, require less maintenance than brushwood fences and polders, although repeated assessment should be made of their stability or requirement for re-orientation.

Constraints

Given their potential influence on coastal process, the biological resource (which could be beneficial in certain circumstances) and the landscape, schemes such as the placement of submerged Thames lighters as breakwaters at Horsey Island require significant scientific justification in order to achieve consent (where this included detailed modelling the down-drift effects of the lighters). With the introduction of legislation such as the Conservation (Habitats &c.) Regulations 1994, it is likely that it would be more difficult to obtain consent for such an approach today (Mark Dixon, *pers. comm.*).

In general terms, hard engineering may not provide cost-effective and environmentally acceptable solutions to prevent saltmarsh erosion. Such techniques often conflict with “natural” processes and can require expensive repairs and regular maintenance in order to provide an adequate level of coast and flood protection from the effects associated with climate change.

Potential negative effects

The potential impacts of offshore wave breaks are similar to those associated with sedimentation fields, including visual intrusion, smothering of the invertebrate communities if accretion rates are high, local scour around the structures and potential hazard to navigation. Approaches such as the sinking of barges, in particular, can have an impact on the foreshore, as the fill material may be excavated from the landward side of each barge, removing this material from the mudflat.

Monitoring

It is important to determine the most suitable distance offshore, orientation and spacing of breakwater structures by modelling prior to installation. It may also be necessary to re-orientate breakwater structures as offshore conditions change, although this can be expensive. The minimum data requirements to assess site suitability are, therefore:

- Historical analysis of maps and aerial photographs to determine the rate of saltmarsh retreat and changes in the high and low water marks;
- Topographic contour mapping of the foreshore (mudflat and saltmarsh), corrected to Ordnance Datum, to give an elevation that may be related to tidal inundation;
- Measurement of the wave environment and tidal regime; and
- Modelling of the wave climate, tidal currents and sediment transport to determine orientation and spacing, requirement for shore-connecting groynes or suitability of foreshore recharge.

Post scheme monitoring should be similar to that recommended for brushwood fences and polders (see Section 5.3.3) as the aim of enhanced accretion on the foreshore is the same. In addition, however, the wave climate within and around the breakwater should be measured at intervals to check the design functions and ensure that it is still functioning as required.

Locations

Breakwaters have been placed offshore at various locations in Essex, including Horsey Island and on the Dengie Peninsula. For more information regarding specific schemes at Dengie, the reader is referred to Hodder and Burd (1990).

Further information
Colenutt, A. (2001*). Saltmarsh Management Techniques: a review*. New Forest District Council Coast Protection Group.
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5.3.6 Other management techniques

Any management system should aim to control unfavourable influences, so that events such as trampling, pollution and/or eutrophication can be prevented or at the very least minimised.
Techniques include:

Source control

Source control, that is, the control of pollutant inputs to a saltmarsh system at source, can only be achieved through local cooperation with adjacent land owners, particularly service providers (such as water treatment companies) and farmers. Identifying the source of any pollution is key to managing the problem, e.g. sewage discharge or the runoff of fertilisers/pesticides (including their de-flocculants).

Maintaining close relationships with local landowners should remedy most of these problems. If, however, the problem continues then the relevant regulatory authority may need to be informed.

Management of a pollution event

Works to restore a saltmarsh after an oil spill can be important, because cleaning vegetation and sediments is very difficult. The main generic options are:

- Mechanical recovery offshore from the marsh;
- Dispersal (using oil spill dispersants) offshore; and
- Booming of saltmarsh shorelines and inlets.

Of these options, if saltmarshes do become oiled, *the best approach is often to allow natural recovery*. However, intervention may be needed if:

- Free oil is present which may be spread with tidal action.
- Oil on the marsh surface threatens birds or other wildlife.
- The recovery time of vegetation is predicted to take several years.

If intervention is required, the main clean-up techniques include:

- Physical containment and recovery - booming and skimming of oil on the water in creeks and pumping bulk oil from the marsh surface, depressions and channels;
- Low pressure water flushing – however, results are variable, and the method must be used before oil penetrates the sediment;
- Sorbents - the rapid deployment of sorbents can reduce penetration into sediments;
- In-situ burning of oiled vegetation - while burning can increase damage, in winter, much of the vegetation is dead and the ground is likely to be wet enough to protect underground systems from heat damage; and
- Vegetation cutting – this may be justified if there is a threat to birds or other wildlife. This will have a lesser effect on subsequent yield if it is undertaken in autumn and winter.

Improvement of drainage

The management of drainage inputs to the site to control freshwater input, for example, can also only normally be undertaken with the co-operation of adjacent landowners. As for source control, the key to resolving this issue is the identification of the problem and then getting agreement to any remedial action that is necessary. This may involve the control of water inputs via a sluice or improving drainage to facilitate the flushing of water though the marsh. It may include altering existing or historic drainage patterns (potentially associated with land claim/reclamation) within the saltmarsh itself.

Again, defining the objectives of the improvement action will be central to determining the action that ought to be undertaken. In some instances, for example, changes to salinity can increase diversity. However, large scale inputs of freshwater will most often lead to the loss of saltmarsh vegetation.

Management of local erosion due to ship wash

This can be simply resolved, normally in conjunction with the body responsible for navigation, through an imposed (and enforced) restriction on the speed of vessels, to a speed that reduces the wash caused. It may also be necessary to consider changing the direction of approach of vessels, to alter wave direction, in the vicinity of an eroding saltmarsh.

Management of access

Continued public access to a particular saltmarsh area might sustain localised trampling and possible disturbances of nesting birds (in the summer) or wintering wildfowl. Even small numbers of pedestrians (particularly walking dogs) can disturb roosting and nesting birds (Boorman, 2003). The identification of areas sensitive to trampling or disturbance should be undertaken to assess whether access is having a damaging effect. Where necessary, the provision of public information on potential adverse effects and limited or re-routed access may be acceptable (Boorman, 2003). This can be achieved through the use of information boards that encourage appropriate use. The existence of Public Rights of Way around much of the UK's coast, however, can represent a constraint to limiting or diverting access.

5.3.7 Other hard engineering techniques

As discussed earlier, there has been a move away from hard engineering techniques which aim to halt erosion and/or promote accretion to softer techniques which aim to work with natural processes. However, although these techniques are receiving less attention, they could be used in the future on a smaller scale based on the site specific circumstances (and potentially in combination with sediment recharge or vegetation planting). In the past, such techniques have included:

Rock barriers

Rock barriers work in a similar way to sedimentation fences, in that they combat erosion by reducing wave energy and tidal currents, and produce calm water in their lee which enhances sedimentation (see Section 5.3.3). They can, however, have a significant ecological, hydrodynamic and landscape implications.

Rock armouring/revetments

Rock armouring or revetments have been used to halt lateral erosion at the leading edge of the saltmarsh and in creeks. They protect the cliff edge from mass failure by providing protection from wave action and tidal currents, but will limit the ability of the marsh to evolve or respond to changing forces, such as sea level rise.

Historically, this form of protection has been undertaken on the Humber, Severn Estuary and in the Wash. For a detailed case study regarding the Humber scheme refer to Appendix D.

The use of 'soft' revetments has also been employed where rolls of coconut matting (coirs) have been placed along the eroding saltmarsh cliff face. This largely experimental technique was implemented on Lymington marshes with limited success. The reader is referred to Case Study D.5 for a more detailed description of the technique and recommendations for improvements to the scheme.

5.3.8 Other erosion management techniques

Increasing roughness

In an attempt to combat erosion, enhancing the bed roughness has also been attempted using artificial seaweed. This consists of polypropylene fronds attached at one end to a geotextile mat which is anchored to the seabed. However, this has been largely unsuccessful due to the difficulties of attaching the mats to the unstable bed under breaking wave conditions.

Other techniques to increase surface roughness have included seeding mudflats with mussel sprats. Further information on this subject is provided in Soft engineering *techniques for high and low energy coasts* produced by UK-CHM (Defra and JNCC). The full report can be downloaded at:
www.chm.org.uk/library/ecosys/marine/ETMC001.pdf.

Invertebrate exclusion mats

Recent research by Hughes and Paramour (2004) has demonstrated that saltmarsh accretion and colonisation of pioneering species can be promoted by removing invertebrates using mulch mats (Appendix . A2.4.2) In particular, they discuss the effects of the polychaete worm, *Nereis diversicolor*, in terms of sediment instability (through burrowing) and herbivory (feeding on *Salicornia* spp seeds). They also suggest that the decline in recent years of the seagrass *Zostera* spp. may also contribute to saltmarsh erosion and suggest that sea grass beds could be transplanted to dissipate wave energy.

5.3.9 Managed realignment

Summary

Managed realignment is a so-called 'soft engineering' coastal management technique that has received considerable attention in recent years. Rather than working against nature (e.g. by fighting erosion) the approach adopts a method which allows the landward migration or creation of intertidal habitats (including saltmarsh) by the removal or breaching of an existing sea defence. Under the terms of the EU Habitats Directive

(92/43/EEC) and the Rio Convention it is seen as a suitable method for the creation of compensatory habitat following the loss of intertidal through, for example, land claim, dredging, coastal squeeze or coastal defence works. Nevertheless, the potential influence of realignment sites on the wider estuarine system can be significant. Therefore, extensive baseline survey is required to model or predict these effects, and to determine whether they are acceptable, before such a scheme should be progressed.

Managed realignment is not, therefore, strictly a technique for the *management* of saltmarsh. However, as discussed in Section 5.2, it is an important option in the range of options available to coastal/estuarine managers for both coastal defence and the maintenance of intertidal habitats. For that reason, it is also covered here.

Trimley Marsh Managed Realignment Site © Chris Gibson, English Nature

Description

Managed realignment broadly involves constructing a new flood defence line inland of the original, promoting the creation of saltmarsh (or a combination of mudflat and marsh) on the land between the old and new lines and, finally, removing the front sea wall either partially or wholly. In most situations, in the past, the land between the defences will have been reclaimed (from the intertidal) and thus, through shrinkage during drying out and possibly continued accretion seaward of the defence, may be at a lower elevation than the habitat in front of the sea wall. Infilling may therefore be necessary to help generate the required conditions for the new habitat. Such schemes can involve the use of dredged material, pumped onto the site in order to build up the level of the sediment to an appropriate height for marsh development. However, equally, surcharging a site with sediment may not be necessary, depending on the prevailing local conditions. This ideally results in the development of a new area of saltmarsh habitat, which acts as a protective buffer to the new sea wall and the higher ground behind.

The use of tiered defences involves creating a new sea defence line inland of the original and allowing only a degree of overtopping of the front defence. The rear defence will be at a higher level than the front line and protected by the front line and intervening land. The irregular overtopping of the front defence should allow halophytic vegetation to colonise and the creation of a new area with an enhanced ecological value.

Trimley Marsh Managed Realignment Site © Chris Gibson, English Nature

Controlled abandonment (as distinct from managed realignment) is more suitable in locations where there is a natural rise to higher ground and no new defence line is necessary. Again, however, active management is likely to be required to create new areas of saltmarsh behind the present sea wall. In this instance, once marsh becomes established, maintenance of the coastal defence would be discontinued and, with eventual failure of the defence, full tidal inundation of the newly created saltmarsh would occur. Both forms of managed retreat produce a wider intertidal profile that is better able to respond to coastal processes and to reduce the effect of coastal squeeze.

These approaches differ from *do-nothing*, in that some form of active management is carried out to create either a new saltmarsh habitat or a new sea defence line, or a combination of both. In addition, all such schemes should be monitored regularly to assess the changes in the new marsh and to determine whether any additional work is required. This is more likely to result in a viable saltmarsh than simply allowing the wall to disintegrate and flood the land behind, and should therefore be more successful in terms of both sea defence and habitat creation.

Techniques for creating and regenerating saltmarsh are well documented and the reference list at the end of this section provides relevant sources of information. In particular, comprehensive guidance on managed realignment techniques is provided in the CIRIA guide 'Coastal and estuarine managed realignment - design issues' (Leggett *et al.*, 2004). This report is divided into three sections, intended to provide easy access for different users. Part I explains the objectives of managed realignment; Part II discusses whether realignment is appropriate for a particular site and how it may be achieved; and Part III provides technical guidance on design and implementation. A review of managed realignment schemes that have been implemented is also provided in Appendix 4.1.1 of the document. The review identifies examples of best practice and lessons learnt relating to scheme design and associated impacts, discussing four case studies in detail. The reader is, therefore, directed to this document for a more in depth discussion of managed realignment and the conditions required to successfully implement a scheme. The rest of this section provides a summary of the main points that need to be considered when management realignment is an option.

There are many issues that need to be addressed when selecting a suitable realignment site. The main points are summarised in Box 5.5.

In addressing some of these considerations baseline data will need to be collected to predict/model the effects that the realignment scheme will have both in the realignment site itself and on the wider estuary. Such baseline data should include:

- Topographic surveys of the realignment site and adjacent marshes;
- Bathymetric surveys of the estuary;
- Current and suspended sediment monitoring; and
- Biological monitoring.

Box 5.5	**Key points to consider in the selection of a managed realignment site**
Tidal prism	The volume of water entering and leaving the estuary on each tidal cycle. This will be modified by increasing the intertidal area and could affect net accretion/erosion status of the estuary.
Morphology	Returning the estuary to a quasi-natural shape to allow processes to function 'naturally'.
Site history	Was the site previously saltmarsh? A past history of saltmarsh growth will mean that conditions favourable to such exist in the estuary.
Soils	How modified are the original marsh soils. Ongoing research is suggesting that land-use history is important in marsh generation success.
Surface elevation	Is the site high enough for saltmarsh vegetation to survive? Following initial claim, land often sinks due to compaction and dewatering. Land which has been cut off from the sea for long periods of time may well be lower than the limit of vegetation colonisation.
Surface gradient	Marsh zonation from pioneer to mature upper communities relies on a slope which, in turn, is related to submergence time.
Sediments	All marshes are fine grained, although some degree of variation exists. Increased coarser sediment due to land use practices may mean that drainage is too great.
Creek networks	Natural creeks are complex structures. Some debate exists as to whether it is advantageous to artificially create these or allow them to develop naturally (on reclaimed sites, residual creeks are often still apparent).
Tidal hydraulics	Main ebb/flood channels and current velocities. This factor will control the required width of the breach.
Breach location	It is important to avoid breaches open to predominant wave direction, as these can lead to scour and erosion.
Sediment budget	Is there enough sediment available for marshes to grow and develop without having a detrimental impact on the rest of the estuary?

Constraints

The Defra/Environment Agency (2002) review of managed realignment as a flood and coastal defence management option identified a number of potential constraints affecting opportunities for realignment. The relative importance of these factors will vary between schemes but, in general, consist of the following:

- Consents and legislation;
- Environmental issues;
- Funding and financial compensation; and
- Opposition from the community.

Each of theses constraints are discussed in more detail in the CIRIA managed realignment guide (Leggett *et al*., 2004).

Potential effects

- Risk of increased erosion in other areas of the estuary due to an increase in the tidal prism, which causes faster tidal currents.
- Short term loss of grazing in the interval between the die-off of terrestrial plants (due to saltwater irrigation), on what was rough grazing pasture, and colonisation by saltmarsh.
- Loss of ecologically valuable terrestrial habitat.
- Creation of saltmarsh and mudflat habitat that counteracts that lost to other mechanisms (such as coastal squeeze).
- Providing the opportunity for the coast line to respond 'naturally' to changes in estuary processes.
- Increased coastal habitat for nature conservation purposes.

Monitoring

Monitoring will have an important role, at both the implementation and post-project stages, in the assessment of the impacts of the project and to determine if the design is operating as intended. Normally, implementation monitoring will involve observing and recording any particular features, such as archaeological finds, that become exposed during construction or any impacts on, for example, shellfisheries. Post-project monitoring, and an associated action plan, may be set as a condition of a consent or license for the works (and will often be covered in an Environmental Impact Assessment).

The results of post project monitoring might lead to a re-design (or some other form of intervention or even compensation) where an unacceptable outcome is shown to occur. Intervention should only occur, however, where the degree of change is unacceptable (compared to pre-defined criteria) and/or where an unacceptable change has been shown to exist for a sufficiently long period of time; it is important to recognise that sites will evolve over time and so the need (or otherwise) to react to initial change should be carefully evaluated. Monitoring of projects can also feed into other projects by providing an understanding of scheme design and performance.

The principal monitoring techniques which apply to managed realignment include:

- Topographical survey;
- Monitoring intertidal accretion rates;
- Monitoring intertidal erodability;
- Flow monitoring;
- Monitoring scour and counter wall erosion; and
- Ecological monitoring.

For a more detailed discussion on monitoring for realignment sites the reader is referred to Defra (2002) and CIRIA (Leggett *et al*., 2004).

Locations

The first managed realignment scheme in the UK was implemented in 1991 at Northey Island, Essex and was followed by schemes at Orplands and Tollesbury, also in Essex. Several schemes have been carried out since, largely in the south east region, and most recently at Abbots Hall Farm (Essex) and Frieston (Lincolnshire). The reader is referred to the CIRIA guide (Leggett *et al.*, 2004) for a listing of managed realignment sites established in the UK to date. Case study examples are also provided in Appendix D.

Further information
The application of managed realignment for coastal defence and habitat creation has resulted in a number of papers and publications detailing best practice and lessons learnt. For example, Garbutt *et al.* (2003) and CEH (2002) note that colonisation of saltmarsh species will only occur in areas where the flooding frequency is considerably lower than that which characterises the environments in which the species concerned would normally grow. At both Northey Island and the Tollesbury realignment sites, pioneer vegetation has colonised at levels at which middle and high marsh species might be expected to grow. It is also becoming clear that sediment condition is critical to species colonisation, where the formation of compact substrates can preclude colonisation. Crooks *et al.* (2002) and Hazelden & Boorman (2001) discuss the relationship between sediment condition and drainage and suggest that realignment schemes should take into account pre-existing drainage systems and the possible benefits of engineering these systems prior to tidal inundation to facilitate saltmarsh establishment and growth. The RSPB have also produced a useful report detailing lessons learnt from a realignment scheme in the Cromarty Firth in Scotland (Chisholm *et al.*, 2004) and provide recommendations for project management.
The reader is referred to a very useful report published by English Nature discussing the success of various restoration schemes in producing intertidal habitat for birds (Atkinson *et al.*, 2001). The full document can be downloaded in three parts at: http://www.english-nature.org.uk/pubs/publication/PDF/ENRR425_1.pdf http://www.english-nature.org.uk/pubs/publication/PDF/ENRR425_2.pdf http://www.english-nature.org.uk/pubs/publication/PDF/ENRR425_3.pdf
Atkinson, P.W., Crooks, S., Grant, A. & Rehfisch, M.M. (2001). The success of creation and restoration schemes in producing intertidal habitat suitable for waterbirds. English Nature Research Reports. Report No 425.
Crooks, S., Scuhtten, J., Sheern, G., Pye, K. & Davy, A. (2002). Drainage and elevation as factors in the restoration of saltmarshes. *Restoration Ecology* Vol. 10 No. 3, pp. 591-602
Defra and Environment Agency (2002). *Implementing managed retreat as a flood and coastal defence strategic option.* R&D Project number FD 2008, Halcrow, 2002.
Garbutt, A., Gray, A., Reading, C. & Brown, S. (2003). *Saltmarsh and mudflat development after managed realignment*. Proceedings of the 38th DEFRA Flood and Coastal Management Conference, 2003.
Hazelden, J. & Boorman, L.A. (2001). Soils and managed retreat in South East England. *Soil Use and Management*. Vol 17. pp 150-154.
Leggett, D.J., Cooper, N. and Harvey, R. (2004). *Coastal and estuarine managed realignment – design issues*. CIRIA. Report No 681.

5.3.10 Regulated tidal exchange systems

Summary

Regulated tidal exchange is a form of saltmarsh creation that allows the controlled inundation of previously defended land with saline water, using a combination of pipes and sluices. It differs from realignment schemes in that the sea wall remains intact. It is a potentially valuable tool in two particular scenarios: where coastal defences are likely to remain in place for the foreseeable future; and as the first phase of a longer term realignment strategy. A small number of projects have been developed in the UK but there are examples of larger projects overseas in the Netherlands, Germany and the United States.

Like manager realignment, this is not strictly a technique for the management of saltmarsh however, again, it is an option that should be considered as part of a broader strategy for managing marsh habitat (i.e. coastal management).

Description

Regulated Tidal Exchange (RTE) Systems enable an area behind a sea defence to be gradually converted to saltmarsh and/or mudflats. The process uses pipes, sluices or tide gates to allow regulated tidal flushing by seawater to create saline or brackish conditions behind the defence. This is a slow process that allows the land and local species to adjust their soil chemistry to the more saline conditions required by saltmarsh and siltation to proceed gradually.

There are several techniques used to control the flow of sea water and not all techniques are suitable at all sites; some are more suitable for creating mudflats than saltmarsh. Techniques include:

- An open culvert, with no tidal flap through the sea wall. Tidal water will flow in and out on every tide as long as the invert level is around the mean low water mark. A variation on this method is to have a drop board on the landward side to prevent water flowing out of the culvert, creating a permanently flooded area.
- Culverts with manually operated flaps that let water through into an impoundment at high tide over several high tides, until desired water level is reached.
- Self regulating tide gates (SRTs) have one moving part and an adjustable float system, allowing the SRT to stay open and float on flooding and ebbing tides until the specified desired water level has been reached, at which point the SRT will close and stay closed. When the tide recedes on the outside of the site, the SRT automatically reopens, allowing the impounded water to flow out.
- Electronically operated tide gates. Flow is regulated by a vertical lift, rectangular tide gate on the seaward side that opens and closes electronically at desired water levels, which are monitored by pressure sensors. The gate is normally open for a short period on each rising and falling tide.

There are several essential requirements of potential sites for RTE:

- An existing sea defence such as a seawall into which a pipe, sluice or tidegate could be integrated;
- An area that can be flooded without flooding adjacent farmland (may require a bund to be constructed behind the primary defence);
- A nearby source of sea water to permit saltwater flushing. Sea water should ideally have enough suspended sediment to enable accretion at a higher rate than sea level rise;
- The site must be no less than 0.1m lower than sea level at the highest part of the tidal cycle;
- The site must have a tidal range of at least 3m;
- Impermeable underlying geology, not prone to erosion (i.e. not peat or chalk); and
- Gradients of at least 1-6%, this will determine the ratio of saltmarsh to mudflat.

When developing a RTE scheme it is essential to ensure adequate water exchange and a sufficiently high rate of accretion to keep pace with predicted sea level rise. Broadly speaking, sites with less than 450-500 inundations a year will tend to develop into saltmarsh, while those with 450-600 will tend towards mudflat.

RTE can be useful in large managed realignment schemes where it is impractical to allow all areas that may potentially flood to be inundated at once. It therefore provides the opportunity for a phased approach to managed realignment. Large sites may be compartmentalised and only small areas introduced to tidal inundation at any one a time, to potentially minimise impacts. RTE may also be a useful prior to breaching a managed realignment site. By exposing land behind the defence line to carefully controlled inundations, the land may be encouraged to 'warp up' to a higher level (through sedimentation) in preparation for breaching or the removal of a defence.

Artificial Internal Creeks, Goosemoor RTE Site © AJ Bellamy

However, RTE is a particularly useful technique where defences are likely to stay in place for some time. Furthermore, a new defence may not need to be constructed, potentially representing a cheaper option than managed realignment. RTE may also be appropriate at a number of sites in eastern England, where managed realignment may have negative impacts on wider estuary systems associated with increased tidal volume.

RTE has many benefits in common with both foreshore recharge and managed realignment, with the added benefit of a higher degree of control over hydrological processes. This means that a site could be set up to encourage a specific type of saltmarsh or mudflat to develop and any undesirable impacts associated with increasing tidal volume following a managed realignment could be controlled.

Constraints

The relatively small hydraulic capacity of spillways, culverts and pipes compared with defence removal or breach creation (realignment) usually tends to restrict their use to smaller sites of only a few hectares in size.

In addition, the existing defence line has to be maintained for as long as the tidal exchange system is to function, so potential defence cost savings associated with breach or bank retreat would not be realised or may be deferred.

Potential effects

The potential effects associated with RTE are similar to those associated with managed realignment (see Section 5.3.9 above).

Monitoring

Monitoring objectives will be similar to those for realignment schemes. In particular, baseline monitoring of ground levels, vegetation, invertebrates, current bird usage, water levels, salinity, changes in vegetation and invertebrates should be undertaken.

Locations

Regulated tidal exchange was first tried at Horsey Island, Essex and has subsequently been trialled in Chichester Harbour, and at Goosemoor Devon (see Case study D.9).

Further information
Chichester Harbour Conservancy, Harbour Office, Itchenor, Chichester, PO20 7AW (01243 512 301).
Sharpe, J., Hirons, G., Kew., J., Pilcher, R., Brooks, W. & Lamberth, C. (2002). *Regulated Tidal Exchange: intertidal habitat without the tears.* 37th Defra Conference of River and Coastal Engineers. 2002.
The CIRIA managed realignment guide also include some information about tidal exchange systems, including those that can be regulated; Leggett, D.J., Cooper, N. and Harvey, R. (2004). *Coastal and estuarine managed realignment – design issues*. CIRIA. Report No 681.

5.4 The financial implications of management

All options for saltmarsh management will have financial implications and these will be different depending on the technique adopted. Remedial techniques (i.e. silt recharge), for example, may be cheaper than hard engineering schemes, but are likely to require regular maintenance in order to be effective. All proposals must be economically sound when the total scheme life is considered and this should include the long term financial investment required to establish the saltmarsh to the point where it is self-sustaining (if this is achievable).

As stated above, the applicability of the technique to each situation must always be considered. In particular, the prevailing physical processes, as well as the key characteristics of the ecosystem, should be understood before a scheme is selected. It is possible that the cheapest scheme, implemented in inappropriate circumstances, could eventually prove to be more costly, either through the requirement for long term maintenance or as a result of impacts experienced elsewhere.

In many cases a remedial scheme may need to be combined with some form of hard engineering, with increasing costs, particularly if the erosive processes are far advanced and an existing defence has become unstable. However, conversely, if a scheme includes hard engineering (in the case of managed realignment for example) it may be possible to reduce the capital and maintenance costs of the engineered defence. It is also important to consider the ecological benefits (as far as is possible, in financial terms) that may arise when selecting the most suitable management option (see Appendices B2 and B3).

In all cases, there will be minimum baseline data collection and monitoring requirements. Monitoring is essential to ensure the success of each scheme and provide supplementary information for future schemes (see Section 6). Long term data collection and monitoring, therefore, should be costed for as part of every saltmarsh management scheme. It should also be recognised that this latter aspect of the work has the potential to contribute major financial savings in the long term.

6 Survey and monitoring of saltmarshes

6.1 Introduction

An essential component of the development of a management scheme to address saltmarsh loss, improve coastal defence value and/or enhance ecological status is to monitor the state of the physical and biological systems. A suitable monitoring strategy, therefore, needs to document and, where possible, quantify the physical and biological change associated with a scheme to refine predictions and to determine the need for any further management measures. Any monitoring strategy should incorporate sound data management, including (at a minimum) metadata (i.e. information) about the data gathered.

Crucially, the monitoring strategy needs to be sufficiently focused to ensure that useful results are derived. Therefore, the selection (and level of detail) of the parameters to be monitored should relate, as closely as possible, to the objectives for which the scheme was developed (e.g. if for ecological purposes, then the monitoring should provide detailed and objective measures of biological parameters and sufficient physical parameters to help explain any changes). The CIRIA Managed Realignment guide (Leggett *et al.*, 2004) includes some useful information on monitoring techniques for physical parameters in saltmarsh environments and the CIRIA guide on *Maximising the use and exchange of coastal data* (Millard & Sayers, 2000) provides sound guidance on data management issues.

Monitoring Blakeney, North Norfolk Site © Royal Haskoning

Whatever monitoring techniques are adopted, it is important to remember that saltmarshes are dynamic systems. It should be understood that change can be natural and, in many cases, is an essential feature of the habitat and how it functions. As discussed throughout this manual, factors influencing change include:

- Sediment availability (size and quantity);
- Sea level (absolute and relative changes);
- Tidal range and water levels (magnitude and frequency and in relation to saltmarsh level);
- Wave climate (magnitude and frequency);
- Location;
- Ecological processes (e.g. succession and colonisation);
- Human action (e.g. enclosure, grazing);
- Grazing (natural such as geese); and
- Pollution and pollutants (impacting upon and stored by the saltmarsh).

Measuring change (e.g. knowing that a saltmarsh is eroding or accreting or that a species is disappearing), however, does not of itself provide the knowledge necessary to determine policy or agree management action. For example although sea level rise may be occurring in a location with saltmarsh loss, the saltmarsh may actually be responding to (adapting and keeping pace with) sea level rise and the loss related to vegetation die-back. Many other factors are likely to have an influence. Tides and tidal range, sediment availability and the nature of the coast all influence the development of saltmarsh. Local weather conditions, including rainfall, discharge rates of rivers and the state of the tide, also contribute to the pressure put on saltmarsh stability; and erosion rates will depend on the strength of the feature being affected by the erosive force. In addition, changes in sea level *per se* (eustacy) are the result of global forces associated with the atmospheric temperature, whether due to human influences or not. Where the land level is stable or sinking (isostacy) the coast will be inundated. Given all of these factors, it may be difficult to determine the precise reasons for the loss of saltmarsh without expert guidance.

Despite this, the fact remains that in some areas (especially south east England) the overall area of saltmarsh is diminishing and, as a consequence, coastal defences are being undermined and land threatened with flooding. The measurement of change in saltmarsh, therefore, can provide a very powerful indication that an adverse effect is occurring, which needs to be addressed.

6.2 Habitat survey

To assess the significance of a particular feature or resource it is essential to know:

- where it is located;
- how wide spread it is;
- how much of it there is; and
- its quality.

Habitat surveys are a basic tool used to assess the value of particular coastal features (such as saltmarsh). They also help to provide:

- the basis for the selection of important conservation areas;
- an assessment of the need for conservation protection;
- a means of record change (in assemblages); and
- a basis of information to assist management decisions.

In the context of monitoring, however, this information is 'passive', as it is concerned with the existing location, scale and nature of the resource (as well as the characteristics of any prevailing activities). Taken on its own, it tells us little about change or the potential causes of change. To establish the status of the habitat and whether intervention is required, by way of protection and or management, information is also needed to establish, amongst other things:

- the extent of any loss due to human activity;
- whether the resource is eroding / accreting;
- whether the resource is suffering die-back;
- the efficacy of protective legislation; and
- the efficacy of management action.

To achieve this repeat surveys are needed. These may be considered as part of a suite of more 'active' approaches to surveillance or monitoring designed to measure change resulting from deliberate actions against a predetermined, desired outcome. Active approaches can be summarised under four headings (relevant definitions are provided in Box 6.1):

- **Monitoring** to help identify and assess impacts, determine action and give feedback on management effectiveness.
- **Surveillance** to identify unforeseen change and, where appropriate, ensure compliance with agreed legislative or other control mechanisms.
- **Prediction** to consider the possible outcome of policy decisions proposed by way of response to an unforeseen incident (e.g. oil pollution) or natural/man induced event (e.g. a storm or sea level rise).
- **Assessment** of the effectiveness of action (management). This is the final stage and allows us to learn from good and bad practice and feed across to other managers.

The methodologies adopted, for the most part, will be the same. It is the level of detail and frequency that might vary and, importantly, the interpretation that is put upon the information which will convert into knowledge. The knowledge gained is crucial to determining how effective management actions are and, hence, in promoting better decision making. The following section provides some specific guidance on survey, monitoring and surveillance methodologies for saltmarshes.

Box 6.1 **Definitions**
Survey Surveying involves the collection of both quantitative and qualitative information about a feature or features using a standardised methodology, but where there is no pre-formed view on the likely findings. Thus, other than identifying what will be surveyed (a species, plant community, habitat or human activity), the primary aim is to obtain data and information on the nature, scale and location of the chosen subject.
Surveillance Repeat surveys provide a means of identifying change over time, for example, in the status of habitats and species or the rate of exploitation of a natural resource. As with the original survey there is no predetermined notion as to what change might be expected and, hence, such surveys should cover areas where current problems do and do not exist. The purpose of the new survey is to establish the nature of any change from the previous 'norm' and provide early warning of change.
Monitoring This implies the need to assess and understand the outcome of a particular course of action, such as the management of a habitat or species or the extent to which resource depletion is sustainable. This may relate to compliance with a standard or deviation from an acceptable state. Monitoring may be quite widespread (e.g. a whole estuary) but should be in proportion to the scale of management action and its potential impacts. Monitoring is often a specific requirement of the consents and licences needed for a management scheme.

6.3 Measuring change

The first step in a measurement campaign (whether as survey, monitoring or surveillance) is usually a desk study to determine what data and information exists already. This should allow, amongst other things, an overview to be made of the regional and local coastal processes and sediment budgets, as well as local habitat changes, and provides a baseline for the local situation against which future change can be compared. Sources of existing information include literature, historic maps and charts, geological maps, aerial photographs and satellite imagery.

The sections that follow provide an indication of appropriate methodologies/available techniques for determining change at different geographical scales.

6.3.1 Satellites as a means of monitoring saltmarsh change

Relatively detailed, ground-based surveys (such as those undertaken by Burd, 1989; Hemphill & Whittle, 2002; Stark et al., 2002) provide the necessary information to establish change in saltmarsh. Changes may be quite small (a few mm change in level) but, nonetheless, significant. However, such survey is resource intensive and expensive to undertake on a regional scale. Remote sensing can provide the opportunity for more frequent observations, albeit at a coarser scale and to determine longer term changes (decadal).

Satellites (currently under-utilised as a source of information on change in coastal habitats) can cover large areas and record cumulative and significant effects (potentially over a period of weeks). However, they are less useful for measuring more rapid or small-scale change. Until recently, a further impediment was the very coarse scale of resolution that could be obtained (of ten to twenty metres, which limited the level of detail available), but recent improvements in periodicy and resolution has reduced this (in some cases to about a metre) and thus, at a strategic level, the need for more traditional forms of spatial survey might be reduced. However, for this to be achieved there must be a clear relationship established between the satellite imagery and the situation 'on the ground'. This rectification is achieved by comparison with direct land measurements. In some cases this is needed on an image-by-image basis and so can be less attractive (as the ground survey is needed anyway), however, the larger the area to be covered and the greater the frequency between surveys the more attractive this approach becomes.

The European Space Agency and the EC through the European Environment Agency are currently developing a maritime information system devoted to integrating Earth Observation data into policy and decision-making in the coastal zone (see CoastWatch, which forms one part of a the European Global Monitoring for Environment and Security initiative http://www.coastwatch.info/cw/index.php). It is not clear if this will be developed as a separate initiative or as part of a wider marine information system. However, it could provide a useful source of information at national/regional scales and may be especially valuable in determining the overall status of the saltmarsh resource.

6.3.2 Other remote sensing techniques

The Environment Agency has demonstrated the use of remotely sensed data to map habitats in the coastal environment, particularly in the intertidal zone. These techniques are capable of distinguishing saltmarsh, algae and bare mud, in addition to water and terrestrial vegetation. Thus the general extent of saltmarsh can be mapped using this method. The method employed involves the use of Light Detection and Ranging (LIDAR); an airborne mapping technique which uses a laser to measure the distance between the aircraft and the ground. The technique, used in conjunction with other remote sensing instruments, results in the production of cost-effective terrain maps, which are used to measure land topography and can be used to assess coastal erosion and geomorphology. (The information can also be used to define or characterise land to be set aside for managed realignment). The combination of a terrain map and vegetation coverage (supplemented with habitat survey) can be used to determine if vegetation is at the right niche level in relation to the tidal frame and be used to indicate the way the saltmarsh at a location is functioning.

The Environment Agency has also generated routines to allow for the removal of surface features from the data sets, including vegetation, such that it may be possible to measure gross change in saltmarsh surface levels using successive surveys. Successful measurement of erosion or accretion helps to identify areas that show a net decrease in the area of saltmarsh. It also provides a means of assessing the effectiveness and long term evolution of those areas currently subject to management, particularly where re-creating or restoring saltmarsh is a key component.

Ground-based measurements of saltmarsh vegetation reflectance, using a portable spectroradiometer, can also be used in combination with remote sensing data to inform saltmarsh management (through the provision of a spectral signature), for example, in relation to grazed and non-grazed saltmarshes. This approach can also, with expert interpretation, distinguish different (assemblages of) vegetation, although again ground truthing is probably required. This technique may, however, be particularly valuable where patterns are not easily visible at ground level or when disturbance to ground-nesting birds should be avoided.

Combined LIDAR and bathymetric survey of the Lymington saltmarsh / mudflat system
© New Forest District Council (elevation data provided by Infoterra)

In March 2000 a three year project entitled *Collaborative Agreement for developing remote sensing techniques for marine SAC monitoring* was initiated between English Nature and the Environment Agency's National Centre for Environmental Data and Surveillance (NCEDS). Three main areas of study were identified that are critical for the use of remote sensing in habitat monitoring: Data preparation and accuracy, Image classification and habitat mapping, and Morphological change. The full report can be downloaded at: www.english-nature.org.uk/pubs/publication/PDF/552R.pdf.

6.3.3 Saltmarsh morphology

Three key morphological attributes of saltmarshes provide a means of detailing both the existing nature of the habitat and the development of new habitat (e.g. as a result of managed realignment). These are:

- Extent - marsh area measured at low water.
- Creek density - measured as creek order and via cross sections.
- Topography - measured as surface elevation.

The extent, creek attributes and surface elevations (although the latter to +/- 0.1m only) of saltmarsh may be measured using remotely sensed data (as discussed above). Aerial reconnaissance, currently undertaken by the Environment Agency and local authorities in eastern and southern England, is a suitable technique for quantifying the extent of habitat and changes in habitat areas. Aerial survey has several advantages over other methodologies, including the existence of long-term archives for many areas. It is also a well established technique and offers the ability to determine surface elevations. Other methods, including CASI (Compact Airborne Spectral Imaging) and LIDAR, offer individual advantages but not the range offered by aerial survey (where CASI will show vegetation cover but does not provide information on levels). The Environment Agency has in the recent past employed a five year rolling programme of aerial survey of coastal areas, with subsequent analysis of the photographs (although coverage may be variable in the future).

Aerial photos (particularly with forward motion compensation) may also be used to determine topography using photogrammetric techniques, although the level accuracy is only suitable for long-term changes or large magnitudes of change (suggested at over 0.1m vertically). Surface elevations of saltmarshes are more accurately surveyed using conventional ground survey techniques and these are currently measured within programmes such as the first Regional Strategic Monitoring Programme established by the Environment Agency's Anglian Region in 1990. This programme includes profiles, extending across saltmarshes where they occur. The programme covers both the open coast (bi-annually) and estuaries landward of the Coast Protection Act (1949) Schedule IV boundaries (on a five-year rolling programme). Within estuaries, bathymetric surveys (which may be undertaken by the Harbour Authority or the Environment Agency) usually incorporate the 'shoreline topography'. The resolution of bathymetric data is not comparable with the ground survey but does provide an indication of the whole estuary and how the system might be changing.

The combination of different methods of survey, monitoring or surveillance should be undertaken with great care and understanding of the differences in accuracy, resolution and the assumptions made.

6.3.4 Vegetation

Systematic surveys of landscapes, habitats and species are a first stage in understanding the biology/ecology of a saltmarsh. Scale is a key consideration when undertaking such surveys. Wide-scale saltmarsh survey, based on an assessment of existing survey data supplemented with field work to cover unsurveyed areas, was used to describe the resource in Great Britain in the mid to late 1980's (Burd, 1989). This information was also used to aid the selection of sites for statutory protection. Attempts have also been made to bring information together at a wider European scale (Dijkema, 1984). Though this study was hampered by the variety of definitions and survey methodologies adopted across Europe, it did provide a broad indication of the nature, scale and importance of the resource.

These studies provide a broad understanding of the distribution, scale and quality of the saltmarsh resource, as well as an indication of some of the issues affecting it. However, they do not tell us anything about change or the causes of change. For this, a series of comparable data are required. In some locations there has been a repeat using the same techniques as the Saltmarsh Survey of Great Britain and some work to quantify change (such as in the Wash) for English Nature.

Saltmarsh zonation and transitions are key elements in assessing and monitoring marsh vegetation. Identifying these elements often requires detailed site surveys timed to occur at particular times of the year. A summary of the relevant communities used in surveys to classify saltmarsh in Great Britain is provided in Appendix A2. Classifications of vegetation can be used to broadly define the different intensities of survey applicable (as they define the variability in the vegetation assemblages) and indicate variability on a widespread geographical basis. The level of classification used must be that most appropriate to the issue for which the information is required. The field survey methodology developed for the National Vegetation Classification (NVC) is typically the most appropriate for the majority of surveys that aim to provide a detailed vegetation map and identify broad changes over time. Details of this can be found in Rodwell (2000).

6.3.5 Species specific studies

Habitats and vegetation patterns are not the only features that require monitoring. Some species have special significance either because of their rarity, special habitat requirements or economic significance. Three elements (Keddy, 1991) can be discerned when monitoring individual species:

- A species is rare or of special interest and managed to protect the population. Monitoring is undertaken to determine if we being successful.
- The species is invasive (and undesirable) and we need to assess if our control measures are effective.
- The species provides an indicator of change in the environment.

The expansion of *Spartina anglica* into many saltmarshes throughout the temperate regions of the world is a particularly important issue for saltmarsh and estuarine conservation. Studying this species should be relatively easy, as it occurs as an extensive monoculture in most of the areas where it has invaded. Airborne mapping would be particularly suitable for monitoring the spread of this species.

Establishing the location and population numbers of species, e.g. birds (especially breeding birds) or invertebrates, is also an essential prerequisite when seeking to establish the ecological value of a saltmarsh. It is important to know where the majority of a population of a species of conservation or commercial significance resides during critical periods of its life cycle. In saltmarshes, many species rely on a particular place in the marsh zonation (e.g. oystercatchers nest above the mean high water mark, where their nests are less likely to be flooded). Other species rely on the nature of the vegetation (e.g. a close-cropped sward is essential for grazing by the sometimes large and significant populations of winter ducks and geese). Several shore bug species (e.g. *Saldidae,* ground dwelling predators) live in different parts of the marsh. *Saldula pilosella* lives at the margins of sheltered pools on the upper shore, *Saldula littoralis* in dense vegetation and *Saldula palustris* occurs on more open sandy/muddy areas, extending further down the marsh than the other species (Kirby, 1992). Other invertebrates may rely on a single plant species for their survival and in some cases different parts of a single plant. Monitoring these species requires specialists in the monitoring techniques for each species or group of species (such as insects or birds).

6.4 Indicators for policy response and management action

6.4.1 Introduction

The importance of saltmarshes to the economic and social fabric of society broadens the need for monitoring, encompassing both the environmental and (socio-) economic issues. Linking these into an assessment of the effectiveness of policy and action, add another dimension to the complexity of a monitoring programme.

Information on future trends in the state of the environment, as well as prospects for socio-economic and sectoral interests, are crucial for determining progress against policy targets and to ascertain, amongst other things:

- Whether current policy measures can be expected to deliver the required improvements, taking into account trends in external factors.
- Whether additional polices might be considered to be necessary to achieve the expected improvements.
- Whether new policy needs are likely to emerge in unmonitored areas.

Developing indicators as an integral part of a strategy for policy formulation is a common approach. Using a variety of techniques, involving existing information and new data derived from remotely sensed sources and traditional survey, monitoring and research, it is possible to establish an integrated approach to saltmarsh management which matches the needs of the coastal zone generally and saltmarshes in particular. For example, we should be able to measure saltmarsh change, relate this to sea level rise and provide a means of assessing different options for sea defence according to economic and social criteria.

6.4.2 Common standards monitoring (CSM) for statutory sites

One of the special functions of the three country agencies (Countryside Council for Wales, English Nature and Scottish Natural Heritage) is the establishment of common standards throughout Great Britain for monitoring nature conservation and, particularly, the ‘condition’ of designated sites. The standards have been developed by these agencies together with the Environment and Heritage Service in Northern Ireland and have been agreed by the Joint Nature Conservation Committee (JNCC). The standards apply to statutory sites designated as Sites of Special Scientific Interest (SSSIs) and Areas of Special Scientific Interest (ASSIs). They also apply to areas designated as part of the Natura 2000 series (Special Protection Areas (SPAs) under the EC Birds Directive and Special Areas of Conservation (SACs) under the EC Habitats Directive), together with Ramsar sites designated under the Convention on Wetlands of International Importance.

Little Egret, *Egretta garzetta,* © Chris Gibson, English Nature

The nature conservation component which is assessed under CSM is not the site itself, but the feature (e.g. specific species and/or habitat) for which the site was designated; and sites may have more than one interest feature. Under CSM, 'conservation objectives' are set for each feature. Key Attributes of the feature (e.g. extent, quality, supporting processes) are identified and broad targets set for each. Monitoring is then carried out to assess the state of these attributes, and an assessment made on the condition of the feature as a whole.

Attributes and targets

For saltmarsh habitats, five mandatory attributes have been defined (see Box 6.2). The targets are for guidance only and should be interpreted in terms of local knowledge of the site, its history and its surroundings. When a target is not applicable to a particluar site it should be excluded, but a record of why the decision was taken should be made (JNCC, 2004).

The presence of notable species (vascular plants) or other important features, e.g. transitions to other habitats, are considered to be discretionary attributes (i.e. indicators of local distinctiveness). It will not be appropriate to use these 'quality indicators' on every saltmarsh site, but where they are part of the reason for notification of the site they should form an integral part of any condition assessment.

Judging the condition of sites

The condition of the feature of interest is assessed against the categories listed in Box 6.3.

Box 6.2	**List of mandatory attributes and associated favourable condition targets for saltmarsh**
Attribute	***Target (examples)***
Habitat extent (including the effects of sea level change)	No decrease in extent from established baseline (subject to natural change)
Physical structure (creeks and pans)	No further anthropogenic alteration of creek patterns or loss of pans compared to an established baseline
Vegetation structure (zonation and sward structure)	Site specific targets should be set according to conservation objectives or the management plan Maintain site-specific structural diversity
Vegetation composition (characteristic species or indicators of negative trends (e.g. the presence of invasive *Spartina*))	Maintain the frequency of characteristic species of saltmarsh zones (see Box 1 section 14 of JNCC (2004) report)
Other negative indicators	No obvious signs of pollution Turf cutting absent or rare

Further information is provided on the JNCC website:
http://www.jncc.gov.uk/csm/guidance/PDFs/CSM_coastal_saltmarsh.pdf

Methods of assessment

The condition of the site or feature of interest is assessed using a variety of methods which should be applied to the reporting unit, which may be a SSSI site unit or SAC. The reader is referred to the JNCC (2004) document for further guidance on suitable assessment methods.

6.4.3 Managed realignment

'Saltmarsh squeeze' (loss of habitat resulting from enclosure and erosion caused by sea level rise and/or other factors, see Section 4.2.3) has occurred in many coastal and estuarine areas, especially in south east England. Reversing this process through the Managed Realignment of flood defences is an increasingly common option for recreating saltmarsh and forms one of the generic options of any flood management strategy. Monitoring the effectiveness of such realignment is important in helping to determine the success of such schemes and can contribute to wider knowledge to help shape the policy on how far, and over what scale (temporal and spatial), this approach to management should be applied.

A summary of a detailed monitoring approach applied at a single site, by way of an example, is provided below:

1. Vegetation survey (based on the NVC classification and survey methodology) over the whole site following inundation, repeated over increasingly long time periods.

2. Establish permanent quadrats for more detailed species (plants and animals) monitoring and consider how surrounding local change might be determined (for background levels of change.
3. Establish frequency of site topographic survey and (within the area and, if appropriate at a control location) permanent locations for measuring sediment accretion and erosion.
4. Establish 'nested' quadrats for more detailed assessment of vegetation change (after Hodgson *et al.*, 1994).
5. As necessary, investigate the factors affecting saltmarsh stability (e.g. pollution, tidal scour, grazing by herbivores).

Box 6.3	**List of mandatory attributes and associated favourable condition targets for saltmarsh**
Favourable - Maintained	An interest feature should be recorded as *maintained* when its conservation objectives were being met at the previous assessment and are still being met.
Favourable - recovered	An interest feature can be recorded as having *recovered* if it has regained favourable condition, having been recorded as unfavourable on the previous assessment
Unfavourable - recovering	An interest feature can be recorded as *recovering*, after damage, if it has begun to show or is continuing to show a trend towards favourable condition
Unfavourable - no change	An interest feature may be retained in a more-or-less steady state by repeated or continuing damage; it is unfavourable but neither declining or recovering. In rare cases, an interest feature might not be able to regain its original condition following a damaging activity, but a new stable state might be achieved
Unfavourable - declining	Decline is another possible consequence of a damaging activity. In this case, recovery is possible and may occur either spontaneously or if suitable management is undertaken
Partially destroyed	It is possible to destroy sections or areas of certain features, or to destroy parts of a site, with no hope of reinstatement because part of the feature itself, or the habitat or processes essential to support it, has been removed or irretrievably altered
Destroyed	The recording of a feature as destroyed will indicate the entire interest feature has been affected to such an extent that there is no hope of recovery, perhaps because its supporting habitat or processes have been removed or irretrievably altered

In some situations a detailed NVC survey monitoring approach may not be required. Important trends can still be deduced from a more targeted, specific approach. For example, monitoring carried out on Trimley Marshes Managed Realignment site (Posford Haskoning, 2004) employs the following approach:

1. Vegetation survey carried out biannually for five years.
2. General walkover survey to record all species.
3. Permanent quadrats (number depends on size of site) for more detailed species monitoring using Domin scores.
4. Estimate of the areal extent of saltmarsh (spot measurements using either tape measure or GPS; where GIS is used to estimate coverage increase/decrease).

It should be noted that whatever monitoring regime is adopted for a scheme, it should be proportional to the size of the scheme and/or the impacts of it. This can be determined at a number of stages in the process but would certainly form part of an Environmental Impact Assessment for planning approval or could form part of a Strategic Environmental Assessment of a plan (for example a flood management strategy or Shoreline Management Plan). Each site (and project) is likely to have a different range of sensitivities that will determine the parameters to be monitored and the level of detail required.

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