C. Natural and Human Factors Leading to Saltmarsh Change

C.1 Physical and ecological processes: change in saltmarsh extent and form

C.1.1 Lateral extent

Although saltmarsh erosion is the most widely perceived problem, expansion of saltmarsh can also cause environmental management problems, most notably when it leads to enhanced estuarine siltation and navigation difficulties, or deterioration in the quality of amenity beaches. For example, colonisation of formerly sandy beaches at Southport and south of Cleethorpes has posed significant problems for the local authority in terms of tourism appeal and bathing water quality.

Short to medium term trends in marsh edge progradation or retreat can often be inferred by examination of the marsh edge morphology. Accreting and stable marsh edges are usually typified by an accretional ramp upon which pioneer and low-marsh vegetation communities become stabilised (A and B in Figure C.1). Erosional margins, on the other hand, are characterised either by the presence of mud-mound topography or by marsh-edge cliffs fronted by toppled blocks (Figure C.1, C and D). Terraced marsh margins (Figure C.1, E) indicate episodic erosion and accretion on timescales of decades and centuries.

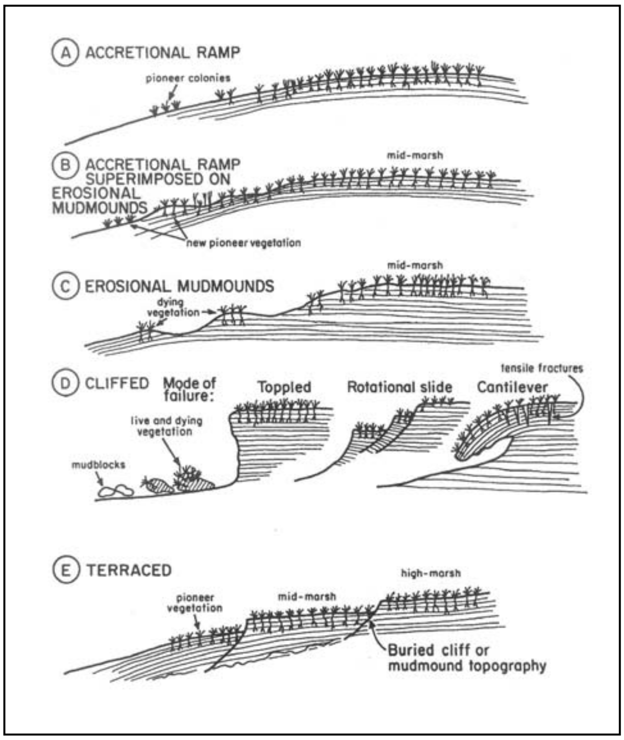

Figure C.1 Marsh edge morphology types, after Pye and French (1993)

Quantitative data on rates of marsh edge retreat can be obtained from comparison of Ordnance Survey maps, Admiralty charts, air photographs or ground surveys of different dates (e.g. van der Wal and Pye, 2004; and Figure C.2).

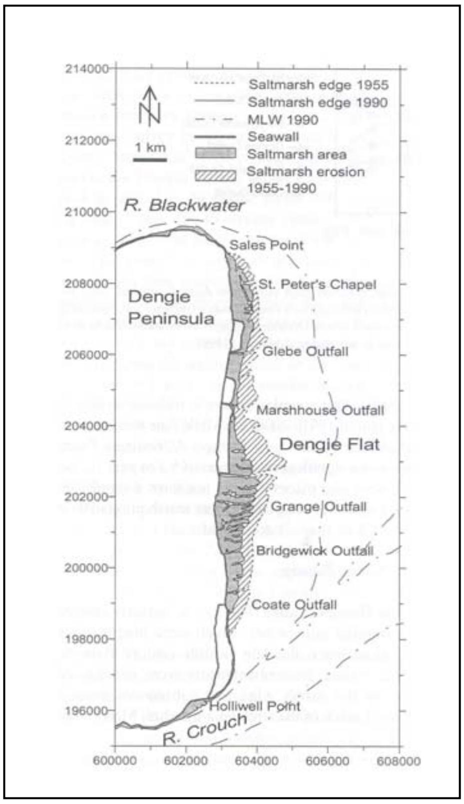

Figure C.2 Changes in the position of the saltmarsh edge along the Dengie Peninsula, Essex, between 1955 and 1990, based on Ordnance Survey maps and aerial photographs (after Pye and French, 1993)

C.1.2 Elevation change

Following initial colonisation of a tidal flat by vegetation, saltmarshes grow vertically until they approach a surface elevation which is in equilibrium with the local tidal frame. Typically, it may take 80-100 years for a marsh to achieve an equilibrium elevation (i.e. to become 'mature'). Comparison of the surface levels of mature marshes with local tidal parameters at different locations around the coast of Great Britain has shown that the relationship varies from region to region. This reflects geographical variations in tidal range, tidal flooding frequency and duration (Pye, 2000). Generally the mature marsh surface has an average elevation which is several centimeters to tens of centimeters below the level of the highest astronomical tide (HAT). Once established, the height differential tends to be maintained if the tidal range and sediment supply characteristics remain unaltered.

Allen (1992) outlined a simple model which relates change in marsh surface elevation to a number of controlling variables:

$$dE/dt = dS_{min}/dt + dS_{org}/dt + dA/dt - dM/dt - dP/dt$$

where:

dE/dt is the change in elevation of the sediment surface relative to the tidal datum
t is time
dS_{min} is the thickness of minerogenic sediment added by the tide
dS_{org} is the thickness of organic sedimentary material
dA is the change in amplitude of the extreme astronomical tide - increase positive
dM is the change in relative sea level (upward positive)
dP is the change in position of the sediment surface due to consolidation.

The value of this model is that it provides a means to evaluate the relative importance of changes in the different factors. In practice, the individual parameters may be difficult to quantify. Short to medium-term sediment accretion, and even changes in surface level, can be monitored, but accurate quantitative data on longer-term changes are difficult to obtain without detailed studies of marsh stratigraphy, sediment ages and engineering properties.

Measurements of short-term surface accretion invariably over-estimate the longer-term net accretion represented by surface elevation change. This is due both to shallow auto-compaction (Allen, 2000b), sometimes misleadingly referred to as 'shallow subsidence' (Cahoon *et al.*, 1995), deep sediment deformation (especially adjacent to major estuarine channels) and diagenetic changes within the sediments.

Field monitoring has shown that vertical accretion rates on saltmarshes can be of the order of up to 10cm per year during the early stages of growth, but are often less than 2mm/yr on mature British marshes.

By definition, lowering of the surface elevation of a saltmarsh relative to the tidal frame can only occur if (a) sediment is physically eroded from the surface or (b) the rate of accretion / net surface level increase fails to keep pace with the tidal frame over time. The former requires partial or complete de-vegetation, caused by an increase in wave activity, overgrazing, biologically-induced or pollution-induced dieback of the vegetation. Failure of the surface to keep up with moving tidal frame may result from a reduction in minerogenic or organic sedimentation rates, a change in tidal amplitude or an increase in compaction rates.

'Drowning' of saltmarshes is highly unlikely unless rates of sea level rise are extremely high (>10 cm/yr) and rates of sediment supply very low. At most sites in eastern England, vertical accretion has easily outpaced sea level rise over the last 40 years (e.g. French and Burningham, 2003).

C.1.3 Changes in creek and marsh surface morphology

Changes in tidal creek morphology (exemplified by channel density, channel volume, plan form and bifurcation ratio) naturally take place in a saltmarsh as it evolves. Based on an analysis of thirteen British marshes, Steel and Pye (1997) developed a model which proposes that tidal creek systems in natural marshes undergo a series of stages which are related to the marsh elevation and frequency/duration and volume of tidal flooding (Figure C.3).

Channels initially develop on the precursor mudflat or sandflat surface but become more numerous and better organised as the marsh begins to rise in the tidal frame. The drainage density increases to a maximum before starting to decline again, as some sections of creek are abandoned. The critical point at which expansion changes to contraction is related to the marsh surface elevation and tidal frame. As a general rule, the maximum drainage density is found when the marsh surface is covered by approximately 280 tides per year.

Variations to this natural pattern of development can be brought about if, for example, a new marsh begins to develop to seaward, effectively lengthening the main creeks, or if some creeks are 'beheaded' by embanking and reclamation. Large-scale reclamation within an estuary may lead to a significant reduction in the estuarine tidal prism, or the tidal prism relating to a specific section of flanking marsh. In some circumstances, the reduction in tidal volume entering and leaving the marsh will result in reduced flow velocities and net sediment accumulation within the creek system. The major channels will become narrower and shallower, while some finger-tip tributaries may be abandoned and develop into linear salt pans or vegetated depressions. In other circumstances, an excess of tidal energy may be maintained within the creek system, resulting in local scouring, creek enlargement and the development of mud basins. Which of these two scenarios occurs is dependent on the general morphology, tidal energy conditions and sediment transport regime within the estuary in question.

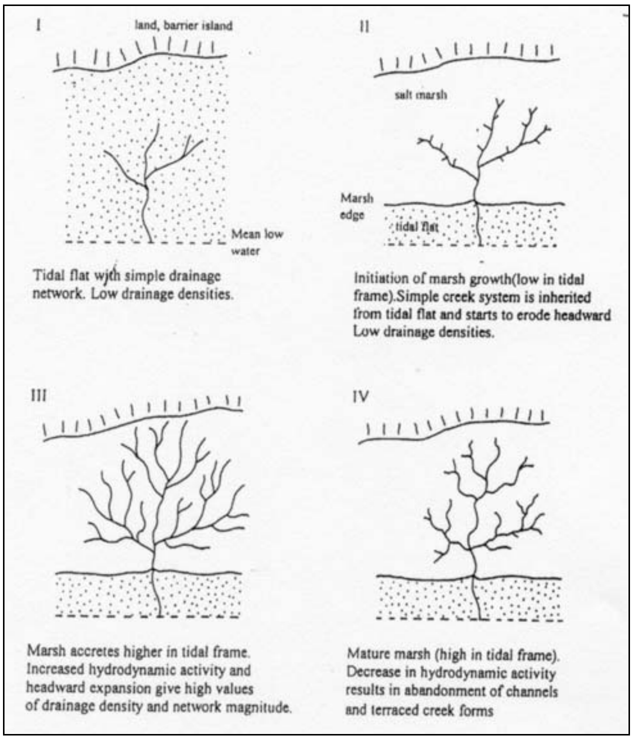

Figure C.3 Schematic model showing stages in the development of tidal creek networks on tidal flats and saltmarshes (after Steel and Pye, 1997)

Many estuarine marshes in Essex and North Kent have suffered from expansion of the creek network following reclamation and/or renewed flooding of formerly reclaimed land. Coalescence of the creeks in some areas has resulted in the formation of extensive mud basins and many such marshes are characterised by a relatively low ratio of vegetated to bare mud surface (Figure C.4). The pattern of erosion within such marshes is often heavily influenced by natural and human-induced differences in the sediment properties (e.g. Crooks and Pye, 2000). Predictions of the likely results of re-introducing tidal waters to a reclaimed area can often be made using data from airborne LiDAR and ground surveys (e.g. Blott and Pye, 2004).

C.1.4 Changes in floristic composition and vegetation characteristics

Vegetation succession is a natural process which occurs during the development of a saltmarsh (Gray, 1992; Adam, 1994; Willis, 2000). Most saltmarsh systems also show marked species zonation, since different species vary in their tolerances to salinity, tidal inundation and energy conditions. There are three main communities of marsh pioneer species which are important in the UK, namely *Salicornia* spp., *Puccinellia* spp. and *Spartina anglica*. *Salicornia* has traditionally been dominant in the more muddy systems of the east and south coasts, but during this century *Spartina* has become increasingly important in these areas. *Puccinellia* has traditionally been the dominant species in the more sandy marshes of western and northern England but, again, *Spartina anglica* has become increasingly important during the past 100 years.

Figure C.4 Aerial photograph of part of Canvey Island, Essex, showing severely eroded area of marsh formed after the breaching of the surround sea wall in 1881 (from Toft et al., 1995)

Each plant species/community has different characteristics in terms of seasonal growth patterns and plant physiology. From a geomorphological process point of view, the density of plant stems, stem height and leaf surface area are properties of particular relevance in terms of the way in which marsh plant interact with tidal currents and waves. Seasonal variations in vegetation cover and plant height have been demonstrated to have a significant effect on wave dissipation over marshes (Moller and Spencer, 2002). Consequently, longer-term changes in plant community composition and growth characteristics may also be expected to have an important effect on marsh sedimentation rates and wave energy dissipation, which in turn is of importance to the flood defence properties of a saltmarsh.

As an example, the timing of the introduction and growth of new *Spartina* marshes varied from area to area in the UK (see Appendix A2.3.3) with different consequences. In many locations on the south coast rapid expansion took place between 1900 and 1930, and was followed by a more variable pattern of localised die-back (which began in the early 1940's) and recolonisation. In Southwest England and South Wales, *Spartina* and other marshes experienced a marked phase of expansion between about 1920 and 1940, continuing until the 1960's, while in West Wales and Northwest England the major phase of expansion did not take place in most areas until the 1960's and 1970's, even though a vigorous *Spartina* hybrid was introduced to these areas in the 1930's and 1940's. During the 1980's and 1990's, further spread of *Spartina* marshes has been very localised. The older *Spartina* marshes have stabilised, been invaded by higher marsh communities or have experienced erosion, particularly in more exposed locations.

In Southeast England, extensive colonisation by *Spartina*, and to a lesser extent other pioneer species, has occurred only in a relatively few areas, for example Shellness at the eastern end of the Swale, and scattered localities in the Medway, the Thames and in the Essex and Suffolk estuaries. Growth of these new marshes has not been sufficient to offset erosional losses of the older marshes elsewhere in the south east, although recent survey data from the Medway Estuary indicates that *Spartina* growth is outpacing erosional loss of non-spartina communities (North Kent CHaMP, 2002).

C.1.5 Changes in vegetation vigour

Changes in the 'vigour' of marsh vegetation, which may be defined as a decrease in the density, height or leaf area, can have a significant effect on tidal current and wave energy dissipation and, thereby, both on marsh surface sedimentation/erosion and the risk of overtopping of sea defences landward of the marsh. In extreme cases, total 'dieback' of vegetation may occur, leaving a largely bare surface or one on which algae becomes established, forming extensive mats. Change in vegetation vigour may be brought about by natural biological and soil successional mechanisms, by pollution or introduced pathogens. Potentially, changes in rainfall and temperature patterns could be significant in promoting or reducing rates of growth. As stated above, extensive dieback is a phenomenon which has been reported to affect *Spartina* marshes in the UK, especially on the south coast. The reasons have been extensively investigated and several possible causal mechanisms have been identified (Pye, 2000; Raybould, 2000).

Grazing can have a major effect on the vigour and general physiology of saltmarsh plants, and hence on physical processes. Many of the more sandy marshes in western Britain are heavily grazed and recharacterised by a relatively short sward (Adam, 2000). Marshes in Eastern England have also been extensively grazed historically but the practice is now much more restricted in most areas. The management of grazing and its effects on saltmarsh ecology is further discussed in Section C4.

C.2 Physical factors which may contribute to saltmarsh erosion

C.2.1 Sea level rise

Numerous studies have defined sea level rise as a major cause of saltmarsh erosion. Relative sea level change affects wave height, tidal currents, position of the water table and the position of high water. During the last glaciation, the coastline was located further seaward than it is today, but sea level rise since the early Holocene has led to the landward migration of the shoreline.

Over shorter timescales, of the order of several decades, changes in sea level can affect both saltmarsh morphology and vegetation community type. Limited sediment supply and an increase in sea level rise can result in erosion of saltmarsh through creek lengthening, landward migration through an increase in wave height, water depth and water turbulence.

Although tide gauge records clearly indicate that global average sea level has risen in the past century (Woodworth, 1987), according to some scientists there is as yet no firm proof that the changes have had any significant effect on UK saltmarshes (Pye, 2000). This may change over the course of the next century if predictions of future accelerated sea level rise turn out to be correct (see also Section C.3.3).

C.2.2 Increase in tidal range

All saltmarshes are within the intertidal zone and are, therefore, exposed to tidal immersion. The once daily (diurnal) or, more commonly, twice daily (semi-diurnal) flooding of saltmarsh and the associated impact of tidal waters is, therefore, an important influence on marsh development.

There is evidence from tide gauge records that tidal range has increased at some stations around the UK coast (Woodworth *et al*., 1991) and that the frequency of extreme high tidal levels, in particular, has increased. Other things being constant, this should bring about acceleration in vertical marsh accretion rates. However, bigger tides result in bigger tidal currents, with the likelihood of increased scour both on the flood and ebb; although, to date, no such link between marsh creek widening and increasing frequency of high tides has been scientifically established.

C.2.3 Tidal asymmetry

Sediment transport in shallow coastal and estuarine environments is influenced to a significant extent by the nature of tidal asymmetry. The deep water tidal wave becomes distorted as it enters shallow coastal waters and estuaries, the nature of the distortion being dependent on non-linear interaction between the offshore tide and nearshore shelf and estuarine morphology (Pye, 2000). The nature and causes of tidal asymmetry in estuaries has recently received much attention, but its significance in terms of saltmarsh accretion and erosion has so far received only limited consideration.

Increases in mean sea level and tidal range will result in changes in the way in which tidal waves propagate within estuaries, and this will depend primarily on the length, depth and plan morphology of the estuary. The resultant steepening of the tidal curve may increase current speeds and hence reduce deposition and enhance erosional potential.

C.2.4 Increase in storminess

The stability of saltmarshes can be affected by changes in three aspects of the wind/wave climate: mean wave height; wave directional frequency; and storm surge frequency (linking both extreme waves with extreme tidal levels). Changes in wave energy conditions can have important influences at the mudflat/saltmarsh interface. An increase in significant wave height or a reduction in the recurrence interval will result in more mudflat/saltmarsh erosion due to the reduced time period for recovery. Changes in the direction of waves can also be as important, as changes in longshore sediment transport can occur through slight changes in fetch. Furthermore, since inshore wave height is strongly dependent on water depth, and wave energy is a power function of wave height, changes in the frequency of storm surges may have a considerable impact on saltmarsh evolution. Storm surges frequently result in the breaching of sea defences and may trigger a progressive phase of erosion if repairs to the defence are not made.

C.2.5 Channel migration

Estuarine channels are naturally dynamic and low water channels commonly meander over time. Marshes adjacent to the outside bends of meanders are frequently ‘cliffed’ and experience slow erosion, while marshes adjacent to the opposing slip-off slopes tend to accrete. This pattern may reverse on a timescale of several decades. Good examples have been documented in the Mersey and Humber estuaries, but the process is almost universal. Where natural meander migrations are confined by engineering works, there is often a large-scale, long-term reduction in estuary capacity (O'Connor, 1987; Pye, 1996; van der Wal *et al.*, 2002).

C.3 Historical change in saltmarsh area

C.3.1 Introduction

Variations in the extent and location of saltmarshes around the coast of the British Isles have occurred throughout recent geological time. During the post-glacial marine transgression in the Flandrian Period, saltmarshes were transient features formed on the (now flooded) continental shelves. As sea level rise slowed down, around 4000 years ago, the coastline took on the general character of its present form. The Holocene sea level history of Britain varies in detail from area to area, with some regions, notably southeast and southern England, having experienced slow net sea level rise (albeit with some small positive fluctuations) during that period, while other regions, including much of the north and west, have experienced a net fall in relative sea level (Shennan, 1989; Shennan *et al.*, 2000). These changes and their timing have had a profound effect on the historical development of saltmarsh around the coast.

In some areas, such as on the North Norfolk coast and the Thames Estuary, marsh sediment sequences have accumulated vertically, albeit episodically, over several thousands of years as sea level rose during the Flandrian Period (Devoy 1979; Andrews *et al.*, 2000). Periods of slight sea level regression are recorded in the sedimentary sequences as soil layers, peats or over-consolidated horizons. In these areas there was an only limited seaward progradation of new marshes during the later Holocene, and deposits of younger marsh sediments largely sit on top of older sediments. Elsewhere, as in West Lancashire and The Wash, early to mid Holocene marsh sediments now lie well inland of younger saltmarshes formed in the last few centuries (Tooley, 1992; Pye, 1995; Brew *et al.*, 2000).

Typically, the older marshes around the British coast have been extensively reclaimed in a series of progressive stages, with younger marshes forming (or attempting to form) to seaward after each phase of reclamation.

C.3.2 Land claim

Human reclamation of saltmarsh (i.e. land claim) for agricultural purposes began in several areas in Roman times, but was undertaken extensively from the later Middle Ages onwards (Allen, 1992; 2000b). In eastern and southern England, large-scale reclamation occurred along the margins of most estuaries and areas of marsh-fringed open coast between the 16th and 18th centuries (Gramolt, 1960) and further reclamation was undertaken in the 19th and 20th centuries. There are numerous examples of agricultural land that has been won in this way around The Wash (see Figure C.5), the Ribble Estuary, the Essex and Kent coasts, the Severn Estuary and elsewhere. Estimates of losses from some of the major estuaries total in excess of 91,000ha (Davidson *et. al*., 1991).

Areas such as The Wash, and southeast England generally, 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 or ceased. Following breaching and abandonment of sea defences, new saltmarshes became established on those parts of the re-flooded land that were high enough in the tidal frame to allow plant colonization, while mudflats developed elsewhere. New creek systems became established, initially influenced strongly by the patterns of agricultural 'grip and drain' structures but increasingly, over time, re-establishing a more natural pattern in equilibrium with hydraulic conditions (Crooks and Pye, 2000). In the Severn Estuary, this has had significant implications for morphology and sedimentation both on the reactivated marshes and adjoining areas (Allen, 2000b).

Following enclosure, saltmarshes were often used for grazing domestic stock. This traditional use of the land, without ploughing or agrochemicals, helped to create new habitats of wildlife interest; ‘grazing marsh’. When unimproved permanent pasture is used for low intensity grazing, it often develops a vegetation structure attractive to nesting birds. In winter, surface flooding of parts of these same areas attract wintering wildfowl such as teal, wigeon and waders. The presence of short grassland also provides grazing for waterfowl, including brent-goose. Furthermore, rare species of plants are often found in association with pasture and the brackish water drainage ditches, the latter being particularly important for a number of rare invertebrates.

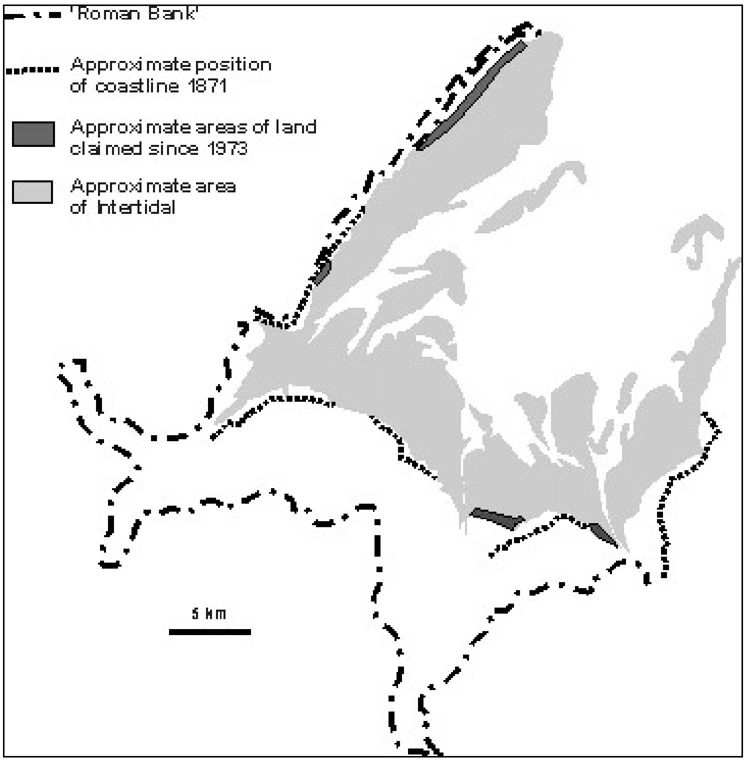

Figure C.5 Saltmarsh enclosure for agricultural use on The Wash (after Doody 2001)

More recently, these semi-natural habitats have themselves been claimed for intensive agriculture. This process has resulted in the loss of nearly 70% of the grazing marshes (and the associated loss of important plant and animal communities) in the Thames estuary since the 1940s (Thornton & Kite, 1990). This loss not only destroys the grassland, but also results in degradation of those ditches which remain through eutrophication and pollution as a result of the use of modern chemical fertilisers and pesticides. This reduction in wildlife value is illustrated in Figure C.6.

C.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. Concern related not only to the potential impact for flood defence and seawall maintenance budgets (i.e. the economic consequences), but also to the loss of an ecologically valuable habitat. In some areas, notably eastern and southern England, large losses of saltmarsh vegetation were recorded during the late twentieth century.

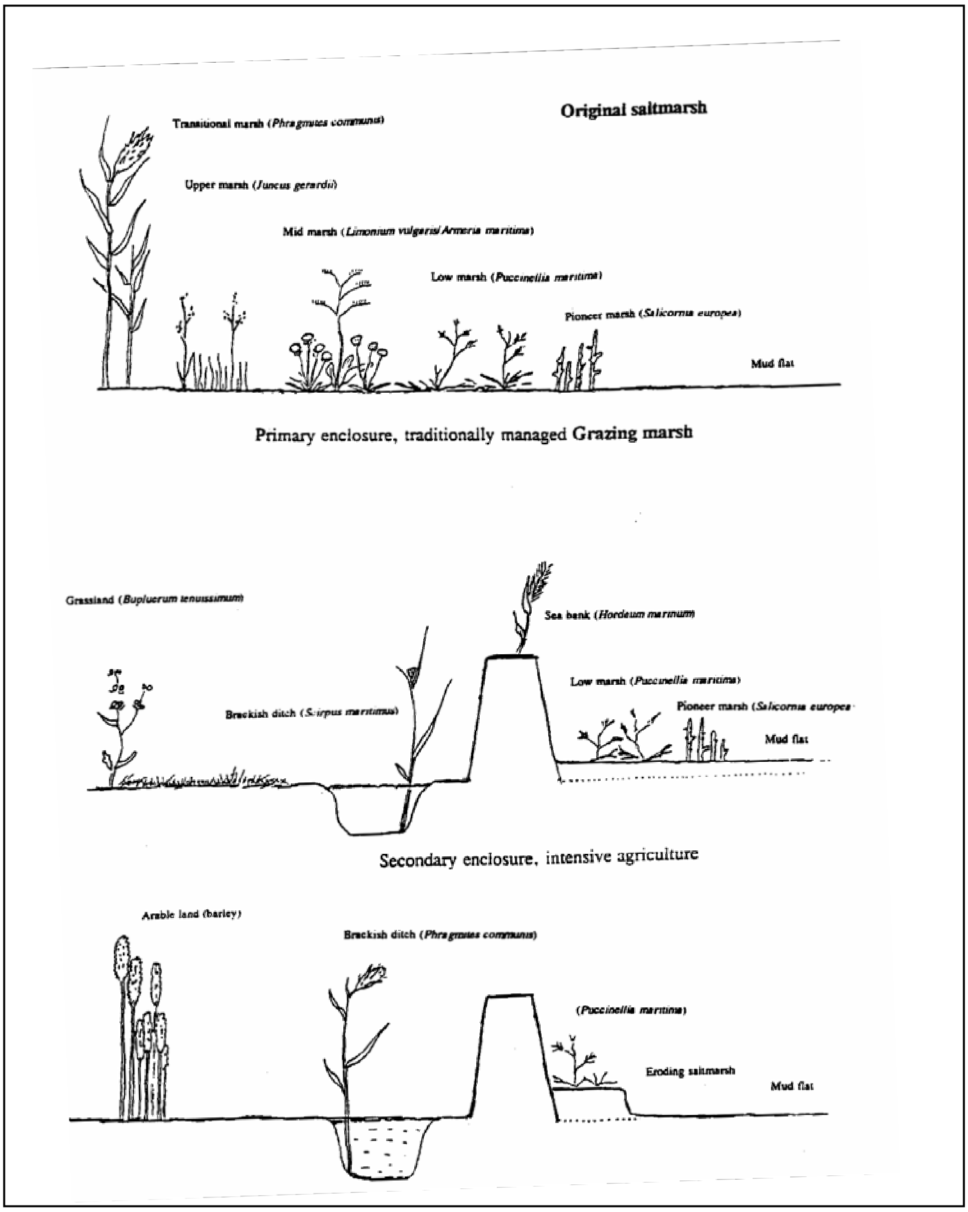

Figure C.6 Development of coastal grazing marsh by enclosure of saltmarsh and its subsequent loss to intensive agriculture (from Toft et al., 1995)

This documented loss of saltmarsh habitat has been attributed to the process of "coastal squeeze", which represents the result of interaction between the reclamation of former saltmarsh habitat (and the presence of defences) and sea-level rise;

although other theories for the loss have been put forward (e.g. the burrowing activity of some invertebrate species; see A2.4.2).

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 4.1). 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).

A fuller description of recent historical changes in saltmarshes in England and Wales, and discussion of the possible contributory factors, is provided in Carpenter and Pye (1997). More detailed consideration is given to the nature and causes of saltmarsh erosion in southeast England by Pye (2000) and van der Wal and Pye (2004).

Left to themselves, natural systems can typically accommodate changes in sea level by moving either landwards or seawards, depending on the direction of relative sea level. Under these circumstances there is no need for intervention. However, together, the reclamation of estuarine areas for agricultural purposes and the construction of flood defences and embanked enclosures have effectively prevented the landward movement of saltmarsh in response to sea-level rise. The natural habitats are therefore 'squeezed' between the embankments (which have moved progressively seawards in the past; see Figure 4.2) and the rising sea level which attempts to move the intertidal zone landward. It is thought that these two effects may be partly responsible for the loss of saltmarshes observed between 1973 and 1988, as described in Burd (1992).

Historically, it was assumed (e.g. in The Wash) that new saltmarsh would develop in front of a new enclosure. However, the coasts in Essex and Kent have shown that this is unlikely to be the normal progression, particularly in areas where relative sea level is rising and where the natural transition between tidal waters and the land has been truncated by an artificial barrier.

C.4 Saltmarsh grazing

C.4.1 Introduction

Several levels of grazing can be defined, as follows:

Light grazing	most of the standing crop is not removed
Moderate grazing	maximum standing crop almost completely removed
Heavy grazing	height <10 cm, all standing crop removed
Abandoned grazing	matted vegetation, no standing crop removed.

These definitions and the grazing levels given below were originally developed for artificial saltmarshes in the Wadden Sea (Dijkema and Wolff, 1983); as such they lie at the upper range of the levels considered to be appropriate for nature conservation, bearing in mind the historical context in which this interest is judged.

C.4.2 Ungrazed / light grazing

Traditionally ungrazed or lightly grazed marshes are those where native herbivores (grazing ducks and geese, hares and rabbits) are the only grazing animals or where levels of stocking by domestic animals are 2 to 3 sheep or 0.7 to 1.0 young cattle per ha, or lower, for 6 months of the year (April to October). Open saltmarshes, with a complete sequence of vegetation from pioneer to strandline and transitions to terrestrial habitats, tend to be the richest biologically. In addition to the good structural diversity, they support plant communities which include several grazing sensitive species, such as sea purslane (*Halimione portulacoides*), sea-lavender (*Limonium vulgare*) and sea wormwood (*Artemisia maritima*); which, as well as being important constituents of the plant communities, are also important for the invertebrate animals which feed or find shelter on them. Breeding birds also find the greater structural diversity good shelter for nests during the breeding season, though in saltmarshes free from all grazing, vegetation may be too dense to support the high nest densities.

C.4.3 Moderate grazing

Historically ungrazed marshes are the exception in Northwest Europe. Most marshes have been used for grazing domestic stock at least at moderate levels. These are usually given as being equivalent to 5 to 6 sheep or 1.0 tp 1.5 young cattle per ha (April to October). Beeftink (1977) recommends 2 sheep or 0.3 cattle per ha (year round) as being the most appropriate to attain the maximum nature conservation interest. These figures lie somewhere between those given by Dijkema & Wolff (1983) for light and moderate levels respectively and suggest that, even at these moderate levels, overall nature conservation value is reduced. Whilst there may be some reduction in the standing crop of plants at the lower end of the grazing regime defined here, plant diversity and bird breeding densities may still be high.

C.4.4 Heavy grazing

Saltmarshes that have a history of heavy grazing by domestic stock tend to lack the attributes typical of the best examples of saltmarsh habitat, i.e. rich and varied plant and animal populations and a varied vegetation structure. Recorded grazing levels equivalent to 9 to 10 sheep or 2 to 2.5 young cattle per ha (April to October) approach those of permanent pasture. In northwest England, where some of the most extensive and intensively grazed sites occur, stocking densities up to 6.5 sheep (year round) or 2 cows (summer) per ha occur (Gray, 1972). At these levels, except at the very upper limits of unenclosed marsh, such as in Morecambe Bay, there is an impoverished flora.

As most, if not all, of the standing crop is removed by grazing in these circumstances, the structural diversity of the marsh is reduced. Consequently, the diversity of invertebrate species associated with taller vegetation decreases as grazing pressures increase. Furthermore, heavy grazing, whilst not necessarily removing the plants upon which the invertebrates are dependant, may reduce the physical structure of the flowers, fruits, seeds so that many species may become excluded (Meyer *et al*., 1995).

At the same time, grazing sensitive species are eliminated and tillering grasses favoured. Over time, a close-cropped sward is produced which is typified by the "bowling green" lawns of northwest England and this is sometimes exploited for turf-cutting. These saltmarshes lack most of the attributes of the more moderately grazed sites but may (in some circumstances) have considerable importance for wintering ducks and geese. A few species, such as Oystercatcher, which breed in more open locations, can be found associated with these heavily grazed sites.

C.4.5 Abandoned (formerly grazed)

Grazing of saltmarsh by domestic stock has become less extensive geographically and there are a number of examples of formerly heavily grazed sites which have been abandoned in recent years. The effect of this is to allow the species favoured by grazing, which are often some of the most vigorous species, to become dominant. These include common saltmarsh grass and sea couch (*Elymus pycnanthus*). After only a few years, the combination of litter accumulation and the growth of the formerly suppressed species tends to result in a dense and matted vegetation structure. Plant species diversity is further reduced and the saltmarsh becomes less suitable for invertebrates and breeding birds.

C.5 Other human influences on saltmarsh change

C.5.1 Dredging, navigation and revetment construction

Both dredging and navigation have been suggested as factors contributing to saltmarsh erosion in the UK. Dredging can have the effect of increasing flow velocities and the proportion of total tidal discharge in the main channel, thereby, reducing the velocities and average shear stresses over the adjoining tidal flats. Under these circumstances, net stability or accretion may be expected in the intertidal area. Dredging can also cause the progressive net movement of sediment from the intertidal flats into the dredged area, due to slumping, rill incision or increased wave erosion over the steepened edges of the channel. The dredged section may also act as a sediment sink, reducing the sediment volume available for deposition over adjacent intertidal areas. The permanent loss of sediment from the system may then occur as a result of the disposal of sediment at sea during the maintenance dredging of navigation channels in estuaries. Vessel movement along navigation channels can also result in erosion of fringing saltmarsh by ship/boat wash, while settling of mud on intertidal flats may be impeded by the increased turbulence generated by ship propellers (Pye, 2000). Solutions to these problems include restricting speeds and limiting the depth and frequency of dredging in estuaries, as well as returning sediment from the navigation channels to the intertidals (sediment recharge).

Dredging and the construction of revetments or training walls can also affect the position and migration of deep water channels in estuaries, thereby creating centres of relatively high or low energy where bank sediments are likely to erode or accumulate. Training walls and revetments act to artificially constrain the natural tendency for tidal channels to migrate. While this may act locally to prevent erosion, the non-equilibrium situation often created is likely to transfer the erosion problem to some other point downstream.

C.5.2 Sediment extraction

Although not an activity occurring today, many marshes in southeast England may have been adversely affected by former sediment extraction principally for brick, tile and pipe manufacture. Saltmarsh has also been excavated as ‘borrow pits’ for embankment construction, to provide moorings and to create oyster pits. The total amount of material removed has not been quantified, but probably runs into many millions of tons. The effects of this have been not only to directly reduce the area of vegetated marsh remaining, but also to disrupt the natural pattern of marsh drainage. Estimates suggest that some 40% of the area of the saltmarsh in the Medway Estuary has been lost in the last 100 years as a result of extraction which took place between 1840 and 1910. Whilst some of this loss may be attributed to the rise in relative sea level which is occurring there, as on the rest of the east coast, undoubtedly the reinforcement of an ebb-dominant regime and the subsequent loss of sediment from the system may be equally or even more important.

At the time of publication of the Estuaries Review (Davidson *et al.*, 1991) extraction of other types of sediment was taking place; in 11 out of 155 estuaries this was thought to involve commercial quantities. In sites like the Ribble Estuary (Lancashire) and the Taw Torridge (Devon), where sand is extracted at the mouth of the estuaries, changes in the sedimentary patterns are occurring, but it is not clear what impact these have on the development of the saltmarsh.

C.5.3 Turf-cutting

Turf cutting is only carried out at a small number of sites in northwest England, usually under licence or some other form of agreement. The process involves the preparation of the turf by the use of reseeding and fertiliser treatment. The practice is designed to perpetuate the short grassy swards which occur in these areas as a consequence of heavy grazing, so that the practice is not directly threatening to the nature conservation of the whole saltmarsh, although it does remove some sediment with the turves. The cut areas do regenerate, but with a different plant community.

It is possible, however, that cessation of this use of the marsh could be followed by improvement of the overall wildlife interest, if stocking levels were also gradually reduced. This could improve structural diversity and lead to a greater invertebrate interest. That is, as long as gradual reductions in stocking levels take place, retaining moderate levels, the overall nature conservation value of the marsh in terms of species diversity and structure could be enhanced.

C.5.4 Hay making

Hay making is another activity that has a very restricted areal extent on saltmarshes; although it is not known to what extent it has influenced the value of the marsh for wildlife in the past. Hay making was practised extensively and may have had a similar impact to grazing; that is, favouring the development of a grassy vegetation and thus reducing invertebrate diversity, breeding bird density and plant diversity. There are few if any current examples of this activity in Great Britain, although mowing of cord grass vegetation is a possible form of its control.

C.5.5 Reed cutting

Cutting of reed (*Phragmites communis*) for use in thatching is a traditional use of the upper and transitional marsh. Reed cutting was undertaken in 12 out of the 155 estuaries covered by the Estuaries Review (Davidson *et al*., 1991), though only in the Tay Estuary is it a major commercial operation. Here, there has been some concern about the impact of cutting on breeding bird populations, such as Reed Bunting and Sedge Warbler, and rotational cutting outside of the breeding season is favoured.

C.5.6 Samphire gathering

Samphire (*Salicornia europea*) gathering is probably a widespread activity on a small scale, though it appears to be little recorded. It does occur in parts of the Norfolk Coast, usually through a form of common right. The activity was recorded in only 9 of the 155 estuaries covered by the Estuaries Review (Davidson *et al*., 1991). There are no recorded impacts either on the vegetation or on other nature conservation interests from the current, low intensity activity associated with hand collection. By its nature, collection of the material can only take place at low tide and in the late summer, before the main wintering bird populations appear.

C.5.7 Spartina

Spartina has had a major impact on saltmarshes throughout England and Wales (see Appendix A2.3.3). The main concern has been the extent to which the species invades and, therefore, reduces intertidal mudflat area, which is important for the winter feeding of some of the more numerous wading birds, such as the Dunlin. This species is thought to have been affected on the Dovey Estuary in west Wales, where a reduction in the population of Dunlin coincided with a rapid expansion of *Spartina*. The key issue from a nature conservation point of view is the extent to which the rapid growth of the vegetation, which in some sites can cover mudflats very rapidly, might compromise the importance of the sites for their wader populations. This concern has led to attempts at control in some sites, originally with herbicides, but more recently using physical means, such as ‘rotoburying’, to control the expansion of the plant.

C.6 Access and amenity

C.6.1 Bird-watching and walking

Although the danger from tidal flooding and the often difficult terrain makes direct access onto many marshes both difficult and unattractive, walking at the edge of the open estuary landscape often takes place. Normally this has little impact either on the saltmarsh itself or the other interests, such as breeding or roosting waders. However, birds feeding in the intertidal zone need secure roosting areas at high tide; these may be particularly important to the survival of individual species during periods of bad weather. Disturbance of these high tide roosts could, therefore, have an impact on some wildfowl and waders if they were continuously disturbed. The energy expended in moving from a roost because of disturbance may also put significant stress on the bird's ability to survive (particularly in hard weather conditions).

C.6.2 Wildfowling

Wildfowling has a direct impact on the quarry species and an indirect impact on others through disturbance and damage to habitat. However, despite the fact that over a million birds are shot annually in Britain as a whole, there is no real evidence of long term losses to the population of those species which can be shot legally. The most vulnerable are protected by the various forms of legislation; in addition, voluntary bans come into force during prolonged spells of hard weather.

Access onto the marsh itself for wildfowling is not considered to represent a problem. However, the desire to improve the availability of habitat for some species (such as Wigeon) in some areas, has lead to the mowing of saltmarsh vegetation, as happens on the Dee, or the digging of scrapes to increase the area of pools on the marsh. Both activities are likely to have a deleterious impact on the richer higher saltmarshes.

C.6.3 Other activities

The other recreational activities listed below which require access to, or through, a marsh have to potential to have a localised impact on the habitat. When used continuously, paths across a marsh can cause compaction of the substrate and may impede drainage. The use of vehicles can be more serious, causing the break up of the surface vegetation and changes to drainage which may ultimately result in erosion. However, this only occurs at a few sites and the damage is usually fairly localised.

Examples of the other main recreational activities that may potentially affect saltmarshes are listed below:

- Boating/mooring;
- Leisure fishing;
- Power boating and jet skiing;
- Sailing;
- Wind surfing; and
- Horse riding.

When taken together with other uses of estuaries for recreational purposes, it appears as though, at least potentially, saltmarshes could be under threat. However, it is not so much the use of the area for activities such as boating, jet skiing etc. which poses the threat, but often the loss of land consequent upon the building of infrastructure associated with them.

Access for other uses such as agriculture, flood defence and oil pollution clean up can cause harm as vehicular use may result in damage to the surface of a marsh. Prolonged use can cause ruts and permanent changes to drainage and may lead to erosion and/or changes in its value for birds.

C.7 Pollution

C.7.1 Oil

Oil is perhaps the most conspicuous contaminant which may affect a saltmarsh. This may be in the form of chronic pollution from discharges by estuary based oil industries or by occasional input from oil incidents occurring at sea. A review of major accidental oil spillages, including the "Torrey Canyon", during the 1960's and 1970's suggests that saltmarsh vegetation often recovers after a single oil spillage (Baker 1979). Chronic pollution, on the other hand, may cause long-term loss of saltmarsh vegetation and effects on individual marshes can be very different from one incident to another. This will depend on a number of factors, which include the fact that some plants are more tolerant to oil than others. In addition, the volatility of the oil itself is important, with the lighter fractions, which are lost most rapidly, being the most toxic.

The presence of oil deposits on a saltmarsh may suggest that its removal should be undertaken as a matter of urgency. Where the crude is heavy and easily picked up it may be possible to remove it mechanically but, as this may cause physical damage to the marsh, it is not recommended, except for the heaviest contamination near to or on the high water line. Evidence from studies in the eastern US suggest that use of chemical dispersants may also be more damaging than leaving the oil to degrade naturally. In general, all possible attempts should be made to prevent contamination in the first instance.

C.7.2 Chemical

Industrial effluents are potentially very damaging to the environment and often unseen. Their impact on saltmarsh vegetation and its associated fauna are little understood. Some studies from the US suggest that heavy metals may affect saltmarsh plants and the invertebrates that ingest contaminated material. However, there is little information on the way in which the saltmarsh acts as a sink for some of these toxins and whether they are then transported to the estuarine system.

In the Mersey Estuary, the deaths of large numbers of waders and other birds in 1979 provides an indication of possible effects where acute pollution has occurred. Here trialkyl lead appears to have built up in the food chain through uptake by the benthic fauna, which was subsequently eaten by the birds. Whilst these incidents are relatively rare, the fact that saltmarshes and their sediments accumulate heavy metals should be a cause for long-term concern. This is particularly important where rising sea level or potentially erosive forces are causing increased loss of saltmarsh and possible re-suspension of toxic substances.

Studies of these relationships, including the impact of pesticide and herbicide residues on the biological components of the marsh, have been very few. Work at Imperial College, London, on the herbicide Mecoprop® shows that rain soon after agricultural applications, may lead to the contamination of drainage ditches and subsequent transport of polluted water onto marsh surfaces. There is also some evidence that vegetated saltmarsh areas remain contaminated from one season to the next. As yet there is no direct link established with possible toxic effects on marsh flora.

Other agricultural chemicals, including herbicides such as atrazine and organo-chlorine insecticides, occur widely in the environment and have been detected in saltmarsh sediments (Scrimshaw *et al*., 1994). Later research by Scrimshaw *et al*. (1996) has shown that these substances are widely distributed in the sediments along the Essex coast, with higher levels in certain areas. Assessing the impact of these chemicals on the biota is, however, difficult as they only occur at very low levels with most of the data relating to the effects on plants and animals at higher concentrations.

Tributyltin (TBT) and its breakdown derivatives are another common polluter of saltmarsh sediments. TBT was formerly used extensively in anti-fouling paint before its harmful effects on marine invertebrates, particularly molluscs, became evident in the 1980's (Bryan *et al*., 1986). Although TBT rapidly degrades in the water column (with a half life of days to weeks) it is much more persistent in anaerobic sediments (with a half life of tens of years). Although little research has been conducted on the effects of TBT on saltmarsh vegetation, there have been reports that it does affect the growth of some saltmarsh species (Boorman, unpublished data).

C.7.3 Sewage and other enrichment

Estuaries have been used for many years as a convenient place to dispose sewage. The enriching effects (eutrophication) of these effluents, when combined with the agricultural run-off of fertilisers, can cause excessive growth of green algae. This may help to decrease the diversity of life in the estuary and can have a detrimental affect on saltmarsh habitat as higher marsh vegetation may become smothered by excess plant material. The extent to which these types of enrichment can be beneficial, i.e. increase productivity within an estuary, is not clear, although there is some evidence that this may result in higher numbers of some bird species feeding in these areas.

The drive over the past two decades to improve the water quality of inputs into estuary systems may reduce the overall nutrient loadings and hence potential productivity, but may lead to an increase in species diversity. This may have possibly caused, or be causing, a reduction in carrying capacity of estuaries for some populations of birds, although this is very difficult to prove and must be set against a return to a more "natural" system and potential increase in the range and diversity of species that these non-eutrophic systems support, together with an improvement in water quality.

C.7.4 Litter

Litter can accumulate on the upper saltmarsh and along the tide line. There are three main sources; the most important of which is the detached material from the plants of the higher marsh. Algae and smaller plant material, such as diatoms and other detritus are the other sources. This natural litter, in the form of decaying algae or other vegetable matter, may be important in providing food for shoreline birds. For example, snow bunting feeds on the seeds deposited among the litter on the tideline on the east coast. This material, through consumption and decay, forms an important component of the overall estuarine food chain.

Much less valuable is the build up of plastic and other man made non-degradable material. This may be unsightly and can lead to the impression that saltmarsh and its adjacent habitats are degraded and unattractive areas, suitable for land claim. It is significant that the results of the investigation of human impacts on estuaries (Davidson, 1991) showed that no fewer than 122 of the 155 estuaries in the review suffered some form of informal (possibly illegal) domestic refuse disposal and 48 had rubbish tips located upon them. There is no information on the long-term impact on saltmarsh vegetation of small deposits of litter on the marsh.