Chapter 10 Saltmarshes

Introduction

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Saltmarshes are vegetated areas in the upper part of the intertidal zone found on the shores of inlets, estuaries and embayments that are sheltered from strong wave action. The vegetation consists of halophytic (salt-tolerant) grasses, herbs and shrubs that can grow in the upper part of the intertidal zone, and are subjected to regular inundation by the sea. Their ecology has been described by Ranwell (1972), Adam (1990) and Packham and Willis (1997). Saltmarshes extend down to about mid-tide level, and have muddy, or sometimes sandy, substrates. They are generally bordered seawards by intertidal mudflats or sandflats, bare of vegetation or with carpets of algae, such as *Enteromorpha* spp., or seagrasses such as *Zostera* spp..

The distribution of active saltmarshes in Britain is shown in (Figure 10.1) British saltmarshes are extensive where the tide range is large and the intertidal zone wide, with a very gentle transverse gradient, as on the shores of the Severn and Dee estuaries, Solway Firth (see GCR site report in the present chapter), and Bridgwater Bay in the Bristol Channel. A distinction has been made between these 'open marshes', which have spread seawards, and 'closed marshes', which occupy areas between landward recurves in the lee of spits such as Blakeney Point, Norfolk, and Culbin, Moray, and barrier islands such as Scolt Head Island, on the North Norfolk coast (see GCR site reports in Chapter 11) and Morrich More, Ross and Cromarty. Closed marshes become lagoons at high tide, then drain out through a system of converging tidal creeks as the tide falls (Steers, 1977).

Although small in areal terms, the west coast of Scotland and the Western Isles support many small and fringing saltmarshes, particularly where relative sea level has risen to create sheltered conditions and a complex shoreline (e.g. Loch Maddy, North Uist). As a whole, the 6567 ha of Scottish saltmarshes comprise some 15% of the British resource. Unlike the saltmarshes of southern and eastern Britain, they generally tend to be grazed, lack high sediment inputs and have a complete transition from halophytic to terrestrial vegetation. They are also characterized by mainly sandy substrates rather than the muds of the English saltmarshes.

Extensive saltmarshes bordered by intertidal mudflats are seen in Poole Harbour, Dorset (Figure 10.2), Southampton Water, Portsmouth Harbour, Langstone Harbour and Chichester Harbour on the south coast of England. These large inlets formed during the Holocene marine transgression, and have persisted because the inflowing rivers are too small to supply much sediment, and because this is a subsiding coast.

On the west coast of Britain, notably in the Welsh and Scottish estuaries and in the Solway Firth (see GCR site reports in the present chapter), saltmarshes are generally firmer than those on the east coast because there are higher proportions of sand in the muddy sediment. Samphire *Salicornia* spp. are again the pioneers, but later colonization is dominated by grasses such as *Puccinellia,* which form a sward on marshland dissected by winding tidal creeks.

In Scotland, there are very few truly muddy saltmarshes; most of the marshes are sandy in character. Scottish saltmarshes tend to have little pioneer vegetation in comparison to those of England, although this rapidly gives way in the main to common saltmarsh-grass *Puccinellia maritima* with plantain *Plantago,* thrift *Armeria* and sea milkwort *Glaux* also common in the grazed swards. In sheltered shores of the Highland area, especially along sea lochs, patchy saltmarsh can develop on stony or rocky substrates. Saltmarsh vegetation has also been recorded on the cliff tops of St Kilda, resulting from wave spray in this exposed setting.

Evolution of a saltmarsh

Saltmarshes begin to form when vegetation colonizes the upper part of the intertidal zone (Pethick, 1984; Frey and Basan, 1985). Saltmarshes have been forming in sheltered sites around the coasts of Britain since the sea approached its present level about 5000–6000 years BP as a result of the Holocene marine transgression. For example, at St Osyth

Marsh, Essex, (see GCR site report in the present chapter) shows by radiocarbon dating that saltmarsh development began at about 4200 years BP (Pethick, 1981).

In accreting intertidal zones, especially in areas where shelter from strong wave action is enhanced because of the growth of protective spits, barriers or shoals, the early stages in the development of a saltmarsh can be studied. Sandy saltmarshes are developing in the lee of The Bar, and its associated spits, within the barrier island complex at Culbin Sands, Moray (see GCR site report in the present chapter and in Chapter 11; Comber *et al.,* 1994), and behind Crow Point at Braunton Burrows, Devon (see GCR site report in Chapter 7).

On the North Norfolk coast (see GCR site report in Chapter 11), the evolution of saltmarshes — where stages in saltmarsh evolution can be traced from east to west between successively-formed recurves on spits at Blakeney Point and Scolt Head Island — has been documented, (Steers, 1960; Pethick, 1980a). There is initial colonization of muddy or sandy areas in the upper intertidal zone by individual halophytic plants (e.g. samphire *Salicornia* spp.), which expand vegetatively and eventually coalesce to form marshland dominated by single species such as common cord-grass *Spartina* spp.. Other species colonize, and the saltmarsh begins to trap sediment (mainly clay, silt and organic matter, sometimes with some fine-grained sand and shells) washed into the vegetated area by waves and currents as the tide rises, and retained by the filtering network of stems and leaves as it falls. Although often characterized as tide-dominated morphology, most saltmarshes are also influenced by wave action as the tide rises and falls. The vegetation diminishes wave action; swards of saltmarsh grass can reduce wave heights by up to 70% and wave energy by over 90%, and, as the water velocity diminishes, fine-grained sediment is deposited (Pethick, 1980b; Mailer, 1998).

Sedimentation is also promoted by the growth of a subsurface root network, which binds the accreting sediment, by the presence of adhesive algal mats on the muddy surface, and by flocculation and precipitation of clay by the salt exuded from marsh plants (Pethick, 1984). In addition, mud that adheres to leaves and stems dries off and falls to the substrate. The processes of seaward spread and upward growth of a saltmarsh are aided by an abundant supply of sediment, but even in the absence of sediment input, saltmarshes can still aggrade by the accumulation of peat derived from the decaying vegetation.

In due course, a saltmarsh is built up to high spring tide level as a depositional terrace, only rarely submerged by the sea, that slopes gently from approximately the high spring tide line (HWOST) to the high neap tide line (HWONT), then more steeply (sometimes as a micro-cliff) to the mid-tide line (Figure 10.3). In the absence of saltmarsh vegetation the mudflats and sand-flats remain as a more variable intertidal slope, and if the plant cover dies, or is cleared away, the saltmarsh terrace becomes dissected and degraded by erosion.

Saltmarsh species tolerate varying depths and durations of tidal submergence, and so spread forward to an intertidal contour that corresponds with these limits. As a result there is often a well-defined zonation of species parallel to the coastline, with plants such as samphire *Salicornia* spp. dominating the lowermost zone that is most frequently submerged by the tide, and sea-rush *Juncus maritimus* and other saltmarsh plants occupying higher zones that are less frequently submerged (Figure 10.3) and (Figure 10.4). These zones could simply represent the occupation by each species of a suitable habitat that moves seawards as accretion continues, but where the vegetation traps sediment that builds up and progrades the substrate, it also prepares the way for the seaward advance of the plant zones (a vegetation succession) on the developing saltmarsh terrace. The vegetation succession then continues with invasion of the landward edge of the saltmarsh by less halophytic species, such as common reed *Phragmites australis* and rushes (e.g. *Juncus* spp., *Scirpus* spp.) together with freshwater wetland species such as swamp scrub including willow *Salix* spp. and alder *Alnus* spp.. Eventually the transition is made to dry-land vegetation (Ranwell, 1972; Packham and Willis, 1997). These later stages in vegetation succession can be seen locally at the back of saltmarsh terraces around Poole Harbour (Bird and Ranwell, 1964; (Figure 10.2)), but they have often been destroyed by hinterland drainage and land-claim. Succession from saltmarsh to freshwater swamp and land vegetation is likely to be accelerated by coastal emergence, and evidence of this may be found in Scottish sites where post-glacial isostatic rebound is in progress, such as at Morrich More, in the Dornoch Firth (Hansom and Leafe, 1990). One of the few saltmarsh successions to woodland in the UK is in Sutherland, where the completion of an embankment in 1816 enabled alder *Alnus* to colonize the saltmarsh at the head of Loch Fleet. The resulting alder woods are so well established that they are now a National Nature Reserve.

Conventionally, algal mats (such as *Enteromorpha* spp.) and seagrasses (notably eel-grasses *Zostera* spp.), which grow on mudflats in the intertidal and subtidal zones, are not regarded as saltmarshes, even though they often prepare the way for saltmarsh encroachment. Seagrasses trap sediment because the plants are erect when the tide is high, and can form a sediment-filtering meadow in which wave heights are reduced by up to 40% and wave energy by 60% (Fonseca, 1996). The substrate is thus raised to form a seagrass bank or terrace that often grows upward and outward as the vegetation spreads. Nevertheless, some seagrass terraces are sharp-edged owing to wave activity or current scour.

Rates and patterns of accretion

Rates of vertical accretion have been measured on north Norfolk saltmarshes, notably at Scolt Head Island (Steers, 1960), where the progressive burial of artificial markers inserted in a saltmarsh showed vertical accretion of up to 8 mm a^{-1}, with variations related to marsh elevation and inundation frequency and the retention of sediment from turbid water overflowing from tidal channel margins. These saltmarshes grow vertically by accretion during ordinary high tides, but the higher parts receive sediment only in storm events (French and Spencer, 1993). In general, vertical accretion is relatively slow at the upper and lower limits of the saltmarsh, and more rapid in the intervening zone, where saltmarsh vegetation forms a relatively dense sediment-trapping cover and is regularly invaded by sediment-laden tidal water. Pethick (1981) found the upper limit of accretion on saltmarshes to lie below the level of the highest spring tides. Marshes, therefore, never quite attain this altitude.

Vertical accretion of up to 15 mm a^{-1} has been measured on saltmarshes in Essex, where coastal subsidence is in progress (Ranwell, 1972). In saltmarshes bordering the Severn estuary, French (1996) used evidence from heavy metal profiles and lead (^{210}Pb) dating to define distinct sedimentary units (between planes dating from 1840–1850, 1936±7, 1971 ± 4 and 1958±4), and shows that vertical accretion (3–4 mm a^{-1}) has been proceeding at about the same rate as sea-level rise in the area. There are at least three saltmarsh terraces bordering the Severn estuary, representing cycles of marsh erosion and accretion. Accretion is most rapid (12.1 mm a^{-1}) on the lower terrace, submerged by every high tide, slower (6.4 mm a^{-1}) on the middle terrace, and slowest (2.3 mm a^{-1}) on the higher terrace, which is inundated only by high spring tides (French, 1996). However, where supply rates are high, accretion responds accordingly. For example, in the sandy saltmarshes of the inner Solway, Harvey (2000) has measured rates of vertical accretion of up to 51 mm a^{-1} in some areas and in excess of 20 mm a^{-1} over wider areas on account of a very healthy offshore sand supply.

The fine-grained sediment deposited in saltmarshes is derived largely from bordering intertidal mudflats and sandflats, which in turn have been supplied with clay, silt and sand by rivers, or similar sediment eroded from cliff and rocky shore outcrops. Fine-grained sediment has also been carried in from the sea floor, especially where there are mudrock outcrops or glacial or periglacial deposits in nearshore shallows, and organic matter derived from seaweeds and marine fauna, especially shelled organisms, has been swept on to marshes. Radionuclides contained in sea water and seabed sediments are also transported onto saltmarshes. Coring of the Solway saltmarshes has revealed ^{137}Cs and ^{241}Am peaks in the subsurface layer that relate to past high levels of emission from the Sellafield Nuclear Fuel Reprocessing Plant in Cumbria (Harvey and Allan, 1998; Harvey, 2000).

Providing there is a supply of fine-grained sediment, and wave action is gentle, saltmarshes can spread rapidly (Figure 10.4). The supply of mud to a saltmarsh increases where fluvial sediment yields are augmented by catchment soil erosion, whcrc the dredging of channels increases muddy sediment in suspension, or where dredged material is dumped on or near marshes, accelerating vertical accretion and progradation. An excessive rate of mud deposition may however blanket and kill saltmarsh vegetation.

Sections through saltmarsh terraces, exposed in the banks of tidal creeks or in cliffs at the seaward edge, as on the saltmarsh at Morrich More, Ross and Cromarty (see GCR site report in the present chapter), generally comprise stratified deposits, with layers of coarser sands within the host sands or muds. These variations are related to wave conditions, storm waves washing sand into the saltmarsh, and mud accumulating as the tides rise and fall in calmer weather. In the Severn estuary the grain size of saltmarsh sediments diminishes from fine-grained sand to silt and clay landwards from the edge of the marsh as the result of sorting of sediment washed in from the seaward side, and there is a similar diminution vertically through the aggraded saltmarsh terrace because of progradation (Allen, 1996a). However, there are often storm-carried sediments, including sand and organic litter, on the upper saltmarsh (Stumpf, 1983), some of which may have been eroded from the seaward edge of the saltmarsh as occurs at Morrich More, Ross and Cromarty and Caerlaverock, Dumfries and Galloway.

Upward and outward growth of saltmarshes can be accelerated by an increase in the rate of sedimentation of the kind that occurred in Cornish estuaries in the 18th and 19th centuries when river sediment yields were augmented by mining waste. A grassy saltmarsh formed as the Fal delta grew rapidly between 1878 and 1973, when the river was carrying large quantities of kaolinite from the china clay workings on Hensbarrow Down (Ranwell, 1974). On the south coast of England rates of accretion have been very slow in areas where excavations made in saltmarshes (e.g. for salt manufacture) have persisted for many decades, as at Budleigh Salterton in Devon (see GCR site report in Chapter 6). In the Medway estuary in Kent large quantities of clay were cut for brick-making and cement production, leaving numerous pits and access canals; although this clay extraction ceased in the 1960s there has not yet been sufficient sediment deposition to obliterate them (French, 1997).

Micro-cliffs

At the seaward margins of many saltmarsh terraces there is a micro-cliff that may be up to 1.5 m high. Examples are seen on the Burry Inlet marshes in south Wales, where the marginal cliff forms a sharp drop to Llandridian Sands (see GCR site report for Carmarthen Bay, Chapter 11), and on the Dengie Peninsula in Essex (see GCR site report, this chapter), where the micro-cliff has been retreating at up to 10 m a^{-1}. Allen (1989) and Harvey (2000) found that saltmarsh micro-cliffs on sandy mud were bolder, often vertical, as in the Solway Firth, in comparison with the more subdued forms on soft mud in the Severn estuary. Where the top of the micro-cliff was bound by plant roots, recession was by way of calving, toppling and rotational slides of individual blocks of sediment together with stripping of surface vegetation (Harvey 2000). In some sites cuffing is accompanied by continuing vertical accretion of muddy sediment in the saltmarsh, building up the saltmarsh terrace even though seaward advance has come to an end.

A saltmarsh micro-cliff may form in various ways. In some places it results from lateral movement of a tidal channel, undercutting the edge of a saltmarsh, but as this is a widespread phenomenon (there are now only a few sites where saltmarshes are spreading seawards), some more general explanation is required. It may be that, as on the sides of developing tidal creeks, seaward margins become oversteepened and cliffed, particularly during occasional storm wave episodes. In navigable estuaries, swash from boats will also tend to cut a cliff at the edge of the saltmarsh, while dredging, by steepening the submerged offshore slope, will also encourage the retreat of the marsh edge. Cliffing of this kind is repaired if there is an abundant supply of sediment to restore the profile and permit vegetation to spread again, but if there is a sediment deficit a saltmarsh cliff will persist. Alternatively, the cuffing of seaward margins of saltmarsh terraces could be a response to a rising sea level, deepening the adjacent water and allowing larger waves to attack the shore, and probably increasing tidal penetration in estuaries. This would also explain the widening and shallowing of tidal creeks that is occurring in saltmarshes in southern England, notably in Poole Harbour, Dorset.

Where the tidal range is large there is sometimes a micro-cliff separating an upper (mature) saltmarsh of firm (often sandy) clay from a lower (pioneer) saltmarsh terrace on soft accreting mud (Pethick, 1992). A double terrace of this kind borders the Solway Firth, where an upper saltmarsh occurs landwards of the high-water line, and a lower saltmarsh seawards, as in the Nith estuary near Dumfries. Similar features are seen on the northern shores of Walney Island, in Cumbria (see GCR site report, Chapter 8), and in Loch Gruinart on Islay (see GCR site report in the present chapter). It is possible that the upper terrace has been cuffed and cut back during a stormy phase, and that the lower terrace represents a stage in rebuilding.

The effects of common cord-grass *Spartina anglica*

Many British saltmarshes have been modified by swards of common cord-grass *Spartina anglica.* This is a fertile hybrid that arose by the crossing of the native British species *S. maritinza* with *S. alterniflora,* a non-native species that was accidentally introduced in the 1820s from the eastern USA. After the hybrid *S. anglica* originated in Southampton Water in about 1870 (Carey and Oliver, 1918) it was introduced to many estuaries, subsequently advancing across intertidal mudflats and rapidly building up marshland, and spreading to new areas (Figure 10.5). It has been used in the past to stabilize and land-claim tidal flats in estuaries in various parts of the world.

Early stages of *Spartina* invasion can be seen in the lee of Holy Island (see GCR site report in Chapter 11), and on the Humber mudflats behind the spit at Spurn Head (see GCR site report in Chapter 8) where clones spread on to sandy intertidal areas. In Poole Harbour, the arrival of *S. anglica* in 1899 was followed by the rapid expansion of saltmarshes into broader and higher terraces covered entirely by this plant (Figure 10.2). At the same time, intervening creeks and channels became narrower and deeper, indicating that there had been a transference of muddy sediment from these into the areas of spreading *Spartina.* On the north Norfolk coast and in the Dee estuary, experimental introduction of *S. anglica* modified natural saltmarshes and led to the evolution of broad depositional terraces in the intertidal zone (Oliver and Salisbury, 1913; Bird, 1963). Marker (1967) recorded the rapid spread of *S. anglica* introduced in 1922, noting that it had become the pioneer colonist on accreting mudflats.

In Britain some of the older *Spartina* marshes now show evidence of die-back, especially along the seaward margins and in enclaves that become saltpans (Doody, 1984, 1990, 1992). The ecological reasons for die-back are not fully understood, but it is often associated with nitrogen deficiency, sulphide accumulation and waterlogging. At the seaward margins where the sward dies, sediment previously trapped is released, and there is a receding micro-cliff. Die-back of *Spartina* along creek margins has led to erosion of marsh edges and resulted in the widening and shallowing of tidal creeks and channels. The process may be cyclic in the sense that released mud is deposited in new or reviving *Spartina* marshes elsewhere. Bird and Ranwell (1964) reported that in some sectors in Poole Harbour *S. anglica* was still advancing, mainly in the upper estuary, whereas in others there was die-back and erosion, notably in Brand's Bay near the marine entrance. These trends have continued, although advance was very localized by the end of the 20th century. Recent *Spartina* die-back has been noted in the Solway marshes (Harvey, 2000).

In Scotland, north of the Solway, *Spartina* is not common. It occurs on the west coast at only a few isolated sites, such as Luskentyre, Western Isles (see GCR site report, Chapter 9) whereas at the east coast it is only a minor component reaching its northern limit in the Cromarty Firth (Hill, 1996, 1997).

Saltmarsh creeks

Studies of saltmarshes, particularly on the north Norfolk coast, have shown that as saltmarsh terraces are built up, the ebb and flow of the tide maintains a system of tidal creeks, the dimensions of which are related to the volume of water flowing up and down them as the tide rises and falls (Pethick, 1984, 1992; (Figure 10.6)). Typically dendritic and intricately meandering, they are channels within which the tide rises until the water floods the marsh surface. They are also drainage channels into which some of the ebbing water flows from the saltmarsh. They are thus like minor estuaries, particularly where they receive freshwater from hinterland runoff, or seepage from bordering beaches and dunes.

In the early stages, tidal creeks are relatively wide and shallow in cross-section, but as saltmarsh terraces rise and expand the creeks become narrower and deeper, and their banks higher and steeper, with frequent local slumping (Figure 10.7). Blocks of compacted mud, often with clumps of saltmarsh vegetation, collapse into the creek, especially where the banks are burrowed by crabs. Some tidal creeks are fringed by natural levees formed by deposition of sediment as the rising tide overflows, especially where such plants as orache *Atriplex* spp. have colonized the bordering banks. This pattern is more often found on the lower (and younger) seaward fringes of saltmarshes, the inter-creek areas becoming flatter as sedimentation proceeds.

Dendritic tidal creek systems give way to more rectilinear tidal creeks on some saltmarshes, as on the shores of Loch Gruinart on Islay and at Morrich More in the Dornoch Firth, north-east Scotland (see GCR site reports in the present chapter). Straight sub-parallel creeks across saltmarshes are more often found where the tide range is large and the transverse gradient small, or where the rate of seaward spread of saltmarsh has been rapid. In Bridgwater Bay on the southern shore of the Bristol Channel, where the tidal range is about 10 m, saltmarsh creeks run parallel and orthogonal to the coastline, whereas in Poole Harbour (Dorset), a microtidal estuarine embayment, creek patterns in bordering saltmarshes are mainly dendritic (Ranwell, 1972) (Figure 10.8).

The morphology of tidal creeks is related to sediment type, plant cover and tidal range. There are clearly defined steep-edged tidal creeks in saltmarsh terraces built largely of cohesive day, as in Poole Harbour, but they become shallower and wider where the saltmarsh is sandier, as in the estuaries opening into Cardigan Bay. Saltmarsh creek patterns are trellised where linear cheniers of shelly sand have been deposited by storm surges, and channels have been cut through these. In cross-section, tidal creeks tend to be rounded furrows where accretion is in progress, to show asymmetry on meanders where erosion balances accretion, and to be rectilinear where erosion is dominant.

Studies of creek systems on the saltmarshes of Scolt Head Island in Norfolk (see GCR site report in Chapter 11) have shown that the exchange of water and sediment with the bordering marshes varied with current velocity as the creek water rose to over-bank levels. Vertical growth of the saltmarsh led to increasingly intermittent sediment transport in the creeks, fewer tides reaching the velocity required for the entrainment of channel sediments. However, some of the alternating submergence and drainage of a saltmarsh results from inflow and outflow across the seaward fringe rather than through creek systems (French and Stoddart, 1992).

Saltpans and pond holes

Saltpans (also known as 'pond holes') are small shallow depressions that may form as the result of the blocking of part of a tidal creek by slumping, as residual unvegetated areas within a developing saltmarsh, or as the result of local die-back of saltmarsh vegetation (Pethick, 1974; Steers, 1977). Some originated as the result of the collapse of subsurface cavities. They are flooded at high tide, and remain bare of plants because evaporation makes the trapped water hyper-saline. Many become rounded as the result of scour by small waves and circulating currents generated by winds blowing across them. Numerous saltpans occur on saltmarshes between shingle recurves on Blakeney Point on the North Norfolk Coast (Figure 10.9); see also GCR site report in Chapter 11) and they are also extensive on saltmarsh terraces, such as those bordering the Cree estuary in south-west Scotland (see GCR site report in the present chapter). On many Scottish saltmarshes, creeks, abandoned owing to sea-level changes, form the basis of several series of linear saltpans that mirror the old creek pattern, and often drain via subsurface pipes, for example, Morrich More, Ross and Cromarty, has good examples of such abandoned networks (Smith, 1978; Hansom and Leafe, 1990.)

Freshwater swamps

Reference has been made to freshwater swamps on the landward margins of saltmarshes, where they represent a late stage in vegetation succession to land vegetation, but freshwater swamps also fringe the shore in coastal lagoons, estuaries and sheltered embayments. They are dominated by common reed *Phragmites australis* often with rushes (e.g. *Juncus* spp.) and sedges (e.g. *Bolboschoenus maritimus = Scirpus mar-itimus*), which can grow out into water about 1 m deep, such as at Luce Sands, south-west Scotland (see GCR site report in Chapter 7). As in saltmarshes, freshwater swamps of this kind reduce wave action and current flow, and promote accretion of sediment, particularly silt and clay, in such a way as to build up a depositional terrace. Seasonal decay of freshwater swamp vegetation produces organic matter, which is deposited with the trapped sediment, and where the sediment supply is meagre this organic matter may accumulate on the depositional terrace as fibrous peat deposits. In due course the terrace is built up to high-water level, and land vegetation (scrub and woodland) then moves in. The outcome is progradation of the coastline by swamp encroachment, a process that is demonstrable on the shores of coastal lagoons where salinity is relatively low, as in Loe Pool in Cornwall, Slapton Ley in Devon (see GCR site reports in Chapter 6) and Abbotsbury Swannery at the western end of The Fleet in Dorset (see GCR site report for Chesil Beach in Chapter 6).

Impacts of human activity

Saltmarshes in Britain have been reduced in area by widespread coastal land-claim, generally by embanking upper marshes for conversion to pasture or cultivation. Extensive areas south of the Wash have been reclaimed in this way over the past few centuries (Kestner, 1962; Doody, 1987; Robinson, 1987; Halcrow, 1988, Hill, 1988; Mortimer, 2002), and where associated peat deposits have been compressed, dried out, or destroyed by burning or oxidation, the land surface has subsided. Over the same period, saltmarshes seaward of embankments and seawalls have narrowed as the result of erosion ('coastal squeeze'), particularly on subsiding parts of the coast in east and south-east England (Doody, 1996). In Scotland, some 50% of the former intertidal area of the Forth estuary has been subject to claim over the last 400 years, resulting in the survival only of remnants of saltmarsh (Hansom *et al.*, 2001).

Saltmarshes have also been modified by pollution, and by the dumping of waste material of various kinds. Some saltmarshes have also been modified locally where channels have been excavated or tidal creeks widened and deepened to permit boat access and provide anchorages, and in some places excavated material has been dumped alongside to form hard ground for harbour facilities. Mention has been made of excavation of clay from the Medway marshes and elsewhere.

In recent years the costs of maintaining low-lying reclaimed areas by maintaining the flood banks have led to suggestions that such areas should be abandoned and allowed to revert to saltmarsh, which has plants, animals and birds with important nature conservation value (Doody, 1996). Such 'managed re-alignment' has been implemented at a few small sites, notably on Northey Island in the Blackwater estuary, Essex. A number of other land-claimed saltmarsh sites are under review, including other Essex sites, Slimbridge beside the Severn estuary, Porlock Marsh in north Devon and Skinflats in the Firth of Forth (Hansom *et al.,* 2001). A small RSPB site at Nigg Bay in Ross and Cromarty has recently undergone managed re-alignment, the first *in* Scotland to do so. The further advantage of such managed re-alignment is that given ideal conditions the re-established saltmarshes should build up to, and in future keep pace with, rising sea levels (French, 1997).

The GCR saltmarsh sites

The sites described in this chapter and those site described in Chapter 11 that contain saltmarsh in the assemblage (see (Figure 10.1)) represent the five saltmarsh types in Allen and Pye's (1992) classification that divides saltmarshes on the basis of their physical site-type and situation.

1. Open coast marshes — Dengie, Solway Firth (North coast), North Norfolk, Morrich More,
2. Estuarine back-barrier marshes — Culbin, Morrich More, North Norfolk, Keyhaven, Burry Inlet, Dengie (small area), St Osyth,
3. Estuarine-fringing marshes — Cree, Solway Firth (south and north), St Osyth, Morrich More, Burry Inlet,
4. Embayment marshes — Cree, Solway Firth (south),
5. Loch- or fjord-head marshes — Loch Gruinart.

In this chapter, the site descriptions are arranged so that the northernmost on the North Sea coast is provided first, followed by the remainder in a clockwise order.

Further GCR sites that contain important saltmarsh localities are described in Chapter 11 of the present volume, where the saltmarsh forms part of a geomorphologically important coastal assemblage.

Since these GCR sites were first selected, there have been two national surveys of saltmarshes, Burd (1989) for the Nature Conservancy Council, and Pye and French (1993) for the former Ministry of Agriculture, Fisheries and Food. Readers are referred to these sources for a more comprehensive view of saltmarshes in Britain.

Saltmarshes as biological SSSIs and Special Areas of Conservation (SACs)

In Chapter 1, It was emphasized that the SSSI site series is constructed both from areas nationally important for wildlife and GCR sites. An SSSI may be established solely for its geology/geomorphology, or its wildlife/habitat, or it may comprise a 'mosaic' of biological and GCR sites that may be adjacent, partially overlap, or be coincident. Therefore there are a number of coastal SSSIs that are primarily selected for their wildlife conservation value, but implicitly will contain interesting coastal geomorphology features that are not included independently in the GCR because of the 'minimum number' criterion of the GCR rationale (see Chapter 1; Sherwood *et* ed., 2000). Therefore there are some areas of saltmarsh that are crucially important to the natural heritage of Britain are not described in the present geomorphologically focused volume, but are conserved for their habitat value as SSSIs.

In addition to being protected through the SSSI system for their national importance, certain types of saltmarsh are 'Habitats Directive'-Annex I habitats eligible for selection as SACs (see Chapter 1). As well as being eligible for SAC selection in their own right, saltmarshes can be an important component of some SACs selected for the Annex I type

'Estuaries'. Furthermore, many saltmarshes are of international ornithological importance, primarily for breeding waders and wintering wildfowl, and for this reason may be designated Special Protection Areas under the Birds Directive, and/or as Ramsar sites.

Saltmarsh SAC site selection rationale

For the two relatively widespread Annex I coastal saltmarsh types occurring in the UK, '*Salicornia* and other annuals colonising mud and sand' and Atlantic salt meadows, sites have been selected to represent their geographical range and ecological variation. Generally, the largest areas of the habitat type have been selected. Preference has been given to sites where saltmarsh forms part of well-developed successional sequences, and there are transitions to other high-quality habitat assemblages at many of the selected sites. For the two rare saltmarsh types, 'Mediterranean and thermo-Atlantic halophilous scrubs' and '*Spartina* swards', all sites known to support significant examples have been selected as SACs. Only sites that are dominated by the native cord-grasses *Spartina maritima* and *S. alterniflora,* or the rare and local hybrid *S.* x *townsendii* have been considered for selection as *Spartina* swards, not stands of the widely introduced invasive common cord-grass *Spartina anglica.* Although a prominent feature of many estuaries, monoculture swards of the latter species are of little intrinsic value to wildlife, and in many areas *S. anglica* is considered a threat to the intertidal feeding-grounds used by large populations of wading birds and wildfowl. Attempts have been made to control *S. anglica* at several sites over many years.

(Table 10.1) lists saltmarsh SACs, and indicates which of the sites are also important as part of the GCR and are described in this chapter.

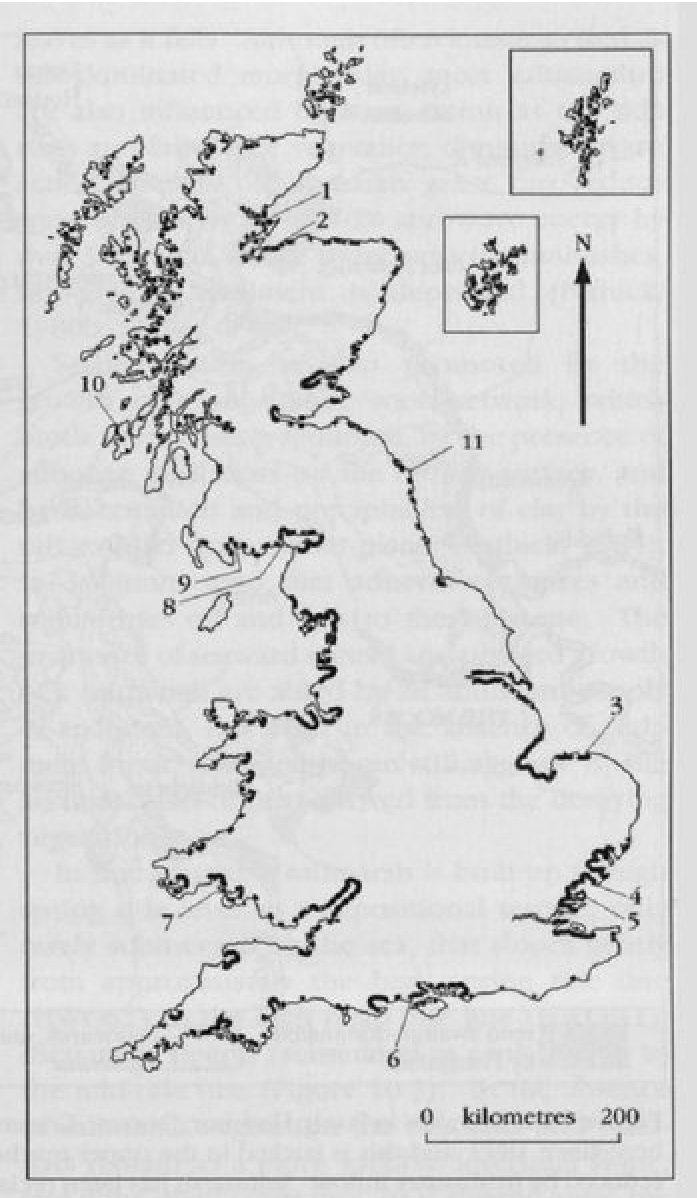
(Table 10.1) Candidate and possible Special Areas of Conservation in Great Britain supporting Habitats Directive Annex I coastal saltmarsh habitat(s) as qualifying European features. Non-significant occurrences of these habitats on SACs selected for other features are not included. (Source: JNCC International Designations Database, July 2002.)

SAC name	Local authority	Saltmarsh extent (ha)
Alde, Ore and Butley Estuaries	Suffolk	390
Carmarthen Bay and Estuaries/ Bae Caerfyrddin ac Aberoedd	Abertawe/ Swansea; Caerfyrddin/ Carmarthenshire; Penfro/ Pembrokeshire	2764
Chesil and the Fleet	Dorset	21
Culbin Bar	Highland; Moray	203
Dee Estuary/ Aber Dyfrdwy*	Cheshire; Fflint/ Flintshire; Wirral	2431
Dornoch Firth and Morrich More	Highland	539
Drigg Coast	Cumbria	162
Essex Estuaries	Essex	3770
Fal and Helford	Cornwall	70
Glannau Môn (Cors heli)/Anglesey Coast (Saltmarsh)	Ynys Môn/ Isle of Anglesey	191
Humber Estuary*	City of Kingston upon Hull; East Riding of Yorkshire; Lincolnshire; North East Lincolnshire; North Lincolnshire	840
Kenfig/ Cynffig	Pen-y-bont ar Ogwr/ Bridgend	20
Mòine Mhór	Argyll and Bute	94
Morecambe Bay	Cumbria; Lancashire	1897
North Norfolk Coast	Norfolk	19
North Uist Machair	Western Isles / Na h-Eileanan an Iar	82
Pembrokeshire Marine/ Sir Benfro Forol	Penfro/ Pembrokeshire	274
Pen Ll■n a'r Sarnau/Lleyn Peninsula and the Sarnau	Ceredigion; Gwynedd; Powys	748

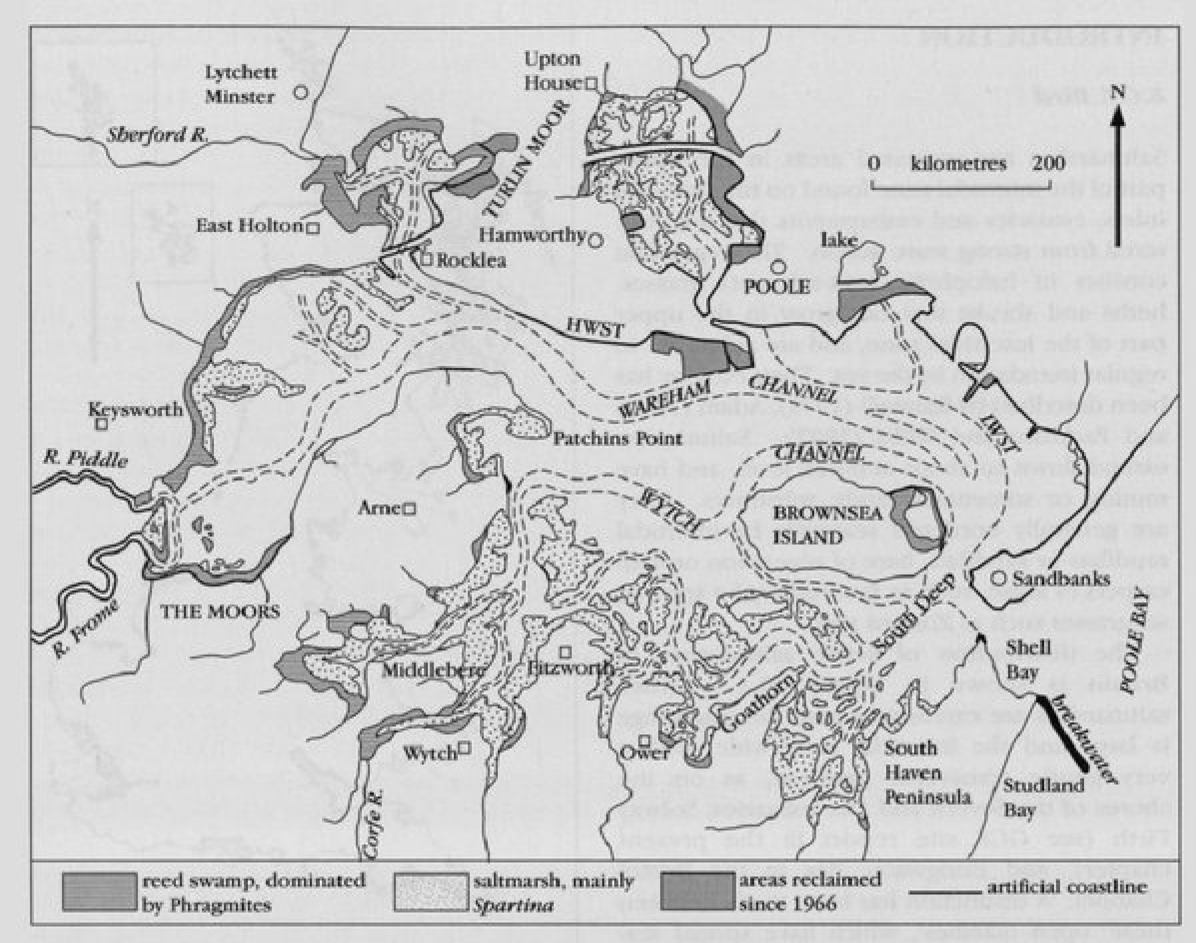
Plymouth Sound and Estuaries	Cornwall; Devon; Plymouth	192
Severn Estuary/ Môr Hafren*	Bro Morgannwg/Vale of Glamorgan; Caerdydd/ Cardiff; Casnewydd/Newport; City of Bristol; Fynwy/ Monmouthshire; Gloucestershire; North Somerset; Somerset; South Gloucestershire	656
Solent Maritime	City of Portsmouth; City of Southampton; Hampshire; Isle of Wight; West Sussex	2276
Solway Firth	Cumbria; Dumfries and Galloway	4171
The Wash and North Norfolk Coast	Lincolnshire; Norfolk	3341

* Possible SAC not yet submitted to EC.

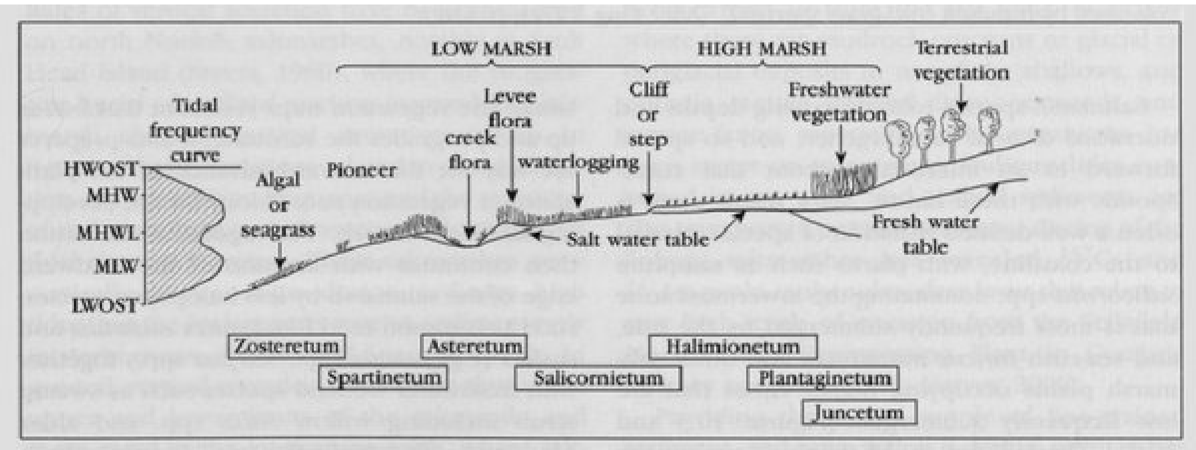
Bold type indicates a coastal GCR interest within the site



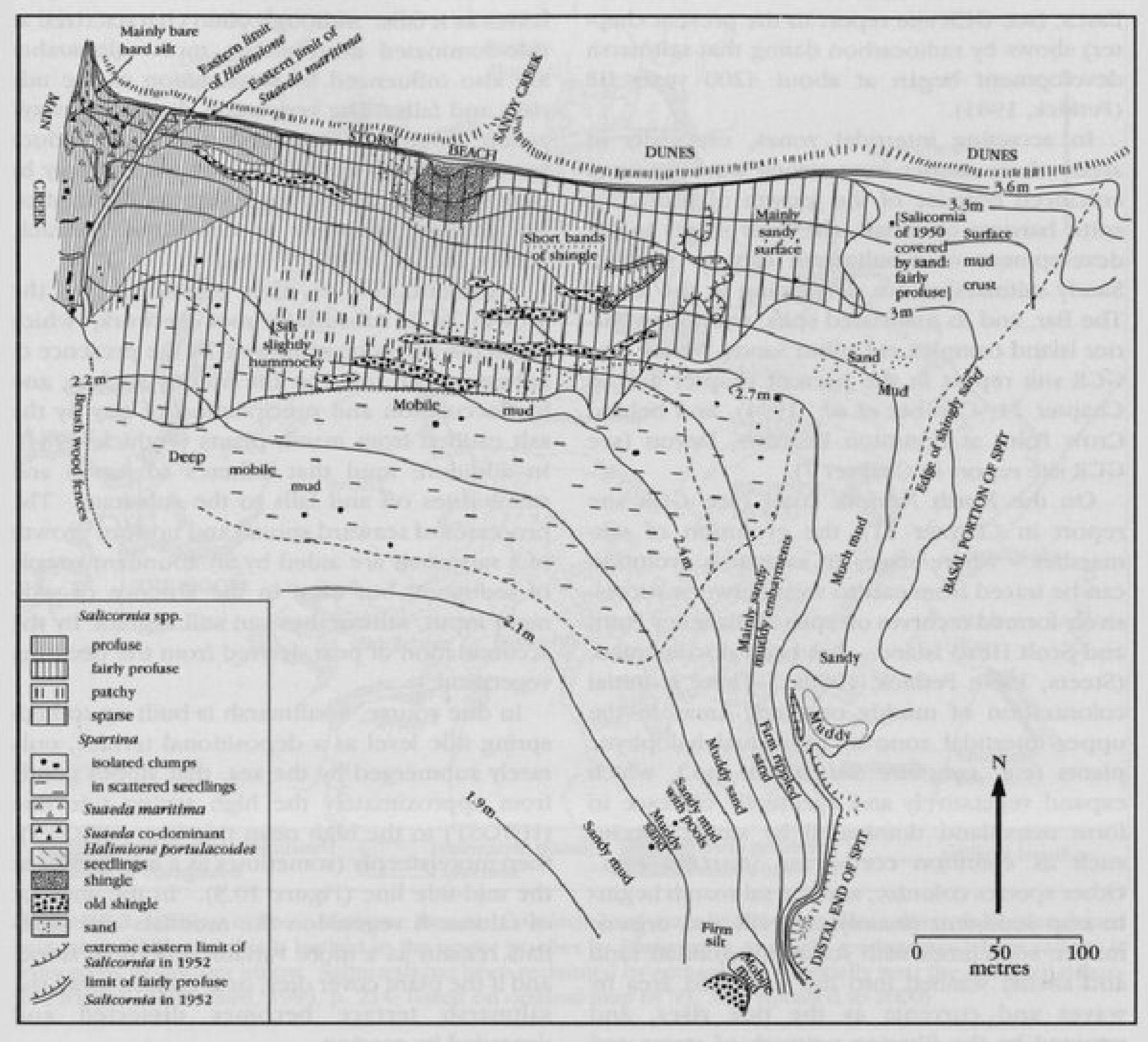
(Figure 10.1) The generalized distribution of active saltmarshes in Great Britain. Key to GCR sites described in the present chapter or Chapter 11 (coastal assemblage GCR sites): 1. Morrich More; 2. Culbin; 3. North Norfolk Coast; 4. St Osyth Marsh; 5. Dengie Marsh; 6. Keyhaven Marsh, Hurst Castle; 7. Burly Inlet, Carmarthen Bay; 8. Solway Firth, North and South shores; 9. Solway Firth, Cree Estuary; 10. Loch Gruinart, Islay, 11. Holy Island. (After Pye and French, 1993.)



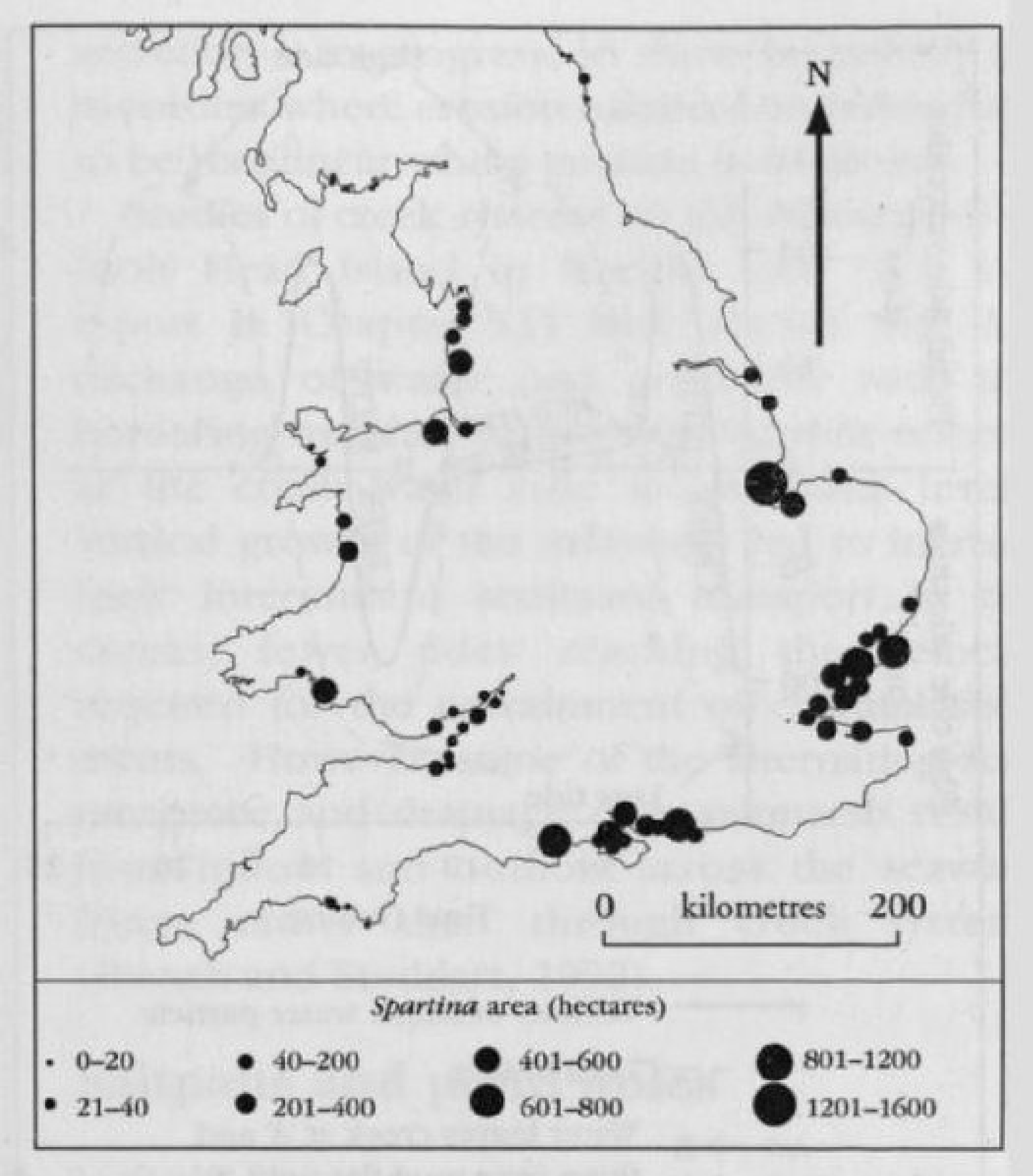
(Figure 10.2) Marshes in Poole Harbour, Dorset. Common cord-grass Spartina anglica saltmarsh has developed here since 1899, and this is backed in the upper reaches by Phragmites australis reedswamp, where salinity is reduced by freshwater inflow. Saltmarsh has been reclaimed by embanking, especially near the northern urbanized fringes. (After Bird, 1984, p. 214; based on original map by V.J. May, updated to 2000)



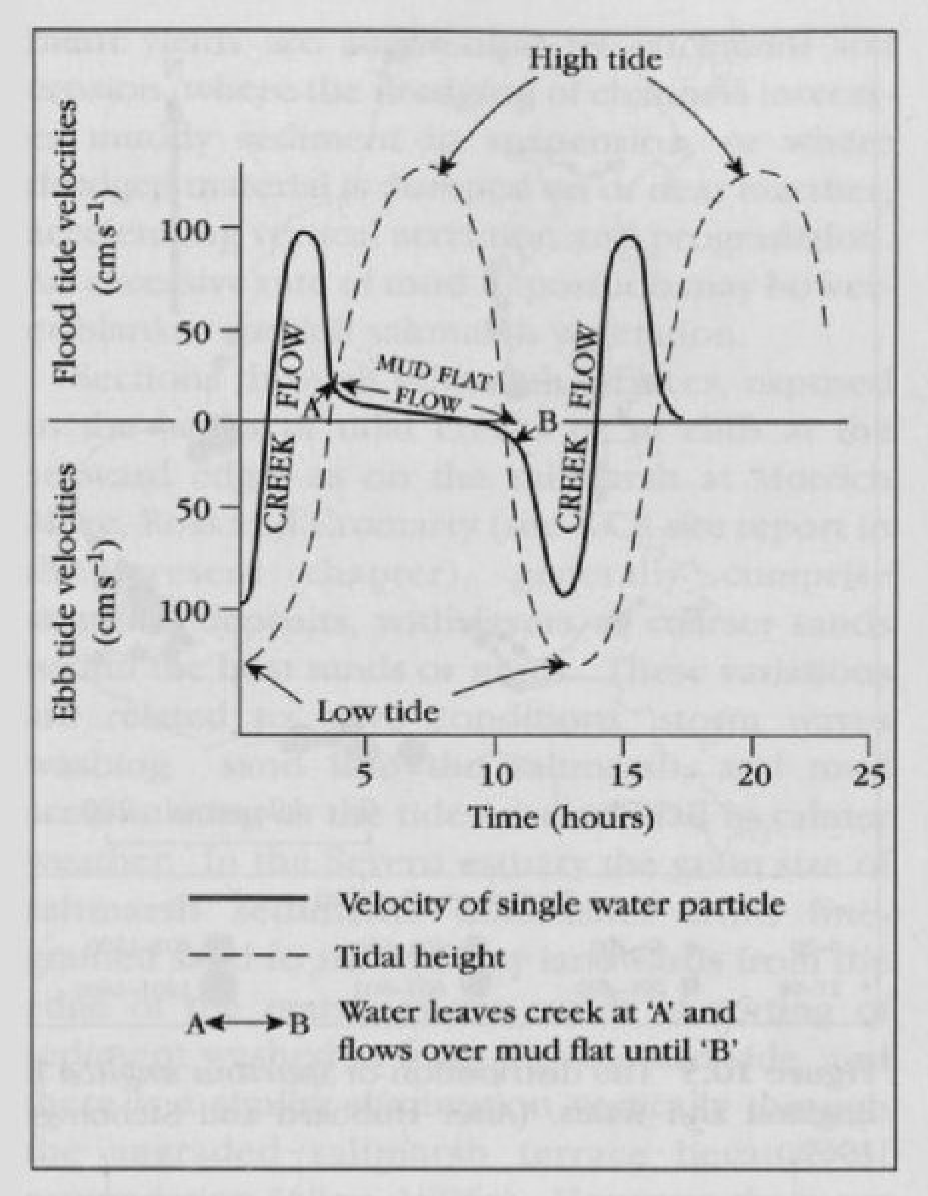
(Figure 10.3) Typical saltmarsh vegetation zonation: the dominant species found in England and Wales at each level are named in the boxes. In Scotland, the sandy saltmarshes are dominated by common saltmarsh-grass Puccinellia. (After Carter, 1988, p. 344.)



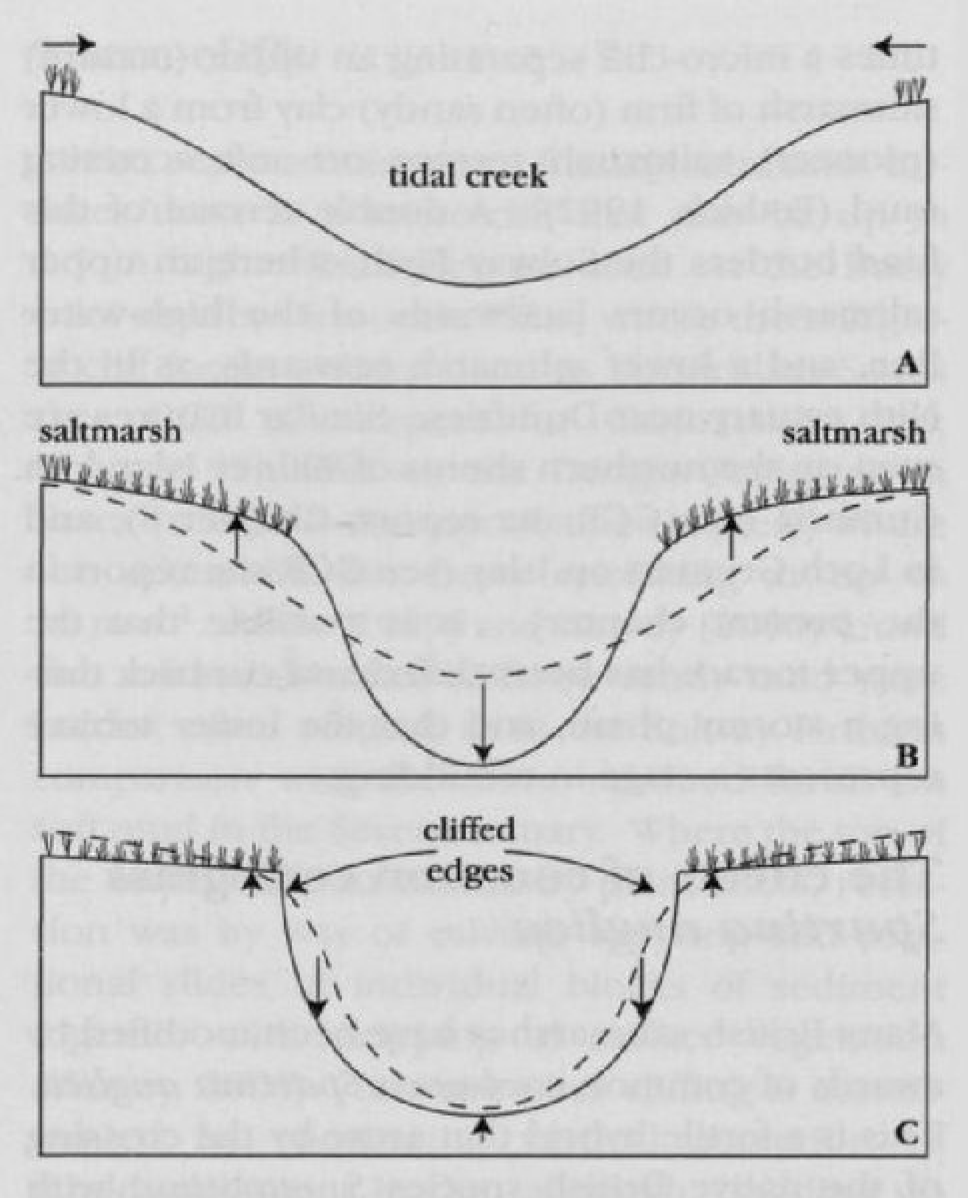
(Figure 10.4) Map of the saltmarsh at Gibraltar Point, Lincolnshire, recording the position in 1951. The marsh was growing on the landward side of the spit; the area was re-surveyed in 1959, by which time 15–30 cm of sediment had built up the marsh surface over most of the area, and the low-lying mud and sand of 1951 had been colonized by common cord-grass Spartina. (After King, 1972a, p. 428.)



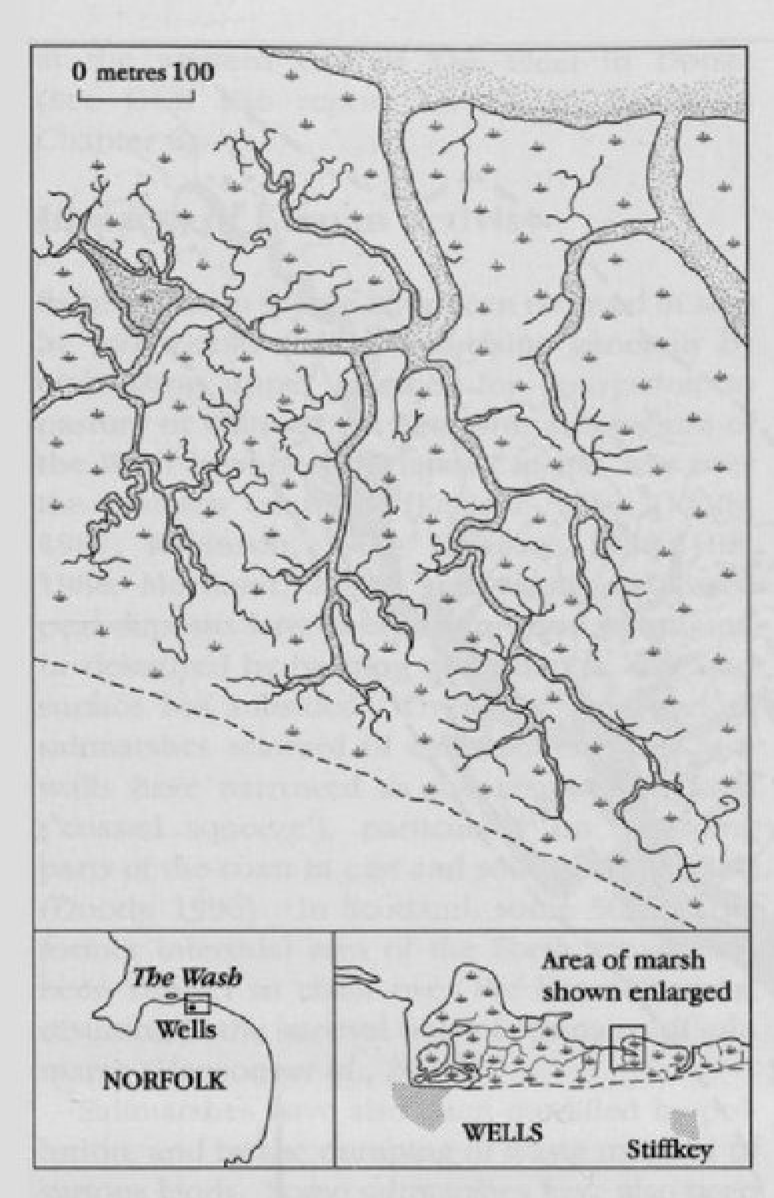
(Figure 10.5) The distribution of Spartina anglica in England and Wales. (After Hubbard and Stebbings, 1967.)



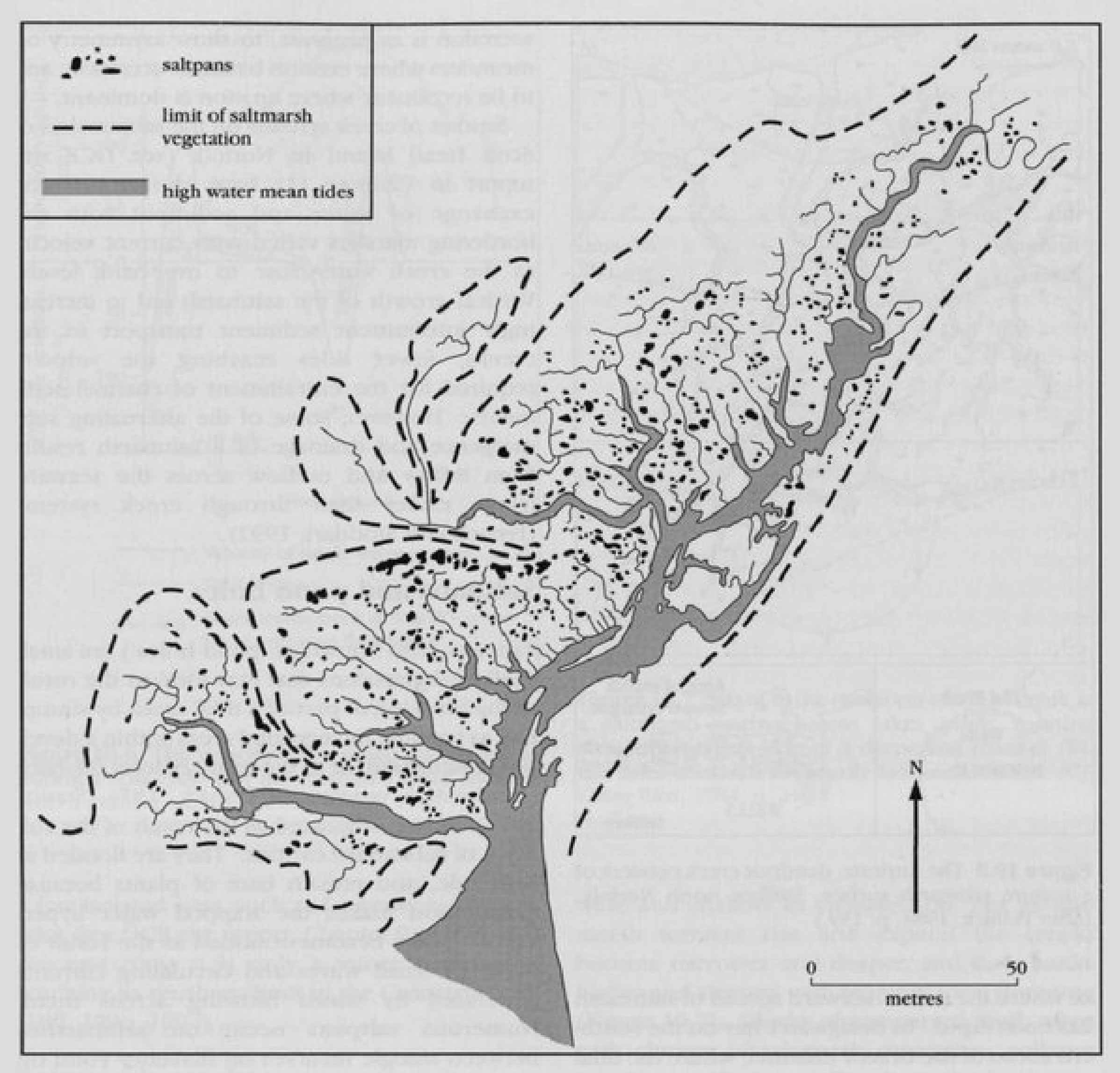
(Figure 10.6) The velocities of a single water particle during a tidal cycle as it moves from a creek channel onto a mudflat surface. (After Pethick, 1984.)



(Figure 10.7) Stages in the evolution of a tidal creek as a saltmarsh encroachment takes place, forming terraces on either side of a deepening channel (B), the sides of which eventually become unstable (C). (After Bird, 1984, p. 213.)



(Figure 10.8) The intricate, dendritic creek network of a mature saltmarsh surface, Stacey, north Norfolk. (After Pethick, 1984, p. 159.)



(Figure 10.9) The distribution of saltpans on a saltmarsh at Blakeney Point, north Norfolk. (After Pethick, 1984, p. 164.)

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Pen Llŷn a'r Sarnau/ Lleyn Peninsula and the Sarnau	Ceredigion; Gwynedd; Powys	748
Plymouth Sound and Estuaries	Cornwall; Devon; Plymouth	192
Severn Estuary/ Môr Hafren*	Bro Morgannwg/ Vale of Glamorgan; Caerdydd/ Cardiff; Casnewydd/ Newport; City of Bristol; Fynwy/ Monmouthshire; Gloucestershire; North Somerset; Somerset; South Gloucestershire	656
Solent Maritime	City of Portsmouth; City of Southampton; Hampshire; Isle of Wight; West Sussex	2276
Solway Firth	Cumbria; Dumfries and Galloway	4171
The Wash and North Norfolk Coast	Lincolnshire; Norfolk	3341

* Possible SAC not yet submitted to EC.
Bold type indicates a coastal GCR interest within the site

geomorphology, or its wildlife/habitat, or it may comprise a 'mosaic' of biological and GCR sites that may be adjacent, partially overlap, or be co-incident. Therefore there are a number of coastal SSSIs that are primarily selected for their wildlife conservation value, but implicitly will contain interesting coastal geomorphology features that are not included independently in the GCR because of the 'minimum number' criterion of the GCR rationale (see Chapter 1; Sherwood *et al.*, 2000). Therefore there are some areas of saltmarsh that are crucially important to the natural heritage of Britain are not described in the present geomorphologically

(Table 10.1) Candidate and possible Special Areas of Conservation in Great Britain supporting Habitats Directive Annex I coastal saltmarsh habitat(s) as qualifying European features. Non-significant occurrences of these habitats on SACs selected for other features are not included. (Source: JNCC International Designations Database, July 2002.)