Solent Protection Society

Protecting the Solent and its Environment for Future Generations

Solent Protection Society

What Future for the Solent's Saltmarshes?

Proceedings of the Solent Protection Society Conference

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Solent Protection Society

The Solent Protection Society

"The mission of the society is to ensure the ecological and environmental well-being and wise management of the Solent area, its natural beauty and amenities, so that these may continue to be enjoyed by present and future generations.

In pursuit of its mission the society will take an active and constructive part, either by itself or with other organisations and bodies with similar interests and concerns, to safeguard the natural beauty and amenities of the Solent area, with special attention towards its creeks, rivers, harbours, and adjacent waters, including Southampton water, Portsmouth, Langstone and Chichester harbours to the east and the Needles channel to the west; to the foreshores and surrounding lands, picturesque and historic buildings, domestic and commercial developments, roads and bridges, trees, rights of way, advertisements, litter, other eyesores, and, the implications of ecological, environmental and climatic changes for the area irrespective of from whence they have emanated."

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WHAT FUTURE FOR THE SOLENT'S SALTMARSHES?

SOLENT PROTEC TION SOC IETY C ONFERENC E

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Solent Protection Society

PREFAC E

What Future for the Solent's Saltmarshes?

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Solent protection Society c ouncil

The Solent's saltmarshes represent one of the area's most important habitats, supporting a unique range of flora and fauna, and help to protect the coastline from the effects of the sea.

It is commonly known that saltmarshes have been disappearing at an alarming rate in the Solent, but the causes have been shrouded in controversy. The loss of saltmarshes has been attributed variously to: dieback of Spartina (a major component of their vegetation); sea level rise and increased storminess; eutrophication; dredging; and other reasons. Because the Solent's shorelines are so built up and lined with hard defences, there are very few places where saltmarshes can evolve inland naturally through coastal processes, as the sea advances. For similar reasons, the opportunities to form new saltmarshes through 'managed retreat' (the planned setback of defences) are very limited. The future of our saltmarshes is uncertain, to say the least.

The debate about what is happening to the saltmarshes, and why, is resumed with renewed vigour whenever proposals for change come forward, whether it is port development at Dibden Bay or the introduction of larger ferries between Lymington and Yarmouth.

Because of all these concerns, the Solent Protection Society took the initiative to hold a one-day conference about the Solent's saltmarshes and their future. It was held at the National Motor Museum, Beaulieu, on Wednesday 17th September 2008. The main elements of the programme were:

- The importance of saltmarshes for biodiversity and coastal defence;
- What has been happening to the Solent's saltmarshes, and why;
- What is predicted to happen over the next 50 to 100 years, and what are the policy implications;
- A panel discussion, involving representatives of key authorities and agencies, about future policy and actions and whether the current institutional arrangements will be fit for purpose.

The fact that the Conference was attended by 120 people bore testimony to the importance and topical nature of the theme, which helped the Society to attract eminent speakers. This, in turn, is reflected in the high quality of the papers in this document, the Conference Proceedings, which will assist greatly in improving our understanding of the importance of saltmarshes, the reasons for their loss, and what might be done to slow the rate of loss, or to compensate for losses through habitat creation, drawing inspiration and encouragement from lessons from around England (especially the Humber and Thames estuaries).

Copies of the papers, along with the conclusions from the Conference and more details on this topic and other aspects of the Society's work, can be viewed on the Society's website at www.solentprotection.org.

The Solent Protection Society would like to thank the sponsors of the Conference: the Beaulieu Estate for providing an excellent venue, and BP for funding the publication of the Proceedings.

Postscript: Concern about the Solent's saltmarshes is not a new phenomenon. In fact, the Solent Protection Society organised a symposium on 'Spartina in the Solent' in June 1975 and a 'Solent Saltmarsh Symposium' in May 1981. The Proceedings of both events were edited by Jack Coughlan and Fay Stranack. Jack was able to attend the 2008 Conference but, sadly, Fay died just before the event following a long illness.

SOLENT PROTEC TION SOC IETY SALTMARSH C ONFERENC E

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A SUMMARY OF ONGOING RESEARCH RELATED TO SALTMARSH AND MANAGED REALIGNMENT

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Abstract

Saltmarshes have been the subject of extensive research over many years. As well as gaining the interest of biologists, physical processes within the marsh, such as accretion of the marsh surface, have been measured in some detail since at least the 1920's. Over the years there have been various attempts to develop a fuller understanding of the inter-relationship between physical and biological processes within saltmarshes. As is often the case, advances often go in step changes, usually driven by the advent of new technologies or paradigms. Over the last ten to twenty years there has been such a change with the ability to capture and manipulate spatial data in sufficient detail to be able to resolve not only surface topography but also variations in vegetation and a number of relevant physical properties. This in turn means that there is now a far greater ability to investigate the relationships between physical and biological properties. This brief review paper seeks to highlight some of the advances related to our understanding of saltmarsh dynamics and how this knowledge can be used to improve efforts in saltmarsh restoration and in particular managed realignment schemes. Some consideration is also given to the areas that would benefit from new or further research.

introduction

Intertidal areas and saltmarshes are a critical interface between land and sea on sheltered shores typical of estuaries and tidal inlets. In this brief review of recent research this is considered from two perspectives, namely saltmarsh dynamics and saltmarsh restoration. The first part of this paper explores the key attributes that control the dynamic response of saltmarshes, as an integral part of estuary and tidal inlet eco-morphodynamics. These are sub-divided into the main influences as follows:

- Setting, antecedent conditions and the role of accommodation space;
- Hydrodynamics (waves, tides and sea level);
- Sediment supply, sedimentation and marsh erosion/accretion;
- Morphology of the marsh platform;
- Biological productivity, competition and community dynamics;
- Anthropogenic and other influences.

Some specific considerations with respect to the Solent are included, to provide a local context.

The second part then considers restoration and, more specifically, managed realignment, where reclaimed areas are opened up to once again be subject to tidal influence, and our ability to implement such schemes with a sufficient degree of confidence in the intended outcome. The focus here is on research that supports the design of such schemes, with practical guidance on implementation and management being found in a number of guides (see web sources).

To conclude, some of the future research needs are highlighted.

part 1. Saltmarsh Dynamics

There are a number of excellent syntheses of the current state of the art available in the literature. The paper by Friedrichs and Perry (2001) addresses saltmarsh morphodynamics in some detail, focussing on the physical rather than the biological processes and organised to address the processes that influence the marsh over a range of scales, from flow around the vegetation up to basin wide effects. A more cross-cutting coverage, focussing on biology, physical processes and the morphological response is provided in the volume by Fagherazzi *et al.* (2004). Useful papers on the morphology, ecology, conservation and engineering significance of saltmarshes can also be found in the two volumes edited by Allen and Pye (1992; 2000).

Setting

The geological setting will usually determine the constraints on the overall basin geometry. This in turn implies a constraint on the tidal prism which is then closely related to the equilibrium channel morphology; limited tidal prisms will give rise to smaller inlet/marsh systems with shallow channels and larger systems developing in relict morphology will tend to have deeper channels (Friedrichs & Madsen, 1992). Such constraints can also influence the tidal propagation and resulting asymmetry, as discussed below.

Estuarine accommodation space is the volume available for sediment or water storage in an estuary. It is a function of relative sea level change, basin hypsometry (which usually equates with the late Pleistocene valley system on Holocene timescales) and sediment supply. Empirical analysis of this determines when natural equilibrium (geomorphic) thresholds, are likely to be exceeded, instigating a change in the state of the estuary, such as from well defined relatively fixed to highly transient migratory channels. The concept was initially developed for the interpretation of sedimentary basins within sequence stratigraphy (cf. Vail *et al*. 1977), and has been applied to the Humber Estuary by Rees et al. (1998). It showed that sudden, widespread, changes in depositional environments in the estuary have occurred at certain times since the last glaciation and sought to explain why the channel migrated substantially away from its present position at about c.4000 and 700 years BP respectively (Rees *et al*. 2000), on the basis of changes in the energy or equilibrium morphological instability in the estuary.

It may be expected that during periods of limited accommodation space, lateral migration, and associated erosion, of the estuary channel will be more common than in periods of abundant accommodation space. Certainly in the Humber, the periods of substantially reduced Holocene accommodation space appear to coincide with the main erosional episodes when the sedimentation patterns within the estuary switched. This suggests that available accommodation space may well have influenced channel dynamics during the Holocene. What is clear is that during periods of limited accommodation space, extensive sparsely vegetated sand or mudflats are a characteristic feature of the estuary, and saltmarshes are uncommon. In contrast, where the accommodation space is increasing with time, the conditions are more conducive to a stable channel alignment with the potential for intertidal areas to develop marsh vegetation. Today the saltmarshes in the Humber cover less than seven percent of the intertidal area compared with periods in the mid-Holocene when they covered the majority of intertidal areas (Townend *et al*. 2007). A similar variability over the Holocene has been reported for other UK estuaries, including Southampton Water (Long *et al*. 2000).

A corollary to accommodation space is the concept of marine transgression, sometimes referred to as estuary rollover (Allen, 1990b; Pethick, 1996; Long *et al*. 2000). The concept is that as sea level rises, so the estuary adjusts to maintain its form (in a Lagrangian rather than Eulerian sense) and in doing so, migrates landward. Within an estuary, the 3D form means that landward expansion of the steeper slopes in the system provides a source of sediment for the vertical accretion of the more horizontal surfaces (Townend & Pethick, 2002). It follows that a stable marsh that is keeping pace with sea level rise, will transgress inland at a rate that reflects the hinterland topography (Morris, 2007).

Hydrodynamics

The influence of sea level rise is closely linked to the setting and the issues of accommodation space and marine transgression, as already outlined. However, this also has a very direct impact on marshes. Their ability to adjust rapidly to such changes is well documented (Reed, 1988; Pethick, 1992; Day *et al*. 1999; Morris, 2000) and has more recently been represented in models of marsh response (Morris *et al*. 2002; Morris, 2007; Kirwan & Murray, 2007; D'Alpaos *et al*. 2007b; Knaapen *et al*. 2008). However, this does not always provide a simple explanation for marsh accretion and erosion. Other factors, such as changes in larger-scale processes within the estuary, together with various anthropogenic interventions, can often have as much of an influence as the direct impact of sea level rise (French & Burningham, 2003).

Marshes are also subject to strong seasonal variations due to the annual biological cycle which is adapted to the variations in tidal range that occur over a spring-neap cycle and annually (Morris *et al*. 2002; Mudd *et al*. 2004). There is also evidence to suggest that marshes are responding to the lunar nodal tidal cycle (18.6 year period), with biological growth enhanced and mineralogical sedimentation reduced during phases of amplified tidal range and the opposite during the phases of suppressed tidal range (French, 2006) and this can be represented in estuary/creek/marsh models (Kirwan & Murray, 2005; Townend *et al*. 2008b).

The influence of waves is interesting because it has been explored from two perspectives: the role of saltmarshes in dissipating energy and thereby providing a form of sea defence (Pethick, 1998; Möller *et al*. 2001) and the impact of wave exposure on saltmarsh communities (Gray, 1992; Carniello *et al*. 2007). Considerable progress has been made over recent years in quantifying the effects of saltmarsh vegetation on the dissipation of wave activity (Möller *et al*. 1999; Möller, 2006; Augustin *et al*. 2008; Suzuki *et al*. 2008). However, converting this into some form of predictive tool requires the ability to characterise surface topography and bed roughness over large spatial scales and to take be able to represent both the stochastic nature of storm events and the seasonal variations in the vegetation (Möller and Spencer, *pers. comm.*).

The combined influence of tidal range and wave/storms also gives rise to significant differences in the nature of the morphological form and response of the saltmarsh. Microtidal estuaries are reliant on storms to supply sediment and as a consequence are observed to respond rapidly by accreting vertically and expanding horizontally. In contrast, marshes in meso- and macrotidal estuaries are dependent on recurrent tidal action (Stumpf, 1983; French & Spencer, 1993) but as a consequence may be better able to keep pace with accelerating sea level rise because of the influence of enhanced sediment concentration and flood dominance as tidal range increases (Friedrichs & Perry, 2001). The relative influence is also of relevance when considering the lunar nodal cycle, where for microtidal systems the storm influence can be of the same magnitude and tends to mask the lunar nodal tidal signal in records of marsh accretion (French, 2006).

The nature of any tidal asymmetry is also significant in determining the delivery of sediment to the marsh. Whilst this is characterised in terms of the stronger peak currents on the flood or ebb by Friedrichs and co-workers (Friedrichs & Aubrey, 1988; Friedrichs & Perry, 2001), Dronkers emphasises the important role of the period of slack water between flood and ebb phases and its importance for the deposition of fine sediments (Dronkers, 1986; 1998; 2005). Interestingly it is not uncommon for both influences to be happening in tandem, such that the peak velocity is ebb dominant, encouraging the export of coarser sediments, and the slack before ebb or flood is flood dominant, giving rise to the import of fine sediments (French & Stoddart, 1992; Townend & Whitehead, 2003). However, preferential movement onto the marsh can also happen, regardless of any tidal asymmetry, as a consequence of settling lag (Postma, 1967) and because of the higher sediment concentrations moving on to the marsh during the flood, compared to those moving off during the ebb (Krone, 1987).

While the flux of salt into the saltmarsh decreases with increasing elevation, the sediment salinity of the interstitial water does not display any simple or consistent relationship with elevation. The lower saltmarsh has frequent and prolonged periods of tidal inundation. Consequently the sediment salinity is relatively constant, rarely exceeding or different to that of the flooding water. At higher elevations, however, climate also plays an increasing influence and leads to a much greater variability in sediment salinities (Adam, 1990).

Over the marsh platform, the vegetation plays a crucial role in modifying the flow regime. Over recent years there have been a number of studies looking at idealised representations of saltmarsh vegetation in the laboratory (Malki *et al*. 2007; Graham & Manning, 2007), using real saltmarsh translocated to the laboratory (Pethick *et al*. 1990), and in the field (Neumeier & Amos, 2006; Neumeier, 2007) and developing theoretical descriptions of flow within the marsh canopy (Nepf, 2004). The key consequences of the damping of the flow is to enhance settling within the marsh and to substantially limit the potential for erosion of the marsh surface, such that even large surge and wave events do not give rise to significant amounts of vertical erosion within the marsh platform (Pethick, 1992) and may even lead to enhanced accretion (van Proosdu *et al*. 2000).

Sediment Supply

Sedimentation in saltmarshes dominated by inorganic supply rather than organic production (often referred to as allochthonous) relies on the advection of fine sediments from the estuarine source. This depends on a complex interaction of concentration at the edge of the marsh, the time that tidal waters are over the marsh, the flow over the marsh platform and through the vegetation, settlement and trapping processes and the distance into the marsh. Efforts to understand the processes involved are longstanding and Ranwell (1964) reports direct measurements of saltmarsh accretion from the 1920's onwards.

A key determinant of sedimentation is thought to be the hydroperiod; the percentage of time that water is over the marsh (Reed, 1990). This does however generate opposing influences within the marsh. Whilst the hydrodynamically driven sedimentation increases the greater the hydroperiod, biological productivity will tend to be reduced because of the greater stress on the plants. This effect may also mean that the dominant influence will vary across the marsh, with inorganic sedimentation dominating in the lower marsh and progressively giving way to organic sedimentation in the higher marsh.

For allochthonous marshes, changes in hydroperiod are believed to allow the marsh to continuously adjust the rate of accretion, so remaining near equilibrium and responding rapidly to fluctuating rates of sea level rise and changes in tidal range (Krone, 1987; Allen, 1990a; French, 2006). Subsidence can also enhance the rate of sedimentation by creating a greater over-depth. For this reason marshes dominated by organic matter and with only a limited supply of minerogenic sediment may find it more difficult to keep pace with accelerated rates of sea level rise (Friedrichs & Perry, 2001).

Various authors have proposed rate equations for the change in elevation, which essentially sum the individual contributing rates due to minerogenic settlement, organic production, changes in sea level and tidal range, and any autocompaction of the underlying sediments (Allen, 1992; Krone, 1987; Morris *et al*. 2002). In general, processes that tend to increase the local concentration of suspended sediments will increase the minerogenic contribution to accretion. So tidal velocity, wind waves, proximity to the estuary turbidity maximum, increased coastal erosion, changes in tidal asymmetry and biological activity may all alter the availability of sediment (Friedrichs & Perry, 2001). Biological activity can be through biostabilisers, such as the action of microphytobenthos (Paterson, 1989; Black & Paterson, 1998; Sutherland *et al*. 1998), or through bioturbators such as worms, snails and crabs (Widdows *et al*. 2004; Perillo & Iribarne, 2003).

Distance from the source (creeks and channels) has also been found to be important. Vegetation enhances settlement rates so that the amount of sediment available in suspension decays rapidly away from the source. As a consequence the banks of tidal creeks tend to accrete faster than the inner area of the marsh. For the marsh as a whole to keep pace with sea level rise, it follows that any point on the marsh must be within a certain distance if it is not to be left behind, forming a saltpan or new creek. This is consistent with the observed spatial distribution of creek systems and the probability distribution of overmarsh path lengths (Marani *et al*. 2003). The exception to this is under storm conditions, when sedimentation is not controlled by the creeks and will tend to be in shore parallel bands with the marsh behaving more like a beach (Pethick, 1992; Friedrichs & Perry, 2001).

Changes to the flow regime influence the rate of settlement and hence deposition. This is enhanced by the plant canopy which traps sediment in a number of ways (Ranwell, 1964; Morris *et al*. 2002). This is a function of the morphology of the vegetation, its size and density relative to the flow field. Some species also collect sediment on their stems and leaves (eg *Spartina alterniflora* and *Phragmites australis* (Stumpf, 1983) but not *Juncus*, *Aster tipolium*, *Salicornia* and *Pucinellia* (French & Spencer, 1993), enhancing deposition by as much as 50% (Friedrichs & Perry, 2001). Attempts have been made to represent these influences explicitly in saltmarsh models (Temmerman *et al*. 2004; Mudd *et al*. 2004; Marani *et al*. 2007), although it is often treated as part of a biomass dependent enhancement to the settling velocity (Morris *et al*. 2002; Knaapen *et al*. 2008).

An area that has not received a lot of attention to-date is the manner in which the sediment within the marsh canopy is itself modified by the influence of the vegetation. Some recent work in a laboratory flume has examined the impact on floc size within the suspended sediment and how this influences the settling velocity (Graham & Manning, 2007). There remains a need to look at this influence for other saltmarsh species and to try and replicate the work in the field, or at the very least endeavour to characterise suspended particle matter more accurately in some site surveys.

A further consideration, related to sediment supply and the extent of tidal inundation, is the proportion of sand and mud deposited. This can change the nature of a saltmarsh plant community by altering the drainage conditions. In East Anglia, for example, the zonation of vegetation in estuarine marshes is reported to be simple, while along the open coast it is more complex, being characterised by extensive central areas of “general marsh” communities rich in algal flora and *Sea purslane*. Grain size may also play a role, more locally, within saltmarsh creek systems.

The damping of the flow across the marsh greatly reduces the potential for any surface erosion and even surges and waves do not appear to cause long-term surface erosion, any losses being restored by the more regular tidal inundation (Pethick, 1992). However erosion of the seaward edge is more common and can have a number of causes. Erosion during storms is part of the overall marsh/tidal flat adjustment to maximise the resilience and cross-shore dissipation of wave energy. Waves caused by passing ships can also have a corrosive effect and in relatively sheltered but busy waterways this can be as significant as wind-wave effects (ABP Research, 2000). When examining erosion of marsh cliffs, or creek channel sides, it should be borne in mind that erosion may be simply a part of the ongoing process of regeneration, where erosion of the cliff provides material for redistribution on the mud profile (during storms) or on the marsh surface (under marine transgression). Providing there are no other constraints (such as sea walls to landward in the case of marine transgression) then there may be little or no net erosion.

Morphology

The locations of major channels are generally inherited (Eisma *et al*. 1998) from terrestrial drainage, constraints (e.g. due to underlying bedrock), or incised tidal channels (Friedrichs & Perry, 2001). Observations generally support the concept of channel formation across tidal flats through headward erosion (Collins *et al*. 1986; Symonds & Collins, 2007) and this type of behaviour has recently been reproduced in both physical and numerical models (D’Alpaos *et al*. 2005; D’Alpaos *et al*. 2007a). It is generally accepted that after the initial development stage, the tidal network is largely stable (French & Stoddart, 1992) and that the subsequent development of marsh vegetation tends to reinforce and preserve this initial network (Rinaldo *et al*. 2004).

There is considerable evidence that marsh morphology is near equilibrium over time scales of decades to a few centuries (Reed, 1988; Allen, 2000b; French, 2006). The various mechanisms for adapting to the prevailing conditions means that marshes are able to respond rapidly to changes in the forcing conditions and the prevailing state at any given time often represents a relatively short-term dynamic balance (Friedrichs & Perry, 2001). Thus it is this short-term adaptability that serves to maintain a longer-term stability within marsh systems.

Whilst some marshes, such as those in the Mississippi basin, comprise vast relatively flat areas intersected with a dendritic channel network, others border estuaries and inlet systems which have a significant 2D spatial topography. In the former the development of saltmarsh is dominated by vertical accretion (Cahoon *et al*. 2004; Nyman *et al*. 2006), whilst in the latter the cross-shore form can also constrain the form of the marsh (Pethick, 1992; Woolnough *et al*. 1995) and models need to take account of such spatial influences (Fagherazzi & Sun, 2004; French, 2006; D'Alpaos *et al*. 2007b; Kirwan & Murray, 2007). Furthermore, very little work has been done on the role of the marsh cliff and its influence on the morphology of the cross-shore profile. Whilst cliff formation can be shown to be a consequence of the enhanced accretion induced by the vegetation (e.g. by application of the model proposed by Morris *et al*. 2002 on a typical equilibrium cross-shore profile), it has also been shown to influence wave action and to erode dramatically under storm conditions (Pethick, 1992; Möller & Spencer, 2002; Suzuki *et al*. 2008). The presence of a cliff may also be a function of the amount of sediment loss due to wave erosion, with cliff erosion under high deposition and low wave action, and no steep "cliff" slope under high levels of wave action (Pethick, 1992; van de Koppel *et al*. 2005).

The characterisation of some of these spatial influences has benefited greatly from the development of spatial data capture and analysis techniques. The large data sets now available have allowed some very detailed work on spatial scaling (Marani *et al*. 2003; Rinaldo *et al*. 2004) which has highlighted significant differences between tidal and fluvial networks. The latter exhibit strong power law behaviour of a type that indicates scale invariant form, reflecting the fact that there is a dominant process (rainfall-runoff) at all scales (Rodríguez-Iturbe & Rinaldo, 1997). In tidal landforms there is a lack of such scaling, reflecting the competing nature of a number processes (Rinaldo *et al*. 2004), so that characteristic watersheds do exist. However, it should be noted that despite the geometric scales associated with the marsh morphology, vegetation patches do exhibit some scale-free characteristics (Marani *et al*. 2006).

There are also interesting differences within marsh-flat systems. For example, channels across the tidal flats tend to be broader and shallower with width to depth ratios that bear some similarity to fluvial systems ($8<B/D<50$), whereas channels within the marsh have a characteristic value ($B/D=6$ for Venice Lagoon marshes). In saltmarsh creeks, the role of the vegetation and the cohesive properties of the sediment are thought to play significant role in the erosional processes, resulting in more deeply incised channels (Rinaldo *et al*. 2004; Chen & Collins, 2007). These generic characterisations of key system properties are particularly useful in the design of restoration or habitat creation schemes, as discussed further below.

Saltmarsh Ecology

Variations in the distribution of vegetation occurs over a range of scales and the ability to capture this through conventional field surveys is limited. The availability of airborne and satellite remote sensing data now allow vegetation to be mapped at a resolution that can discriminate between the different marsh species. This has not only allowed a much more comprehensive assessment of key spatial properties of marsh and tidal networks (Marani *et al*. 2003; Rinaldo *et al*. 2004) but also provided the data with which to investigate spatial relationships within the vegetation and between the vegetation and the physical environment (Marani *et al*. 2006).

The traditional view is that saltmarsh species distribution is linked to variations in soil elevation, hydroperiod, or inundation frequency (Reed, 1990; Gray, 1992; Morris *et al*. 2002). Given a profile with a gradient of tide-related factors, each species will occupy a section of the gradient. As the number of species increases, the ability of any one species to occupy its full range diminishes and there is evidence of broader niches occurring when there are fewer species present (Gray, 1992). There is now a substantial body of data drawn from a wide variety of locations to lend support to these types of relationship (Beeftink & Rozema, 1988; Sánchez *et al*. 1996; Boorman *et al*. 2001; Day *et al*. 1999). It has also been suggested that the distance from, and size of, the channels may also be a critical factor (Sanderson *et al*. 2001). However, the literature includes evidence that biomass production (as one measure) increases away from channels in some cases (Bertness, 1991) and decreases in others (Morris *et al*. 2002), as noted by Marani *et al*. (2005).

A distinction between small scale (local) dependence on elevation, which does not hold over larger scales has recently been observed in the Wadden Sea (Bockelmann *et al*. 2002). Similarly, studies by Silvestri *et al*. (2005) confirmed a strong and consistent elevation dependence in the sequence of saltmarsh species but found that the elevation range of individual species was quite different at the four sites examined within Venice Lagoon. On investigation they found that soil salinities at the different elevations were similar and not explained very well by distance from the channel. Duration and frequency of flooding at the sites did not provide a possible explanation. Furthermore there was no indication that nutrient levels or light were influencing the observed variation in zonation. This led to the conclusion that whilst salinity and tidal regime are clearly important, their influence is likely to be indirect and filtered by subsurface hydrological dynamics.

This idea has since been pursued in some detailed modelling of the soil-water-vegetation interactions and in particular the vegetation feedback on soil aeration. Essentially, plant transpiration influences hydrological processes over the marsh and so alters the subsurface groundwater levels. Increased evapotranspiration rates promote an air flux into the soil, which enhances biomass production. In addition flow within the unsaturated layer of the subsurface can induce an aerated layer that persists even during periods of tidal inundation (Ursino *et al*. 2004; Marani *et al.*2006). Having noted that some species are preferentially found on the higher ground alongside creeks and channels (e.g. *Puccinellia palustris*, *Inula crtihmoides* and *Sueda maritima*) and others are found across the marsh (e.g. *Spartina maritima*, *Limonium narbonense* and *Juncus maritimus*) and ascribing this to the greater dependence of some species to the level of oxygen supply (Silvestri *et al*. 2005), Marani *et al*. (2006) go on to suggest two possible feedback mechanisms:

(i) vegetation promotes surface accretion, which tends to increase soil elevation and hence oxygen availability within the soil, and this, in turn, increases biomass production;
(ii) plant transpiration increases sediment aeration, which also enhances biomass production.

It is also suggested that this interplay between plant transpiration and infiltration also plays an important role in initial colonisation of mudflats. Pioneer vegetation, better adapted to hypoxic conditions are able to become established in the more aerated conditions close to channel and creek margins. This helps to establish layers of permanently aerated soil within which other (more sensitive) species can become established. The resulting increased presence of vegetation favours sediment deposition and will therefore reinforce the transition to a marsh system (Marani *et al*. 2006).

Inevitably the above arguments link closely with the nature of underground production and its subsequent decomposition. In general the below ground production is equal to or exceeds what occurs above ground. Furthermore, the above ground litter does not generally make a significant contribution to the sedimentation of the marsh surface (Blum & Christian, 2004). For marshes that are more dependent on organic production the rate of below ground production is critical to their survival under conditions of accelerated sea level rise (Nyman *et al*. 1990; 2006; Cahoon *et al*.2004). More generally, one can expect the low marsh to be dominated by minerogenic sedimentation and the mid to high marsh to be dominated by below ground production, as already noted.

The organisation of vegetation patterns is not entirely determined by the spatial organisation of tidal channels and creeks (which have well defined characteristic scales), or the available marsh area (where plant patches occupy all available scales) and probably derives its scale-free characteristics from competition or biotic processes acting at all scales (Silvestri & Marani, 2004). Such competition between species has indeed been shown to have a significant influence on the distribution across the marsh (Randerson, 1979; Long, 1990). Experiments performed by removing one of the species present in the transition zone between species suggests that the competitive advantage can be altered over relatively short distances and elevations (Gray, 1992). This is elegantly illustrated by the model proposed by Morris (2006; 2007), where the extent of individual species can be altered by the interaction between species and this is closely related to the relative biomass productivity of the individual species at given elevations. This same interdependence can be captured in models that use some form of logistic model to represent reproduction and mortality (e.g. Marani *et al*. 2007), again by making the rates elevation dependent. It should also be noted that interspecific competition has been shown to be sensitive to variations in climate, but highly variable at the individual species level, such that predicting how communities will respond to climate remains difficult, even for relatively simple and well studied systems (Bertness & Ewanchuk, 2002).

Other sources of spatial variability can arise due to variations in soil properties and biochemical properties, pH, redox, etc. (Crooks & Pye, 2000) and the influence of bioturbators (e.g. the action of crabs or burrowing worms (Minkoff *et al*. 2006; Widdows *et al*. 2004)), which may create preferential flow pathways and so alter soil aeration (Marani *et al*. 2006).

Dynamics can also come into play, as one species modifies the environment primarily for its own gain but in so doing increases the opportunity for other species. For example the shelter and higher elevations created by pioneer species allows more sensitive species to become established (Bruno, 2000; Bouma *et al*. 2005). These effects can in turn alter the flow regime and, where marshes are discontinuous, promote a distinct morphology around clumps or tussocks of marsh vegetation and further reinforces the idea that spatial structure results from scale-dependent interactions between plant vegetation and hydrodynamics (Temmerman *et al*. 2005; Temmerman *et al*. 2007; van Wesenbeeck *et al*. 2008).

Prolonged submergence can prevent sufficient oxygen reaching the roots of the saltmarsh grasses. It may also prevent adequate nitrogen uptake, or induce sulphide toxicity (Reed, 1990; Day *et al*. 1999). In contrast to wave erosion, the first areas to degrade are within the body of the marsh and the most distant from the channels (Friedrichs

& Perry, 2001). In some places localised water-logging can lead to the formation of salt pans, which can remain as stable features over long periods of time (Pethick, 1984).

Anthropogenic and other influences

As noted earlier, any action that influences the sediment supply to the marsh is likely to have some influence on marsh development. Activities such as dredging in adjacent channels can produce sudden influxes of sediment if there is substantial over-spilling as part of the dredging process (ABP Research, 1999) or create a sediment sink within the estuary (due to over-deepening) and the subsequent removal sediment from the system (ABP Research, 1995; ABPmer, 2001; Friedrichs & Perry, 2001; Cox *et al*. 2003) . Regular trawling for cockles and oysters over shallow nearshore beds may also provide a short-term enhancement of sediment concentrations.

Reclamations and sea walls can also constrain a marsh and limit the potential for marine transgression. Although the general model of marine transgression is now widely accepted and there is substantial evidence of the impact sea walls have on marshes (Reed, 1988; Pethick, 1992), it is also important to recognise that 'coastal squeeze' is not a universal truth and, in some circumstances, saltmarshes may increase in area, despite the constraining influence of sea walls (French & Burningham, 2003).

External influences can also be natural, or part of the approach to marsh management. For example grazing on the marsh by overwintering geese is one cause of predation which can be beneficial or detrimental depending on the grazing intensity (Bos *et al*. 2004; Esselink *et al*. 1997). Experience in the UK and the Netherlands suggests an appropriate level of sheep grazing can be beneficial to overall marsh stability, promoting short dense swards of vegetation (Berg *et al*. 1997). Occasional burning has also been found to enhance the volume of organic material and the rate of elevation recovery on marshes around the Gulf of Mexico (Cahoon *et al*. 2004).

Recent research suggests that the shell fragments on the mudflat can move significant distances over a single tide. These appear to collect at the toe of the saltmarsh cliff and are then thrown up on to the marsh surface under certain wave and tide conditions. The resultant mound then smothers the underlying vegetation. In addition, the shells at the toe of the saltmarsh cliff enhabce the scour and "tunnel" under the Spartina bed, so causing clumps of the marsh to collapse onto the mudflat (Quaresma *et al*. 2007). This would appear to be enhancing the block failure mechanism of the marsh cliff, of the type characterised by van Eerdt (1985).

Solent Saltmarshes

Within Southampton Water *Spartina* saltmarsh became particularly prevalent from the mid 19th century, with the hybridisation of the native species *Spartina maritima* and the native American species, *S. alterniflora*. The male sterile form *S. townsendii* was recorded in 1870 and a subsequent doubling of chromosomes led to the fertile form *S. anglica*, which proved remarkably adept at colonising intertidal muds. This led to a rapid period of saltmarsh advance, with rates of up to twenty metres a year being observed. From about 1930 this trend began to reverse and since then there has been an ongoing phase of erosion. Historical analysis using aerial photographs has provided some further detail on the more recent changes, Table 1 (ABP, 2000).

This advance and subsequent retreat is characteristic of saltmarshes in many areas along the south coast and notably in the Solent and Poole harbour (Tubbs, 1980). The reasons for this die-back are not wholly understood (Goodman, 1957; ABP Research, 1995; Tubbs, 1999) and may be due to:

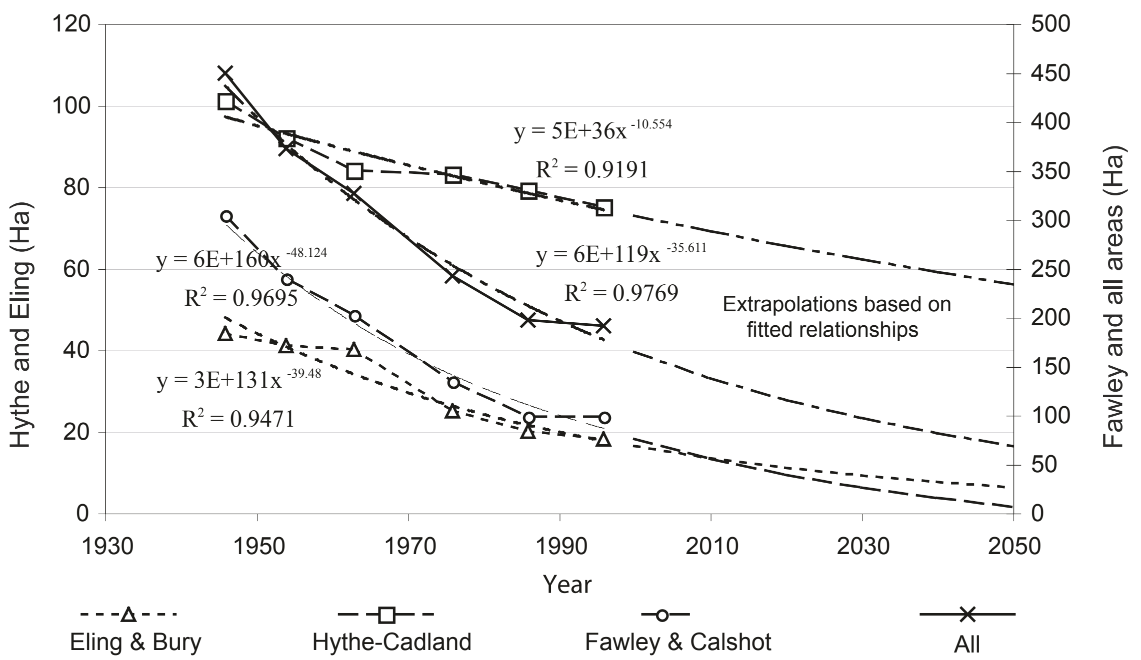
- Smothering by fine sediment;
- Continuing genetic evolution of the species;
- Inadequate drainage, probably as a consequence of the rapid rate of development;
- Highly anaerobic soils with a high proportion of fines and a high sulphide content;
- Restoration of a balance in the estuary, following perturbation caused by rapid advance of saltmarsh;
- Changes in climate leading to changes in wave exposure.

Table 1. Saltmarsh Areas in Southampton Water between 1946 and 1996 (Abp, 2000)				
year	Fawley & calshot (ha)	Hythe to cadland creek (ha)	Eling & bury (ha)	Whole Estuary (ha)
1946	304	101	44	449
1954	239	92	41	372
1963	202	84	40	326
1976	134	83	25	242
1986	98	79	20	197
1996	98	75	18	191

Historical analysis of aerial photographs of Southampton Water, suggests that the dominant ongoing process is one of frontal erosion. On-going monitoring of the saltmarsh using CASI[1] images, suggests that the main body of the marsh is not suffering from internal desiccation and the dendritic network of channels appears to be very stable. This would tend to suggest that the last two reasons for die-back, in the list given above, are the more probable.

There is some evidence that the landward boundary of the Fawley to Calshot marsh has retreated by about fifteen metres in thirty three years, i.e about 0.45 metres per year. This is unlikely to continue because the marsh now abuts the seawall for much of its length. Elsewhere there is only limited scope for transgression, due to either the rising land levels or the presence of sea walls. Consequently, the changes in area for the marshes within Southampton Water are related primarily to landward retreat of the front edge. Nonetheless, although there has been an ongoing loss of saltmarsh over recent years (1946-96), there is a progressive reduction in the rate of erosion, Figure 1.

Figure 1. Historic changes in saltmarsh area for Southampton Water (Abp, 2000)



The rapid growth of saltmarsh in Southampton Water towards the end of the 19th century constitutes a major perturbation on the estuary system. There is no evidence to suggest that this was driven by physical factors but rather by the introduction of the hybrid species, *Spartina anglica*, which was able to establish a niche. In fact, it was so successful that it rapidly increased the area of marsh to such an extent that the storage volume within the estuary was altered. This also "engineered" an environment that could support other species (by providing shelter) that were ultimately capable of out competing the hybrid at higher marsh elevations (Bouma et al. 2005). It therefore seems

[1] Compact Airborne Spectrographic Imager, a type of infrared imaging technique.

likely that at least a part of the recent losses observed on these marshes is a consequence of a readjustment of the system back to some form of dynamic equilibrium consistent with the sediment supply, available accommodation space and interspecific competition (the latter aspect is illustrated in figure 4 of Morris, 2007).

part 2. Managed Realignment

The removal of existing flood defences has been variously referred to as managed retreat, managed realignment and habitat creation or restoration, depending on the underlying objectives of the particular scheme. For the purposes of this review, managed realignment is the form of coastal adaptation that removes a part, or all, of a seawall in order to allow some additional land area to be subject to tidal action. This may, or may not, require the provision of modified defences, or defences set back on a new line, to protect local assets.

The two main drivers for promoting managed realignment are the need to adapt to sea level rise, or to create habitats to compensate for losses due to individual coastal developments. On unprotected coasts, as sea level rises, the shore is able to move landwards, giving rise to marine transgression. However, around many coasts and estuaries, the existing defences fix the interface between land and sea. By preventing the process of transgression from taking place it is often the case that the more seaward part of the shore profile continues to move landward but because the upper part of the profile is held by the sea defences, the intertidal, in front of the defences, gets narrower. This is sometimes referred to as 'coastal squeeze' and is a process that has been exacerbated by past land reclamations in many instances (Reed, 1988).

Here we briefly review the process of designing such schemes and, in so doing, note some of the recent research developments that are beginning to provide a better understanding and hence the ability to deliver this type of scheme with greater confidence and well bounded uncertainties. A fuller discussion on site design can be found in (Townend et al. 2008a) and on a number of websites (see sources below).

Scheme Design

There are usually a number of options as to how a particular site is developed, although the most common is to simply breach the existing wall and create a new area of mudflat and saltmarsh to the rear. Alternatives include tidal creeks, breached sea wall or complete removal of the sea wall, managed breaches with sluices to control flow, saline/brackish lagoons and the provision of flats and islands. The choice will depend on which option, or combination of options, best meets the objectives for the site and the constraints that are invariably posed by the specific setting of the site

Typically the design process will encompass the following steps:

(i) confirmation of design objectives;
(ii) identification of design constraints;
(iii) selection of site (if not predetermined);
(iv) characterisation of the site;
(v) determination of target habitats and species (if required);
(vi) field investigations;
(vii) develop site layout and design any features to be constructed;
(viii) sensitivity and risk assessment;
(ix) construction programme, costings and tender documents;
(x) design and specification of monitoring programme.

identification of Design c onstraints

A number of physical and ecological factors will limit or constrain what can be achieved at a given location. The relevant design constraints must therefore be identified at the outset of the design process. For a managed realignment the constraints might typically include:

physical constraints	Habitat constraints
• maximum area, length and width of the site; • existing level of site in tidal frame; potential • to remove sea wall; • surrounding bathymetry, extent of adjacent intertidal and distance to main channel; • underlying geology and lithology; • availability of suitable surficial sediments; • freshwater input.	• habitat value of existing site and adjacent sites; • target species and habitats (if a compensation or mitigation scheme); • exposure to waves (storms and ship wake); • water quality and sediment quality; • levels of disturbance.

Site c haracterisation

The success of the created habitat will be dependent on the existing physical, chemical and biological characteristics of the site and adjacent environment (Parker *et al*. 2004a; 2004b). Much of this information will need to be obtained through field surveys, literature review or the analysis of existing data sources.

Investigations will usually need to address:

- Sediment and substrate characteristics
- Hydrodynamic, hydrological and morphological characteristics
- Habitat and species characteristics

(see www.estuary-guide.net for further details).

The process of designing a scheme, based on all the above considerations, is most effectively begun with a walk-over of the site and an interrogation of the topographic maps of the site (e.g. using LiDAR survey data). Topographic maps can be used to identify features such as relic creeks in historically reclaimed land and these can be the best guide to designing a scheme because they betray the natural morphology and thus indicate the best approach to achieving habitat restoration .

Layout and Design

Managed realignment can be used in one of two ways. The most common use, is as a means of creating, or reinstating, habitat within a particular site. The alternative is to use managed realignment as a means of improving the resilience of an estuary. This can be done by selecting the location of the site(s) to enhance the dissipation of the tidal wave and by increasing the accommodation space (the area the estuary occupies as it migrates landwards in response to sea level rise) by removing rather than simply breaching the sea walls (Townend & Pethick, 2002). In some cases the latter may need to be done in stages; first breaching the walls to allow the site to accrete to a level compatible with the external mudflat or saltmarsh and then, some time later, removing the remaining sea wall (or allowing it to simply collapse over time).

The nature of the openings to the site will depend on the type of habitat to be created. This can range from the complete removal of the existing sea wall, as just noted, through the formation of one, or more, breaches, to the use of some form of structure such as culverts, weirs and sluices. Standard texts on hydraulic engineering provide details on the design of culverts, weirs and sluices (Chow, 1959), and a method for designing a breach in a sea wall is given in Townend (2008).

Within the site, there is invariably a need to provide some means for the tide to propagate into the area. Where the chosen option requires marine inundation, it is often necessary to provide a series of channels or ditches to promote both influx and drainage of the tidal waters. In many instances it may be appropriate to simply modify the existing field drains to establish a coherent network. This may not be ideal from a morphological point of view but, by using what is there, the amount of earth works and hence costs are minimised. In sites without extensive field drains, it is necessary to develop a dendritic channel network that fits within the planned topography for the site. For sites that have been historically reclaimed and are being reinstated, it is often possible to identify the original channel network on aerial photographs. This is because the infilling and subsequent differential settlement of the original channels produces minor differences in level and drainage across the surface which are visible in vertical air photographs. These can be used as a template for the channels in the reinstated site.

However, in some sites it is necessary to develop a channel layout based on the site topography and the habitats that are to be supported. Various guidance is available on the hydraulic and morphological geometry required for successful habitat restoration schemes (Krone, 1993; French, 1996; Haltiner *et al*. 1997; Friedrichs & Perry, 2001; Williams *et al*. 2002). In addition, a number of models are beginning to be developed that are able to represent the evolution of saltmarshes and mudflats and provide a more process based means of establishing how creek networks (Marani *et al*. 2003; D'Alpaos *et al*. 2005; Temmerman *et al*. 2005; Hood, 2007) and saltmarshes (Mudd *et al*. 2004; Morris, 2006; D'Alpaos *et al*. 2007b; Marani *et al*. 2007; Temmerman *et al*. 2007; Kirwan & Murray, 2007) are likely to develop.

Where possible, meanders should be introduced into the main creeks, as this reduces the available fetch and hence the influence of waves (1992). Subdivision of the area by a series of branching creeks, further helps with dissipation of tidal energy and the reduction of wave propagation. It is also the most efficient way to both drain the site and provide a supply of water and sediment across the whole of the intertidal surface.

Recent developments in the understanding of saltmarsh behaviour and its interaction with the hydraulics and morphology makes it possible to estimate the likely extent of saltmarsh and the associated sediment demand. Traditionally, saltmarsh extent has been defined using empirical equations relating the presence of particular species to the tidal range, hydroperiod (duration of submersion) and exposure (see paper by Grey in 1992). More recent developments relate the behaviour to the available sediment supply, tidal conditions and biomass density (Morris *et al*. 2002; Temmerman *et al*. 2004). For preliminary design it is sufficient to know the likely species, the optimum depth below high water of the marsh community and the maximum depth below high water that any of the species present is able to colonise.

The un-vegetated slope for a mudflat can be developed using some form of idealised intertidal profile (Lee & Mehta, 1995; Friedrichs & Aubrey, 1996). A developed marsh will tend to intersect this profile around the maximum colonisation depth and then, depending on the wave exposure, can form a step, rapidly grading up to the optimum marsh elevation. If the site is left to develop this transition naturally, it may give rise to a significant sediment demand.

The basis for developing a channel layout will be constrained by the size of the site, its length and breadth, the number of breaches, and the requirements that:

- the channel network is sufficient for the area to be drained, and
- no point on the marsh is more than a defined distance from a channel.

The relative level of the intertidal alongside the tidal channels and its slope away from the channels, determines site hypsometry and hence the potential for saltmarsh colonisation. If the site is simply opened up to tidal influence, the hypsometry of the site will largely determine the distribution of habitats. Where specific habitat objectives have been set, it may be necessary to move material around the site, or import/export material to achieve the desired topographic variations and hence habitats.

Whilst the foregoing focuses on how to establish site layouts to achieve the desired habitats, there are a number of other considerations that need to be worked through in order to develop a robust design. The sort of questions that have to be addressed include:

- How will site change the hydraulic and sedimentary regime in the area adjacent to the site?
- Is there sufficient flushing of the site?
- Will the breach cause channel incisions in the existing mudflat?
- Will the flows in and out of the site disturb other interests (navigation, recreation shell fisheries, etc)?
- Is there any contamination in any of the sediments that are likely to be disturbed?
- What is the balance of saline and freshwater in the site and is this appropriate for the target habitats?
- What is the potential impact on offsite flood hazards and drainage?
- Is there any requirement to include public access or other community benefits on the site?
- Is there any threat from invasive species?

The full range of issues to be considered are addressed in the Habitat Review (ABP Research, 1998, available at www.estuary-guide.net) and in various publications (Zedler, 2000; Zedler & Callaway, 2001; Williams & Faber, 2004; Leggett *et al*. 2004, and a number of websites - see sources).

Once an outline layout has been established, this can be modelled and the layout refined to achieve the desired performance. This will usually entail the use of well established models to examine water flows, sediment transport and morphological change (Abbott & Price, 1994; Reeve *et al*. 2004; French, 2008). To make an assessment of the long-term development of the site and its impact on the surrounding area a hybrid model (Huthnance *et al*. 2007) such as the regime model (Wright & Townend, 2006; Spearman, 2007) or simplified box models such as ASMITA (Aggregated Scale Morphological Interaction between a Tidal Basin and the Adjacent coast, Stive *et al*. 1998) can be used. As already noted, a number of models are now becoming available that can represent the evolution of creek networks, saltmarshes and mudflats (Marani *et al*. 2003; D'Alpaos *et al*. 2005; Hood, 2007; Mudd *et al*. 2004; Morris, 2006; D'Alpaos *et al*. 2007b; Marani *et al*. 2007; Kirwan & Murray, 2007) and detailed process models are being extended to include biological processes such as biostabilisers, bioturbators and vegetation such as saltmarsh (Widdows *et al*. 2000).

c onclusions

To apply the type of models that are now being developed, we need much more extensive data sets, such as:

- Data to generalise the relationships proposed by Morris *et al.* (2002) between biomass and marsh depth for a range of species in different geographical locations;
- Data on more detailed relationships involving stem density and height as functions of biomass, again related to elevation, distance from creek, and inundation/hydroperiod (Mudd *et al*. 2004);
- Data on soil organic matter, with particular emphasis on below ground productivity and decomposition (Blum & Christian, 2004; Cahoon *et al*. 2004).

Very little such data exists for UK saltmarshes. This could be achieved in a period of a few years with a focussed field campaign. More difficult is the data needed to validate the models, in particular the response of marsh systems under the combined influence of sea level rise and variations in tidal range due to the lunar nodal cycle. This requires data on sedimentation and accretion rates, as well as biomass data to be taken on defined profiles over a period of at least 20 years. Although some limited data sets are available (French, *pers. comm.*) and it is possible to make use of surrogate data sets to infer change (e.g. aerial photographic data), more detailed data sets will be needed if this type of model is to be used confidently in a predictive manner.

Although some quite detailed models of flow through saltmarsh vegetation have now been developed, there is a need to simplify the representation of resistance so that it is based on properties that are more readily observed in the field, or can be rapidly characterised from remote sensing data (Nepf, 2004; Silvestri & Marani, 2004). Drag around vegetation is usually at very low Reynolds numbers and this is not currently well defined and yet is important if inundation time and advection of sediments is to be accurately represented (Mudd *et al*. 2004). This extends to experiments of the turbulent energy, dissipation and settling velocity, all as a function of biomass at low Reynolds numbers which have been explored to a limited degree in the laboratory but hardly at all in the field (Neumeier & Amos, 2006; Graham & Manning, 2007).

Although work on scaling of saltmarsh vegetation coverage has identified relationships for individual species, the distribution of species is likely to be strongly influenced by interspecific competition. This may also have a strong role in the observed variability in marsh zonation. There is therefore a need to develop a better understanding of the relative importance of sub-surface controls on soil aeration (Marani *et al*. 2006) and the role of competition between species (Gray, 1992; Morris, 2007).

Given the complex interplay between inorganic and organic sedimentation within marsh systems, and the subsequent role this plays in processes such as autocompaction (Cahoon *et al*. 1995; Allen, 2000a) there may be a need to track the respective contributions in the next generation of models, so that any feedbacks between the two can be better represented (Mudd *et al*. 2004).

Finally, in order to improve the management of saltmarsh, there is a need for a better understanding of the role of saltmarsh within the trophic cascade (Finke & Denno, 2004) and how this is influenced by predation at a range of scales (Berg *et al*. 1997; Bos *et al*. 2003; Minkoff *et al*. 2006), or by other induced stresses such as burning (Cahoon *et al*. 2004), dredging (Friedrichs & Perry, 2001), cheniers (Quaresma *et al*. 2007) and sea walls (French, 2008).

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http://www.intertidalmanagement.co.uk/contents/index.htm
http://www.abpmer.net/omreg/
http://www.saltmarshmanagementmanual.co.uk/
http://www.estuary-guide.net/
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THE IMPORTANCE OF SALTMARSHES FOR BIODIVERSITY

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What are Saltmarshes and Where do they Occur?

Saltmarshes are highly productive plant communities inhabiting many coastal fringe areas around the UK. They are occupied by flowering plants and grasses that can tolerate periodic covering by seawater, forming on the upper parts of intertidal mudflats on sheltered coastlines where fine sediment is deposited by the sea. They will grow as far as the upper limit of the high-tide, where it is still occasionally inundated by the sea and stretch across and down the shore, often forming extensive creek systems where the tide drains. Saltmarshes are typically found on low energy coasts such as estuaries, inlets and behind barriers such as islands or shingle spits. Most of England's saltmarshes are concentrated in the major estuaries of eastern and northwest England, as well as the large estuaries of the southeast coast such as the Solent and Thames. Because of variation in the sediment type, saltmarsh composition also varies around the country with the muddier east and south coast saltmarshes tending to be made up of different species from those of the sandy sediments more characteristic of the west coast. Other environmental factors such as salinity and the land-management regime are also important in determining species composition.

plate 1. Spartina saltmarsh at Hythe, Southampton Water

Different species of saltmarsh plant have different tolerances to saltwater and tend to occupy particular vertical zones on the shore. This zonation has typically four main zones: pioneer, lower, middle and upper saltmarsh. The upper saltmarsh zones are highly diverse and include species that produce colourful displays of flowers, such as sea-lavender, thrift and sea-aster. The low and pioneer marsh communities experience a greater number of tidal inundations and as a result of this, the vegetation communities often have a lower diversity and are composed of halophytic plants such as the common saltmarsh grass *Puccinellia maritima* and Samphire (*Salicornia*).

The most recent saltmarsh surveys of the UK estimate the total extent of saltmarsh (including transitional communities) to be approximately 45,500 hectares (England 32,500 hectares, Scotland 6,747 hectares, Wales 6,089 hectares, and Northern Ireland 215 hectares) with some of the most extensive tracts occurring on the east coast of England, Thames estuary and the Solent.

Why are they important?

Saltmarshes have a high ecological value. They are a rare and specialised habitat in their own right and many of the plants which occur there survive nowhere else. They are also the life-blood for a wide range of other species such as birds, fish and insects. Saltmarshes play a fundamental role in the functioning of estuaries and their evolution over time and have a pivotal role in management of an estuary's sediment budget. They also operate as a key source of primary production.

plate 2. bury Saltmarsh, Southampton Water

Particular saltmarsh species have a special ecological interest. The Solent is one of the country's most important locations for Cordgrass *Spartina* spp. This saltmarsh grass is an important pioneer colonising a wide range of substrates from very soft muds to shingle, in areas sheltered from strong wave action. It occurs on the seaward fringes of more mature saltmarshes, on creek sides, and may colonise old pans in the upper marsh. The native species, *Spartina maritima* (small cordgrass) is known to occur in only a few locations such as Newtown Harbour on the Isle of Wight and is considered rare in the UK.

Spartina alterniflora (smooth cordgrass) is a naturalised North American species thought to have been introduced to the UK. It is also rare and occurs only in Southampton Water. The sterile hybrid of small and smooth cordgrass, *Spartina x townsendii* (Townsend's cordgrass) is found only in the Solent whereas *Spartina anglica* (common cordgrass), a fertile hybrid, is now widespread and found in many locations around the country. In many areas, such as the Solent, it is now the dominant saltmarsh species. It forms extensive saltmarsh stands and creeks that support other plants and animals and it often forms a valuable precursor to other saltmarsh species.

Saltmarsh also provides an important food source and feeding area for certain migratory birds such as teal and brent geese as well as roosting areas for overwintering and migrating birds such as waders, especially during severe winter weather. The upper marshes provide excellent high tide roosts, offering a safe haven from the tides and predators. The main high-tide roosts are in areas with little human disturbance, where large aggregations of waders arrive from their various feeding areas. Some saltmarsh areas in the Solent also provide important nesting areas for species of waders, gulls and terns.

Saltmarshes have a crucial role to play in flood and erosion risk management, helping attenuate the force of waves and moderate tidal surges. They are also appreciated by many for their outstanding scenic beauty, captured on numerous paintings and photographs. In many areas they are recognised by law through landscape protection legislation.

Legal protection

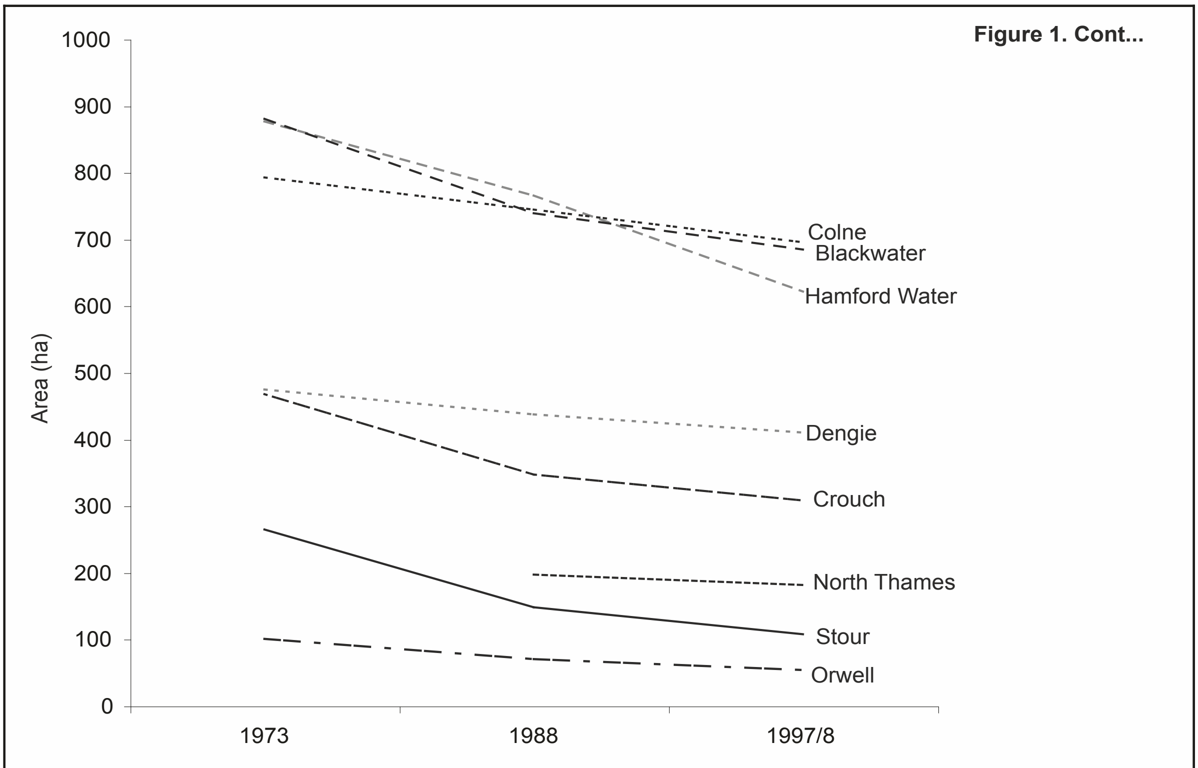
In 1999, England had seventy-one percent, some 32,500 hectares, of the total saltmarsh area of the UK (UK Biodiversity Group, 1999), the majority of which is within Sites of Special Scientific Interest (SSSIs). Under the EC Habitats Directive, saltmarsh, termed Atlantic Salt Meadows, is listed as an Annex 1 habitat and ten areas in Great Britain (including the Solent) have been designated as Special Areas of Conservation (SACs) for their saltmarsh features. In addition, twenty-seven major saltmarsh sites and many smaller ones are designated as Special Protection Areas (SPAs) under the EC Birds Directive. Many saltmarsh areas are also listed as Ramsar sites. Government and statutory bodies do, therefore, have a responsibility to protect and conserve these important saltmarsh areas.

A changing Habitat

Saltmarsh is a dynamic habitat that evolves and changes as it develops. In an accreting system, as the tide inundates the saltmarsh, it deposits silt around the stems and roots of saltmarsh plants, which increases the height of the ground around it. As more silt is deposited, the marsh is less frequently covered by the sea and the marsh becomes higher and as a consequence, the vegetation within the saltmarsh will change in species composition. This natural succession is still occurring in a few areas where saltmarsh is continuing to develop.

Figure 1 shows the general picture is of extensive saltmarsh loss, due primarily to historic enclosures and more recently to erosion. Saltmarshes have been claimed for agricultural land since the Middle Ages, being enclosed and drained for use as grazing-marsh. Since the 1940s, many grazing-marshes have been improved for arable crops, so that many saltmarshes are now directly next to arable farmland, and the upper and transitional saltmarsh communities have been lost. In the Wash, over 800 hectares of saltmarsh was converted to agricultural use between 1970 and 1980 (UK Biodiversity Group, 1999).

Figure 1. The declining area of saltmarsh in the Essex Estuaries (English Nature, 2002).					
	Area (Hectares)			**Area (and percentage) lost**	
	1973	**1988**	**1997/8**	**1973 to 97/8**	**1988 to**
97/8					
Orwell	100	70	54	46 (46%)	16 (23%)
Stour	264	148	107	157 (59%)	41 (28%)
Hamford Water	876	765	621	255 (29%)	144 (19%)
Colne	792	744	695	97 (12%)	50 (7%)
Blackwater	880	739	684	5197 (22%)	5 (7%)
Dengie	474	437	410	64 (14%)	27 (6%)
Crouch	467	347	308	159 (34%)	40 (11%)
~~North Thames~~	~~No data~~	~~497~~	~~181~~	~~No 1973 data~~	~~16 (8%)~~



Although large-scale land claim for agriculture use is now rare, smaller scale losses such as for maritime developments continue to have a cumulative effect. The most significant cause of recent losses and of predicted future losses, is coastal squeeze. This is where saltmarsh that would naturally respond to rising sea levels by migrating landward is unable to do so, because of hard sea-defences resulting in the loss of upper saltmarsh zones.

In south Suffolk, Essex and north Kent estuaries, ten percent to forty-four percent of the saltmarsh area was lost during the period 1973 to 1988. Further work has confirmed the ongoing loss of saltmarsh habitat in south Suffolk and Essex since 1988. In the twenty-five years between 1973 and 1998, over 1,000 hectares of saltmarsh in south Suffolk and Essex was lost to coastal squeeze and development. This pattern is repeated on the south coast of England, where areas of saltmarsh in nine estuaries declined from 1,700 hectares in the 1970s to 1,080 hectares by 2001. It is estimated that saltmarsh has been lost at a rate of over one percent annually since 1994 in parts of southern and eastern England and at one and a half percent annually since 1946 for areas in the Solent region (Cooper *et al*.,2001; Baily and Pearson, 2001; Burd, 1992). In the Solent, some 700 to 800 hectares is predicted to be lost between now and 2100 with some of the fastest rates of loss being seen in the western Solent. As a consequence, the majority of the designated saltmarsh areas in the Solent are recorded as being in an unfavourable condition.

Compounding the effects is the natural die-back of common cordgrass *S. anglica*. The causes of this are not well understood; however where cordgrass dominates and is dying back, the effects of sea level rise and coastal squeeze are exacerbated.

Making Space

If losses continue at present rates, without further re-creation, the targets agreed in the UK Biodiversity Action Plan (BAP) for saltmarsh will not be met. There are also targets to restore the condition of the country's SSSIs and European sites into a favourable condition and to achieve good ecological status of our coastal waters under the EU Water Framework Directive. In addition to the ecological drivers, there are good flood and erosion risk management reasons to restore and create new saltmarsh areas around our coasts.

Currently the creation of new habitat by realigning sea defences and allowing sea water to flood historic areas of land claim is not keeping pace with current losses. The UK Biodiversity Action Plan for saltmarsh suggests that creation of around 100 hectares per year is needed to keep pace with current losses, with a further forty hectares per year for fifteen years to replace the 600 hectares lost between 1992 and 1998.

In total, since 1992 around 150 hectares of managed realignment has taken place, far short of the saltmarsh Biodiversity Action Plan target of 140 hectares per year. Currently, there are firm plans for a further 700 hectares around the country of which only a proportion may become saltmarsh in the future; they will take time to achieve the quality of habitat to merit SSSI designation. The gap between habitat re-created and the action needed is growing.

Natural England is working closely with key partners such as the Environment Agency to develop Regional Habitat Creation Programmes. These set clear targets and work programmes to take forward managed realignment schemes in key locations around the country, to create more natural coastlines and new areas of saltmarsh habitat. These programmes, together with sustainable Shoreline Management Plan and Coastal Strategy policies embracing managed realignment, are essential if we are to meet our BAP and legal requirements.

c oncluding Remarks

Saltmarshes are rare and valuable habitats and are vitally important to the health of our estuaries and sheltered coasts. They play a crucial role in sediment management within estuaries and provide sanctuary and sustenance for numerous wild bird species. Saltmarsh provides shelter and nursery areas for many commercial fish species and is a cherished part of our heritage and landscape.

It is important to recognise that saltmarsh systems are dynamic and constantly evolving and, in the face of rising sea levels and if conditions are right, it will respond by adjusting landward. This requires an adaptive approach to coastal management and a national flood and erosion risk management strategy that works with nature, not against it, realising the many opportunities for using natural habitats on the coast instead of hard defences.

Managed realignment provides the ideal opportunity to accommodate saltmarshes and mudflats in the face of rising sea-levels and to provide cost effective and sustainable sea defences. However, its use in flood management to date is still rare and it will need to be increasingly the preferred option if we are to realistically offset current losses and achieve sustainable coastal management.

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THE IMPORTANCE OF SALTMARSHES FOR FLOOD RISK MANAGEMENT

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Abstract

Coastal flooding from the sea is a continual threat. Lives and property are at risk. The threat is increasing as sea-levels rise, exacerbated by the effects of climate change. Saltmarshes provide an effective first line of defence. A healthy saltmarsh can reduce wave heights and wave energy reaching flood defences. Although they may be of limited value in exceptional flood events, they are a valuable flood defence, reducing the standard of built defences required and as a result, construction costs. Consequently, where appropriate, spending public money on saltmarsh management and creation is justifiable. However, significant losses of saltmarsh have already occurred and with continuing rising sea-levels, further losses are likely in the future. This should be viewed as a major loss of natural flood defences and therefore is a significant concern to flood risk managers. Although not the whole solution, creating new saltmarshes should be an integral part of our portfolio of approaches to managing flood risk in coastal areas.

The Threat of Coastal Flooding

The night of Saturday, 31st January, 1953 is infamous. One of the strongest North Sea storms of the 20th century resulted in the highest storm surge ever recorded along the east coast of England. As a low pressure system tracked southeast across the North Sea, it left in its wake 647km^2 of flooded land. Along the 1,600 kilometres of coast affected, defences were breached in 1,200 places. At least 24,000 houses were damaged: 500 were totally destroyed. Around 200 industrial facilities were also damaged by flood-water. Although more than 32,000 people were evacuated to safety, tragically, 307 people lost their lives. The economic cost, whilst trivial in light of the lives lost, was estimated to be between £40 to £50 million, equivalent to around £1 billion in 2003 prices[1].

A massive investment in upgrading coastal defences followed with defences raised by up to two metres and strengthened, particularly around concentrations of population. The Thames barrier, opened in 1984, was constructed to defend central London. As a result, in the fifty-five years since the North Sea storm, a major coastal flooding disaster has been averted.

However, there is no room for complacency. Recent storms and surge-tides are a timely reminder of the risk of tidal inundation of low lying coastal areas. On 9th November 2007, a deep area of low pressure once more tracked south from Scotland down the North Sea. A surge-tide of up to three metres was predicted along the Norfolk and Suffolk coast: between fifty to ninety centimetres above the Environment Agency's alert level[2]. As the winds were largely offshore, peak tide levels were twenty to thirty centimetres less than anticipated. Despite this, sea level reached its highest levels at Lowestoft (0.71m above alert level) and Great Yarmouth came within ten centimetres of the top of many sea defences. Shingle defence barriers at places like Walberswick and Easton Broad were breached, resulting in tidal flooding of large areas of internationally important wildlife habitats.

More recently, the south coast was battered by storms in March 2008. Some defences were overwhelmed. For example, the shingle defences at Selsey were breached resulting in thirty people having to be rescued by emergency services from a caravan park behind the sea wall.

What is the Current Risk?

Overall, about eleven percent of the area of England (seven percent of Wales) is within the flood risk area[3]. About 2.1 million properties in England (200,000 in Wales) are in flood risk areas affecting 4.3 million people (0.3 million in Wales) [4,5]. Of these, 469,000 properties (100,000 in Wales) are at significant risk. Of the 2.1 million properties at risk in England, 48.5 percent are at risk from flooding from the sea, forty-eight percent from rivers and 3.5 percent from both[6].

Of course, it is not just residential properties that are at risk. Significant and important infrastructure is also at risk with more than a quarter of gas supply sites and more than half of sewerage and water sites being vulnerable to flooding (table 1).

Table 1. important infrastructure (receptors) vulnerable to flooding in England.[7]		
Receptor	Number	%
overall		
Hospitals	90	6 Care
homes	128	7
Schools	1796	7
Health centres	2971	10
Prisons	19	13
Police stations	397	13
Ambulance stations	172	14 Fire
stations	265	14
Electricity sites	8423	15
Railway stations	512	17 Gas
supply sites	23	28
Sewerage & water sites	1145	58

The expected annual damages from flooding in England has been estimated at £1.1 billion (excluding damage to transport infrastructure and agricultural land) and £262 million in Wales[8].

Recognising this risk, we have built flood defences, 24,000 miles of them (raised defences and maintained channels) and 46,000 flood defence structures (table 2)[9]. Of these, the Environment Agency maintains sixty-two percent of the length of coastal and fluvial defences/channels and thirty-seven percent of the structures. The rest, thirty-eight percent of linear defences and sixty-three percent of structures, are owned and maintained by third parties[10]. The condition of these structures as of April 2007 is shown in table 3. The cost of replacing these is estimated at £20 billion.

Table 2. The number of different flood defence assets in England (includes raised defences and maintained channels but not natural channels which are not maintained)[12].		
Flood defence structures	River defences	40,200
	Sea defences	3,800
	Coast protection	1,300
	Other	700
	TOTAL	46,000
Linear flood defences (miles)	Maintained channels	15,300
	Raised defences (man-made)	4,200
	Sea defences (man-made)	900
	Culverted channels	900
	Flood storage areas	600
	Coast protection (man-made)	300
	Raised defences (natural)	300
	Coast protection (natural)	300
	Raised coastal defences (man-made)	100
	Sea defences (natural)	100
	Other	1,000
	TOTAL	24,000

The number of properties protected from flooding continues to improve (table 4). However, over the last nine years on average 13,000 new homes per year have been built in flood risk areas[11].

implications of c limate c hange for Sea Defences

Global atmospheric temperatures have risen about 0.6°C over the last century. It is thought that they will continue to increase by between 1.4°C and 5.8°C throughout the twenty-first century. Mean global sea levels may increase from

Table 3. The condition of defences as of April 2007.[13]			
Defence type	Good/very good	Fair	Poor/very poor
Linear	18,100 miles	16,000 miles	1,900 miles
Structures	26,200	13,400	3,200

Table 4. Number of houses with an improved standard of flood protection between 2003-04 and 2007-08.[14]	
Year	Additional houses protected
2003/04	17,700
2004/05	30,000
2005/06	52,600
2006/07	28,300
2007/08	29,700

between nine centimetres and eighty-eight centimetres by 2100.[15] In the UK, temperatures across the country may rise by between 2^{o}C and 3.5^{o}C by the 2080s. Extreme high water levels which currently have a two percent annual probability of occurring could become ten to twenty times more frequent.[16]

Global sea levels may be rising faster than previously thought, up from 1.8 millimetres a year to 3.2 millimetres.[17] Net sea level rise around Eastern England was estimated to be up to thirty-four centimetres by mid-century, rising to sixty centimetres over the 1961-1990 reference period by the end of the century.[18] These figures have been updated to forty-two centimetres and eighty centimetres respectively.[9] Reflecting this, Defra has increased its allowances for sea level rise in the southeast from a flat rate of six millimetres a year to 8.5 millimetres a year (2025 to 2055) and to fifteen millimetres a year by the end of the century.[20] Surge tides with a two percent chance of happening in any year and an eighty percent chance of happening during an eighty-year lifetime could increase by over one metre.[21]

The impact of this environmental change is that overall, the estimated 1.6 million people in England that are currently at risk from coastal and river flooding could increase to between 2.3 and 3.6 million by 2080.[22] The annual cost of damages in England and Wales due to coastal flooding could increase from between £1 billion to £20 billion by 2080[23]. The proportion of national flooding attributable to coastal flooding is predicted to increase from fifty percent to between sixty to seventy percent. Coastal erosion is expected to increase substantially with average annual damages increasing from between three and nine times: up to £126 million a year by 2080.

Currently, it is estimated that 270,000 properties in eastern England are located within the maximum flood extent of a storm surge event. The number of key service buildings is 1,474. The current total financial losses as a result of a storm surge with current sea levels would be in the region of £2.5 to £6.2 billion.[24] This could increase by forty-eight percent to 404,000 properties following a 0.4 metre rise in sea levels. The number of key service buildings increases to 2156 (fifteen percent fire and ambulance stations, forty percent electricity sub-stations, fifteen percent petrol stations). Total financial losses would rise to between £7.8 to £16 billion.[25]

These impacts would be compounded by likely population growth within the maximum storm surge area in Eastern England, up fourteen percent by 2028. Worryingly, there is expected to be disproportionate growth in the population of the over seventy-fives.

The Role of Saltmarshes in Flood Risk Management

For a number of years, people have argued that more use should be made of natural flood defences such as saltmarshes and sand dunes. It has been a matter of government policy for some time.[26] The policy has been forcefully reiterated in government's new flood and coastal erosion risk management framework, Making Space for Water.[27] Recently, the independent review into the 2007 floods recommended that we do more to work with, rather than against, natural processes.[28]

There is a growing basis of scientific evidence which quantifies the value of saltmarsh as a natural flood defence. Field studies at Stiffkey in North Norfolk suggest that significant wave heights decreased on average by fifteen percent over sand flats, compared to sixty-one percent over saltmarsh. Wave energy decreased on average by twenty-nine percent over sand flats and eighty-two percent over saltmarsh.[29] The difference in wave attenuation was observed irrespective of water depth (at least up to depths of 2.5 metres at which point the difference between saltmarsh and sand flats declined; indeed, others have concluded that it is unlikely that, in terms of wave energy dissipation, saltmarsh provides a significant natural sea defence during storm surge conditions such as those which occurred in 1953[30]). Furthermore, the numeric modelling predicted that the loss of upper saltmarsh to sand flats (e.g. due to saltmarsh erosion) would cause surface friction to be reduced by a factor of ten which would result in average wave heights to double.

The precise extent of wave attenuation of salt marsh will depend on a range of factors and will be site specific. Factors include saltmarsh width, saltmarsh edge (cliff), topography, vegetation type and density, and even season.[31] However, studies from elsewhere confirm the fact that, in general, saltmarshes reduce wave height and energy (see table 5).

The likely effect of saltmarsh on potential flooding is startling. Modelling indicates that if the saltmarsh at Stiffkey was fronting an embankment-type turf covered sea wall (height of 0.4m OD, slope 1:2), the sea-wall would be overtopped in thirty-eight out of the seventy-one observed wave events (fifty-four percent). If the saltmarsh was a sand flat, then overtopping was predicted to occur fifty-two times (seventy-three percent).[32]

An attempt has been made previously to assign a monetary value to saltmarsh as a flood defence. This work assumed that the greater the width of saltmarsh in front of a sea wall, the greater the reduction in wave height and energy and so the lower the costs of building defences (table 6). Whilst this assessment provides a useful indication of potential savings, more accurate assessments are needed. This is because the valuation assumed that the relationship between saltmarsh width and seawall height is linear. This is not the case. For example, forty percent of the wave energy that arrives at the saltmarsh edge at Tillington (Dengie Peninsula, Essex), is attenuated across the first ten metres of marsh. On average, the following twenty-eight metres of marsh attenuate a further sixty percent of wave energy.[33]

Despite this limitation, the saltmarsh valuation provides a starting point for assessing what area of saltmarsh might be desirable when realigning defences and incorporating saltmarsh into the design standard. When the costs of creating saltmarsh (including land purchase costs) are included, we begin to get a clearer idea of the true costs and benefits of saltmarsh as a flood defence (table 7). Taking a purely economic view, because the cost of acquiring land and creating saltmarsh is so high, there comes a point where the flood defence value of the saltmarsh is exceeded by its creation costs. This very simplistic assessment (based on 1995 costs for flood defence construction and saltmarsh costs of £112,000 per hectare[36]), suggests that savings can be made up to thirty metres of saltmarsh created but beyond this, costs may exceed the construction of defences without saltmarsh. However, more work is clearly needed before a robust and reliable valuation can be made.

Table 5. Measured levels of wave attenuation across UK saltmarshes and intertidal flats.[34]

	Mud/sand flat wave height attenuation	Mud/sand flat wave energy attenuation	Salt marsh wave height attenuation	Salt marsh wave energy attenuation
North Norfolk Stiffkey	15%	29%	61%	82%
Dengie Tillingham Bridgewick	21% 24% increase	35% 55% increase	87% 44%	99% 79%
The Wash Wrangle Flats Butterwick Low Breast Sand	16% 23% 36%	10% 36% 56%	91% 64% 78%	97% 72% 91%

Table 6. Effectiveness of saltmarsh in flood and coastal defence.[35]		
Saltmarsh Width	**c rest Height of Seawall**	**indicative c ost**
80 m	3 m	£400 per metre run
60 m	4 m	£500 per metre run
30 m	5 m	£800 per metre run
6 m	6 m	£1,500 per metre run
0 m	12 m	£5,000 per metre run

Table 7. c osts of flood defence construction including the costs of saltmarsh creation.						
Crest height of seawall (m)	Cost per m of seawall (£)	Cost per 100m of seawall (£)	Saltmarsh width fronting seawall (m)	Area of saltmarsh (ha per 100 metre of seawall)	Cost of saltmarsh creation per ha @ £112,000/ha	Total cost (£)
3	400	40,000	80	0.80	89,600	129,600
4	500	50,000	60	0.60	67,200	117,200
5	800	80,000	30	0.30	33,600	113,600
6	1500	150,000	6	0.06	6,720	156,720
12	5000	500,000	0	0.00	0	500,000

Saltmarsh Loss - A Flood Risk Management c hallenge

From this brief assessment, it is clear that in most cases, a healthy saltmarsh in front of a sea wall will reduce wave height and wave energy and thus reduce the risk of flooding on many (but not all) occasions. Whilst further work is needed, the indications are that the scale and costs of defences can be reduced where extensive saltmarshes front seawalls.

Consequently, it should be a great concern - from a flood defence point of view if not for other interests - to see the scale of current and likely future losses of saltmarshes from around the coast of England (table 8). Whilst the overall picture currently is one of maintaining status quo (total area of saltmarsh in Special Protection Areas (SPAs)[37] at designation equal to 9,952 hectares, area in 2004 equal to 9,968 hectares (excluding Foulness)), the area in 2054, based on linear extrapolation of gains and losses, suggests a potential loss of saltmarsh in the region of 500 hectares. Furthermore, a general trend of saltmarsh lost from most sites is masked by potential significant gain in saltmarsh in the Wash which could accrete as much as 2,000 hectares by 2054. As much as 2,545 hectares of saltmarsh could be lost from ten SPAs exhibiting a negative trend. That is 2,545 hectares of flood risk assets lost by 2054.

The fact is that the picture could be a lot worse than the assessment of habitat loss from SPAs suggests. The recently updated UK Biodiversity Habitat Action Plan for Saltmarsh has established a target of needing to create at least 100 hectares of saltmarsh a year just to maintain current extent and an additional forty hectares a year (ninety percent in England) in order to offset historic losses arising in particular as a result of coastal squeeze.[38]

Table 8. Estimated saltmarsh areas (ha) at the date of first designation of each SpA and in 2004, and 2054 based on linear extrapolation of historic rates of change (-ve = loss, +ve = gain)[39]						
SPA Name	Designation year	Area at Designation	Area in 2004	Change in area	Area 2054 Linear	Area Change Linear
Deben Estuary	1996	231.8	214.8	-17.0	108.8	-106.0
Stour and Orwell Estuaries	1994	180.0	117.1	-62.9	None	-314.5
Hamford Water	1993	686.4	527.8	-158.6	None	-721.0
Colne Estuary	1994	692.2	635.9	-56.3	354.4	-281.5
Blackwater Estuary	1995	684.2	621.1	-63.1	270.6	-350.5
Dengie	1994	420.0	393.1	-26.9	258.6	-134.5
Crouch and Roach Estuaries	1998	410.9	344.6	-66.3	N/A	N/A
Foulness	1996	No data	No data	No data	No data	No data
Benfleet and Southend Marshes	1994	140.2	126.4	-13.8	57.4	-69.0
Thames Estuary and Marshes	2000	30.5	27.8	-2.7	None	-34.0
The Swale	1982	254.1	284.5	+30.4	348.5	+64.0
Chichester & Langstone Harbours	1987	563.7	431.9	-131.8	44.4	-387.5
Portsmouth Harbour	1995	70.5	44.1	-26.4	None	-146.5
Solent and Southampton Water	1998	465.6	391.2	-74.4	N/A	N/A
Humber Flats, Marshes & Coast	1994	624.1	643.6	+19.5	741.1	+97.5
The Wash	1988	3939.9	4586.9	+647.0	6608.9	+2022.0
Severn Estuary (south shore)	1995	557.6	577.5	+19.9	688.5	+111.0

c onclusions

Saltmarshes provide a valuable function as a flood defence. They provide a natural barrier in front of built defences, reducing wave height and the wave energy which reaches the defences. Healthy saltmarshes can reduce the scale of defences required, reduce construction and maintenance costs and prolong the integrity of the structure. They can help protect people and property from tidal flooding. However, their role as a flood defence has limitations and it is questionable that they would make a difference in an extreme flood (surge tide) event.

The coastline of UK is approximately 12,400 kilometres. The coast of England and Wales is about 7,000 kilometres:[40] that of England 3,000 kilometres.[41] Given that about twenty-four percent of the coastline of England is fringed with saltmarsh[42], current loss of saltmarsh, especially but not exclusively in front of sea walls, already poses a threat to the integrity of the defences. Future losses due to coastal squeeze, resulting from rising sea levels and exacerbated by climate change, are likely to be significant.

Government policy is clear. It aims to manage the risks from flooding and coastal erosion by employing an integrated portfolio of approaches which reflect both national and local priorities, so as to:

- Reduce the threat to people and their property; and
- Deliver the greatest environmental, social and economic benefit, consistent with the government's sustainable development principles.[43]

It has been estimated that such an integrated portfolio approach could reduce annual flooding losses from a possible £20 billion a year to £2 billion a year by 2080.[44] However, it should be noted that this is still double current expenditure and might require between £22 and £75 billion of new engineering works by 2080.[45] The management and creation of saltmarshes must be part of this integrated portfolio of approaches. It is vital that we redouble efforts to ensure that saltmarshes are used to maximum effect where it is possible and appropriate to do so.

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SOLENT DYNAMIC COAST PROJECT: A TOOL FOR SMP 2

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This paper contains a summary of the results, recommendations and conclusions of the full report that was published by New Forest District Council and the Channel Coastal Observatory in January 2008. The full text is available to download from www.channelcoast.org/reports/ in the 'Other Reports' directory. The historical photography saltmarsh shapefiles can also be downloaded from the 'Other Reports' directory under 'Historical Photography Interpretation'.

introduction

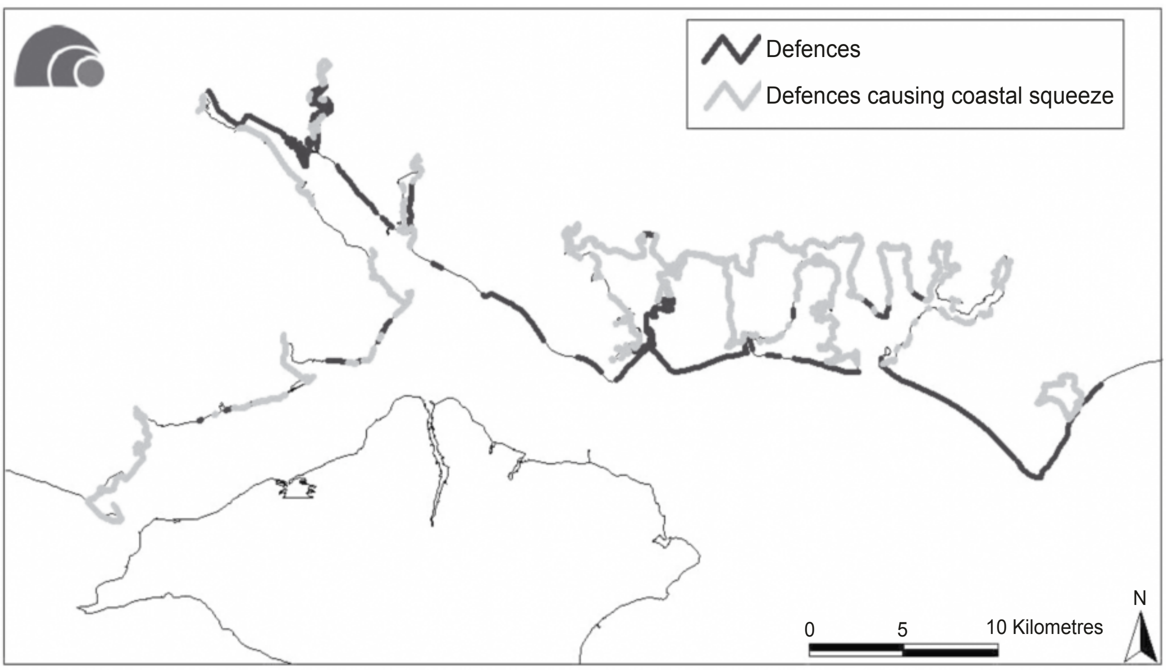
The Solent Dynamic Coast Project (SDCP) was conducted to inform development of the second round Shoreline Management Plan (SMP 2) in order to comply with the requirements of the European Union Habitats and Birds Directives. The focus was on mudflat and saltmarsh habitats as these form the largest expanse of coastal habitats across the north Solent, that are immediately under threat from climate change and coastal management decisions. The consequent effect to coastal grazing marsh was also considered. The main objectives were to:

- Quantify the amount of inter-tidal coastal squeeze over the next 100 years that requires replacement habitat. Identify sites where inter-tidal habitat creation is physically possible.
- Quantify the amount of inter-tidal habitat creation sites that could potentially offset inter-tidal coastal squeeze over the next 100 years.
- Undertake preliminary ranking and assessment of the feasibility of conducting managed re-alignment relative to other impacting variables.
- Develop a region-wide framework of potential inter-tidal habitat mitigation and compensation sites.

The majority of defences in the north Solent are fronted and backed by European designations, such as Special Areas of Conservation (SACs) and Special Protection Areas (SPAs). Maintaining or improving these defences must comply with European environmental legislation. Certain flood defence schemes have been delayed for over two years because replacement inter-tidal habitat could not be found to offset the projected coastal squeeze resulting from the operational works. As a result, the SDCP was initiated on behalf of the operating authorities within the north Solent region.

As a result, the SDCP was initiated on behalf of the coastal defence operating authorities within the north Solent region.

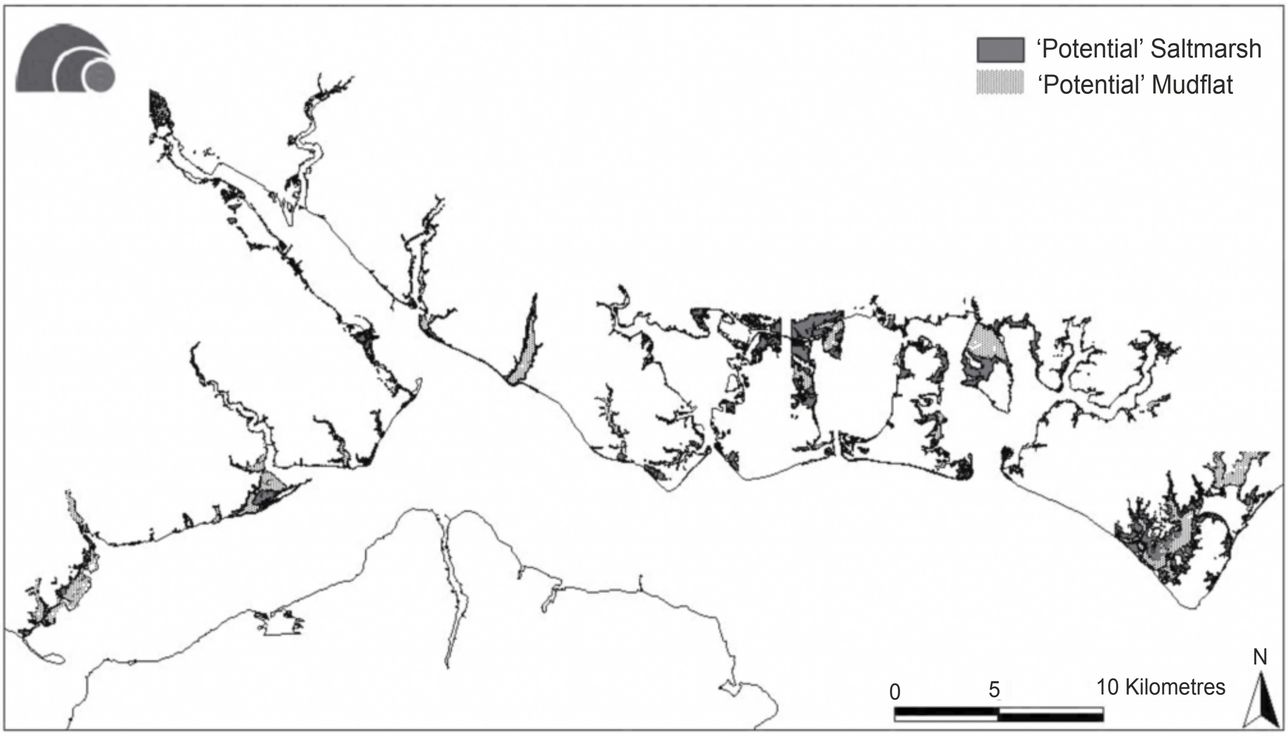
Defences across the north Solent causing coastal squeeze



Results

The SDCP covered the area between Hurst Spit, Hampshire and Pagham Harbour, West Sussex. The project verified mudflat and saltmarsh loss calculated by the Solent Coastal Habitat Management Plan (CHaMP, 2003) using a robust methodology of historical aerial photography interpretation (HPI) and analysis of topographic and tidal elevation data. Predicted changes to existing inter-tidal habitat across the north Solent, regardless of defences or environmental designations, was estimated to be an increase of sixty hectares for mudflat and a loss of 812 hectares for saltmarsh over the next 100 years. Inter-tidal coastal squeeze resulting from maintenance of all existing defences across the north Solent over the next 100 years was estimated to be approximately five hectares of mudflat coastal squeeze and 495 to 595 hectares of saltmarsh coastal squeeze. This predicted 500 to 600 hectare loss provides a worse case scenario, as not all defences will be maintained.

Potential habitat creation sites across the north Solent were identified using topographic and tidal elevation data. A total potential of 3,883 hectares was identified. Once buildings, landfill and sites smaller than 0.5 hectares were removed there were 2,025 hectares to be assessed further. In order to assess the viability of the potential sites (2,025 hectares), local coastal managers were interviewed using a questionnaire based on government economics and environmental criteria devised by the Environment Agency (EA), Natural England (NE) and the Channel Coastal Observatory (CCO). The questionnaire categorised the sites into preferred options for, hold the line, managed re-alignment or no active intervention (abandonment)* for time epochs 0-19, 20-49, 50-100 and 100 plus years.



Of the 2,025 hectares of potential habitat creation sites, only 552 hectares were considered suitable to offset the 500 to 600 hectares projected loss. Key potential habitat creation sites were West Northney, Medmerry, Gillies, Farlington Marshes, North Common, Saltgrass Lane, Lymington Reedbeds, Pagham South, Stoke, Nutbourne and West Wittering. Of the 552 hectares, 135 hectares counts as mitigation because the key sites are within an existing SPA. There may be a shortfall of inter-tidal habitat creation sites in the north Solent over the next 100 years unless NAI sites (686 hectares) can be used as mitigation or compensation to offset future damaging schemes. Hold the line sites (787 hectares) may require further future assessment if resources are made available to re-align them. Approximately seventy-nine hectares of designated freshwater sites were identified as requiring replacement habitat as a result of potential managed re-alignment. A further 328 hectares of freshwater sites would also be lost due to potential NAI without any clear means to replace it.

The work has been undertaken by the key statutory authorities. However, this study has not involved any decision making on the part of any statutory authority. The options suggested in this study are there to facilitate future debate and decision making as part of the SMP process. No landowners or wider stakeholders have been consulted as part of the project. These views will be sought as part of the SMP process. The SMP process will integrate all aspects of sustainable development, social, economic as well as environmental, prior to any final decisions on coastal management being made.

c oastal squeeze versus potential mitigation/compensation within each SpA				
SpA	Squeeze (ha)	pOTENTiAL g AiN (ha)		Deficit (ha)
		Mitigation (inside SpA)	c ompensation (outside SpA)	
Solent and Southampton Water (SPA)	136 - 163	41	11	83 - 112
Portsmouth (SPA)	172 - 206	0	2	170 - 204
Langstone and Chichester (SPA)	195 - 231	92	37	66 - 102
Pagham (SPA)	0	2	367	-369
Total: north Solent range	**500 - 600**	**135**	**417**	**-52 - 48**

c onclusions and Recommendations

Key findings from the Solent Dynamic Coast Project are summarised in the following table.

Key findings	Length/Area
Length of north Solent coastline	314 km Length
of north Solent defences	283 km
Mudflat area now	5549-6311 ha (CHaMP, 2003)
Saltmarsh area now	1042 ha Total
inter-tidal habitat loss over next 100 years	752 ha
Coastal squeeze requiring replacement inter-tidal habitat over next 100 years	500 - 600 ha
Overall potential inter-tidal gain under natural evolution over next 100 years	3883 ha (100 sites)
Sites of potential inter-tidal gain taken forward for further analysis	2025 ha (54 sites)
Sites identified for potential inter-tidal re-alignment	552 ha
Sites identified for potential inter-tidal abandonment	686 ha
Sites identified as potential hold the line	787 ha
Area of potential re-alignment sites that can be used as inter-tidal mitigation/ compensation	552 ha
Area of freshwater habitat requiring replacement from potential inter-tidal re-alignment ha sites	79
Area of freshwater habitat requiring replacement from potential inter-tidal abandonment ha sites	328

The study made the following conclusions and recommendations:

1. More than fifty percent of the flood defences in front of all potential habitat creation sites (re-alignment, NAI and hold the line) in the north Solent will reach the end of their residual life in the next twenty years and a further thirty percent in the next fifty years.

2. Coastal squeeze requiring replacement inter-tidal habitat (500 to 600 hectares) assumed all current defences will be maintained. This is a worse case scenario. Where defences are identified for managed re-alignment or NAI in the North Solent SMP, they will no longer be contributing to coastal squeeze, thus the coastal squeeze target could reduce.

3. Eleven sites were identified for potential managed re-alignment (552 hectares) over the course of the next 100 years, which are all likely to have adequate benefit-cost at the time of re-build.

4. The eleven key sites to focus on for managed re-alignment, in order of ranking are as follows: West Northney, Medmerry, Gillies, Farlington Marshes, North Common, Saltgrass Lane, Lymington Reedbeds, Pagham South, Stoke, Nutbourne, and West Wittering.

5. It will not be possible to balance habitat gains and losses within each Natura 2000 site apart from the Pagham Harbour SPA. A balance across a 'north Solent' scale is the most appropriate.

6. The near-balance of inter-tidal loss and gain across the north Solent is only achievable because of the huge potential habitat creation at Medmerry, potentially contributing around fifty percent of the 500 to 600 hectares required.

7. Based on the assumptions of this study, the north Solent would fall short of around 347 hectares of compensation land without the Medmerry site.

8. Recent national guidance has suggested that in the future, inter-tidal habitat created through NAI could, not only be used to offset the BAP target and help achieve the SSSI target but could mitigate or compensate for coastal squeeze under the Habitat Regulations. This study did not account for this.

9. Operating Authorities could seek to adopt some of the sites categorised as hold the line or NAI to offset any shortfall. Those sites that do not require secondary defences and are non-designated should be addressed first.

10. This study indicates that potential changes to management practice will result in a legal requirement to replace 407 hectares of freshwater habitat. Seventy-nine hectares are from potential re-alignment sites, sixteen hectares are from potential Operating Authorities NAI sites and 311 hectares are from potential private NAI sites. This requirement will not be an obligation for private landowners.

11. The cost of creating and maintaining new, designated freshwater habitat where existing habitat is subject to adverse effect from managed re-alignment requires much greater scrutiny within the SMP process. It is possible that the high cost of such a requirement could significantly alter the pattern of suggested managed re-alignments described in this study.

12. It can take up to fifty years to re-create designated freshwater habitat currently existing behind our seawalls. The fact that most of these sea walls may fail within fifty years puts this habitat at high risk in the Solent.

13. A substantial proportion (over sixty percent) of the defences fronting potential habitat creation sites are managed by private landowners.

14. The HPI and LiDAR and tidal elevation interpretation are complementary tools for assessing historical inter- tidal trends and future change. In addition, the LiDAR and tidal elevation interpretation was a good technique for identifying potential inter-tidal habitat creation areas.

15. A sensitivity analysis will be required for the North Solent SMP in line with new Government guidance on sea level rise, because the old guidance for 6mm per annum guidance was applied in this investigation.

16. The interview procedure with the local coastal managers provided a valuable collaborative exercise between Local Authorities, the EA, NE, County Councils and Harbour Authorities.

The SDCP project assigned sites to epochs on a site by site assessment to form a strategic approach to offsetting inter-tidal coastal squeeze. The potential managed re-alignment sites (552 hectares) maybe politically controversial, particularly with landowners and may not be fully realised until a much later date, if at all. Further investigation and discussion is required prior to re-alignment of these sites. Implications on the geomorphology and hydro-dynamics of estuaries and harbours will have to be considered.

Unless NAI sites can be used for mitigation or compensation, or additional funding is found to re-align sites that are hold the line, then there could be a shortfall of inter-tidal habitat creation in the north Solent. This is likely to be a particular problem, especially if certain sites identified for re-alignment are not implemented.

Findings from the SDCP and detail on individual potential sites will feed into the North Solent SMP. The SMP will decide whether sites are hold the line, managed re-alignment or NAI, and will test this with full public consultation. The SMP will therefore confirm the actual coastal squeeze losses. It is valuable to have a unified approach to offsetting coastal squeeze across not only the north Solent but the Isle of Wight also and between all Operating Authorities. The

EA southern RHCP will be the vehicle for delivery. Findings from the SDCP and Isle of Wight Mitigation Study will feed into the RHCP. It is important to recognise that this project has raised the administrative and political complexities of the Solent with national experts for the first time. As a consequence, the EA RHCP are involving Local Authorities for the first time.

Aside from the SMP process, this study has highlighted the top seven sites in the first epoch that require feasibility studies for realignment. Feasibility studies are underway for Medmerry and Farlington Marshes.

Findings from the SDCP are based on current environmental policies, which lack clarity and are frequently open to ambiguous interpretation. The set of rules applied to rank potential inter-tidal habitat creation sites into time epochs for potential re-alignment or NAI was based on a suite of assumptions that are subject to change.

The work has been undertaken by the key statutory authorities. However, this study has not involved any decision making on the part of any statutory authority. The options suggested in this study are there to facilitate future debate and decision making as part of the SMP process. No landowners or wider stakeholders have been consulted as part of the project. These views will be sought as part of the SMP process. The SMP process will integrate all aspects of sustainable development, social, economic as well as environmental, prior to any final decisions on coastal management being made.

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COASTAL HABITATS, CLIMATE CHANGE AND SPATIAL PLANNING: LESSONS FROM THE SOLENT REGION

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Abstract

Many EU Directives and national biodiversity legislation were written and instigated prior to the full recognition of potential climate change impacts. Compliance with these requirements may now be more difficult to achieve, particularly for coastal areas where the impacts of human pressures and sea-level rise combine. Spatial planning, by integrating biodiversity planning with other planning policies, aims to ensure the most efficient use of land by balancing these competing demands and exploring the wider possibilities of complying with relevant legislation.

To investigate the relative impacts of climate change and human use of low-lying, inter-tidal areas, four case studies in the Solent were used to illustrate potential future threats of several sea-level rise scenarios for mudflat, saltmarsh and coastal grazing marsh habitats over the 21st century. Management issues included constraints imposed by current and historic land use, land ownership, protected habitats and erosion. The results show that historic land use and management decisions have a major influence on the ability to 'maintain or enhance' current habitat areas. In many case study areas, by the 2080s, a loss in saltmarsh areas was found, and the predicted position of saltmarsh areas within the tidal frame was outside the geographic boundary of current designations. The highest losses were shown where historic land use decisions, development and artificial management have restricted the possibility for habitat migration. The lowest loss was exhibited where few defences had been constructed and forward thinking, long-term management decisions were being applied. While managed realignment on the local scale may create new saltmarsh areas, it would also destroy areas of designated grazing marsh. Consequently, planning decisions need to be made at a higher level, where a more strategic, long-term plan-based approach could address some of these issues. For example, by identifying habitats at risk and potential mitigation areas, compensation areas can be protected from development by 'land banking' and long-term management implemented to develop suitable habitat environments. However, although such areas can facilitate change and help to maintain the diversity of coastal habitats, they may not be able to sustain local habitat assemblages at the species level. Spatial planning would need to be integrated with shoreline management planning and soft engineering such as beneficial use of dredge spoil to maximise the future stock of coastal habitats, especially saltmarsh. This investigation has shown that to enable the most effective management of land for biodiversity, planning decisions need to be undertaken today. Equally as importantly, current biodiversity legislation may need to be revised in regard to the geographic boundaries of designated habitats and habitat value in order to achieve the maximum sustainable benefit for biodiversity in the light of climate change.

introduction

Spatial planning aims to integrate planning policies and ensure the most efficient use of land by balancing competing demands within the context of sustainable development, (ODPM, 2004) this includes consideration of national and international legislation for biodiversity. For example, the EC Habitats and Birds Directives require member states to designate areas of importance for particular habitats and species and either maintain or enhance these areas. The impact of climate change on the ability to achieve these requirements is a significant challenge for both shoreline management and the coastal spatial planning process.

Designated EC coastal habitats include saltmarshes and mudflats, maritime cliffs, sand dunes, vegetated shingle, coastal grazing marsh and saline lagoons which affords significant protection to these sites. However, in the Solent, saltmarsh is already declining and long-term sea-level rise and other climate changes such as more intense storms will exacerbate these losses, representing a major challenge for the 21st Century (Pethick, 1992; Burd, 1992; Lee, 2001; Richards et al., 2008). In addition, as the natural adaptation response to sea-level rise for coastal habitats is landward migration, these ecosystems are strongly influenced by anthropogenic impacts, particularly coastal defences (Nicholls and Wilson, 2001; Watkinson *et al.*, 2007). In the UK, as in many places, this has led to the phenomenon of coastal squeeze (Carpenter and Pye, 1994) and estimated losses of 100 hectares of saltmarsh every year (Pye and French, 1993). The setting back of coastal defences to more landward locations (managed realignment) is a recognised response to the loss of saltmarsh and mudflats (Environment Agency, 1999) and a recognition of the natural flood defence value of these habitats on low lying coasts (French, 1997). However this is often to the detriment of other designated habitats located landward of sea defences, such as coastal grazing marsh and saline lagoons.

This paper presents some of the findings from the coastal work package of the INTERREG IIIB funded BRANCH (Biodiversity Requires Adaptation in Northwest Europe to Climate Change) Project (Branch Partnership, 2007). This investigated the impact of sea-level rise on inter-tidal habitats and the issues this would raise for the planning process, including how planning decisions could aid the maintenance of coastal inter-tidal habitats.

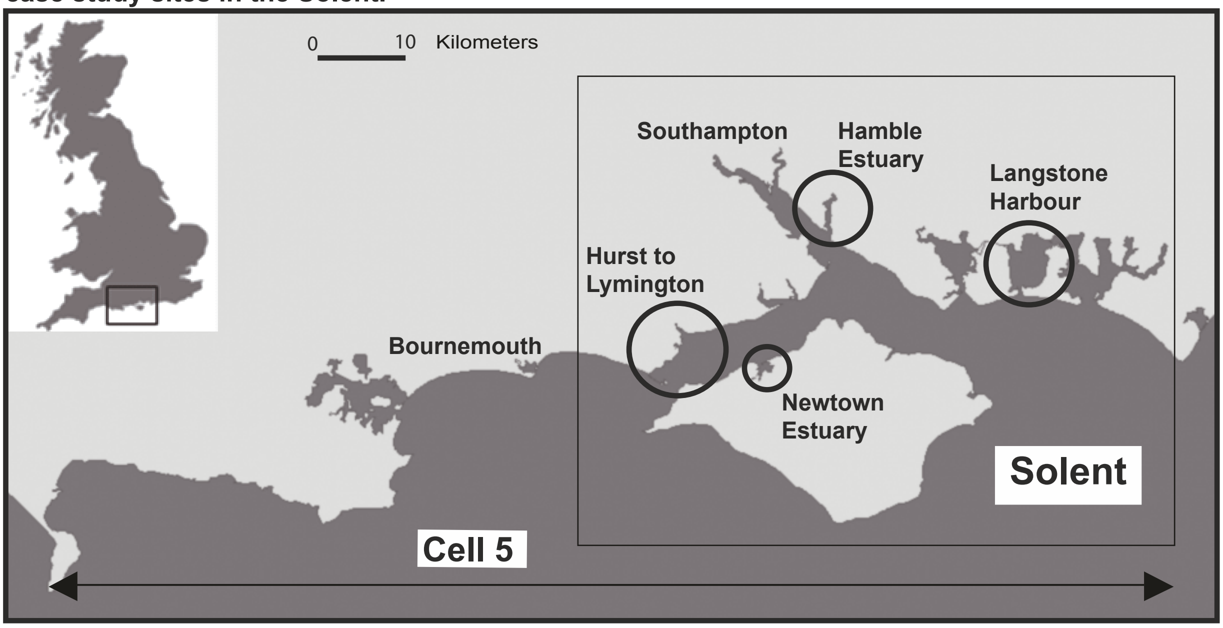
The Solent Region of the UK

UK sediment Cell 5 between Portland Bill and Selsey Bill (Figure 1), includes the Solent and Poole harbour areas, whose rich biodiversity value is reflected by its numerous designations under both national and international legislation. Designated habitats include un-vegetated mudflat, saltmarsh, coastal grazing marsh and saline lagoons which are closely linked to the dynamic spaces provided by natural changes in coastal plan form, elevation and gradient. They are also directly influenced by anthropogenic decisions (Watkinson *et al.,* 2007).

Importantly among these habitats are four major estuaries in the Solent, (see Figure 1) which illustrate the types of management issues common to this coast. Langstone Harbour and Hurst to Lymington are typified as coastal plain estuarine systems with relatively flat or gently sloping surroundings. The Newtown and Hamble estuaries are drowned valley estuaries and in places have steep sided areas. However the management at the two sites is quite different, the Hamble estuary accommodates marina development and although the upper Estuary is unspoilt the lower Estuary is heavily developed, while the Newtown estuary is a generally pristine location with little human intervention.

The rate of saltmarsh loss within Cell 5 is reported to be approximately thirty hectares per year. Stratigraphic studies have shown the formation of intertidal habitats to be linked to changes in the position of mean sea level. Morphological response is both by vertical accretion and by changes in lateral extent and position and is strongly linked to the availability of suitable sediments and accommodation space. Although the mechanisms of loss are not clear (Edwards, 2005; Royal Haskoning, 2004), sea-level rise is considered to be a primary driver. However it is recognised that other drivers, especially storms, waves and precipitation may be significant at the local level.

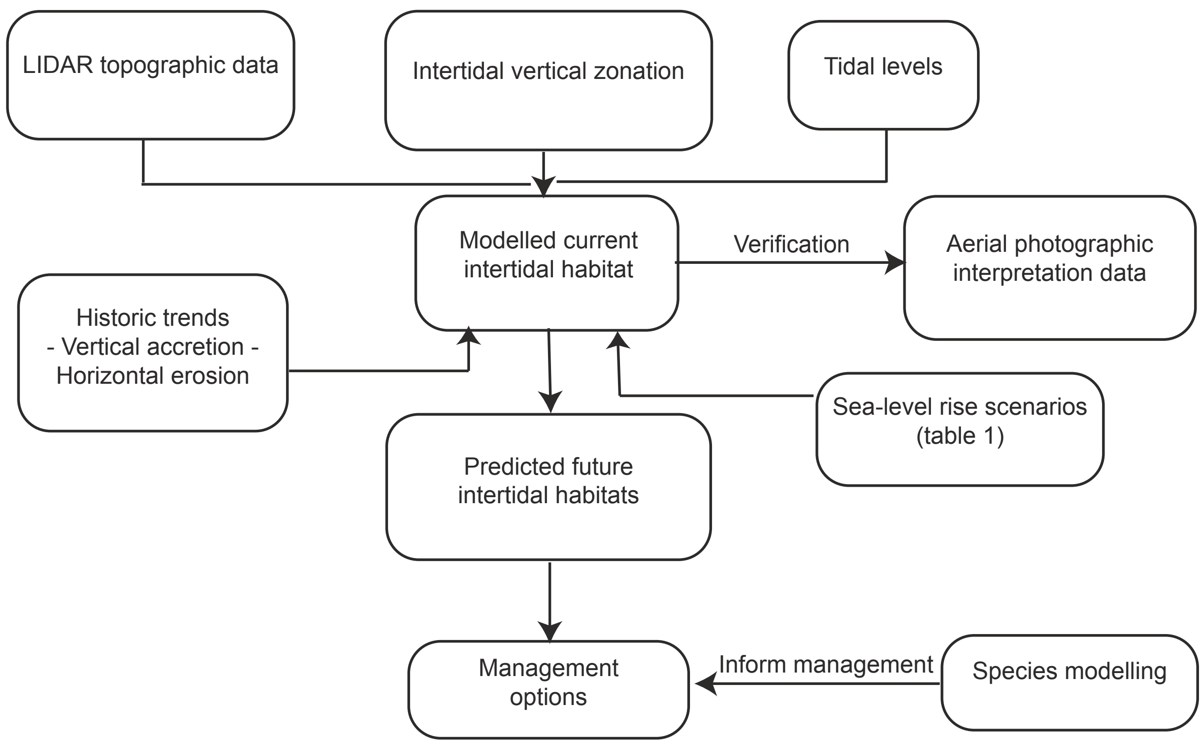
Figure 1. coastal cell 5 (DEFRA, 2006) from Selsey bill to portland bill and the four case study sites in the Solent.



Methodology

The methodology used to determine the current and future distribution of saltmarsh and inter-tidal flats is based on the recognition that elevation of the land relative to the tidal frame is considered to be the single most important factor in determining vegetation cover in inter-tidal areas (Burd *et al*., 1994). Figure 2 illustrates the steps and data used in the analysis which was undertaken within a GIS environment.

Figure 2. Flowchart illustrating the methodology to predict changes in intertidal habitats.



Establishing initial Habitat Extents

LIDAR (Light Detection and Ranging) data, supplied by the Environment Agency, was used to create a baseline topography. LIDAR has been previously used for intertidal habitat distribution, (e.g. Blott and Pye, 2004; Cope *et al*, 2007a, 2007b). Current tidal levels for the sites were then applied to the modelled topography and the distribution of intertidal habitats determined.

The accuracy of the modelled intertidal habitat distribution was verified for the base year by comparison with aerial photographic interpretation (API) using the Integrated Habitat System developed by the Somerset Environmental Records Centre (SERC) and field observations. This process indicated that areas of saltmarsh were over estimated in the modelling in all cases except in the Hamble Estuary. Variations in area of up to 18.3 percent were found. The differences arose mainly in the classification of pioneer saltmarsh (*Spartina anglica* and *Salicornia* spp.), where mudflats grade gently into areas that can be colonised by saltmarsh. Errors were also found in the API datasets, where algal mats and seaweed led to mis-classification, and in the modelling where local factors such as waves may restrict the colonisation of pioneer marsh at a higher level than mean high-water neaps. Limited tidal data also created differences as localised variations were overlooked.

Urban, industrial and archaeologically sensitive areas were identified using data supplied by Hampshire County Council, and a 'mask' created in order to remove these from the analysis and identify where such areas constrained realignment.

predicting Future Habitat Extents

c limate Scenarios

The climate scenarios used were modified from UKCIP02 (Hulme *et al*., 2002) and values reported by the IPCC 3rd Assessment (Church *et al*., 2001). Scenarios were developed for four emission scenarios (Low, Medium-Low, Medium-High and High) over three time periods (2020s, 2050s and 2080s), relative to a 1990s baseline. Annual rates of sea-level rise were calculated for each emission scenario between time slices, current-2020s, 2020s-2050s and

2050s-2080s (see Figure 3) using the values shown in Table 1. The low scenario is similar to current trends observed at the Portsmouth and Southampton tide gauges, while the higher scenarios represent a significant acceleration in the rate of sea-level rise of up to eight times or more for the high emissions. Using the full range of scenarios encompasses the full uncertainty and allows the BRANCH results to be reinterpreted as required: for instance, when the new DEFRA (2006b) sea-level rise guidance was published.

Habitat c hange predictions

Figure 3. Derivation of the sea levels for the 2080's.

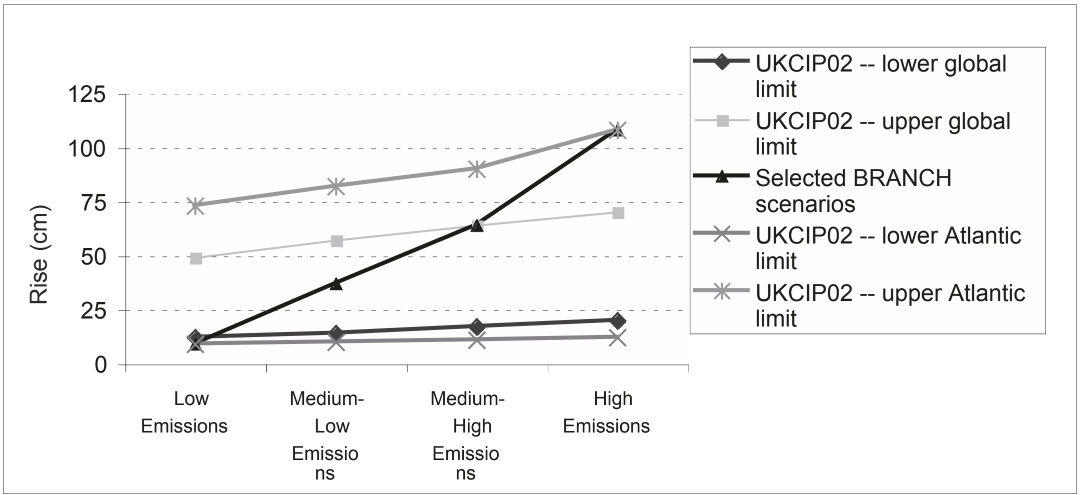


Table 1. Sea-level rise scenarios (relative to 1990) used in the analysis.

Time Scale	Sea-Level Rise							
	Low		Medium-Low		Medium-High		High	
	cm	cm/yr	cm	cm/yr	cm	cm/yr	cm	cm/yr
Current-2020s	4	0.11	11	0.31	16	0.46	23	0.66
2020s-2050s	3	0.1	12	0.4	19	0.63	34	1.13
2050s-2080s	2	0.07	14	0.47	29	0.97	51	1.7

Note: Shaded values represent scenarios of particular interest.

The distribution of intertidal habitats for each of the sea-level rise scenarios and time spans was modelled by adding the expected sea-level rise to the tidal parameters and re-analysing the initial topography. Observations of existing erosional/accretional trends were included in the analysis by modifying the original LIDAR data with accretion applied only to areas initially colonised by saltmarsh. Several values for both erosion and accretion were considered in order to explore the full range of possible future habitat distributions, taking higher and lower values from the literature available for individual sites.

Following the modelling of intertidal areas, the impact on other coastal habitats was assessed by evaluating the potential of a habitat to migrate or adapt in line with three possible future management/adaptation options: (i) the maintenance of the current defence line, (ii) a managed realignment involving the total removal of the current defences and (iii) a selected realignment of appropriate areas. Model outputs were produced as a series of images for each site showing intertidal habitats.

Regional-Scale Analysis Methodology (Selsey bill to portland bill)

A similar methodology was used at a broader scale to investigate the possibilities of developing a more strategic basis for management and planning decisions. The Environment Agency's one in 100 year flood-map (2006) was used as a basis to identify coastal and fluvial floodplain which could be suitable as mitigation/compensation areas. Unsuitable areas for habitat re-creation such as the location of urban and industrial developments and existing designated areas including current grazing marsh were excluded.

Results

case studies

The predicted changes in saltmarsh and inter-tidal flat areas for the medium-high scenario are shown in Table 2. There are distinct differences between the sites, mainly related to their management.

The Newtown Estuary (Figure 1), managed by the National Trust, shows an overall loss by the 2080s (Table 2). However, twenty-nine hectares of land would become saltmarsh as a consequence of natural migration, offsetting the potential impact of sea-level rise. With an accretion rate of 4mm/yr (see Table 2), current areas of saltmarsh will be able to maintain their elevation relative to the new sea level with a net gain predicted. Saltmarsh migration in the upper part of the Hamble Estuary (Figure 1) is also not constrained by development or infrastructure and under several scenarios could persist and colonise new intertidal areas. However, all migration predicted at the sites moves the habitats beyond their current designated boundaries. Figure 4 illustrates the change in area of intertidal habitat until the 2080s for the upper Hamble, with an increase in the total area of saltmarsh due to saltmarsh migration. However, in some areas steep valley sides prevent such migration and coastal squeeze of the saltmarsh occurs. It must be noted that landward migration will have a negative impact on terrestrial habitats, such as locally important areas of oak woodland, and private gardens.

Table 2. Losses and potential gains of saltmarsh by the 2080s for intertidal areas at case study sites for a medium-high sea-level rise scenario. (NA- not applicable)

Site name	Hurst-Lymington				Langstone		Newtown			Hamble	
Erosion (m/yr)	3		5		0.36		negligible			negligible	
Accretion (mm/yr)	0	3	0	3	1.45	2	0	2	4	0	3
Saltmarsh change from baseline extent (ha)	-183	-173	-184	-177	-37	-30	-71	-44	-22	-32	-14
Saltmarsh colonisation – natural migration (ha)	<1	<1	<1	<1	<1	<1	29	29	29	27	27
Net change saltmarsh	-183	-173	-184	-177	-37	-30	-41	-14	+8	-5	+13
Saltmarsh creation (current time) with managed realignment (ha)											
With land use constraints (ha)	80				119		NA			23	
Without land use constraints (ha)	92				325		NA			113	
Coastal grazing marsh lost through managed realignment (ha)	139				72		NA			16	

An additional factor, unique to the Hamble Estuary, is the large area of reed beds (*Phragmites australis*) occupying the transitional zone between the highest astronomical tide and MHWN. The interactions between these habitats appear to be quite complex, particularly with future climate change, and in some locations the reed beds appear to be colonising areas of the intertidal where saltmarsh would be expected. For the purposes of this modelling it was assumed that the reed beds would simply occupy the transitional zone, but there are many factors which could influence their distribution in the future.

In the Lower Hamble Estuary the presence of coastal defences restricts the potential for landward migration of the saltmarsh leading to coastal squeeze, with few opportunities for migration except into private gardens where this may in the future create land-use conflicts.

Figure 4. predicted change in intertidal habitat within the Upper Hamble under a Medium-High sea-level rise scenario (Modelled using 3mm/yr accretion, no erosion).

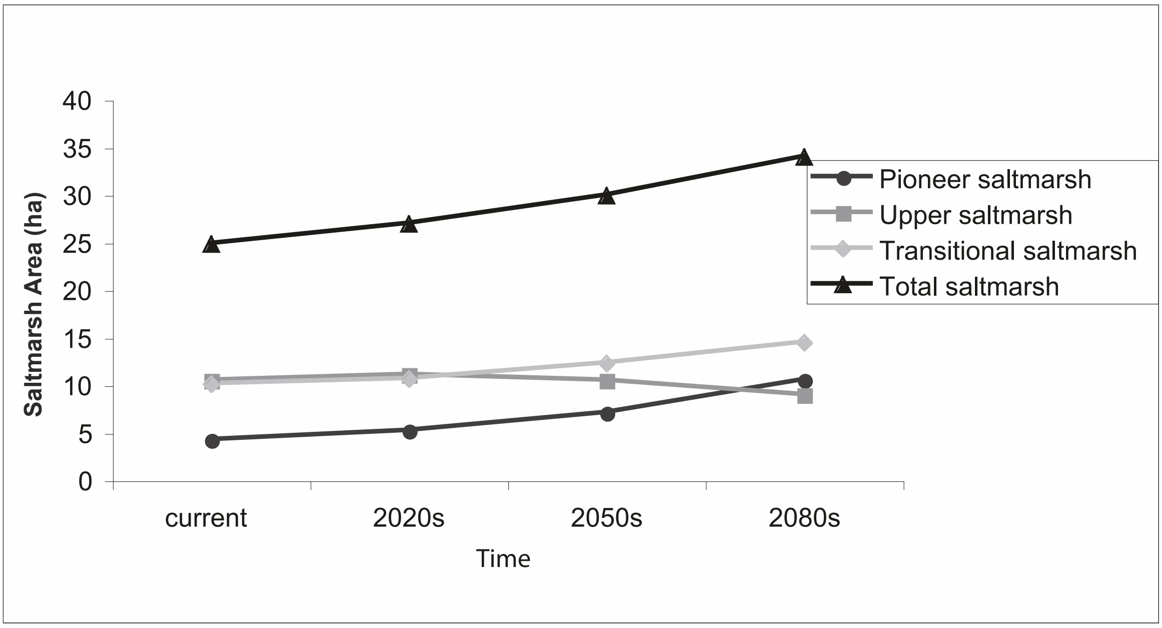
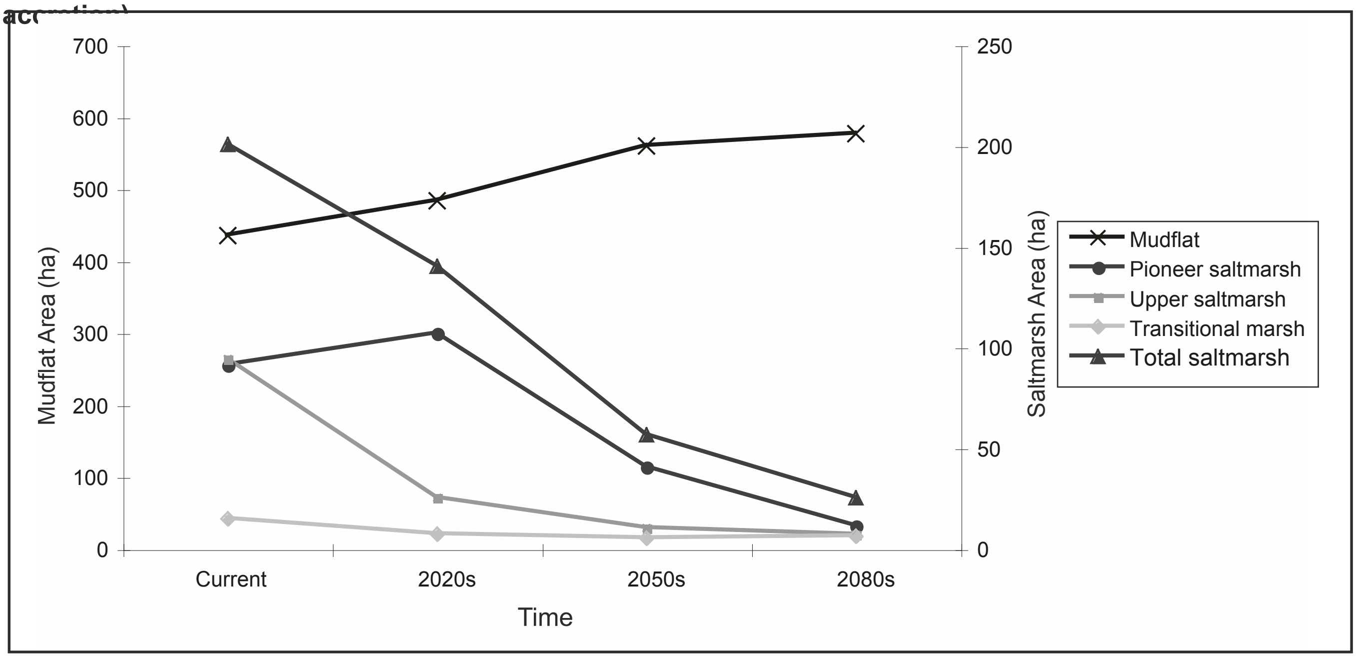


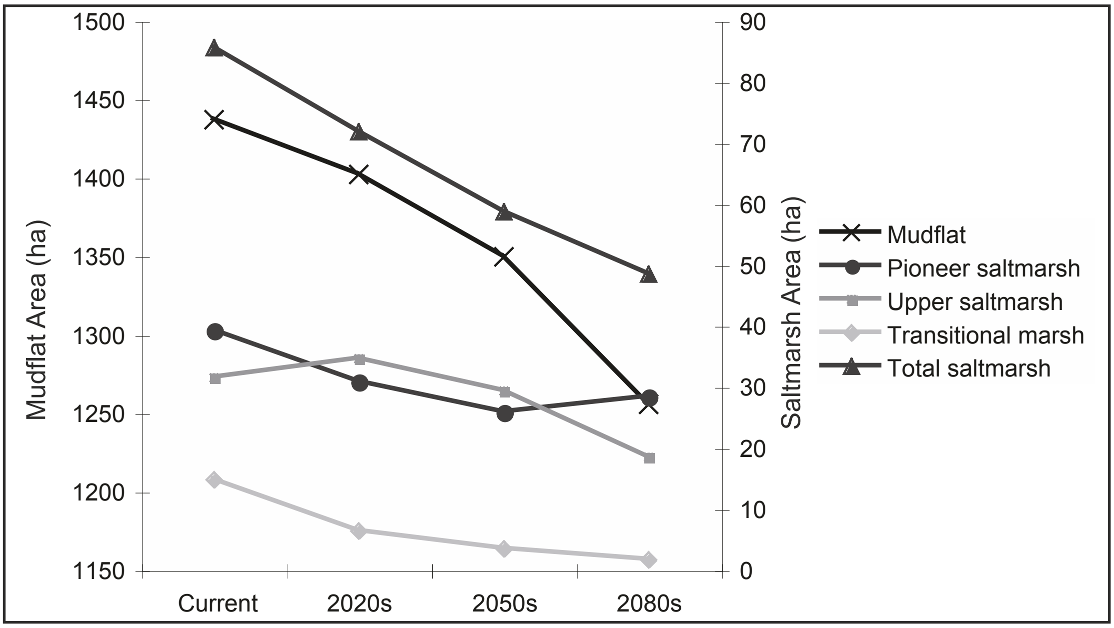
Figure 5. predicted change in intertidal area in the future with current defences maintained at Hurst-Lymington under a Medium-High sea-level rise scenario (Modelled using 3m/yr erosion and 3mm/yr accretion)



At the Hurst to Lymington site (Figure 1) by the 2080s under a medium-high emissions scenario, if the current defences are maintained, mudflat will be the only intertidal habitat present (Table 2 and Figure 5). This is due to the extensive local defences protecting large areas of low-lying grazing marsh.

Even with removal of the current coastal defences, modelling suggests that mudflats will remain the dominant habitat at Hurst-Lymington. This is because (i) the elevation of new intertidal areas formed by realignment will be too low to allow the development of saltmarsh and (ii) potential areas into which saltmarsh might migrate are occupied by landfill and urban areas in the coastal flood plain. Additionally, all designated coastal grazing marsh and saline lagoons, which should be maintained to comply with the Habitats Directive, would be lost if sea defences were realigned to more landward positions. Relocation is a potential option as these are largely artificially managed habitats, but opportunities are minimal within the site due to the competition from urban and industrial land use mentioned earlier.

Figure 6. predicted change in intertidal habitats with a Medium-High emissions sea-level rise scenario in Langstone Harbour (Modelled using 0.36m/yr erosion and 1.45mm/yr accretion).



For Langstone Harbour (Figure 1), where islands are particularly important for ground nesting birds such as the ringed plover (*Charadrius hiaticula*), all habitats decline by the 2080s (Figure 6). The short-term increase in upper/ mid saltmarsh in the 2020s is due to colonisation of small islands in the harbour, which are currently above highest astronomical tide.

However these are increasingly submerged as sea-level rises. Compensation areas are available within the Harbour area, the largest of which is Farlington Marshes. This is 120 hectares (300 acres) of previously reclaimed saltmarsh, protected by a low, 3.5km-long concrete seawall. However, in common with saltmarsh, it is designated under SSSI, SPA and Ramsar conventions and requires the same degree of consideration within the planning process.

Regional-scale results

The regional scale analysis indicated that future habitat extents are largely reliant on management decisions. If the current management policy is maintained, coastal grazing marsh and saline lagoons persist but intertidal mudflats and saltmarsh will decline. Initial results, added to those of the Solent Dynamic Coast project (Cope *et al*., 2007a) and the Isle of Wight Mitigation Strategy (Atkins, 2006), indicate that, under the current management policies, a total of 760 hectares of saltmarsh could be lost by the 2080s under a medium-high scenario within Cell 5. The use of managed realignment in coastal areas could sustain saltmarsh and mudflat habitats to some degree, but this would be at the expense of coastal grazing marsh. However, in non-coastal, fluvial flood plains, consisting mainly of agricultural land, the opportunity exists for potential compensatory habitat creation. At this scale of assessment, analysis of the 1:100 flood map suggests that ca, 21,000 hectares of fluvial floodplain could 'buffer' the losses of coastal grazing marsh (Figure 7) (Gardiner *et al*., 2007).

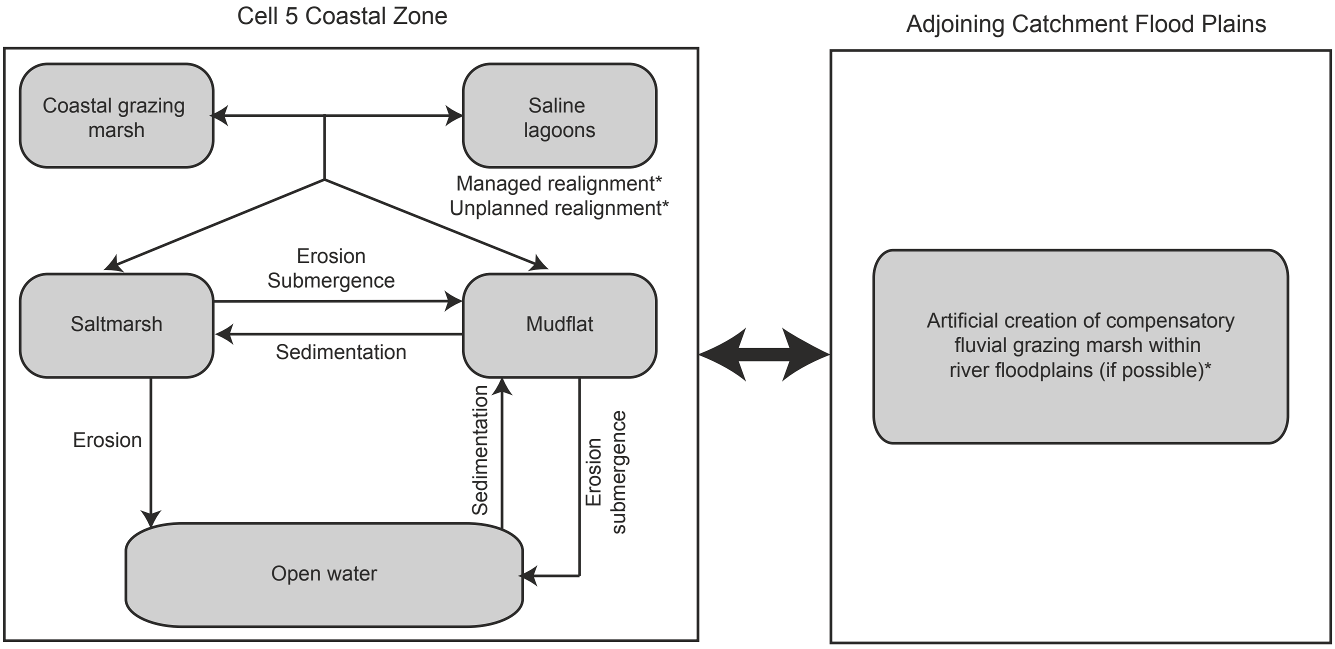
Discussion

The four Solent case studies indicate that, at a local level, a widespread regional decline in saltmarsh and mudflat area is likely by the 2080s with available migration space limited to a few locations such as the Upper Hamble and Newtown Estuaries. Local mitigation of these losses will largely be at the expense of managed realignment across coastal grazing marsh, so it depends on current and future shoreline management decisions.

Newtown Estuary, managed by the National Trust, illustrates many of the benefits of long-term forward planning. Extensive areas of largely agricultural land have been/are being purchased as 'land banks' to allow for long-term natural habitat migration. Consequently, most existing habitats will remain under all but the very high sea-level rise scenarios and importantly, given that sea-level rise will continue beyond 2100 (Nicholls and Lowe, 2006), an assemblage of saltmarsh and mudflats will persist at Newtown under any foreseeable sea-level scenario. This dynamic approach suggests the need for a new approach to designation as habitats will not be fixed in space.

The 'migration' approach is not feasible at the other local sites in the Solent due to significant land use constraints; intense development pressures and historic planning decisions have restricted the availability of accommodation

Figure 7. Habitat and process interactions which need to be considered when analysing coastal change. Those influenced by spatial planning are indicated by an asterisk.



space. As shown by the case studies, under most of the sea-level scenarios the majority of saltmarsh areas will have disappeared by the 2080s. In these cases, the extension of intertidal areas using managed realignment is frequently seen as an alternative method of maintaining stocks of saltmarsh and intertidal mudflats (French, 2001). Such managed realignment potential exists in either previously reclaimed areas or on 'new' areas which lie within the elevational criteria (Hodge and Johnson, 2007). The implication of managed realignment is that the habitats currently occupying these areas become 'at risk'. In historically reclaimed inter-tidal areas, largely occupied by coastal grazing marsh, existing habitats are often 'designated' under the EC Habitats Directive and are also required to be maintained, restored and improved. This creates a direct conflict and requires that either a choice in relative habitat importance is made or that alternative management strategies be investigated. The elevation of the grazing marsh areas also appears to be low to produce large areas of saltmarsh, at least initially. However, the large quantities of dredged spoil produced within Cell 5 could be used to increase intertidal elevations, counter erosional trends and encourage saltmarsh development (Bray *et al*., 2008). A trial in Poole Harbour commenced in May 2008, where spoil from maintenance dredges will be redistributed within the Harbour. However the protocols for such activities are still in the early stages of development (e.g. Nicholls *et al*., 2007b; Widdows *et al*., 2006) and the full benefits and drawbacks are yet to be determined.

An alternative approach is to adopt the long-term 'land banking' policy illustrated in the Newtown Estuary but at a Solent or even wider regional scale. Results from the Cell 5 investigation indicate that with managed realignment to maintain saltmarsh areas, the possibility exists of compensating for lost coastal grazing marsh with freshwater grazing marsh. However the decision to 'bank' these areas needs to be considered within today's planning process, in order to lessen future economic and development competition. There is also the issue that, along with the geographic restrictions discussed earlier, the current UK interpretation of the EC Habitats Directive lacks the flexibility to allow compensation from one habitat type to another. However, a more regional approach is not inconsistent with the spirit of the Habitats Directive.

c onclusions

The results of this project have highlighted several issues which need to be addressed when planning for biodiversity in the future. Firstly, it is important to recognise that coastal habitats are already changing due to a variety of climatic and human-related factors (coastal protection, dredging, reclamation, etc.) and these changes are expected to become more significant during the 21st Century. Secondly, the ability of coastal geomorphic and eco-systems to adapt has been and will continue to be, to a large degree, determined by human constraints which in the long term, planning can influence. In particular, that any mobile landform has the capacity to migrate beyond its designated boundaries has significant planning implications.

Looking at the regional analysis offers a broader view with a different perspective to localised planning issues and allows strategic choices to be made. This indicates a hierarchical structure within the planning process may be applicable, in this study local changes being seen within a regional context; the regional being seen in a national context and the national within a European context. The challenge in this case is to decide at which level relevant directives would be applied and decisions developed, coordinated and implemented. Whichever management policy or approach is adopted planning decisions must be decided over a long timescale. In the 21st century, coastal response to climate change is constrained by land use decisions made in the 19th and 20th centuries, and current land use decisions have the potential to influence coastal response for a similar period into the future. Recognition of the length of time required for a habitat to migrate or develop, particularly in areas which are being newly inhabited, also needs to be built into the planning process.

The adoption of new management techniques also has a role to play in the future management of biodiversity. For inter-tidal areas the beneficial use of dredged sediment is a relatively new approach which has planning implications both in terms of permissions and monitoring. An alternative strategy is creating habitats in a more sustainable environment which are comparable to those expected to decline. This would be consistent with Defra's (2005) 'Making Space for Water' Policy but would require further investigation to ensure that the integrity of the ecosystem is maintained.

Seen in this wider context, spatial planning has the capacity to 'land bank' sufficient space for habitat adaptation and promote planning decisions which enable the migration, dispersal and genetic exchange of wild species. Over the longer (100 year) term, this can maintain biodiversity while maintaining flexibility for planning policies. Importantly, this strategy could give more space for action at the coast by increasing the land area available for long-term realignment.

In conclusion, recognising that localised change is inevitable, planning decisions should be made in a wider context rather than in isolation. Prescriptive in consideration of these issues, the key recommendations are:

- Local decisions should be made within larger scale strategies;
- Flexibility should be built in to the planning process so that the impact of current decisions can be minimised in the future;
- Regulatory requirements and their implementation should be reassessed in light of the impacts of climate change.

Acknowledgements

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THE HABITATS DIRECTIVE AND PORT DEVELOPMENT

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introduction

It is understood and accepted by government, regulatory bodies and some non-governmental organisations (NGOs) that the ports industry will need to continue to adapt to changes in shipping practice, particularly the growth of containerisation. They also understand that shipping can have significant consequences for the promotion of sustainable distribution and reduction of carbon dioxide emissions. To be able to achieve this ports need to be able to do two things. Firstly, they need to make sure that existing sites are used in the most efficient way possible and secondly, where appropriate and where shipping needs demand, they need to expand. In the UK this expansion usually means the development of new riverside facilities to meet the needs of the larger ships associated with container transport. These statements are made against a background that recognises the enormous conservation value of estuaries and that habitat loss in estuaries has been going on for many years for a number of reasons and is still continuing. There have been ports all around the UK coast for many hundreds of years. Over the last two centuries particularly, there has been enormous development and this has largely been carried out regardless of the environment. Without significant changes to the way ports operate and grow, the UK is left with an insoluble issue, namely we need to expand port activity but how can this be done without environmental loss?

As a consequence, port development and port operations have become increasingly contentious from environmental points of view in recent years. This has resulted in some high profile incidents where the UK port industry has been seen as in conflict with the environment and environment protection organisations. This paper outlines Associated British Ports' developing approach to resolving both the issue of port development as environmentally contentious, and the subsequent perception which seeks to see the ports industry as 'anti-environment'. In so doing, it is based on the company's environmental policy that we 'will operate and grow in ways which contribute to sustainable development'. ABP has had transparent environmental policies in place for a number of years which were further enhanced as part of the company's approach to the development of its Corporate Social Responsibility (CSR) policies and practices while it traded as a PLC on the UK stock market. Although the company is now owned by private equity shareholders, these policies have been retained and strengthened as part of their objectives for the company. This is set out in detail in the company's first CSR reports, available on the company website at www.abports.co.uk. By definition doing this successfully means determining ways of meeting the requirements of the EU Habitats Directive.

The EU Habitats Directive

In 1992, the world's leaders attended the Earth Summit in Rio de Janeiro to agree a common approach to conserving our natural heritage. Under the Biodiversity Convention signed at Rio, they accepted responsibility for protecting their respective countries' wildlife, species and habitats.

In Europe, the European Union's Habitats Directive[1] meets the commitments made at Rio, giving Europe-wide protection to certain rare and threatened habitats, plants and animals, on land and at sea and built on the provisions of the Birds Directive[2]. The two Directives together require the establishment of a series of sites, the Natura 2000 series or network. The Natura 2000 network includes two types of area. A Special Area of Conservation (SAC) may be designated where the site supports certain rare, endangered or vulnerable species of plants or animals (other than birds) or if the area supports outstanding examples of habitats, characteristic of the region. If an area supports significant numbers of wild birds and their habitats it may become a Special Protection Area (SPA). Where the designated area includes sea or seashore, it is described as a 'European Marine Site'.

In the UK, the implementation of these Directives has been translated into UK legislation by 'The Conservation (Natural Habitats, &c.) Regulations 1994'. The Regulations came into force on 30 October, 1994. Provision for the earlier implementation of the Birds Directive was made through 'The Wildlife and Countryside Act 1981'. The UK Government decided that SPA sites will be formed from existing Sites of Special Scientific Interest[3] (SSSI). Further SPA's are proposed and new sites are being forwarded to Brussels as the consultation process on each site is completed.

[1] Council Directive 92/43/EEC on the conservation of natural habitats and wild fauna and flora, adopted on 21 May 1992.
[2] Council Directive 79/09/EEC on the conservation of wild birds, adopted on 2 April 1979.
[3] Network of sites notified under section 28 of the Wildlife and Countryside Act 1981.

Under Regulation 34, a management scheme for each site is intended to ensure that the management objectives[4] for the designated site are met and this is based on advice supplied by Natural England (or equivalent in Wales and Scotland) under Regulation 33. However, it is accepted that projects and plans will be dealt with through procedures set out in the Regulations. These introduce a number of important and yet poorly defined concepts: significance, site integrity, cumulative impact and adverse impact, each of which is discussed in more detail below.

Definitions

To date, there is little guidance as to how to assess whether or not a development 'is likely to have a significant effect'. Planning Policy Guidance Note (PPG) 9 suggests that a developer, taking advice from the conservation agency, should consider whether the effect of the proposal is likely to be significant in terms of the ecological objectives for which the site was designated. Experience to date is that when asked whether a scheme is likely to have a significant effect, the conservation agencies take a view based on the information provided.

Having determined that a project or plan is likely to have a significant effect, it is necessary to determine whether the scheme will adversely affect the integrity of the site. PPG 9 defines the integrity of the site as 'the coherence of its ecological structure and function, across its whole area, that enables it to sustain the habitat, complex of habitats and/or the levels of populations for which it was classified'. Where a scheme is likely to have a significant effect, an appropriate assessment is required to examine the likely implications for the site in the context of the site's conservation objectives.

In Hull for example, the port sought a MAFF FEPA licence[5] to promote the Queen Elizabeth Dock reclamation scheme. This was initially granted and then withdrawn upon the enactment of the Habitats Regulations and an appropriate assessment was requested. Consultants were employed to carry out the assessment. Midway through the proposal for a development, called Quay 2005, Natural England raised the question of the combined impact of the two schemes. It was noted that the port also had the powers to construct two further riverside terminals. A cumulative impact assessment to include all these works was therefore initiated.

This is perhaps one of the most difficult issues to address. The Directive applies the question of likely significant effect to projects or plans 'either alone or in combination with other plans or projects'. Even though this issue has been recognised for some years, there is, as yet, little guidance on either the procedural basis for determining what should be included in such an assessment, or how many of the issues which arise should be handled, given the limits to current scientific understanding. To date, focus has been on the scope of any such assessment and developing ways of addressing the cumulative impacts on estuary morphology and, to a lesser degree, how to deal with the issue of loss of habitat and attendant displacement of bird populations.

Regulatory Aspects of port Development

There is a problem. What is fundamentally clear is that it is now widely understood within the UK that the regulatory process, and the number of consents required in order to facilitate port development, is enormously complex and overlapping across many areas of the legal framework. All of the needs for these consents must be addressed in port development project planning, but the two which are significantly the most demanding are the Harbours Act, 1964 which requires Harbour Revision Orders (HRO) approved by the Department for Transport, and the EU Habitats Directive. Within UK law, a single objection to a Harbour Revision Order requires government to seek a public inquiry for any development. By definition, such an approach is adversarial and, if lodged on environmental grounds, means that environmental issues must be debated in wholly legal terms; this contrasts with the nature of ecology as a discipline and how the results of ecological studies are interpreted.

Consequently, the approach that ABP has taken in developing port expansion plans in the last two years has centred around both the need to satisfy the Habitats Directive and the need to satisfy the requirements of the Harbour Revision Order at the same time. Clearly, the Harbour Revision Order is dependent on the approach taken to meet the needs of the Habitats Directive. But the outcome that we aim to seek is one which avoids a public inquiry and therefore, by definition, involves the removal of objections to the Harbour Revision Order. Before describing this process in detail, a further principle needs discussion. As described above, it is widely understood that the Habitats Directive requires assessment of environmental impacts to determine whether any development is likely to have a significant effect on a European site. If this is the case, or it cannot be proven that it is not the case, the Competent Authority is obliged to prepare an appropriate assessment and determine whether the development is likely to have an adverse impact.

[4] These are to be proposed by the relevant conservation agency and agreed by the management group of relevant authorities.
[5] Food and Environment Protection Act licence required for construction below high water.

A major potential source of conflict therefore arises at this juncture. If a port development is deemed to have no likely significant impact by the developer, and this view is not held by the regulatory bodies, further discussion will, by necessity, be on the basis of presenting evidence on both the sides of a serious conflict of opinion. ABP's stance therefore, in the first instance, has been based on resolving, through discussion, whether the development is likely to have significant impact or not. The examples used below describe two cases where adverse impact was identified and one where no likely significant effect was agreed.

ABP's Approach and the Role of Meaningful c onsultation

Taking all the above into account, ABP's approach is therefore summarised as follows and based on the requirements set out in Regulations 48-53:

- Preparation of environmental assessment based on a range of development options.
- Identification of environmental impacts of the scheme in terms of both straightforward ecology and impacts on favourable conservation status of European Marine Sites.
- Decision on likely significant impact and potential adverse impact.
- Use of information based on a full understanding of impacts to determine the needs of compensation and therefore how this information can be used to identify potential compensation options.
- Use of information about wider coastal management issues which may affect decisions on appropriate compensation.
- Production of Imperative Reasons for Overriding Public Interest, IROPI, case.
- Identification and discussion on compensation objectives and possible options.
- Identification of a preferred option which fully addresses the impacts of the scheme and which therefore meets the needs of the compensatory habitat as interpreted through the Habitats Directive.
- Construction of compensatory habitat.
- Monitoring of compensatory habitat to determine how successful they have been in delivering the objectives of the compensation needs.

Central to the above process of complying with the Habitats Directive is the principle that none of this work can be done in isolation by the developer. In other words, for the above process to be successful, it is absolutely essential that from the very outset all of these issues, including the need to determine likely significant effect, are fully discussed with regulatory bodies and appropriate non-governmental organisations such as the RSPB. Experience in the UK in other spheres of activity (such as coastal flood defence) has consistently demonstrated that the only truly successful route to both achieving developments and fully meeting the needs of environmental regulation requires full consultation with environmental bodies. Further, consultation is not only carried out on the basis of supplying information, but it is also designed in ways which ensure that consultees are fully involved and that they all have the opportunity to influence the decision and design processes. This fundamental principle is quite simply the most significant driver in ensuring that port developments can be achieved and that they can be achieved without resorting to adversarial processes such as public inquiries. It is also based on the understanding that environmental bodies, such as Natural England and RSPB, recognise and understand that the Habitats Directive does not impose a moratorium on development but that it seeks to ensure that developments do not adversely effect the integrity of European sites.

immingham Outer Harbour and Quay 2005

Two schemes are planned for ABP's ports in the Humber Estuary at Immingham and Hull, respectively. The first scheme will provide an Outer Harbour on the South bank of the Humber creating Ro/Ro berths to meet the urgent requirements of shippers in the estuary. Quay 2005 comprises the reclamation and re-use of 7.5 hectares of old jetties on the North bank of the Humber at Hull and also provides increased riverside facilities for larger ships. Both schemes have been in the planning process for a number of years (Quay 2005 was originally known as Quay 2000!). However, significant progress on environmental issues was only possible once consensus had been reached with all parties on the issue of likely significant effect. Following extensive environmental assessment, and full consultation on the approach and findings of these assessments, a consensus decision was reached that Quay 2005 with mitigation would not have any likely significant effect but that Immingham Outer Harbour would have and that it should be seen as adverse. This is largely because Immingham Outer Harbour will remove 22.5 hectares of mudflat from the estuary and, even though this is currently outside the designated European Marine Sites, it is not possible to prove that it will not adversely affect them.

These decisions were, and remain, pivotal to the whole approach of working together, allowing, through subsequent discussion, ABP and environmental bodies to meet each of the bullet points described above. As a consequence, ABP is currently preparing designs of a reduced number of options which provide compensatory habitat at two sites within the estuary. The first of these, on the North bank, will create fifty-five hectares of intertidal habitat including saltmarsh and mudflat. The second area, at Chowderness, on the South bank, will create 12.5 hectares of mudflat and other intertidal habitat. The closure of a sluice, which discharges fresh water from the River Freshney in Grimsby, will lead to the restoration of a further four hectares of intertidal mudflat on the South bank of the estuary. Individually, and together, the three components of this compensation package match both the impacts of the schemes and create additional habitat for the overall estuary. For that reason they also meet the two key objectives for compensatory habitats which were identified, again through extensive discussion at the outset of the process:

- Firstly, that the compensatory habitats must meet the needs of the Habitats Directive, and how these are interpreted to set the design parameters for compensation habitat. In the case of Immingham Outer Harbour, this therefore requires a minimum of 25.5 hectares of mudflat to provide appropriate habitat for the birds, such as Black-tailed Godwits, which would be displaced as a result of the development.
- The compensatory habitats should also contribute to the longer term sustainable management of the estuary which is a shared objective not just of the environment bodies, but also of ABP as a company, whose policy is to contribute to sustainable development.

Therefore, the final design for the compensatory measures was undertaken within the framework for sustainable estuary management set out in the UK under the Environment Agency's Humber Estuary Shoreline Management Plan. This was developed to set out long-term sustainable management for the extensive flood defences which have been constructed along much of the Humber Estuary shoreline, and was designed to accommodate the dynamic nature of the estuary.

The HRO and the Habitats Directive

The current state of this work is that ABP is seeking guidance from environmental bodies on a number of design options for the works and whether we can achieve consensus on a preferred option. However, to meet the needs of the legislative framework described above, it is also essential that the conundrum provided by the relationship of the Harbour Revision Order and the Habitats Directive is also resolved. As stated earlier, if there is an objection to the Harbour Revision Order there must be a public inquiry. The conservation bodies will not withdraw their objections without confirmation that all compensatory measures will be undertaken. As a consequence a stalemate is reached with the result that the only possible outcome is a public inquiry. To remain meaningful, the consultation process must include the avoidance of a public inquiry as one of its objectives if possible and if only conservation bodies object. What is also clear is that this is a legal, rather than environmental, issue and that therefore it is logical that legal means should be used to resolve it. This is provided by the preparation of legal agreements which commit ABP to deliver the compensatory measures regardless of conditions associated with the granting of a Harbour Revision Order. It should, however, be emphasised that the UK Department for Transport emphasises that it is extremely unlikely that they would ever grant a Harbour Revision Order without conditions, if those conditions had been discussed and agreed with relevant bodies prior to determination. In other words, the provision of legal agreements between developer and conservation bodies provides a 'belt and braces' approach.

ipswich Turning c ircle

This is a smaller scheme which involves creating a turning circle in the upper reaches of the Orwell estuary to facilitate ships turning without resorting to complicated manoeuvring in a busy part of the river. The scheme involves dredging mud adjacent to the main channel and will remove about three hectares of mudflat. Initial environmental assessment and consultation suggested that the work which is outside, but close to, a European site would not have an adverse impact. However, as studies went on, this view was amended to the safer position that it was difficult to demonstrate that the work would not have a significant impact. An IROPI case has been prepared and compensation works include the development of a small managed retreat site immediately downstream of the site. This scheme will restore a meander which was previously lost through reclamation of land as well as create some four hectares of intertidal mud and saltmarsh. In addition, because the scheme will link in with Environment Agency flood defences, we will also be constructing flood defences at the back of the scheme which contribute to the Agency's own long term flood defence strategy for Ipswich, thereby saving public expense.

c onclusions

We may, for the moment, continue to be able obtain approvals on a piecemeal basis. Indeed this may be the only possible approach at present, given the uncertainties associated with the Directive. We must however anticipate the eventuality that, in due course, we may be required to adopt a more strategic approach to our developments, or that we will reach a threshold and no more schemes will get approval. It is to be hoped that we can, in parallel, get agreement for a more strategic approach towards the provision of mitigation, or compensation. To do this means that we will need to work even more closely with organisations such as Natural England to identify mechanisms whereby port operation and development are built in as a constructive part of the Management Schemes required under the Directive. It is fair to say at this stage that, while there are as yet no concrete proposals, there is at least dialogue. Along with significant changes taking place in coastal management and flood defence there has never been a better opportunity for such innovative and truly collaborative thinking.

Fundamental to any success is the need to work closely and constructively with all environmental interests, statutory and non-statutory, to identify shared objectives for the work and to plan all of it within the context of holistic and long term sustainable management for estuaries.

SALTMARSH RESTORATION AND HABITAT CREATION: ENVIRONMENT AGENCY'S PERSPECTIVE

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introduction

The Humber flood risk management strategy[1] is an approach to flood risk management on a comparable scale to that of the Solent. It has developed a strategic approach to the restoration and creation of saltmarshes and other habitats, especially to address the impacts of coastal squeeze. It is useful to assess some of the factors that have influenced the development of the strategy and how these might compare to the situation in the Solent. Such a comparison may provide a helpful steer on the way forward for delivering sustainable flood risk management solutions in the Solent. The Humber strategy can be accessed at www.environment-agency.gov.uk/regions/northeast/411697/1315425/.

This paper remains work in progress (and probably always will). It makes observations about the situation in the Humber and the Solent. It is designed to stimulate a debate about the best way forward for the provision of sustainable flood and coastal erosion risk management in the Solent. These are the personal views of the author and does not in any way necessarily represent the Environment Agency's views or position.

A brief comparison between the Humber and the Solent

The Humber	The Solent
Approximately 90,000 hectares of land around the Humber is at risk of flooding from a storm surge in the North Sea.	Area of land at risk around the Solent approximately 223.7 square kilometres.
Nearly 400,000 people living near the estuary are at risk of tidal flooding.	Number of people at risk from tidal flooding in the Solent is approximately 25,000 (if there were no defences).
A significant proportion of those living around the estuary (not necessarily at risk of tidal flooding) live in a small number of conurbations - 331,000 living in Hull and Grimsby.	Solent is heavily populated with over 821,000 people living within the 2001 census areas of Southampton, Eastleigh, Fareham, Gosport, Havant and Portsmouth (not necessarily at risk of tidal flooding).
More than eighty-five percent of the land at risk from tidal flooding is agricultural.	A significant amount of the land at risk of tidal flooding around the Solent is urban.
Pattern of land ownership - some large areas are in single ownership (but possible multiple tenancy) e.g. Sunk Island owned by the Crown Estate.	Complex pattern of land ownership. Some large areas in single ownership (MoD land in Hampshire in Fareham, Gosport, Portsea Island).
A large area of the Humber is designated as SPA and SAC. The vast majority of the area is intertidal with few areas of freshwater habitats included. The number of designations is low. See table 2 for more detail.	A large area of the Solent is designated as SPA and SAC. A significant area is intertidal/marine but there are also significant areas of freshwater habitats included. The number of designations is high. See table 2 for more detail.
Most of the designated interest is tide-wards of the flood defences with only small areas of brackish and freshwater habitats designated behind defences.	Significant areas of designated brackish and freshwater habitats behind sea defences which constrain opportunities for intertidal habitat creation.

[1] Environment Agency (2008) Planning for the rising tides: the Humber flood risk management strategy. Published March 2008.

The Humber continued..	The Solent continued..
There is 'space' to adjust to coastal change. In particular, to create new intertidal habitats on freshwater habitats (to replace those displaced) e.g. Alkborough (400 hectares +), Paull Holme Strays (80 hectares), Chowderness, Welwick, Donna Nook.	'Space' for creating new habitats highly constrained. Opportunities do exist but unlikely to be on the scale possible in the Humber.
Costs of acquiring land both for flood defence purposes and habitat creation is high but so far has not proved prohibitive.	Cost of acquiring land is extremely high and is already proving to be a major constraint.
Habitat being created in advance of 'need' so there is minimal delay in progressing appropriate flood risk management schemes.	Schemes have already suffered delays due to difficulties in securing required habitat creation as quickly as needed.
One single flood risk management strategy covers the whole of the estuary and performs the function of a Shoreline Management Plan. £325 million now approved for works over the next twenty-five years with £80 million to be invested in the next five to ten years.	Multiple flood and coastal erosion risk management strategies in the Solent. Current SMPs do not cover all intertidal areas. However, new generation of SMPs (e.g. N. Solent) will do in the future.
There are approximately 235 kilometres of raised flood defences in the Humber, of which about 182 kilometres (seventy-seven percent) are EA or largely EA managed. Approximately 52 kilometres are privately or mostly privately managed.	A significant proportion of raised flood defences around the Solent are managed by local authorities and other third parties.
At present, the defences provide a reasonable standard of protection but in fifty years, with no improvements, the standard for much of the estuary will become poor.	The standard of protection in places in the Solent is already poor, although some areas are protected to some degree such as Southampton, Portsea Island and Hayling Island.
Sea versus land levels rising currently at 1.8mm per year.	Current sea level vs land levels rising at a much higher rate than in the Humber (current Defra allowance is 4.0mm/year up to 2025).
An extremely good understanding of the geomorphology of the estuary not least due to data routinely collected by the ports industry and University.	An extremely good understanding of the geomorphology of the estuary not least due to data routinely collected by the ports industry, University and local authorities (e.g. Solent dynamic coast project).
Partnership approach involving local authorities, industry (e.g. ports), regional development agency, Natural England, NGOs.	Partnership approach being developed and includes local authorities, NGOs and Natural England.

Table 2. SpA and SAc Designations in the Humber and Solent.			
Designation	Area (ha)	Designation	Area (ha)
Special protection Areas			
Humber Estuary SPA	37630.24	Pagham Harbour SPA	636.68
		Chichester & Langstone Harbours SPA	5810.03
		Portsmouth Harbour SPA	1248.77
		Solent & Southampton water SPA	5505.86
		Total	13201.34
Special Areas of c onservation			
Humber Estuary SAC	36657.15	Solent Maritime SAC	11325.09
		Solent & Isle of Wight lagoons SAC	36.24
		South Wight Maritime SAC	19862.71
		Total	31224.04

c onclusions

There are a number of factors that have helped ensure that the Humber Strategy is a success. These include a single plan strategic approach, relatively straightforward flood defence management arrangements, availability of (relatively) affordable land for making space for water, relatively simple site designation situation and a strong partnership approach. There are also a number of factors that are in common with the situation around the Solent. In particular, the geomorphology of both estuarine systems are well understood.

The approach to planning for the delivery of flood risk management in the Humber could provide a useful model for managing flood risk management in other large estuarine systems. However, it does not necessarily provide the whole solution. There are differences between the Humber and the Solent (and indeed other estuarine systems) which may prove critical. The impact of these (and other differences) need to be taken account of when developing a strategic approach to managing flood risk in the Solent.

Furthermore, there are a number of lessons that can be drawn from our experience in planning Humber flood defences, and we need to take account of these in the Solent. These include:

- The planning progress was too slow especially in the early years of strategy development.
- Too many policy issues had to be tackled within the project. Policy issues need to be identified and resolved at the outset before strategy development starts.
- The consultation process was not sufficiently focused particularly once implementation of strategy development had begun.
- Too few links were made with other big strategic projects (e.g. ports development). There was too little feedback to the wider organisation, and too little connection with operational Flood Risk Management teams.
- There was a lack of clarity about what the legal and policy drivers were and what they meant in practice in the context of the strategy (e.g. biodiversity obligations and targets).

CONSERVING DYNAMIC COASTLINES – TACKLING THE CHALLENGE

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The following is a summary of the talk given by Tim Collins at the Conference.

I lead on national policy for flood management and that is the main focus of my presentation. The Conference has heard about some of the practical aspects, but what is key to delivering solutions is an understanding of what policy mechanisms and directions are available to Natural England and the government.

Saltmarshes and all coastal habitats are dynamic, and living with that dynamic is a real challenge whether it is an accreting system or an eroding one. The Conference has heard a lot about losses in the Solent, but in Essex the on-going loss of saltmarsh is around fifty hectares per year; the UK loss is estimated to be 100 hectares annually. Habitat losses can impact on both wildlife interest and make flood management a challenge; if seawalls are undermined there is increased risk of flooding for people and properties. There is a shared interest in managing the system and conserving it for the future. It was suggested earlier that we should consider adopting a Dutch-style solution, such as reinforcing sea walls by armouring. However, in Essex one kilometre of seawall protects only twenty hectares of flood plain and spending the amounts of money necessary cannot be justified. The Environment Agency estimates that over fifty percent of seawalls in Essex are no longer economic to maintain. Their refurbishment would not be economic as the value of the assets they are protecting is much less than the cost of refurbishment.

Other mechanisms have been tried. For example, at Hamford Water in Essex, Thames barges were sunk in order to provide a wave-break to protect the saltmarsh and subsequently sand and shingle was placed along the line of the barges. However this material has rolled over and has buried some of the existing saltmarsh that it was intended to protect. Thus it has not worked in the way envisaged, but this reflects the dynamism of the environment. An alternative approach (as used, for example, in the Wadensee) would be to fence off blocks to help accretion of sediment, but the wattle fences used to capture sediment are underwater obstructions at high tide. Would this regimented landscape be acceptable in the Solent? In the Netherlands one kilometre of seawall protects significantly more land (tens of square kilometres) than in the UK as more than fifty percent of the country is below sea-level, and so they have a vested interest and have little option but to manage their coastline in robust ways. However, even the Netherlands is operating managed realignment in a few locations.

What is Natural England's approach to these issues? A key part of policy is that a strategic approach must be adopted. This is not the sole responsibility of Natural England. Any solution must be delivered in a holistic way and signed up to by all who are involved and have a direct interest, whether operating authorities or local communities. We have to recognise that coastal habitats (such as saltmarshes and sand dunes) are dynamic and will continue to change. We need to anticipate what might happen as a result of climate change, expecting rates of sea-level rise to increase as we go through the century. This needs to be addressed. Finally, we are committed to working with others to deliver sustainable solutions, not just operating authorities but also communities who have a vested interest. The strategic approach cannot be imposed but it has to be understood and signed up to by those whom it will impact upon.

The strategic approach to coastal management has been around for over fifteen years, initially with published guidance in relation to shoreline management plans from MAFF and more recently by Defra. Shoreline management plans and strategies are the key mechanism for taking relevant decisions. One of the things that came out of the first generation of shoreline management plans is that they did not understand the needs of wildlife habitats particularly well. As a result Defra, the Environment Agency and English Nature (now Natural England) undertook the Living with the Seas Project which was an EU funded initiative that looked at flood management in the context of the Habitat Regulations; it sought to address how the coast would change, looked at the changes in the long term, looked at options to meet future requirements and considered what monitoring would be necessary.

A number of plans were produced around the country, including the Solent. This was known as the Solent Coastal Habitat Management Plan (or Solent CHaMP), more recently this work has been developed further by the Solent Dynamic Coasts Project. However these are information documents to inform the strategic decision making process; they do NOT provide the strategic decisions themselves. These sit within the Shoreline Management Plan process which includes a consultative mechanism. One of the key reasons for choosing the Solent as a pilot CHaMP ten years ago was because we had the expectation that trying to conserve all the important wildlife sites in and around the Solent in situ was not going to be possible. One of the reasons is that a significant percentage of the land around the Solent is already developed and whilst it may, theoretically, be possible to identify areas where we can recreate lost inter-tidal habitats, delivering this aspiration through schemes that can achieve consent may not be realistic.

We may need to look more widely, at a regional or even national level, to secure the conservation of some of these important wildlife systems.

Flood management decisions need to be taken in the context of national policy, funding arrangements, strategic planning, information on coastal squeeze, and targets. Ten years ago Defra changed its flood risk management criteria so that there “must be no question of European sites being lost”. More recently Defra also produced guidance which sets out how operating authorities should address the issue of “coastal squeeze” and how they should assess flood management plans and projects and look at a strategic approach to compensation needs.

We now have a more strategic approach to shoreline management, with guidance which explicitly states that when drawing up shoreline management plans environmental needs must be taken into account. More recently government has shifted to a series of outcome measures in relation to flood management for operating authorities, such as the number of houses to which flood risk should be reduced. There are two environmental outcome measures; one relates to ensuring that Sites of Special Scientific Interest (SSSIs) are in good condition, (24,000 hectares) and the other to the creation of new habitat. This target requires that 300 hectares of inter-tidal habitat (mudflats and saltmarsh) should be created in the next three years.

Finally we must not forget that we are trying to create and maintain healthy ‘ecosystems’ that are great for wildlife, support prosperous communities and provide exciting, dynamic landscapes that we can all enjoy.

WALLASEA ISLAND WETLAND C REATION PROJ EC TS

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Abstract

Wallasea Island is a large area of historically reclaimed agricultural land that lies entirely within the flood plain between the Crouch and the Roach estuaries in Essex. The defences around the island have been identified as being at risk of unmanaged breaching and, as a result of this risk, the Environment Agency's Flood Management recommends that managed realignment is considered as a possible long-term policy for Wallasea. The Strategy highlights that, without intervention, natural breaching could lead to significant flooding of the island and adverse impacts on the hydrodynamics of the estuary and increased stress on estuary defences.

In response to a combination of the flood risk and the suitability of the site as an area for new coastal habitat creation (given its size, location, elevation and the lack of built development), Wallasea Island has been identified as a site for a range of coastal defence and habitat creation initiatives. This includes a completed large-scale managed realignment and new proposals for further habitat creation that will achieve a mix of coastal protection, socio-economic and environmental objectives. These are innovative schemes which illustrate the variety of coastal management options that are available on such a site.

The most significant completed project is the Defra-led managed realignment project which involved the creation of 115 hectares of new intertidal habitat and, for which, final breaching took place in July 2006. It represents one of the largest man-made coastal wetlands in Europe in terms of the amount of habitat created and in terms of the increase in water volume within the adjacent estuary (Crouch). This realignment followed on from, and linked with, an initial seawall construction project which was carried out by Wallasea Farms Ltd. which was undertaken to protect the farmland and infrastructure along the vulnerable north side of the island. The elevation of the island is ideal for mudflat creation and so, to also achieve the habitat creation and compensation targets for saltmarsh, this project included the large-scale importation of maintenance dredge arisings to raise land elevations to a suitable level.

A five year monitoring study is underway to accompany this project and to date the findings indicate that the changes to within-estuary flows arising from the increased tidal prism are of a relatively small-scale. They confirm the original predictions of the hydrodynamic modelling that informed the Environmental Impact Assessment and provide valuable lessons about the efficacy of implementing schemes of this size. Within the site, sediment accretion levels have been higher than predicted and its ecological development has been relatively rapid. Large numbers of overwintering birds were observed in the first two winters; there has been extensive colonisation by invertebrates and saltmarsh plants are growing well across the imported dredge sediments and in other suitable areas within the site.

In light of these findings, as well as experience of habitat creation and management elsewhere in the UK and abroad, the RSPB are proposing a further flood alleviation and coastal habitat creation initiative which (including associated mitigation measures) will cover most of the rest of the island. To achieve this the RSPB are developing an innovative design that is likely to include a combination of managed realignment and regulated tidal exchange techniques. The important aspect will be to ensure that the design meets the long-term flood management requirements for the estuary while also minimising the hydrodynamic effects on the system and the effects on other users of the estuaries.

The landowner (Wallasea Farms Ltd.) has also separately identified a novel multi-functional coastal defence, marina development and habitat creation project on this island. Currently in its feasibility phase, this scheme would involve the development of a new counter-wall that joins the western edge of the Defra realignment site and the construction of a new marina on land immediately adjacent.

Further details about these projects are presented in this paper which focuses on a detailed review of the practical aspects and lessons arising from the Defra realignment and the objectives of the RSPB scheme.

[1]This paper reproduces a previous paper prepared jointly for the Defra/EA Flood and Coastal Management Conference in July 2008 by Colin Scott, (ABPmer), Mark Dixon, and John Sharpe, (RSPB) and David Collins (ELM Environment and Planning). This proceeding paper has been slightly updated with new information obtained during subsequent surveys.

Wallasea island - c oastal Flood Risk and Site Suitability

Wallasea Island is a large area (approximately 800 hectares) of historically reclaimed agricultural land that lies at a relatively low tidal elevation (one metre above ODN) and entirely within the flood plain between the Crouch and the Roach Estuaries in Essex. The defences around the island have been identified as being at high risk of unmanaged breaching over the next twenty to fifty years.

The Environment Agency's Flood Risk Management Strategy for the Crouch and Roach estuaries (Environment Agency 2006) recommends managed realignment as the long-term flood management policy for Wallasea Island, subject to it being the most economically viable option and further assessment. The Strategy also highlights that, without intervention, natural breaching could lead to significant flooding of the island and adverse impacts on the hydrodynamics of the estuary and increased stress on the existing estuary defences.

In response to a combination of this flood risk and the suitability of the site as an area for new coastal habitat creation (given its size, location, elevation and the lack of built development), Wallasea Island has been identified as a site for a range of coastal defence and habitat creation initiatives. This includes a completed large-scale managed realignment and new pioneering designs for a landscape-scale realignment, a regulated tidal exchange project and for multiple benefit projects that achieve a mix of coastal defence, socio-economic and environmental objectives.

Together these innovative schemes (both past and future) represent an illustration of the variety of coastal management options that are available on such a site. They also provide a very good demonstration of how the lessons of past schemes can directly inform the application of future schemes so that progressive improvements in the quality, scale and functionality of such schemes are achieved. In summary therefore, the past and possible future initiatives on Wallasea Island and their core objectives are as follows:

- **The Defra managed realignment**. Completed in 2006, Defra worked with assistance from Wallasea Farms Ltd to extend the length of new counterwall and breach the existing sea walls to create a new managed realignment site in compensation for habitat losses at Lappel Bank and Fagbury Flats.
- **The RSpb Wallasea island Wild c oast project**. Currently in its development and assessment phase, the RSPB intend to create a very large area of new coastal wilderness including mudflats, saltmarsh, saline lagoons and brackish marsh. This will be designed to support nationally important breeding, wintering and passage bird assemblages and act as a major RSPB contribution to adapting to climate change on the coast as well as offsetting past losses of these coastal habitats.
- **A potential mixed use marina and managed realignment site**. Currently in its feasibility phase, Wallasea Farms Ltd are separately considering the potential for constructing a new counterwall that joins the western edge of the Defra realignment site and then constructing a new marina on land immediately adjacent.

Further details about these projects are presented below focusing on a detailed review of the practical aspects and lessons arising from the Defra realignment and objectives of the RSPB scheme.

The Defra Managed Realignment (completed in 2006)

introduction

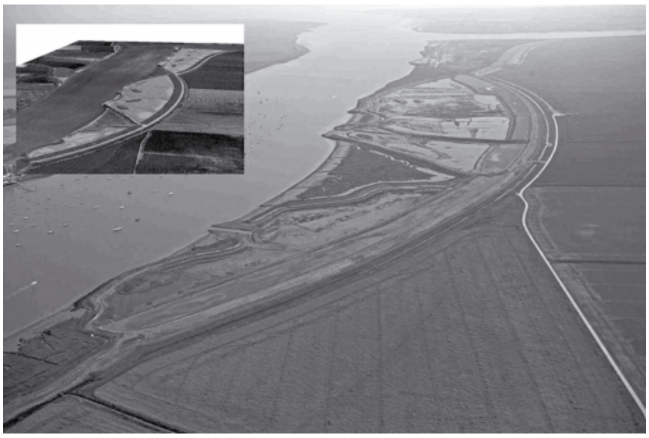
The construction work on the Wallasea Wetland Creation Project was completed in July 2006. It involved the creation, through managed realignment, of 115 hectares of new intertidal habitat on the north shore of Wallasea Island on the Crouch Estuary in Essex (Figure 1 and Plate 1). The site now represents one of the largest man-made coastal wetlands in Europe with the volume of water entering and leaving the site on each tide ranging from 790,000m^3 to 1,700,000m^3 on neap and spring tides respectively. This project was led throughout by the Department for Environment Food and Rural Affairs (Defra) Wildlife, Habitat and Biodiversity Division (formerly the European Wildlife Division). However, it also relied on the involvement of a large number of companies, organisations and individuals who each played major roles in its implementation.

Figure 1. Location of Wallasea island

project Objectives, c onsents and c onstruction

The aim of the Wallasea project was to create new mudflat and saltmarsh to compensate for losses of these two habitats (and the associated impacts on seabird species that used them) that occurred following port developments at Lappel Bank in the Medway Estuary and at Fagbury Flats in the Orwell Estuary (Figure 1). Following a comprehensive site selection exercise, which involved the consideration of over 200 potential sites across the Greater Thames Estuary Natural Area (GTENA), the north side of Wallasea Island was selected as the preferred site for this compensation for the following key reasons:

plate 1. Aerial view on day of final breaching (j uly 2006) with inset of the pre-breach g iS visualisation.



- It was big enough to provide the habitat needed (and therefore attract the large number of birds that had used the wetlands that had been destroyed).
- It was not going to cause damage to the surrounding estuary or adversely affect those who use it.
- It was going to improve the flood protection levels on the island in the short term and the whole estuary in the long term.

Following the completion of an Environmental Impact Assessment (EIA) to accompany this proposal in November 2004, all supporting licences and consents for the scheme were obtained in 2004. The final planning permission was awarded in February 2005 and a Works Licence from the Crouch Harbour Authority was granted in April 2005. Construction of the wetlands was completed on 4th July 2006 when, on the final day of breaching, 330 metre length of sea wall material was removed at three final breach points during a single seven hour tidal window (Plate 2). The works were funded by Defra at a cost of around £7.5m which included an extensive site investigation and selection programme as well as all legal, public consultation, monitoring and scheme build elements of the project.

plate 2. Final breaching work (8000m^3 of material removed during a seven hour tidal window).

plate 3. Dredged mud being pumped through a pipeline and into a retaining bund to settle out.

The landowner Wallasea Farms Ltd assisted throughout and was responsible for the submission of the Planning Application and, post construction, is responsible for maintaining the new sea walls. The site is currently managed by the RSPB on behalf of Defra.

The original scheme design for Wallasea was developed by Defra and this was then tested and refined by ABPmer who investigated how the site would function; what effects it would have on the Crouch and Roach Estuaries and what its environmental impacts would be. These studies were based on extensive surveys and numerical modelling work along with surveys of existing wildlife on the site (e.g. reptiles, water voles, invertebrates and birds). This information was used to inform the EIA. The modelling work allowed the site to be designed so that it had minimal impacts on the estuary. Faber Maunsell provided the engineering design for the construction of a new secondary sea wall which was set back from the existing sea defences by up to 400 metres. This new wall (Wall B) was an extension to one that had been designed by Faber Maunsell and constructed three years previously (Wall A) for the landowner (Wallasea Farms Ltd). The design used material that was sourced on site by the excavation of extensive shallow scrapes which after breaching were inundated by the incoming tide to create shallow lagoons once the existing sea defences were breached. Given the alignment of the new secondary walls, the site as a whole was separated into three discrete areas with no exchange of water flow between them so that it acts as three individual and contiguous realignment sites (Area A west, Area A east and Area B). The original design for the wetlands and the 2007 morphology are shown in Figures 2 and 3 respectively.

Figure 2. pre-breach schematic plan of new wetland habitat (2004).

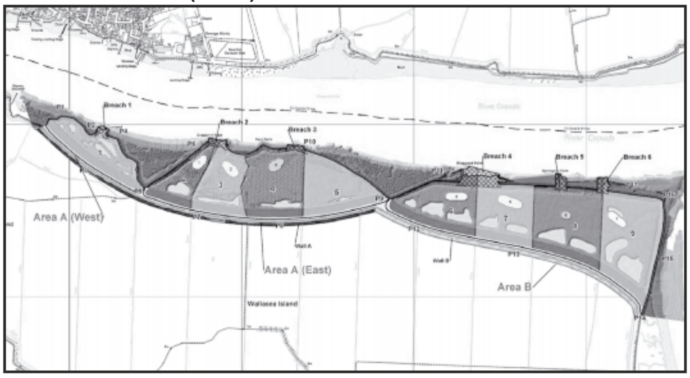
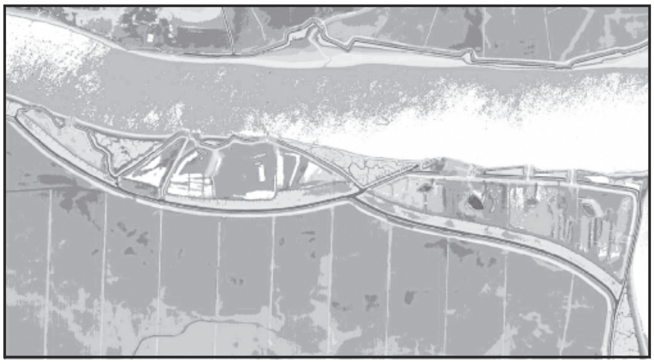


Figure 3. post-breach LiDAR elevation map (2007).



Site Development and Hydrodynamic Effects

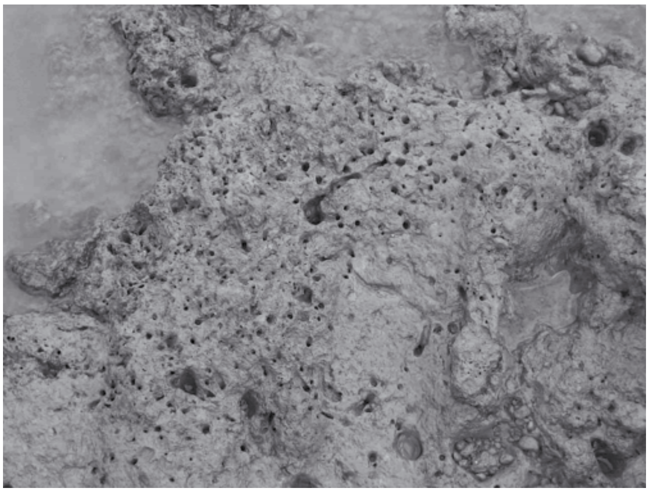
In less than two years, the site has already delivered many of the ecological functioning characteristics that it was designed for. In particular, it has shown very positive signs in terms of its likelihood of achieving its compensation targets (for habitats and birds) and has benefited several protected habitats and species. In this context it is notable that the designers of the site (Defra) gave consideration to delivering extra biodiversity value beyond the standard requirements of the compensation targets under the Habitats Regulations. Some of these were identified as the mitigation requirements within the EIA (e.g. to offset impacts to aquatic invertebrates and water vole from the land flooding) while others are extra features designed to maximise ecological value and biodiversity. To determine how the site develops and verify the effects of the increased water volume in the estuary a five-year monitoring programme is underway and the results for the first year after breaching (2006/07) have been reviewed (Jacobs/ABPmer 2008) and are summarised below along with some extra unpublished information from surveys undertaken in the 2007/2008 period.

Estuary Hydrodynamics: The flow monitoring work has, overall, confirmed the findings of the original hydrodynamic modelling work which concluded that any changes would be small in scale and are not expected to have any perceptible effect on the estuary flows and morphology. However, further studies will be carried out including surveys of the shape of the estuary channel and of the shoreline habitats to confirm that there have been no significant adverse effects on the features from the extra volumes of water now entering and leaving the estuary.

Mudflat Habitat: The majority of Wallasea Island, and thus the area within the new realignment site, is at an elevation half way between Mean Low Water and Mean High Water Neap and was thus ideal for mudflat development. Monitoring has demonstrated that this new mudflat is already functioning and is already productive in terms of the invertebrate and fish species that it supports (Plates 4 and 5).

plate 4. Mudflat habitat and natural creeks formed within Area b (October 2007).

plate 5. Area of exposed clay with dense piddock holes (October 2007).



Saltmarsh Habitat: Given the low lying nature of Wallasea Island, a band of elevated land was created in front of the new walls to create an area of saltmarsh. This was done by importing dredged sediment materials and discharging these between the secondary sea walls and a retaining bund at the back of the site to a level around the Mean High Water Spring (Plates 3 and 6). By October 2007 there was around a five percent covering of mainly Glasswort/Samphire as indicated in Plates 7 and 8. By August 2008 (two years after the breaching) there had been a substantial increase in the coverage of saltmarsh plants to around seventy percent of the recharge area (Plate 9). Saltmarsh plant species were also widely distributed across other suitably elevated areas, such as the berms

plate 6. Area of recharge sediment before breaching (May 2006).

plate 7. Saltmarsh plants (mainly Samphire) growing across recharge (October 2007).

plate 8. Saltmarsh plants (mainly Samphire) growing across recharge (October 2007).

plate 9. Saltmarsh plants growing across recharge after two years (August 2008).

plate 10. Diverse saltmarsh plants on bund in Area A3 (October 2007).

plate 11. Diverse saltmarsh plants on bund in Area A3 (August 2008).

behind the old seawall and internal bunds, that were present in-situ prior to the development (Plates 10 and 11). After two years, the emerging saltmarshes were dominated, as expected, by Salicornia spp. but there was also good coverage of *Suaeda maritima* and most of the species that are present in the mature saltmarshes outside the site were recorded inside the site.

Overwintering waterbirds: The site is primarily designed to provide feeding and roosting habitat for wildfowl and waders and during the first winter after the breaching fifty-five different bird species were recorded at peak abundances of between 2000 and 4000 birds. Throughout the first winter most of the birds were roosting rather than feeding and by January 2007 the birds recorded represented seventy-one percent and twenty-two percent of the compensation targets for roosting and feeding birds respectively. All the main compensation target indicator species were present in the first winter. By the end of the second winter (March 2008) a total of sixty-three different species had been recorded and the abundance of waterbirds reached in excess of 8000 on one occasion. With the increases in bird abundance between the first and second winter there was an increase in the numbers that were recorded feeding (about 600 in January 2007 to over 1000 in January 2008) but interestingly the proportion of birds feeding remained the same between the two years (at around twenty percent of all those present).

protected species: In addition to the habitats and birds described above, the creation of which are the core design elements of the project, the site and its mitigation habitats have also been found to support the following protected species and features of interest over the first two years: breeding birds, terrestrial and aquatic insects, otters, water vole, brown hare and adders. Many of these occur around the new borrow-dyke habitat to landward of the new seawalls which was specifically designed to be morphologically complex in order to maximise its ecological diversity (Plates 12 and 13).

plate 12. borrow dyke behind Wall b during construction (August 2004).

plate 13. borrow dyke behind Wall b after realignment (October 2007).

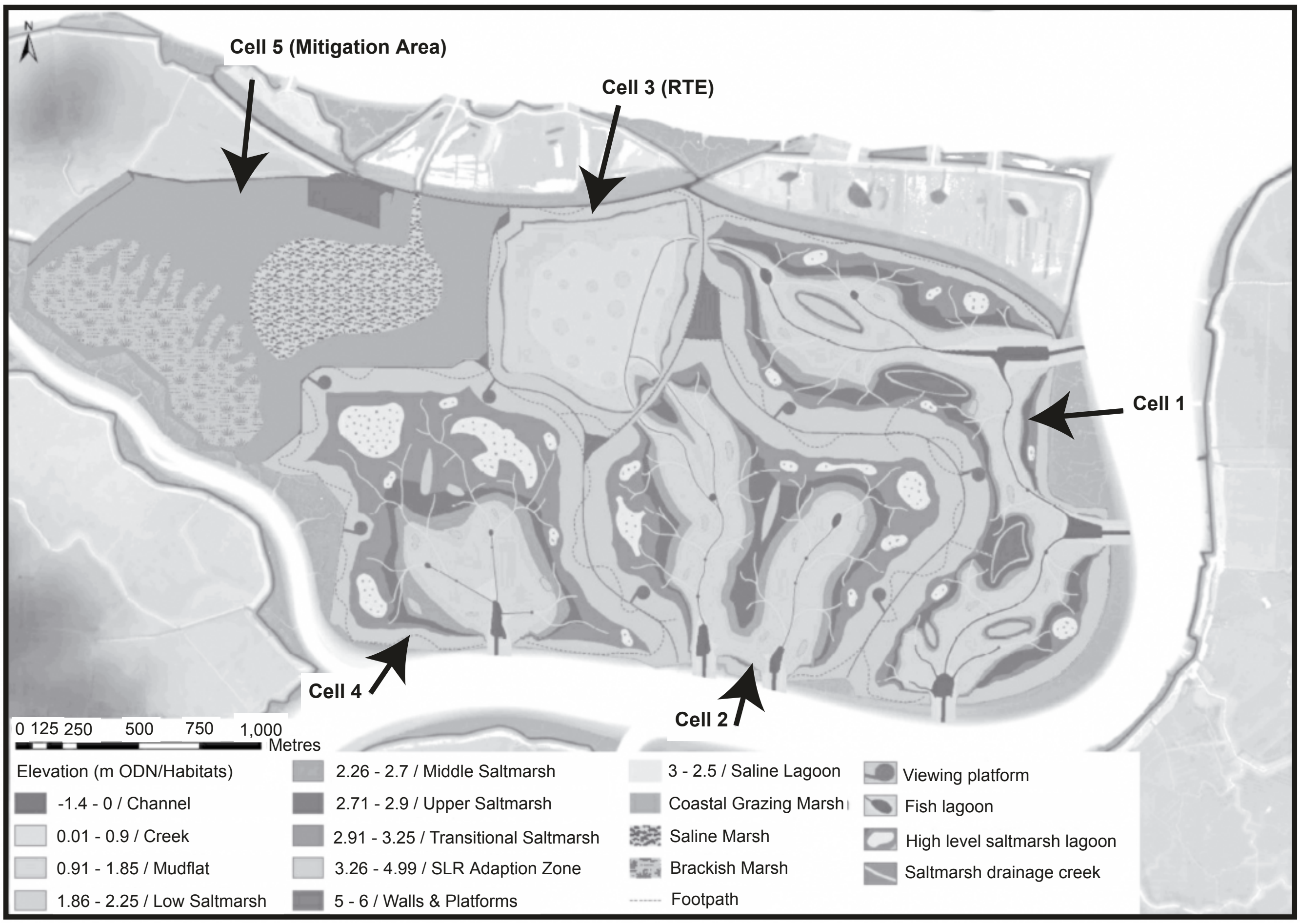
The RSpb Wallasea island Wild coast project

In response to the combined flood protection needs at Wallasea as well as the positive ecological developments that have been observed following the Defra Scheme, the RSPB believes that the remainder of the island can be used to create a wilderness of mudflats, saltmarsh, shallow lagoons and pasture, which will support nationally important breeding, wintering and passage bird assemblages and act as a major RSPB contribution to adapting to climate change on the coast (RSPB 2008).

Coastal habitats in England and Wales support over two million wildfowl and wading birds each winter, and more pass through during spring and autumn migration. Consequently the conservation of these habitats is a high priority for the RSPB, and the Society actively supports achievement of the UK Biodiversity Action Plan targets for coastal saltmarsh and mudflat. These targets seek to achieve no net loss of these habitats, currently assessed as being lost at the rate of 600 hectares per year combined (UKBAP 2006), mainly due to rising sea levels and climate change. There is an additional target to create a further 3600 hectares by 2015 to offset historic losses.

The majority of such saltmarsh and mudflat habitats and the wildlife they supported were destroyed historically by en-walling for mainly agricultural land claim, with natural coastal processes and climate change exacerbating the situation. The Essex coast which had some 30,000 hectares of saltmarsh in 1600, now has only 2,500 hectares left. Benefits for the restoration of such habitats extend beyond the obvious wildlife gain for birds, plants, fish and invertebrates to include a reduction in flood management costs, improved water quality and potential to act as carbon soaks.

Figure 4. Habitat distributions across the island under preliminary design for the RSpb project.



Since 2000, the RSPB have worked with Wallasea Farms Ltd to identify possibilities for habitat creation on this site. They now have the opportunity to purchase 736 hectares of agricultural land, with the potential for mudflat and saltmarsh creation in a phased and managed way. The precise design of the site is under review at the present time and will be influenced by the availability of marine and other sediment that can be used to raise land levels on the island and reduce water exchange volumes. The principal design objectives will be to create a high quality wildlife habitat, while at the same time limiting hydrodynamic impacts and reducing future flood risks and it is expected to require a combination of Regulated Tidal Exchange (RTE) and managed realignment techniques. At this stage though (September 2008), it is proposed to phase the construction works over a number of years from 2009 to 2015 and divide the site into five separate, but linked, bunded sections. Dividing the site into sections will have multiple benefits. It will: allow for an historic landscape restoration; limit design risks and allow for design improvements at each phase; control financial outlay; enable integration of public access; allow for controlled hydrodynamic adjustment to adjacent estuaries; and provide opportunities to existing species to migrate within the area. A proposed design is shown in Figure 4 and Plate 14.

Such a project would act as a national ‘flagship’ to demonstrate sustainable options for coastal management and landscape restoration for adapting to climate change on the coast, with attendant wildlife gain, flood management benefit, recreation and educational use, beneficial use of materials from large construction sites, co-operation between the needs of industry and wildlife, and with the potential to enhance the local economy and employment prospects. An information and education centre could be added as the site develops.

The design, within the constraints of potential fill material type and quantity, will be ecologically-led to provide habitat

plate 14. 3D visualisation of the preliminary design for the RSpb project.

for nationally important feeding and breeding birds with features for plants, marine and terrestrial invertebrates and mammals. The existing properties and businesses on Wallasea Island will not be adversely affected by the plans and the RSPB will work closely with all interests in developing the project. A wide range of organisations have been invited to join and support the project partnership. Local people and key stakeholders will be involved in informing the design process. Final design will include, subject to suitable access management, open space and footpath routes for appropriate public enjoyment.

A Mixed Use Marina and Managed Realignment Site

In a separate initiative, but one cognisant of the emerging RSPB scheme, Wallasea Farms Ltd have identified a proposal for extending the Defra site's counterwall to the west to create a further twenty-five hectares of intertidal habitat (through managed realignment) and also for excavating a 460-berth marina in adjacent land. Like the RSPB project, this proposal offers multiple environmental and socio-economic benefits and outcomes. Crucially, it will reinforce the levels of coastal protection afforded to the island along its north bank (where defences are in a poor condition). This proposal is in its feasibility phase at present but even at this early stage it offers, alongside the Defra and RSPB proposals, an excellent example of integrated multi-functional design in the coastal zone.

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SOUTHERN REGION HABITAT CREATION PROGRAMME: DELIVERING ENVIRONMENTAL OUTCOMES IN THE SOLENT

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introduction

The Department for Environment, Food and Rural Affairs (Defra) encourage the Environment Agency to adopt a strategic and proactive approach to compensatory habitat creation. Compensatory habitat is required when European Designated Sites (Special Areas of Conservation (SAC) and Special Protection Areas (SPA)) are damaged or experience loss due to flood risk management works or coastal squeeze. This includes both intertidal and freshwater habitat. Where a strategic assessment of future habitat needs has been made, a controlled form of land acquisition is acceptable (Defra, 2003) with the intention of creating habitat in advance of loss. Defra have also set the Environment Agency Outcome Measures for Biodiversity Action Plan (BAP) habitat creation and remedies for Sites of Special Scientific Interest (SSSI) in unfavourable condition. This strategic approach can be applied to all these requirements for habitat creation. This is the role of the Regional Habitat Creation Programme (RHCP).

Habitat creation Drivers

The Environment Agency's environmental obligations come from a number of sources and are summarised below.

Natura 2000 European Sites

Natura 2000 sites encompass Special Protection Areas (SPAs) established under The Birds Directive and Special Areas of Conservation (SACs) established under the Habitats Directive. The Environment Agency also treat Ramsar wetland sites as part of the Natura 2000 network.

Plans or projects should aim to have no adverse impact on a Natura 2000 site. This will be assessed within a Habitat Regulations Assessment. In some cases this may not be possible. Where projects or plans have an adverse impact on a Natura 2000 site, we have a legal obligation to provide compensatory habitat to ensure the network of sites is maintained. This includes where habitat is lost as a direct impact of works or habitat loss over time due to coastal squeeze. A change in habitat (for example, from freshwater to intertidal) would also require compensation.

As a general rule, compensatory habitat must be delivered as close to the site of loss as possible. There is more flexibility when compensation is for coastal squeeze habitat loss. Compensatory habitat must be 'secured' before the project or plan causing the habitat loss can be signed off.

The Environment Agency also has a duty to protect Natura 2000 sites. For example, if a freshwater Natura 2000 site was behind a seawall we would have to take appropriate steps to ensure the site is maintained. This could be through maintaining the defence, or if there is a policy to withdraw maintenance, we would have to recreate the habitat elsewhere.

Defra public Service Agreement for Sites of Special Scientific interest (SSSi) Target

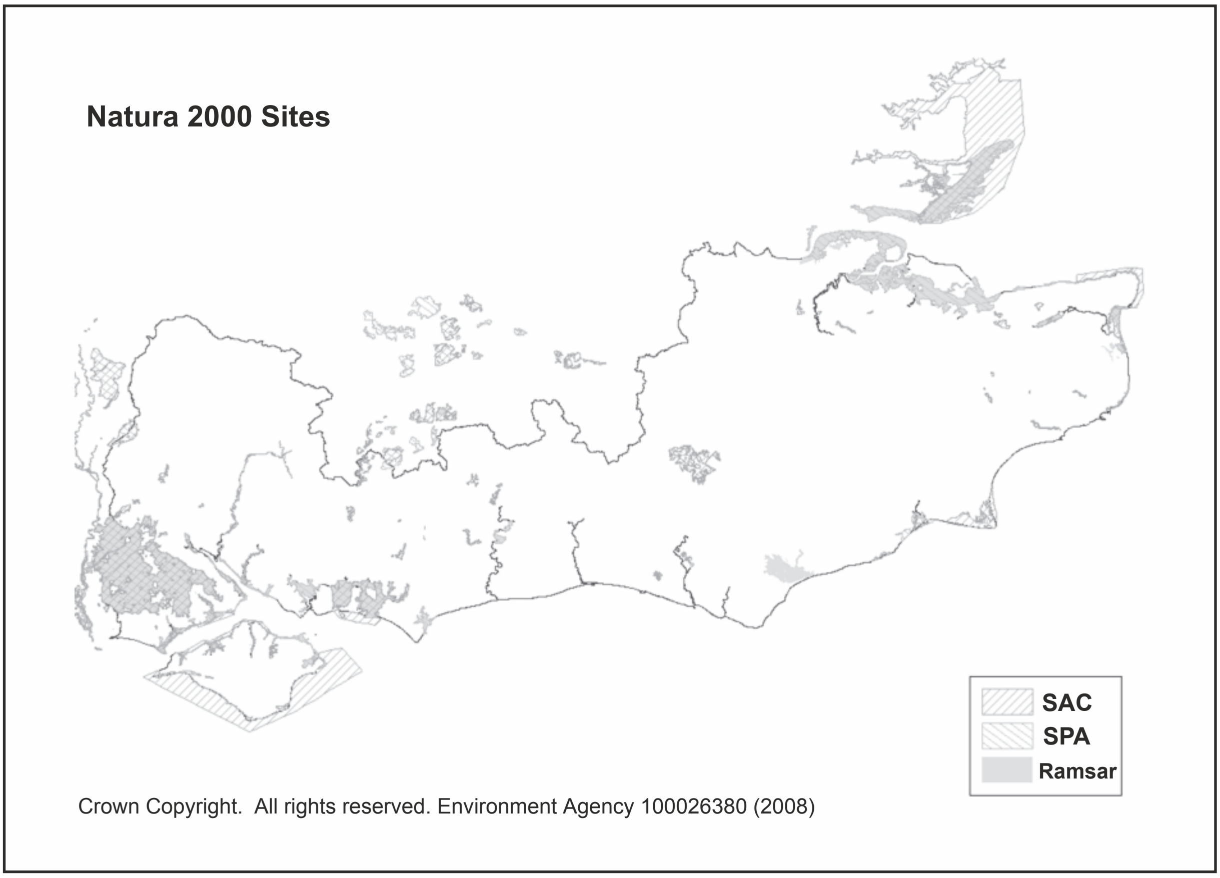
Defra has a Public Service Agreement (PSA) target to have at least ninety-five percent of SSSI area in recovering or favourable condition by 2010.

Natural England has developed a 'remedies' database which outlines the actions required to meet the PSA target. The Environment Agency has signed up to deliver 'remedies' where we are the body best placed to take action. This includes a wide range of remedies including review of abstraction licences, invasive species management, review of discharge consents, water-level management plans and intertidal habitat creation.

Responsibility for much of this work sits with Flood Risk Management. Work on priority Water Level Management Plans is well underway, and this will deliver favourable or recovering status for many freshwater SSSIs by 2010.

There are several remedies which require us to create intertidal habitat to offset losses resulting from coastal squeeze. In Southern Region, approximately 5,000 hectares of SSSI is listed as being in unfavourable condition due to coastal squeeze.

Figure 1. Natura 2000 sites in Southern Region.



In Southern Region we have agreed 'Estuary Complexes' for the Thames and Solent estuaries with Natural England to help us meet our PSA target. The Solent Estuary Complex boundary is shown in Figure 2. This allows us to treat all the SSSI units within a complex as one, rather than addressing coastal squeeze within each individual unit, which may not be possible in some locations. This means that delivering the correct habitat creation anywhere within the estuary will turn the whole complex to 'recovering' status.

Natural England require a programme of works to be in place, and work to have started on a habitat creation site within each estuary complex by 2010 in order to award 'recovering' status and for us to meet our target.

The Regional Habitat Creation Programme must deliver 100 hectares of intertidal habitat within the Solent Estuary Complex, and twenty hectares of intertidal habitat within the Thames Estuary Complex (working with Anglian Region) to meet our PSA target.

biodiversity Action plan (bAp) Habitat

The Environment Agency has a corporate target to deliver no net loss of BAP habitat and to create at least 800 hectares of new BAP habitat nationally over the next three years as a result of flood risk management activities.

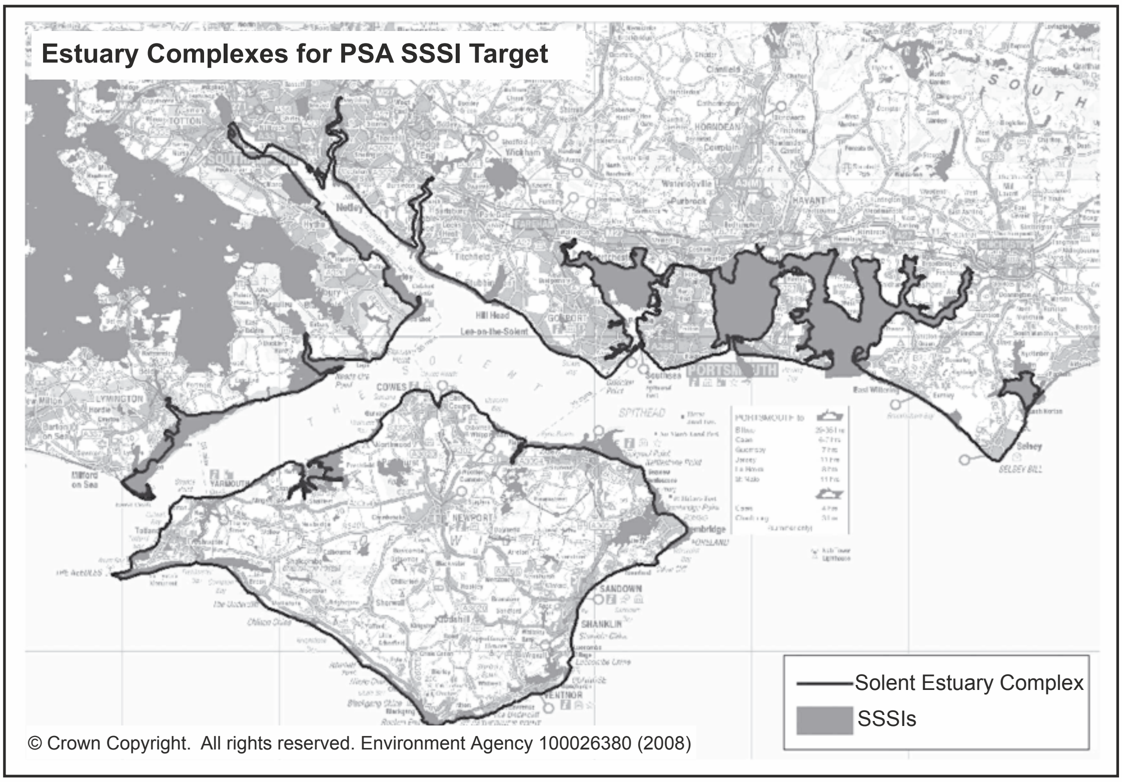
The national 800 hectare target consists of at least 300 hectares of intertidal habitat (saltmarsh and mudflat) with the remainder comprising non-intertidal wetland habitat. Other wetland BAP habitat includes chalk rivers, coastal sand dunes, coastal vegetated shingle, grazing marsh, lowland meadows, lowland raised bog, reedbed, saline lagoon and wet woodland. This target is divided between the eight Environment Agency regions on an annual basis.

We should also be aiming to ensure no net loss of BAP habitat as a result of our projects and plans. In some circumstances we may be changing one BAP habitat type for another, for example, freshwater habitat to intertidal habitat. In these cases we would take advice from Natural England on whether replacement habitat would be required.

phases of the Regional Habitat creation programme

The RHCP programme comprises of three phases.

Figure 2. Solent Estuary c omplex.



phase 1 identifies losses and gains of both internationally designated and BAP habitats due to flood risk management activities. This information is captured in a database which enables us to quantify the amount and type of habitat required to offset our losses due to Flood Risk Management activities.

phase 2 identifies broad areas that have the potential to be used for compensatory and BAP habitat creation. This involves using a GIS habitat search tool to identify suitable sites based on a set of physical habitat attributes. These broad areas have been screened further with the help of Area teams' local knowledge.

phase 3 provides a programme of habitat creation works for our compensatory needs, SSSI Public Service Agreement (PSA) and BAP targets. Once the programme of works is established and approved, habitat creation schemes will begin. This will involve taking steps to secure land through purchase or legal agreement and delivering habitat creation on the ground.

Habitat Requirements

Using this process the habitat losses from Environment Agency and Local Authority projects and plans have been assessed. In the next 100 years there is a requirement for approximately 1,660 hectares of habitat for the region, and there are three broad areas where the need for habitat creation is concentrated. This is due to compensatory habitat requirements and the need for habitat to meet the PSA target. These are the Thames Estuary, South Kent and the Solent.

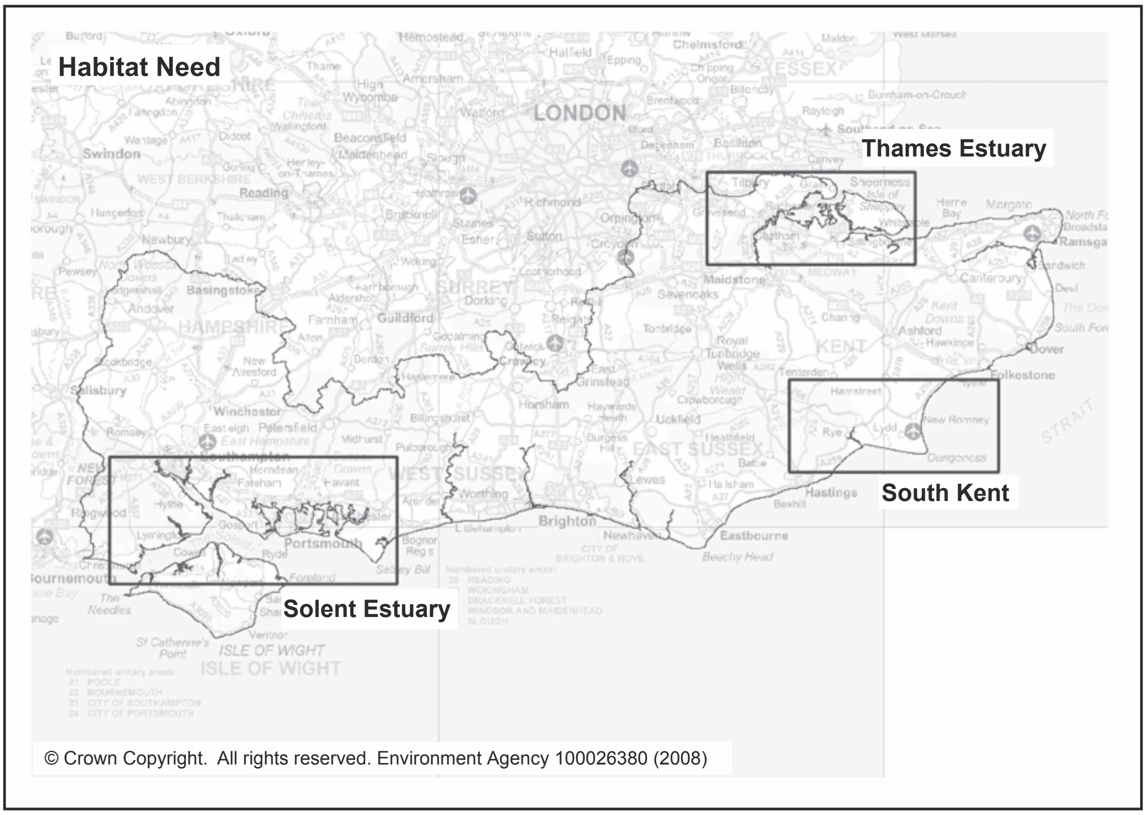
Solent Estuary Requirements

The North Solent Shoreline Management Plan (through the Solent Dynamic Coast Project) highlights a need for 600 hectares of intertidal habitat over the next 100 years. The realignment areas required to provide this habitat are often designated for their freshwater interest, and this results in the need for 553 hectares of freshwater compensatory habitat.

Coastal Defence Strategies in the estuary show a need for over eighty hectares of freshwater habitat and over 200 hectares of intertidal habitat.

One hundred hectares of intertidal habitat are required within the Solent Estuary Complex to meet the PSA SSSI target. Work must have started on PSA target projects by 2010 to meet the target.

Figure 3. Requirement for compensatory habitat.



The need for habitat in the Solent Estuary Complex is the highest in Southern Region. The Solent shows a need double that of the Thames Estuary.

Delivering the Habitat c reation programme in the Solent

The RHCP has identified several sites within the Solent Estuary where intertidal habitat creation may be possible. We have also identified potential sites for freshwater habitat creation. Using the outputs from the Solent Dynamic Coast Project and a matrix system, we have developed a programme of works that will enable the Environment Agency and Local Authorities to meet our habitat creation requirements.

Options for Land Acquisition

Where compensatory habitat is required, the site needs to be secured for that habitat in perpetuity. The most obvious method for achieving this is to acquire the freehold to the land through land purchase from the current owner. This can be done through negotiation or possibly through compulsory purchase, where it can be demonstrated that the site is necessary for carrying out our function.

Land purchase may not be necessary if the site is already in other public ownership, e.g. Local Authority owned. Another possibility is to enter into a legal agreement with the owner which will require the habitat to be maintained in perpetuity. This could apply where the owner is an environmental charity with similar objectives for the site.

Where habitat is being created for one of the other drivers (PSA target, BAP habitat) land acquisition is not required. In these circumstances, we could contribute either financially or in-kind, through studies or site works, to the habitat creation, which would allow us to claim the habitat towards our targets. The landowner may be eligible to claim environmental stewardship funding.

Options for Land Management

Where we own land we have a responsibility to ensure that the site is managed. This could be carried out by our own staff, but the preferred approach would be to use a partner organisation more specialised in this kind of work.

Working in partnership

The Habitat Creation Programme has been developed working closely with Natural England and Local Authorities. The programme relies on future partnerships with these organisations and conservation organisations for habitat delivery.

Monitoring and Updating the programme

It is recognised that the habitat needs will require updating as more information becomes available and as assumptions change, particularly as SMPs and strategies are completed and UKCIP08 is published. Also, opportunities may arise at sites not identified at this stage. It is anticipated that having a good understanding of our habitat needs should, in particular, enable opportunistic land purchase, where we become aware of suitable land for sale.

Further Details

If you would be interested in working with the Environment Agency or would like further details about the Habitat Creation Programme, please contact the authors at the address above or at the following e-mail addresses, Ruth.Jolley@environment-agency.gov.uk or Rebecca.Reynolds@environment-agency.gov.uk.

SALTMARSH RESTORATION: BENEFICIAL USE OF DREDGE SPOIL A SOLENT FEASIBILITY STUDY

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introduction

Saltmarsh and mudflat systems are an important resource for many reasons. They act as a natural and sustainable coastal defence and a sink for sediments. They are of vital importance for biodiversity, containing unique habitats and supporting, for example, wading bird species of the highest international importance for conservation and specialised halophyte plants. At the same time they are a source of nutrients contributing to the productivity of our coastal and estuarine systems. Our coastal marsh systems contribute to the unique coastal landscape of some parts of Britain, notably across the Solent, with numerous cultural associations. Without them we would be poorer in many ways.

Evidence has mounted over recent decades that these unique natural resources are in steep decline; across southern Britain there is a general trend of habitat loss. This decline may be associated with numerous inter-linking factors, including coastal squeeze, sea level rise, erosion, reclamation, heavy metal and organic pollution, algal smothering, hybrid dieback, tidal inundation and changing wave climate, amongst others (e.g. Adam 1990; Winn *et al.* 2003; Bertness *et al.* 2004; Wolters *et al.* 2005 a & b). Although there is evidence in the literature that all of these factors are contributing to the loss of saltmarsh area, their combination may be site specific and often hard to unravel; so management strategies to arrest declines are problematic. Managed realignment has, so far, been the main contributor to the reduction of saltmarsh decline in Southern Britain; creation of new saltmarsh by deliberate flooding has been undertaken on the UK east coast (Boorman *et al*., 2002). However, in the Solent no large scale projects have taken place. Eleven sites identified in the region for managed realignment by Cope *et al*., (2007) could produce around 598 hectares of saltmarsh and 189 hectares of mudflat, but this would not be sufficient to compensate for the predicted losses over this century (see below).

Across the Solent the declines in saltmarsh area have been well studied and thoroughly catalogued. There were 1,361 hectares of saltmarsh in 2001 in the Solent (Bray and Cottle, 2003), but these are rapidly declining. The details make stark reading: for example, between 1956 and 2001 seventy-two percent of saltmarsh was lost from Langstone Harbour, and sixty-three percent from Portsmouth Harbour (Baily & Pearson, 2007), and this trend can be seen at almost all saltmarsh sites in the region. Interpretation of aerial photographs from 1971 to 2001 indicates possible losses of 736 hectares over this century, i.e. a fifty-eight to seventy percent loss (Bray and Cottle 2003), furthermore a recent study has suggested even greater losses are possible, perhaps as much as 812 hectares loss by 2100 (Cope *et al.* 2007).

Management of sediment supplies is central to maintaining saltmarshes and associated mudflats, but can sit uncomfortably with other interests. In an industrialised coastal area like the Solent, dredging has to take place to allow large scale shipping and other maritime activity to continue and develop; this is crucial to the prosperity of the region. Substantial amounts of sediment (over eleven million tonnes (wet weight)) were removed from the shipping channel in Southampton Water in 1997-1998 during capital dredge works, and annual maintenance dredging removes over 0.5 million tonnes; a further capital dredge is currently proposed. Almost all of this material is disposed offshore at sites off the Isle of Wight (Nab and Needles), so it is effectively removed from the Solent coastal system. This has the potential to contribute to geomorphic change (e.g. sediment draw-down) in mudflats and marshes in the dredged area (see Morris, 2007).

Research carried out by the University of Southampton has indicated that this may also have impacts for sensitive environments in the vicinity of the disposal sites (Bray, 2005). Raised levels of imposex, (imposition of male sex organs on a female of a species) caused by tributyltin have been identified in dogwhelk (*Nucella lapillis*) at intertidal sites relatively near to dump sites west of Plymouth Sound and at the south coast of the Isle of Wight; both of these locations are Natura 2000 sites.

From these potentially deleterious biological and physical impacts a strong case may be made for exploring alternatives to offshore dumping, and if possible re-using dredged material within the system from where it originated. Beneficial use of dredgings is promoted by the Marine and Fisheries Agency (formerly Marine Consents and Environmental Unit), which provides advice and a register of potential sources. A Licence is required, along with, in most cases Appropriate Assessment and an Environmental Impact Assessment under National and EU Law. Several other consents are required including planning permission, flood defence and harbour authority, so the process of simply gaining consent is not straightforward. In addition many stakeholder groups are likely to have concerns over the potential impacts on their interests. However, the outcomes of beneficial use projects are potentially considerable, in economic and environmental terms, so all interested parties should consider proposals impartially and on their overall merits.

The work presented here will be expanded when ongoing work scoping the beneficial use of dredged material in the Solent region for the Environment Agency and Hampshire County Council has been completed and becomes publicly available. This report will also include a review of potential methods of restoration and detail on how to address contamination issues.

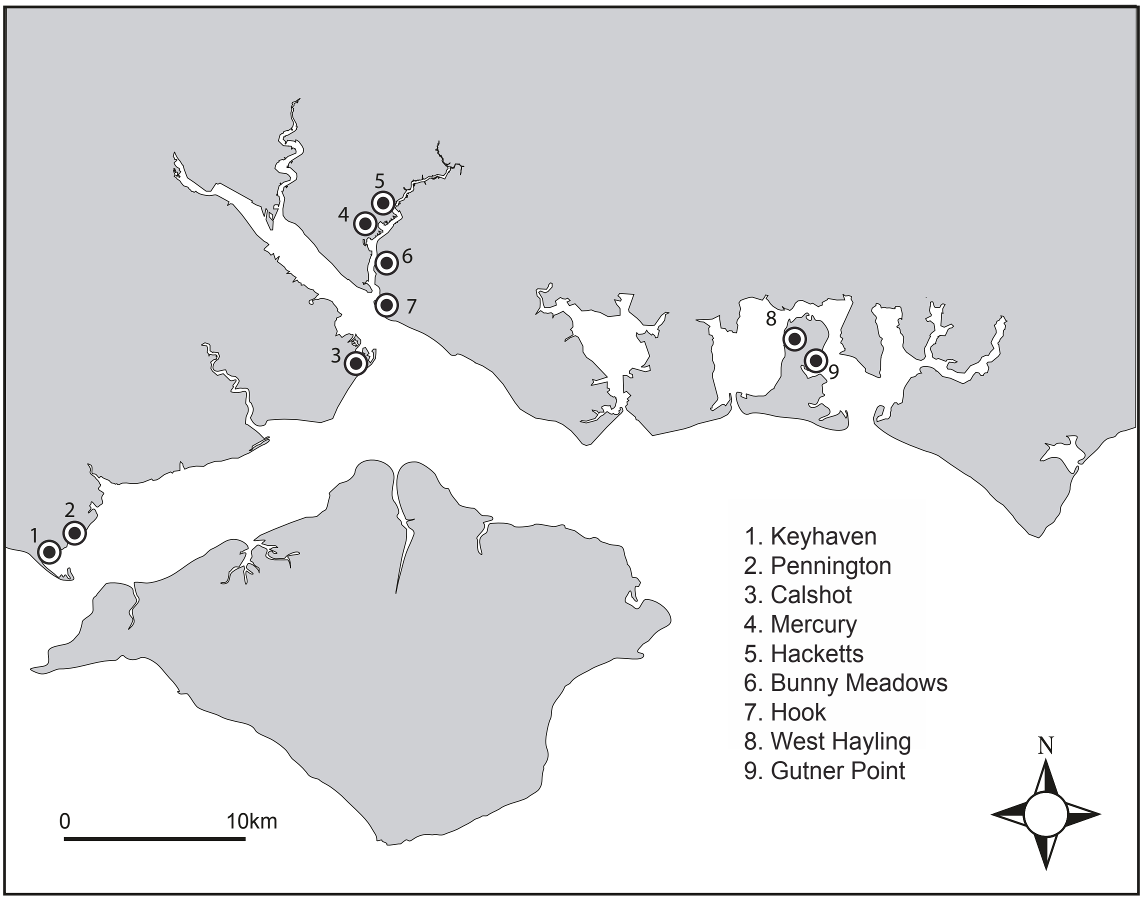
This paper presents an outline methodology for identifying and prioritising sites for beneficial use of sediment in the Solent area. It is illustrated with a case study of a site on the River Hamble.

Methods

Study Area

The project covers the north Solent, between Hurst Spit, Hampshire and Pagham Harbour, West Sussex. Hampshire County Council identified nine potential restoration sites which they owned where saltmarshes were currently present.

Figure 1. Hampshire c ounty c ouncil sites for potential restoration.

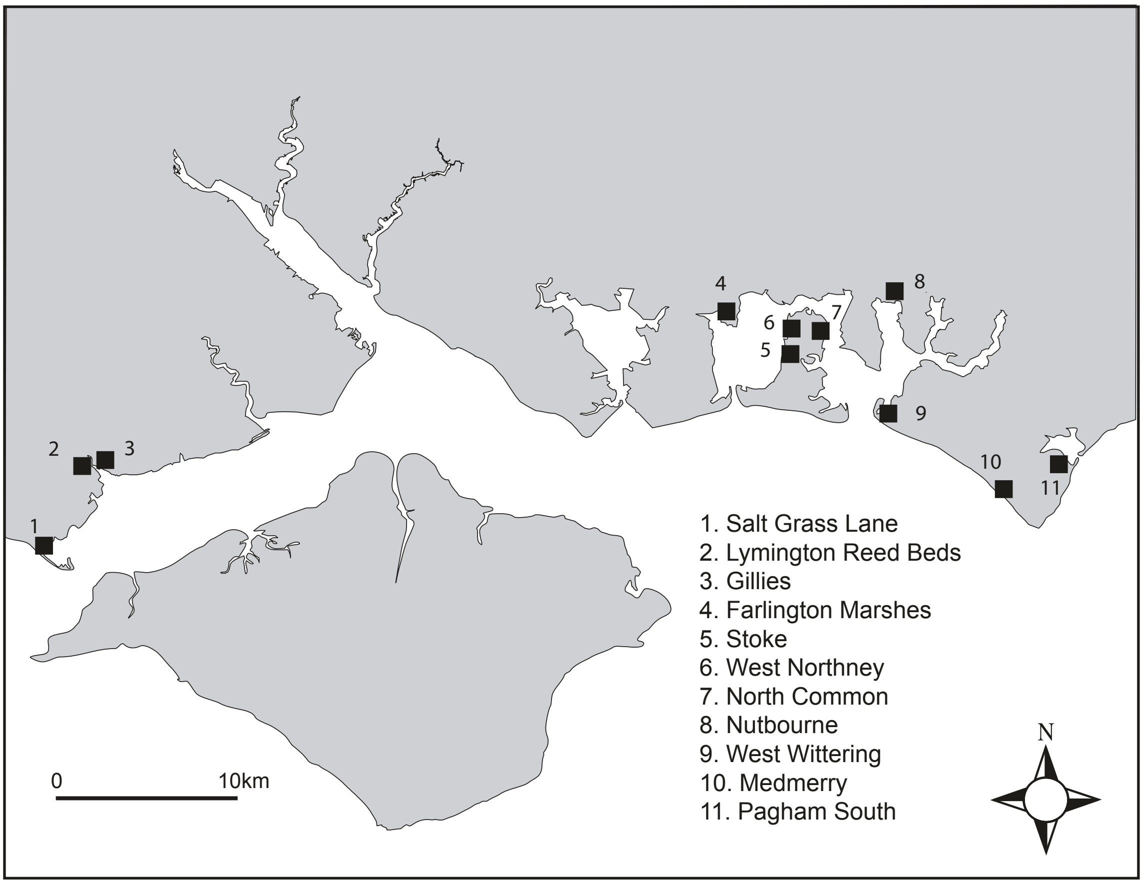


The Environment Agency proposed a further eleven sites identified by the Solent Dynamic Coast Project for potential intertidal habitat creation through managed realignment using sediment recharge to increase mudflat height thus encouraging saltmarsh growth (Figures 1 and 2).

Key Factors for Site Selection

Key factors affecting the success of saltmarsh creation are summarised below (ABP Research & Consultancy Ltd, 1998, Atkinson *et al.*, 1998, Atkinson *et al.,* 2001, DEFRA and Environment Agency, 2005, Nottage and Robertson, 2005). The process of saltmarsh creation should ensure that there is no adverse effect on the environment or activities in the surrounding area.

Figure 2. Environment Agency sites identified for recharge following managed realignment.



1) **presence of existing natural saltmarshes** - the proposed area indicates the existence of favourable conditions for saltmarsh creation. This may also supply new sites with saltmarsh propagules and, where colonisation is slow, assisted seeding can be considered.

2) **Elevation** - the minimum elevation at the proposed site should be around MHWN, or at a level that would experience 450 to 500 tidal inundations a year. The elevation of surrounding natural marsh should be considered. In the past the most successful marshes have been approximately 2.1 metres OD (Ordnance Datum) when breached (or 400-500 tidal inundations per year) with the height of established marsh being 2.34 metres OD (<300 tidal inundations). As a general rule, saltmarsh forms at site elevations of 2 to 3 metres OD and mudflats elevations of <1m OD.

3) **Drainage** - drains increase sediment stability by supplying the marsh surface with sediment and nutrients. This reduces waterlogging, which is detrimental to plant colonisation and survival and dissipating tidal energy. Experience from the US concluded that sites which are too high do not develop adequate drainage systems and lack habitat diversity (ABP, 1998). The relic creek network should be enhanced. If natural creek development is slow, excavation of a drainage system should be considered. The creation of marsh at the Tollesbury managed realignment site found that creeks did not begin to develop until about twenty to thirty centimetres of sediment had accreted on top of an agricultural site surface. This suggests the importance of excavating drainage channels in areas suitable for saltmarsh creation. Therefore, when choosing a site, access for earth-moving vehicles needs to be considered. Without such intervention it is recommended that sites slope gently to level slightly lower than needed for saltmarsh development as natural saltmarsh drainage will form in the accreting sediment, producing marshes of better quality and diversity.

4) **Surface gradient** - site gradient determines species biodiversity, with more natural slope giving greater habitat diversity. Flat sites may result in poor diversity dominated by pioneer or low marsh species; optimum is one to two percent (<1:50).

5) **Soil grain size** - sediment grain size, composition and porosity affect drainage characteristics and organic content, and can influence the elevation of species colonisation and the outcome of plant competition. Finer sediments would be best to use in saltmarsh restoration.

6) **Sediment Supply** - needs to maintain an accretion rate sufficient to offset predicted sea level rise. The presence of healthy marshes close to a proposed site would indicate a suitable location in terms of sediment supply.

7) **c ontamination** - areas away from major pollutant sources are preferable.

8) **Land c onservation value** - sites selected for saltmarsh creation should not have a high conservation value (such as SSSIs, Natura 2000, Ramsar sites etc).

9) **Local Economic Activities -** all current activities such as oyster and mussel farms in the vicinity of the proposed site should be mapped and checked that they are not likely to be adversely affected by the creation of the recharge site. Mitigation measures to offset these impacts may be expensive. For example, at Freiston in Lincolnshire, the implications of managed realignment on oyster farms were not considered. Following the breach of the site, large volumes of sediment drained off the site and caused rapid channel deepening and erosion. Suspended sediment was washed through an oyster farm on to mudflats south of the site causing siltation and burial of oyster racks, which had to be moved at great cost (DEFRA and Environment Agency, 2005).

10) **Accessibility** - sediment retention at disposal sites may be problematic. The behaviour of fine material is difficult to predict unless protected in some way or placed in quiet locations. When selecting intertidal areas for recharge, consideration of the accessibility and costs for appropriate vessels/plants/machinery to handle the material and the possible indirect ecological impacts of sediment re-suspension must be considered; for example re-suspended material may smother adjacent saltmarsh or shellfish areas.

Method for identifying Sites

In order to identify potential intertidal recharge sites, three priority factors were identified. Firstly, it was necessary to quantify saltmarsh loss rates and to establish historic saltmarsh areas, enabling assessment of restoration need. Secondly, existing/potential mudflat areas had to be identified, as well as the sediment requirement to convert these areas to saltmarsh. Finally, it was necessary to clarify suitable potential sources of recharge sediment from maintenance dredge sites within the Solent.

Historic Rates of Saltmarsh Loss

Site-specific saltmarsh change rates driven by local factors such as *Spartina* dieback, wave attack, sea level rise, dredging, reclamation, development and pollution were identified through aerial photography interpretation (Civco *et al*., 1986). In addition the Solent Dynamic Coast Project (Cope *et al*., 2007) quantified saltmarsh loss between the 1940s and 2002 through similar methods. Aerial photography was obtained from a variety of sources, including the National Monuments Record Centre (NMR) and local authorities; photographs were scanned, geo-rectified and mosaiced and saltmarsh areas digitised. The majority of aerial photographs were taken at low tide between April and September at a scale of approximately 1:10,000. Average error for the historic photography geo-rectification and digitising was approximately +/- 6 to 12 metres (1940s-1991) and +/- 2.2 metres for photography taken after the year 2000. Saltmarsh loss in each location was calculated from these data.

LiDAR and Tidal Level interpretation

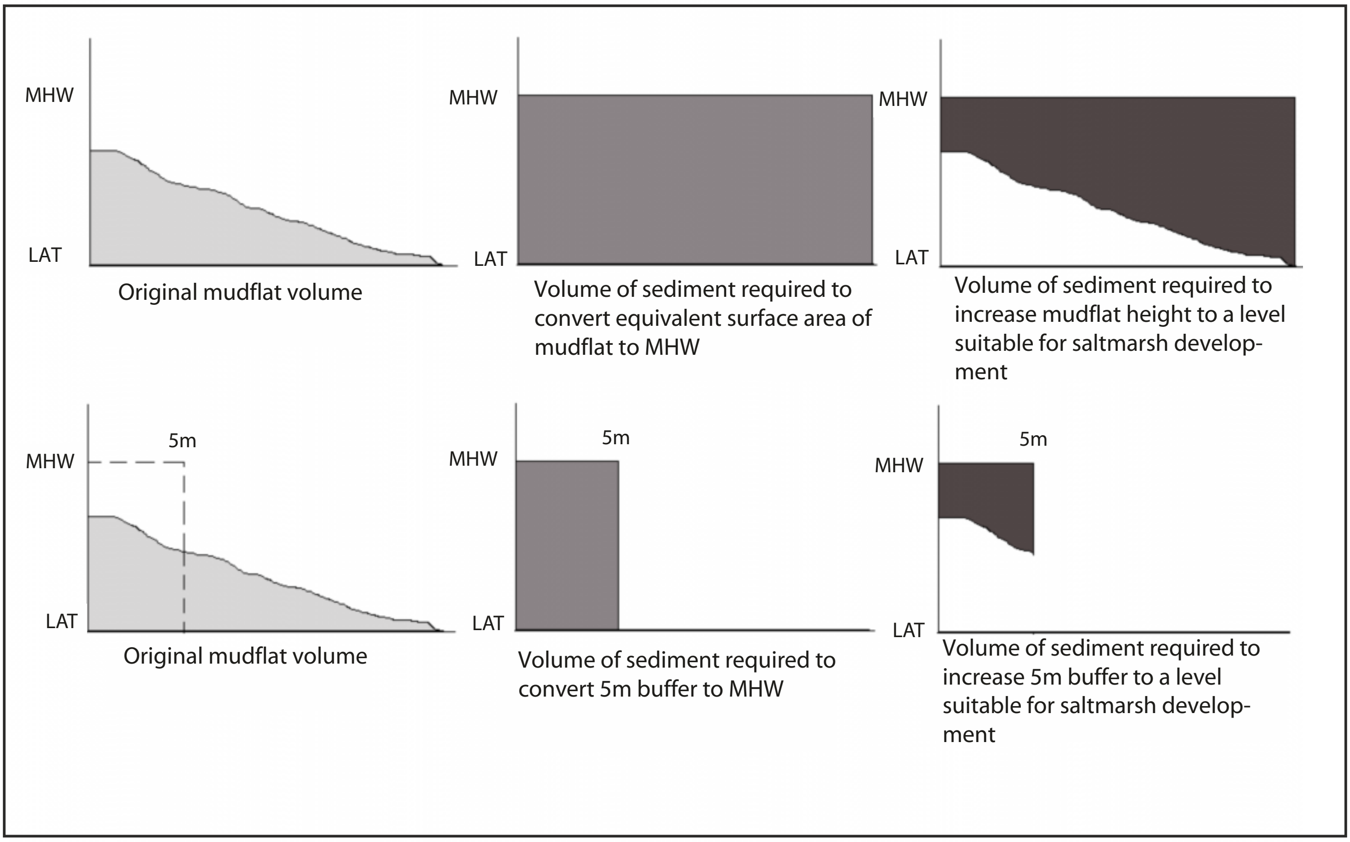
The duration and frequency of tidal inundation in relation to land elevation and gradient is one of the most crucial factors promoting mudflat and saltmarsh development. Inappropriate elevations have resulted in the failure of a number of schemes in the USA (Pontee, 2003). Elevation influences the frequency and duration of tidal inundation, as well as the exposure to wave action, all of which affect primary colonisation (Pontee, 2003). Colonisation of the saltmarsh or mudflats by vegetation can only commence once the surface level has been raised sufficiently high in the tidal frame by physical sedimentation (Joint Nature Conservation Committee (JNCC), 2004). Williams and Lester (1994) found that the intertidal zone in North West Europe typically showed a distinct landward zonation from mudflats through to low or pioneer marsh, middle marsh, high marsh and on to terrestrial vegetation. Mudflat exists between lowest astronomical tide (LAT) and mean high water neap (MHWN), whilst saltmarsh plants usually colonise between MHWN and highest astronomical tide (HAT). The range of individual species is a combination of their relative ability to tolerate tidal submergence and factors related to this such as soil anaerobics and interspecific competition with increasing elevation (Gray, 1992).

Based on this, LiDAR data were ‘flooded’ to corresponding tidal elevations to determine expected ranges of intertidal habitat coverage. Tidal levels for the region were interpolated for the different saltmarsh areas from 2007 data (Table 1). LiDAR accuracy was two metres in the x, y and +/- 15cm in the z direction. UK experience has shown that saltmarsh recreation proceeds best between elevations of mean high water neap (MHWN) and mean high water spring tides (MHWS) (Pontee, 2003).

The generated intertidal areas were compared to past and present aerial photography to verify the extent of saltmarsh and mudflat. At potential managed realignment sites, areas were similarly flooded behind the existing defences to determine potential intertidal areas. To calculate the volume of existing mudflat and saltmarsh areas, the intertidal area was converted to a 3D profile using heights from the LiDAR data in ARCView 9.2, from which surface area and

Table 1. Tidal Data for the Solent Region. (All figures given in metres) proudman Oceanographic Laboratory, (2007)							
port Name	Northing	Easting	HAT	MHWS	"MHW"	MHWN	LAT
Hurst Point 431776 89089 1.06 0.87 0.67 0.47 -1.55 Lymington 432907 96509 1.53 1.34 1.08 0.81 -1.92 Bucklers Hard							
441104 100274 1.73 1.41 1.06 0.71 -2.51 Warsash 449272 105905 2.13 1.76 1.41 0.71 -2.40 Southampton 442203							
109549 2.19 1.89 1.49 1.08 -2.78 Calshot Castle 449307 102198 2.19 1.76 1.36 0.96 -2.44 Bursledon 449287 109611							
2.29 1.86 1.46 1.06 -2.58 Lee-on-the-Solent 456371 100417 2.13 1.76 1.36 1.06 -2.34 Portsmouth 462243 100483 2.39							
1.98 1.55 1.12 -2.59 Northney 472760 104327 2.59 2.16 1.61 1.06 -3.06 Bosham 479801 104430 2.55 2.16 1.66 1.16							
no value Dell Quay 483352 102632 2.55 2.16 1.66 1.16 no value Itchenor 479858 100724 2.45 2.06 1.56 1.06 -2.89							
Chichester Harbour 475188 98801 2.51 2.05 1.61 1.16 -2.53 Pagham 490492 97190 3.16 2.55 1.90 1.25 -3.16							
Selsey Bill -3.02		485852	93405	2.81	2.30	1.75	1.25

Figure 3. c alculating volumes of sediment to convert mudflat to saltmarsh.



volume calculations above a plane (LAT) could be derived. To determine the volume of sediment required to convert the mudflat to saltmarsh, the existing mudflat area was converted to a 3D profile of specified height, the volume above LAT was recorded and the initial mudflat height subtracted. The levels chosen were MLWN, MHW and MHWS as pioneer species establish between MLWN and MLW and mid/upper species between MLW and MHWS. Sediment volume required for extension of the marsh edge by five metres, twenty metres, fifty metres, and 100 metres over the mudflat was calculated to simulate accretion and the required sediment volume calculated (Figure 3). To estimate the volume of sediment required to re-establish previous historic saltmarsh areas, results were interpolated against the historic saltmarsh surface areas, this was achieved by applying a trendline to data.

Dredging Data

Dredging data was obtained from CEFAS (the Centre for Environment, Fisheries & Aquaculture Science) by licence number and dump site; a list of the abstraction sites and associated contaminants was also provided. Data were combined to give a list of Solent maintenance dredging sites and associated volumes. Recommended sites are defined as those which are experiencing saltmarsh erosion, require a minimum volume of sediment to increase the saltmarsh area and have a nearby source of appropriate dredge material to raise mudflat height to levels potentially suitable to promote saltmarsh recolonisation.

Figure 4. Saltmarsh change 1946-2007 at Mercury Marsh, Hamble.

Results

The twenty sites identified were examined in detail. The sediment requirements for different scenarios at each site were estimated. Prioritisation was undertaken on the basis of sediment availability and other outlined factors.

The following case study has been included for illustrative purposes only. No decisions have been made regarding which site(s) may be suitable for potential recharge and/or realignment at the time of going to press.

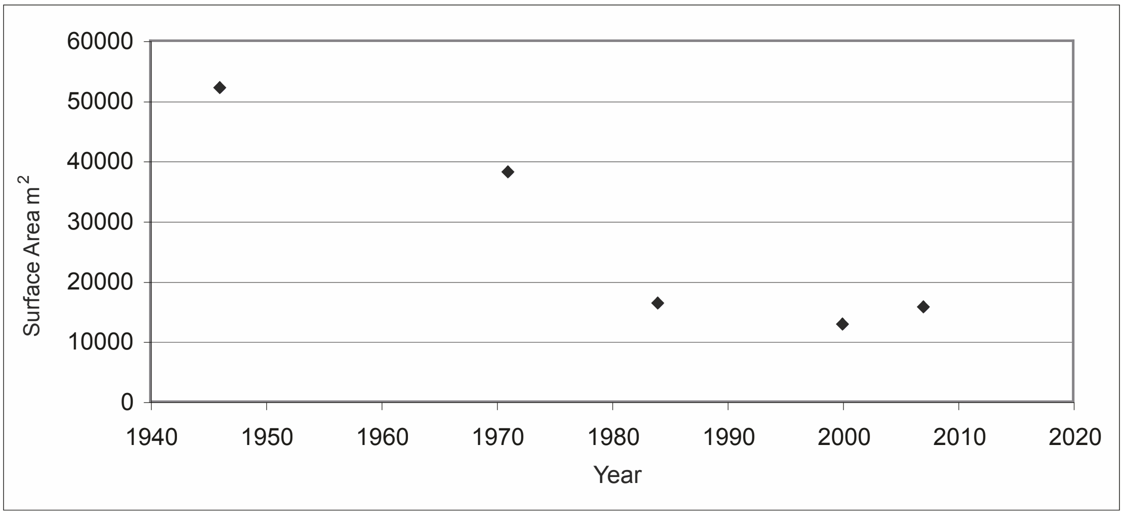
Mercury Marsh, Hamble: Historical Saltmarsh c hange

The most significant problem relating to creation or restoration at Mercury marsh is that the majority of land is too high to promote saltmarsh growth. Figure 4 illustrates saltmarsh area converted to land since 1946 totalling 22,644m^2. It would require removal of 33,523m^3 of sediment to lower the area to HAT, the highest tide where transitional saltmarsh species grow.

Table 2. Historical saltmarsh change at Mercury Marsh (based On Hpi)

year	Surface Area m^2	Source	period	Total Loss m^2	% loss	% loss pa
1946	52,235	CCO	1946-2007	36,486	0.70	0.01
1971	38,221	CCO	1971-2007	22,472	0.59	0.02
1984	16,363	CCO	1984-2007	614	0.04	0.00
2000	12,915	CCO	2000-2007	-2,834	-0.22	-0.04
2007	15,749	LTEI				

Figure 5. Historical saltmarsh change – Mercury Marsh, Hamble.



The rate of saltmarsh decline at Mercury marsh appeared to slow (Figure 5 and Table 2) between 1946 and 2007, with edge erosion as the dominant process (Figure 6). Through a site visit it was noted that the saltmarsh element had largely disappeared and the remainder had accreted to become dominated by *Phragmites australis*, grading to terrestrial. The reduction in loss may be due to the relative consolidation of the sediment by more abundant reed and terrestrial vegetation.

Requirements for potential Mudflat Recharge - Mercury Marsh

The mudflat area for potential recharge is shown in Figures 7 and 8. The volume of sediment required to convert the complete area of mudflat at Mercury marsh to a level suitable for saltmarsh growth has been estimated, but is not available at the time of going to press.

potential Locations of Dredged Material

As has been discussed, one potential method of recharging saltmarsh is the reuse of dredged sediments. Analysis of dredging data showed that during 2006-2007 sediment from twenty-six separate areas was disposed of at licensed dumping sites in and around the study area. This totalled 153,926 tonnes of material, potentially available for recharge schemes. There was at least one disposal of sediment for each month of 2006/2007, however monthly tonnages varied considerably. A minimum value of 536 tonnes was disposed of during August 2007, to a maximum of 387,549 tonnes in November 2007. This clearly illustrates one problem associated with using dredge material in recharge schemes. The volume of sediment available can fluctuate considerably and may not be available at the most appropriate time for a recharge scheme. In addition, those disposals that occur regularly tend to be for relatively low tonnages of sediment while those that generate large sediment volumes occur infrequently and may be associated with capital dredge schemes. This becomes an issue where regular sediment inputs to a recharge scheme are required. For instance, in 2006 and 2007 there were twenty-four disposals from Bedhampton Quay i.e. occurring every month; however, of these the maximum dumped was 1,072 tonnes. By contrast there were only two spoil disposals from dredging at Yarmouth (Isle of Wight) Harbour, however one was in excess of 380,000.

A further consideration when assessing the dredged material suitability for recharge schemes is the chemical composition of the sediment. For example, whether it is contaminated by heavy metals or hydrocarbons. CEFAS carry out routine analysis of a suite of pollutants, which can be related to ‘Action Levels’. These are used by CEFAS as part of a ‘weight of evidence’ approach to assessing dredged material and its suitability for disposal at sea. Hence by extension within this project, its suitability for use in recharge projects can be assessed.

At the time of writing, the sites assessed using outlined methods are being considered through the volumes of material required under the scenarios for restoration or habitat creation. Availability and contaminant status of sediment is also being considered, as are a wide range of other key factors as outlined.

Figure 6. Saltmarsh extents 1946-2007 at Mercury Marsh, Hamble.

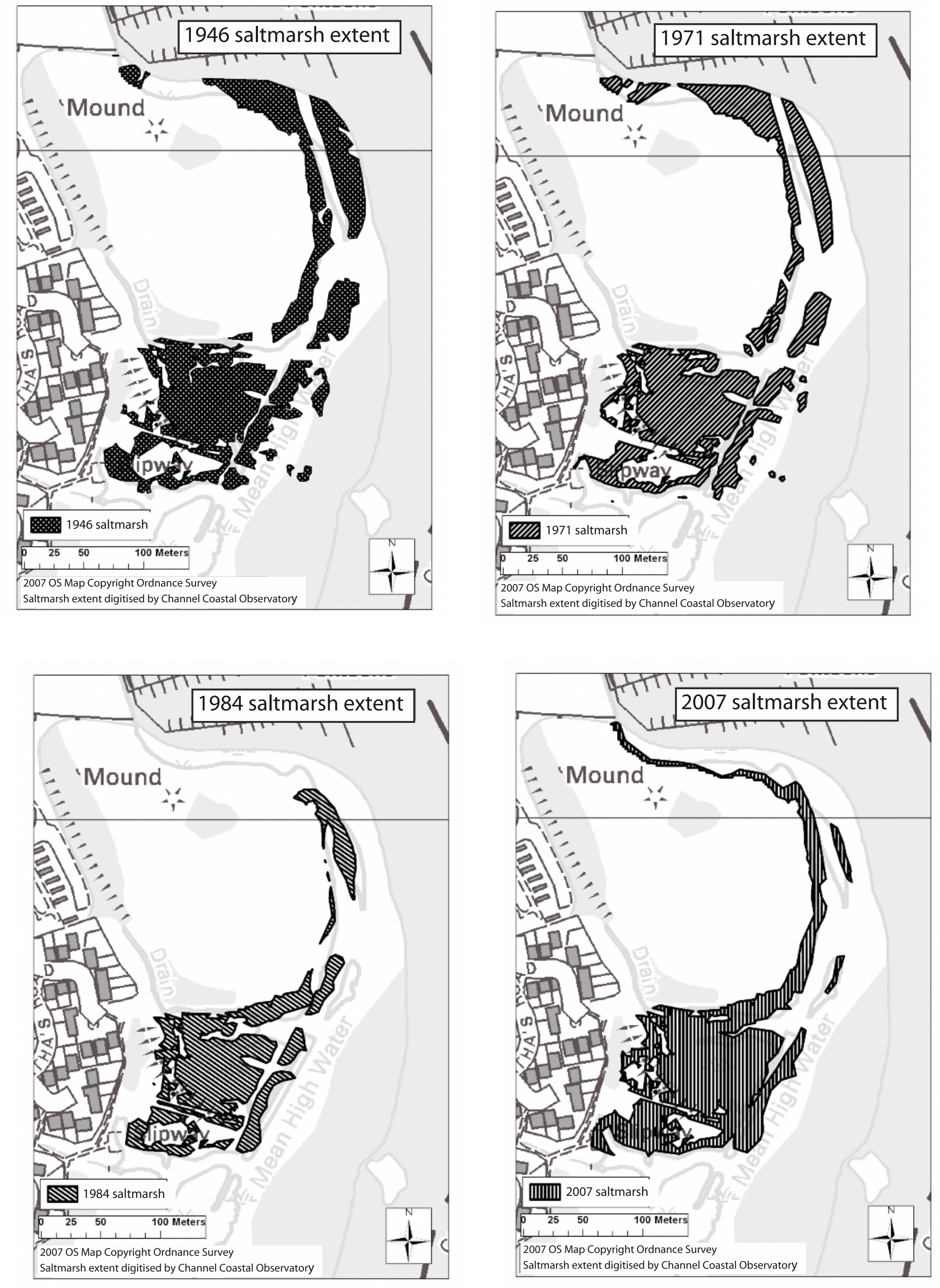


Figure 7. Area selected for potential mudflat recharge, Mercury Marsh, Hamble.

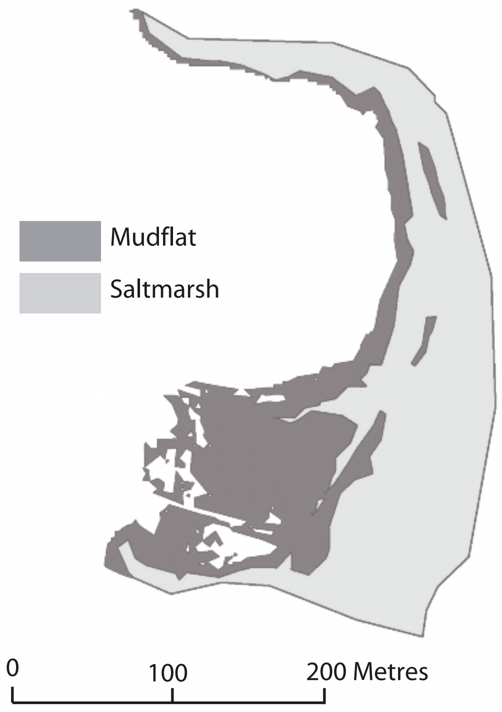
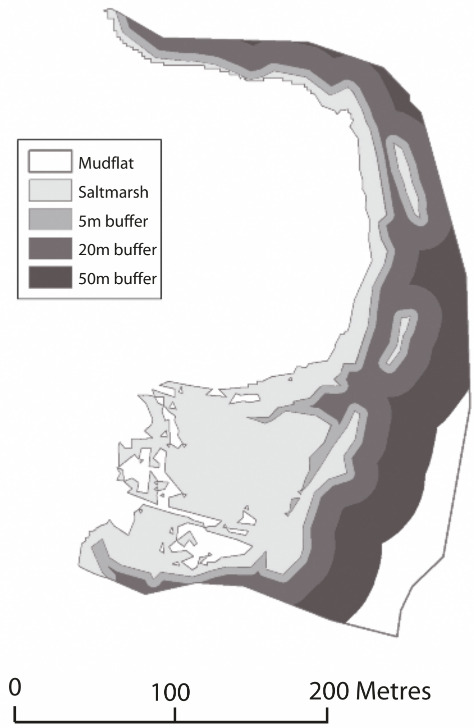


Figure 8. Existing saltmarsh and potential salt marsh buffers at Mercury Marsh, Hamble.



c onclusion

The method presented here has the potential to deliver considered options for identifying trial sites and assessing the feasibility of habitat creation or restoration using local dredged material. However, this process may be lengthy. This will in part be due to engaging and establishing stakeholder consensus and addressing legislative and political requirements. Monitoring the success or failure in at least the medium term will also be necessary before a wider, and more strategic approach can be considered for adoption. What is not in doubt is that the loss of natural resources on the Solent coasts is of immediate and grave concern. The need for the assessment of coastal management options such as discussed here could not be more appropriate and timely.

Acknowledgements

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ASSESSING THE USE OF TERRESTRIAL LIDAR TO MONITOR SEDIMENT CHANGE IN A SOLENT SALTMARSH

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Background and Context

Saltmarshes are important as natural habitats and for coastal defence, but are subject to significant erosion and change. Measuring and monitoring this change can be difficult. Accurately capturing small morphological variations, whilst covering the required area of interest, can be time consuming and logistically difficult. High resolution Digital Elevation Models (DEMs) can accurately represent landform variability. Light Detection and Ranging (LiDAR) generate high resolution data used to represent three dimensional surfaces. These data may be useful to consider topographic and sediment volume change. This work considers the validity and accuracy of terrestrial LiDAR as a method for monitoring saltmarsh change.

Beaulieu Saltmarsh

Plate 1. Scanning Beaulieu saltmarsh

The internationally and nationally designated Beaulieu estuary is part of the North Solent National Nature Reserve and saltmarshes within the estuary have been subject to natural and man-made change. A partnership working between Natural England and the estate landowners, principally Beaulieu, Cadland and Exbury and tenant farmers through Nature Reserve Agreements (NRAs) has ensured the maintenance and enhancement of many of these features. More recently Environmental Stewardship (ES) Scheme management options have been applied. However, this partnership has been unable to address the accelerating saltmarsh erosion, loss of which in the Beaulieu Estuary is estimated to be up to 1.8 hectares per annum. This is cause for considerable concern as saltmarsh presently extends across only 132 hectares (approx.) of the 822 hectares NNR.

LiDAR Scanning Methodology

Monitoring of saltmarsh change requires high detail survey data. A trial survey at Beaulieu used a static terrestrial LiDAR scanner to achieve this which incorporated details such as vegetation, drainage channels and overall marsh elevation. A terrestrial 3D laser scanner consists of a portable head unit that emits a near infra-red laser pulse through a window of 360 degrees in the horizontal and 270 degrees in the vertical. The time taken for a pulse to reflect back from a solid surface is recorded. A standard scan will take approximately four to ten minutes to complete and will capture approximately six million points. Each point has 3D co-ordinates (x,y,z), RGB colour and a reflectivity index. The 3D co-ordinate properties allow an operator to measure the distance between any two points in the scan, so the data can be treated as a high detail digital survey.

Figure 1. Location map

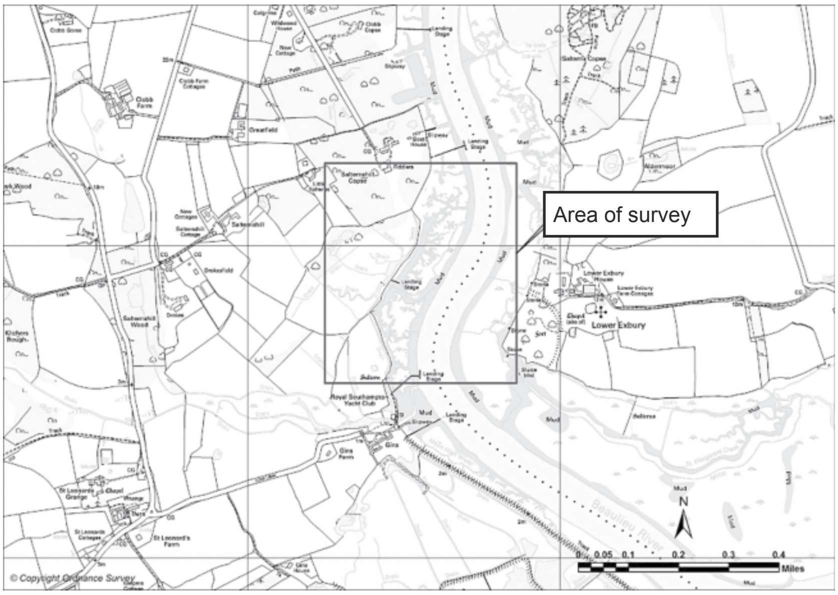


Figure 2. LiDAR image looking northeast and southeast.

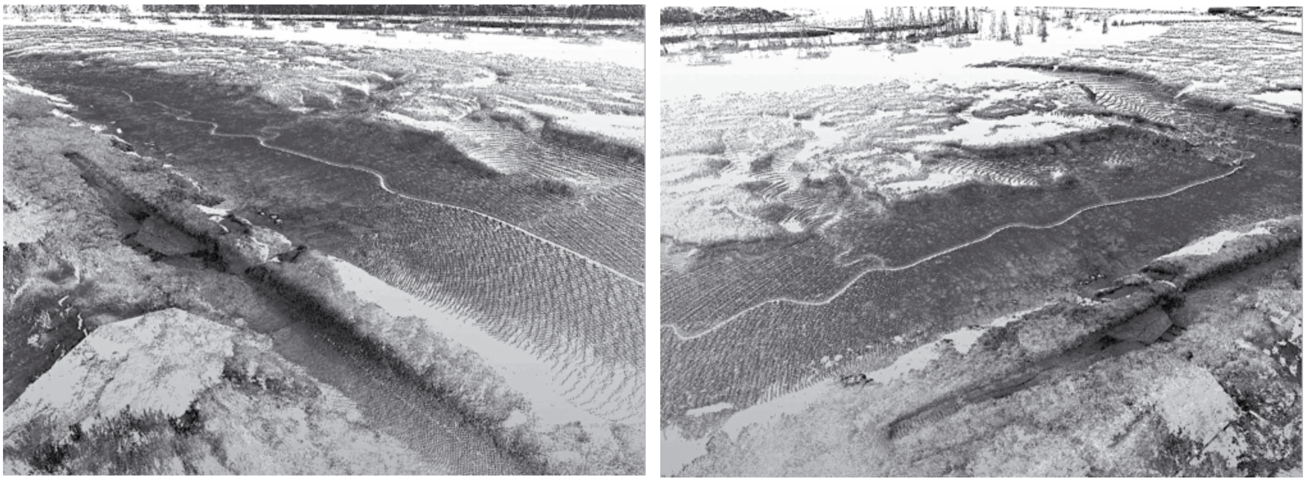
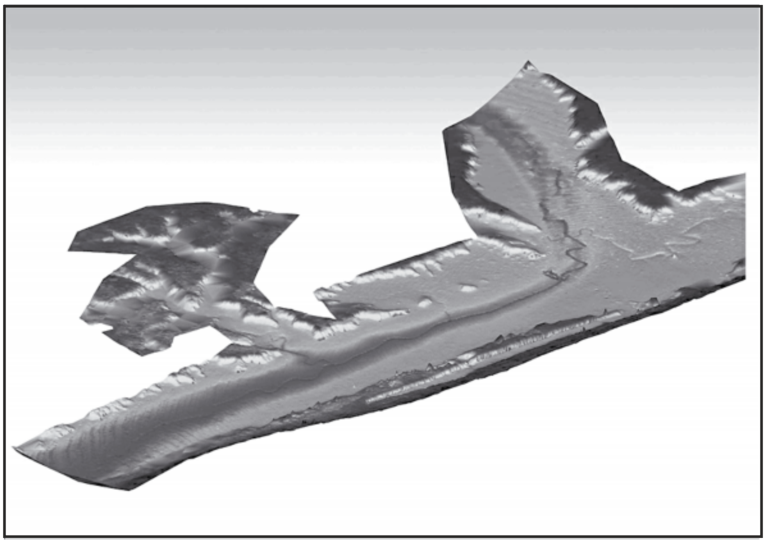


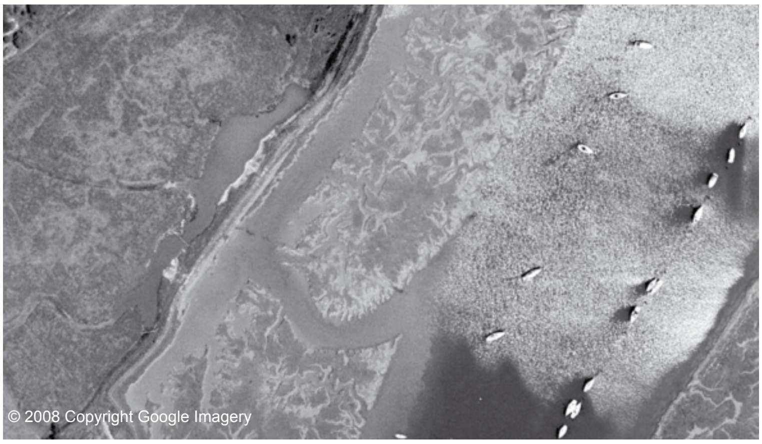
Figure 3. Elevation



Beaulieu Saltmarsh - physical processes

Saltmarshes are highly dynamic features, for example, their temporal variability in elevation, extent and diversity of related flora can be high. This may be a result of several factors, including: biopeturbation; sea level rise; increase in tidal range; tidal asymmetry; increase in storminess; channel migration; and human influences, e.g. land claim, coastal squeeze, dredging and pollution. Saltmarsh erosion occurs when sediment loss outweighs accretion, potentially due to wave erosion or sediment draw down due to dredging. This may be exacerbated by associated decline of plant communities thus loss of binding roots. Fine grained sediment deposition can occur when wave shear stress is reduced. This is not a linear process - deposited material can become resuspended, but sediment deposition increases over time until final settlement and relative consolidation has occurred. The process can be enhanced by increasing the time over which settling can occur e.g. impounding high tide waters and allowing settling before draining the waters off ('dewatering').

plate 2. Area scanned



Saltmarsh Restoration

Natural England is working with a Beaulieu River property owner and partners to restore areas of saltmarsh adjacent to a former boardwalk which is also being restored (Plate 3). It is anticipated that sediment accretion may be promoted through use of brushwood fences in the creeks. These comprise two rows of wooden stakes, back-filled with newly cut brushwood material. This 'low-tech' approach is a proven traditional land reclamation technique used notably at Dengie on the UK east coast, and in the Wadden Sea. The objective at Beaulieu is to achieve at least 400 square metres of saltmarsh restoration through the capture of naturally suspended material, by enhancing sedimentation through flow attenuation. Fences will be positioned to allow relatively unimpeded tidal ingress, whilst significantly reducing ebb tide water velocity, resulting in deposition upstream of the barriers. Over-topping will occur circa mid-tide level and partial permeability of the brushwood fences will work to channel runoff in a non-erosive manner thus avoiding loss of settled material.

plate 3. beaulieu saltmarsh

beaulieu Saltmarsh Restoration LiDAR Monitoring

This method is untried/unproven in this situation and as a result, resource provision for detailed monitoring and, if necessary, for structure modification has been necessary. Through the Arup/University of Southampton/Natural England partnership, a baseline LiDAR scan was undertaken in August 2008 (Figures 3). This will be used to monitor deposition or erosion against post brushwood installation thus aiming to aid Natural England site management.

Acknowledgements

The research funding for this project is made available through Arup's internal investment funding. The project is a joint venture between Arup and the University of Southampton. Natural England and the Beaulieu Estate have kindly provided support and information to enhance the monitoring capability using terrestrial laser scanning technology.

C HANG E IN SEDIMENT STORES AROUND AN AC TIV E PORT: A C ASE STUDY OF SOUTHAMPTON WATER

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introduction

Eighty of the 170 commercial ports in the UK lie within or near areas protected under the EC Habitats Directive. Port development is likely to impact habitats, through activities such as reclamation and dredging by altering sediment budgets and sediment morphology. Port development is likely to continue in order for ports to remain economically competitive in the world market. Current EU legislation requires assessment and mitigation for the environmental impacts that future port development may cause.

Aim and Objectives

To investigate the impact of historic port development on the storage of sediment within estuaries using Southampton Water as a case study (Figure 1). By understanding the impacts of port development on sediment stores within the channel and intertidal zone, the impact of future port development can be better predicted and mitigated.

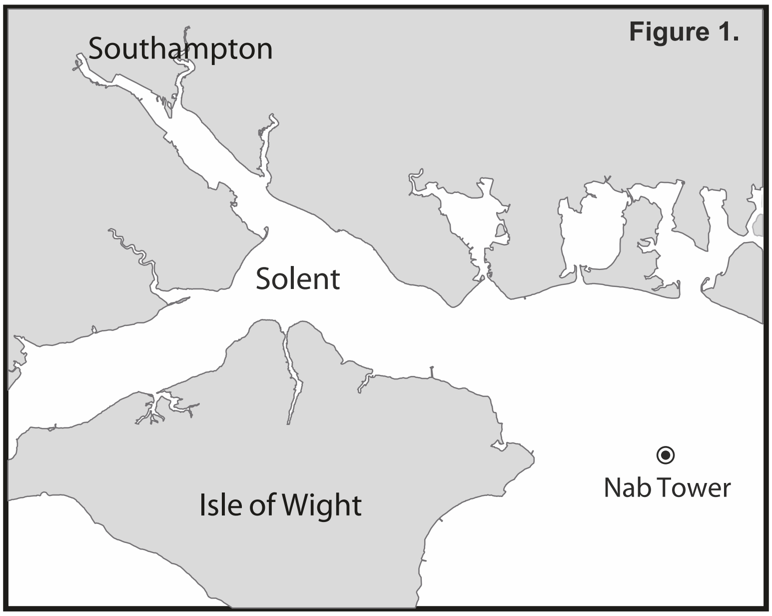


Figure 1.

Method

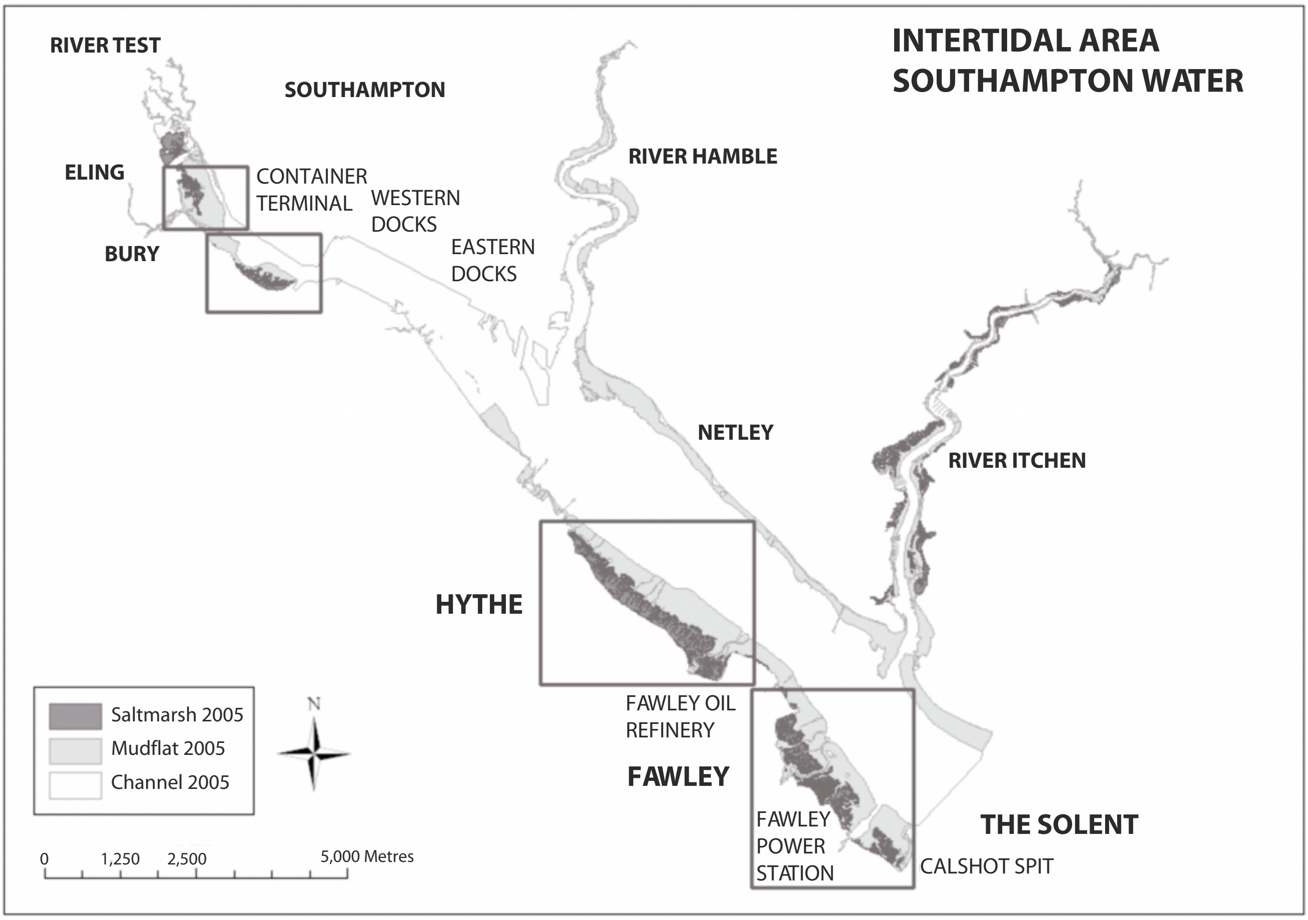
To investigate the influence of port development the estuary was divided into four sections (Figure 2):

- Eling, north of the container terminal;
- Bury, opposite the Port;
- Hythe, which lies along the main shipping channel; and
- Fawley, an area of managed saltmarsh.

The changes in area of saltmarsh and mudflats were quantified by digitising historic maps and aerial photographs between 1889 and 2003. This information was combined with available topographic data to convert to volumes.

Bathymetric surveys of the channel between 1783 and 2005 were interpolated to calculate volume and area changes of the channel.

Figure 2.



Results

Reclamation was the largest contributor of intertidal change, removing forty three percent of the salt marsh and thirty four percent of the mudflats between 1889 and 2003 (Figure 3). Erosion of Eling and Bury marshes, opposite the container terminal, increased when the terminal was developed between 1966 and 1978 (Figure 4). Fawley marsh loss reduced following management by replanting and reseeding of the marsh by the Esso Oil Refinery during the 1970s. There was an overall decline of the intertidal zone volume by 246,000m^3 between 1889 and 2003. During the period 1783 to 2005, the volume of sediment stored in the channel declined by forty three million cubic metres. The channel has deepened and surface area declined during the study period (Figure 5).

c auses for the Reduction in Stored Sediment

Intertidal erosion is caused through a combination of regional dieback of *Spartina anglica*, changes in wave direction, and increased ship wash. Erosion of the intertidal zone should result in the shoaling of the channel, as found by Raybould (2000), however dredging for navigation has resulted in the channel deepening, removing sediment completely from the estuary system to a dumping ground off the Isle of Wight at the Nab Tower (Figure 1). Maintenance dredging continues the cycle of sediment loss from the estuary. The deepened, narrow channel causes wave energy to focus on the saltmarsh cliffs, encouraging further saltmarsh erosion.

c onclusions

Reclamation was the largest contributor to the decline in sediment stored in the intertidal zone and channel between 1889 and 2003. There is insufficient sediment available within Southampton Water to sustain intertidal zone areas combined with rising sea levels. Dredging activity completely removes sediment from the estuary system. Future estuary management and mitigation for port development should focus on sediment management; the sediment supply to the intertidal zone could be increased by recycling the dredge material within the estuary system.

Figure 3.

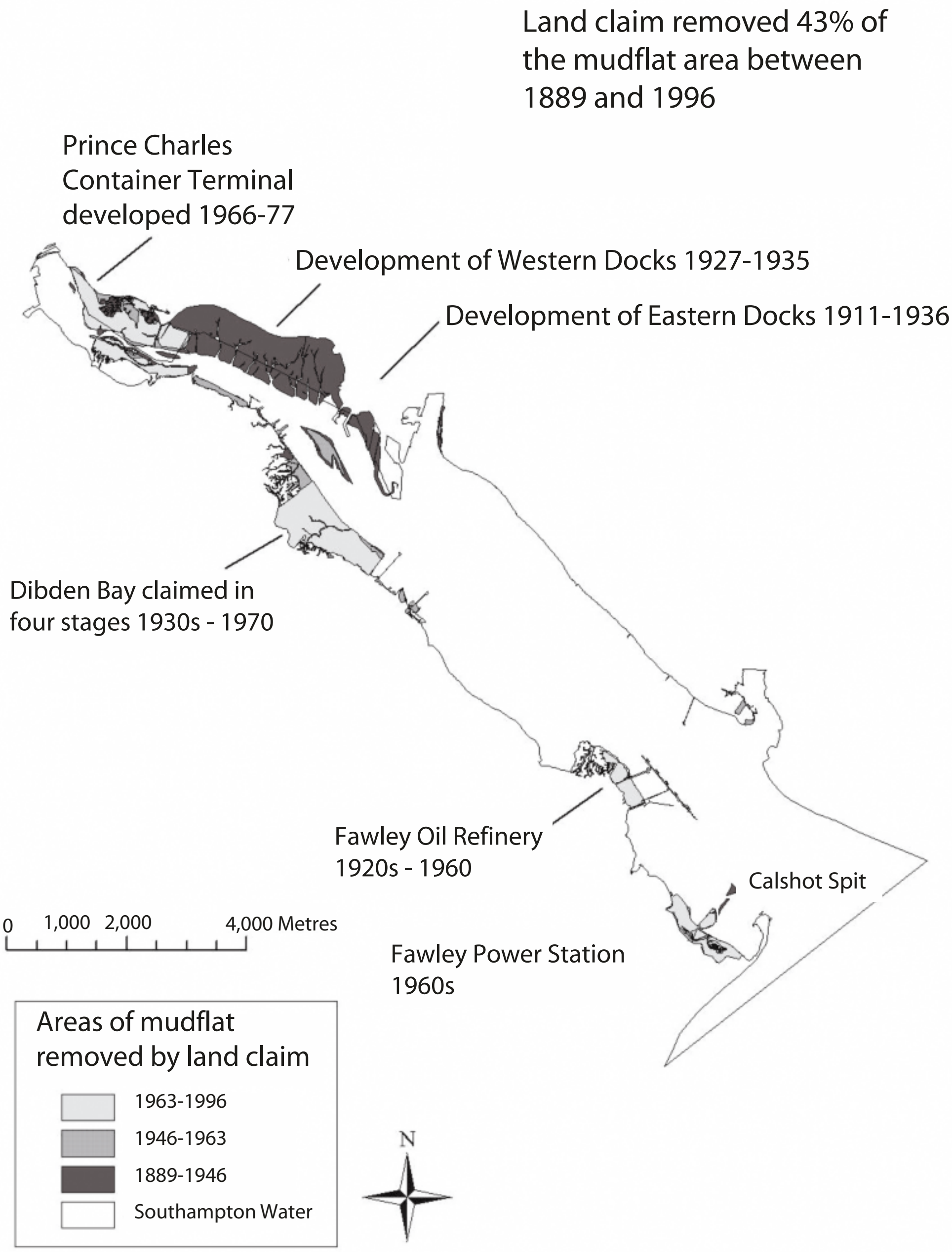

Land claim removed 43% of the mudflat area between 1889 and 1996
Prince Charles Container Terminal developed 1966-77
Development of Western Docks 1927-1935
Development of Eastern Docks 1911-1936
Dibden Bay claimed in four stages 1930s - 1970
Fawley Oil Refinery 1920s - 1960
Calshot Spit
Fawley Power Station 1960s
0
1,000
2,000
4,000 Metres
Areas of mudflat removed by land claim
1963-1996
1946-1963
1889-1946
Southampton Water
N

Figure 4.

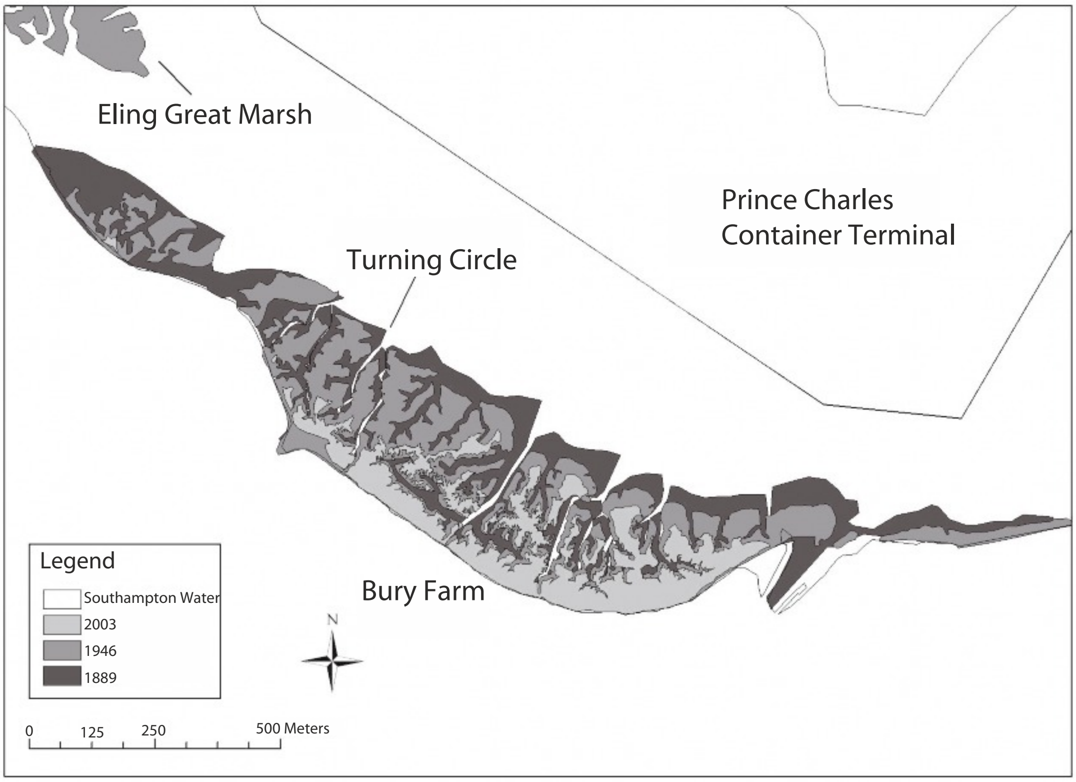
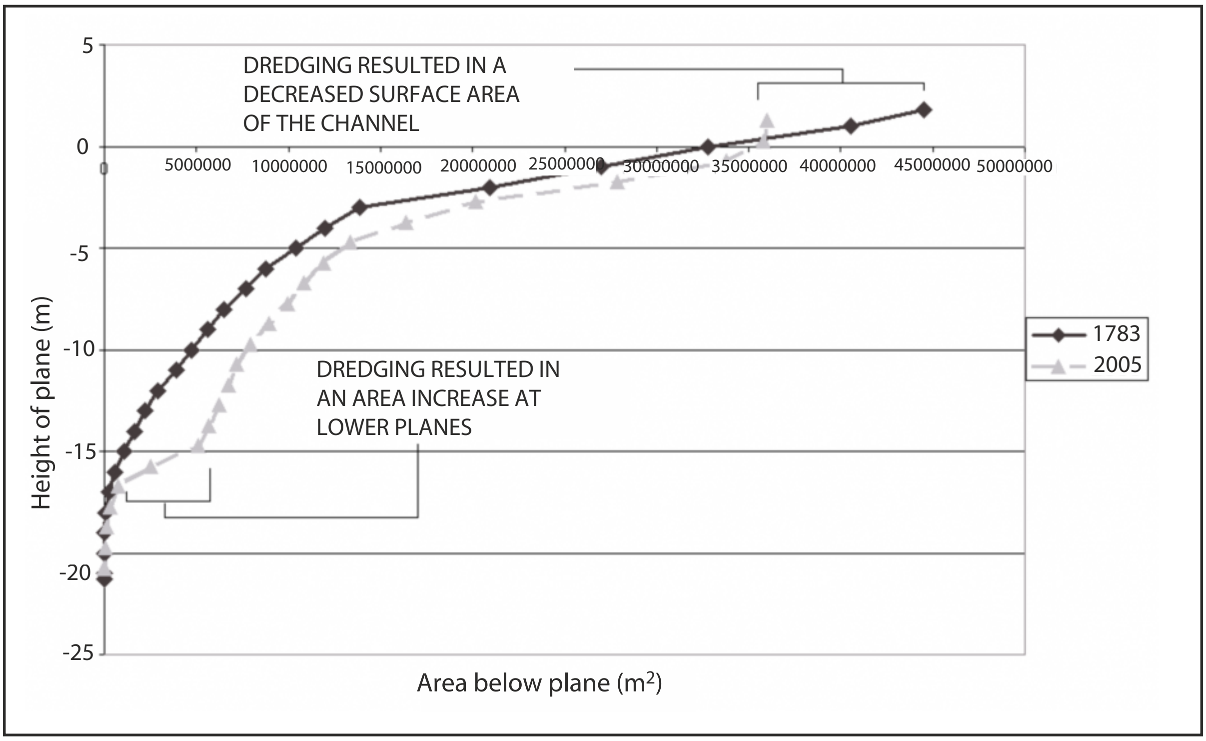


Figure 5.



Future Work

Quantification of the change in the historic sediment budget for Southampton Water is needed to fully understand the relationship between port activity and sediment storage within the estuary. The accuracy of survey methods has increased over the past 100 years and, although the trends of channel and intertidal zone change can be seen, further work is needed to quantify the associated error.

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Reference

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Solent Protection Society

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