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Project identification

1. Defra Project code: FD 1922
2. Project title: Managed realignment at Tollesbury
3. Contractor organisation(s):
   Center for Ecology and Hydrology
   CEH Wallingford
   Crowmarsh Gifford
   Wallingford
   Oxon
   OX10 8BB. UK
4. Total Defra project costs (agreed fixed price): £ 107,219.00
5. Project: start date .... 14 April 2003
   end date .... 31 March 2008

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Executive Summary

7. The executive summary must not exceed 2 sides in total of A4 and should be understandable to the intelligent non-scientist. It should cover the main objectives, methods and findings of the research, together with any other significant events and options for new work.

This report presents the combined results of a continued programme of research into the ecology of the 'managed realignment' site at Tollesbury, Essex, on the east coast of the UK. The results should, therefore, be viewed in conjunction with those from the earlier work that was started in 1995, when the area was first exposed to inundation by sea-water, and reported in 2002 (Reading et al., 2002). During 2007, the final year of a 5 year monitoring programme, research was completed on sediment accretion and invertebrate colonisation by ecologists from the Centre for Ecology & Hydrology (CEH) and on soil/sediment strength and stability by Rothamsted Research.

Invertebrate colonisation

- The total number of invertebrate species recorded from within the Tollesbury managed realignment site (n=21) was higher than in the marsh (n=16).
- The mean density, per sample, of all but one of the species common to all eight sites was highest in those from the managed realignment site.
- There was a gradient, between the upper and lower shore levels, in the mean number of species found per sample, with the highest numbers occurring in the lower shore samples.
- After an initial high rate of increase in the total number of species found at Tollesbury, each year between 1995 and 1998, the rate declined between 1998 and 2007.

Sediment accretion studies

- Accretion on the Old Hall and Tollesbury saltmarshes, adjacent to the Tollesbury managed realignment site, continued at a rate of 3-4mm/year. There was no significant difference in the rates of change before and after the creation of the Tollesbury managed realignment site.
- Within the realignment site the accretion rate during 2006/07 (9.6mm) showed a decrease over that reported for 2005/06 (11.2mm). Since 1996 there has been a steady decline in the annual rate of sediment accretion of 1.6mm (0.6-2.1mm).
-

Saltmarsh monitoring

- Between 1995 and 2007 there were significant changes in the frequency of occurrence of some plant species in the saltmarshes adjacent to the realignment site they were not correlated with the creation of the realignment site.

- By 2007 13 ha of the 21 ha realignment site were covered by saltmarsh vegetation that comprised 21 plant species. The upper elevations of the realignment site were dominated by *Puccinellia maritime* whilst the lower elevations were dominated by *Salicornia europaea* agg. and *Spartina anglica*.

Soil studies

- Sediment strength and stability were measured during early September 2003 and early September 2007, over five different vegetation zones and along three transects within the managed realignments site at Tollesbury during its continued development as a saltmarsh and sediment ecosystem.

- Within the site, saltmarsh plants were found on sediments with shear strengths ranging from 5 to 70 kPa with both *Salicornia europaea* and *Spartina anglica* occurring over this entire range. Greater species diversity occured where the sediment was stronger than 30 kPa, but there were no significant plant communities where shear strength fell below 5 kPa.

- The colonisation of the lower elevation vegetation zones (c & d) in 2007 by *Spartina anglica* was associated with a reduction in shear strength and stability of the surface sediments compared with 2003 when *Salicornia europaea* was dominant. However, where *Spartina anglica* colonised the mud flat (zone e), strength and stability both increased.

- Creeks formed once the weak rapidly accreting sediment exceeded a critical depth of 20 – 30 cm on top of the much stronger underlying agricultural soil.

- The lower extent of the *Salicornia europaea* extended along the faster draining, stronger (up to 18 kPa) and more stable creek margins. There was some evidence that these plants may contribute to higher sediment strength. In 2007 the colonisation by *Spartina anglica* of the creek margins we characterised in 2003 resulted in the disappearance of these creeks. We found little evidence of significant creek formation in areas where *Spartina anglica* dominated.

Project Report to Defra

8. As a guide this report should be no longer than 20 sides of A4. This report is to provide Defra with details of the outputs of the research project for internal purposes; to meet the terms of the contract; and to allow Defra to publish details of the outputs to meet Environmental Information Regulation or Freedom of Information obligations. This short report to Defra does not preclude contractors from also seeking to publish a full, formal scientific report/paper in an appropriate scientific or other journal/publication. Indeed, Defra actively encourages such publications as part of the contract terms. The report to Defra should include:
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MANAGED REALIGNMENT – AN OVERVIEW OF THE TOLLESBURY PROJECT

INTRODUCTION

This chapter reviews some generic issues raised by the Tollesbury monitoring work. In addition to summarising the key lessons learned from Tollesbury, it attempts to draw some wider conclusions about the environmental aspects of managed realignment.

Rising sea levels, coupled with the high cost of maintaining sea defences, have led coastal managers to look for more cost effective and sustainable methods of coastal protection. Managed realignment has, over the past decade, been increasingly used to fulfil these requirements. Although the technique is now practised widely throughout north-west Europe (Wolters et al 2005a), the potential scale, and the design and siting of particular schemes remain fairly contentious issues, with some stakeholder disputes unresolved and disagreement about the wider impacts remaining (Scott, 2007; Townend & Pethick, 2002). Despite this, there remains a strong case for its use as a strategic tool for sustainable estuarine management, on both economic and nature conservation grounds.

When the Tollesbury project was conceived in the early 1990's, the only previous experience of managed realignment in the UK was the Northey Island scheme, further up the Blackwater estuary. Here, a short length of sea defence was removed, and 0.8 ha of grassland was re-exposed to tidal inundation (Dagely, 1995). Although the Northey Island site accumulated sediment and, over time, salt marsh plants colonised the area, uncertainties remained over the implementation and viability of larger schemes on low lying agricultural land. The Tollesbury site, along with the Orplands managed realignment site, was the first 'large-scale' managed realignment scheme in the UK (see E.A., 1999, for results from the Orplands project).

The main objective of the CEH-led research and monitoring programme, begun at Tollesbury in 1994, was to remove some of the uncertainties about returning agricultural land to intertidal habitat, and specifically to address the following questions (MAFF 1996):

- Will natural re-colonisation recreate saltmarsh within the managed realignment site and, if so, over what time scale?
- Is it possible to aid the processes of natural colonisation directly or indirectly?
- Will there be any deleterious effects to the existing saltmarsh?
- Will the hydraulic effects on the estuary/coastline be as predicted by modelling? And
- Will the form and sequence of sea wall removal minimise the possibility of any adverse effects on the adjacent estuary?

Here we deal mainly with the first three questions which relate to the ecological studies (see Reading et al 2002. for other results).

THE DEVELOPMENT OF SALT MARSH AND CHANGES IN PLANT COMPOSITION

Although the reliability of managed realignment as an appropriate technique for saltmarsh restoration has been under debate (Hughes & Paramor 2004; Morris *et al*. 2004; Wolters *et al*. 2005b), experience so far has shown that, where the elevation has been suitable, vegetation has colonised. The Tollesbury project has shown that, with fairly minimal pre-treatment and management, allowing tidal ingress through a simple, relatively small breach onto low-lying agricultural land will quickly produce intertidal mudflats which are colonised by saltmarsh plants.

After the sea defences were breached in 1995, the existing terrestrial vegetation within the realignment site was quickly killed with the reintroduction of tidal inundation. As part of the initial research programme, saltmarsh plants, seeds and turfs of saltmarsh vegetation were planted or sown on the site to assess whether a rapid cover of vegetation could be established, prior to natural colonisation (Garbutt et al. 2006; Reading et al. 2002). Establishment of the introduced plants and seeds was poor, and it was recommended that managed realignment sites in low energy environments, located near natural marshes should be left to regenerate naturally. Prior to tidal inundation, four treatments, replicating possible land use scenario's, were trailed. The treatments were; stubble left from a wheat crop; ploughed land; cultivated land (level, bare earth); and abandoned agricultural land with rye grass and ruderale species. Plant colonisation on the four different land use types was measured, with results showing shoot densities of *Salicornia* spp. were about 40% higher in the vegetated plots than plots left unvegetated. The remnants of the terrestrial vegetation, even when killed off by saltwater inundation, provided the best surface for initially trapping propagules and subsequently retaining seedlings. Future projects should consider leaving existing vegetation on the site prior to inundation, either uncut or a high cut, if mown. Experience has shown that areas of managed realignment sites compacted by construction traffic take longer to be colonised by saltmarsh plants in the early stages of site development. It is recommended that these areas are lightly cultivated prior to inundation.

The regeneration of saltmarsh vegetation after managed realignment relies on regular tidal inundation as the key agent for the dispersal of seeds and plant fragments into a site. Saltmarsh seeds can float in sea water for varying amounts of time, from a few hours to several months. Most seeds retain their viability in salt water and germinate when exposed to freshwater conditions. Experience from UK sites to date has shown that, after realignment, relatively rapid colonisation of pioneer and low marsh species occurs, provided they are present in a nearby source area and the elevation is suitable. Although several nationally scarce plant species were recorded within the Tollesbury site by 2007, colonisation of 'high marsh' species (e.g. *Armeria maritima*, *Plantago maritima*, *Juncus gerardii* and *J. maritimus*) was restricted, even though the elevation of the site was within these species' range. This was thought to be a combination of the species' relative scarcity in the local species pool, and subsequent low number of seeds available to colonise (Wolters et al. 2005c). In addition, a dense cover of *Puccinellia maritima* restricted the 'gaps' within the vegetation into which plants could colonise. The distribution of plant species on salt marshes is a balance between tolerance and competition and it appears that, within the realignment site, this has not yet been achieved.

The lack of less common, 'high marsh' species is not restricted to the Tollesbury site. Several studies have examined salt marshes that have regenerated on reclaimed land following breaches in embankments due to storm events as analogues for managed realignment. These reports show that, in some cases, it can take decades for plant communities to reach equilibrium with natural reference conditions, and the regenerated plant communities can lack certain species (Burd 1992; Onaindia *et al*. 2001). Garbutt & Wolters (2008) surveyed the plant communities of regenerated salt marshes within managed realignment sites, and sites of abandoned reclamations up to 107 years old, in Essex. In common with Tollesbury, plant diversity within the regenerated marshes was lower than in adjacent natural marshes, and was correlated with a greater abundance of *Spartina anglica*. The plant communities were, in general, representative of less diverse communities or those typical of lower elevations. It is perhaps surprising that given the low levels of plant species diversity found in the salt marsh flora, differences were detectable over such long timescales. This suggests that the vegetation communities may be relatively static or that severe disturbances are rare. Seedling recruitment in salt marsh communities is generally precluded in dense vegetation by competition from adults, as the Tollesbury experience shows. If the vegetation within the de-embankment sites is relatively static there may be little opportunities for new species to colonise.

The sparsely vegetated mudflats that typify the early phases of saltmarsh development within realignment sites provide ideal conditions for the establishment of *Spartina anglica*. Whilst *Spartina* is now currently accepted as an integral part of the flora of European salt marshes (Lacambra et al. 2004), its presence in the early stages of saltmarsh regeneration may be less desirable. The dominance of *Spartina* in the Tollesbury site, questions the ability of the regenerated marshes to 'function' in a way that reflects natural marsh processes. Restoration theory attempts to set criteria from which success can be measured, such as composition, sustainability, biotic interactions and nutrient retention relative to a 'natural' base line (Zedler, 2001). The establishment of *Spartina* early in the development of saltmarsh within managed realignment sites gives the regenerate marshes a very different starting point to that of natural marshes, and may affect the eventual outcome of habitat creation efforts. The results presented here should not be interpreted as the inevitable failure of saltmarsh creation schemes in matching reference conditions, but as a cautionary note that in fact, restoration efforts may never fully replace natural wetland functions. They will, however, almost certainly fulfil their intended purpose of providing coastal protection through the dissipation of wave energy and the provision of bird feeding areas. Whether managed realignment sites are any less valuable for nature conservation, or in the services they provide, requires further attention.

Effects on existing marshes

Whilst there were changes in the frequency of saltmarsh plant species growing on the Tollesbury marshes adjacent to the site, there was no evidence to suggest that the creation of the managed realignment site was the cause. Pre- and post-breach differences appear to be part of longer-term trends. The changes in frequency may be part of a natural cycle in response to population dynamics or may be a response to changes in the natural environment. The changes in plant frequency are occurring against a background of large-scale loss of saltmarsh in the region. It is estimated that the total saltmarsh loss, in Essex, between 1973 and 1998 exceeds 1,000 hectares (Cooper et al. 2001). There were increases in *Spartina anglica* and declines in *Atriplex portulacoides* between 1994 and 2007, on the marshes adjacent to the site. Although these changes were not linked to the creation of the managed realignment site, the results raise issues about the long-term stability of the saltmarsh communities of the region and their ecology. The balance between sediment accretion and erosion, in relation to elevation, primarily determines the stability of saltmarsh communities. Whether the increasing frequency of *Spartina* into the system alters this balance, and the natural dynamics of the plant communities, remains uncertain.

SEDIMENTS

The rate of sediment deposition within managed realignment sites can be extremely rapid in the early phases of implementation, with up to 50mm per month being recorded at Paull Holmes, the Humber estuary, UK (Boyes & Mazik 2004). These rates are short lived however, with low lying areas predicted to build up sediment to find equilibrium profiles, around that of relative sea level rise (Temmerman *et al*. 2004). The Tollesbury managed realignment site appears to be responding in this way where the amount of sediment being deposited is reducing over time, from 31mm a year in 1995-96 to 9 mm a year by 2006-07. In time, the surface of the site would be expected to build up to a level equivalent to that of the adjacent natural marshes. This can be observed at the many 'accidental' breach sites in Essex, where sea walls have been breached by storm events in the past (e.g. the storms of 1953). The present level of the marshes regenerated within these sites is comparable to that of the adjacent natural marshes.

The build up of sediment within the site allowed a greater area of mud flat to be colonised by saltmarsh vegetation, presumably in response to an increase in elevation. Sediment infilling will have a long-term impact on the future of the site, both for the conservation interest and flood defence. The reduction in the area of mud flat will impact on feeding areas and roost sites used by birds within the site. By 2007, there was transition from mud flat through pioneer to low and mid marsh vegetation communities within the site (albeit dominated by *Spartina anglica*). This is uncommon in the Essex region where most saltmarshes are cliffed on their seaward edge leading to a scarcity of pioneer communities. If deposition continues, as expected, there will be a gradual infilling of the site up to the level of the surrounding marshes, with the consequent loss of the pioneer/low marsh communities. This process is probably inevitable, given a constant supply of sediment, but should be considered when mitigating for losses of pioneer communities elsewhere.

The natural salt marshes, adjacent to the Tollesbury managed realignment site, appear to be able to maintain their position in the tidal frame, despite projected eustatic changes. A constant rate of vertical accretion was recorded throughout the 14 year monitoring programme at around 3mm-4mm a year, similar to rates predicted by sea level rise for the region. There was no evidence that the creation of the managed realignment site had any effect on sediment deposition on the marshes adjacent to the site.

COLONISATION BY INVERTEBRATES

Whilst the creation of saltmarsh must be of primary concern when realigning seawalls for coastal defence objectives, the creation of intertidal mudflats is none the less valuable. Intertidal mud- and sand flats are important feeding areas for shorebirds, and some wildfowl, during the low water period when they are exposed, and for diving ducks and fish when they are submerged.

Initial colonisation of the Tollesbury managed realignment site by intertidal invertebrates was rapid. Fourteen species were recorded within the site, two months after the breach and 18 to 19 species a year there after until 2007. In 2007, 21 species were recorded in the site, with *Littorina littorea* (edible periwinkle) and *Palaemonetes varians* (a crustacean) recorded for the first time. In total, 31 species of invertebrate were recorded between 1995 and 2007. Species consistently recorded included, *Cerastoderma edule* (cockle), *Macoma balthica* (baltic telin), *Scrobicularia plana* (peppery furrow shell), *Eteone longa* (a bristle worm) *Nephtys hombergii* (cat worm), *Nereis diversicolor* (rag worm) and the common shore crab, *Carcinus maenas*.

The rate of establishment of intertidal invertebrates can be related to their mobility, both as adults and as juveniles, where many have planktonic larval stages. Colonisation of a newly created site also appears to be related to the availability of suitable sediments. At Tollesbury it was observed that invertebrate colonisation only occurred in the newly accreted sediments within the site, and were absent from the original, consolidated agricultural substrate. Mazik et al. (2007) recorded a species poor invertebrate assemblage, one year after the creation of the Paull Holme managed realignment site, composed predominantly of early colonising species of Oligochaeta and Nematoda (small worms), although a total of 20 species of invertebrate were recorded. More sedentary species, such as bivalves, rely on planktonic larval stages to colonise new sites and it may be several years before a stable population of these relatively long-lived species becomes established.

Atkinson et al. (2004) found that birds were quick to colonise the Tollesbury realignment site, either for roosting or to feed. In the first few years after realignment, waterbird assemblages were generally variable and large changes were observed adjusting to the biological and physical evolution of the site. Numbers of wading birds were low in the first year after creation but increased thereafter, reflecting the development of the invertebrate community within the mudflats of the site. Species such as knot and dunlin, which foraged on small polychaetes (worms), colonised the area before species, such as oyster-catcher and black-tailed godwit, which feed on larger bivalves. The subsequent development and establishment of stable bird communities will be determined by the evolution of the site and the availability of suitable prey species, or safe areas to roost. As sediment infilling continues, and saltmarsh plants continue to expand their range within the site, invertebrate diversity and abundance will adjust accordingly, and will be reflected in the species of birds that use the site.

SOIL STRENGTH AND STABILITY

Experience from the Tollesbury monitoring programme has shown that the key difference between saltmarsh creation through managed realignment and natural saltmarsh development lies in the former being based on soils which, although marine in origin, have over many years become terrestrial in their chemical and physical characteristics. The changes that occur during this process of desalination are many and varied, but the non-reversible changes are critical. These changes include the consolidation of the soil through irreversible drying and the loss of organic matter through oxidation. Although prolonged flooding will increase the moisture content, the soil may never return to its original state. Following the first six years of monitoring at the Tollesbury site, the underlying agricultural sediments were both very strong and highly resistant to erosion (Watts et al. 2003). It is thought that this ‘over consolidation’ forms a soil horizon with low hydraulic conductivity that restricts sub-surface drainage within the developing marsh sediments. As a result, the overlying, newly deposited marine sediments have a high water content and low critical shear stress (above which erosion is likely to occur). Within the Tollesbury site, saltmarsh plants were found on sediments with shear strengths ranging from 5 to 70 kPa. *Salicornia* spp. and *Spartina anglica* occurred over this entire range. Greater species diversity occurred where the sediment was stronger than 30 kPa, at the highest elevations.

The low strength and high water content of the sediment in the low lying areas of the site was thought to be a constraint to plant colonisation (Garbutt, 2006). Following an increase in the abundance of *Spartina* between 2003 and 2007, there was a fourfold increase in shear strength of the sediments from 0.6 kPa to 2.5 kPa; however, this sediment still remains very weak. Whether dewatering, or plant colonisation, led to the increase in soil strength is not clear. At the lowest elevations of the site, the sediment behaves rather like a viscous liquid. If the geography of the site changes, possibly as a result of secondary breaching in the original sea wall, there could be movement of sediment over the stable former agricultural soils. In 2007, there were several parts of the old sea wall that were less than 1 m wide, eroded by internally generated waves, and one area where the wall was around 0.75 m lower than the its original height.

Creeks are an important and integral part of saltmarshes, distributing sediments to the interior of the marsh, allowing aquatic organisms’ access to habitat, and providing drainage following tidal inundation. Because of the potential for sediments within managed realignment sites to have high water content, the development of a creek network appears fundamental to the establishment of saltmarsh vegetation. Creeks only appeared to form within the Tollesbury site in the newly deposited marine sediments and only when the sediment exceeded a critical depth (between 20 and 30 cm). This was probably due to the low velocity and sheet flow of the water in the first few years after the creation of the site. By 2003, the newly formed creeks had ribbons of *Salicornia europaea* growing on their banks, extending the lower limit of *Salicornia* below its main range in the rest of the site. This corresponded with a rapid drop in shear strength, 1 m from the creek centre line. In the presence of *Salicornia*, mean shear strength values were 18 kPa compared with 10 kPa where the banks were bare. The large increase in strength and stability in the creek margins was thought to be due to rapid drainage and consolidation of these margins. Here water content and bulk density were similar to soils, 0.5 – 1.0 m higher in elevation.

KEY FINDINGS

- With minimal pre-treatment and management, allowing tidal ingress through a simple, relatively small breach onto low-lying agricultural land will quickly produce intertidal mudflats which are colonised by saltmarsh plants.
- Managed realignment sites in low energy environments, located near natural marshes, should be left to regenerate naturally.
- Future projects should consider leaving existing vegetation on the site prior to inundation, either uncut or a high cut, if mown.
- Soils that are compacted during construction of managed realignment sites should be lightly cultivated prior to inundation, as compacted soils restrict plant colonisation.

- At Tollesbury, and other local managed realignment sites, plant diversity was lower than in adjacent, natural saltmarshes. The saltmarshes were, in general, representative of less diverse communities than natural marshes, or those typical of lower elevations.

- The establishment of *Spartina* early in the development of saltmarsh gives regenerate marshes a very different starting point to that of natural marshes, and may affect the eventual outcome of habitat creation efforts.

- There was no evidence to suggest that the creation of the managed realignment site was the cause of pre- and post-breach differences in plant species frequency.

- Sediment deposition rates within the realignment site appeared to follow expected patterns, where after initial high deposition, there was evidence of a slow down towards equilibrium profiles.

- There were no differences in pre- and post-breach sediment deposition rates on the natural marshes, adjacent to the site.

- Colonisation of intertidal invertebrates was rapid and after 2-3 years species richness had stabilised, although abundance changed through time. Invertebrates did not colonise the former agricultural soils.

- The underlying agricultural sediments of the Tollesbury site were very strong, highly resistant to erosion and probably form a barrier to sub-surface drainage, leading to water logging of newly accreted marine sediments.

- The development of a creek network appears fundamental to the establishment of saltmarsh vegetation.

References to published material

9. This section should be used to record links (hypertext links where possible) or references to other published material generated by, or relating to this project.

REFERENCES

Atkinson, P., Crooks, S., Drewitt, A., Grant, A., Refisch, M.M. Sharpe, J., Tyas, C.J., 2004. Managed realignment in the UK – the first 5 years of colonisation by birds. *Ibis* 146, 101 – 110.

Boyes, S., Mazik, K., 2004. Paull Holme Strays – accretion/erosion monitoring. Monitoring report to the Environment Agency. Institute of Estuarine and Coastal Studies, University of Hull, UK.

Burd, F. 1992. *Historical study of sites of natural sea wall failures in Essex.* Institute of Estuarine and Coastal Studies, English Nature Research Reports, No. 15. English Nature, Peterborough, UK.

Cooper, N. J., T. Cooper & Burd, F. 2001. 25 years of salt marsh erosion in Essex: Implications for coastal defence and nature conservation. *Journal of coastal conservation* 9, 31-40.

Dagley, J. R., 1995. *Northey Island managed retreat scheme*. English Nature Research Reports, No. 128, English Nature, Peterborough.

Environment Agency, 1999. *Results of post breach monitoring of Orplands coastal realignment*. Report to the Environment Agency by HR Wallingford.

Garbutt, R.A., Reading, C.J., Wolters, M., Gray, A.J., & Rothery, P., 2006. Monitoring the development of intertidal habitats on former agricultural land after the managed realignment of coastal defences at Tollesbury, Essex, UK. *Marine Pollution Bulletin* 53, 155-164.

Garbutt, A. & Wolters, M., 2008. The natural regeneration of salt marsh on formerly reclaimed land. *Applied Vegetation Science*. In press.

Hughes, R.G. & Paramor, O.A.L. 2004. On the loss of saltmarshes in south-east England and methods for their restoration. *Journal of Applied Ecology*, 41, 440-48.

MAFF, 1996. *Tollesbury Managed Realignment Experimental Site*, Summary Report on Research & Other Activities 1994-96, Ministry of Agriculture, Fisheries & Food, London.

Mazik, K., Smith, J.E., Leighton, A., Elliott, M., 2007. Physical and biological development of a newly breached managed realignment site, Humber estuary, UK. *Marine Pollution Bulletin*, 55, 564-578.

Lacambra, C., Cutts, N., Allen, F., Burd, F., Elliott, M., 2004. *Spartina anglica: a review of its status, dynamics and management*. English Nature Research Reports, Number 527, Peterborough, UK.

Morris, R.K.A., Reach, I.S., Duffy, M.J., Collins, T.S. & Leafe, R.N. 2004. On the loss of saltmarshes in south-east England and the relationship with *Nereis diversicolor*. *Journal of Applied Ecology* 41, 787-91.

Onaindia, M., Albizu, I. & Amezaga, I., 2001. Effect of time on the natural regeneration of salt marsh. *Applied Vegetation Science* 4, 247-56.

Reading, C.J., Gray, A.J., Paramor, O.A.L., Garbutt, R.A., Watts, C.W., Spearman, J.R., Barratt, D.R., Chesher, T., Cox, R., Hughes, R.G., Mann, J.L., Myhill, D.G., Rothery, P., Semmence, J. & Wolters, M., 2002. Managed realignment at Tollesbury and Saltram. Final Report. Defra/NERC contract. CSA 2313. Defra, London.

Scott C. R., 2007. *Wallasea wetland creation scheme: lessons learned*. Proceedings of the CIWEM Rivers and Coastal Group winter meeting: from Directive to detail: a joined-up response to flooding? London 26th January 2007.

Temmerman, S., Govers, G., Wartel, S., Meire, P., 2004. Modelling estuarine variations in tidal marsh sedimentation: response to changing sea level and suspended sediment concentrations. *Marine Geology* 212, 1-19.

Townend, I. & Pethick, J., 2002. Estuarine flooding and managed retreat. *Philosophical Transactions-Royal Society of London Series*, 360: 1477-1495.

Watts, C.W., Tolhurst, T.J., Black, K.S., Whitmore, A.P., 2003. In situ measurements of erosion shear stress and geotechnical shear strength of the intertidal sediments of the experimental managed realignment scheme at Tollesbury, Essex, UK. *Estuarine Coastal and Shelf Science* 58, 611-620.

Wolters, M., Garbutt, A., & Bakker, J.P. 2005a. Salt-marsh restoration: evaluating the success of de- embankments in North-west Europe. *Biological Conservation* 123, 249-268. Wolters, M., Bakker, J.P., Bertness, M.D., Jefferies, R.L. & Moller, I. 2005b. Saltmarsh erosion and restoration in south-east England: squeezing the evidence requires realignment. *Journal of Applied Ecology* 42, 844-51.

Wolters, M., Garbutt, A., Bakker, J.P., 2005c. Plant colonization after managed realignment: the relative importance of diaspore dispersal. *Journal of Applied Ecology*, 42, 770-77.

Zedler, J.B. 2001. *Handbook for restoring tidal wetlands*. CRC Press. New York, US.