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SID 5 Research Project Final Report

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Project identification

1. Defra Project code: FD1911
2. Project title: Freiston Shore Managed Realignment
3. Contractor organisation(s):

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4. Total Defra project costs (agreed fixed price): £ 186,470
5. Project: start date .... 01 September 2001
   end date .... 01 February 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.

The aims of the Freiston shore managed realignment scheme were:

- To create a sustainable flood defence scheme through the establishment of salt marsh
- To establish a salt marsh community of botanical value, and to provide a suitable habitat for invertebrates and birds
- To avoid adverse impacts on existing habitat on adjacent salt marsh and mudflat
- To establish new brackish water habitat by creating a lagoon landward of the realignment site (monitored by RSPB)

The main objectives of the part of the monitoring programme led by CEH with CCRU were set out by Halcrow Ltd. for the Environment Agency and were as follows:

- To monitor the natural development of the salt marsh in the realignment site
- To check that there are no adverse impacts of the scheme to the existing adjacent salt marsh

This was to be achieved initially by monitoring sedimentation and vegetation colonisation and establishment inside the realignment site and outside the site along permanent transects. Later in the programme annual invertebrate and fish surveys were also undertaken. A more detailed explanation of these methods is included in section 9 of this form. Results and conclusions are also included in section 9, however the main findings of the monitoring programme are detailed below :

Sedimentation measurements:
Accretion trends within the site were comparable with those in the existing salt marsh neighbouring the site. The marsh-mudflat transition zone showed fluctuating sediment levels, typical of this dynamic area. Nearest to the central breach anomalously high levels of sedimentation were recorded in the first 2 years, resulting from washed in material from the eroding breach and widening creeks.

Vegetation colonisation of the realignment site.
Vegetation establishment has been highly successful (where no standing water). All common species are widespread in the realignment site. Pioneer annuals were first to colonise in 2003; replaced by a succession of expected perennial species, particularly at higher elevations. The mean total vegetation cover (calculated from the sum of individual species cover, which can exceed 100% in dense and diverse vegetation due to overlapping species) for all sites together inside the MR has increased from 37% in

2003 to 86% in 2006. Mean total cover of all sites outside at the equivalent elevation range (2.7-3.3mODN) varied between 95% and 97% over 5 years of monitoring. At the current rate of establishment coverage is estimated to match the outside salt marsh by 2010, although achieving equivalent vegetation community composition will take more time

Invertebrate colonisation of the realignment site.
The majority of invertebrate taxa present on the existing salt marsh had, by 2006, colonised the managed realignment (MR).

Fish utilisation of the realignment site.
Studies showed that the managed realignment acts as an important nursery habitat for a range of different fish species, including bass, sprat and herring, throughout the entire tidal cycle.

Data on fish and invertebrates was restricted due to the limitations of sampling representative communities inside and outside the site at difference elevations and tidal levels. Such work would suit more intensive post-graduate research.

Sediment properties: grain size, total N, organic matter and moisture content.
The sediment properties in the MR site were comparable to the salt marsh outside of the MR at equivalent elevations.

Creek and drainage development
Creek and drainage development were not monitored quantitatively, however, observations were made during the study. Prior to breaching ploughing and raking was undertaken to remove furrows and prevent channelling of water. In addition, some creeks were excavated to join up with the breaches. Since the breach the these creeks have rapidly developed with new creeks forming.

Conclusions and Recommendations:
Time and spatial scale of monitoring
The length and spatial scale of monitoring at Freiston provided meaningful data on salt marsh development. The sedimentation measurements produced reliable long-term trends which can be difficult to extract from the 'noisy' annual variations in accretion rates.

Monitoring methods
Elevation in relation to the tidal frame is a significant factor for salt marsh vegetation establishment and survival. Combining the vegetation surveys at Freiston with the sediment monitoring and measurements of elevation was highly effective for explaining the data and comparing the developing realignment site with the adjacent salt marsh.

In contrast to realignment sites elsewhere, vegetation rapidly developed at Freiston. Monitoring ascertained that vegetation development resulted from both site elevation and the abundance of propagules from adjacent marshes. Propagule abundance is not frequently monitored at realignment sites, however data from Freiston demonstrates the importance of the data.

Drainage and creek development
Early development of an efficient drainage system may be critical for successful salt marsh creation. Creeks supply the marsh surface with sediment and nutrients, dissipate tidal energy and drain the marsh during the ebb tide. Good drainage increases sediment stability and reduces waterlogging which is detrimental to plant colonisation.

Drainage and creek development is an area where more research is required, specifically on hydrodynamic and topographic attributes (e.g. design of optimum breach widths in relation to the volume capacity) and on internal site features such as slope, creek profiles, creek densities and design. This is particularly important if the size of future realignment sites becomes more ambitious.

Realignment scheme management
Freiston provided an excellent case study of partnership working and site acquisition between HMP, RSPB, Defra and the Environment Agency.

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:

- the scientific objectives as set out in the contract;
- the extent to which the objectives set out in the contract have been met;
- details of methods used and the results obtained, including statistical analysis (if appropriate);
- a discussion of the results and their reliability;
- the main implications of the findings;
- possible future work; and
- any action resulting from the research (e.g. IP, Knowledge Transfer).

This summary covers two reports (Brown *et al.* 2007, for the period 2002-2006; and Brown 2008, for the 2007 survey) produced for the Environment Agency on the results from monitoring the development of the Freiston managed realignment site since it was breached in August 2002. Each of the two reports contains a summary at the front of the reports.

Comparisons were made with the adjacent salt marsh to assess the progress of the realignment site and to ensure that there were no unexpected adverse effects on the existing salt marsh. The monitoring programme comprised measurements of sedimentation (accretion/erosion); vegetation colonisation, establishment and succession; invertebrate colonisation; and fish utilisation of the realignment site.

The survey in 2007 was limited to one accretion and vegetation survey inside the realignment site only, so in summarising the two reports together here, the summary results are given for the findings after four years (up to 2006) so that the realignment site can be compared with the adjacent salt marsh, and also for the additional accretion and vegetation data for the final year of monitoring in 2007 inside the realignment site.

Six permanent transects were set up outside the realignment site and five transects were initally set up inside the realignment site. An additional transect was set up inside the site in 2004 to fill in the largest gap between transects. This area could not be set up initially due to contractors with earth moving equipment creating a twin-branched creek leading to the central breach. Permanent monitoring sites were set out along the transects, to measure accretion and to survey vegetation. The elevation of each site was measured in 2005 using an RTK GPS.

Accretion/Erosion measurements

Accretion was measured by the Centre for Ecology and Hydrology (CEH) using 5 buried expanded steel plates positioned randomly along a 5m strip at each sampling site. Accretion measurements were taken twice annually, in spring and autumn from spring 2002 outside the realignment site and from autumn 2002 inside the realignment, up to autumn 2006. In 2007, funding was limited to taking one set of measurements in autumn in the realignment site only (although CEH measured the sites in spring 2007 and the results are included in the accretion graphs in Brown 2008). At each survey interval five readings were taken down to each of the five plates at each site to calculate an average value for each plate. The site means and standards errors were calculated from the average values for the five plates. At the front of the marsh on the mudflat, which is dissected by numerous small channels, accretion was measured between five pairs of levelled canes, using a builder's level placed in a precise position on the canes and made level in all planes (using wire extensions for support). Measurements were taken from the level to the sediment surface from 5 positions on the level. The mean site value was calculated from the average values for each pair of canes.

All vegetated salt marsh sites outside the realignment have shown continued accretion during the monitoring period, ranging between 7mm and 100mm in four years between September 2002 and 2006, depending upon their position on the marsh. The lower pioneer marsh-mudflat transition zone showed fluctuating sediment levels between years, typical of this dynamic area.

All sites inside the realignment have accreted sediment since the initial baseline measurements, with 25 out of the 30 sites set up initially in 2002 building up between 5.5mm and 56mm over four years to September 2006, depending upon their positions along the transects. Five sites nearest to the central breach showed anomalously high levels of sedimentation (from 82mm up to 198mm after 4 years). Deposition here was particularly high in the first 1-2 years following the breach and was almost certainly supplemented by material deposited from the eroding breach and extensive creek erosion and widening in this area. Elsewhere in the realignment site sediment accretion has been relatively steady except at two waterlogged sites which have been under several centimetres of water and showed fluctuating values. After 5 years (by September 2007) 25 out of the 30 sites set up in 2002 built up between 6mm and 73mm of sediment, depending upon their positions along the transect gradients. The five sites influenced by washed in material from around the central breach had accreted from 99mm up to 215mm of sediment.

The elevations of sites inside the realignment were measured in 2005 and ranged from approximately 2.76mODN to 3.26mODN. Sites outside cover a greater elevation range, from 2.09mODN to 3.29mODN. Elevation is of key importance for the amount of accretion on vegetated salt marsh, so to compare summary results for accretion inside and outside the realignment, the sites outside were divided into two elevation categories: >2.75-3.3mODN (equivalent to the realignment site) and <2.75mODN.

Mean annual accretion rates (September to September) were calculated for the realignment site and the values were adjusted to 52 week intervals. When all sites in the realignment were included in the calculations, the mean annual accretion rate was highest in the first year (2002 to 2003) at 16.7mm, but dropped to between 7.4mm and 10.7mm in the four subsequent years (9.0mm in 03-04; 7.4mm in 04-05; 9.2mm in 05-06; and 10.7mm in 06-07). When the two underwater sites and the five anomalous sites around the central breach were excluded from the calculations, the mean annual accretion rate in the first year was reduced to 8.1mm and in subsequent years the mean annual accretion rate varied between 5.7mm and 8.4mm with no consistent trends (6.7mm in 03-04; 5.7mm in 04-05; 7.8mm in 05-06; and 8.4mm in 06-07).

Outside on the salt marsh at the equivalent elevation range (2.7-3.3mODN) the annual accretion rate was 9.9mm in 2002-3 and varied between 5.6mm and 8.2mm from 2003 to 2006 (7.1mm 03-04; 5.6mm 04-05; 8.2mm 05-06).

The rates inside the site (excluding the outliers) were similar to those outside and the inter-annual variations in accretion matched the pattern outside.

There was a highly significant inverse relationship (as expected) between accretion and elevation outside the realignment, and also inside the site once the major outliers (high accretion sites near the middle breach) were removed. The data overlapped between approximate elevations of 2.95-3.2mODN, but at lower elevations accretion was higher in the more sheltered conditions of the realignment site than on the more exposed salt marsh outside.

On average, winter accretion was found to be higher than summer periods both inside and outside the realignment site. Several (pre- and post-depositional) factors may contribute to this including lower levels of suspended sediment in summer, post-depositional dewatering and compaction, and erosion (lifting) of dry cracked surface layers in summer.

In conclusion, the data showed that accretion rates inside the realignment site (excluding the high deposition sites influenced by the central breach) were in general comparable with rates outside, although slightly higher inside the sheltered realignment site at lower elevations. The overall similarities in accretion rates over most of the elevation range and the matched pattern of natural inter-annual variation inside and outside the realignment indicated that accretion has been occurring at expected levels on the newly created salt marsh.

Surface elevation change measurements (SET technique)

Measurements of surface elevation change using the Sedimentation Erosion table (SET) technique were made by the Cambridge Coastal Research Unit (CCRU) at Freiston Shore between November 2002 and September 2006. Strong spatial and temporal controls on surface elevation change were apparent, both outside and inside the managed realignment site.

Patterns of elevation gain and loss were highly dynamic on unvegetated mudflat surfaces outside the managed realignment site. Permanently vegetated salt marsh surfaces outside the site showed long-term (November 2002 – September 2006) mean elevation gains of 4.5-7.8mm at sites north and south of the managed realignment ('far field') and 23.6-24.4mm at sites fronting the site and between the major channels draining the breaches ('near field'). At the near-field sites the progressive gains in surface elevation seen until June 2004 have been replaced by patterns of seasonal variation in surface elevation change similar to those seen at the far-field sites.

Sites within the managed realignment site close to breaches showed long-term (November 2002 – September 2006) surface elevation gains of 30–101mm. By comparison, more isolated sites to the rear of the managed realignment site have shown elevation gains (November 2002 – September 2006) of 6.9– 8.9mm. High gains (33.4mm), however, have characterised one internal site close to the head of an excavated channel, suggesting the importance of artificial creek networks in supplying sediments to breach-distant internal locations relatively high in the tidal frame. CCRU reported that a site close to, and north, of the central breach and a site in the northwest corner of the site have both shown minimal surface elevation change since April 2005, suggesting that sediment supply to the northern half of the site may have changed adversely since this time.

However, data from the CEH plate sites in this northern region showed no evidence to indicate any problem with sediment supply. Also, a creek has since formed near the SET site north of the central breach and the northwestern corner of the site is the highest elevation area of the site, where accretion has been low because of the elevation.

Measurements of surface elevation change (SET data) could not easily be compared with the measurements of surface accretion (buried plates) as the SET site elevations were not all known at the time of reporting. However, two sets of SET and plate sites within 10m distance from each other showed very close agreement between mean total surface elevation change and mean total net accretion over a similar monitoring time period, and other sites within approximately 30m of each other were also in good overall agreement. The SET elevations have since been measured by CCRU and they will be comparing data from the two methods.

Vegetation colonisation of the realignment site

The entire managed realignment (MR) site lies at an elevation suitable for salt marsh vegetation to grow and all were vegetated (by 2006) except for two sites which have been covered with standing water. All mean values given in this summary exclude these 2 sites.

Vegetation was surveyed annually in September by CEH in 5 x 1m^2 quadrats laid over the accretion plate sites both inside and outside the realignment site. The percentage cover of each vascular plant species and bare ground (also permanent water, algae and litter) was recorded in each quadrat by two people until agreement was reached. Species occurring at a cover of <1% were recorded as present (+) and given a value of 0.2% in the database. Where accretion was measured between pairs of canes a 1m^2 quadrat was placed between each pair of canes (with 0.75m in front and 0.25m behind, to avoid trampling in the quadrat area when taking the accretion measurements).

Larger 5m x 5m quadrats (divided into 25 x 1m^2 cells) were set up outside the realignment site to provide ground reference data for remote sensing (e.g CASI images). The presence of each plant species within each of the 25 cells was recorded and tabulated as the frequency of occurrence (also the occurrence of algal mats, bare mud or litter with a cover value greater than 10% in a cell) and the total percentage cover was estimated for the entire 25m^2 quadrat. Nine 5m x 5m quadrats were set up inside the realignment in 2003 and an additional quadrat was added in 2005.

The vegetation data summarised below refers to the 5m x 1m^2 quadrats, although additional information from the larger quadrats is mentioned where relevant.

By 2006, the mean percentage ground cover (100% - bare ground estimate) in the 5 x 1m^2 quadrats at sites inside the MR ranged from 7% at one site first colonised in 2006 (poor drainage in previous years), followed by 39% at the next most sparsely vegetated site, up to 98-99% at three sites in the highest part of the realignment. Thirty two of the 34 vegetated sites were covered with 60% vegetation or more, of which 25 sites had more than 80% ground cover and 11 sites more than 90%. Sites outside on the salt marsh in the same elevation range, varied between 80% - 98% mean total ground cover.

By 2007, the lowest mean total percentage vegetation ground cover (100 - % bare estimate) was 23% at the site first colonised in 2006 up to 97% in one of the highest elevation sites. Vegetation ground cover has increased between 2003 and 2006 at the monitoring sites. Some sites showed a slight decrease in ground cover in 2007 compared with 2006, due to a drop in cover of pioneer annuals which are being replaced by typical perennial salt marsh species, but the spread in cover of the latter was not always sufficient to offset the decline in the initial colonisers. The mean total ground cover (100% - bare estimate) for all sites in the MR increased from approximately 40% in 2003 to 84% in 2006 (81% in 2007).

The mean total vegetation cover (calculated from the sum of individual species cover, which can exceed 100% in dense and diverse vegetation, see text in reports for more explanation) for all sites in the realignment has increased from 37% in 2003 to 86% in 2006 and 89% in 2007. Mean total cover outside on the salt marsh at the same elevation range varied between 95% and 97% over 5 years of monitoring between 2002 and 2006.

The continued increase in vegetation cover in the realignment site appears to be on track for cover to reach an equivalent value to that outside at the same elevations by about 2010. However, it may take longer for the realignment site to reach equivalent vegetation community composition.

As elevation is of key importance for plant establishment and species zonation, mean total vegetation cover was calculated for three different elevation ranges. The outside salt marsh was not included in the 2007 monitoring requirements, so the realignment data for 2007 were compared with the outside vegetation surveys between 2002 and 2006.

On the pioneer salt marsh outside the realignment at <2.7mODN mean total vegetation cover was similar in 2002 and 2003 (approximately 33%) but has since increased, reaching 61% in 2006. There is no equivalent of this elevation range inside the realignment site.

In the lower half of the elevation range inside the MR (2.7-2.99mODN) mean total vegetation cover in the realignment site had increased to 72% in 2006 and 80% by 2007, still lower than the mean cover outside on the salt marsh at this elevation, which was 93% in 2006. Mean total cover decreased slightly in the MR between 2004 and 2005, due mainly to a large decrease in annual *Salicornia europaea* cover in 2005, and a decrease in the size of the annual plants (*Salicornia europaea* and *Suaeda maritima*).

At 3.0-3.15mODN mean total percentage vegetation cover inside the MR had reached 87% by 2006 and 90% in 2007, compared with 97% outside in 2006 (range 02-06 outside: 97-105%). Vegetation cover levelled off between 2004 and 2005 inside the MR due to lower *Salicornia europaea* cover although other species had increased to partially offset this decline.

Vegetation spread was most rapid at the highest elevation category (3.16-3.3mODN) inside the realignment site and had reached a mean total cover value of 98% by 2005, which has changed little since (98% in 2006, 97% in 2007) and which was comparable with cover values outside (98-104%) at this elevation range.

Sixteen out of the 17 species found on the salt marsh outside the realignment site, had been noted in the realignment site by 2006. The exception was *Triglochin maritima* (Sea Arrow-grass), which was only seen occasionally on the outside marsh. All of the common / abundant species outside were also common in the realignment site.

Up to eleven species in total were recorded overall in the realignment quadrats between 2003 and 2007, although not all were found in all years (8 to 10 species in a single year, 9 in 2007). A total of 12 species were recorded in the 9 larger (5 x 5m) quadrats over the years of monitoring (8-11 species in different years). Nine species were recorded in the quadrats on the salt marsh in all years, of which the 7 most abundant were also common inside the MR.

The mean species number recorded in the MR site 5m x 1m^2 quadrats increased from approximately 4.3 in the first two years to 5.71 in 2006, equivalent to the mean values recorded in the quadrats outside (5.46-5.77) between 2002 and 2006 at the same elevation range (2.7-3.3mODN). Mean species number was 6.09 inside the realignment quadrats in 2007.

In the lowest elevation category (2.7-2.99mODN, excluding flooded site TFS1), mean species number in the realignment quadrats had increased from 2.88 in 2003 to 5.09 in 2006. By 2007 mean species number was 5.73, within the range found outside (5.31-6.15) between 2002 and 2006.

At 3.0-3.15mODN (excluding underwater site TBS1) mean species number increased from 4.1 in 2003 to 5.83 in 2006, comparable to the mean number for the salt marsh outside (5.50-5.83). Mean species number increased further in this elevation range in the realignment site by 2007 to 6.17.

At the highest elevation category (3.16-3.3mODN), mean species number varied between 5.46 and 6.27 from 2003 to 2006, and was 6.36 in 2007. These mean values were higher than the range outside the realignment on upper sites (5.29-5.43).

The pioneer annuals were the first to colonise the realignment site and *Salicornia europaea* and *Suaeda maritima* were the dominant species throughout the site in 2003, at all elevations. Between 2003 and 2006, these pioneer annuals remained the most abundant species at lower elevations in the realignment, although by 2007 *Puccinellia maritima* had spread to become the second most abundant species after *Salicornia europaea* (overtaking *Suaeda maritima*) in the lowest elevation range category. Perennial species have established and spread, particularly at the higher elevations, where the annuals have been replaced by *Puccinellia maritima* as the dominant species. *Atriplex portulacoides*, extremely abundant outside on the salt marsh at higher elevations has shown a steady increase at higher elevations in the realignment site, and by 2006 was the second most important cover species after *Puccinellia* in the highest elevation range category (3.16-3.3mODN).

The species mix in each elevation range was similar inside and outside, although the relative species abundances were still different by 2007, particularly for the dominant species in the two upper elevation categories. At the lowest elevation range (2.7-2.99mODN) the two annual pioneer species, *Salicornia europaea* and *Suaeda maritima*, were the most important cover species both outside and inside the realignment to 2006 (*Puccinellia maritima* had just overtaken *Suaeda maritima* in cover abundance in the realignment in 2007). The main difference between the realignment site and the salt marsh outside at the lower elevation range was that *Salicornia europaea* and *Puccinellia maritima* cover have decreased outside (*Salicornia* since 2002, *Puccinellia* since 2004). In the realignment site *Puccinellia maritima* was still increasing in cover by 2007, although *Salicornia europaea* was at a similar cover value to that in 2006. *Aster tripolium* and *Spartina maritima* were found at greater mean cover outside than inside, but they have both been increasing in cover inside the realignment each year. *Atriplex portulacoides* has increased in cover both outside and inside the realignment site in this elevation range.

The main difference between the salt marsh and realignment site at elevation range 3.0-3.15mODN was that *Puccinellia maritima* was dominant in 2002 outside on the salt marsh but subsequently decreased in mean cover along with *Salicornia europaea*, while *Atriplex portulacoides* increased its cover to become the most abundant species by 2005 and increased its cover further by 2006. In the realignment quadrats, *Puccinellia maritima* spread very rapidly between 2003 and 2005 to become the most abundant species and has continued to expand its cover. *Atriplex portulacoides* has also increased its mean cover steadily each year but was still at a much lower cover value than outside in 2007 at this elevation range.

The main difference between outside and inside the realignment in the upper elevation range category (3.16-3.3mODN) was that *Atriplex portulacoides* was the most abundant species from 2002 on the salt marsh outside and has increased its mean cover steadily while *Puccinellia maritima* has decreased in cover. Inside the Freiston realignment, *Suaeda maritima*, followed by *Salicornia europaea* were the dominant species in 2003, but both have decreased in cover since to values similar to outside the site by 2007. *Puccinellia maritima* spread rapidly to become the most abundant species by 2005 although its cover has changed little since, and it may have reached its peak cover abundance. *Atriplex portulacoides* has spread steadily to become the second most important cover species by 2006, and may replace *Puccinellia maritima* as the dominant cover type in future.

The 5 x 1m^2 2006 quadrat data at each individual site in the MR and outside were compared according to their NVC community designations and the order of the most abundant species (>10% cover) at each site.

The comparisons re-inforced our findings from the mean cover values and showed that there was considerable agreement in species composition and dominant species between the realignment and outside, and in several cases the equivalent NVC designations were found. The greatest similarities between the realignment site and outside were in the lowest elevation category. Higher sites above 3mODN in the MR had a similar species mix to outside, but as noted above, relative abundances of species were still different in 2006 and most of the sites were still undergoing succession to achieve the typical dominant perennial species and typical NVC communities found outside.

The overall impression from the species composition data according to elevation category and comparison of community designations was that succession of perennial species in the upper half of the elevation range of the site has been occurring rapidly and (by 2006) to a rough approximation was one ‘elevation category’ behind the community composition outside the realignment. It is difficult to predict how long it will take for the MR site to reach equivalent species abundance and community types, but in the four year report up to 2006 (Brown *et al.* 2007) it was suggested that if the major perennials continue to spread at the rates observed in the realignment site between 2003 and 2006, the communities (and relative species abundances) could be equivalent to those outside at the same elevations within (approximately) a further five years (by about 2012). The results from the final year (2007) survey indicate that community trends have continued to progress towards a closer match with the adjacent salt marsh.

The composition of species and succession in the larger 5 x 5m quadrats is described in the reports and the trends observed in these quadrats were similar to those reported for the smaller quadrats. Between 2.7-2.99mODN the quadrats were dominated by *Salicornia europaea*, followed by *Suaeda maritima*, and these annuals have persisted as the most abundant species between 2003 and 2006. At >3.0-3.3mODN the early dominance of *Suaeda maritima* and *Salicornia europaea* was overtaken by *Puccinellia maritima* by 2005 as the most abundant species, with a very rapid increase in the *Puccinellia* between 2004 and 2005, particularly in the highest sites in this category (>3.2mODN). One of the two sites lying above 3.3mODN was colonised by *Elytrigia atherica* in 2003 and this species has increased and retained its dominance, while the annuals have decreased to very low cover. The other site was set up in 2005 to provide ground reference data for an area with *Atriplex portulacoides* as the dominant plant and this species has increased its cover between 2005 and 2006.

One of the 5 x 1m^2 quadrats at each site was divided into 100 (10cm x 10cm) cells and the presence of each species was recorded for each of the cells to give a percentage frequency of occurrence. This gives an indication of distribution across the quadrat. All of the main species increased in frequency between 2003 and 2006 (no further measurements after 2006), and perennial species such as *Puccinellia maritima* and *Atriplex portulacoides* increased in both frequency and cover as they have spread across the quadrats, with the most rapid increase at mid and upper elevations. The relationship between frequency and cover was different for the annuals, *Salicornia europaea* and *Suaeda maritima*. Frequency increased rapidly as more individuals colonised all parts of the quadrat but cover of *Salicornia europaea* declined in some years even when frequency increased, and frequency of *Suaeda maritima* at higher elevations increased at the same time that cover decreased year on year. The main reason for the mismatch was due to a marked decrease in the size of these annual plants from larger and fewer individuals in the early years of colonisation, to more frequent but much smaller specimens as the site developed with other competing species.

In conclusion, vegetation establishment and spread within the Freiston realignment site has been highly successful. All common species found outside the site have been found inside, and were present at their expected elevations. Mean species number was comparable between the realignment and the salt marsh, and even greater inside at the highest elevation sites. Perennial plants have been increasing their cover year on year and replacing the annual pioneer species as the most abundant cover types, particularly in the upper half of the elevation range, and some sites were approaching similar community compositions to the outside marsh by 2006-2007. Time will tell whether the site continues to develop to reach the equivalent vegetation community types and diversity on the adjacent salt marshes in this area of the Wash. There appears to be no reason or indication to suggest that it will not.

Invertebrate colonisation of the realignment site

Invertebrates associated with salt marsh were sampled adjacent to each site on all of the transects within the managed realignment and also adjacent to the upshore portion of sites from a selection of the transects on the established salt marsh outside the realignment.

Invertebrates were sampled by three methods: pitfall traps placed in the sediment for 3 days during neap tides; sediment scrapes between the salt marsh plants; and sweep netting of vegetation.

The majority of littoral and salt marsh invertebrate taxa found on the existing salt marsh outside the breached sea wall had, by 2006, colonised the managed realignment. The five species that were not detected inside were only found infrequently outside in very low numbers, and were not widely distributed, so their absence from the managed realignment samples may not be significant.

Littoral and salt marsh invertebrate taxa that were widely distributed inside the managed realignment were also widely distributed outside and there were no littoral and salt marsh invertebrate taxa which were widely distributed outside the sea wall but not within the managed realignment.

Several littoral and salt marsh species have increased in abundance in the samples taken inside the site between 2002 and 2006, these were *Carcinus maenas* (shore crab), springtails, the beetles *Dicheirotrichus gustavi* and *Pogonus chalceus*, *Hediste diversicolor* (ragworm), *Hydrobia ulvae* (laver spire shell) and plant bugs/hoppers. Other taxa that have increased in abundance inside the managed realignment were nematodes, flies and unidentified oligochaete worms (which may include littoral/salt marsh species). None of these taxa (except unidentified oligochaete worms) were caught in increasing numbers over this time period outside of the breached sea wall.

Therefore, the diversity, abundance and distribution of invertebrates across the managed realignment have increased significantly between 2002 and 2006. Comparisons with data assimilated in parallel from the marsh outside the breached sea wall indicated that these increases were a consequence of invertebrate taxa colonising suitable newly-available and developing habitats within the managed realignment.

There was no clear correlation within the managed realignment between marine sediment depth and numbers of burrowing invertebrates found, and observations during the sampling periods indicated that these organisms were able to bury into the agricultural soil beneath the accumulating marine sediment, and so were not dependent on the latter for colonisation.

Fish utilisation of the realignment site

In order to identify those species utilising the managed realignment site at Freiston Shore, and assess the value of this newly available habitat to fish populations, annual fish surveys were carried out during the late summers of 2003, 2004, 2005 and 2006.

Using micromesh seine and fyke nets, a total of 11570 individuals of 12 species were captured. Due to time restrictions it has only been possible to identify fish of the family Clupeidae to family level, although it was evident that these consist of a mix of both sprat and herring. Of the 12 species caught, 11 of these have been caught inside the newly flooded realignment area, with only six species caught outside the breached site. The fact that fewer species were caught on the established marsh could be attributed to the difficulties associated with sampling this large area during a restricted time window, governed by the tidal cycle. If the same sampling effort could be applied to the natural salt marsh, it is likely that all the species caught within the realignment area would also be captured on the natural marsh.

The addition of a second survey during 2004, carried out over neap tides, revealed that the permanently flooded network of channels on the realignment site, continue to act as an important nursery zone for 0+ fishes, during periods of non-connectivity with the sea.

Samples of fish from 2004 were used for dietary analysis, due to the numbers of fish available and the broader comparisons that could be made according to various states of the tide. The species used for analysis were restricted to bass and mixed species of the family Clupeidae (i.e. sprat and herring), due to their commercial importance.

The 2004 survey revealed a dramatic decline in numbers of three-spined stickleback from those numbers found in 2003. The numbers of stickleback and their relative composition in terms of the community decreased further in 2005 before showing some sign of recovery in 2006. The continuation of a decline in numbers between 2003 and 2005 suggests that this was a relic freshwater population of the pre-realignment site, which have limited tolerance to the post-breach saline intrusion. The presence of three-spined sticklebacks within the realignment post breach of the sea defences was thought to be a result of sporadic linkage via the sluice (wheel pool), which provides limited periods of connectivity with the adjacent wetland.

The realignment site at Freiston Shore is clearly acting as an important nursery area for a range of different fish species, including bass, sprat and herring, which must be considered as high economic importance. Preliminary data regarding the diet of juvenile fish using Freiston Shore has shown the site continues to provide a valuable nursery habitat throughout the entire tidal cycle, with the continuous utilisation of permanently flooded channels and food resources within these waterbodies.

The results from these surveys suggest that the creation of additional ponded areas within a managed realignment area would further enhance the quality of this habitat to juvenile fishes. This would offer an increase in available habitat outside the period of spring tide inundation of the site, thus decreasing competition for food resources, while promoting enhanced growth rates and survival.

Pilot study on sediment properties: grain size, total N, organic matter and moisture content

A brief pilot study of sediment properties was undertaken in September 2005 from the monitoring sites on four transects outside the realignment site and four transects inside the MR. Three sediment cores were taken to a depth of about 10cm at each station on the salt marsh outside the MR. Deeper cores (to about 15cm depth) were taken inside the MR and divided into the newly accreted marine sediment and the agricultural soil underneath, and more cores were taken if it was necessary (to collect sufficient material for analysis). At upper elevations where there has been little sediment accretion, surface scrapes were taken to collect sufficient deposited sediment.

Total N was converted to ammonium-nitrogen by digestion with sulphuric acid and a potassium sulphate and copper sulphate catalyst, and the ammonium liberated with sodium hydroxide was removed by steam distillation and determined titrimetrically. Organic matter was determined by mass loss on ignition and moisture content was determined by oven drying to constant weight. Grain size analysis was carried out using a Coulter Counter at CEH Dorset.

The range of values for organic matter, total nitrogen, and moisture content in the managed realignment site and outside on the salt marsh overlapped at equivalent elevations, and all showed a significant positive correlation with increasing elevation.

This relationship was not explained by sediment grain size parameters as these showed no correlation with elevation. The most likely explanation for the relationship between organic matter, total N and moisture with elevation is the influence of vegetation (above and below ground production) which increases in density with elevation.

At the lower end of the elevation range inside the realignment site, organic matter, total N and moisture content were lower than outside on the salt marsh, and vegetation density was also lower than outside. At the upper end of the elevation range inside the realignment site, organic matter, total N and moisture content were higher than outside. It was suggested that this may be due to the influence of dead terrestrial vegetation trapped in the shallow accreted sediments at higher levels inside the realignment site.

As expected, there was no relationship between elevation and the measured parameters in the underlying agricultural soil in the realignment site, except for a slight but significant increase in total N with increasing elevation where the surface layer of accreted marine sediment is a few mm deep. Total N content may be influenced by atmospheric inputs and also by penetrating salt marsh plant roots and additions from detritus and terrestrial vegetation killed by seawater inundation (although we found no corresponding increase in total organic matter with elevation in the agricultural soil).

It is encouraging to find that the sediment properties (particularly organic matter and total nitrogen status) measured in the managed realignment showed similarities to the adjacent reference marsh. This may be a good indication that processes in the sediments may also be comparable, although more detailed comparative studies of the functional aspects of salt marsh sediments such as nutrient cycling in managed realignment sites and reference marshes would be needed to confirm this.

Overview, lessons learned and recommendations

The final Chapter (9) in Brown *et al* (2007) summarises the key findings and lessons learned from monitoring the Freiston realignment site. As well as reviewing and discussing the results of the monitoring programme, and making some comparisons with other managed realignment sites, this chapter also includes general observations on site condition including site drainage, creek development (bank erosion and headward extension), and makes recommendations for future work and aspects of managed realignment for consideration in future schemes.

We found no clear evidence to suggest that the realignment site has had any adverse effects on the adjacent salt marsh in general as accretion rates have been steady and vegetation cover in the pioneer zone increased over the 5 years of monitoring outside the realignment site as the sediment level has built up. However, some of the salt marsh in front of the realignment has been lost due to the widening and deepening of the creeks carrying water away from the site, particularly from the central breach, followed by the southern breach. From salt marsh edge to salt marsh edge this creek was estimated (by eye) to be approximately 25-30m wide over much of its length through the vegetated marsh.

Combining the vegetation surveys with the sediment monitoring sites and measurements of elevation has proved to be extremely useful for explaining the data and comparing the developing realignment site with the adjacent salt marsh at like-for-like elevation categories.

The Freiston realignment site has been quick to develop vegetation, undoubtedly due to its appropriate elevation and also due to the abundant source of propagules from the extensive adjacent marshes.

The site was colonised rapidly in the first year by pioneer annuals, primarily *Salicornia europaea* and *Suaeda maritima* which are abundant on the wide pioneer zones on the marsh outside, followed quickly by the establishment and spread of perennial species particularly at higher elevations in the site. Succession from pioneer species to the perennial dominants present outside the site at equivalent elevations appears to have been occurring rapidly, although we have little experience from other realignment sites to tell us how long it will take to achieve equivalent communities from these good initial conditions.

Some other sites that have been breached with the intention to produce salt marsh are still developing and have yet to produce a wide salt marsh habitat or vegetation communities that are equivalent to adjacent salt marsh. Sites differ in initial conditions and in some cases e.g. Tollesbury in Essex (breached in 1995) sites were initially too low in the tidal frame to develop salt marsh until they had warped up to appropriate levels. At Tollesbury just 6ha out of 21ha were colonised by vegetation after 6 years.

The Paull Holme Strays realignment site in the Humber estuary was breached in 2003, and parts of the site, primarily the southern sector, were at elevations suitable for salt marsh establishment. However, colonisation of bare areas at elevations suitable for salt marsh vegetation was less in the first year of monitoring (2004) than at Freiston. *Salicornia europaea* was found only occasionally, and *Suaeda maritima* was not noted in the monitoring quadrats at Paull Holme Strays until 2005. Both these pioneer annuals are far less common or extensive in cover in the narrower salt marshes of this area of the Humber Estuary, compared with the wide pioneer zones in the Wash and north Lincolshire south of the mouth of the Humber. The most important pioneer species in the Humber is *Spartina anglica* (Common Cord-grass) and the lower areas of the Paull Holme Strays realignment site (<2.6mODN) have been colonised primarily by this species. Colonisation by mid to upper marsh species was also initially slower at Paull Holme Strays than at Freiston, probably because the natural salt marsh (providing propagules) in this area of the Humber is less extensive.

The results of the monitoring survey at Freiston showed that plant species composition has been changing and developing into vegetation communities similar to those outside at equivalent elevations. The Freiston site therefore provides a valuable opportunity to follow the rate of successional processes and to answer the question of how long it takes to create a salt marsh of equivalent community composition when initial conditions are suitable for salt marsh development. It is therefore recommended that the vegetation monitoring is continued for a further 5 years, along with accretion rates which are important to explain the findings and to ensure that the site continues to develop successfully. If it is necessary to undertake this at a reduced level of intensity, we recommend that accretion measurements are undertaken annually and that vegetation monitoring is carried out every alternate year.

Invertebrate sampling at managed realignment sites has generally been concerned with intertidal benthic infauna in mudflat areas of the sites. There have been few studies of invertebrates associated with vegetated salt marsh. Studies on rates of establishment of fauna associated with developing salt marsh vegetation and comparisons of faunal diversity in new salt marsh and established reference marsh might provide another aspect for assessing success of salt marsh creation or restoration. However, the diversity of fauna and seasonal and weather-dependant activity of some of the organisms make such comparisons difficult in a short annual survey within the resources of a monitoring programme. This type of study would be better suited to a more intensive research project.

Similarly, the fish survey work was constrained by time and tides. But in view of the economic importance of some juvenile species utilising salt marshes as nursery ground, and the relatively few studies in Europe, research on feeding behaviour, salt marsh food webs, fish habitat use and requirements (e.g. creek configuration, design and complexity) would merit further attention to enhance the fisheries resource quality of future realignment sites if this is to be one of the aims.

Although outside the scope of the main purpose of this report, our observations on creek widening and erosion in front of the realignment and inside the site, and on poor drainage in parts of the realignment suggest that initial conditions at future realignment sites could be improved to optimise the success of these schemes.

Good drainage increases sediment stability, and reduces waterlogging which is detrimental to plant colonisation and survival. Creeks are important for supplying the marsh surface with sediment and nutrients and dissipating tidal energy, and for draining the marsh during the ebb tide. In the months following the site breach there was a significant ponding effect on the site during spring tides which were not draining out through the breaches before the next incoming tide refilled the site. This would have created a challenging environment for salt marsh plants other than pioneer species which can withstand greater inundation times. However, a year after the breaching the breaches had widened sufficiently to drain the realignment area between flooding tides.

Although the site in general drains between each spring tide, the gradient of the realignment site is less than the salt marsh outside the realignment and there is a considerable amount of standing water left on the site between tidal inundations and over neap periods. This feature may be beneficial to birds but is detrimental to sediment stability and vegetation establishment.

However, several large creeks have been developing at the site, cutting back particularly from the central breach and from the old field drain running behind the old embankment. In places, escpecially inside the central breach area, this has been dramatic, with large blocks of soil breaking off.

At Tollesbury, embryo creeks were reported to form only in the newly accreted sediments once a critical depth (20-30cm) was reached, and were not cutting through the underlying agricultural soil. Creek development probably depends upon several factors including site history (time since reclamation, post-reclamation physical and chemical changes in the soil), soil type, grain size and compaction. At Freiston, the agricultural soil of the formerly reclaimed land does not form a barrier to creek formation. The site was one of the last areas to be reclaimed from the sea (in 1983) and sediments of this side of the Wash are coarser (sandier) than the muds fronting Essex salt marshes and the agricultural soil appears quite loosely consolidated.

Although creek development inside the site will improve drainage, there are areas of possible concern where there are several large creeks developing close to each other (mainly inside the central breach area) and it is possible that the marsh in between might collapse. Also, because the site is relatively flat in places there are areas with a lot of standing water where shallow channels are developing over a wide area and may result in a general lowering of the surface. Further monitoring may be necessary to determine trends in accretion / erosion in these areas of the site.

More research may be needed on hydrodynamic and topographic attributes such as the design of optimum breach widths in relation to the volume capacity of the site on high spring tides, and on internal site features such as slope (for drainage), creek profiles, creek densities, complexity and design (relevant also for juvenile fish use of these sites). This is particularly important if the size of future realignment sites becomes more ambitious, such as at Alkborough, a large (≈400ha) site which has recently been breached (in 2006) in the Humber Estuary.

It is recommended that a detailed topographic survey of elevations to produce a contour map is carried out on sites selected for future realignment schemes. A pre-breach survey would pinpoint any areas where water might be trapped and slow to drain, and would be helpful for improving the design of a pre-breach starter drainage system. Elevations combined with information on local accretion rates would allow prediction of the likely extent and timescale for salt marsh establishment, and increasing the range of the slope on a site would increase the diversity of plant community types and improve the conservation value of a site.

In theory it would be possible to contour sites to create elevations appropriate for particular communities, such as transitional vegetation, although if such communities are rare in the area there may be an insufficient supply of propagules for such a zone to develop naturally.

Although a topographic survey and any necessary contouring of a site and excavation of drainage creeks will increase initial costs, they are worth consideration in cases where there may be potential problems with drainage that cannot be easily remedied post-breach.

Conclusion

In conclusion, the results of the ecological monitoring programme have been very encouraging. Most areas of the Freiston site have been accreting sediment at a rate similar to the adjacent salt marsh at the same elevation range and the development of salt marsh vegetation and subsequent succession towards similar vegetation communities to those outside at equivalent elevations has been rapid compared with some other realignment sites.

Vegetation cover at higher elevations on the site was similar to that outside the realignment after four years. It remains to be seen how long it will take before the vegetation community composition (and relative abundance) is equivalent to the adjacent salt marsh, but it seems probable that this could be achieved in just a few more years (perhaps by 2012). Continued monitoring of accretion and vegetation cover and composition for a further five years would be valuable to check that the site continues to build up sediment and to establish the time scale needed to create salt marshes by managed realignment when initial conditions are good (in terms of appropriate elevations and propagule supply).

Many invertebrate fauna associated with the salt marsh have increased in abundance, and the site is functioning as a nursery area for juvenile fish, which are also able to exploit the site in the flooded dykes during neap tide periods. The addition of shallow pools or pans could improve the nursery role of a site for fish fry, and research on fish behaviour in salt marshes suggests that there may be scope for incorporating certain attributes of creek design and complexity to enhance this salt marsh function.

Parts of the realignment are not draining after the tide has receded, which may be beneficial to birds but reduces sediment stability and hinders the development of salt marsh vegetation which helps to bind and stabilise the sediment surface. There are areas of the site without defined drainage channels where there are indications that the surface level may not be accreting further, and may be eroding. This would prevent the establishment of a dense covering of vegetation and warrants further monitoring.

Creeks have been developing through the agricultural soil on the site, and eroding and cutting back dramatically in some areas. Our observations suggest that more research is needed to achieve optimum breach design, site gradient and design of starter creek systems (profiles, pattern and density). Some sites may require more pre-treatment than simply providing for tidal ingress. Although this would involve additional costs at the outset, it is likely to be cost-effective in the long-term if it ensures successful development and continued sustainability of salt marshes created by managed realignment.

The objectives of future schemes need to be clearly defined, along with the criteria by which the success of a scheme can be judged. Research into how best to achieve and assess the desired outcome needs continued support. Any future requirements to deliver particular conservation goals or salt marsh function will present a considerable challenge for habitat creation as not all aspects of how to do this are well understood. There are still gaps in our knowledge about precise habitat requirements of some salt marsh associated species, and how optimum conditions could be encouraged by site design (pre-treatment) or management techniques.

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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.

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