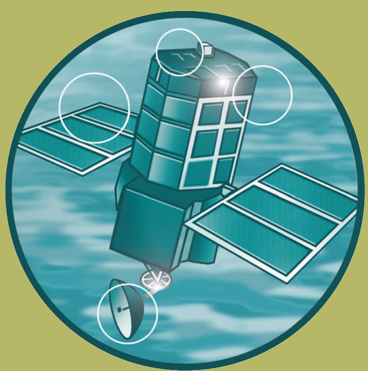
Joint Defra/EA Flood and Coastal Erosion
Risk Management R&D Programme

Wash Banks Flood Defence Scheme Freiston Environmental Monitoring 2002-2006

R&D Technical Report FD1911/TR



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This document provides information to Defra and Environment Agency staff, researchers, coastal partners and consultants about the monitoring at the Freiston Shore Managed Realignment between 2002 and 2006. This report supports the document "Freiston Shore Managed Realignment – Environmental Monitoring 2007" and details the monitoring methodologies referred within it. Both reports constitute R&D outputs from the joint Defra/Environment Agency Flood and Coastal Erosion R&D Programme, project FD1911.

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Executive summary

This report describes the results of four years of monitoring the development of the Freiston managed realignment site since it was breached in August 2002. 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.

Accretion/Erosion measurements

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 building up between 5.5mm and 56mm over four years, depending upon their positions along the transects. Five sites nearest to the central breach showed anomalously high levels of sedimentation (up to 198mm), thought to be due to washed in material from the eroding breach and widening creeks inside the site close to the breach.

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 total accretion inside the realignment site was greatest in the first year (15mm, 2002-3) and has been lower since (9.3mm, 2003-4; 7.7mm, 2004-5; 8.6mm 2005-6). The few exceptionally high accretion sites had a major influence on mean values, particularly during the first year. When these sites were excluded from the calculations the mean total accretion over the 4 years was 7.9mm, 5.4mm, 5.8mm and 7.3mm, respectively, and closer to values from outside the realignment at the same elevation range: 9.0mm, 7.4mm, 5.8mm and 7.7mm, respectively (also highest in the first year).

Mean annual rates of accretion were calculated for all the monitoring sites inside and outside the realignment on the vegetated marsh at the equivalent range of elevations (>2.75-3.3mODN). Rates were calculated from data up to 2005 because the markers for two of the upper salt marsh sites were lost to cattle damage in 2006. There was a highly significant inverse relationship (as expected) between accretion rates 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.

The mean annual accretion rate for all sites inside the managed realignment was 10.6mm. This value was reduced to 6.7mm when the outliers were excluded, and was closer to the mean annual accretion rate of 7.3mm outside on the salt marsh at the same elevation range. In the lower portion of the elevation range (2.75-3.0mODN), the mean annual accretion rate was 14.7mm (12.2mm excluding the outliers) inside the realignment, and 9.4mm outside on the salt marsh in this range. At the higher end of the elevation range (above 3mODN) the mean annual accretion rate inside the realignment was reduced substantially from 8.5mm to 4.5mm when the outliers were excluded, and was close to the mean rate outside (5.0mm) at these elevations.

The sample median is a useful representative of the data set for sites in the realignment as it is not affected by the high values for the sites close to the central breach. The median annual accretion rate for inside the site overall (elevation range 2.75-3.3mODN) was 7.42mm, close to the median annual accretion rate of 7.33mm outside the site at equivalent elevations. A good agreement was also found for the upper range (3.0-3.3mODN) inside the site (4.23mm) compared with outside (4.87mm), but the median annual accretion rate was still higher inside the sheltered realignment site (13.6mm) than outside on the salt marsh (8.9mm) in the lower portion of the elevation range (2.75-3.0mODN).

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 indicated that accretion has been higher inside the realignment at the lowest elevations compared with outside on the salt marsh, but the overall similarities between median annual accretion rates inside and outside the realignment over most of the equivalent elevations, and between the mean and range of total accretion values when the anomalously high sedimentation sites were excluded, 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 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. 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 region showed no evidence to indicate any problem with sediment supply.

Measurements of surface elevation change (SET data) cannot be easily compared with the measurements of surface accretion (buried plates) until we have all the elevation measurements for the SET sites, except for where the

SET and plate sites are situated very close together. 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.

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.

By 2006, the mean percentage ground cover (100% - bare ground estimate) in 5 x 1m^2 quadrats at sites inside the MR ranged from 7% at one site (first colonised in 2006), 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. The mean total ground cover (100% - bare estimate) for all sites in the MR increased from approximately 40% in 2003 to 84% in 2006.

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.

If vegetation spread continues to increase at a rate similar to that observed between 2004 and 2006, a mean total cover value close to that outside in the same elevation range is predicted to be reached between 2008 and 2010. However, it may take longer for the realignment site to reach equivalent vegetation community composition.

Elevation is a key factor for the establishment and survival of different salt marsh species, therefore total vegetation and species composition was compared according to elevation categories.

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.

In the lower half of the elevation range inside the MR (2.7-2.99mODN), the mean total vegetation cover had increased to 72% in 2006, still lower than the mean cover outside 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, the mean total percentage vegetation cover inside the MR had increased to 87% by 2006, compared with 97% outside in 2006 in this elevation range (range of cover values outside 2002-6 was 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 inside the realignment was most rapid at the highest elevation category (3.16-3.3mODN), reaching a mean total percentage of 98% by 2005 (and in 2006), which was the same value as cover outside the MR in this elevation range (range of cover values outside 2002-6 was 98-105%).

A total of 16 typical salt marsh species have been recorded in the MR site (out of 17 seen outside in the Freiston area), and all of the common species on the salt marsh were also common in the realignment site. Up to 11 species have been recorded in the realignment site quadrats overall, but varying slightly between years (2003: 9 species, 2004: 8, 2005: 9, 2006: 10). 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 5 years outside (5.46-5.77).

At elevations 2.7-2.99mODN, mean species number in the MR quadrats increased from 2.88 in 2003 to 5.09 by 2006. Outside, mean species number increased from 5.31 in 2002 to 6.0 in 2006.

Between 3.0-3.15mODN, mean species number increased in the MR from 4.1 in 2003 to 5.83 in 2006, a similar mean value to outside in this elevation range.

At 3.16-3.3mODN, where the rate of increase in total vegetation cover was the greatest, species diversity was also the highest from the outset, with mean species number varying between 5.46 and 6.27, and higher than outside (5.29-5.43).

The pioneer annuals *Salicornia europaea* and *Suaeda maritima* were the first to colonise the realignment site and were the dominant species throughout the site in 2003, at all elevations. Between 2003 and 2006, these pioneer annuals have remained the most abundant species at lower elevations in the realignment but other species have established and spread, particularly at higher elevations above 3mODN where the annuals have been replaced by the perennial *Puccinellia maritima* which spread rapidly between 2003 and 2005 to become the dominant species by 2005. The perennial *Atriplex portulacoides*, extremely abundant outside on the salt marsh at higher elevations has shown a steady increase at higher elevations in the MR, and by 2006 was the second most important cover species after *Puccinellia maritima* in the highest elevation range category (3.16-3.3mODN).

The nine larger quadrats ($25m^2$) in the realignment site showed the same trends as the smaller ones. 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.

All of the main species increased in frequency between 2003 and 2006 (in $1m^2$ quadrats divided into 100 cells), 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 were more widely distributed, colonising more cells of the quadrats, 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.

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-enforced 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 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 if the major perennials continue to spread at the rate observed in the last two years, the principal author would hazard an estimate that this could be achieved within about five more years (i.e. by about 2012).

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. 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

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

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) summarises the key findings and lessons learned from monitoring the Freiston realignment site. As well as reviewing the results of the monitoring programme, 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.

Contents

Figures

Plates and photos

Tables

Appendices

1. General Introduction

Dr S.L. Brown, CEH Dorset

Flood defence embankments around the Wash play a vital role in protecting a vast area of low-lying land from Cambridge in the south to Lincoln in the west. The sea defences at Freiston Shore provide protection to 80,000 ha of low lying agricultural land, villages and the town of Boston (Halcrow 1999).

The Freiston Shore Managed Realignment is one of the largest managed realignment sites to be created in the UK, to date. Prior to the realignment, the sea defence bank, foreshore and land at Freiston was under ownership of Her Majesty's Prisons (HMP). The land was the last area around the Wash to be reclaimed from the sea (in 1983) and was used for arable cultivation since its reclamation. The flood defence embankment fronting what is now the realignment site projected further into the Wash than the embankments to the north and south (see Figure 1.1) and the marsh in front was narrower with less developed vegetation (primarily low marsh and pioneer zone) compared with the more mature and extensive marshes to the north and south. The foot of the sea wall was exposed to wave attack and was showing signs of erosion, requiring repair and maintenance by HMP.

Costs of strengthening and maintaining the bank in its existing position were considerably higher than those associated with retreating the line of flood defence. Therefore Freiston Shore was selected as a site suitable for salt marsh creation by managed realignment, which would also bring environmental benefits. The land was bought from HMP by RSPB, and the maintenance of the flood defences was adopted by the Environment Agency. New flood defence embankments were constructed around the back of the site to create a 66ha salt marsh/mudflat realignment area and a 15ha area with a lagoon landward of the new sea defences behind the southern part of the intertidal realignment. The realignment site was breached (3 breaches) in August 2002.

The aims of the Freiston Shore managed realignment scheme (part of the Wash Banks flood defence scheme) are:

- 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 to existing habitat and adjacent salt marsh and mudflat
- To establish new brackish habitat through the excavation of a borrow pit landward of the setback bank (monitored by RSPB)

The objectives of the Wash Banks environmental monitoring programme for the salt marsh component carried out by the Centre for Ecology and Hydrology (CEH) and the Cambridge Coastal Research Unit (CCRU) are to monitor the development of the salt marsh within the realignment site (sedimentation and establishment of flora and fauna) and to check that there are no adverse impacts of the scheme to the existing adjacent salt marsh habitat. The ecological monitoring requirements of the programme were set out by Halcrow Ltd. for the Environment Agency and comprise the following post-breach surveys to be undertaken inside and outside the site:

- Accretion/erosion surveys (2 per year, for 5 years)
- Vegetation surveys (1 per year, for 5 years)
- Invertebrate surveys (1 per year, for 4 years)
- Fish surveys (1 per year, for 4 years)

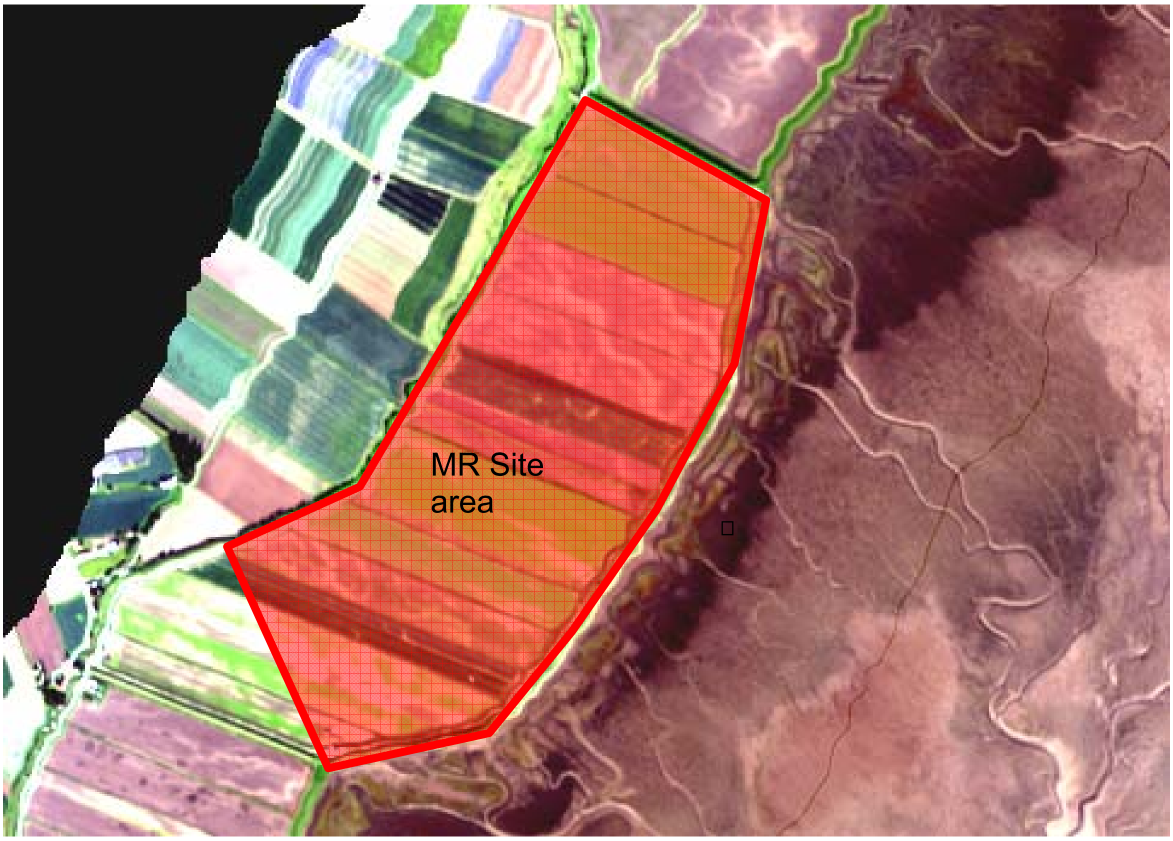
Sediment sampling (storage for possible future analysis, once per year)

(a) Location of Freiston Shore

Figure 1.1.

(a) Location of the Freiston Shore Managed Realignment

(b) CASI false colour image of the area selected to create the intertidal salt marsh / mudflat (zone outlined in red) Image from the Natural Environment



(b) CASI Image of the realignment site (pre-breach) and lagoon area (≈ 78 ha overall)

The details of the monitoring proposed by CEH and CCRU were set out in the tender for the programme.

The monitoring programme was divided into two phases: Phase I of the project comprised setting up permanent transects and sampling sites for measuring sedimentation and surveying vegetation, and taking the initial measurements. In Phase II, accretion and vegetation measurements were continued, and additional surveys of invertebrates and fish at the realignment site were undertaken. The data and summary presentations were supplied to the EA, but there was no component for analysis and report writing for the early years of the programme.

This report details the findings of the monitoring programme from its outset, up to the end of the 2006 survey season. A supplementary report on additional measurements (accretion plates and associated vegetation survey) for one monitoring period in September 2007 is to be produced by January 2008.

1.1 Approach

An integrated approach to monitoring the ecological and physical components (relating vegetation surveys and accretion/erosion measurements to elevation) is the best way to gain the most insights into the development of the new salt marsh, and to interpret any changes in the salt marsh vegetation outside the realignment site.

To achieve this, permanent transects and sampling sites were set up inside and outside the realignment site to measure accretion/erosion, and vegetation development (inside the site) and vegetation changes (outside the site). Each site was surveyed for its elevation so that any observed changes in vegetation species establishment and succession could be related to accretion and elevation. Where appropriate, invertebrate samples (e.g. pitfall traps) were taken next to the accretion and vegetation survey sites and sweep netting was also done in the general vicinity of these sites. Scrapes for infauna in areas not vegetated were taken where such areas were found. But in general, this approach could enable the colonisation by invertebrates to be examined in relation to elevation and vegetation development during the monitoring programme. Fish surveys were concentrated in the southern part of the managed realignment site and the adjacent outside marsh as time was limited by the duration of high spring tides.

Accretion/erosion

This was measured using 2 approaches:

1. Surface accretion (or loss) using marker horizon methods, in this case buried expanded stainless steel plates. This method integrates surface

deposition and near-surface below-ground productivity over short to medium timescales (e.g. annual / biennial re-measurements). As it is a relatively inexpensive method, a large number of plates can be set out over the marsh surface, giving good spatial cover over the area of study.
2. Sedimentation Erosion Table (SET) measurements to measure changes in surface elevation relative to a sub-soil datum. This method allows for the assessment of shallow subsidence, or post-depositional autocompaction.

Vegetation surveys

These were carried out at different scales:

1. Macro- vegetation surveys.
   5m x 5m (25m^2) permanent quadrats were set out in different vegetation types, to provide ground reference data for remote sensing images (e.g. CASI). Data from these quadrats would show any large scale changes monitored by the NERC overhead flights during the monitoring programme

2. Detailed vegetation surveys.
   (a) Measurements of percentage cover of species in 5 x 1m^2 permanent quadrats at each of the sedimentation plate sites (outside and inside realignment site).
   (b) Detailed measurements of plant frequency distribution on a local scale during colonisation, establishment and spread in one of the 1m^2 quadrats at each of the accretion monitoring sites in the realignment. Each quadrat was divided into 10cm x 10cm subcells (100 subcells per m^2).

Invertebrate surveys

At the time of writing the tender for the programme, there was no information on the elevation of the Freiston site, and it was assumed that part of the site would be intertidal mudflat at least until the sediments had built up to levels suitable for vegetation. The suggested methods were written on the basis of experience and work at Tollesbury, Essex, where the site was initially too low for vegetation colonisation except for a narrow strip at the back of the site. Most of the invertebrate colonisation at Tollesbury has therefore been by intertidal benthic fauna, sampled by taking sediment cores during early autumn.

The Freiston site is much higher in the tidal frame than the Tollesbury site, and once the approximate elevations were known it was expected that vegetation would colonise most, if not all of the site, as the elevation was suitable for salt marsh establishment. During Phase II of the programme (post-breach), a different sampling strategy from that proposed in the tender was employed to capture invertebrates associated with the developing and adjacent salt marsh, comprising a combination of pitfall traps (during neap tides when the site was not flooded), sweep netting, and sediment scrapes in unvegetated areas.

Fish Surveys

These were carried out once annually during the summer in Phase II of the programme. Due to time constraints (working at the top of the tides, except for one additional survey of permanently flooded areas in the realignment), the fish surveys were concentrated in the southern part of the site, with surveys on the outside marsh immediately south of the realignment site. Details of the sampling and survey methods are given in the Chapter on Fish Surveys (Chapter 7).

1.2 Timing of activities:

Sampling times are shown in a chart in Table 1.1.

- Pre-breach set up of transects and sampling sites for measuring sedimentation with buried plates and canes (see methods), outside the realignment site in October 2001
- First ground reference vegetation survey for CASI flights in October 2001. Further ground reference surveys in September each year (2002-2006).
- Pre-breach set up of transects and sampling sites within the realignment site in April 2002.
- Baseline accretion / erosion measurements outside the realignment site in April 2002.
- Site breached in August 2002.
- Baseline accretion / erosion measurements inside the realignment site and first post-breach measurements outside the realignment site, in September/October 2002. Further monitoring of accretion / erosion in April and September each year, inside and outside the realignment site (2003- 2006).
- First (5 x 1m^2 quadrats) vegetation survey September 2002 (no salt marsh vegetation inside the realignment quadrats immediately after the breach). Further vegetation surveys over the accretion monitoring sites, inside and outside the realignment site in September each year (2003-2006).
- Set up of SET accretion monitoring sites outside the realignment in October 2002, and inside the realignment in November 2002
- Baseline measurements of SET sites outside and inside the realignment site (November/December 2002). Further monitoring of SET sites in April and September each year 2003-2006.
- First invertebrate survey outside and inside the realignment site in October 2002. Further invertebrate surveys in September 2003-2006.
- First fish survey August 2003. Further fish surveys in August 2004 -2006.

- Measurements of elevations at each sedimentation plate and cane site, and associated vegetation survey sites carried out in 2003. Re-surveyed for positions and elevations in 2005 (this data used in the report).

1.3 Reference

Halcrow, 1999. Wash Banks Hobhole to Butterwick Low Engineers Report. Report to the Environment Agency, Anglian Region. 25pp.

Table 1.1. Timing of site set-up and monitoring surveys

		2001				2002												2003												2004												2005 & 2006
		S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	
MR Site Breach													■																													
Sediments Site set-up	**OSMR**		■																																							
	MR								■																																	
Sediment measurements	**OSMR**								■					■	■						■					■							■					■				Apr & Sep 05,06
	MR													■	■						■					■							■					■				Apr & Sep 05,06
CCRU SETS installation & first	**OSMR**														■																											
baseline measurement	**MR**															■																										
SET measurements	**OSMR**																				■					■									■			■				Apr & Sep 05,06
	MR																				■					■									■			■				Apr & Sep 05,06
Vegetation Survey	**OSMR**		■											■												■												■				Sep 05,06
(2001:ground reference only)	**MR**													■												■												■				Sep 05,06
CASI Flights			■																							■																Sep 06
Invertebrate sampling	**OSMR**														■											■												■				Sep 05,06
	MR														■											■												■				
Fish Survey	**OSMR**																								■												■					Aug 05. 06
	MR																								■												■					

2. Transect and Site Establishment

Dr S.L. Brown, CEH Dorset

Six transects perpendicular to the shore (i.e. down the marsh profile) were set up outside the managed realignment site in early autumn 2001, approximately one year before the site was breached, extending between a few hundred metres north and south of the realignment site. The transects were labelled Transects 1-6, running north to south, with two north of the realignment site (T1 and T2), two in front of the site (T3 and T4), and two south of the Freiston site (T5 and T6), of which the last (T6) was set up in 1995 by S.L. Brown (CEH), under the Land Ocean Interaction Studies (LOIS) programme. The positions of the monitoring sites along these transects are shown in Fig. 2.1.

Along each transect, sites were selected along the marsh profile for ecological measurements, including accretion monitoring and surveys of vegetation cover and species in 5m x 1m^2 quadrats lying over the accretion sites. The number of sites along each transect varied between 5 and 8, according to the extent of the marsh, and were as follows: Transect 1: 6 sites (initially 7 were set up but the site closest to the shore was subsequently trampled heavily by cattle, making accretion measurements impossible); Transect 2: 8 sites; Transects 3 and 4: 5 sites each; Transects 5 and 6: 7 sites each. Therefore a total of 38 ‘permanent’ monitoring sites were established on the natural marsh outside the realignment area. Site positions are referred to by Transect (T) number, followed by Site (S) number down each transect, for example T6S4 is Site 4 along Transect 6. Note that on Figure 2.1 site positions are numbered without the T&S because of space restrictions, so for example, T6S4 on the figure is 6.4

We were unable to establish transects inside the site at the same time as those outside, because contractors with earth-moving equipment were due to come on site to make initial preparations for the breaches. In Spring 2002, 5 transects (labelled with letters for easy distinction between inside and outside the realignment site): TA to TE running from north to south were set up across the site perpendicular to the new defence embankment (i.e. downshore), avoiding areas designated for contractors to create some artificial starter creeks. Six sites were set up for accretion and vegetation monitoring along each of the 5 transects (30 sites in total). Tall posts were hammered into the ground at each site in addition to the site marker canes, to mark their position before mechanical cutting of the tall dense thistles that grew during the summer before the breach. Some of the smaller site markers were destroyed by the machinery, but the plates for measuring accretion were undamaged and we were able to find them all and re-establish the markers before taking the initial baseline measurements for these in September 2002. Initially, the largest gap between transects was between Transect D and Transect E. This area was left because it was a zone where contractors would be creating a twin-branched creek. However, to achieve a more evenly distributed cover of monitoring sites, we decided to set up an additional transect with 6 monitoring sites in this zone in summer 2004 and initial baseline measurements were taken in September 2004. This new transect was labelled Transect E and the previous Transect E (further south) was re-named Transect F and the early results associated with this transect have been re-labelled accordingly. Therefore there were 30 sites inside the realignment in 2002-2003, increasing to 36 sites from summer 2004.

The larger 5m x 5m vegetation quadrats, set up to provide ground reference data for remote sensing images were positioned along the transects on the salt marsh outside the realignment site. Nine quadrats were also set up inside the realignment and the positions of these are shown in Fig. 2. 2.

CCRU set up eleven sites (6 outside the realignment and 5 inside) for accretion measurements using the Sediment Erosion Table (SET) technique. The positions of these are shown in Fig. 2.3 (and also in their report, Chapter 4).

2.1 Site Positions and Elevations

CEH accretion site elevations were initially recorded in 2003 using a Pentax Total Station theodolite, tied into local Environment Agency benchmarks. Site positions were measured using a Trimble RTK GPS during 2005 and site elevations were re-measured at the same time. The positions and elevations of the nine 5m x 5m vegetation quadrats inside the realignment were also measured using the RTK GPS. The elevation data collected in 2005 are used in this report.

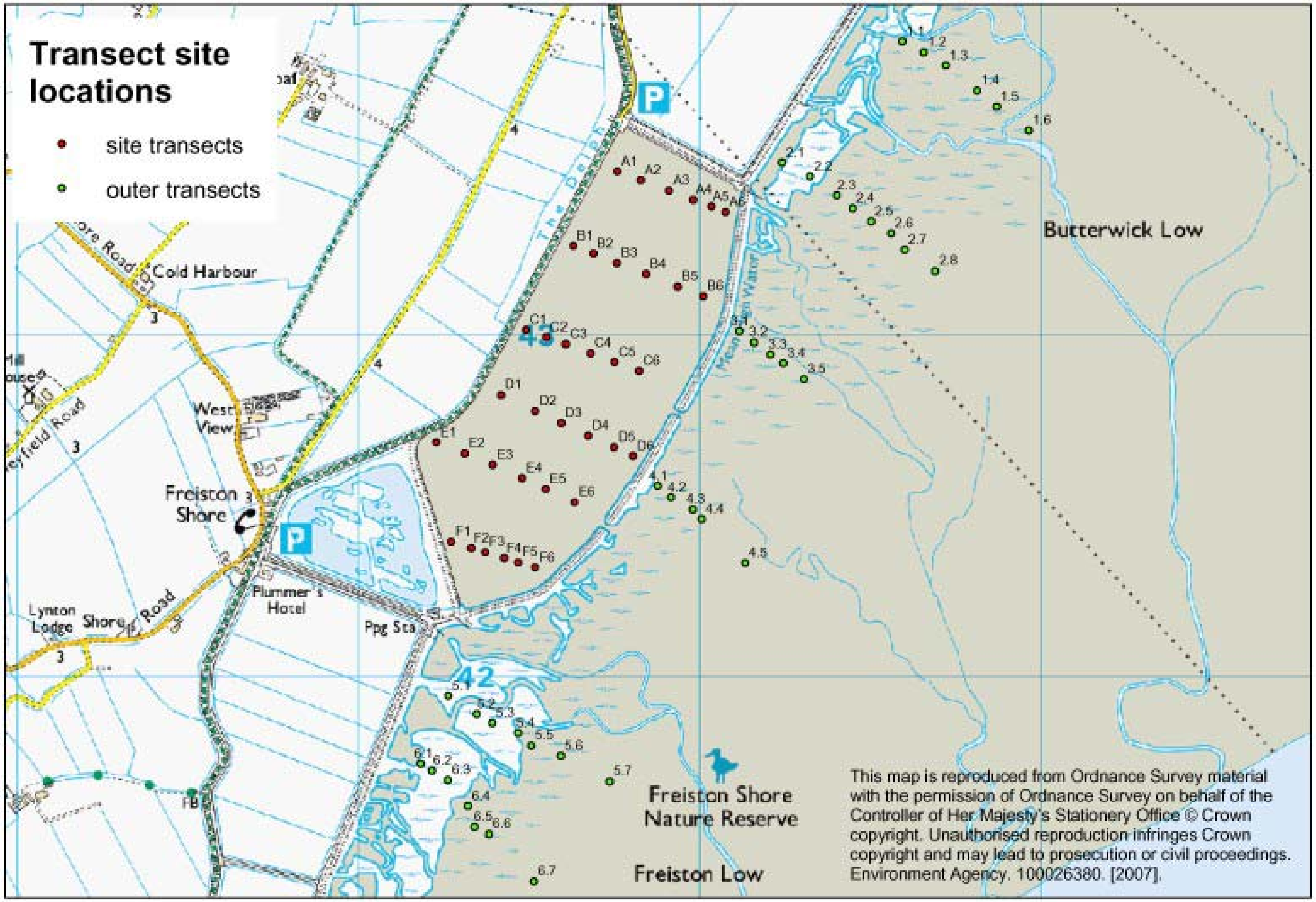


Fig. 2.1. Map of Accretion monitoring and vegetation (5 x 1m² quadrats) survey site locations

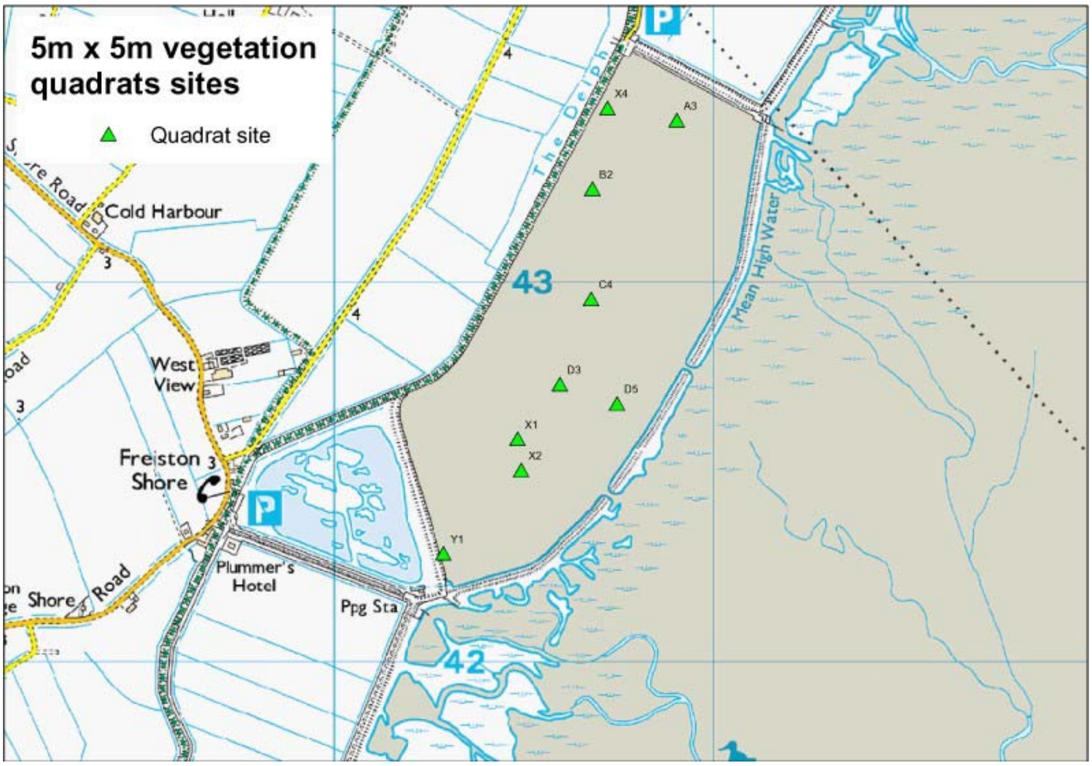


Fig. 2.2. Map of 5m x 5m vegetation quadrats inside the realignment site

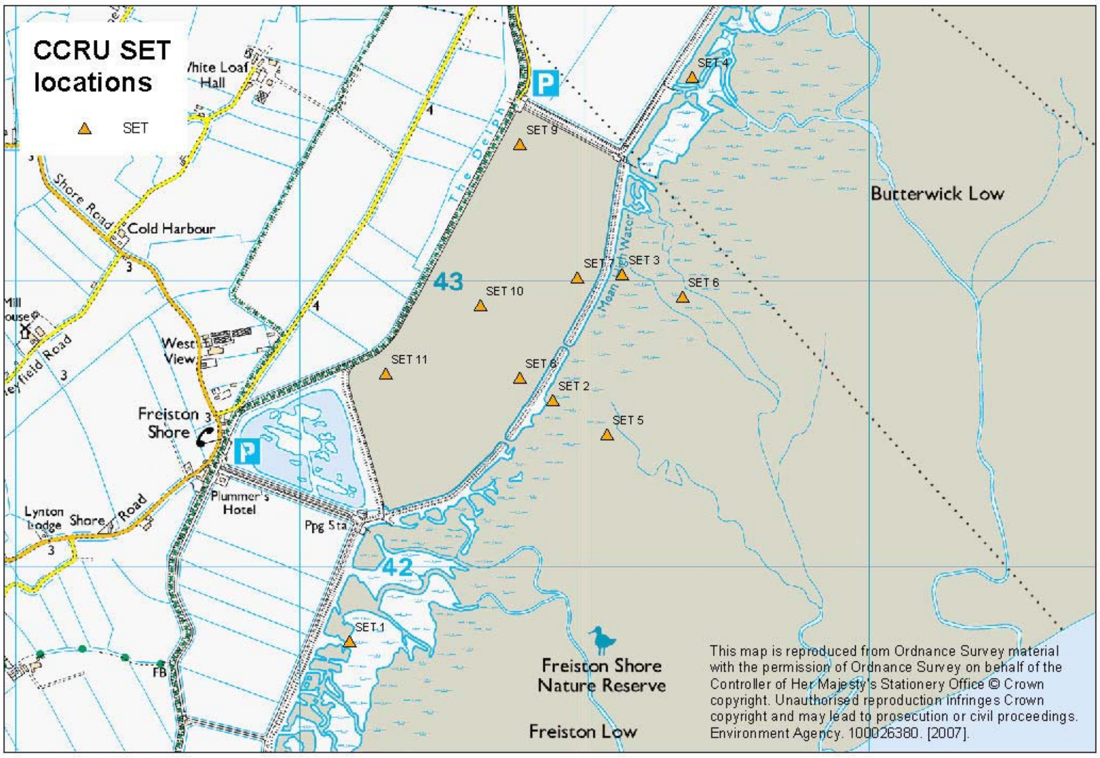


Fig.2.3. Map of CCRU SET site locations

3. Accretion / Erosion

Dr S. L. Brown, CEH Dorset
Mr A. Garbutt, CEH Monks Wood

3.1 Summary

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. At lower elevations (pioneer marsh - mudflat transition) there were marked fluctuations in sediment levels between years, typical of this dynamic zone.

All sites inside the realignment have accreted sediment since the initial baseline measurements, with 25 out of the 30 sites set up initially building up between 5.5mm and 56mm over four years, depending upon their positions along the transects. Five sites nearest to the central breach showed anomalously high levels of sedimentation (up to 198mm), thought to be due to washed in material from the eroding breach and widening creeks inside the site close to the breach.

Elevations of sites inside the realignment 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 total accretion inside the realignment site was greatest in the first year (15mm, 2002-3) and has been lower since (9.3mm, 2003-4; 7.7mm, 2004-5; 8.6mm 2005-6). The few exceptionally high accretion sites had a major influence on mean values, particularly during the first year. When these sites were excluded from the calculations the mean total accretion over the 4 years was 7.9mm, 5.4mm, 5.8mm and 7.3mm, respectively, and closer to values from outside the realignment at the same elevation range: 9.0mm, 7.4mm, 5.8mm and 7.7mm, respectively (also highest in the first year).

Mean annual rates of accretion were calculated for all monitoring sites inside and outside the realignment on the vegetated marsh at the equivalent range of elevations (>2.75-3.3mODN). Rates were calculated for the data up to 2005 because the markers of two upper sites on the adjacent salt marsh were lost to cattle damage in 2006. There was a highly significant inverse relationship (as expected) between accretion rates 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.

The mean annual accretion rate for all sites inside the managed realignment was 10.6mm, reduced to 6.7mm when the outliers were excluded, and which was closer to the mean annual accretion rate of 7.3mm outside on the salt marsh at the same elevation range. In the lower portion of the elevation range (2.75-3.0mODN), the mean annual accretion rate was 14.7mm (12.2mm excluding the outliers) inside the realignment, and 9.4mm outside on the salt marsh in this range. At the higher end of the elevation range (above 3mODN) the mean annual accretion rate inside the realignment was reduced substantially from 8.5mm to 4.5mm when the outliers were excluded, and was close to the mean rate outside (5.0mm) at these elevations.

The sample median is more representative of the data set for sites in the realignment (unaffected by the high accretion site values). The median annual accretion rate for inside the site overall (elevation range 2.7-3.3mODN) was 7.42mm, close to the median annual accretion rate of 7.33mm outside the site at equivalent elevations. A good agreement was also found for the upper range (3-3.3mODN) inside the site (4.23mm) compared with outside (4.87mm), but the median annual accretion rate was higher inside the sheltered realignment site (13.6mm) than outside on the salt marsh (8.9mm) in the lower portion of the elevation range (2.75-3.0mODN).

On average, winter accretion was found to be higher than summer periods both inside and outside the realignment site. Several factors (pre- and post-depositional) 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 indicated that accretion has been higher inside the realignment at the lowest elevations compared with outside on the salt marsh, but the overall similarities between median annual accretion rates inside and outside the realignment over most of the equivalent elevations, and between the mean and range of total accretion values when the anomalously high sedimentation sites were excluded, indicated that accretion has been occurring at expected rates inside the newly created salt marsh habitat.

3.2 Introduction

The locations of sites for monitoring accretion in the new managed realignment site and on the adjacent salt marsh are shown in Fig. 2.1. (in the previous Chapter on Transect Establishment). We measured accretion outside the realignment as well as inside to enable us to check whether the newly created intertidal area is building up sediment in a comparable way to the existing marsh, and also to check for any unexpected adverse impacts from the realignment site on sedimentation processes outside on the natural marsh.

There is considerable spatial variation in sedimentation between upper marsh elevations and the low pioneer zone due to different inundation frequencies and duration. There can also be considerable lateral variation. To achieve a good estimate of sediment accretion across the large area of the realignment site and adjacent marsh, we used inexpensive methods of monitoring sedimentation (buried expanded metal plates or levelled pairs of canes) so that we could set up a large number of sites, running from the upper zones down to the marsh front on several permanent transects. These numerous sites were supplemented by 11 additional monitoring sites with a Sediment Erosion Table (SET, undertaken by CCRU -see Chapter 3). The SET method measures the surface elevation change and accounts for the influence of subsurface processes (e.g. compaction) on elevation change.

3.3 Methods

Along each transect, sites were selected down along the marsh profile to take accretion measurements together with vegetation cover and composition in permanent quadrats at the same locations. Methods for measuring accretion (see below) were installed and left for 5-6 months to allow regrowth of disturbed vegetation around the plate edges before the initial baseline measurements were taken. These initial baseline measurements were taken outside the realignment in April 2002, and inside the realignment area in September 2002, just after the site was breached.

3.3.1 Sedimentation Measurements along Transects

Sedimentation was measured at sites along the transects using either (a) buried expanded stainless steel metal plates, which allow drainage through the plate, and root growth, or (b) pairs of canes set up to support a builders' level (Brown 1998). The method used was chosen according to various factors including ground conditions and expected rates of accretion or erosion. Generally we use plates in firmer marsh sediments, and canes in softer substrates, ridge and runnel zones, and on mudflats. Buried plates were used exclusively within the realignment site and on most of the adjacent marsh except for the mudflat or lower pioneer zone at the limit of continuous marsh vegetation.

At each monitoring site 5 plates, each 15cm x 15cm, were buried horizontally below the surface, by digging up a small 'turf', setting in the plate and replacing the turf (see Photo 3.1. below). Plate positions were selected randomly along a 5m strip perpendicular to the transect, marked with bamboo canes at each end of the 5m strip, with an additional back cane approximately 1m behind the central plate. Each individual plate position was marked with a kebab stick near the corner of the plate.

Typically the plates are buried at approximately 10cm depth below the surface, however there were some difficulties going to this depth inside the realignment site as the ground was rock hard and covered with hard clods of earth. In most cases, plates were buried at depths between approximately 6cm-10cm.

At each survey interval, 5 measurements were taken down to each plate, accurate to approximately 1mm (except where sites were underwater and the high water content of the mud makes it difficult to determine the surface), to give an average value for each of the five plates. The site means for sediment accretion and standard errors were calculated from the average values of the 5 sets of plates at each site. Increasing values through time indicate accretion.

Plate depth at a few sites inside the realignment was reduced after the initial breaching because the first influx of water moved around the loose surface clods of earth. The initial baseline measurements were taken after there had been a few tidal floodings so some of the clods would have started to break up (but some material may have been moved around by the tide during the first winter sampling interval - see results).

At the front of the salt marsh, in areas of mounds and channels, or ridges and runnels, the topography is not suited to plate burial because digging would collapse surface features. Here, 5 pairs of 1.3m-1.5m long canes set approximately 115cm apart were pushed into the substrate to approximately ¾ of their length until their tops were level. Accretion was measured at each sampling interval by placing a builders' level in a precise position on the canes and made level in all planes (with the help of wire extensions, see Photo 3.2. below). Five measurements were taken down to the sediment surface, from positions on the level determined randomly at the outset but permanently marked for subsequent readings. The site means and standard errors were calculated from the average values of the 5 sets of canes at each site. Decreasing values through time indicate accretion.

3.3.2 Site Positions and Elevations

Site positions and elevations were measured using a Trimble RTK GPS during 2005, and the data was post-processed with Trimble software. The elevations tabulated are the mean values of 3 readings for the buried plate sites (plates 1, 3, and 5), and the mean values of all 5 of each of the cane sites (as these were set further apart).

Photo 3.1. Inserting an expanded metal 'accretion' plate. Five plates were set out at random intervals along a 5m strip at each sampling site.

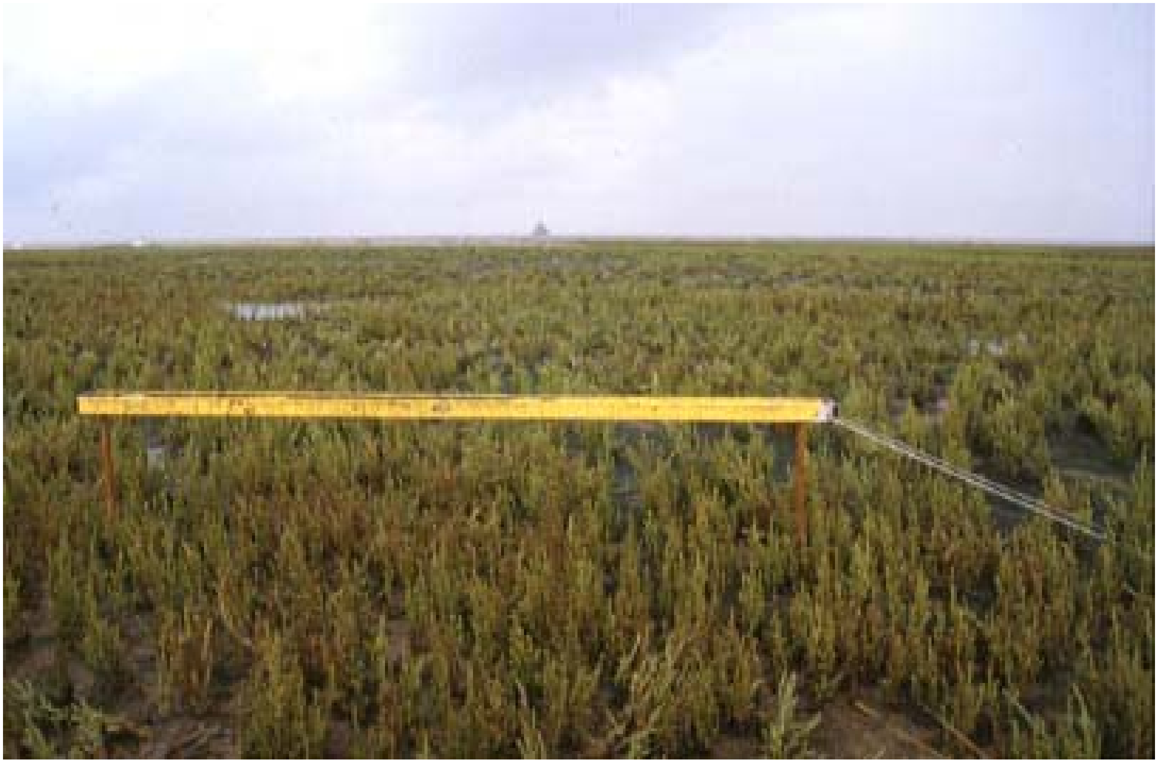


Photo 3.2. Accretion / erosion bar (builders' level) set across a pair of levelled canes. Five pairs of levelled canes were set out at each sampling site.

3.4 Results

The data showing sediment level changes between each sampling interval for all sites are provided on a CD. Elevations for all of the sites are given in Appendix 3.1 at the back of this chapter.

Cumulative measurements from the start of the monitoring programme are shown graphically, in 2 ways. First, the total sediment level change (total accretion and/or erosion) for each site outside the realignment is shown in histograms in Figs 3.1 to 3.6, and for inside the realignment in Figs 3.7 to 3.12. The figures are drawn to the same scales for easier comparison, except for two sites near the middle breach on Transect C which received much higher deposition.

Secondly, the progression of sediment accretion (or erosion) from the start of the monitoring programme to September 2006 at each site along each transect is shown in Figures 3.13 to 3.19 for sites on the adjacent salt marsh (from April 2002 to September 2006) and in Figures 3.20 to 3.25 for sites inside the realignment (from September 2002 to September 2006). Mean values for each site are plotted ± standard errors, and the elevations for each site (measured in 2005) are shown against each plot.

3.4.1 Sediment Accretion on the Natural Marsh outside the Managed Realignment

Total net sedimentation [1] from the first baseline measurements (April 2002, after site installation in Oct.2001) up to September 2006, for sites on the natural salt marsh, is shown in Figs 3.1-3.6. The measurements have been taken for 6 months longer outside the realignment site than inside the site, so the histograms for outside on the salt marsh are divided into 2 periods: from April 2002 to September 2002, and September 2002 to September 2006, to allow accretion outside and inside the site to be compared over the equivalent 4 year period of measurements (September 2002 – September 2006). In describing the results, each site is labelled with the transect number (T) and site number (S), for example: T5S4 is site 4 on transect 5.

The full-length transects north and south of the realignment (Transects 1, 2, 5 & 6) showed a typical pattern of accretion for a wide salt marsh with a shallow gradient. Typically, sedimentation increases downshore to approximately the limit of continuous dense vegetation. Thereafter, the levels start to drop off in the less densely vegetated pioneer zone and continue decreasing to the marsh front. The lowest site on each of these 4 transects (T1S6, T2S8, T5S7, T6S7) showed erosion of sediment from the start of the monitoring programme. These sites lie in areas heavily dissected by small creeks and pans at the transition between marsh and mudflat, with very sparse vegetation, primarily individual annual Common Glasswort (*Salicornia europaea*) plants and the occasional

[1] The measurements are strictly of net sedimentation /net accretion (i.e. sediment deposition minus losses e.g. from resuspension, drying out and surface compaction etc.) but are referred to in this report as simply sedimentation or accretion.

small clump of Common Cord-grass (*Spartina anglica*). This area is very dynamic, with cycles of erosion and accretion occurring at different spatial and temporal scales, for example in the formation of pans and channels in some areas, while neighbouring areas fill up with sediment again over time.

The two shorter transects in front of the realignment (T3 and T4) showed a rather different pattern of sedimentation (Figs 3.3 and 3.4) compared with the longer transects north and south of the realignment site. The amount of sediment deposited on sites on transect 3 increased only to site 2 and then dropped off downshore, while on transect 4 the highest deposition was at the upper site and decreased towards the front of the marsh, where sediment has been lost at the lowest site on the mudflat. The range of elevations at sites on Transects 3 and 4 are equivalent to the sites on the seaward half of the full length transects, where the total accumulated sediment also decreased from the pioneer zone to the mudflat.

Excluding the six lowest mudflat sites which have mostly eroded (-34mm to + 1mm), the remaining 32 sites on the salt marsh transects outside the realignment built up between 1 and 104mm of sediment over the 4 years and 5 months from the beginning of the project (7mm -100mm in four years between September 2002 and September 2006) depending upon their position on the marsh. The highest deposition was at T2S6 (104mm April 2002-September 2006; 100mm in 4 years), followed by 2 sites on Transect 1 with 85mm and 68mm (79mm and 60mm between September 2002 and September 2006). The remaining 29 sites built up between 9mm to 57mm of sediment from the baseline measurements (7mm to 50mm between September 2002 and September 2006).

Generally there has been continuous accretion of sediment on all vegetated salt marsh sites on Transects 1-6 (Figs 3.13 – 3.19). The lowest bare mudflat sites showed fluctuating sediment levels and all but T3S5 (0.9mm accreted) were between approximately 0.4mm and 34mm lower in September 2006 than at the start of the study. This reduction in the measured surface level was not necessarily representative of the entire mudflat zone at the elevations of these sites, and over a longer period of measurement these areas are likely to build up again. This is explained further in the discussion.

3.4.2 Sediment Accretion inside the Realignment Site

In general, sites showed an increase in accumulated sediment going down each transect from the back of the site towards the old (breached) sea wall (Figs 3.7 – 3.12). Five sites experienced much higher sedimentation than the rest, most notably TCS5 and TCS6 which have built up 116mm and 198mm of sediment respectively, during the 4 years of measurements, followed by the lower three sites on Transect D (sites 4-6) which have accreted 82mm to 107mm of sediment. These sites are close to the middle breach where a lot of material appears to have been washed in from the eroding breach sides and widening creeks just inside the breach area.

The remaining 25 sites on Transects A,B,C,D and F have accreted between 5.5mm and 56mm, depending on their positions on the transects. This was a similar range to the accretion measurements on most of the vegetated salt marsh sites outside the realignment area. A comparison between the range of elevations of the sites inside and outside the realignment and an analysis of the relationship between accretion and elevation is made in following sections. Accretion on Transect E, which has only been measured for two years, ranged from approximately 8mm at the top of the transect, increasing to 31mm at the bottom (seaward end).

The cumulative change in sediment level at each sampling interval is shown in Figs 3.20 – 3.25. Most sites have accreted sediment over time, except for a few of the higher sites e.g. Transect A, sites 2 and 3 which levelled off during the second year but which have accreted more sediment subsequently. All sites have accreted sediment since the initial baseline (zero) measurements.

There were some initial minor early losses of surface sediment (up to 1.8mm, at TBS2) during the first winter period on some sites in the upper half of Transects A-C (TAS1&2, TBS1-3, TC2). Prior to breaching and tidal flooding, the soil on the realignment site was very dry with numerous hard clods on the surface and it is likely that these will have been rolled around during the first few inundations before the clods were fully broken down. It was difficult to take accurate first measurements on the realignment site because of air spaces trapped in the matrix of dead terrestrial vegetation under the layer of deposited marine sediment. It takes time for the vegetation to decay and the sediment to settle down, particularly on the less frequently flooded higher areas in the northern half of the site (less weight of new sediment deposited).

Some sites were underwater and difficult to measure at times (very fluid mud surface), for example, TAS6 and TDS6 which were covered by a film of surface water most of the time until summer 2004, and particularly TBS1 and TFS1 which have been under several centimetres of water more or less since the site was breached (TBS1 was once found to be dried out in hot weather after a neap period with no tidal cover).

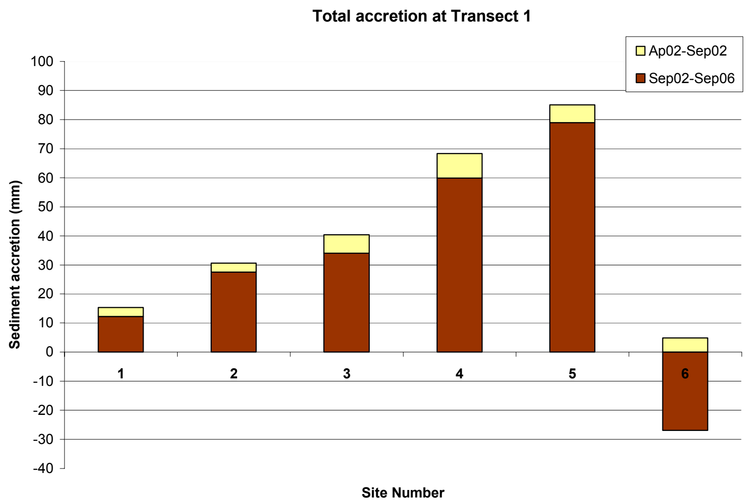


Fig. 3.1

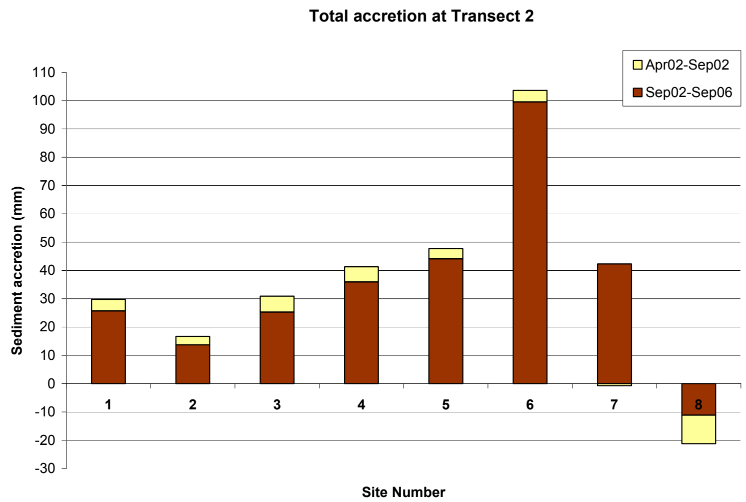


Fig. 3.2

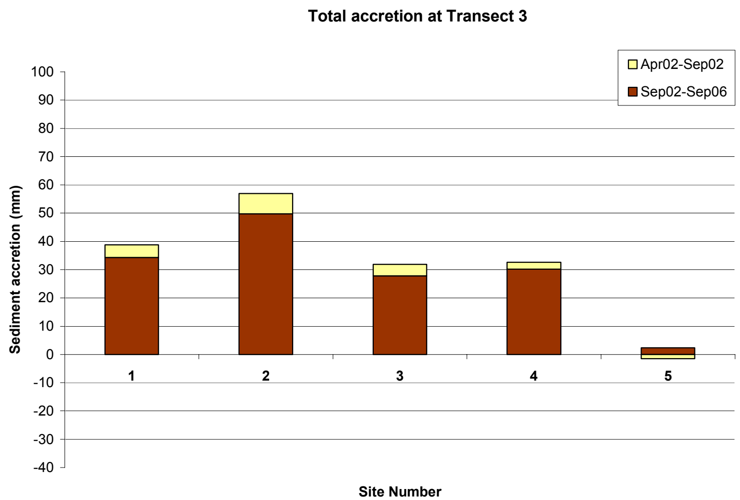


Fig. 3.3

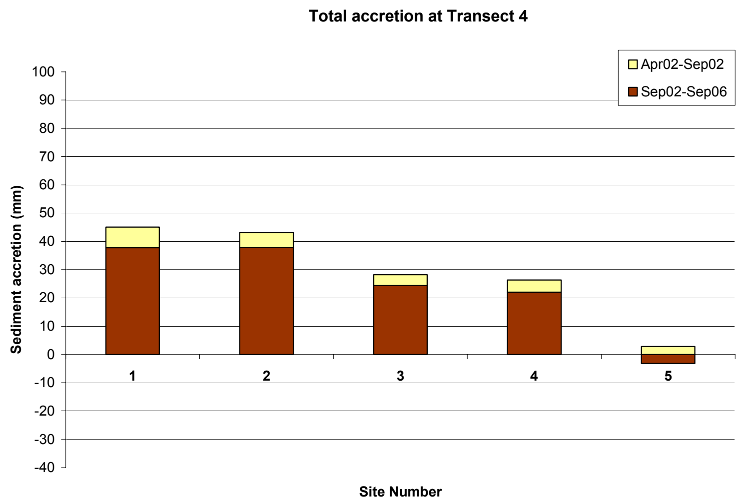


Fig. 3.4

Figs 3.1 – 3.4. Total accretion to September 2006 on Transects 1-4 outside the realignment site

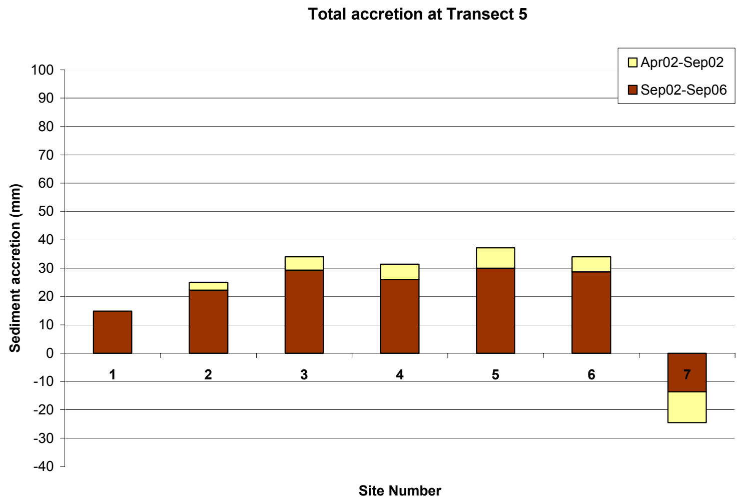


Fig. 3.5

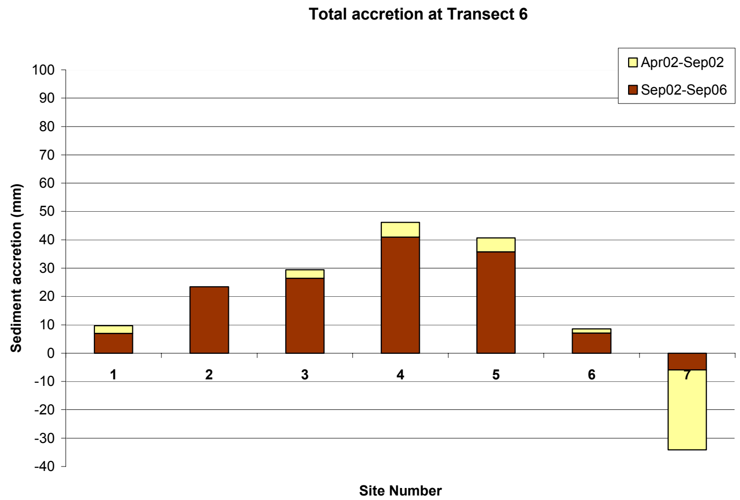


Fig. 3.6

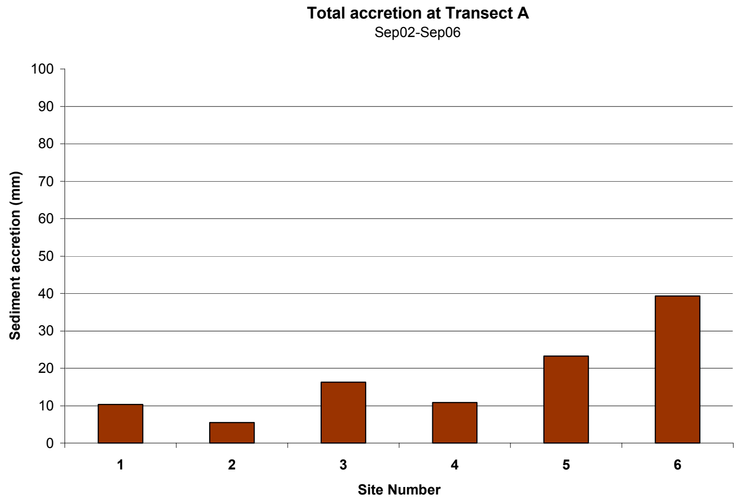


Fig. 3.7

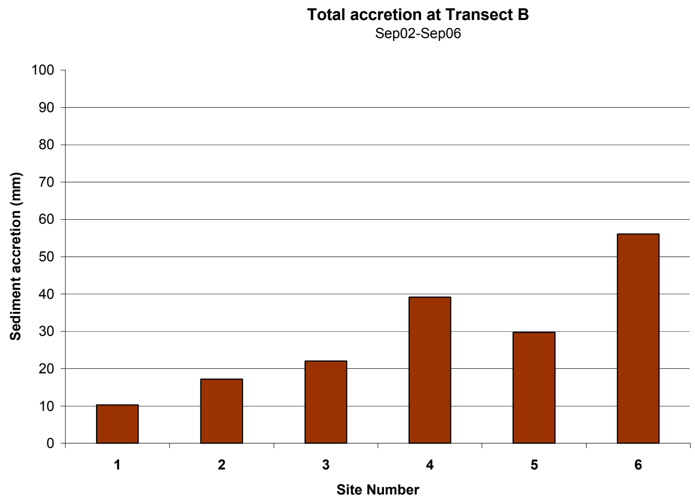


Fig.3.8

Figs 3.5 – 3.8. Total accretion to September 2006 on Transects 5-6 outside the realignment, and on Transects A-B inside

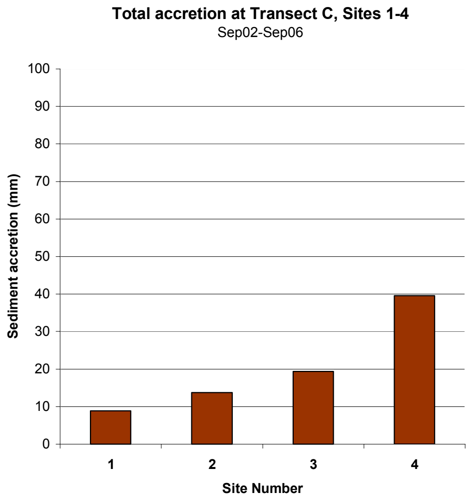


Fig. 3.9a

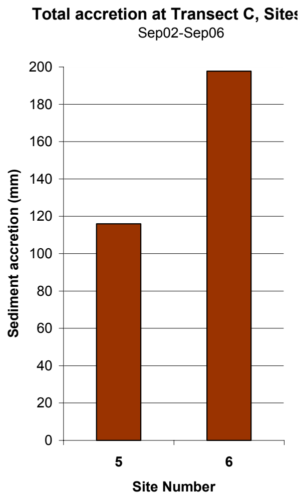


Fig. 3.9b

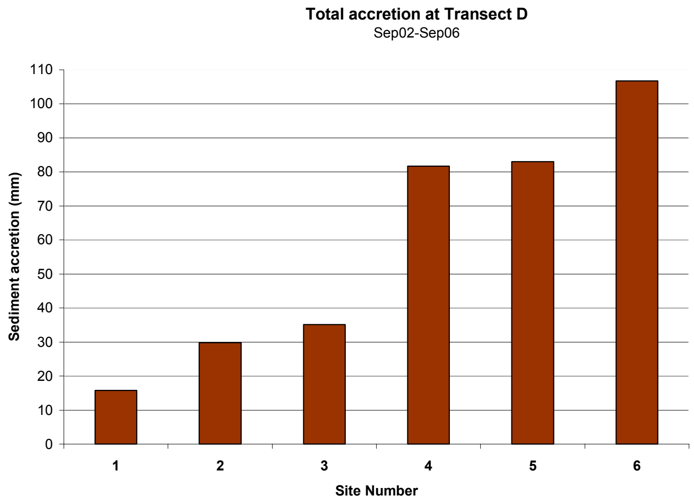


Fig. 3.10

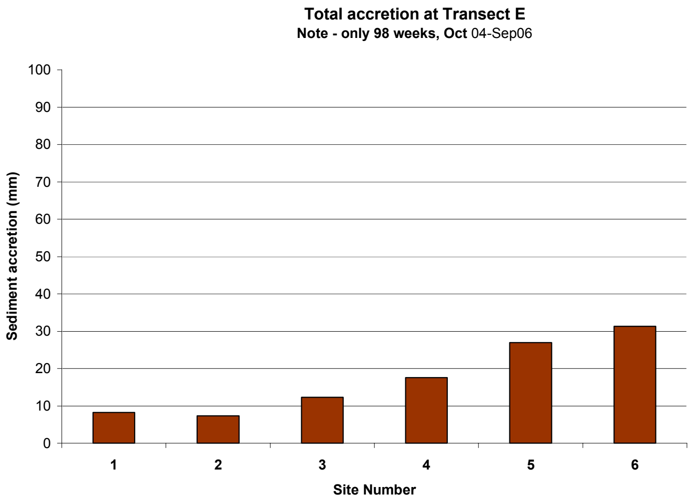


Fig.3.11

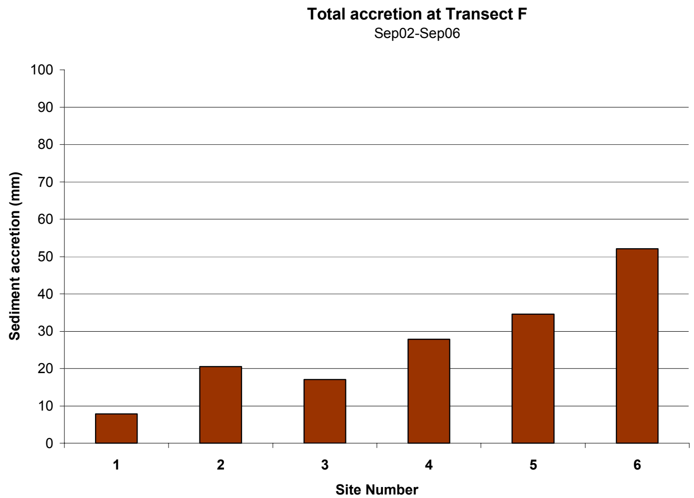


Fig.3.12

Fig. 3.9 -3.12. Total accretion to September 2006 on Transects C-F inside the realignment [Transect E from Sept. 2004]

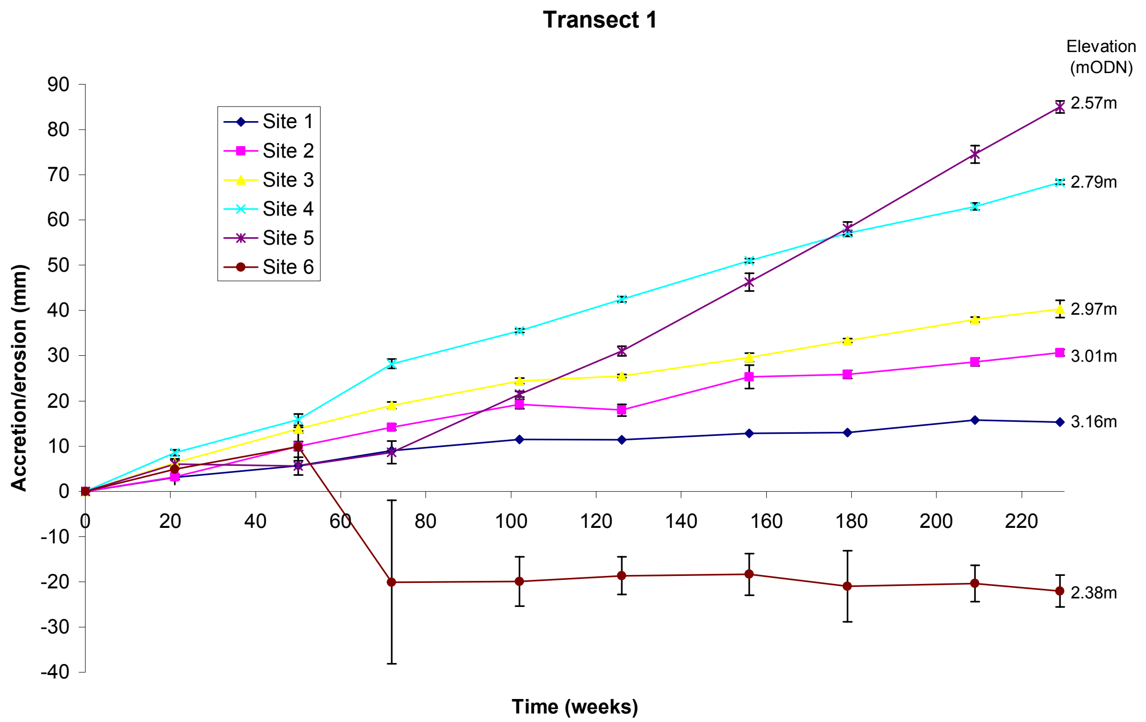


Fig. 3.13

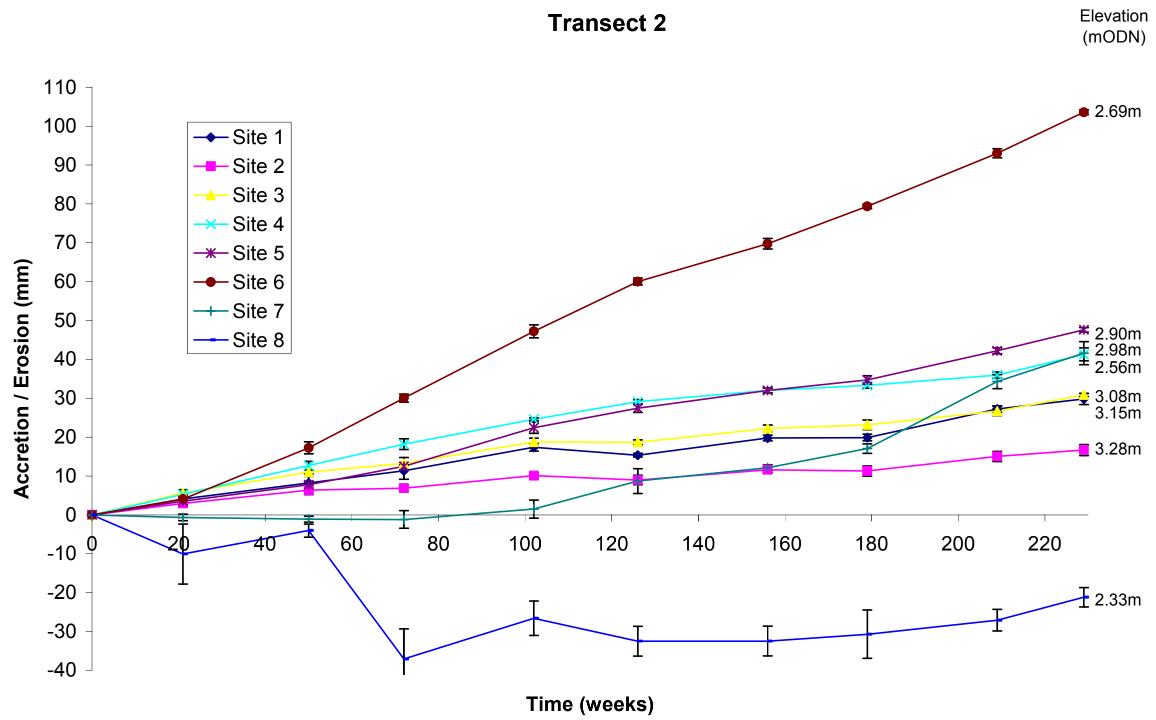


Fig. 3.14

Figs 3.13 and 3.14. Accretion up to September 2006 at sites on Transects 1 and 2 (mean site values ±SE)

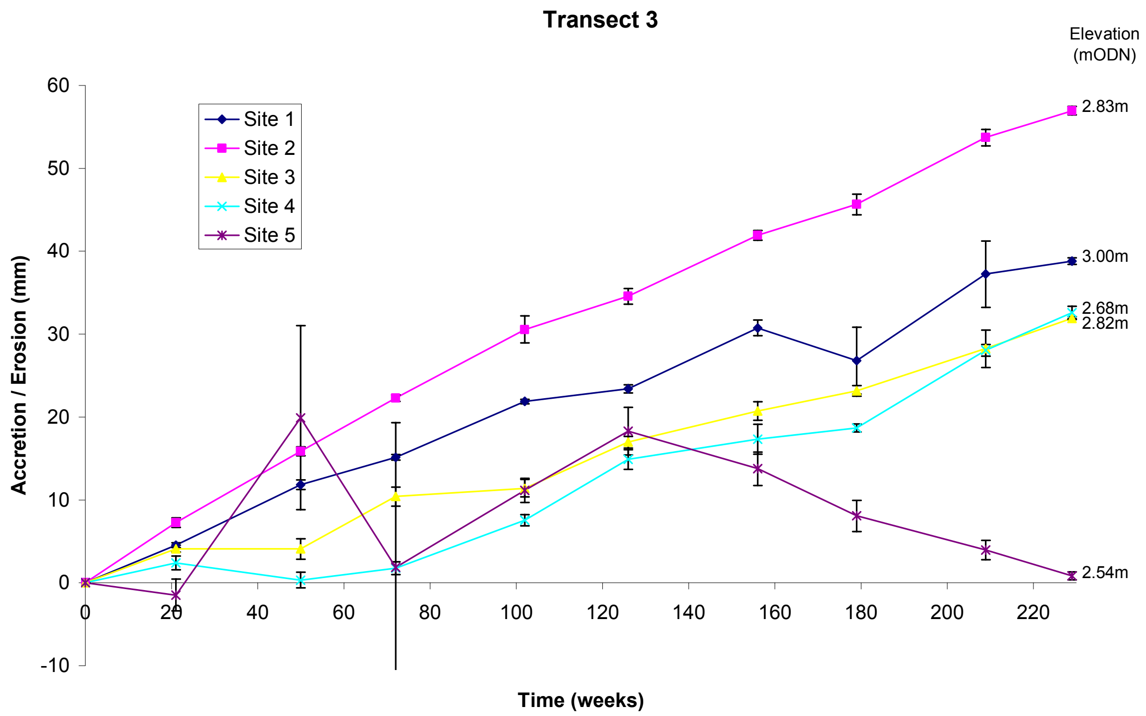


Fig. 3.15

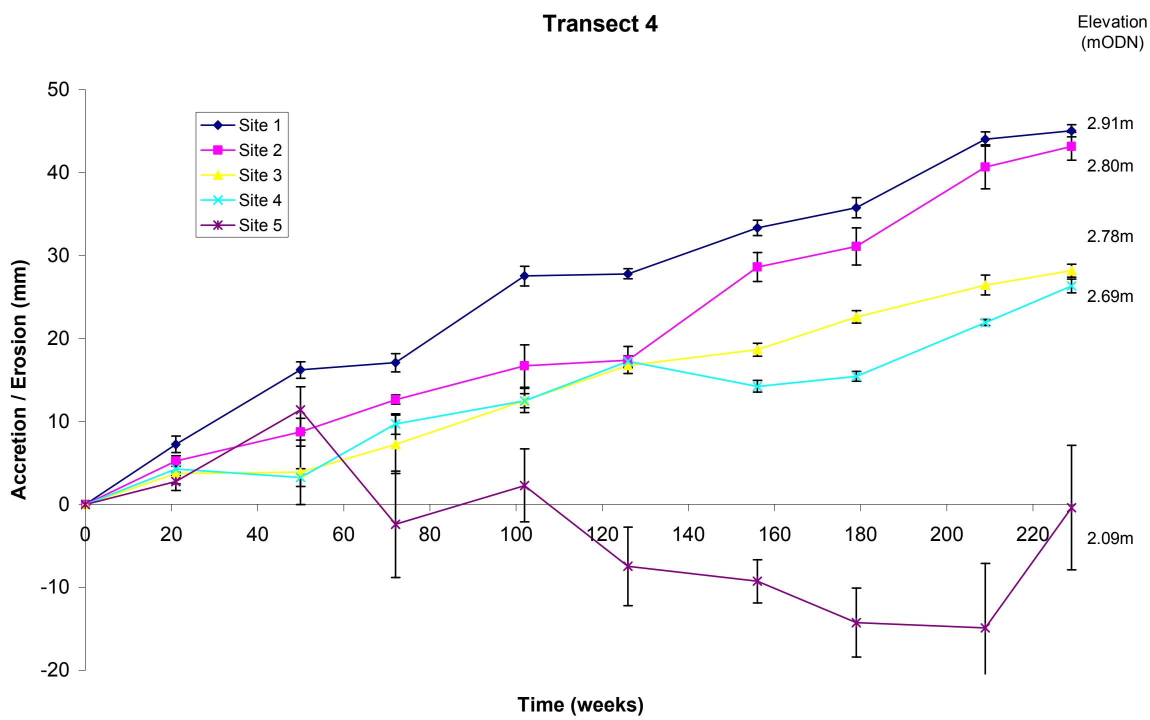


Fig. 3.16

Figs 3.15 and 3.16. Accretion up to September 2006 at sites on Transects 3 and 4 (mean site values ±SE)

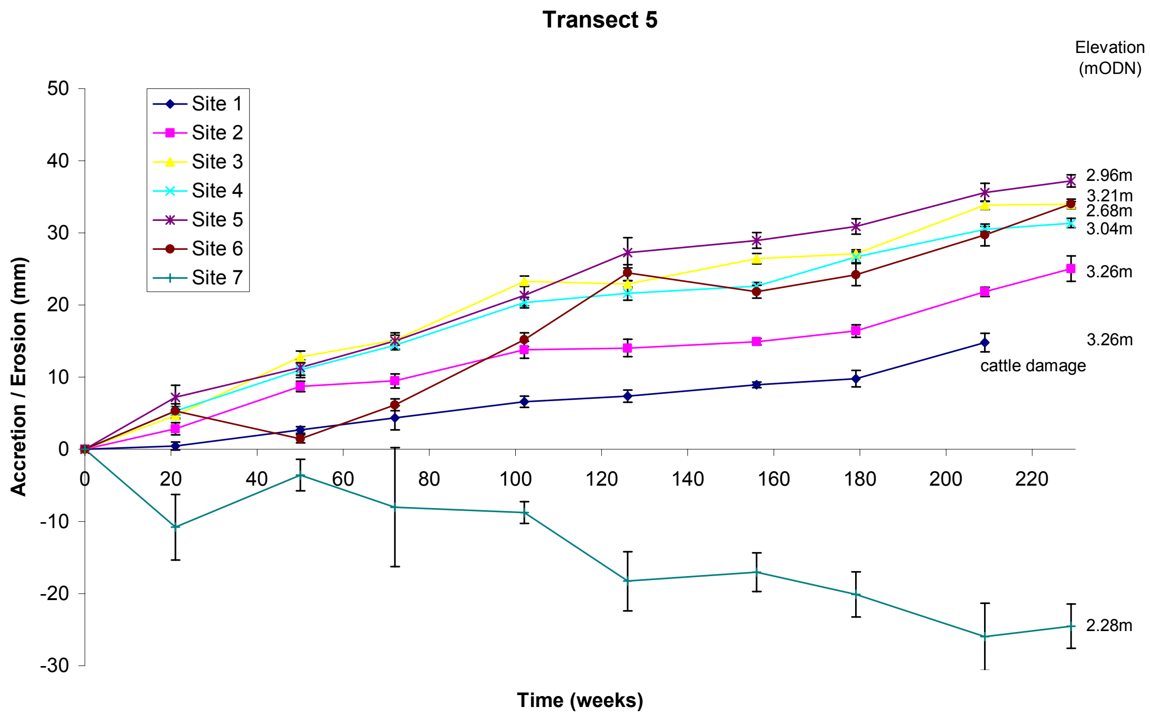


Fig. 3.17

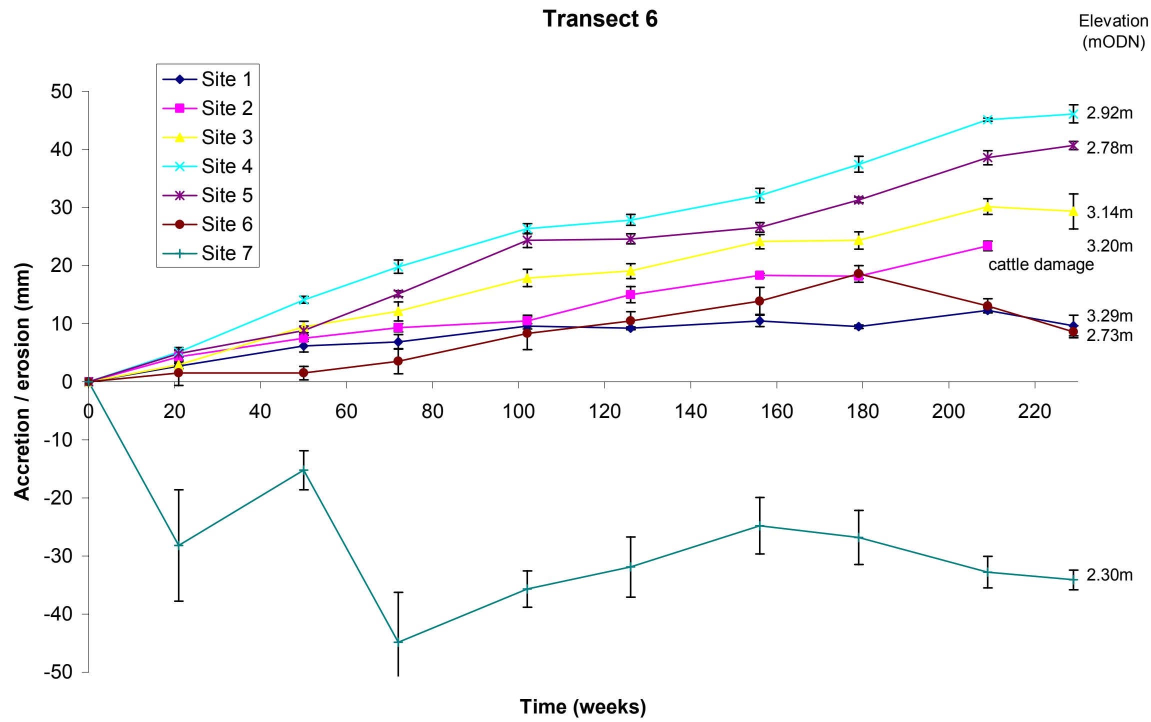


Fig. 3.18

Figs 3.17 and 3.18. Accretion up to September 2006 at sites on Transects 5 and 6 (mean site values ±SE)

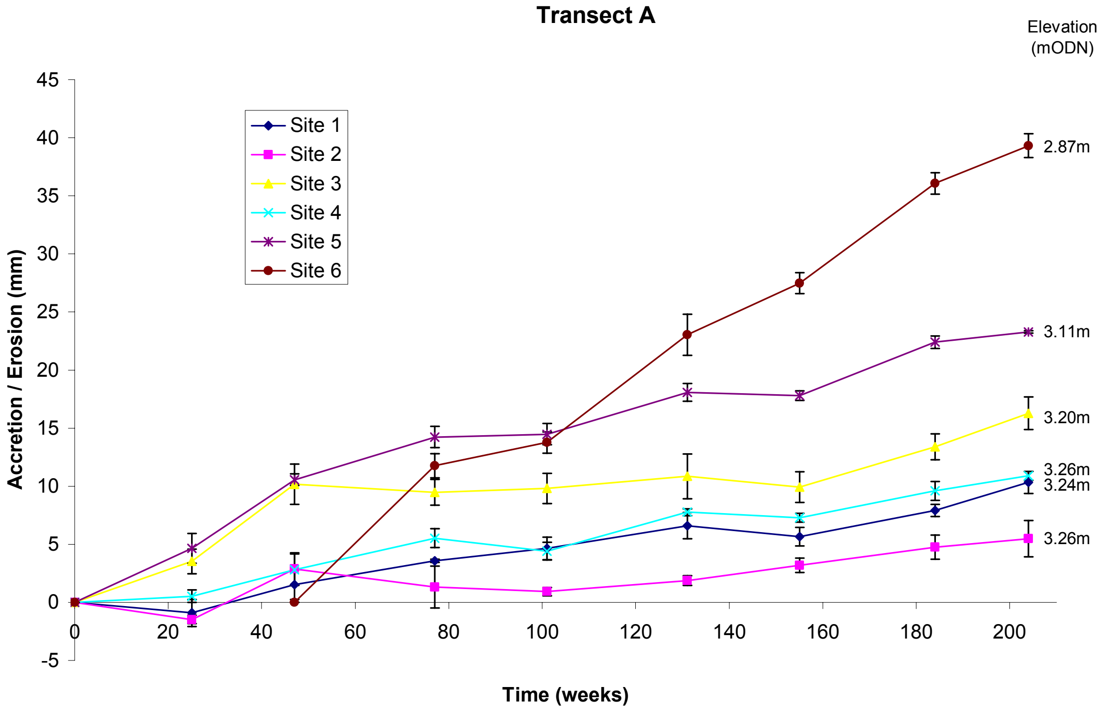


Fig. 3.19

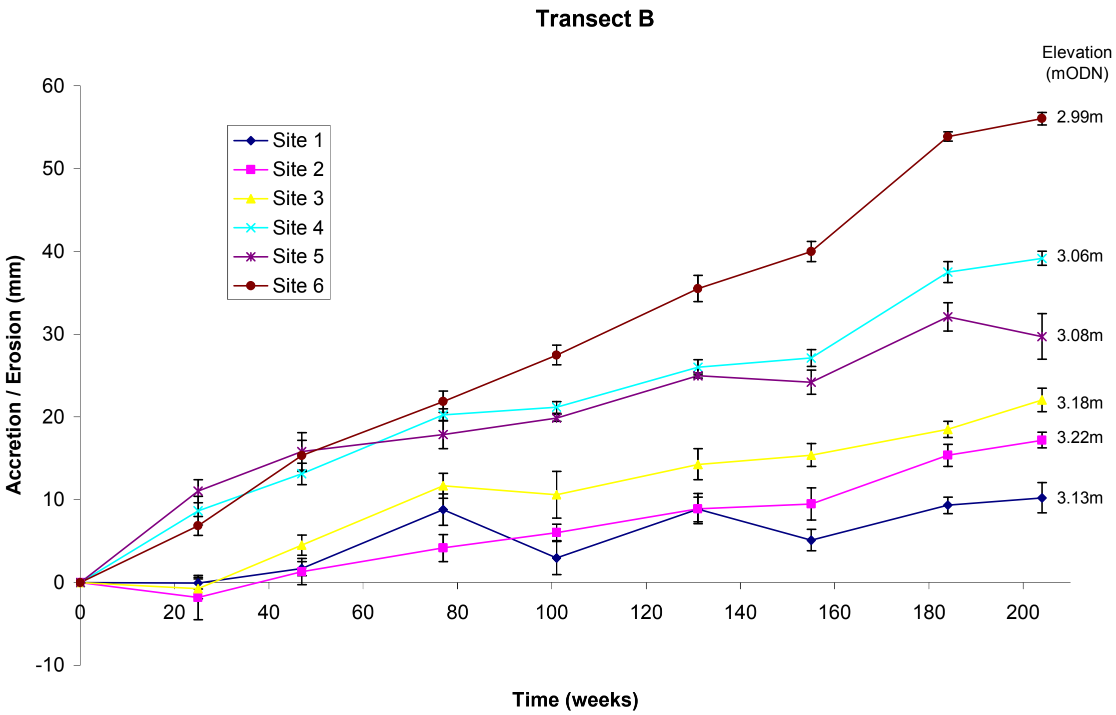


Fig. 3.20

Figs 3.19 and 3.20. Accretion up to September 2006 at sites on Transects A and B (mean site values ±SE)

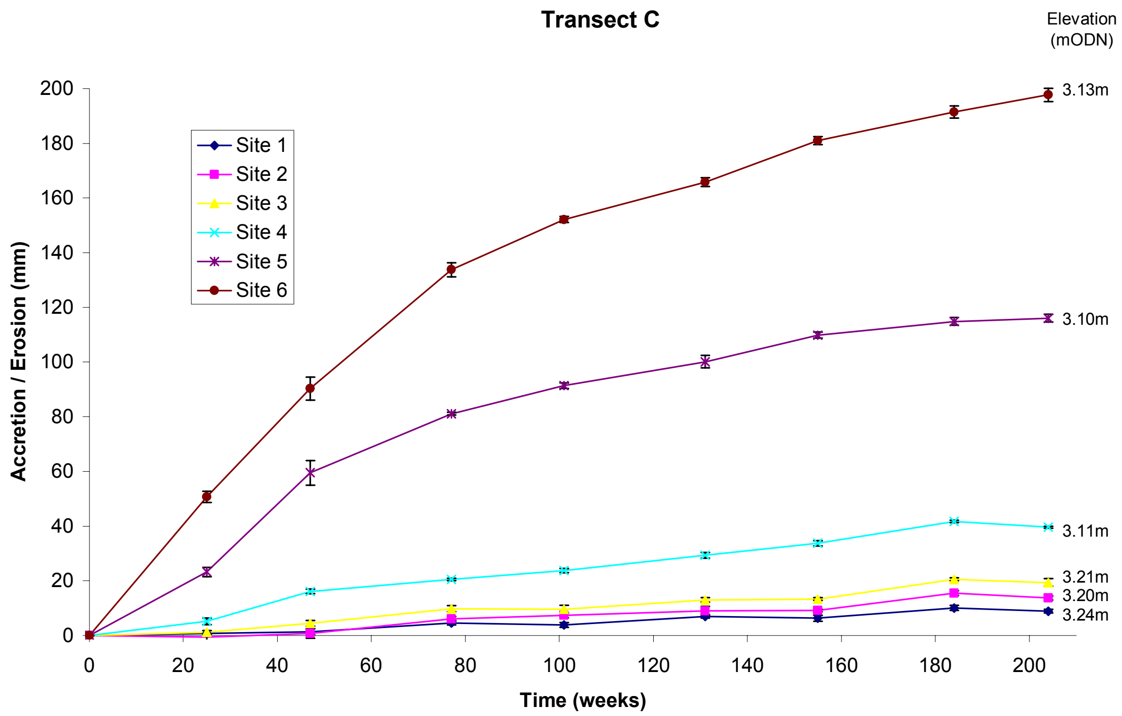


Fig. 3.21

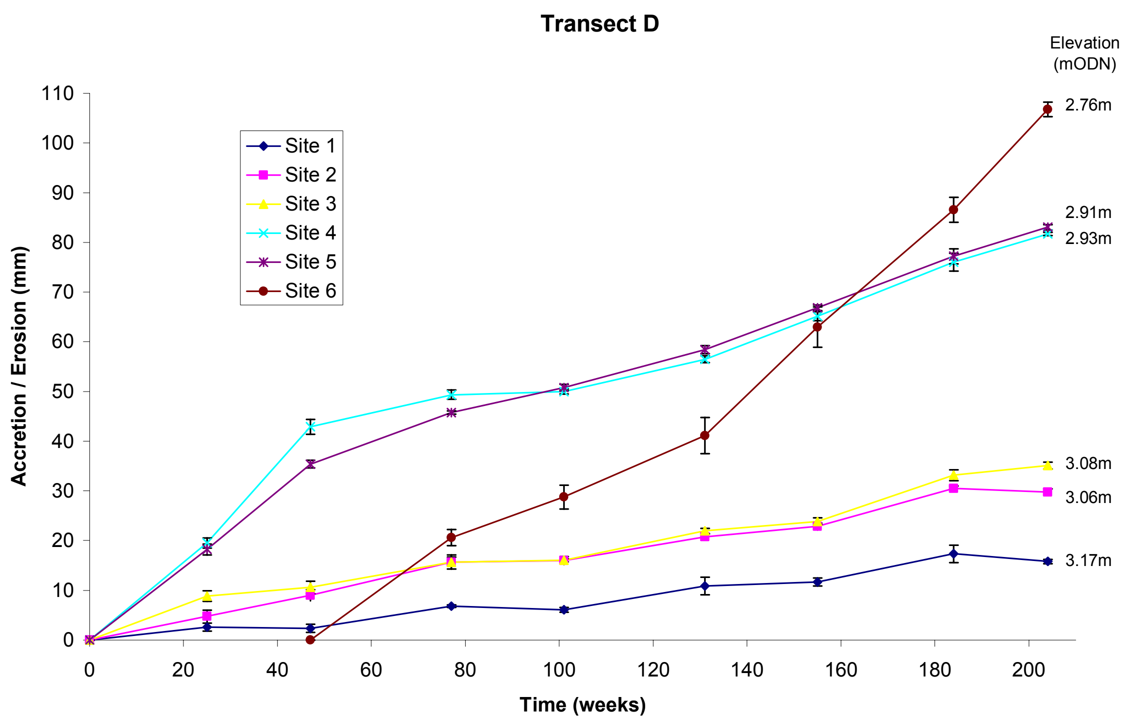


Fig. 3.22

Figs 3.21 and 3.22. Accretion up to September 2006 at sites on Transects C and D (mean site values ±SE). Note very high accretion at Transect C sites 5 and 6 (near to the middle breach)

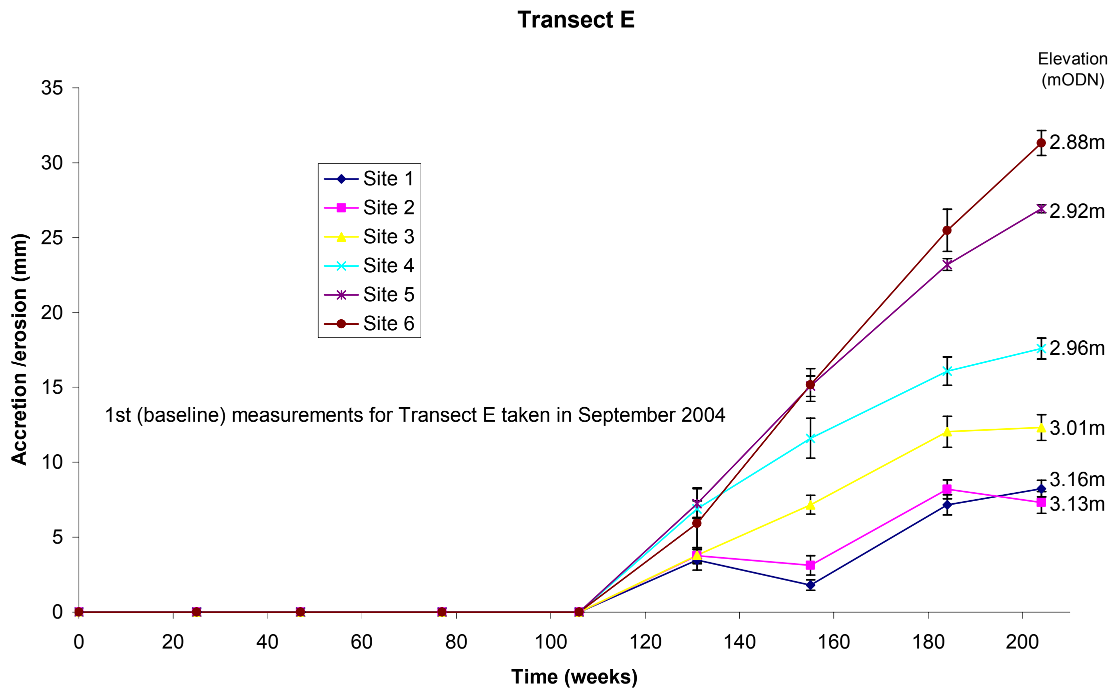


Fig. 3.23

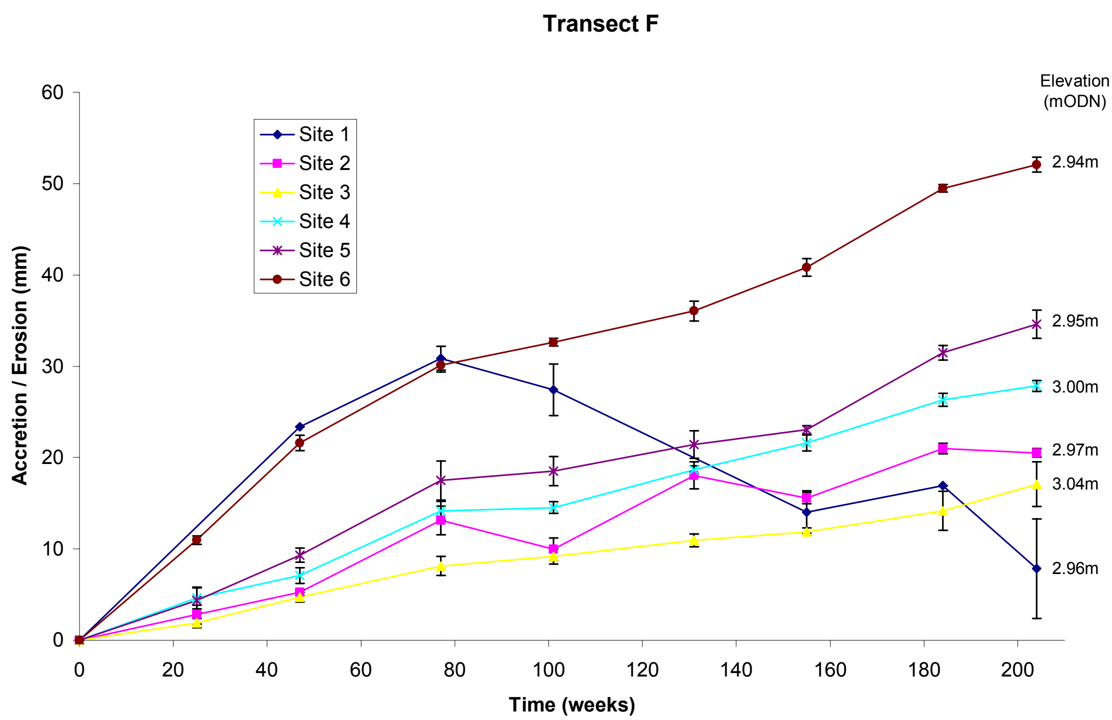


Fig. 3.24

Figs 3.23 and 3.24. Accretion up to September 2006 at sites on Transects E and F (mean site values ±SE)

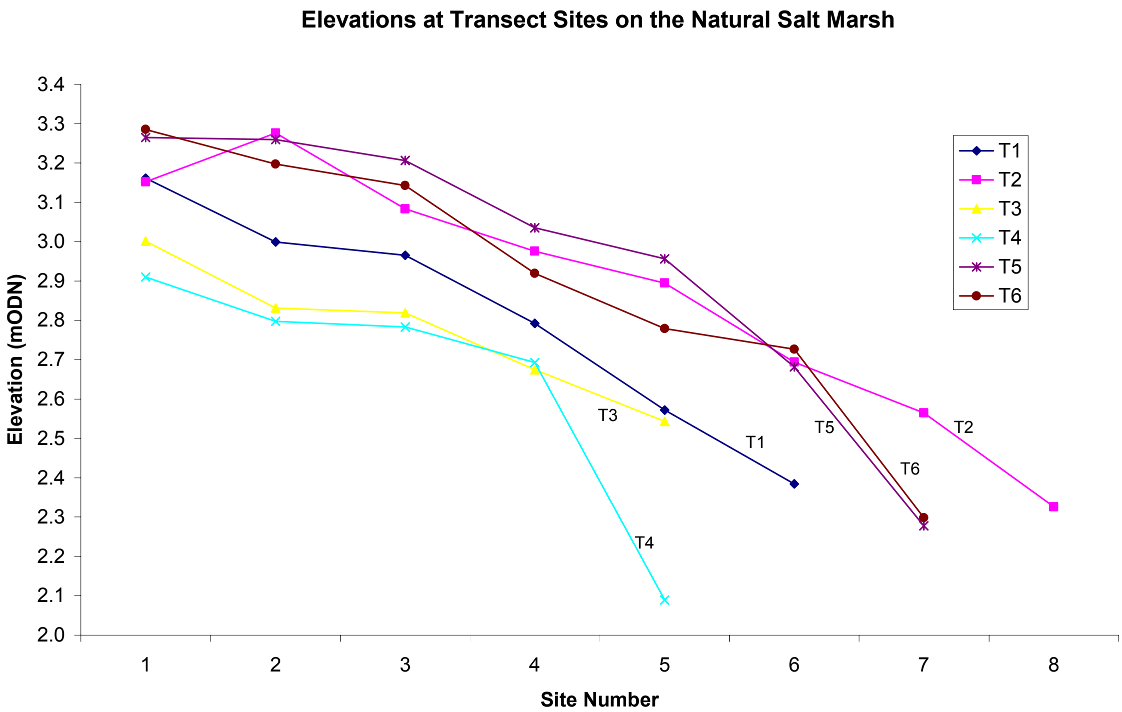
3.4.3 Comparison of Sedimentation inside and outside the Managed Realignment

The range of elevations measured in 2005 along the monitoring transects are shown in Fig. 3.25. Sites on the natural salt marsh extend from 3.29mODN on an upper marsh site (T6S1) down to the lowest site at 2.09mODN (T4S5). Inside the managed realignment the range of elevations is more restricted from 3.26mODN at the highest sites (TAS2 and TAS4) down to 2.76mODN at the lowest (TDS6). The complete range of elevations of all sites inside the realignment and outside (i.e. not separated into transects) is shown in Fig. 3.26.

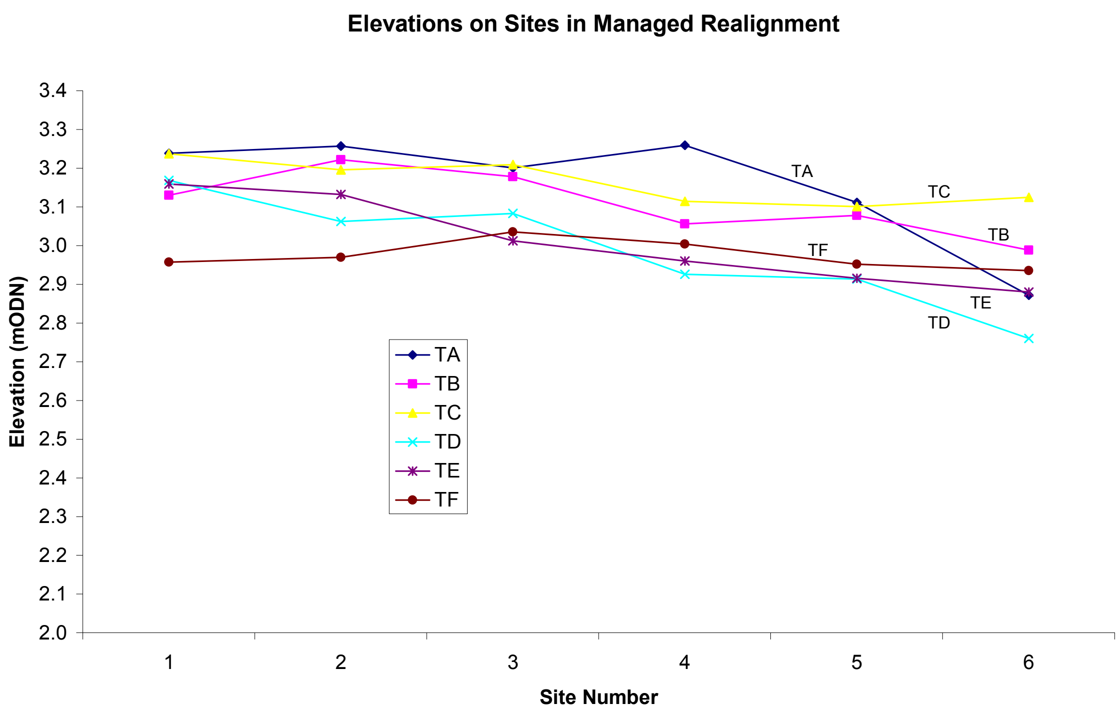
As a first look, the mean total accretion and range of sediment accreted at sites inside and outside the realignment split into elevation categories and over the same time period (4 years between September 2002 and September 2006 are summarised in Table 3.1 below. The table excludes Transect E which has been measured for two years after set-up in 2004. When the high accretion sites thought to be influenced by wash-in from the middle breach were excluded (second row of the table), the range of total accretion values inside the realignment were similar to those outside the Freiston site at the same elevation range, and the means were much closer.

Table 3.1. Range of total accretion (mm) after 4 years inside the Freiston site (excluding Transect E, set up in 2004) and outside on the salt marsh at sites with the same elevation range

Location	Total Accretion Mean (mm)	Total Accretion Range (mm)	Sites
INSIDE MR	39.6	5.5 to 198	All sites (except Transect E)
INSIDE MR, excluding Sites influenced by middle breach	23.4	5.5 to 56.0	Excluding TCS4-6, TDS4-6
OUTSIDE MR, at elevations equivalent to those inside MR (>2.75mODN)	29.8	7.0 to 59.8	T1S1-S4; T2S1,3-5; T3S1-3; T4S1-3; T5S2-5; T6S1,S2-5 (T5S1 & T6S2 damaged by cattle in 2006).
OUTSIDE MR, elevations lower than 2.75mODN	20.3	-26.9 to 99.6	T1S5,6; T2S6-8; T3S4,5; T4S4,5; T5S6,7; T6S6,7



(a) Outside MR. Elevations range between 2.09 -3.29mODN



(b) Inside MR. Elevations range between 2.76 to 3.26

Fig. 3.25. Elevations at the monitoring sites (measurements taken in 2005)

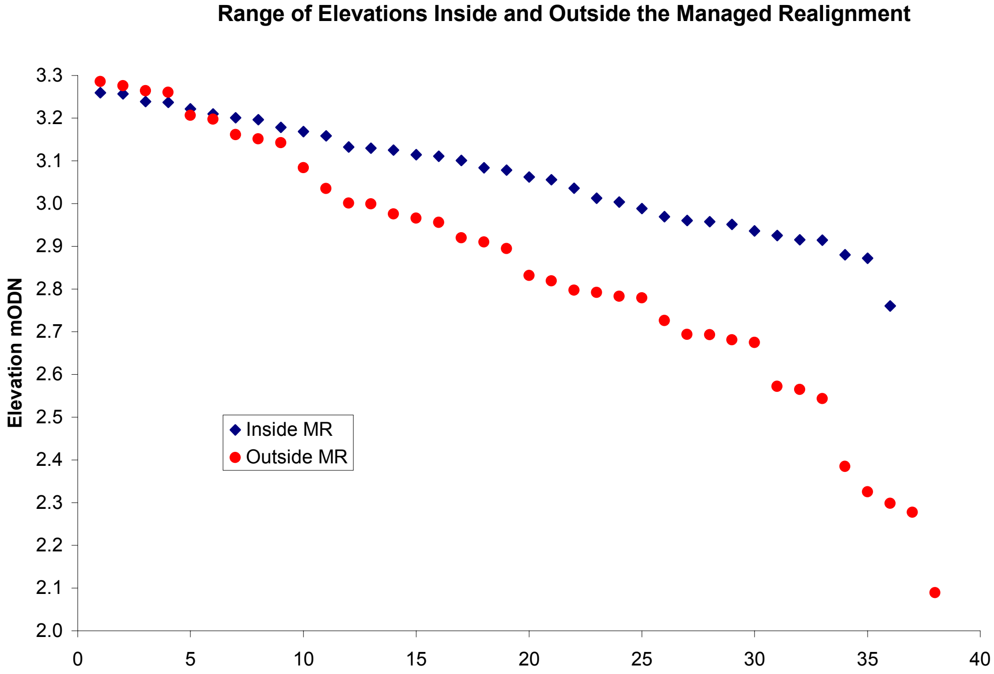


Fig. 3.26. Range of elevations at all sites inside and outside the managed realignment

The mean total accretion for each year (autumn to autumn) is plotted in Fig. 3.27. Inside the realignment the mean total accretion was greatest in the first year (15mm, 2002-2003) but has been lower since (9.3mm in 03-04, 7.7mm in 04-05, and 8.6mm in 04-06). There has been exceptionally high sedimentation at a few sites, at the lower (seaward) end of Transects C and D opposite the middle breach, particularly during the first year of monitoring. These few high accretion sites had a major influence on the mean values, making it difficult to compare accretion in the realignment with that on the natural salt marsh. We believe that the high accretion here was due to material washed in from the central breach (discussed further in the following section), so the total means have also been calculated without these sites (2^{nd} set of histograms in Fig. 3.27), and over the four years they were 7.9mm, 5.4mm, 5.8mm and 7.3mm, respectively. The third set of histograms shows mean total accretion for all sites outside the realignment that lie in the same elevation range as inside (>2.75mODN). The values were similar to those inside (9.0mm, 7.4mm, 5.8mm and 7.7mm over four years between 2002 and 2006) and indicate that accretion was also higher outside the realignment in the first year of monitoring than in subsequent years. Sites outside on the salt marsh below 2.75mODN (sparsely vegetated pioneer zone / salt marsh-mudflat transition) showed marked fluctuations between years, with an overall loss of sediment in the first year (-2.5mm), but a gain of 9.9mm in year 2, 3.9mm in year 3 and 8mm in year 4. The final set of histograms shows the mean result from combining all sites outside on the salt marsh and mudflat.

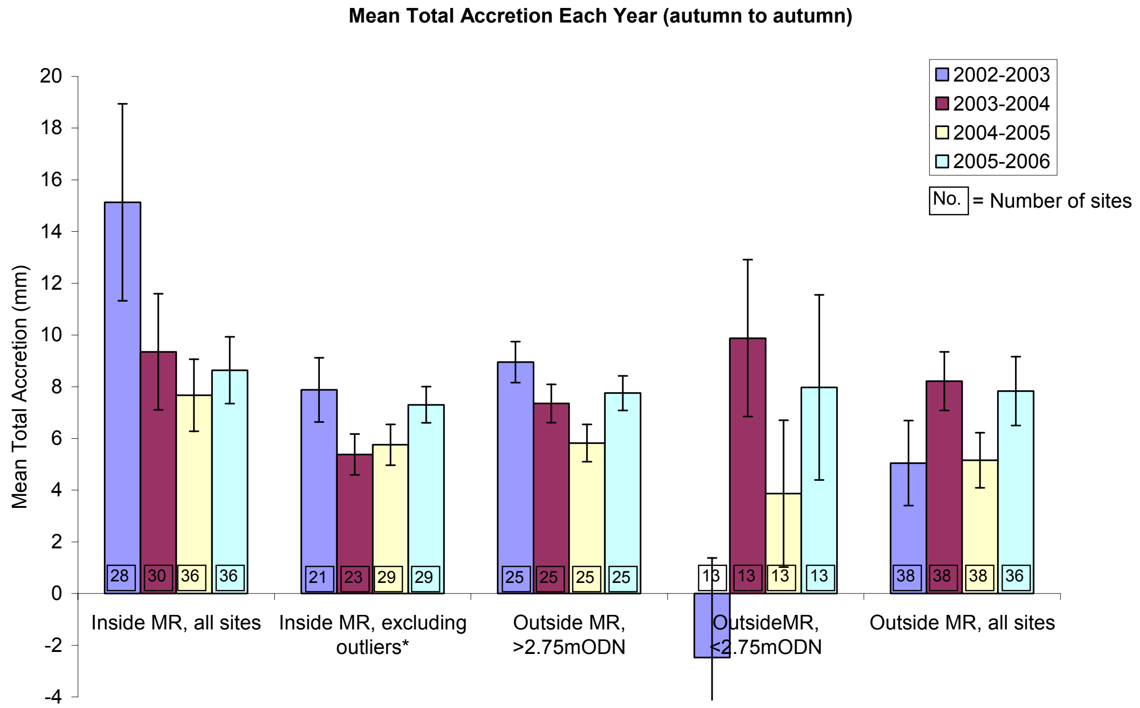


Fig. 3.27. Mean total accretion for each year, from autumn to autumn, inside and outside the realignment site. Inside the realignment: data from all sites, and from sites excluding outliers identified in accretion *vs* elevation analysis (see text). Outside the realignment: data from sites >2.75mODN (equivalent range to inside the realignment), data from sites <2.75mODN, and data from all sites together. No. = number of sites. There were 2 missing values in the first year inside the realignment (sites underwater which could not be measured), and 6 additional sites were added in 2004 (Transect E). Two of the higher elevation sites outside the MR were lost from the data set in 2006, due to cattle poaching of the surface and loss of site markers.

3.5 Analysis And Discussion

For a better comparison of sediment accretion at all sites inside and outside the realignment site it is necessary to account for both the time differences in the monitoring period and the influence of elevation. Therefore, the approximate annual rate of accretion has been calculated for each site ((total accretion / monitoring duration in weeks) x 52) and is tabulated in Appendix Table 3.3.

The accretion rates for sites outside on the salt marsh were calculated from the total accumulated deposition between September 2002 to September 2005 (158 weeks) to match a similar period of measurement for the transects inside the site (155 weeks, except for the more recently installed Transect E where the time period was 49 weeks to September 2005). These rates were calculated for an interim report on data up to 2005 and they have not been re-calculated to September 2006 because two of the higher salt marsh sites were damaged by cattle poaching. The purpose of calculating these approximate accretion rates was to examine the relationship between accretion and elevation outside and inside the realignment site over a similar time period. There have been no obvious major changes in accretion rates over the last year from observations of the figures showing cumulative accretion.

The annual rates of accretion on the natural salt marsh outside the realignment site are plotted against elevation in Fig. 3.28a. The rate increased with decreasing elevation down to a zone between approximately 2.6m – 2.8mODN where after it decreased at the marsh front.

The annual rates of accretion inside the realignment site are plotted against elevation in Fig. 3.28b, using the same scale as outside for better visual comparison. Inside the realignment, all sites are higher than 2.87mODN, except one (TDS6) at 2.76mODN. Accretion rates increased with decreasing elevation, as expected. There were two very obvious outliers at approximately 3.1mODN with very high rates; these were the aforementioned sites TCS5 and TCS6 which appear to have been greatly influenced by washed in sediment from the middle breach area.

A comparison of the accretion rates and regression lines for all sites outside and inside the realignment with an equivalent range of elevations (> 2.75m - <3.3mODN) is shown in Fig. 3.29. The data overlapped over some of their range although the spread within the realignment was much greater. The correlation between accretion rates and elevation outside the realignment was significant (p=0.000) and the regression analysis gives the R-Sq (adj.) value of 55%. For all accretion rate data from inside the site the R-Sq (adj.) was just 12.3% and the correlation was not significant (p=0.020), and there was no significant difference between the slopes of the regressions (multiple regression analysis of variance, t_{57df} = 1.42, p=0.162).

Removing the two very obvious outliers (TCS5 and TCS6) improved the relationship and generated a significant correlation (Fig. 3.30, p=0.000, R-Sq (adj.) = 67.4%). This analysis identified some outliers: TCS4, TDS4, TDS5, TDS6, in other words an additional site in the lower half of Transect C and the three lower sites on Transect D. Transect C and D are either side of the middle breach and it is likely that the lower halves of these transects have received additional sediments washed in from the middle breach and sediment mobilised from earth-moving works in the area. This zone of the site was covered with unconsolidated sandy sediment from the outset, presumably due to the works associated with creating the breach and an artificial creek network inside the site to link to the breach. A similar area of reworked sediment and digger tracks was also obvious at the southern breach and creek excavation area. A transect was not set up here at the outset because of the construction activity (Transect E was set up later, in 2004).

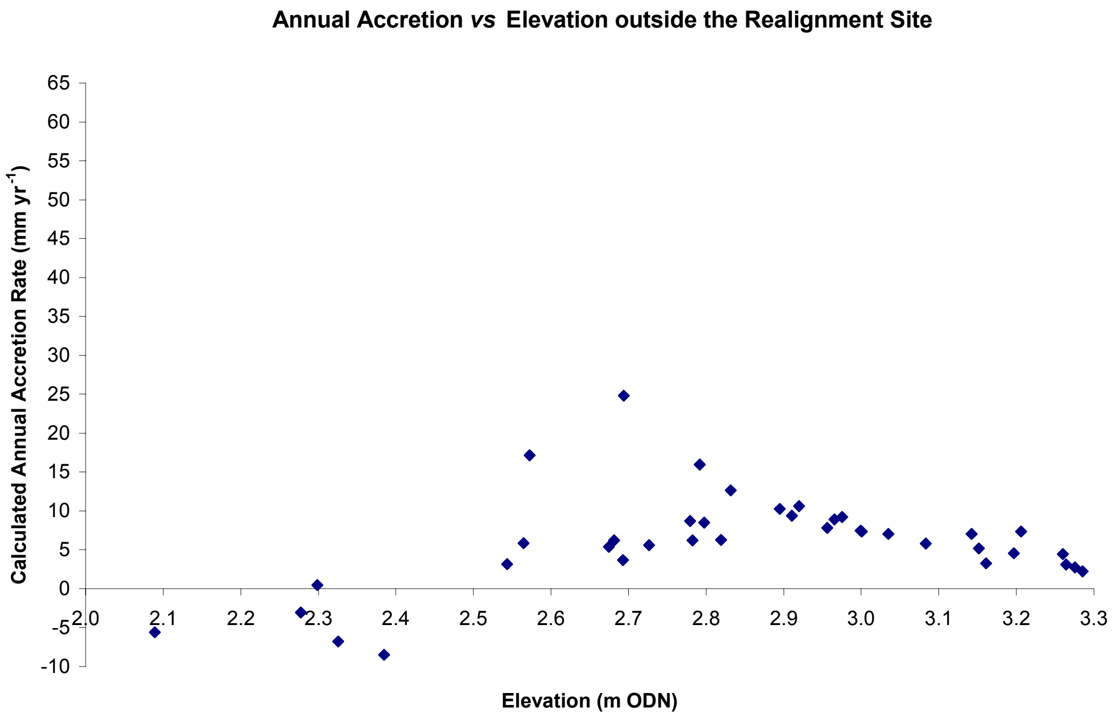
The extent of the bare sediment area opposite the middle breach is visible in the aerial image of the realignment site (Image 3.1), taken in 2003. Judging by the amount of runnels and channel formation that we have observed in this area, there must have been a lot of sediment movement associated with the tidal flow in and out of the middle breach.

Image 3.1. Airborne Thematic Mapper Image (NERC) of Freiston Realignment and coastal salt marsh and mudflat (taken September 2003). Note the large fan-shaped area of bare sediment (blue colour) opposite the middle breach inside the site. It is also interesting to see the remnant pre-reclamation salt marsh dendritic creek patterns in the field north of the realignment site.

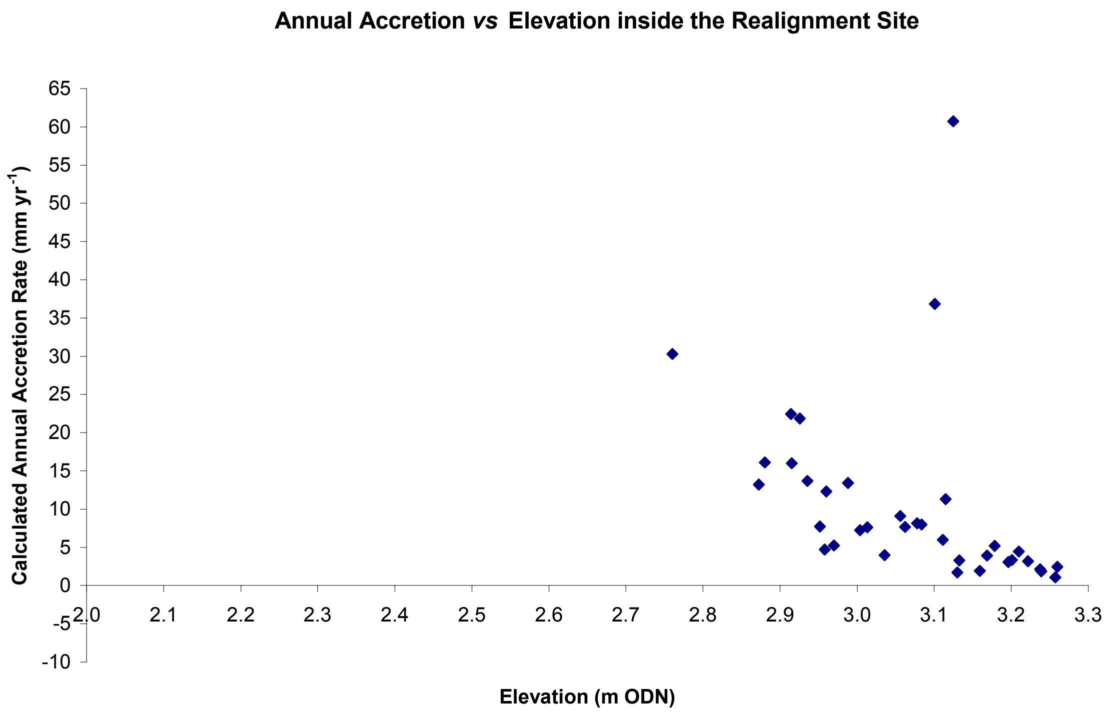
A further outlier identified in the regression analysis was TFS1. This site has been permanently under several centimetres of water throughout the monitoring period, and the top layer of sediment is almost liquid, making the depth from the surface to the plates impossible to measure with the same accuracy as other sites.

The analysis was repeated again to see the effect of removing the outliers described above. This generated the best relationship between accretion and elevation inside the realignment site (see Fig. 3.31) in which the R-Sq (adj.) value was increased to 74.5%.

As noted above, these 3 graphs show the accretion rate data for sites at elevations >2.75mODN to <3.3mODN. The data points from outside and inside the site overlapped between elevations of approximately 2.95m to 3.2mODN. However, at lower elevations accretion was higher inside the shelter of the realignment site than on the natural marsh outside, and at higher elevations accretion was lower inside the Freiston site than outside. Multiple regression analysis of variance showed statistically significant differences in the two slopes of the regressions when the 2 main outliers (TC5&6, Fig.3.30) were excluded (t_{55df} = 5.00, p=0.000), and when all outliers (Fig.3.31) were excluded (t_{50df} = 4.30, p=0.000).



(a) Outside the managed realignment site



(b) Inside the managed realignment site

Fig. 3.28 (a & b). Annual accretion rates vs. elevation outside and inside the managed realignment site. Annual accretion rates were calculated for the equivalent interval for both areas, i.e. between September 2002 and September 2005.

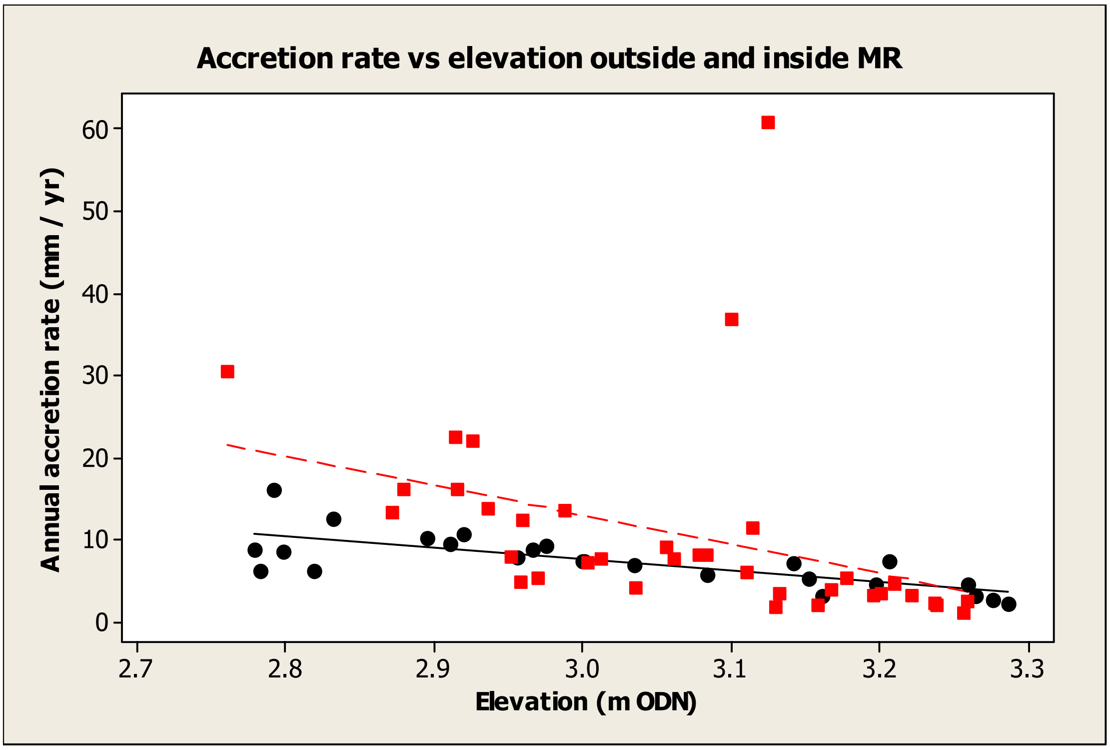


Fig. 3.29. Annual accretion rate *vs* elevation outside (black) and inside the managed realignment site (red), at the equivalent elevation range (> 2.75mODN). Outside MR: Pearson Correlation = -0.754, p=0.000; Regression R-Sq = 56.8%, R-Sq (adj.) = 55.0%. Inside MR: Pearson Correlation = -0.385, p=0.020; Regression R-Sq = 14.8%, R-Sq (adj.) = 12.3%

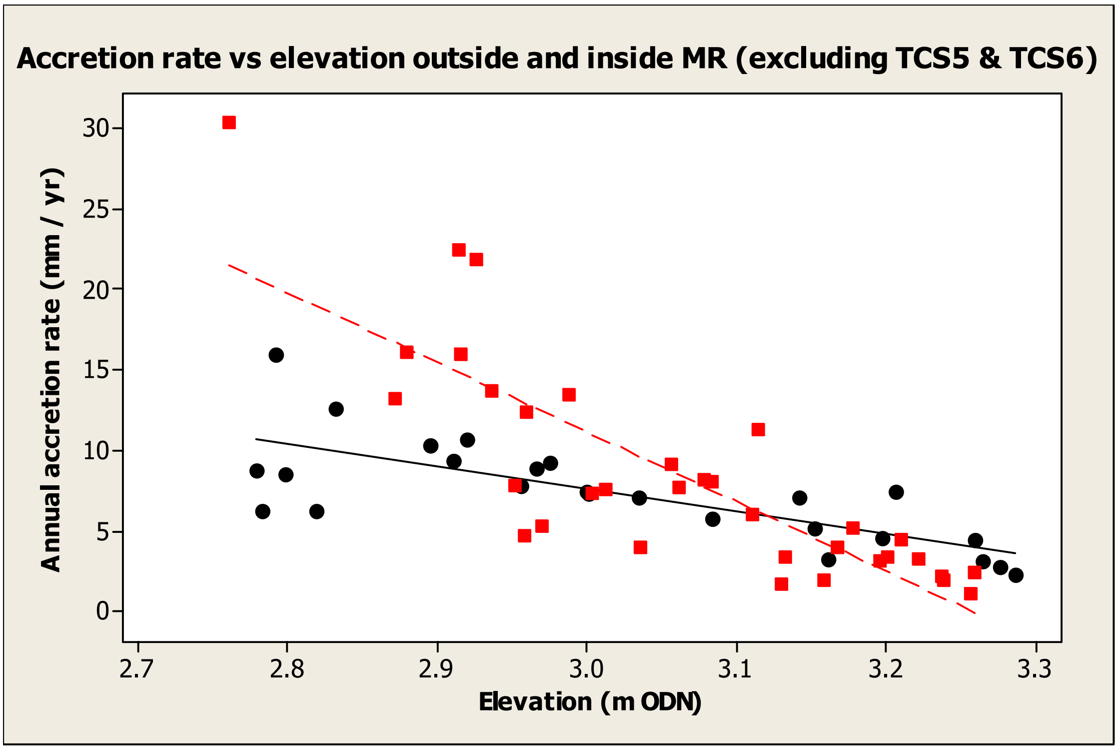


Fig. 3.30. Annual accretion rate vs elevation outside (black) and inside the realignment site (red) at the equivalent elevation range (>2.75mODN), excluding 2 main outliers in the realignment (TCS5 & TCS6). Outside MR: Pearson Correlation = -0.754, p=0.000; Regression R-Sq = 56.8%, R-Sq (adj.)

=55.0%. Inside MR: Pearson Correlation = -0.827, p=0.000; Regression R-Sq = 68.4%, R-Sq (adj.) =67.4%

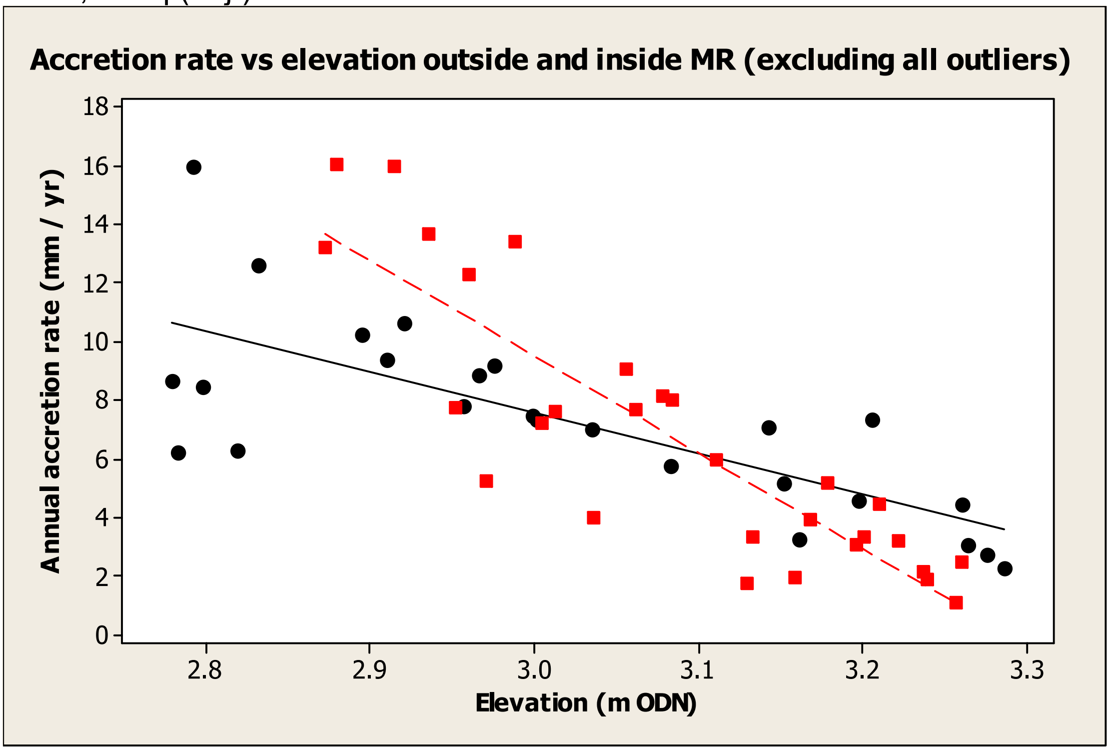


Fig. 3.31. Annual accretion rate vs elevation outside (black) and inside the realignment site (red) at the equivalent elevation range (>2.75mODN), excluding outliers in the realignment (see text for details). Outside MR: Pearson Correlation = -0.754, p=0.000; Regression R-Sq = 56.8%, R-Sq (adj.) =55.0%. Inside MR: Pearson Correlation = -0.869, p=0.000; Regression R-Sq = 75.4%, R-Sq (adj.) =74.5%

3.5.1 Mean and Median Annual Accretion Rates grouped into Elevation Categories

The mean and median annual accretion rates (in mm) are shown in Table 3.2, for inside and outside the realignment site, grouped into categories of elevation range. In addition to values for all sites, we have calculated the mean (and median) accretion rates for these categories when the sites identified as outliers in the analysis of the relationship between accretion and elevation were excluded (i.e. sites thought to be influenced greatly by washed in sediment from the widening central breach area, plus one site that was permanently underwater and hard to measure accurately).

The mean annual accretion rate calculated for all sites inside the managed realignment was 10.6mm. Sites on the natural salt marsh outside but within the same elevation range (i.e. only sites between 2.75 and 3.3mODN) were found to have a lower mean annual accretion rate of 7.33mm. When the major outliers in the realignment (identified from the relationship between accretion and elevation) were excluded the mean accretion rate value was reduced to 6.7mm, much closer to the outside sites.

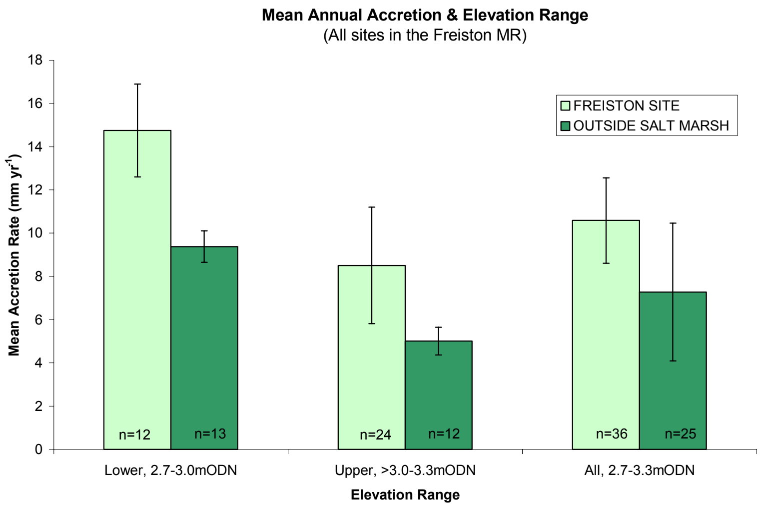
In the lower half of the elevation range (2.75-3.0mODN) inside the realignment, the mean annual accretion rate was 14.7mm (12.2mm with the outliers excluded). Outside on the salt marsh in this range the value was lower, at 9.4mm. In the upper elevation range (>3.0-3.3mODN) in the realignment, the mean annual accretion rate was 8.5mm. This value was reduced substantially to 4.5mm when the outliers were excluded. This is because the two highest accretion sites (TC5&6, total accretion over 3 years: 110mm and 181mm; mean accretion over the 3 years: 36.8mm and 60.7mm, respectively) are within the 3.0-3.3m ODN elevation range, where the lowest rates of accretion would be expected if the sediment supply was just from offshore or picked up from the fronting salt marsh-mudflat surface by incoming tides. Outside on the salt marsh above 3.0mODN the mean value was 5.0mm, close to the value inside the site when the outliers were excluded.

The calculated mean accretion rates for equivalent elevation categories inside and outside the realignment are also shown graphically in Fig. 3.32. When all sites in the realignment were included in the calculations (Fig. 3.32a) mean accretion rates were higher in the realignment site than outside at both lower and upper elevation range categories (standard error bars show no overlap). When the two very high accretion sites near the breaches (TCS5 & TCS6, Fig. 3.32b) were excluded, their marked effect on the mean values for the upper elevation range was evident because without them, the values inside and outside the realignment were similar. When all the outliers identified by the analysis were excluded (lower half of Transects TC and TD and the permanently waterlogged site TFS1, Fig. 3.32c) the difference between mean accretion rates inside and outside the realignment in the lower elevation range category was reduced, but still showed a higher mean accretion rate inside the realignment site.

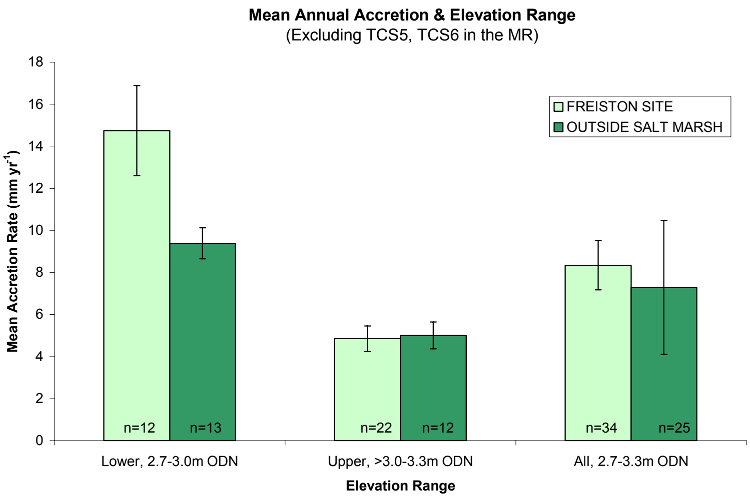
Because the few anomalously high accretion sites have such a major influence on the mean values, the sample median (middle observation in the data range) is more representative of the data set than the mean. Median values for annual accretion rates at equivalent elevation range categories inside and outside the realignment site are also shown in Table 3.2 and they are plotted in Fig. 3.33. Outside the realignment, the median values were close to the means in all elevation categories. Inside the realignment, for all sites (2.75-3.3mODN) we have noted above that the mean annual accretion rate was 10.6mm, reduced to 6.7mm when the outliers were excluded. However, the median annual accretion rate (without any points excluded, i.e. all sites) was 7.42mm, very close to the median for this range outside the realignment, which was 7.33mm. Because two sites in the upper elevation range (3.0-3.3mODN) in the realignment have exceptionally high accretion values, the mean value (including these sites) was approximately twice the median value for annual accretion at this range. The median annual accretion rate was 4.23mm and close to the median value for outside the realignment for this range, which was 4.87mm. The median annual accretion rate inside the site in the lower elevation category (2.75-3.0mODN) was still higher (13.6mm) than outside in the same range (8.9mm). This fits with the observation made previously in the analysis of the relationship between accretion and elevation that accretion in the realignment has been higher than outside at the lower end of the elevation range.

Table 3.2. Calculated mean and median annual accretion rates at different elevation ranges in the managed realignment site and outside on the salt marsh. Rate calculated from data over 3 years, autumn 2002-2005
N = Number of sites

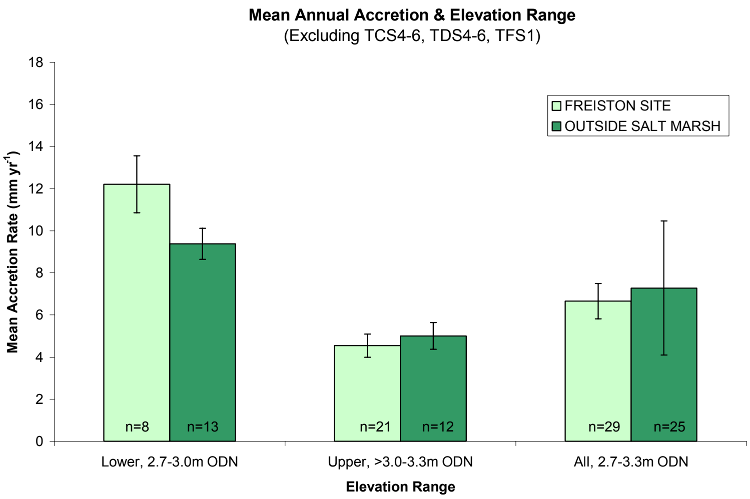
Location	N	Mean Elevation mODN (±SE)	Median Elevation mODN	Mean Annual Accretion mm (±SE)	Median Annual Accretion mm	Sites
Inside MR all elevations 2.75-3.3mODN	36	3.07 (±0.021)	3.08	10.6 (±1.97)	7.42	All sites
Inside MR 2.75-3.0mODN	12	2.92 (±0.018)	2.93	14.7 (±2.14)	13.6	All sites: A6,B6,D4-6,E4-6,
Inside MR >3.0-3.3mODN	24	3.14 (±0.016)	3.13	8.51 (±2.69)	4.23	All sites
Inside MR all elevations excluding sites identified as outliers from the analysis of accretion *vs* elevation	29	3.09 (±0.022)	3.08	6.66 (±0.838)	5.22	Excluding C4-6, D4-6, F1 (sites probably influenced by wash-in from the middle breach and an underwater site)
Inside MR 2.75-3.0mODN excluding outliers from analysis	8	2.93 (±0.014)	2.94	12.2 (±1.36)	13.3	Excluding D4-6, F1
Inside MR >3.0-3.3mODN excluding outliers from analysis	21	3.14 (±0.018)	3.16	4.54 (0.548)	3.92	Excluding C4-6
Outside MR on Salt Marsh all elevations 2.1-3.3mODN	38	2.84 (±0.050)	2.86	6.06 (±0.997)	6.21	All sites
Outside MR equivalent elevations to inside the MR (2.75-3.3mODN)	25	3.02 (±0.050)	3.00	7.28 (±0.637)	7.33	1.1-1.4, 2.1-2.5, 3.1-3.3, 4.1-4.3, 5.1-5.5, 6.1-6.5
Outside MR 2.09-2.74mODN	13	2.50 (±0.060)	2.56	3.71 (±2.59)	3.67	1.5, 1.6, 2.6-2.8, 3.4, 3.5, 4.4, 4.5, 5.6, 5.7, 6.6, 6.7
Outside MR 2.75-3.0mODN	13	2.88 (±0.023)	2.89	9.38 (±0.733)	8.9	1.2-1.4, 2.4, 2.5, 3.2, 3.3, 4.1-4.3, 5.5, 6.4, 6.5
Outside MR >3.0-3.3mODN	12	3.17 (±0.027)	3.18	5.01 (±0.381)	4.87	1.1, 2.1-2.3, 3.1, 5.1-5.4, 6.1-6.3



(a) All sites in the managed realignment



(b) Excluding the very high accretion at TCS5 & TCS6



(c) Excluding outliers (see text) TCS4-S6, TDS4-S6, TFS1

Fig. 3.32a-c. Mean Annual Accretion Rates *vs.* Elevation Categories, inside and outside the Realignment Site

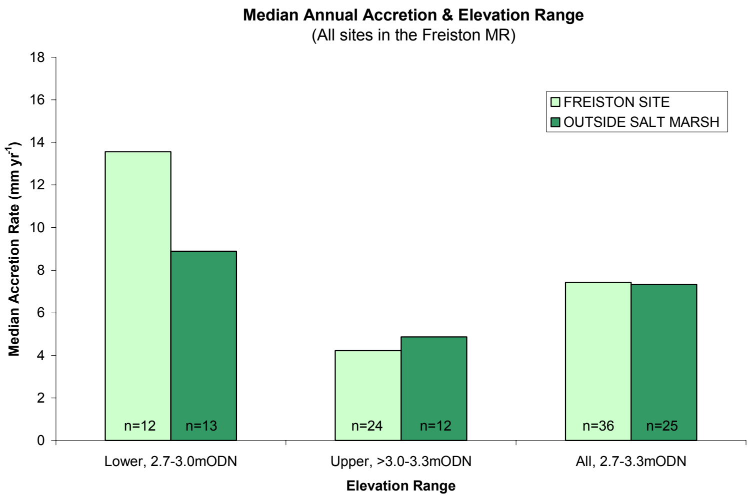


Fig. 3.33. Median Annual Accretion Rates *vs.* Elevation Categories, inside and outside the Realignment Site

3.5.2 Seasonal Differences in Accretion

To test for any seasonal differences (winter periods *vs* summer periods) in accretion, the data for each site were first converted into accretion rates per lunar month for each sampling interval to account for slightly different intervals of measurement ((sediment level change between each sampling interval / interval in weeks) x 4). The monthly rates for the summer period (2003, 04, and 05) were then plotted against the preceding winter period (2002-03, 03-04, 04-05) for each site. Hence each point on the graph represents the accretion rate in the two periods of each year at the same site. Any incomplete sets of paired data (a few in the realignment underwater in the first year or so) were excluded from the analysis. The graphs are shown in Fig. 3.34 for the managed realignment area, and Fig. 3.35 for all sites outside the realignment on the salt marsh. Fig. 3.36 shows the data for sites on the natural marsh at the same elevation range as inside the realignment area.

The axes of the graphs are drawn at the same scale range so that the diagonal line bisecting the axis represents zero difference between winter and summer rates. Points below the diagonal line are sites showing more accretion during the winter period; points above represent sites with more accretion in the following summer period. Points below zero on the axes are sites which have eroded.

Differences between winter and summer monthly accretion were analysed with Wilcoxon matched pairs signed ranked tests, for each yearly period, and for all years together (i.e. mean of winter and summer accretion per month). The statistics are summarised in Table 3.3.

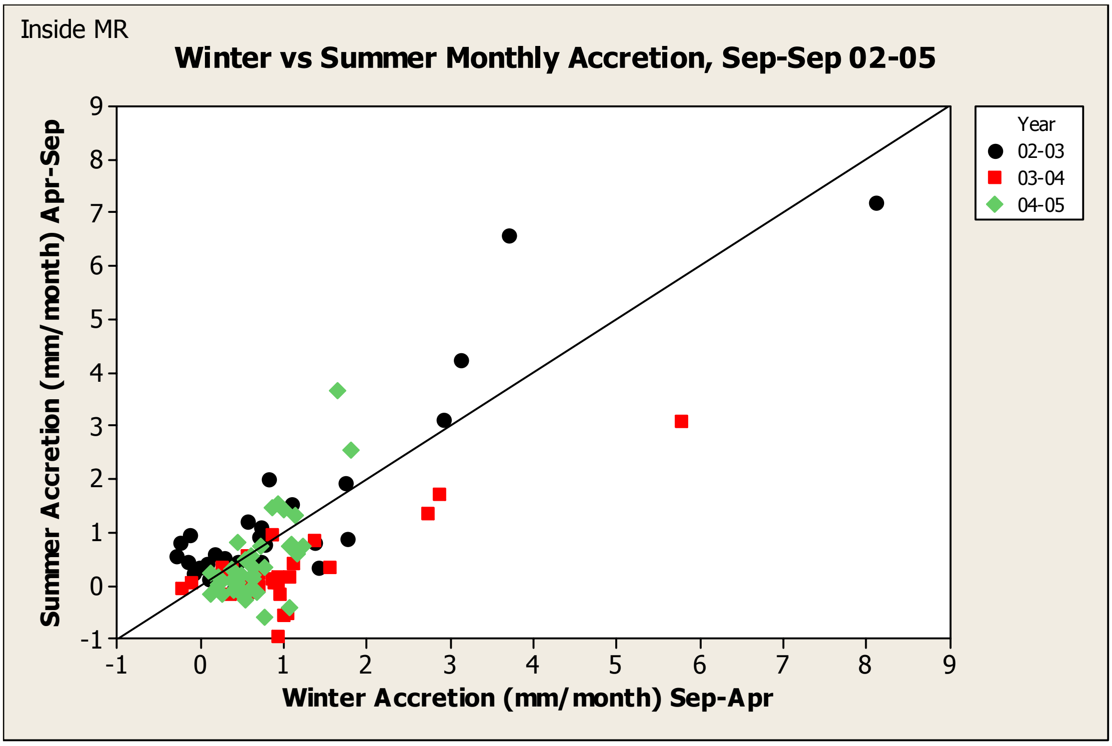


Fig. 3.34. Winter *vs* Summer Monthly Accretion from September 2002 to September 2005 inside the Managed Realignment Site. Lunar month (4 weeks, spring-neap cycle).

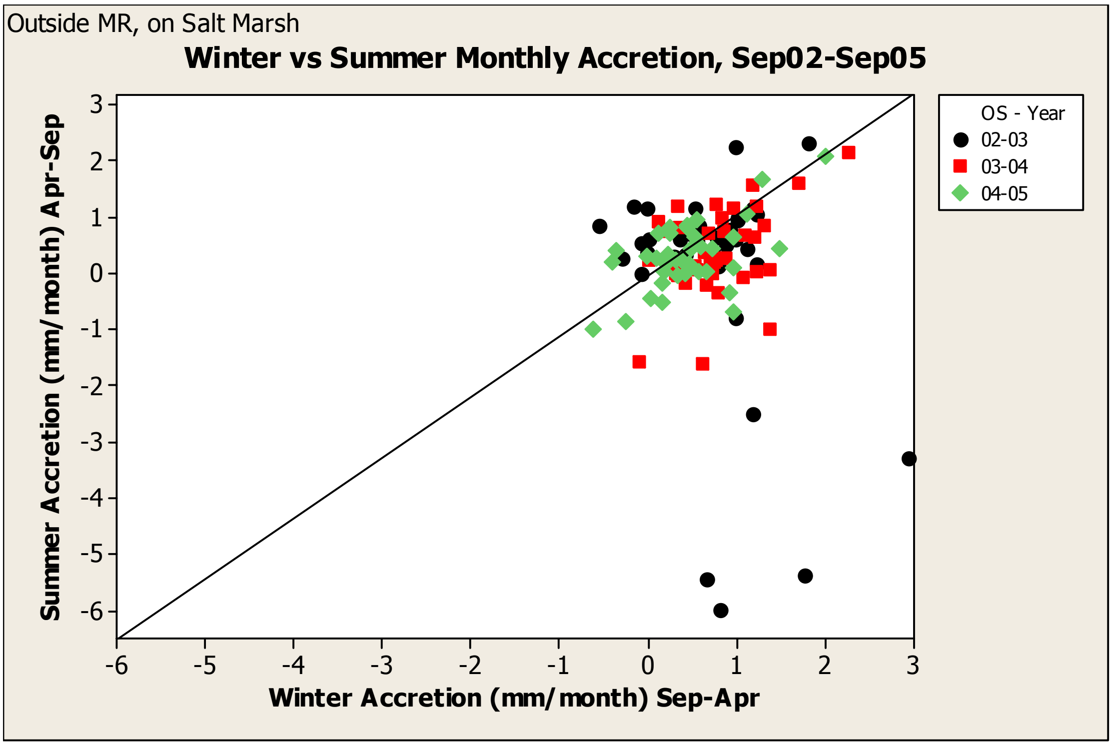


Fig. 3.35. Winter *vs* Summer Monthly Accretion from September 2002 to September 2005 outside the Managed Realignment Site on the Salt Marsh. Lunar month (4 weeks, spring-neap cycle).

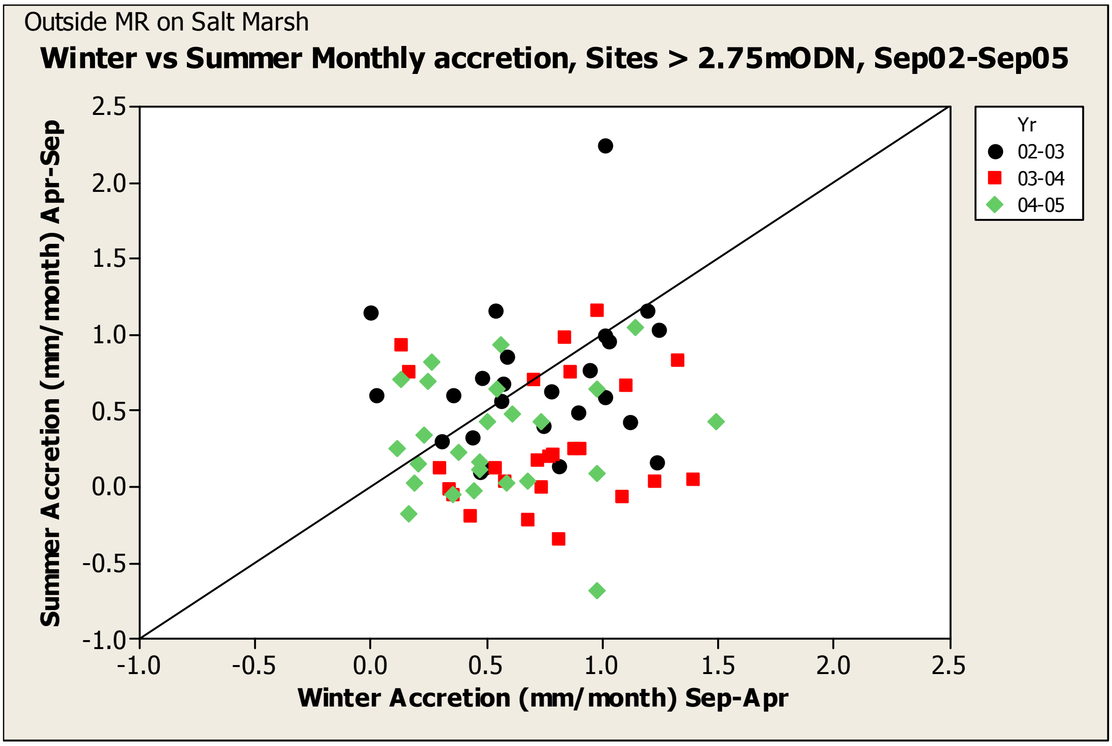


Fig. 3.36. Winter *vs* Summer Monthly Accretion from September 2002 to September 2005 outside the Managed Realignment Site on the Salt Marsh at Elevations >2.75mODN. Lunar month (4 weeks, spring-neap cycle).

Table 3.3 shows that in the first year of measurements (2002-03) more sites in the realignment showed a greater accretion per lunar month during the summer of 2003 than in the previous winter period, but this was the only instance where summer accretion was greater than the preceding winter period. One of the factors contributing to this was undoubtedly the loss of sediment over some of the sites in the first winter period as the initial tidal floodings moved around the clods of soil that were hardened on the surface before the breach (in Fig. 3.34 there are several points (black symbols) below zero for winter accretion 2002-3, indicating erosion during this period). This occurred particularly at the higher, less frequently flooded sites (Sites 1 & 2 on Transects A & B, Figs 3.19 & 3.20). Also, three of the lower sites on Transect C (Sites 4 & 5) and D (Site 4), which have shown enhanced sediment deposition thought to be from erosion of the enlarging central breach and creeks in the area, accreted more sediment during summer 2003 than in the first winter period (Figs 3.21 & 3.22). In the following two years, accretion was significantly greater during the winter periods than during the summer seasons.

Outside the realignment at all sites, there was no significant difference between winter and summer accretion in the first year (2002-03) or in the last year (2004-05), but monthly accretion was significantly greater during the winter period 2003-2004 than in summer 2004. For sites outside at equivalent elevations to the realignment sites (i.e. excluding the lower sites at the marsh front) differences in winter and summer accretion were not significant in the first year, but in the subsequent two years (2003-2005) there were significantly more sites with greater accretion in the winter periods compared with the following summers periods (Table 3.2).

Table 3.3. Results from Wilcoxon matched pairs signed Ranked Test for significant differences between monthly accretion at each sample site during summer (Apr-Sep) and the previous winter period (Sep-Apr).
Test of median difference = 0.000 versus median difference ≠0.000.

N= number of sample pairs, † =missing sample pairs (sites underwater in the realignment, omitted for these years). For analysis over entire period (02-05), missing pairs were omitted.
S>W = number of sites where summer accretion > winter accretion
W>S = number of sites where winter accretion > summer accretion
%W>S = percentage of sites where winter accretion > summer accretion
Significance: *, **, *** = test probability, significant at p<0.05, 0.01, 0.001, respectively. NS = not significant.
Managed Realignment Site: N=30 sampling sites September 2002-4, N=36 sites 2004-5 (Transect E added)

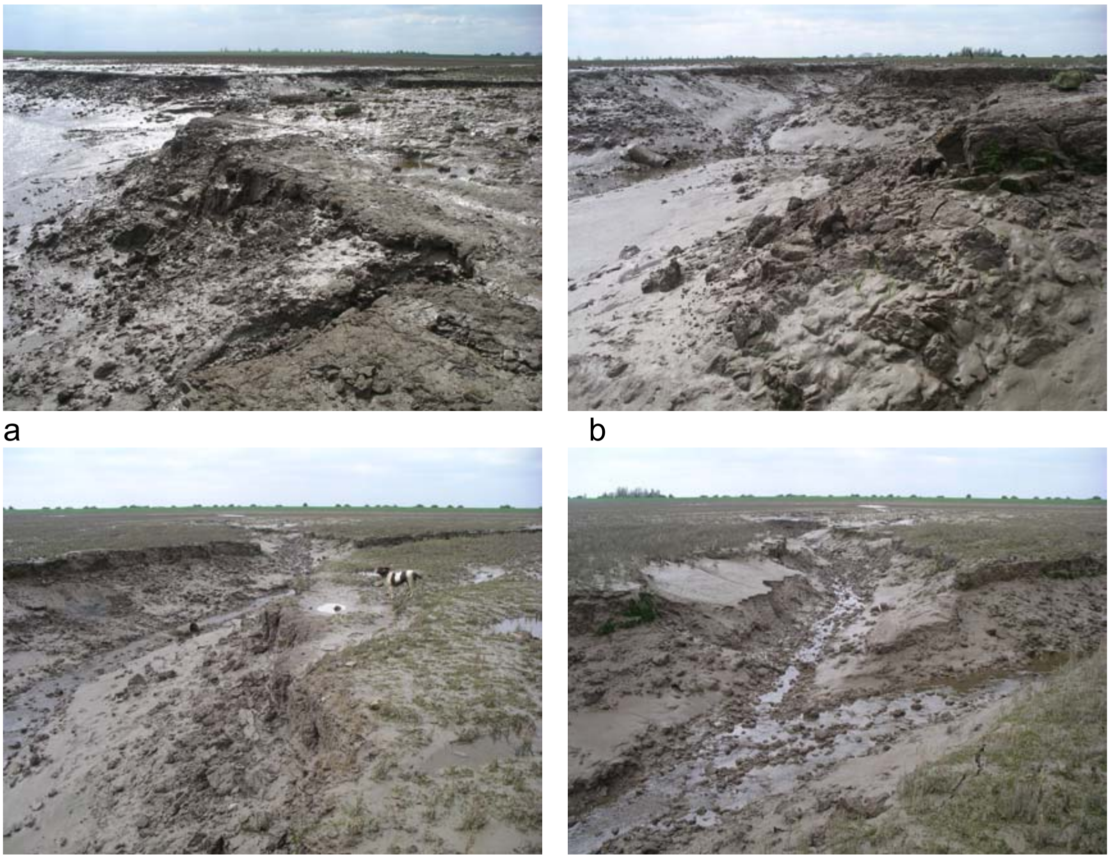
Year	**N**	**S>W**	**W>S**	**%W>S**	**Wilcoxon Statistic**	**Estimated Median difference (S-W) mm**	**p**	**Significance**
Managed Realignment Site								
02-03	27†	19	8	30%	271.0	0.2700	0.050	* S>W
03-04	30	4	26	87%	20.0	-0.7075	0.000	** W>S
04-05	35†	8	27	77%	164.0	-2.2765	0.014	* W>S
02-05	**27†**	**9**	**18**	**67%**	**92.5**	**-0.1998**	**0.021**	***W>S**
Outside MR on Salt Marsh								
02-03	38	16	22	58%	306.5	-0.1035	0.357	NS
03-04	38	10	28	74%	149.0	-0.3860	0.001	** W>S
04-05	38	14	24	63%	256.0	-0.1410	0.098	NS
02-05	**38**	**11**	**27**	**71%**	**199.0**	**-0.2712**	**0.013**	***W>S**
Outside MR on Salt Marsh, elevation >2.75m ODN								
02-03	25	9	16	64%	131.5	-0.0645	0.412	NS
03-04	25	5	20	80%	44.0	-0.4935	0.001	** W>S
04-05	25	7	18	72%	87.0	-0.2160	0.044	* W>S
02-05	**25**	**5**	**20**	**80%**	**57.0**	**-0.2465**	**0.005**	**** W>S**

Over all years, a significantly greater number of sites accreted more sediment in the winter periods than in the following summer periods (mean values for accretion per lunar month for winters compared with summers from 2002 to 2005). Inside the realignment site, 67% of the sites showed greater winter accretion, and 71% of the sites outside the realignment showed greater winter accretion, increasing to 80% when just sites above 2.75mODN were analysed (Table 3.3).

3.6 Discussion

The accretion measurements have shown a continued build up of sediment inside the realignment site, and outside on the vegetated salt marsh. Elevation is of key importance for the amount of accretion occurring on a salt marsh. Generally, the highest level of accretion is found in the zone of continuous vegetation behind the marsh front and pioneer zone, and accretion decreases with increasing elevation as higher sites experience fewer tidal inundations bringing in suspended sediment available for deposition. A significant inverse relationship between accretion and elevation was found for the natural salt marsh, and also for the realignment site once the two very marked outliers close to the middle breach were removed. This relationship was strengthened further when the lower 3 sites for Transects C and D and the underwater site on Transect F (liquid mud) were excluded from the analysis. We consider it justifiable to omit the lower sites on Transects C and D as there is evidence to suggest that these sites were influenced greatly by washed in material from the eroding breach, and from creek construction and subsequent bank erosion in this area. The breaches have widened considerably since the beginning of the monitoring programme and the sediment at these lower sites, particularly the bottom two sites closest to the breach (TCS5 & S6) appeared coarser (sandier) in consistency than sediment settled out elsewhere on the realignment away from the vicinity of the breaches. A fan of largely bare sediment opposite the central breach was observed from ground observations and the aerial image (Image 3.1). The elevation at these sites is sufficient for vegetation colonisation, but we think that colonisation was sparse here because of the rapid deposition of washed in sandy material supplementing the suspended sediment coming in from outside and smothering seedlings. Furthermore, erosion (widening) of the drain sides and creek development inside the site has been particularly dramatic just inside the central breach (Photo 3.3a-d), with large blocks of material breaking off as creeks have been cutting back, widening and deepening inside the site here (see also Photo 9.5. in the overview, Chapter 9). The loose material from the creek development must be adding to the suspended load in this area.

Outside the realignment, the inverse relationship between accretion and elevation was found to break down below elevations between approximately 2.6-2.8mODN (Fig. 3.27a), in the region of the sparsely vegetated pioneer zone (mainly annual *Salicornia europaea*, Common glasswort) where there is insufficient vegetation to enhance net deposition (often by reducing resuspension of deposited sediment, e.g. Brown 1998) or to bind the deposited sediment (by plant root systems).



a b c d

Photo 3.3. Inside realignment opposite the central breach (a & b) and creek inside realignment draining to central breach (c & d). Photos: Sue Brown, April 2006.

The lowest sites on Transects 1, 2, 4, 5 and 6, range between approximately 2.1-2.4mODN and showed a loss of sediment (erosion) between 2002 and 2006, although T4S5 has gained sediment since April 2006 and by September the site was back to the original 2002 level. The lowest site on Transect 3 (2.54mODN) showed fluctuating levels (Figs. 3.13-3.18), returning to the original 2002 level by September 2006. The mudflat on these transects is highly dynamic and consists of relatively flat sections divided by small shallow channels. The channels change position and pans develop and then and fill in again over time on the sections between. The fact that the measurements at 4 out of these 6 sites show overall erosion was in part due to the initial conditions for site set-up as we chose flat central areas of the mudflat surface between the channels to install our parallel canes for accretion measurements. When a pan or channel forms between say just one of the 5 pairs of canes at each site, the overall (mean) measurement for the site will be reduced. Over a longer period of time, these pans or channels may fill in with sediment again and others will form elsewhere so this zone may show cycles of erosion and accretion over a longer period than the four and a half years of measurements outside the site, although two of the sites had returned to original levels by 2006. It is likely that many years of accretion measurements would be needed in this zone to show any long-term consistent trends in sedimentation. If the salt marshes are able to continue to build up and to advance seawards at this side of the Wash embayment, these zones will eventually become colonised with perennial vegetation that will stabilise the sediment. On the southern and eastern section of the Wash, for example at Sutton Bridge in the south, and at Wootton in the eastern corner near Kings Lynn, the salt marsh has advanced seawards by many tens of metres since 1995 (S.L.Brown, personal observation).

We have shown that the accretion rates inside and outside the realignment were comparable (overlapped) at higher elevations (from approximately 2.95mODN and above, excluding the anomalous sites influenced by the middle breach). However, the fitted regression lines through the two data sets differ in their slopes and indicate that at elevations below approximately 2.9mODN, accretion has been higher inside the realignment. The same observation was found at the Paull Holme Strays managed realignment site in the Humber Estuary (Brown and Brown 2006), where the difference at lower elevations was even greater and the inverse relationship between accretion and elevation continued on the mudflat area at Paull Holme Strays. This was probably due to less resuspension of deposited sediment on the ebb tide draining the marsh and mudflat within the more sheltered site, compared with the more exposed marsh and mudflat outside.

The Freiston data also indicate that accretion has been slightly lower inside the site at the top end of the elevation range (at 7 sites from ≈ 3.2mODN up to the highest site at 3.26m). It seems reasonable to suppose that more of the suspended sediment brought in by the tide is deposited before reaching the highest sites under the more sheltered conditions in the realignment area.

In general, accretion has been greater at most sites in the winter periods than in summer. Several factors relating to pre- and post-depositional processes may contribute to this: a lower level of suspended sediment carried in the water column during the summer; dewatering and compaction particularly at sites which have received the greatest deposition; and drying out of exposed sediment in summer in areas exposed during neap tides, particularly where there is no dense protective vegetation cover. In hot weather the mud surface cracks into polygons and the surface layers curl up and may be lifted out by the next spring tides.

3.7 Conclusion

Accretion rates inside the realignment were generally similar to those outside on the natural salt marsh within a similar range of elevations. However, there were a few sites with extremely high levels of sedimentation inside the realignment area, opposite the middle breach. We believe that the high sedimentation here was due to material washed in from the eroding breach and widening creeks just inside the breach area. This makes comparison with the natural salt marsh difficult because these few sites had a major influence on calculated mean values. However, there was good agreement between mean accretion rates at upper elevations (> ≈3.0mODN) when the outliers were removed. Median values are useful for comparison as they are more representative of the data set under these circumstances. A close agreement was found for median annual accretion between the realignment site and outside the sites for the full range of equivalent elevations (2.75-3.3mODN) and for the higher elevation category (3-3.3mODN). Median values for the lower elevation category (2.75-3.0mODN) were higher inside the realignment site than outside.

When the anomalous very high deposition sites were removed from the calculations, a significant inverse relationship was found between accretion and elevation inside the realignment as well as outside on the vegetated salt marsh. Although there was considerable overlap in the data from outside and inside the realignment site, there was a significant difference between the slopes of the regressions and evidence of higher accretion at lower elevations within the range under the more sheltered conditions of the realignment (as noted also when comparing median values). This has also been found at the Paull Holme Strays realignment site in the Humber Estuary (Brown and Brown 2006).

On average, winter accretion was found to be higher than summer periods inside and outside the realignment site. Factors which may contribute to this include lower levels of suspended sediment in summer, post-depositional dewatering and compaction, and erosion of dry cracked surface layers in summer in areas without a dense cover of protective vegetation.

In conclusion, the data indicate that accretion has been higher inside the realignment at the lowest elevations compared with outside on the salt marsh, but the overall similarity between median annual accretion rates inside and outside the realignment, and between the range of total accretion values inside and outside the site (when the anomalously high sedimentation sites are excluded) at similar elevations, indicates that the process of accretion has been occurring at expected levels inside the newly created salt marsh habitat.

3.7.1 References

Brown, S.L. 1998. Sedimentation on a Humber saltmarsh. *In*: K.S.Black, D.M.Paterson and A.Cramp (eds) *Sedimentary Processes in the Intertidal Zone.* Geological Society, London, Special Publications, **139**, 69-83.

Brown, S. L. and Brown, S. 2006. Paull Holme Strays, Intertidal Vegetation, Accretion and Erosion Monitoring. Report to Halcrow Group Ltd. and the Environment Agency. NERC Centre for Ecology and Hydrology, CEH Dorset.

3.8 Appendix 3

Appendix 3.1. Elevations at the Freiston Monitoring Sites

Measured in 2005

T=Transect, S=Site, S.E.=Standard error

OUTSIDE MANAGED REALIGNMENT

Transect & Site	Elevation (mODN)	S.E.
T1S1	3.16	0.014
T1S2	3.01	0.004
T1S3	2.97	0.007
T1S4	2.79	0.008
T1S5	2.57	0.019
T1S6	2.38	0.029
T2S1	3.15	0.003
T2S2	3.28	0.010
T2S3	3.08	0.005
T2S4	2.98	0.005
T2S5	2.90	0.002
T2S6	2.69	0.006
T2S7	2.56	0.000
T2S8	2.33	0.004
T3S1	3.00	0.005
T3S2	2.83	0.010
T3S3	2.82	0.004
T3S4	2.68	0.005
T3S5	2.54	0.010
T4S1	2.91	0.007
T4S2	2.80	0.004
T4S3	2.78	0.001
T4S4	2.69	0.006
T4S5	2.09	0.018
T5S1	3.26	0.010
T5S2	3.26	0.008
T5S3	3.21	0.008
T5S4	3.04	0.004
T5S5	2.96	0.017
T6S6	2.68	0.004
T5S7	2.28	0.008
T6S1	3.29	0.010
T6S2	3.20	0.003
T6S3	3.14	0.004
T6S4	2.92	0.006
T6S5	2.78	0.001
T6S6	2.73	0.027
T6S7	2.30	0.026

INSIDE MANAGED REALIGNMENT

Transect & Site	Elevation (mODN)	S.E.
TAS1	3.24	0.027
TAS2	3.26	0.003
TAS3	3.20	0.004
TAS4	3.26	0.018
TAS5	3.11	0.002
TAS6	2.87	0.008
TBS1	3.13	0.009
TBS2	3.22	0.005
TBS3	3.18	0.012
TBS4	3.06	0.007
TBS5	3.08	0.007
TBS6	2.99	0.002
TCS1	3.24	0.002
TCS2	3.20	0.012
TCS3	3.21	0.018
TCS4	3.11	0.020
TCS5	3.10	0.007
TCS6	3.13	0.008
TDS1	3.17	0.002
TDS2	3.06	0.008
TDS3	3.08	0.010
TDS4	2.93	0.005
TDS5	2.91	0.006
TDS6	2.76	0.008
TES1	3.16	0.005
TES2	3.13	0.004
TES3	3.01	0.005
TES4	2.96	0.004
TES5	2.92	0.005
TES6	2.88	0.021
TFS1	2.96	0.006
TFS2	2.97	0.004
TFS3	3.04	0.009
TFS4	3.00	0.018
TFS5	2.95	0.007
TFS6	2.94	0.004

Appendix 3.2. Notes on comparisons between CEH sites and CCRU SET sites

The results from monitoring the CCRU SET sites are given in the next chapter. The following are brief notes on comparisons of their data with ours from the sediment plate measurements.

Measurements of surface elevation change (SET data) cannot be easily compared with the measurements of surface accretion (buried plates) without all the elevation measurements for the SET sites, except where the SET and plate sites are very close (e.g. within approximately 10m). Two sites very close to each other are SET 1 and T6S1, and SET 8 and TDS6. However, there can be considerable spatial variation in accretion (even for sites at similar elevations). This was particularly evident at plate sites close to the central breach (lower half of Transects C and D). A few of the CCRU SET sites are relatively close to the CEH sites (within approximately 10-30m) but most are further away. The cumulative surface elevation change and total net accretion between autumn 2002 and autumn 2006 for the SET sites and nearest CEH sites is shown in the table below. Close sites, especially those within 10m, showed good agreement in mean total net accretion over a similar monitoring period. We will make further comments when elevation data is available for all of the SET sites.

Both methods of accretion measurement found an intra-annual variation in net accretion at many sites where accretion was greater during the winter period than the summer months.

CCRU SET sites	SETS, mean surface elevation change (mm) Nov 02-Sep06	Closest CEH plate sites	Buried plates, mean total net accretion (mm) Sep/Oct 02-Sep06
SET 1	7.8mm	T6S1 (close, within 10m)	7.0mm
SET 2	23.6mm	T4S1	37.8mm
SET 3	24.4mm	T3S1	34.3mm
SET 4	4.5mm	No CEH site in area	
SET 5	30.0mm	T3S4 (similar zone but not close)	30.2mm
SET 6	15.0mm	T4S4, not close	22.0mm
SET 7	60.3mm (but creek forming here	Between TBS6 and TCS6 but not close	56.0 197.7
SET 8	104.0mm	BetweenTDS6 (close, within 10m) and TDS5	106.8mm 83.0
SET 9	6.9mm	Quite close to TAS1 and TAS2 (within 30m)	10.3mm 5.5mm
SET 10	33.4	TCS3 TCS4	19.4 39.6
SET 11	8.9mm	Quite close (within 30m) to TES1 and TES2	 8.2mm (2 years only) 7.3mm (2 years only)

4. Sedimentation – Erosion Table (SET) Monitoring at Freiston Shore, 2002 - 2006

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4.1 Summary

- Measurements of surface elevation change using the Sedimentation Erosion table (SET) technique have been undertaken at Freiston Shore between November 2002 and September 2006. Strong spatial and temporal controls on surface elevation change are apparent, both outside and inside the managed realignment site.

- Patterns of elevation gain and loss are highly dynamic on unvegetated mudflat surfaces outside the managed realignment site. Permanently vegetated salt marsh surfaces outside the site show long-term (November 2002 – September 2006) mean elevation gains of 0.45 – 0.78 cm at sites north and south of the managed realignment ('far field') and 2.44 – 2.36 cm 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. It is not possible, however, to isolate changes in surface elevation that can be attributed to changing creek hydrodynamics and sedimentation consequent upon former defence line breaching.

- Sites within the managed realignment site close to breaches show long-term (November 2002 – September 2006) surface elevation gains of 3.0 – 10.1 cm. By comparison, more isolated sites to the rear of the managed realignment site have shown elevation gains (November 2002 – September 2006) of 0.69 – 0.89 cm. High gains (3.34 cm), 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. A site close to, and north, of the central breach and a site in the NW 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.

- Measurements of surface elevation change should be compared to the measurements of surface accretion being undertaken simultaneously at the site. Such comparisons will reveal more about the nature of near-surface soil processes than is possible from the results of each of these different techniques in isolation.

4.2 Introduction

Maintenance, restoration and (re-)creation of coastal salt marshes requires a better understanding of the controls and constraints on wetland accretionary dynamics than that currently available. In particular, data is required on i) the relationship between sedimentation, vertical accretion and surface elevation change and ii) the interaction of these processes, themselves subject to considerable spatial and temporal variability, with local hydrodynamics, tidal inundation characteristics and, in the longer term, with relative sea level rise. Knowledge of these dynamics is particularly important for sites of managed realignment on low-lying coasts; current data is very sparse but is urgently needed as input into improving guidelines for site establishment and subsequent evolution towards sustainable salt marsh communities.

The non-intrusive Surface Elevation Table – or SET - method has been developed (Cahoon *et al.,* 1995; Cahoon *et al.*, 2002) to provide site-specific information on these key processes and interactions through measurements of surface elevation change. When combined with simultaneous measurements of vertical accretion from artificial soil marker horizons, this methodology allows for the determination of not only the accretion and elevation trajectories of salt marsh relative to sea-level rise but also the influence of subsurface processes on elevation change. The latter has been termed ‘shallow subsidence’ (Cahoon *et al.*, 1995) to distinguish it from long-term, deep subsidence on a geological scale.

A global network of monitoring stations using the SET methodology is being developed and now includes nearly 200 coastal wetland settings in 15 countries, monitored by more than 60 scientists (Cahoon *et al.*, 2006). In the UK, SET stations have been established on the North Norfolk coast and within the Suffolk estuaries (Spencer *et al., in litt*.). As record length increases, it will be possible to include the Freiston Shore stations in this network.

4.3 Methods

There are 11 SET locations at Freiston Shore, of which six monitoring sites are outside the managed realignment and five inside the site (Figure 1, Table 1). For the purposes of this report they are grouped as follows:

Monitoring site characteristics	Sites
Outside the managed realignment, vegetated salt marsh:	1 – 4
Outside the managed realignment, un-vegetated mudflat:	5, 6
Inside the site, near to breaches:	7, 8
Inside the site, far from breaches:	9 – 11

Each monitoring site generates 36 repeat point measurements, consisting of nine repeat measurements from the N, S, E, and W quadrants at each monitoring site. Measurements are reported as a monitoring site mean. It is a characteristic of the type of surface found in these intertidal environments that there can be considerable variability in measurements at any one monitoring point; this is reflected in the standard deviation of the monitoring site means.

This report covers two monitoring intervals, from September 2005 to April 2006 and from April 2006 until September 2006; these two monitoring periods represent the 7th and 8th re-measurements respectively. The complete record of survey intervals is shown in Table 2. This report also reviews the entire record of surface elevation since the breaching of the former sea defences in August 2002.

4.4 Results

Results are shown in Tables 3 and 4 and Figures 2 – 5. Results can be grouped by location, as suggested above.

4.4.1 Monitoring sites 1 – 4:

These sites are located in the high intertidal zone, immediately to seaward of the old sea defence line (Figure 1). Monitoring point 1 (to the south of the managed realignment) and 4 (to the north) lie outside the immediate zone of influence of the breaches (i.e. ‘far field’), whilst monitoring points 2 and 3 might be expected to be influenced by the breaches and their seaward channel systems (i.e. ‘near field’).

At sites 1 and 4, long-term (i.e. since November 2002) mean changes in surface elevation have been 0.78 and 0.45 cm (Figures 2C and 5A, Table 3), corresponding to rates of change of 2.0 and 1.2 mm a^{-1} respectively. These changes in surface elevation may represent typical surface elevation changes on relatively undisturbed salt marshes in the south western area of The Wash, including an element of response to contemporary regional sea level rise. Historical tide gauge records from Immingham (1960 – 1995) and Lowestoft (1956 – 1995) indicate changes in mean sea level of 1.11 +/- 0.52 mm a^{-1} and 1.18 +/- 0.48 mm a^{-1} respectively (Woodworth *et al.,* 1999); Shennan and Horton's (2002) analysis of Late Holocene (last 4,000 years) sea level change suggests that geological subsidence may account for 0.6 to 0.8 mm a^{-1} of this total.

Whatever the explanation behind these changes, they also provide a useful 'baseline' against which to consider the behaviour of other sites at the Freiston Shore managed realignment. Within the inter-annual trend exhibited by sites 1 and 4, there is in addition a clear intra-annual signal in surface elevation variability, with a tendency for elevation increases in the winter months to be followed by minimal additions, or even slight lowering, of surface level over the summer months (Figures 3 and 4A). This has been seen at both sites, but has been more marked at site 4 (Figures 3 and 4A, Table 4C, 4D). These patterns may be a result of either variations in inputs, or post-depositional processes, or a combination of these two sets of controls. Variation in sediment input may be a function of tidal regime, with differing inundation frequencies between the two time periods and thus differences in sediment supply, or of seasonal variations in sediment concentrations (perhaps in turn related to winter v. summer variations in wave energy levels in The Wash). Post-deposition, seasonal variations in elevation may reflect sediment consolidation processes following a period of high sediment input and/or reflect the shrinkage of 'settled mud' when exposed to summer temperatures. At site 1, these intra-annual variations appear to have been superimposed on a longer-term reduction in surface elevation change since April 2004 (Figure 5A). Such a pattern has been less clear at site 4, with a stabilisation of surface elevation over the three measurement periods between April 2005 and April 2006, but with a marked loss of surface elevation in the time period between April and September 2005 to give a trend since April 2004 similar to that at site 1 (Tables 4B-D; Figures 4A and 5A).

Long-term mean surface elevation gain at monitoring sites 2 and 3 has been greater, at 2.36 and 2.44 cm respectively (Table 3, Figure 5A). This may be a function of proximity to large creek systems (Figure 1) which might be expected to supply sediments for vertical accretion at these sites. It may also, of course, be related to the impact of changes in tidal creek hydrodynamics and salt marsh surface accretion related to renewed tidal exchange, focussed on the breaches, and increases in tidal prism. It is, however, difficult to isolate this particular effect from natural system variability at the present time. It is suggested that the simple pattern of progressive increases in surface elevation seen at sites 2 and 3 in the period November 2002 – June 2004 represent the adjustment of these sites to the disturbance in hydrodynamic and sediment regimes following breaching (completed in August 2002), a process largely completed by summer 2004. At both sites, since June 2004 progressive gains in surface elevation have been overlain by the pattern of seasonal variation in surface elevation described above for sites 1 and 4; this has given a series of reversals (site 2) or plateaux (site 3) in the record of increases in surface height (Figure 5A). At site 3 the pattern of change has been very similar to that at site 1, situated to the south of the managed realignment (Figure 4A). At site 2, the magnitude of these intra-annual fluctuations in surface elevation change have been of much greater amplitude than at sites 1, 3 and 4. It is not possible to say if this increase in magnitude is due to greater inter-annual variations in sediment input (from proximity to large creek systems), or to greater intra-annual variations in post-depositional processes of wetting and drying acting on greater thickness of deposited sediment, or to some combination of initial sedimentation dynamics and post-depositional processes, including the role of the vegetation canopy in influencing sediment deposition and consolidation.

4.4.2 Monitoring sites 5, 6:

Monitoring points 5 and 6 are located to the east of monitoring points 2 and 3 respectively (Figure 1). They lie beyond the permanently vegetated salt marsh, in an area which grades seaward from seasonally and sparsely vegetated surfaces to un-vegetated mudflats between linear, shore-normal creek systems (Figure 1, Plate 1). Surface elevation at these sites is highly dynamic, both in terms of the behaviour of mean site elevation and at the level of individual point behaviour which is reflected in the swings in elevation changes between monitoring periods of *ca.* ±1 cm and exceptionally high values for standard deviation. Whereas since November 2002 site 6 has shown a modest height gain of 1.5 cm, site 5 has shown a long-term elevational loss of over 3 cm (Figures 2, 4B and 5B, Tables 3 and 4). In general, there has been little coherence of signal between sites 5 and 6, although since April 2005 the two sites have shown similar patterns of elevation change (Figure 4B). Shifts between erosional and depositional behaviour are well known from unvegetated intertidal surfaces (e.g. Coles, 1979). Furthermore, the surface of the mudflat at both these sites is characterised by an undulating surface topography with numerous semi-circular depressions, or ‘pans’. Some of the changes recorded at these sites, therefore, reflect processes taking place at this meso-scale, including pan extension, the collapse of the cliffed margins of pans and depression infilling.

4.4.3 Monitoring sites 7, 8:

Both these monitoring points lie inside the managed realignment site but relatively close to breaches (Figure 1). Long-term elevation gain has been high, at 6.03 cm and 10.41 cm for sites 7 and 8 respectively (Table 3, Figure 5B). In the first two monitoring periods, the rates of surface elevation change at both these sites were significantly higher than at any other monitoring point, at *ca*. 1 cm a^{-1} at monitoring site 8 and over 2 cm a^{-1} at monitoring site 7 for both periods (Table 4A). These high rates were interpreted as resulting from accretion from sediment inputs from breach-related creek and sea defence borrow pit sources. To what extent these sediments were ‘new’ sediments brought in by the flood tide and to what extent they were ‘local’ re-mobilisations of sediments associated with breach construction could not be determined. Whilst high surface elevation gains were maintained over the second winter period (September 2003 – June 2004; Table 4B), there was a brief reduction in elevation gain at site 8 after June 2004 (Table 4B, Figures 3 and 4) and at site 7, high elevation gains were replaced by a brief period of elevation loss (Table 4B). It has been suggested previously (Spencer *et al*., 2005) that the cessation of high elevation gains reflected an exhaustion of local sediments released by site breaching and the excavation of channels within the realignment site. In addition, the rapid and sustained height gains at these two sites since November 2002 may have brought surfaces to a level where they are now susceptible to drying out and shrinkage under summer climatic conditions. More specifically, site 7 was initially characterised by shallow runnels, which may have acted as small-scale settling ponds, thus encouraging the accelerated settling of fine sediments. As these runnels filled with sediment, and were replaced by a higher, topographically simple surface (Plate 2), a natural decrease in the rate of surface elevation gain at this site might have been expected (Figure 5B).

From June 2004 until April 2005, surface elevation change at site 7 showed the typical pattern of winter surface elevation increase and summer surface elevation decrease seen at the salt marsh sites outside the breaches but with the elevation increase June 2004 – April 2005 being 1.5 to 5 times that experienced at the more ‘natural sites’. Summer surface elevation decreases were broadly comparable between site 7 and sites 1 to 4 (Table 4C). Since April 2006, elevation change has been minimal (*ca.* 0.1 cm per measurement period) and there has been no evidence of any intra-annual signal (Figures 3, 4B and 5B, Table 4D). This change in behaviour appears to correlate with the headward extension of an incised channel which drains into the major borrow pit channel landward of the former seawall. The approach of this channel towards the SET site was noted in September 2005; by April 2006 it had extended into the monitored area, making re-measurement of the N and E quadrants impossible (site means from April 2006 have thus been based on 18 re-measurements (from the W and S quadrants not 36 points)). In September 2006, the upper cliffed margin to the channel was *ca.* 40 cm high (Plate 3). It seems likely that the development of this drainage network, although physically running through the margin of the SET monitoring area, has now hydrodynamically isolated this site from sediment exchanges. It is probable that these exchanges are now being focussed at more landward locations, beyond the headward limit of the developing creek system. The presence of collapsed blocks on the sides of the channel (Plate 3) indicates that headward extension is also being accompanied by channel widening. If this process continues, the aluminium benchmark pillar for SET site 7 will be compromised. If this occurs then it will not be possible to take any further measurements at site 7.

Apart from a single period of minimal surface height increase (0.16cm) recorded between June and September 2004, site 8 showed a simple trend of progressive surface elevation gains from November 2002 to April 2006 (Figure 5B). The overall height gain since November 2002 has been over + 10 cm (Table 3), more than three times the gain seen by any other station. There was, however, a subsequent decline in the rate of elevation change to September 2006 (Figure 4B). These recent fluctuations, between September 2005 and

September 2006, showed the typical intra-annual pattern of elevation increases in the winter months followed by minimal additions of surface level over the summer months. They were comparable to the behaviour of site 2, the nearest SET station on the salt marsh outside the re-alignment site, although over the entire monitoring period (November 2002 to September 2006), site 8 experienced a marked surface elevation change (1.2 cm) compared to a slight surface lowering (-0.2 cm) at site 2 (Figure 5B).

4.4.4 Monitoring sites 9 – 11:

These monitoring sites all lie to the rear of the managed realignment site (Figure 1). Monitoring sites 9 and 11 lie at the northern and southern extremities of the site respectively. These locations lie far from any creek networks within the site which might help supply sediment. Nevertheless, long-term (post-November 2002) surface elevation changes at these sites have seen mean elevation gains of 0.69 – 0.89 cm, in excess of the long-term means at sites 1 and 4 (Table 3). Both sites 9 and 11 show a period of more rapid elevation gain in the period between September 2004 and April 2005 (Figure 5C), perhaps indicating greater sediment inputs over stormier winter conditions. However, it should be noted that elevation change since April 2005 has been low, particularly at site 9 (Figure 4C). This pattern at site 9 was similar to that seen at site 7, again suggesting that patterns of sediment input to this northern part of the re-alignment site have changed adversely since April 2005. Monitoring site 10 lies in the centre of the site and at a more seaward location (Figure 1); here the long-term mean elevation gain has been sustained, reaching 3.34 cm by September 2006 (Table 3, Figure 5C). Perhaps importantly, however, it lies close to the headward limit of one of the artificial creek networks constructed within the realignment site. Sediment supply from this creek may explain the higher surface elevation gain at this location relative to sites 9 and 11 during the second (Table 4B), third (Table 4C) and fourth (Table 4D) winter monitoring periods (Figures 3, 4C and 5C) and point to the importance of artificial creek networks in supplying sediments to breach-distant locations high in the tidal frame.

4.5 Discussion

The 2002 - 2006 monitoring of the SET sites both inside and outside the Freiston managed re-alignment site shows that it is possible to identify coherent patterns of surface elevation gain and loss which can be related to environment (unvegetated mudflat, vegetated salt marsh, managed realignment site surfaces) and to position (distance from creek, distance from breach). Understanding site behaviour following the re-establishment of tidal exchange after defence breaching thus requires attention to spatial sampling strategy in order to incorporate these controls. Temporal sampling issues are also important. Importantly, the extension of monitoring to September 2006 has further confirmed the intra-annual variation in surface elevation change between the ‘winter’ and ‘summer’ sampling periods. The fact that this behaviour is seen across a range of sites both outside and inside the managed realignment site, but excluding the unvegetated mudflat sites, is noteworthy. Such a pattern suggests that these variations in surface elevation change are most probably due to intra-annual variations in sediment supply and to the subsequent behaviour of these sediments after they have been deposited on intertidal surfaces.

The results of the monitoring reported here also suggest that the surface elevation trajectories vary greatly, both within and outside the realignment site. While some sites have continued to follow an almost linear trend of surface elevation increase (e.g. sites 8 and 10, Figure 5B-C), others have shown signs of stagnation/stabilisation (e.g. site 7, Figure 5B). In the context of rising relative sea level, it is critically important to continue to observe these patterns and establish the significance of these longer term trends. The real value of the SET technique thus comes from long (> 5 year) records of surface elevation change, which filter out short-term variability. Only then can questions as to the longer-term performance of wetland surfaces be addressed. It is recommended, therefore, that the bi-annual monitoring of the SET stations at Freiston Shore should be continued for a further five years.

As has been done elsewhere, these measurements of surface elevation change should be compared to the measurements of surface accretion being undertaken by Dr S. L. Brown, CEH, Dorset. Such comparisons should reveal more about the nature of near-surface soil processes, both within and outside of the managed realignment, than is possible from the results of each of the different techniques in isolation. Such insights may well have important implications for the management of managed realignment sites.

4.5.1 Acknowledgements

These studies have benefited from discussions, often in the field, with Sue Brown, CEH Dorset, and Angus Garbutt and Andrew Thomson, CEH, Monks Wood. Field monitoring has been undertaken with the valued assistance of Steve Boreham, Chris Rolfe, Adrian Hayes, Dan Freiss and Andrea Balbo, all of Department of Geography, University of Cambridge.

4.5.2 References

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4.5.3 List of Tables

A: Time period $T_0 – T_1$: 28 (sites 4, 7-11) and 29 (sites 1-3, 5-6) November 2002 to 7 April 2003 (all sites). Time period $T_1 – T_2$: 7 April 2003 to 18 September 2003 (all sites).
B: Time period $T_2 – T_3$: 18 September 2003 to 2 June 2004. Time period $T_3 – T_4$: 2 June 2004 to 16 September 2004.
C: Time period $T_4 – T_5$: 16 September 2004 to 21 April 2005. Time period $T_5 – T_6$: 21 April 2005 to 30 September 2005.
D: Time period $T_6 – T_7$: 30 September 2005 to 27 April 2006. Time period $T_7 – T_8$: 27 April 2006 to 19 September 2006. Note: due to headward creek erosion, site means at site 7 in both time periods are based on 18, rather than 36, measurements.

4.5.4 List of Figures

4.5.5 List of Plates

Plate 4.1. Seasonally vegetated mudflat outside the managed realignment, Freiston Shore, April 2005 (photograph: S. Boreham).

Plate 4.2. SET instrument deployed at site 7 (category: inside the managed realignment, close to the breaches; see Figure 1 for exact location), April 2005. Note less consolidated sediments infilling unvegetated former runnels at this site (photograph: S. Boreham).

Plate 4.3. Surface collapse due to headward creek expansion at site 7, September 2006 (photograph: A Balbo). Upper creek bank cliff *ca.* 40 cm high. Note vegetation cover in comparison to Plate 2.

Table 4.1. GPS Co-ordinates for SET sites, Freiston Shore Managed Realignment.

SET Site No.	Easting	Northing
1	40177	41747
2	40893	42581
3	41139	43022
4	41386	43715
5	41351	42945
6	41084	42463
7	40982	43015
8	40779	42659
9	40781	43487
10	40639	42914
11	40307	42677

Table 4.2. Survey intervals by SET site, Freiston Shore Managed Realignment.

SET Site No.	T_0	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8
1	29.11.02	07.04.03	18.09.03	02.06.04	16.09.04	21.04.05	30.09.05	27.04.06	19.09.06
2	29.11.02	07.04.03	18.09.03	02.06.04	16.09.04	21.04.05	30.09.05	27.04.06	19.09.06
3	29.11.02	07.04.03	18.09.03	02.06.04	16.09.04	21.04.05	30.09.05	27.04.06	19.09.06
4	28.11.02	07.04.03	18.09.03	02.06.04	16.09.04	21.04.05	30.09.05	27.04.06	19.09.06
5	29.11.02	07.04.03	18.09.03	02.06.04	16.09.04	21.04.05	30.09.05	27.04.06	19.09.06
6	29.11.02	07.04.03	18.09.03	02.06.04	16.09.04	21.04.05	30.09.05	27.04.06	19.09.06
7	28.11.02	07.04.03	18.09.03	02.06.04	16.09.04	21.04.05	30.09.05	27.04.06	19.09.06
8	28.11.02	07.04.03	18.09.03	02.06.04	16.09.04	21.04.05	30.09.05	27.04.06	19.09.06
8	28.11.02	07.04.03	18.09.03	02.06.04	16.09.04	21.04.05	30.09.05	27.04.06	19.09.06
10	28.11.02	07.04.03	18.09.03	02.06.04	16.09.04	21.04.05	30.09.05	27.04.06	19.09.06
11	28.11.02	07.04.03	18.09.03	02.06.04	16.09.04	21.04.05	30.09.05	27.04.06	19.09.06

Table 4.3. Long-term surface elevation change (minus values indicate site erosion) at the 11 Sedimentation – Erosion Table (SET) sites at Freiston Shore. Time period T_0 – T_7: 28 (sites 4, 7-11) and 29 (sites 1-3, 5-6) November 2002 to 27 April 2006 (all sites). Time period T_0 – T_8: 28 (sites 4, 7-11) and 29 (sites 1-3, 5-6) November 2002 to 19 September 2006 (all sites).

SET Site No.	T_0 – T_7		T_0 – T_8	
	Mean (cm)	SD (cm)	Mean (cm)	SD (cm)
1	0.95	0.27	0.78	0.49
2	2.56	0.57	2.36	0.45
3	2.28	1.32	2.44	0.49
4	0.94	0.45	0.45	0.63
5	- 2.72	4.51	-3.26	4.63
6	1.67	0.69	1.49	0.97
7	5.92	1.49	6.03	1.42
8	8.91	1.21	10.14	1.09
9	0.63	0.65	0.69	0.47
10	3.09	0.84	3.34	0.79
11	0.72	0.69	0.89	0.86

Table 4.4A. Surface elevation change (minus values indicate site erosion) at the 11 Sedimentation – Erosion Table (SET) sites at Freiston Shore. Time period T_0 – T_1: 28 (sites 4, 7-11) and 29 (sites 1-3, 5-6) November 2002 to 7 April 2003 (all sites). Time period T_1 – T_2: 7 April 2003 to 18 September 2003 (all sites).

SET Site No.	T_0 – T_1		T_1 – T_2	
	Mean (cm)	SD (cm)	Mean (cm)	SD (cm)
1	0.19	0.30	- 0.02	0.32
2	0.45	0.30	0.36	0.33
3	0.31	0.58	0.29	0.41
4	0.19	0.34	- 0.12	0.33
5	0.53	0.64	- 1.45	2.27
6	0.02	0.57	- 0.01	0.99
7	2.71	1.93	2.01	0.76
8	1.01	0.82	0.99	0.54
9	- 0.02	0.42	- 0.04	0.55
10	0.15	0.49	0.51	0.66
11	0.09	0.26	0.02	0.25

Table 4.4B. Surface elevation change (minus values indicate site erosion) at the 11 Sedimentation – Erosion Table (SET) sites at Freiston Shore. Time period $T_2 – T_3$: 18 September 2003 to 2 June 2004. Time period $T_3 – T_4$: 2 June 2004 to 16 September 2004.

SET Site No.	$T_2 – T_3$		$T_3 – T_4$	
	Mean (cm)	SD (cm)	Mean (cm)	SD (cm)
1	0.38	0.32	0.07	0.22
2	0.81	0.36	- 0.39	0.45
3	0.72	0.32	0.09	0.29
4	0.42	0.36	- 0.24	0.36
5	- 0.59	1.47	1.76	3.85
6	1.07	1.25	- 1.21	4.38
7	1.88	0.61	- 0.37	0.85
8	1.52	0.31	0.16	0.42
9	0.20	0.38	0.16	0.47
10	0.78	0.61	0.06	0.45
11	0.22	0.37	- 0.15	0.92

Table 4.4C. Surface elevation change (minus values indicate site erosion) at the 11 Sedimentation – Erosion Table (SET) sites at Freiston Shore. Time period $T_4 – T_5$: 16 September 2004 to 21 April 2005. Time period $T_5 – T_6$: 21 April 2005 to 30 September 2005.

SET Site No.	$T_4 – T_5$		$T_5 – T_6$	
	Mean (cm)	SD (cm)	Mean (cm)	SD (cm)
1	0.21	0.23	- 0.11	0.16
2	0.71	0.53	- 0.05	0.42
3	0.26	0.37	- 0.01	0.82
4	0.28	0.33	0.10	0.25
5	- 2.02	4.30	- 1.42	1.68
6	1.19	4.14	0.09	0.34
7	1.11	0.58	- 0.04	0.63
8	1.77	0.49	1.56	0.30
9	0.38	0.34	- 0.03	0.38
10	0.66	0.31	0.26	0.28
11	0.43	0.43	- 0.02	0.27

Table 4.4D. Surface elevation change (minus values indicate site erosion) at the 11 Sedimentation – Erosion Table (SET) sites at Freiston Shore. Time period T_6 – T_7: 30 September 2005 to 27 April 2006. Time period T_7 – T_8: 27 April 2006 to 19 September 2006. Note: due to headward creek erosion, site means at site 7 in both time periods are based on 18, rather than 36, measurements.

SET Site No.	$T_6 – T_7$		$T_7 – T_8$	
	Mean (cm)	SD (cm)	Mean (cm)	SD (cm)
1	0.23	0.22	- 0.16	0.38
2	0.69	0.48	- 0.20	0.41
3	0.63	0.95	0.16	1.26
4	0.31	0.29	- 0.49	0.33
5	0.47	1.21	- 0.53	0.34
6	0.53	0.34	- 0.20	0.41
7	0.09	0.46	0.12	0.86
8	1.91	0.40	1.23	0.37
9	- 0.02	0.62	0.06	0.43
10	0.67	0.46	0.25	0.22
11	0.14	0.14	0.17	0.17

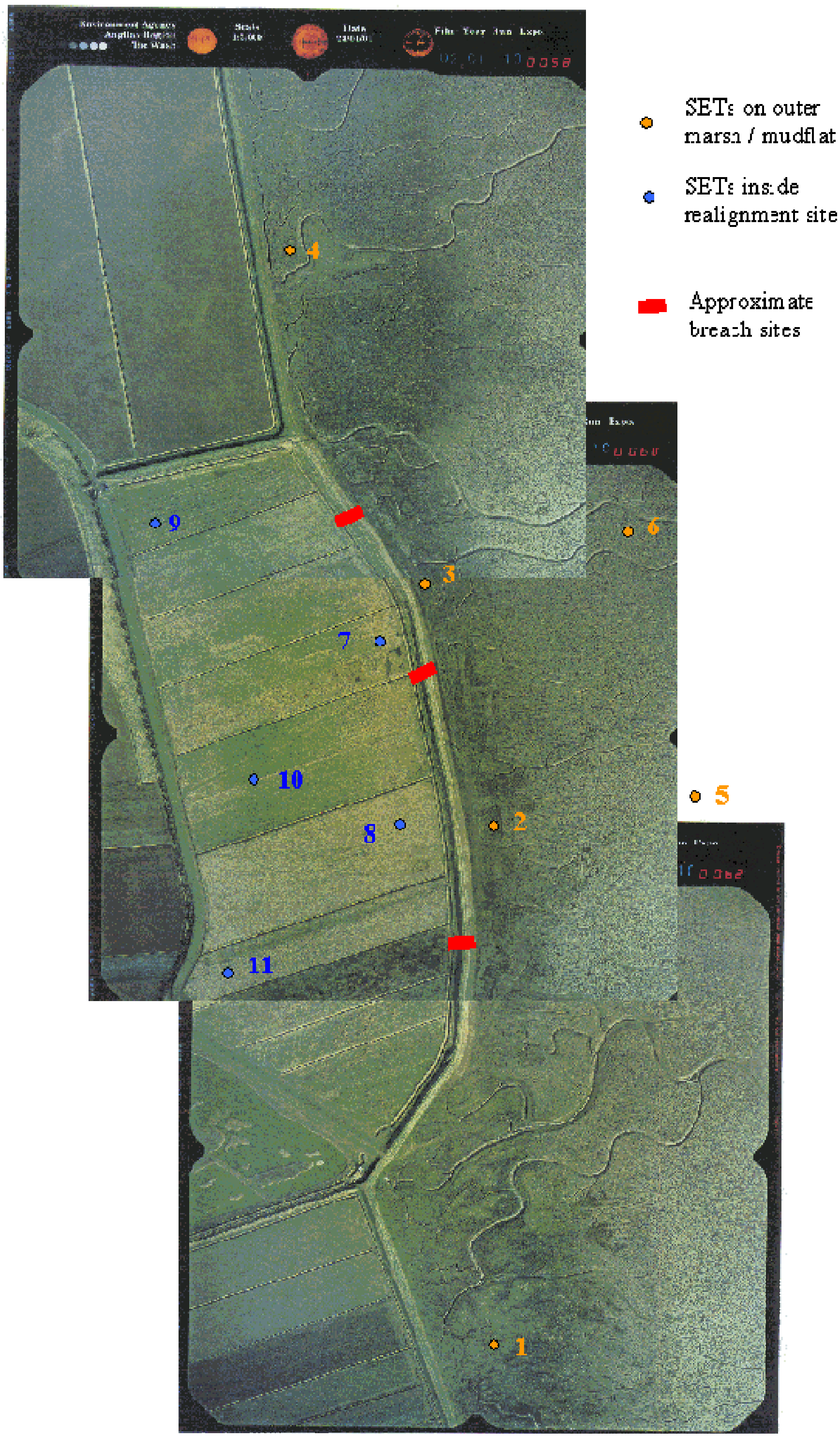


Figure 4.1. Freiston Shore Managed Realignment Site, with SET locations.

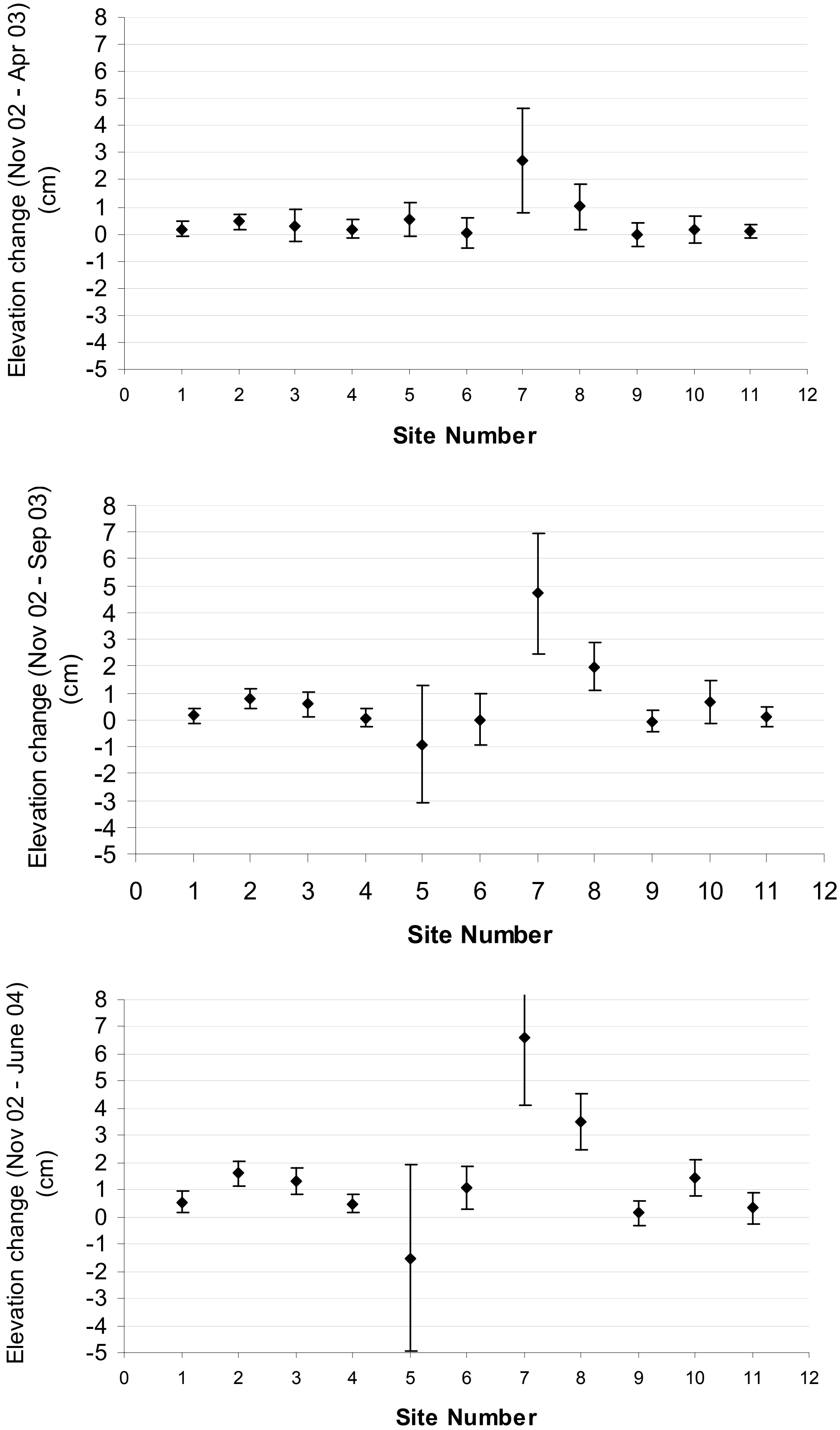
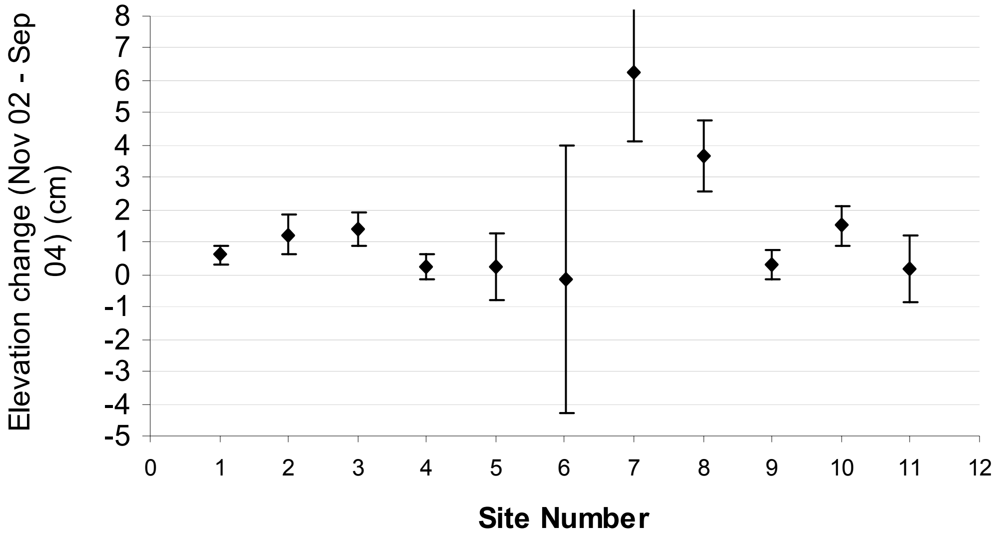
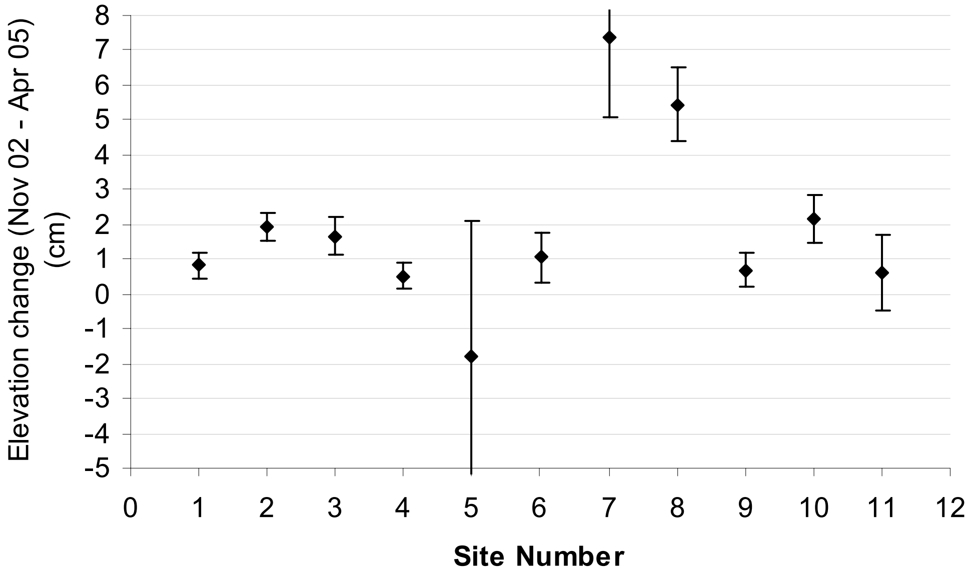


Figure 4.2A: Cumulative surface elevation change by site from start of monitoring (November 2002) to April 2003 (upper), September 2003 (middle) and June 2004 (lower).





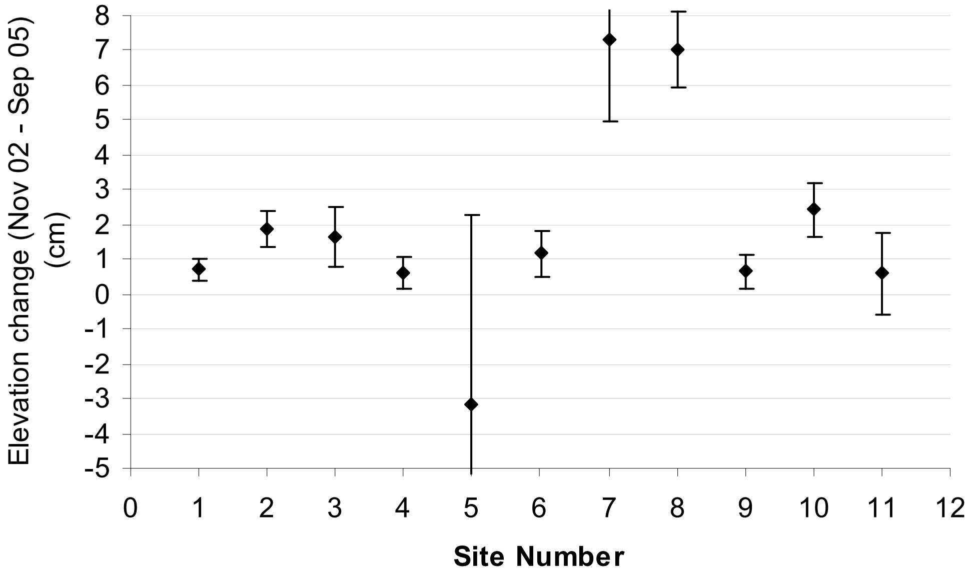
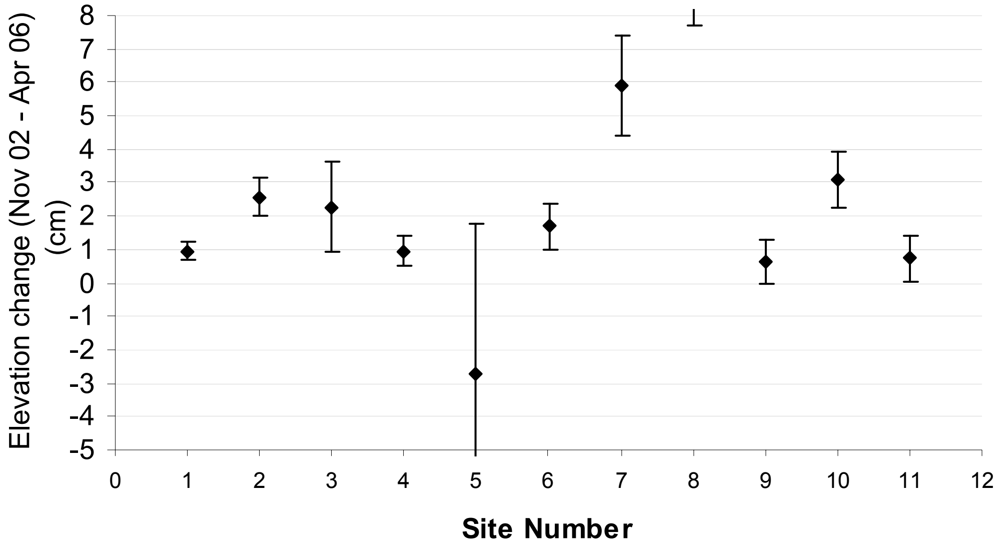


Figure 4.2B: Cumulative surface elevation change by site from start of monitoring (November 2002) to September 2004 (upper), April 2005 (middle) and September 2005 (lower).



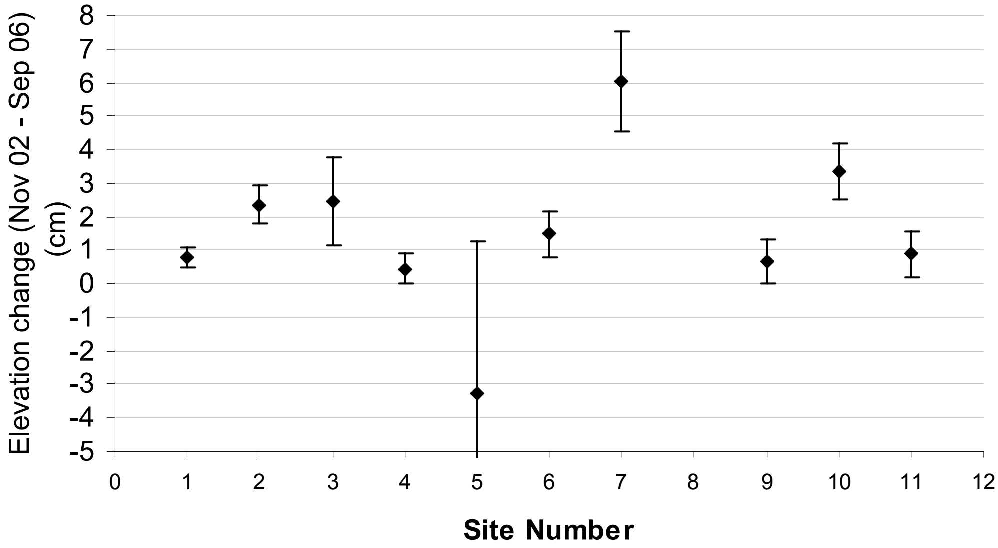


Figure 4.2C: Cumulative surface elevation change by site from start of monitoring (November 2002) to April 2006 (upper) and September 2006 (lower).

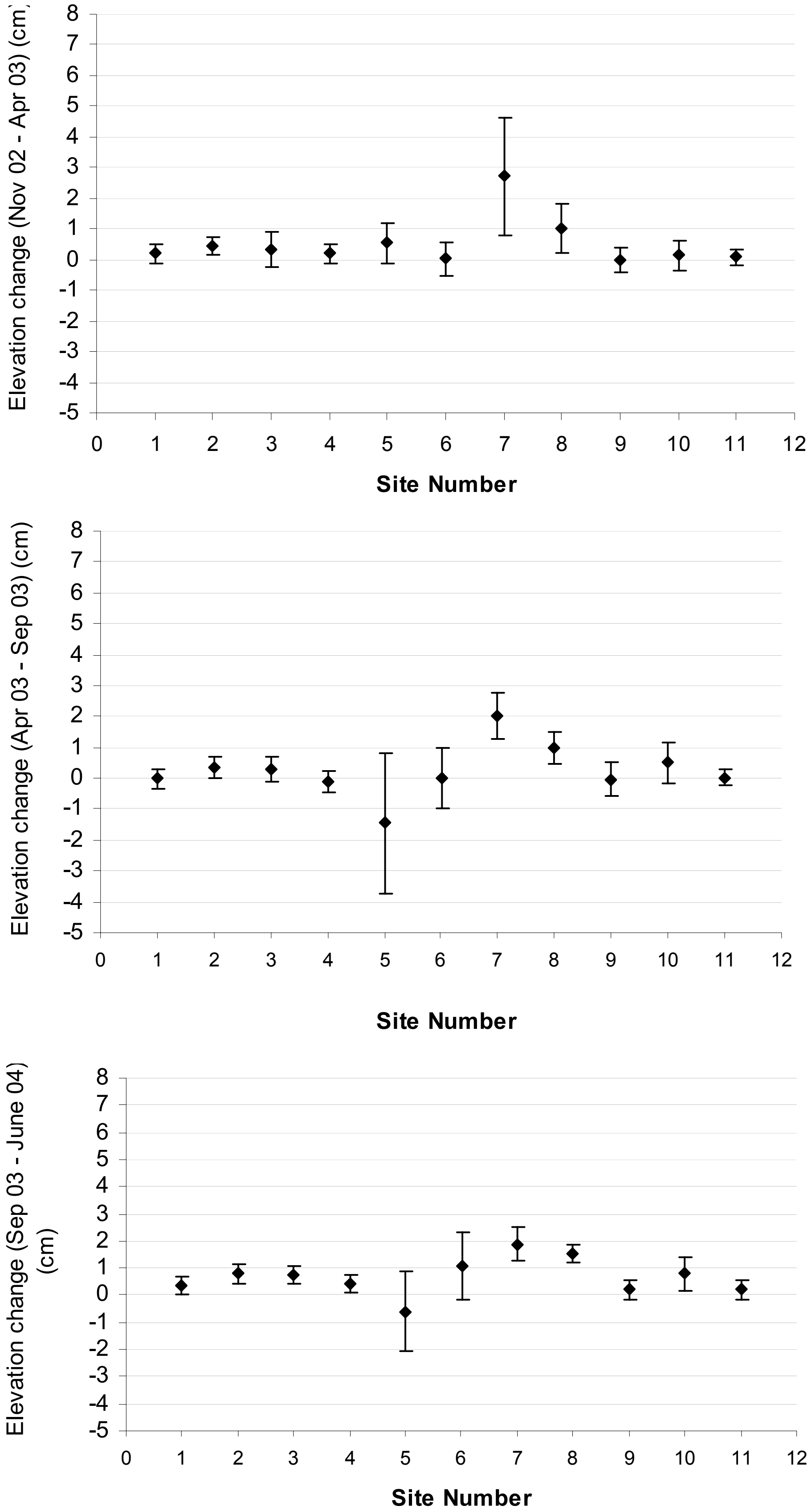
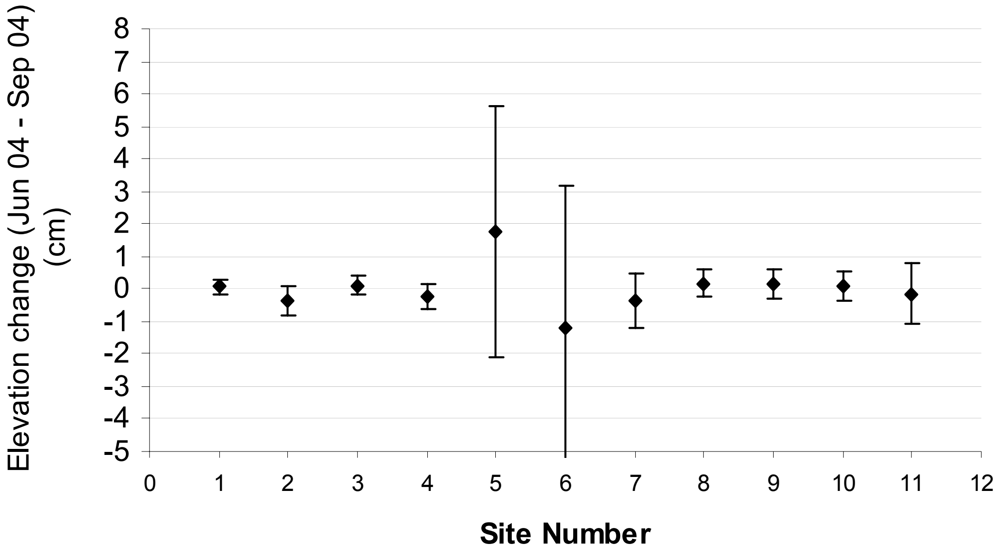
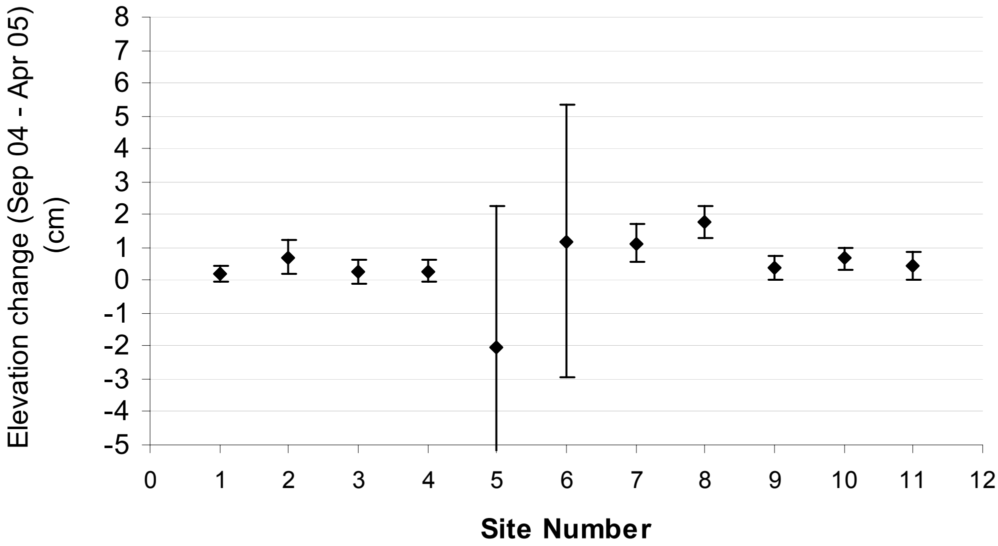


Figure 4.3A: Surface elevation change by site between monitoring periods. From start of monitoring (November 2002) to April 2003 (upper), April 2003 - September 2003 (middle) and September 2003 - June 2004 (lower).





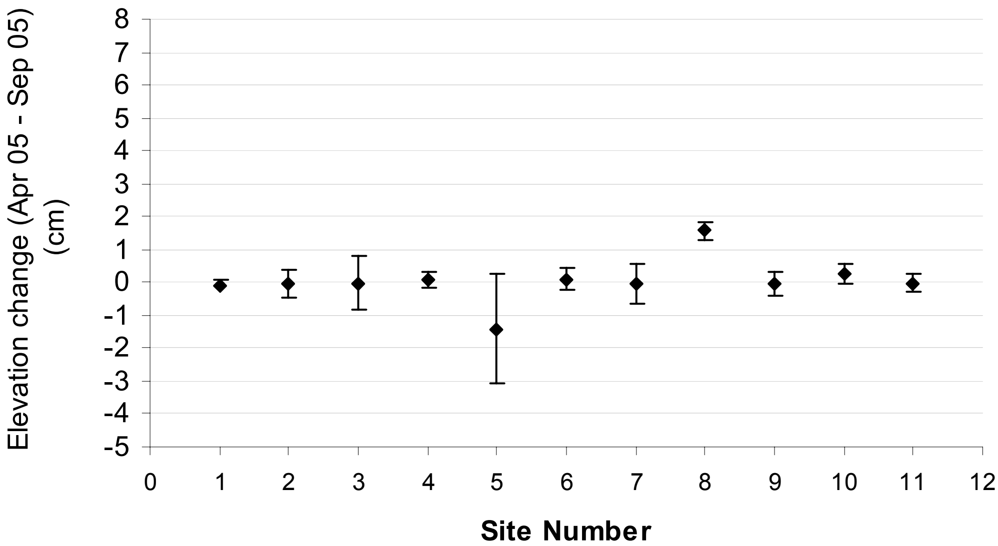
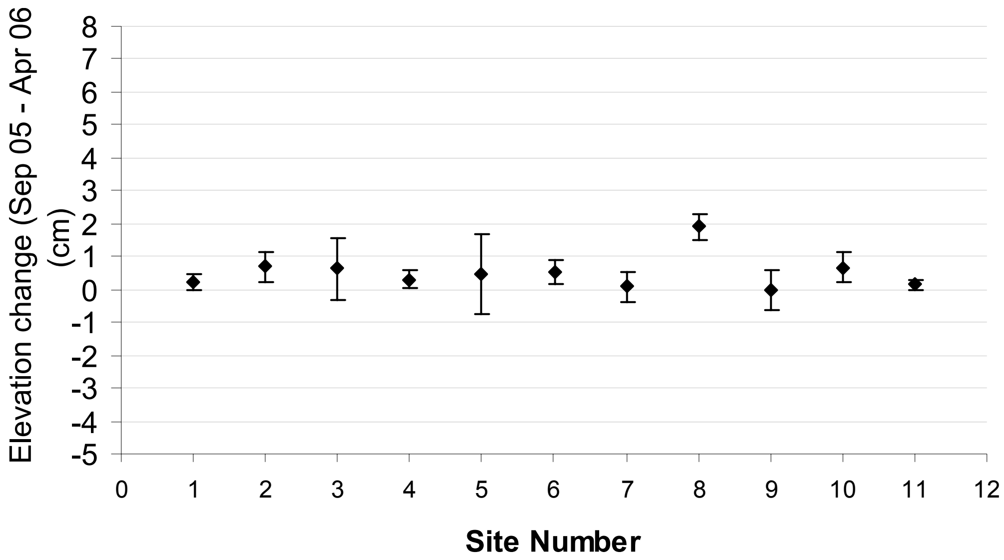


Figure 4.3B: Surface elevation change by site between monitoring periods. From June 2004 to September 2004 (upper), September 2004 to April 2005 (middle), April 2005 to September 2005 (lower).



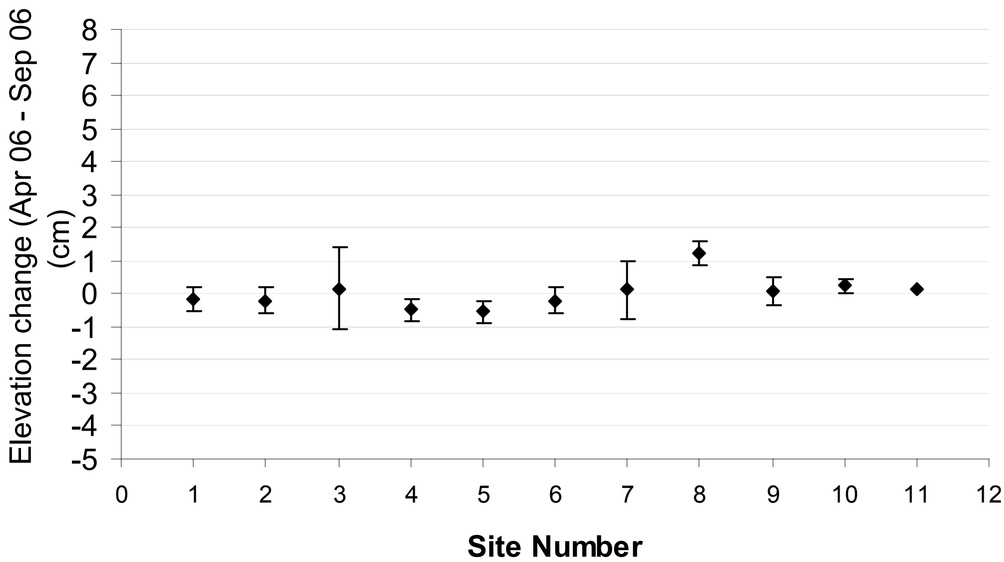


Figure 4.3C: Surface elevation change by site between monitoring periods. From September 2005 to April 2006 (upper), April 2006 to September 2006 (lower).

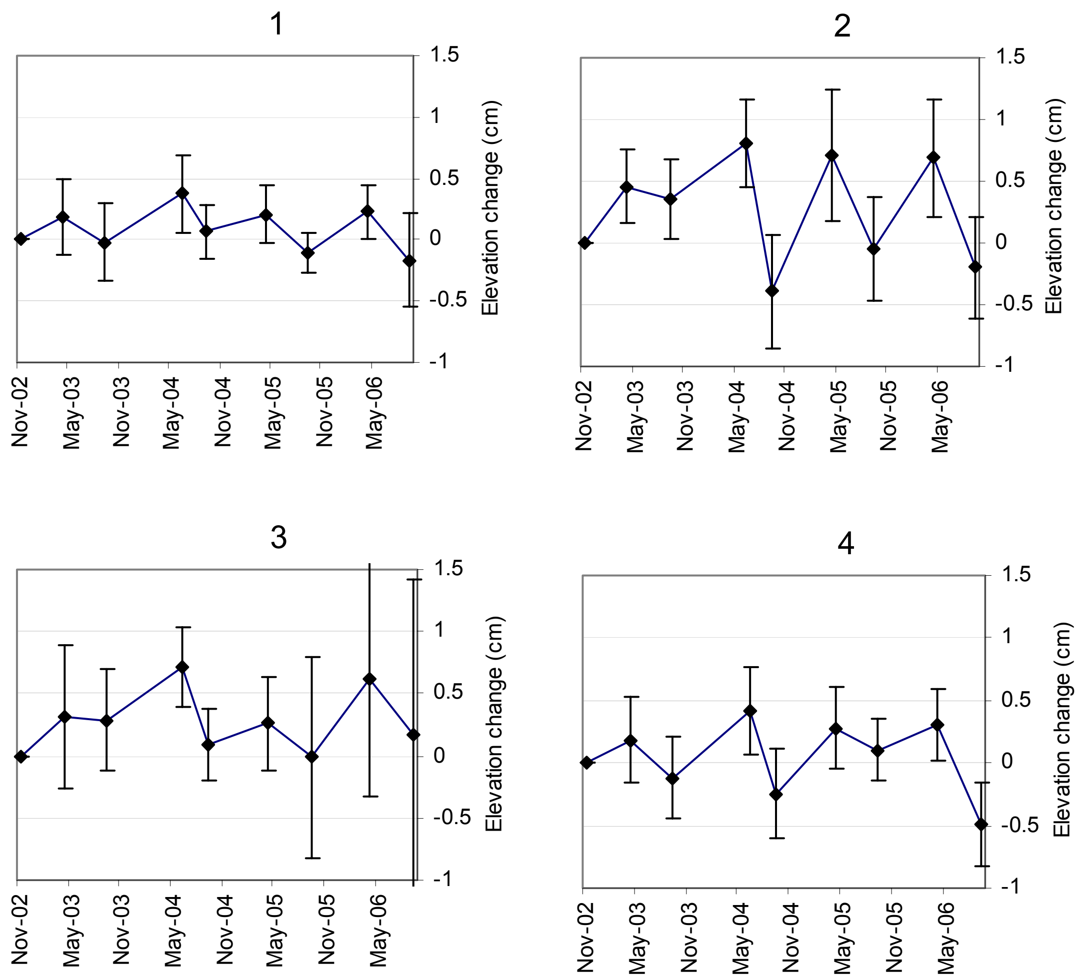


Figure 4.4A. Surface elevation change over time, November 2002 – September 2006. For details see Table 4A-D. Note: change over individual time periods is plotted at the date of the survey at the end of that period. Sites 1 – 4 (outside the managed realignment, permanently vegetated salt marsh).

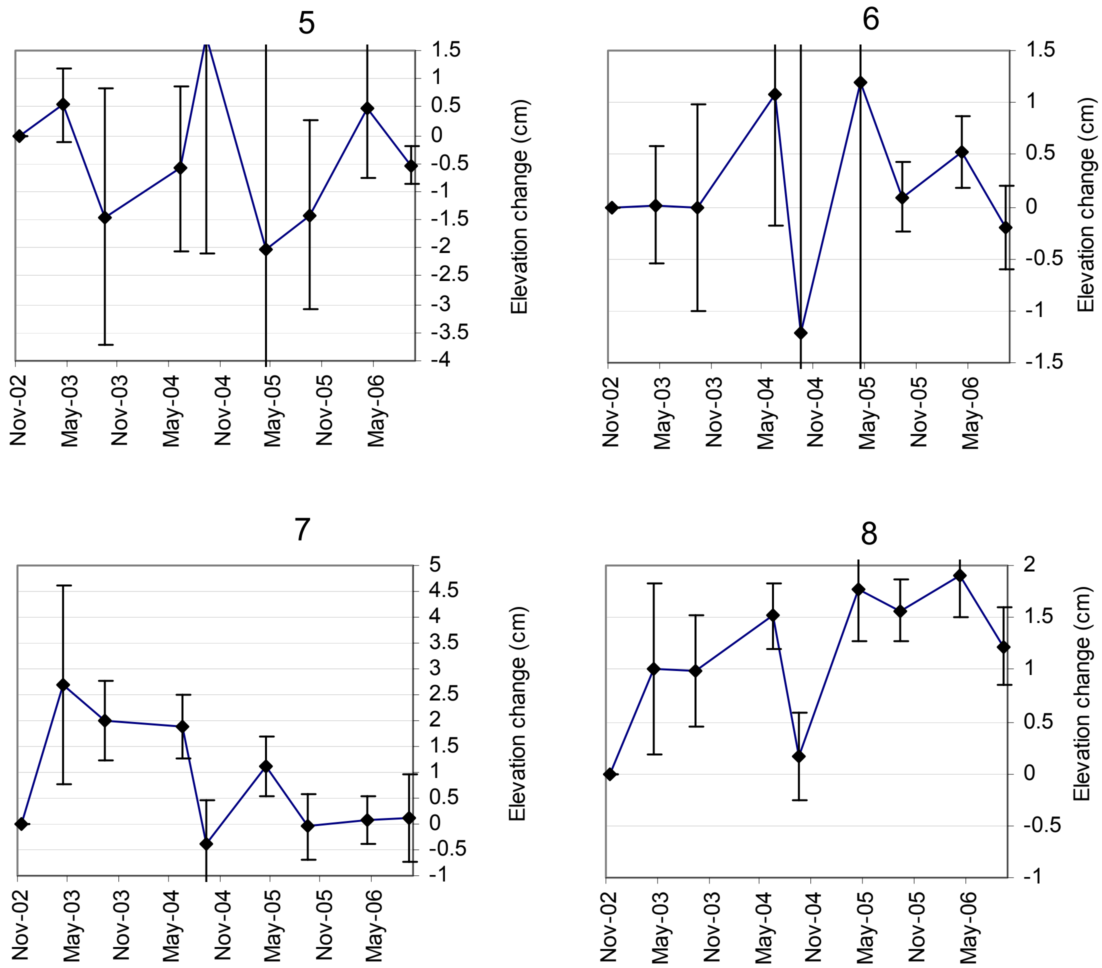


Figure 4.4B. Surface elevation change over time, November 2002 – September 2006. Sites 5 and 6 (outside the managed realignment, unvegetated mudflat) and Sites 7 and 8 (inside the managed realignment, near to breaches).

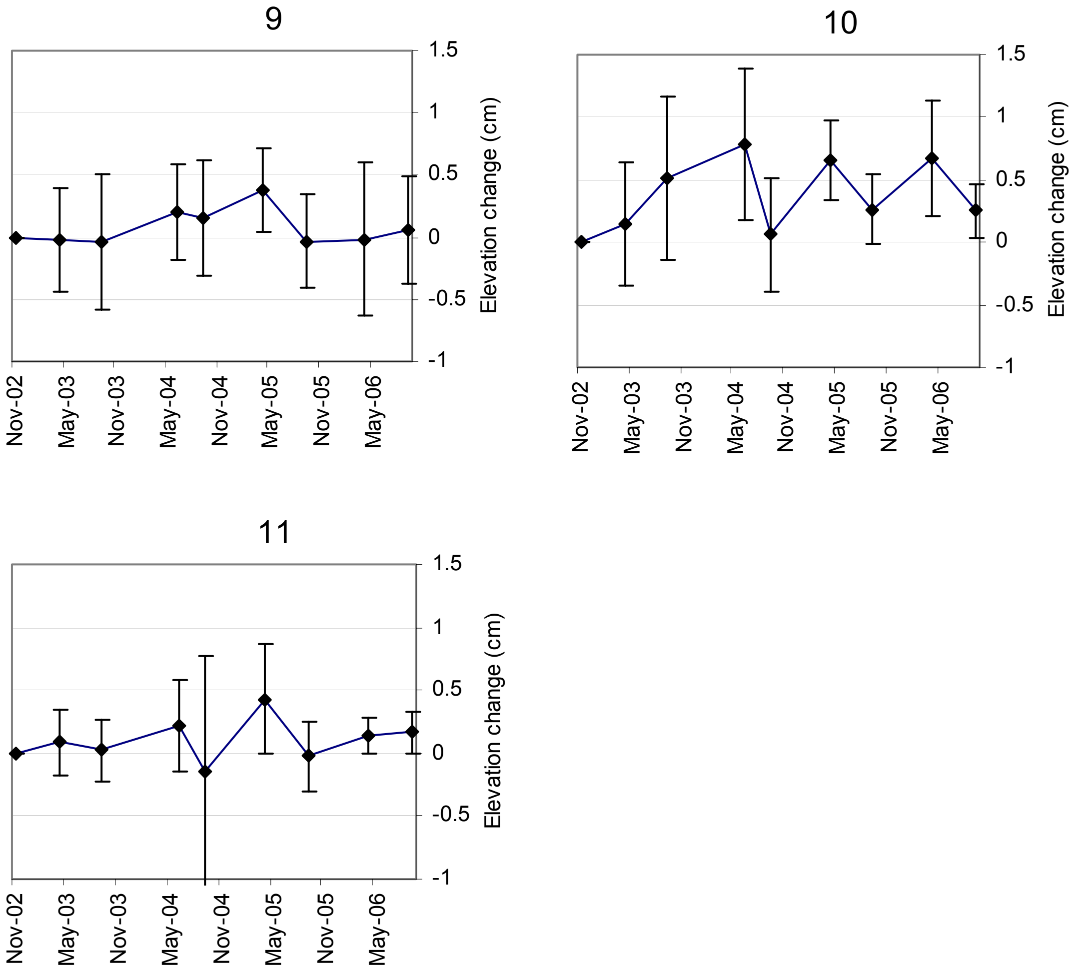


Figure 4.4C. Surface elevation change over time, November 2002 – September 2005. Sites 9 – 11 (inside the managed realignment, far from breaches).

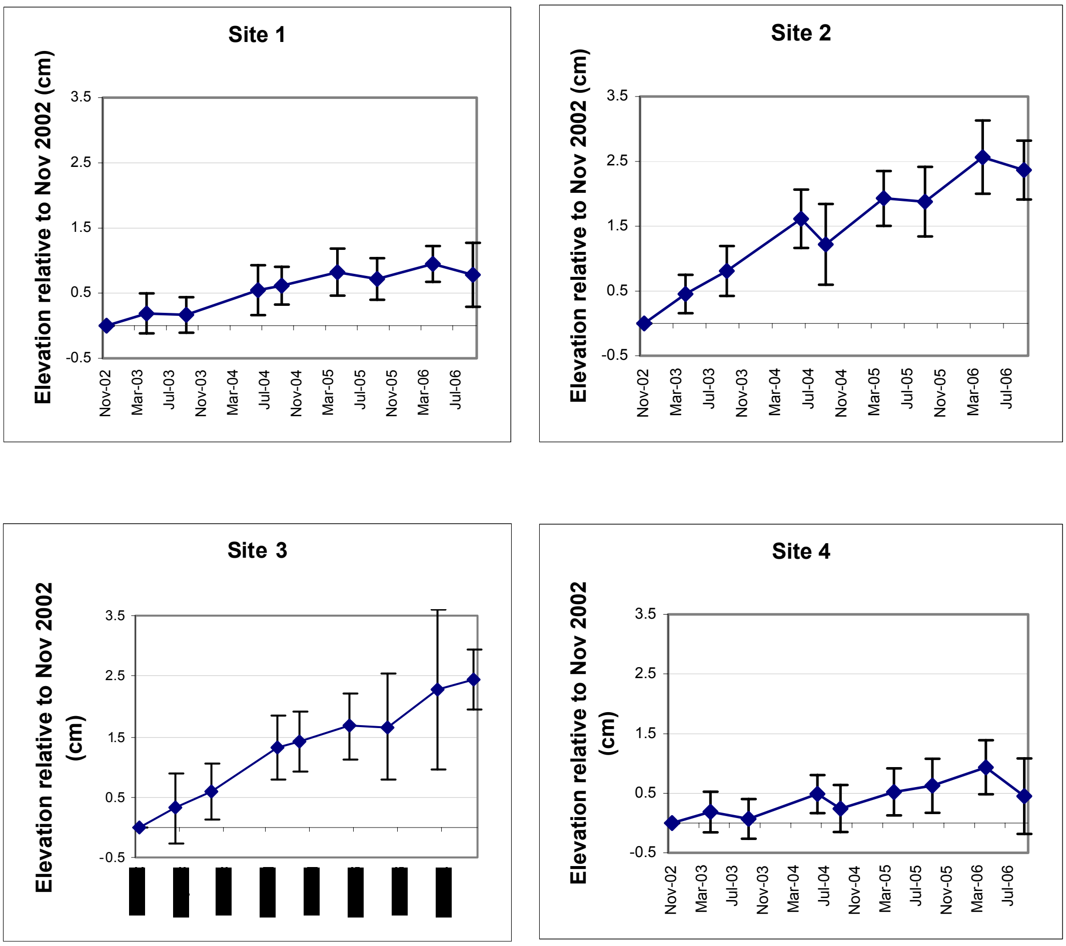


Figure 4.5A. Cumulative surface elevation change over time, November 2002 – September 2006. For details see Table 4A-D. Sites 1 – 4 (outside the managed realignment, permanently vegetated salt marsh).

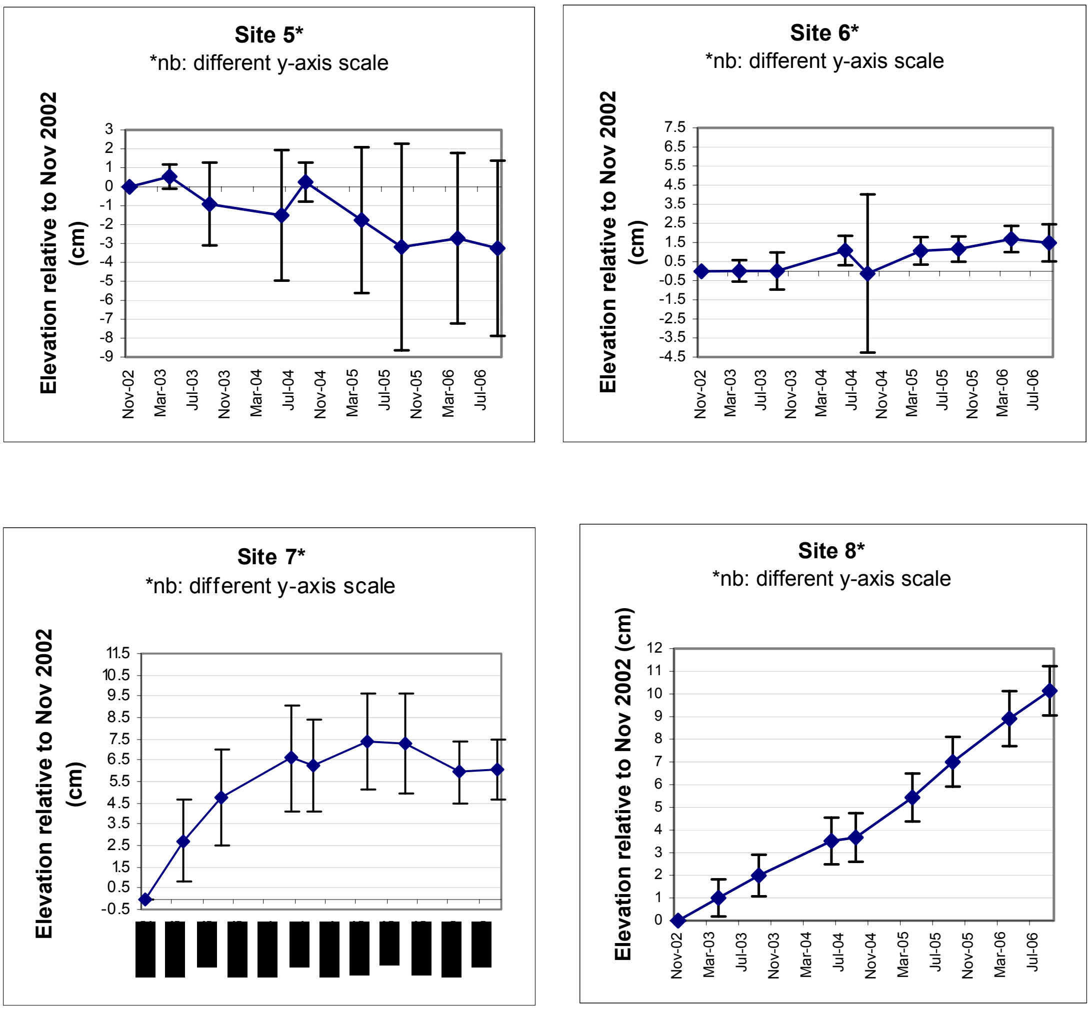


Figure 4.5B. Cumulative surface elevation change over time, November 2002 – September 2006. Sites 5 and 6 (outside the managed realignment, unvegetated mudflat) and Sites 7 and 8 (inside the managed realignment, near to breaches).

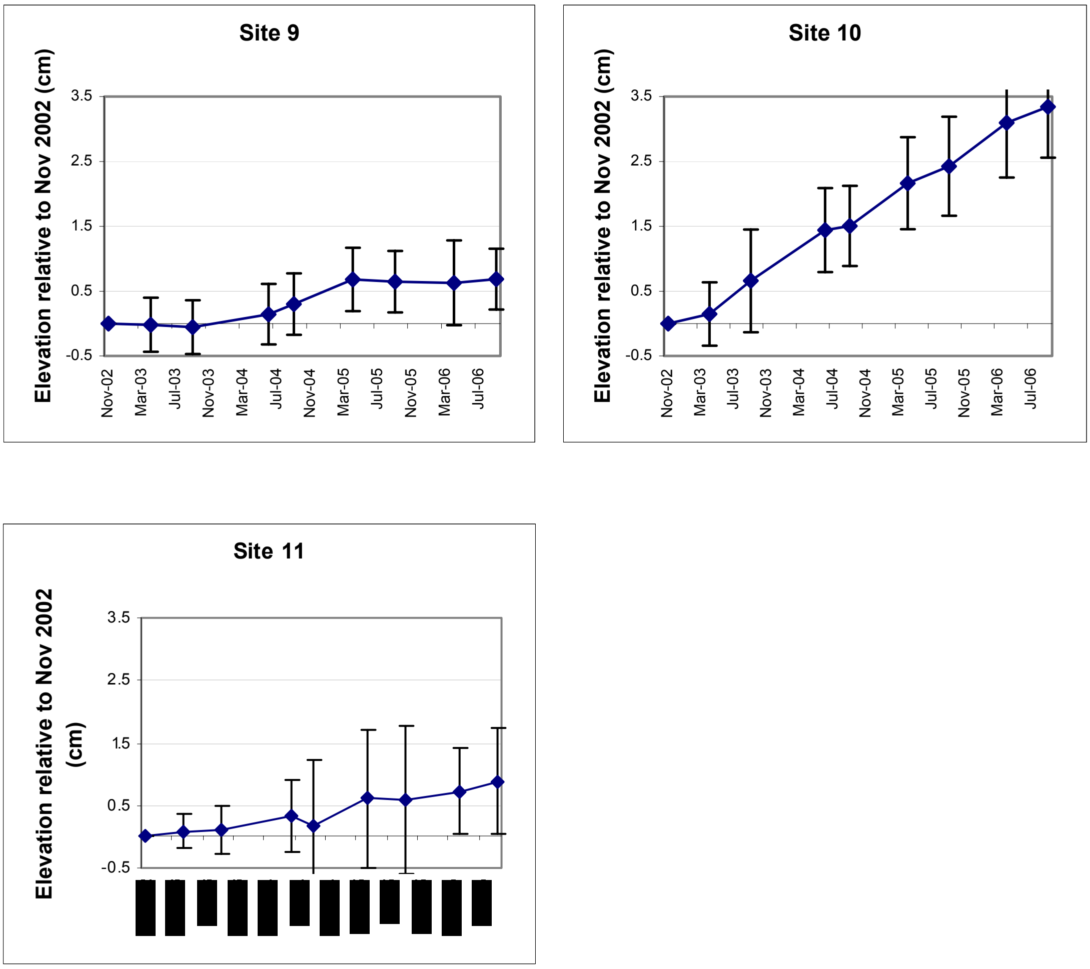


Figure 4.5C. Cumulative surface elevation change over time, November 2002 – September 2006. Sites 9 – 11 (inside the managed realignment, far from breaches).

Plate 4.1. Seasonally vegetated mudflat outside the managed realignment, Freiston Shore, April 2005 (photograph: S. Boreham)

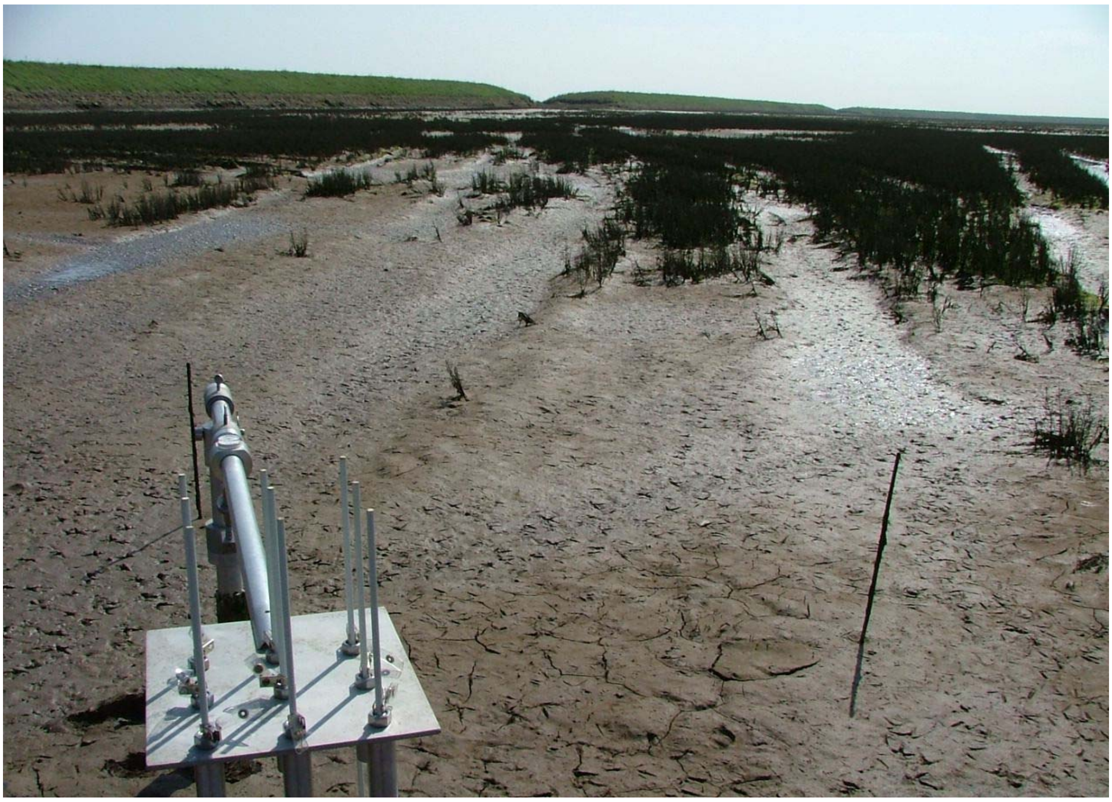


Plate 4.2. SET instrument deployed at site 7 (category: inside the managed realignment, close to the breaches; see Figure 1 for exact location), April 2005. Note less consolidated sediments infilling unvegetated former runnels at this site (photograph: S. Boreham).

Plate 4.3. Surface collapse due to headward creek expansion at site 7, September 2006 (photograph: A Balbo). Upper creek bank cliff ca. 40 cm high. Note vegetation cover in comparison to Plate 2.

5. Vegetation

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5.1 Summary

The entire managed realignment (MR) site lies at an elevation suitable for salt marsh vegetation to grow. The vegetation monitoring quadrats are between 2.7-3.3mODN (elevations measured in 2005) 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.

5.1.1 Mean total percentage vegetation cover

By 2006, the mean total percentage ground cover in 5 x 1m^2 quadrats at individual sites inside the MR ranged from 7% at one site (only colonised in 2006), 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% cover and 11 sites more than 90%. Sites outside on the salt marsh in the same elevation range, varied between 80% and 98% mean total cover.

The mean total vegetation cover (from the sum of individual species cover, see text for explanation) of 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 (2002-2006). On the pioneer salt marsh outside at <2.7mODN mean total vegetation cover was similar in 2002 and 2003 (approximately 33%) but has since increased each year since to 61% in 2006.

If vegetation spread continues to increase at a rate similar to that observed between 2004 and 2006, a mean total cover value close to that outside in the same elevation range is predicted to be reached between 2008 and 2010. However, it may take longer for the realignment site to reach equivalent vegetation community composition.

Elevation is a key factor for the establishment and survival of different salt marsh species, therefore total vegetation and species composition data were compared according to sub-categories within the total elevation range.

In the lower half of the elevation range inside the MR (2.7-2.99mODN), the mean total vegetation cover has increased to 72% in 2006, still lower than the mean cover outside 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 individual annual plants (*Salicornia europaea* and *Suaeda maritima*).

At 3.0-3.15mODN, the mean total percentage vegetation cover inside the MR increased to 87% by 2006, compared with 97% outside in this range. Percentage cover levelled off between 2004 and 2005 inside, due to a drop in *Salicornia europaea* cover, although other species had increased to partially offset this decline.

Vegetation spread inside the realignment was most rapid at the highest elevation category (3.16-3.3mODN), reaching 98% mean total cover by 2005 (similar in 2006), which was the same value as that outside in this elevation range.

5.1.2 Species number

A total of 16 typical salt marsh species have been noted in the MR site (out of 17 seen outside in the Freiston area), and all of the common/abundant species on the salt marsh were widespread in the realignment site by 2006. Eleven species have been recorded in the quadrats overall in the realignment site, with some differences between years (2003: 9 species; 2004: 8; 2005: 9; 2006:10). Nine species were recorded in the quadrats outside the realignment site in all years, of which the 7 most abundant species were common to both inside and outside quadrats.

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 5 years outside (5.46-5.77).

At elevations 2.7-2.99mODN, mean species number in the MR quadrats increased from 2.88 in 2003 to 5.09 by 2006. Outside the realignment site, mean species number increased from 5.31 in 2002 to 6.0 in 2006 (6.15 in 2005).

Between 3.0-3.15mODN, mean species number increased in the MR from 4.10 in 2003 to 5.83 in 2006, a similar mean value as outside in this elevation range.

At 3.16-3.3mODN, where the rate of increase in total vegetation cover was the greatest, species diversity was also the highest from the outset, with mean species number varying between 5.46 and 6.27, and higher than outside (5.29-5.43).

5.1.3 5 x 1m^2 quadrats: Species composition

In the first year of colonisation of the realignment site, the pioneer annuals *Salicornia europaea* and *Suaeda maritima* were the dominant species throughout the site.

Salicornia europaea was the dominant species in the pioneer zone on the salt marsh outside the MR, below 2.7mODN, followed by *Suaeda maritima*. These two annuals were also the most abundant at 2.7-2.99mODN, although *Salicornia europaea* and *Puccinellia maritima* decreased in cover at this elevation range over the 5 years of monitoring while *Atriplex portulacoides*, which was rare in 2002, has increased its cover to 6%. Other species (in descending order of cover importance): *Spartina anglica* and *Aster tripolium* were recorded with a mean cover of 13-14% in 2006; *Puccinellia maritima* at 7%; and *Spergularia media* and *Sarcocornia perennis* were recorded with mean cover of <2% in 2006.

Inside the MR at 2.7-2.99mODN, *Salicornia europaea* followed by *Suaeda maritima* were still the most abundant species in 2006, with fluctuating cover values but showing an overall increase in cover between 2003 and 2006. *Puccinellia maritima* increased in mean cover to 8%, and other species (in descending order of cover): *Atriplex portulacoides*, *Spartina anglica* and *Aster tripolium* have all spread since 2003 to between <1% and 3% in 2006. The only species found outside in the quadrats but not yet recorded inside in the quadrats (by 2006) at this elevation range was *Spergularia media.*

Outside at 3.0-3.15mODN, *Puccinellia maritima* was the dominant species in 2002, but has since declined along with *Salicornia europaea*, while *Atriplex portulacoides* has increased to become the most abundant species by 2005. *Suaeda maritima* has increased slowly and *Aster tripolium* cover has varied. The remaining species: *Sarcocornia perennis* and *Spergularia media* were recorded at <1% in 2006.

Inside the MR at 3.0-3.15mODN, *Salicornia europaea* followed by *Suaeda maritima* were the most abundant species in 2003. Their cover has fluctuated since but was higher in 2006 than 2003. *Puccinellia maritima* spread most rapidly between 2003 and 2005 when it had become the most abundant species, with a similar cover value in 2006. *Atriplex portulacoides* has increased steadily to 5% in 2006, and *Aster tripolium* and *Spartina maritima* have increased slowly to 1-2%, with *Spergularia media* at <<1%. The only species found outside in the quadrats but not yet recorded inside at this elevation range (by 2006) was *Sarcocornia perennis*.

Outside the MR at 3.16-3.3mODN, *Atriplex portulacoides* was the most abundant species in 2002, but followed closely by *Puccinellia maritima*. In the 5 years of surveying *Atriplex portulacoides* has increased steadily while *Puccinellia maritima* has decreased rapidly. *Suaeda maritima* and *Aster tripolium* were recorded in 2006 at <3% and <1%, and *Spartina anglica* and *Limonium vulgare* were found rarely (at <<1%). *Salicornia europaea* was not found in 2006 (although 2 sites were lost to cattle damage).

Inside the MR at 3.16-3.3mODN, *Suaeda maritima* followed by *Salicornia europaea* were the most abundant species in the first year but both had declined in mean cover by 2006. *Puccinellia maritima* spread rapidly, particularly between 2004 and 2005, to become the dominant species, remaining at a similar cover value in 2006. *Atriplex portulacoides* has increased steadily each year to become the second most abundant cover species by 2006. *Aster tripolium* has also increased, but more slowly. Other species:

Spartina anglica, *Spergularia media*, *Cochlearia sp.*, *Elytrigia atherica* and *Sarcocornia perennis* were recorded at low cover values <1% in 2006. One species found outside in the quadrats: *Limonium vulgare* (local and uncommon) has not yet been recorded in the quadrats inside the realignment site (by 2006).

In summary, the pioneer annuals *Salicornia europaea* and *Suaeda maritima* were the first to colonise the realignment site and were the dominant species throughout the site in 2003, at all elevations. Between 2003 and 2006, these pioneer annuals have remained the most abundant species at lower elevations in the realignment, but other species have established and spread, particularly at the higher elevations, where the annuals have been replaced by the perennial *Puccinellia maritima*, which spread rapidly between 2003 and 2005 to become the dominant species by 2005. *Atriplex portulacoides*, extremely abundant outside on the salt marsh at higher elevations has shown a steady increase at higher elevations in the MR, and by 2006 was the second most important cover species after *Puccinellia maritima* in the highest elevation range category (3.16-3.3mODN).

5.1.4 5m x 5m quadrats in the MR: Species composition

The nine larger quadrats in the realignment site showed the same trends as the smaller ones. 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 these annuals were initially the most abundant species but were overtaken by *Puccinellia maritima* by 2005 which spread rapidly between 2004 and 2005, particularly in the highest of these sites (>3.2mODN) in this category. One of the two sites lying above 3.3mODN was colonised by *Elytrigia atherica* in 2003 and this species has spread, while the annuals have decreased to <1% cover. The other site was set up in 2005 to provide ground reference data (for remote sensing) for an area with abundant *Atriplex portulacoides*, and this species increased its cover between 2005 and 2006.

5.1.5 Percentage frequency in the MR

All of the main species increased in frequency between 2003 and 2006, and perennials such as *Puccinellia maritima* and *Atriplex portulacoides* increased in both frequency and cover, 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 more than mean cover, and in the case of *Suaeda maritima* at higher elevations frequency increased at the same time that cover decreased year on year. The main reason for the mismatch was due to a decrease in the size of these plants as other competing species established in the quadrats.

5.1.6 Individual sites: NVC Communities and comparisons of most abundant species

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-enforced our findings from the mean cover values and showed that there was considerable agreement in species composition and dominant species between the realignment site and the outside salt marsh at equivalent elevations, and in several cases the equivalent NVC designations were found. The greatest similarities between the realignment and outside were in the lowest elevation category. Higher sites above 3mODN in the MR had a similar species mix to outside, but relative abundances of species were still different by 2006. However, the trends in species cover showed that the relative abundances of species in the MR site have been changing each year and moving towards those found outside at similar elevations.

The overall impression from the species composition data according to elevation category (above) and comparison of community designations was that succession of perennial species in the upper half of the elevation range of the site was occurring rapidly by 2006 and 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 if the major perennials continue to spread at the rate observed in the last two years, the principal author would hazard an estimate that this could be achieved within about five more years (≈ 2012).

5.1.7 Conclusion

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 species have been increasing their cover year on year and replacing the annual pioneer species as the dominant cover types, particularly in the upper half of the elevation range, and some sites were approaching similar community compositions by 2006. 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.

5.2 Introduction

Vegetation monitoring is the most obvious structural measure for assessing the success of creating a salt marsh by managed realignment by comparison with data from a reference marsh, in this case immediately adjacent to and in front of the realignment site. Because salt marsh vegetation exhibits zonation of its component species according to its elevation within the tidal frame, which changes with sediment accretion, it is most useful to monitor the vegetation in association with accretion measurements and with information on elevation as these attributes can help to explain the results of the vegetation surveys. This approach is useful to interpret the vegetation establishment and succession inside the realignment site and to explain any changes outside on the salt marsh (for example, if there were any unwanted effects of the realignment on the adjacent marsh, such as vegetation loss or reversal of natural successional processes).

Although several managed realignment sites have now been created around the UK coast, experience is still relatively limited. Sites may take a considerable time to develop into a salt marsh that can be considered equivalent to natural salt marshes in the region if initial conditions are not appropriate for salt marsh development. Success and rates of salt marsh colonisation and establishment will vary according to site-specific conditions, and information from each new site will add to our knowledge of how best to achieve the required outcome.

5.3 Methods

Permanent quadrats were set up at 3 different scales: 25m^2, 5 x 1m^2, and 1m^2 divided into 100 sub-cells. These three scales were used for the following reasons: (1) 25m^2, primarily to produce ground reference data for remote sensing images, (2) 5 x 1m^2 to monitor vegetation in association with accretion measurements, and (3) 1m^2 divided into 100 cells (realignment site only) to look at details of vegetation colonisation, establishment and succession at a local scale.

5.3.1 Five x 1m^2 quadrats

The 5m x 1m^2 were surveyed in conjunction with the accretion plates (see Figure 5.1, and Photo 5.1) so that any changes observed in the vegetation inside and outside the managed realignment site could be related to the measured changes in sediment level (accretion or erosion) at each site. A 5m x 1m^2 rope quadrat was laid out and the percentage cover of all vascular plant species was recorded in each of the 1m^2 quadrats. Species occurring at a cover of less than 1% were recorded as present (+) and given a value of 0.2% in the data base for analysis and plotting graphs. The percentage cover of bare ground, algae, permanent water, and litter was also noted. The vegetation was recorded by two people until agreement was reached on our estimations of cover. In dense vegetation the total percentage cover can exceed 100% where different species overlap in cover. A photograph was taken at each survey.

At the seaward end of transects outside the site, where accretion was measured between 5 pairs of level canes, the 1m^2 vegetation quadrats were set up 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 (see Figure 5.2). A photograph was taken at each survey.

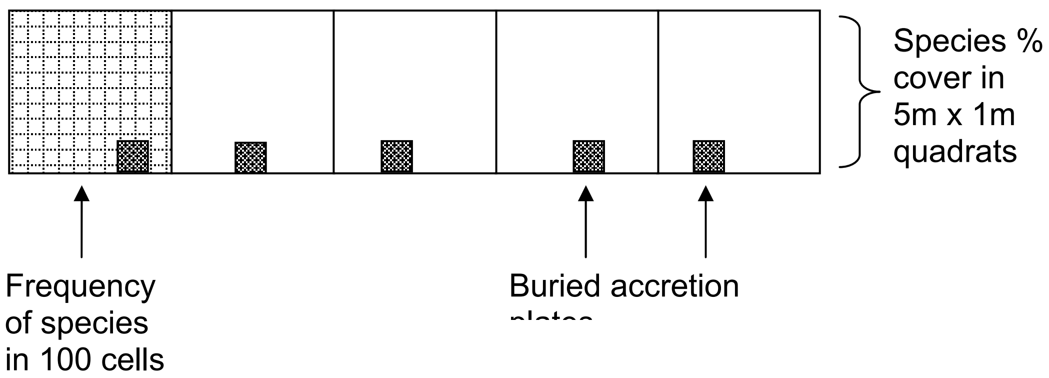


Fig.5.1. Quadrat design for vegetation monitoring (5m x 1m)

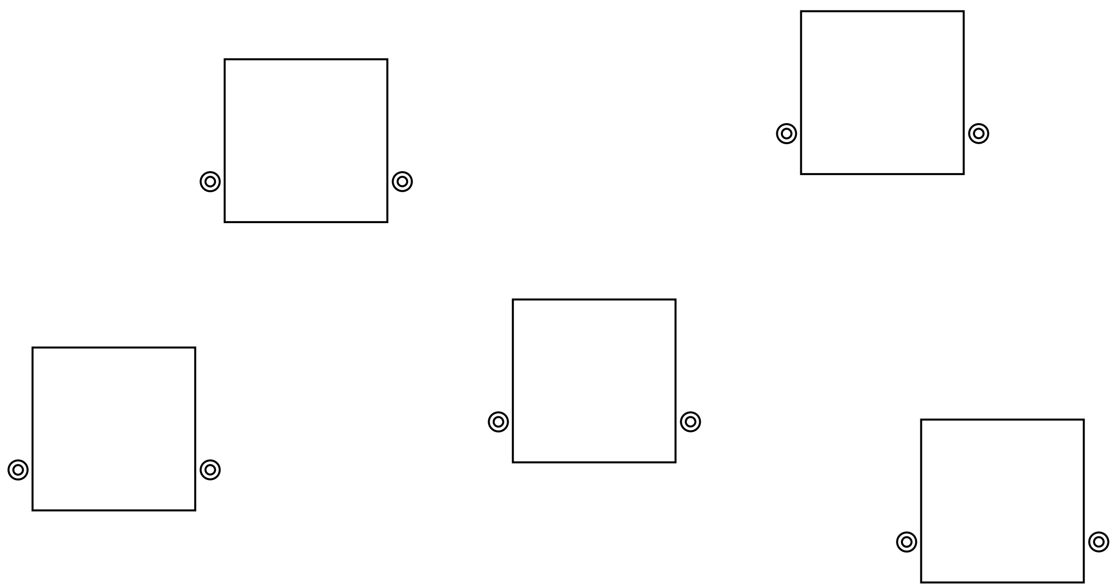


Fig. 5.2. 1m^2 vegetation quadrats between sets of accretion canes (plan view)

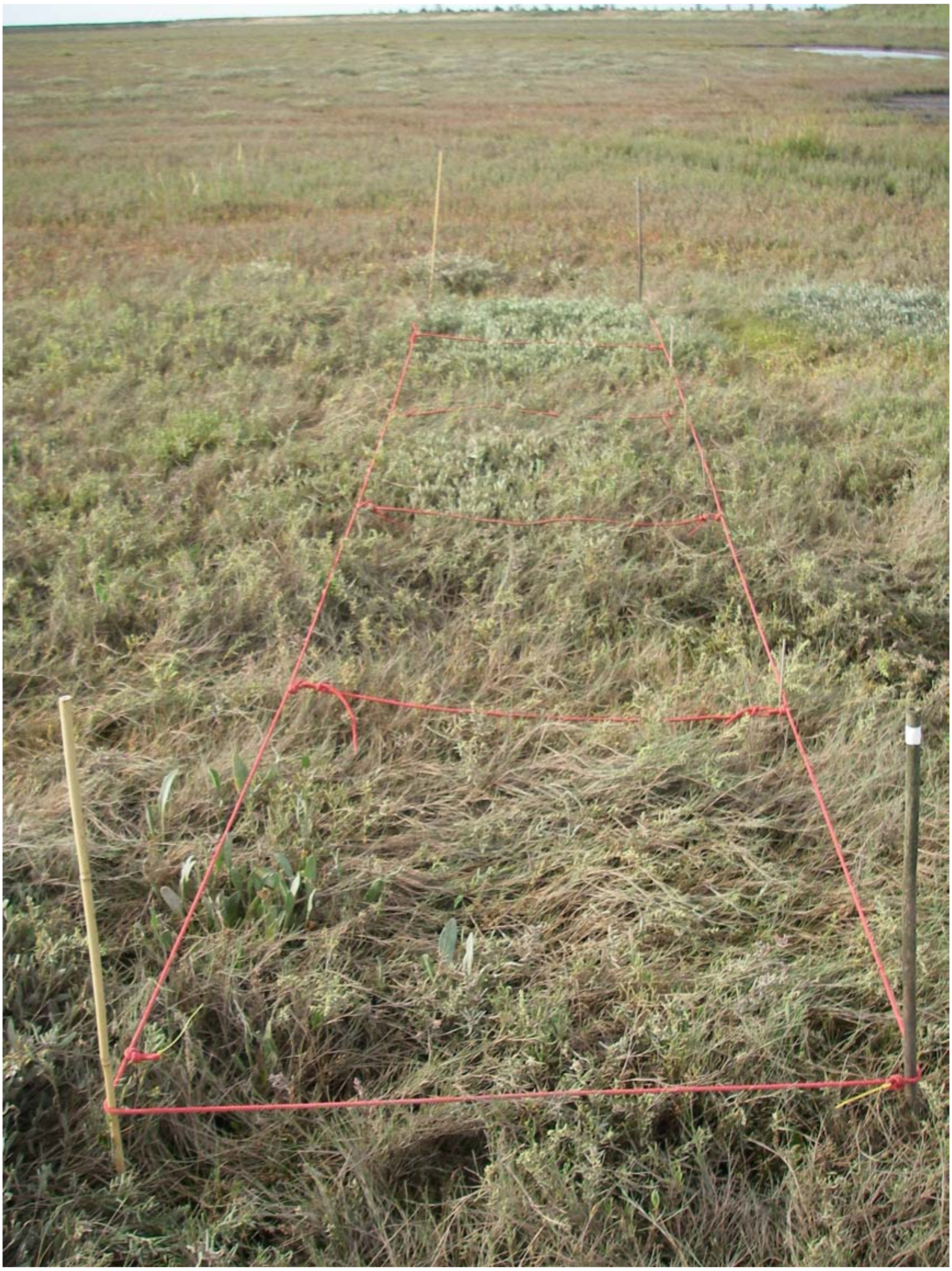


Photo 5.1. 5x1m^2 quadrat

5.3.2 Detailed 1m2 quadrats

A micro-scale survey in one of the 5m x 1m^2 quadrats (divided into 100 cells, each 10cm x 10cm, Photo 5.2) was carried out at each survey site inside the realignment area to allow detailed observations on the colonisation, establishment and spread of salt marsh species at the different elevations on the newly created salt marsh. The presence of each plant species (and also algae, bare mud, litter and permanent water with a cover value greater than 10%) was recorded for each of the cells to give the percentage frequency of occurrence. Commonly the presence is recorded when a plant is rooted in a cell. This is straightforward for upright species, but a single plant of some ground-spreading species such as *Atriplex prostrata* (Spear-leaved Orache), and the smaller *Spergularia marina* (Lesser Sea-spurrey), can take up a considerable amount of ground space. In this case, a species would be recorded in a cell if its horizontal stems were in contact with the ground. Plants such as *Atriplex portulacoides* (Sea Purslane) are initially small, occupying a single cell. As they develop to form large bushes, they were counted in a cell if they occupied the entire cell.

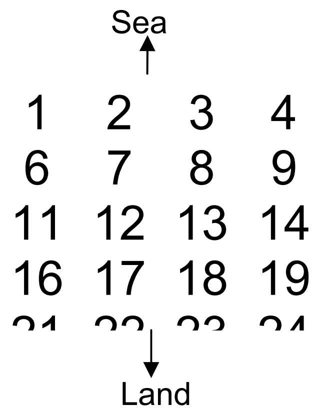
Photo 5.2. 1m^2 quadrat divided into 100 cells

5.3.3 25m^2 quadrats

Large 5m x 5m quadrats (divided into 25 x 1m^2) were set up outside the realignment primarily to provide ground reference data for remote sensing (e.g. CASI images) and therefore sites were chosen to represent different combinations of vegetation cover types. As the sediment accretion sites were also set up at different elevations and vegetation types almost all of the large quadrats were located very close to the accretion sites, within 2-10m away on the same cover type and elevation. Some additional areas just below the sea wall (short grazed grass, trampled areas (cattle), mud and stones) and bare sediment on the mudflat were surveyed in Year 1 to complete the cover types for the remote sensing classification, but these were not subsequently resurveyed. The position of each survey point was recorded by GPS. Photographs of the survey quadrats were taken from all four corners in Year 1, to supplement the recording and aid image classification. In subsequent years photographs were taken from the southeast corner to provide visual documentation for any change (or lack of change). Nine 5m x 5m quadrats were set up inside the realignment in 2003 (one was not found subsequently), and one was added in 2005 to provide a good example of an area with *Atriplex portulacoides* as the predominant species.

A 5m x 5m rope quadrat, divided into a grid of 25 x 1m^2 cells was set between the corner markers. In the first year the percentage cover of each vegetation species, bare mud or sand, algae and water was recorded in each of the 25 cells for a detailed initial characterization of the site, co-inciding with a CASI overflight by the NERC (Natural Environment Research Council) aircraft. In subsequent years the presence of each plant species within each of the 25 cells was recorded and tabulated as the frequency of occurrence (number of cells out of 25) for each quadrat, together with the occurrence of algal mats, bare mud or litter with a cover value greater than 10%. The total percentage cover of each vascular plant species, algae, bare mud and water was estimated for the entire 25m^2 quadrat. It is difficult to make an accurate estimation of total percentage cover in a large quadrat as the impression of species cover can vary according to perspective (direction of view), so it is helpful to walk around the quadrat to view it from all sides during the assessment. Recording was undertaken by two people until agreement was reached on estimations of cover. A sediment scrape sample was collected from the quadrats in the first year for analysis of particle size to aid description of sediment type in the CASI images.

The convention for surveying the 25 cells of the large quadrats was as follows:



Remote sensing (CASI) was carried out by the NERC in October 2002, at the time of the first survey. In Year 2 (2003) the vegetation survey was undertaken in mid-September and co-incided with an overflight by the NERC aircraft testing a new instrument, a CASI capable of imaging in shortwave infrared wavebands (SWIR), and a further remote sensing survey was carried out during the vegetation survey in September 2006.

The ground reference data from the 5m x 5m quadrats was used to:

- Categorize ground cover into classes appropriate for classification of CASI data
- Quantify the classes in terms of % cover of plant species and other cover types (e.g. mud, sand, water)
- Assess the variation of cover types within the classes
- Relate the classes to NVC classification

The processing of CASI data was undertaken by CEH Monks Wood. For further information, contact Geoff Smith or Andy Thomson at CEH Monks Wood.

5.4 Results

Figures for mean total percentage vegetation cover (from the sum of individual species cover) are shown in Appendix A5.1 for transects and sites on the salt marsh outside the managed realignment, and Appendix A5.2 for transects and sites inside the realignment.

Figures showing the percentage cover of plant species in 5 x 1m^2 quadrats at each site are shown in Appendix A5.3 for sites on the salt marsh outside, and in Appendix A5.4 for sites inside the realignment.

The percentage frequency of occurrence of plant species in 100, 10cm x 10cm, cells in a 1m^2 quadrat at each site in the realignment is shown graphically in Appendix A5.5.

The ground reference data (for remote sensing, 5m x 5m quadrats) are shown graphically (stacked histograms) for sites outside the realignment and inside the realignment in Appendix A5.6a & b, with accompanying notes in Appendix A5.6c. Results for sites inside the realignment are also plotted graphically (unstacked histograms) and discussed within this chapter. An ATM image is shown in Appendix A5.7.

Scientific and common names for plant species found on the Freiston salt marsh are tabulated in Appendix A5.8.

5.4.1 5 x 1m^2 Quadrats outside the realignment site: Summary observations on total vegetation ground cover by transect

The mean total percentage vegetation ground cover in 2006 outside the realignment is shown in Fig. 5.3. Ground cover was calculated from 100-% bare estimate (bare included any algal cover and standing water). Ground cover (100-% bare) gives the most useful impression of the extent of colonisation and cover in the early stages of marsh development on a newly created site (showing how much area is still available for colonisation). Therefore ground cover is shown for individual sites inside the realignment site in the next section, and for completion the equivalent values are described in this section for the adjacent salt marsh.

In later sections where total vegetation cover is compared between the realignment site and outside (and shown on the same graphs), the total vegetation cover was calculated from the sum of cover of individual plant species. In well-covered plots with several species, total vegetation cover values can exceed 100%, sometimes over 120%, because of species overlap (layering), but there can still be a few percent of bare ground when viewed from above. Total vegetation cover from the sum of species cover was used for comparison between the realignment site and the adjacent salt marsh because it is a more equitable way of indicating cover density, diversity and species layering. At low diversity (one species or just a few sparse species) there will be zero or little difference between ground cover and total vegetation cover, but the difference in estimates increases with increased diversity and species layering. In other words, two sites may have the same ground cover when viewed from above, for example 3% bare ground, 97% vegetation ground cover, but one of them may just have one or two species with individual species cover summing up to 97% and the other may have several overlapping species in which individual species cover adds up to (for example) 116%. The mean total percentage vegetation cover over all years from 2002 to 2006 for individual sites outside the realignment site calculated from the sum of cover estimates for individual species is shown in Appendix A5.1.

By 2006, vegetation ground cover ranged from 8% at the lowest elevation site (T4S5) up to 98% at some upper sites (Fig. 5.3). The lowest mean total percentage vegetation ground cover for sites within the elevation range found in the managed realignment (>2.7mODN) was 80% at T5S4. As expected, the upper sites on the salt marsh outside the realignment had the greatest vegetation ground cover.

Outside MR: Mean total % vegetation ground cover (100-bare), 2006

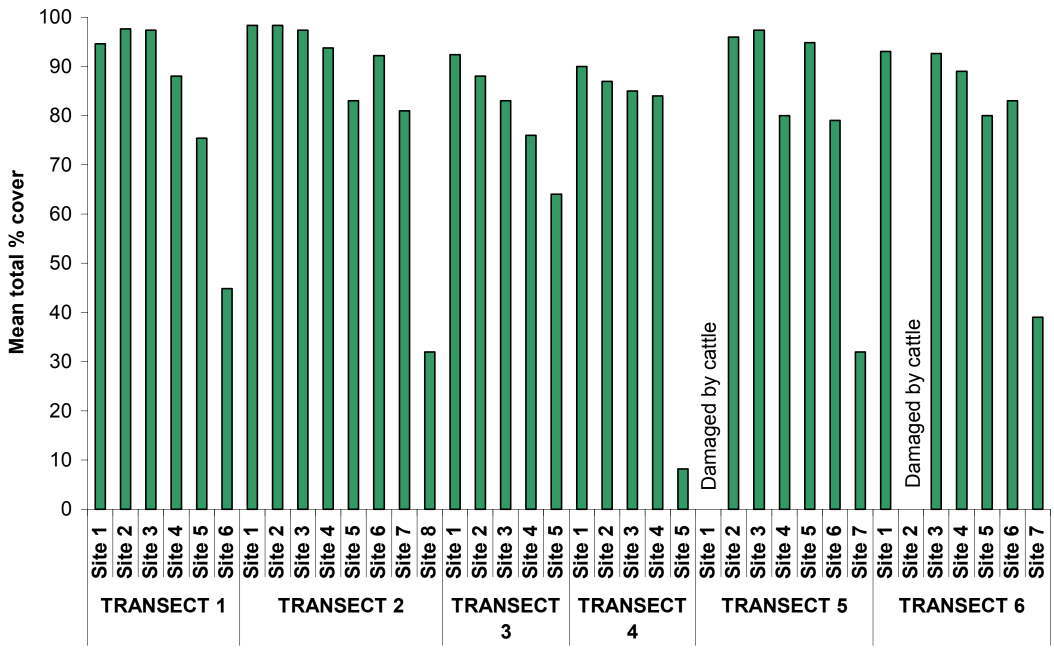


Fig. 5.3. Mean total percentage vegetation ground cover (100 – % bare ground) at sites on Transects 1-6 outside the realignment in 2006.

Mean total percentage vegetation ground cover for each site on Transects 1-6 from 2002 to 2006 outside the realignment is shown in Figs 5.4-5.9.

Ground cover fluctuated between >90% to 99% in all years at upper sites on transects north and south of the realignment at the following sites: T1 sites 1-3, T2 sites 1-4, T5 sites 1-3, and T6 sites 1 and 2; and on T3 site 1 in front of the realignment.

Over 80% ground cover was estimated for all years on T1 site 4, T2 site 5, T3 site 2, T4 site 1, T5 sites 4 and 5, and T6 sites 3 and 4. Lower sites have shown an increase in ground cover as established species have spread and the sites have built up sediment over the years of the study between 2002 and 2006 to elevations suitable for other species to colonise and grow. For example, T1 site 6 has increased from 8% to 45% ground cover; T2 site 8 from 4% to 32%; T3 site 5 from 5% to 64%; T4 site 5 (the site with the lowest elevation) from 0% to 8%; T5 site 7 from 3% to 32%; and T6 site 7 from 0% to 39% ground cover.

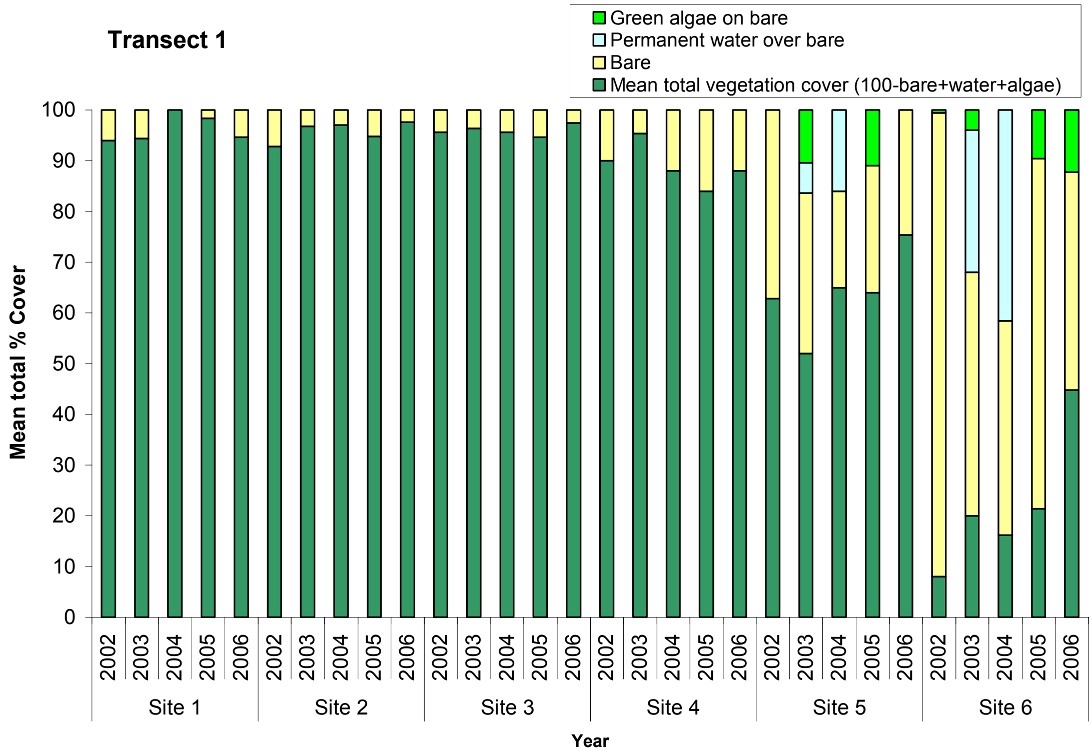


Fig. 5.4. Mean total percentage vegetation ground cover (100-% bare) on Transect 1

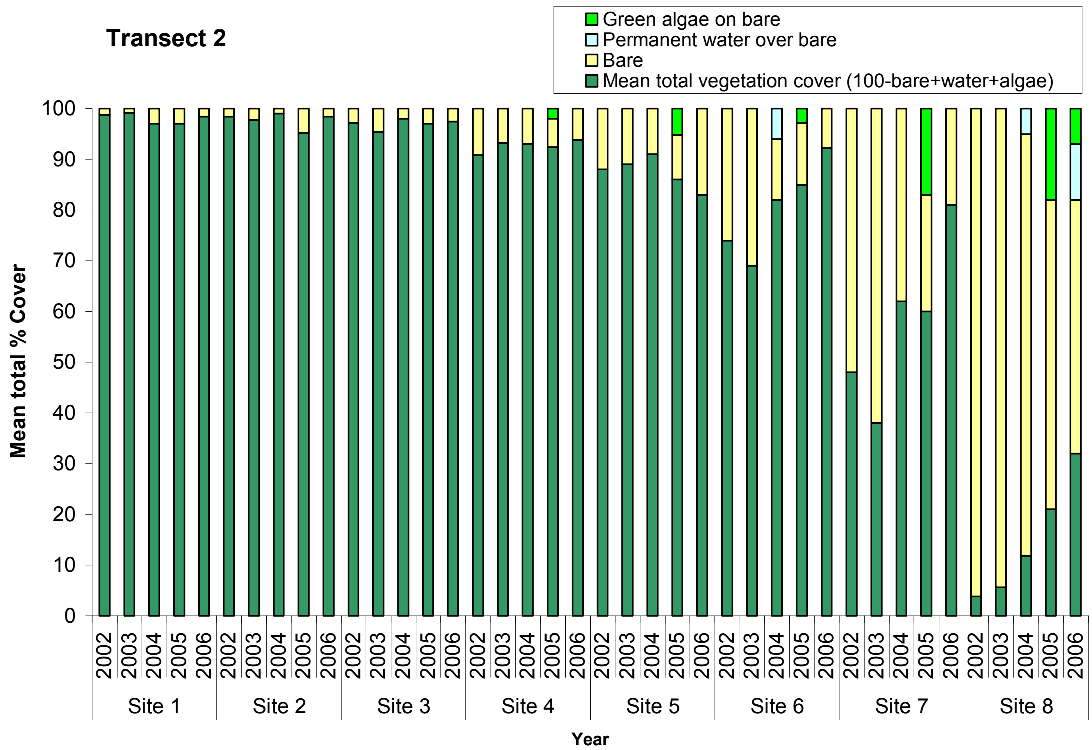


Fig. 5.5. Mean total percentage vegetation ground cover (100-% bare) on Transect 2

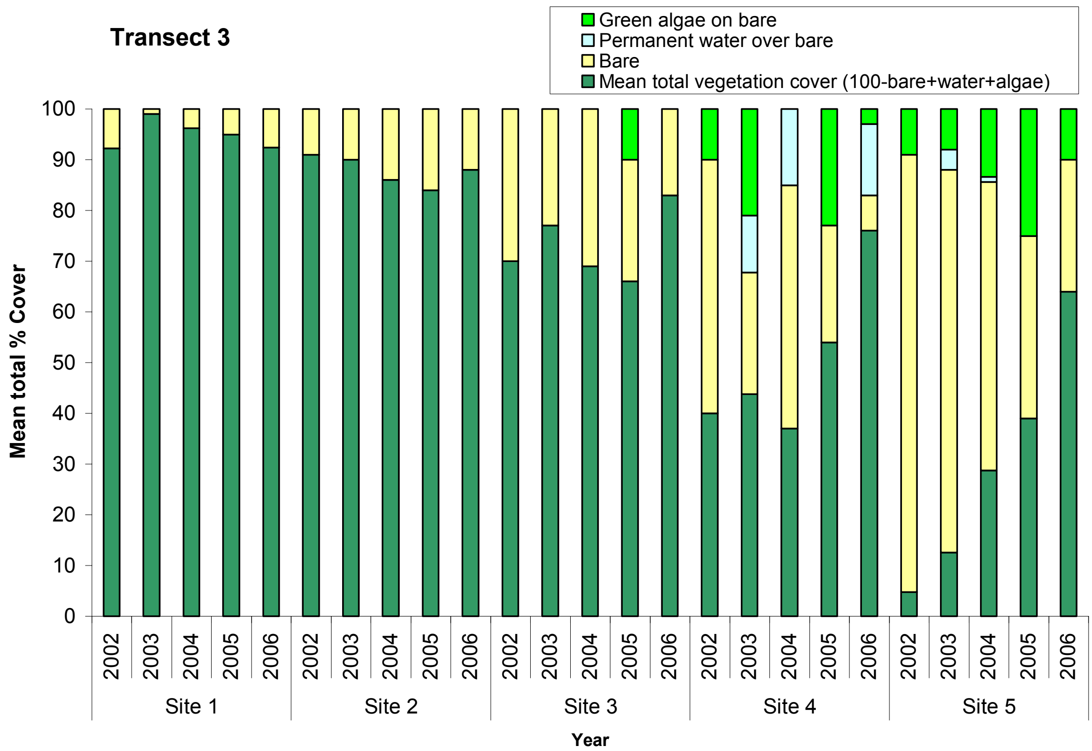


Fig. 5.6. Mean total percentage vegetation ground cover (100-% bare) on Transect 3

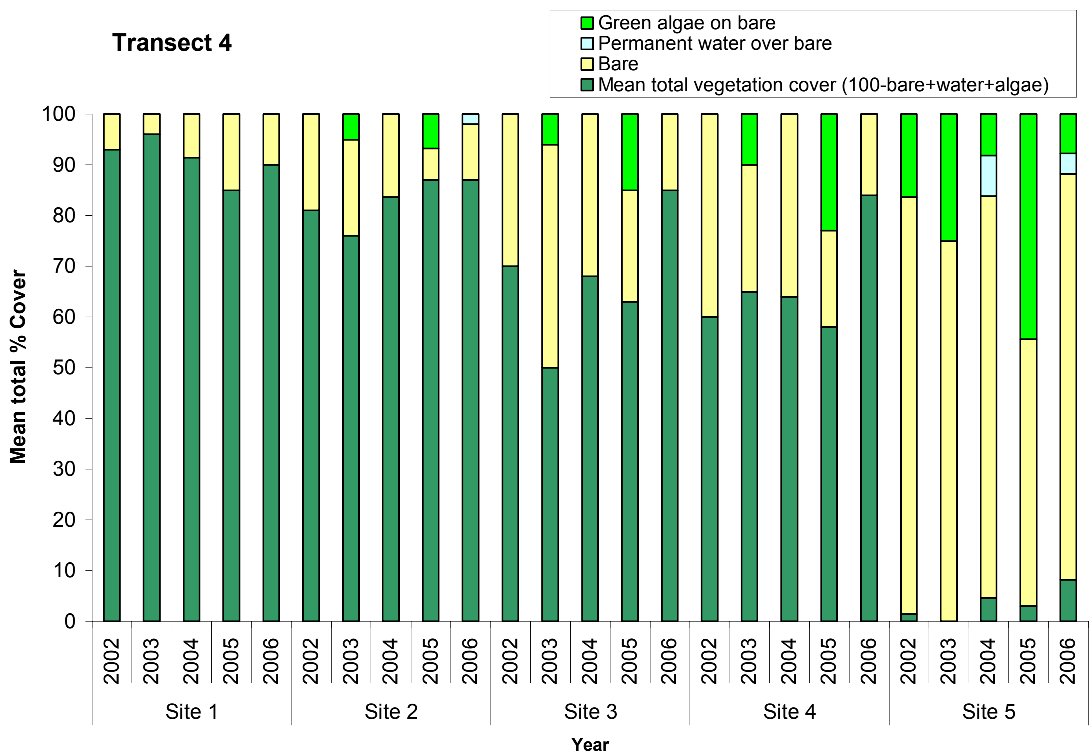


Fig. 5.7. Mean total percentage vegetation ground cover (100-% bare) on Transect 4

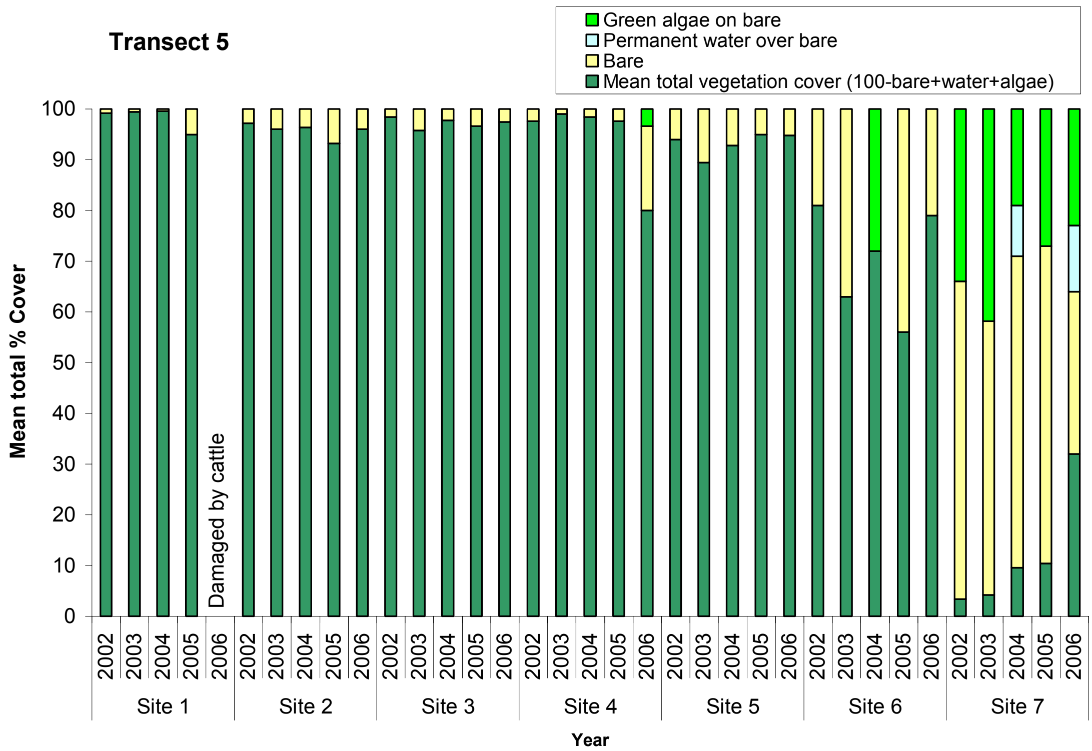


Fig. 5.8. Mean total percentage vegetation ground cover (100-% bare) on Transect 5

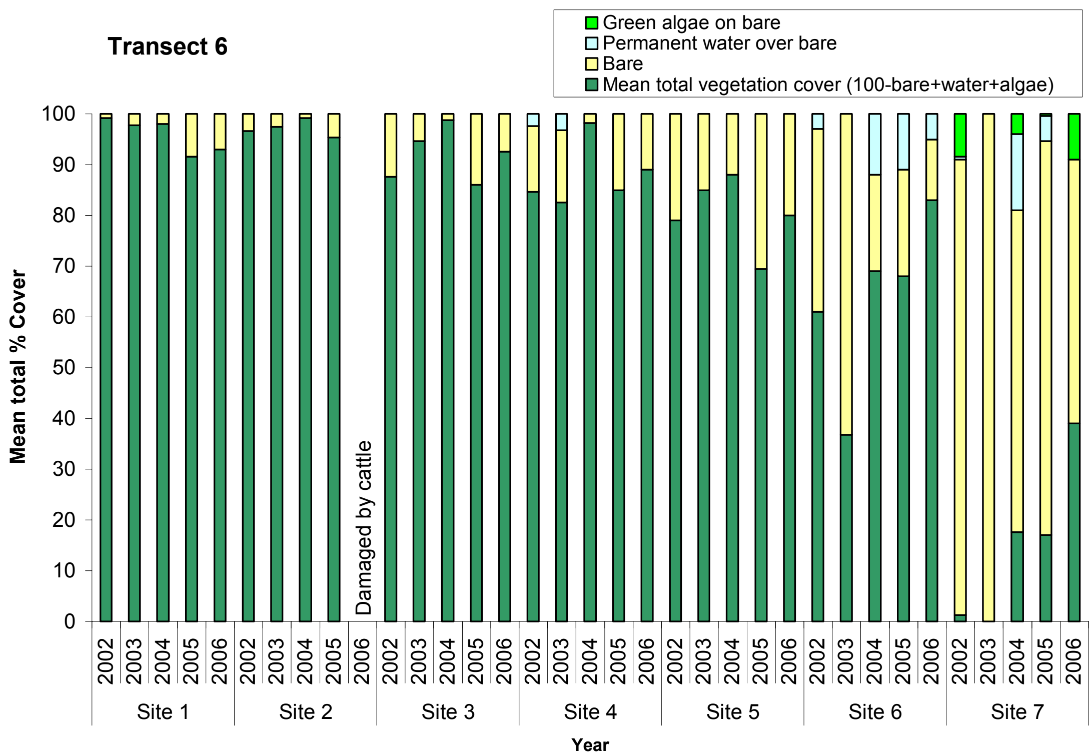


Fig. 5.9. Mean total percentage vegetation ground cover (100-% bare) on Transect 6

5.4.2 5 x 1m^2 Quadrats inside the realignment site: Summary observations on total vegetation ground cover by transect

Mean total percentage vegetation ground cover (100% - bare estimate) inside the realignment site in 2006 is shown in Fig. 5.10. The lowest mean total ground cover was 7.2% at Transect D Site 6 (first colonised in 2006), followed by 39% at TDS4, and the highest 98-99% was found at the top of Transect A (Sites 1-3) in the northwest corner at the highest elevations on the managed realignment.

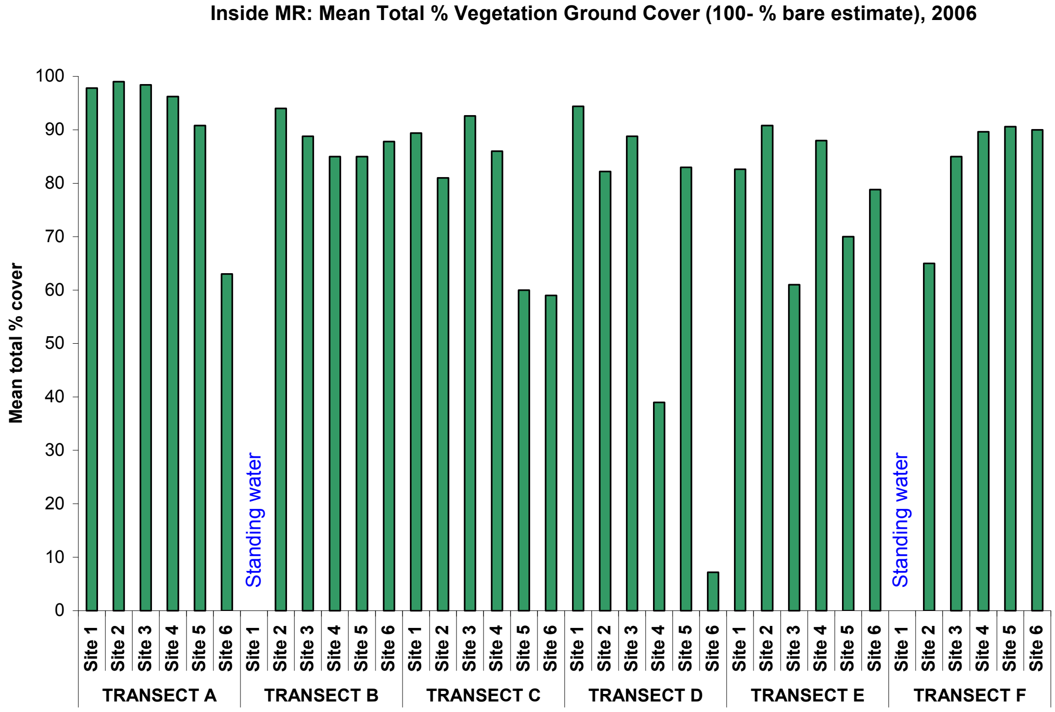


Fig. 5.10. Mean total percentage vegetation ground cover (100 – % bare ground) at sites on Transects A-F inside the realignment in 2006.

Mean total percentage vegetation ground cover for all years on sites inside the realignment is shown in Figs 5.11 to 5.16. Mean total percentage vegetation cover from the sum of individual species estimates is shown in Appendix A5.2.

Apart from sites covered in several centimetres of standing water for all or most of the study period, where conditions were unsuitable for vegetation establishment, vegetation ground cover has increased between 2003 and 2006. By 2006, the lowest mean total percentage vegetation ground cover was 7.2% at TDS6, a site which was first colonised in 2006 after experiencing poor drainage in previous years, followed by 39% at TDS4 (Fig. 5.10). The remaining 32 sites were covered with 60% vegetation or more, of which 25 sites were recorded with over 80% mean vegetation ground cover, and 11 sites had exceeded 90% mean ground cover by 2006. Several sites (particularly in the lower elevation parts of the site, Transect D to F) showed either similar values or a slight decrease in mean total vegetation ground cover in 2005 compared with 2004. Cover estimates were undertaken by two people until an agreement is reached, but are subject to some error (estimated in trials with each surveyor making an independent estimate before discussion to consensus, to be a maximum of 10% at cover values from 35% to 65%; 5% at cover values from 15% to 35% and 6% to 85%; and <5% outside these ranges, down to 1-2% at cover values up to 5% or >95%). However, the observed decrease in total ground cover at some sites between 2004 and 2005 is considered to be real and due mainly to fluctuations in cover by early pioneer annual species, primarily *Salicornia europaea*, which had a much lower cover in 2005 at many sites inside the realignment compared with 2004. At some sites the decrease in *Salicornia europaea* was offset by increases in the annual *Suaeda maritima*, or replacement and spread by perennial species such as *Puccinellia maritima* (particularly at higher sites). This is described later in this chapter.

Vegetation ground cover on Transect A (Fig. 5.11) has increased year on year in sites 1-5, from between 34% and 70% after one year (in 2003) up to between 91% and 99% in September 2006. Site 6 on Transect A was covered in water for the first year and a half after the breach, but has since drained to the creek running behind the old embankment, and cover has increased from 13% in 2004 to 63% by September 2006.

All sites on Transect B (Fig. 5.12), apart from Site 1 which had poor drainage and standing water following spring tides, have increased their ground cover from between 43% and 61% in 2003 to between 85% and 94% in 2006. Sites 4 and 5 had a similar to slightly lower ground cover in 2005 than in 2004.

Transect C (Fig. 5.13) Sites 1-4 increased their ground cover from between 38% and 48% in 2003, up to 81% - 93% in 2006. Site 4 had slightly lower ground cover in 2005 than in 2004. Sites 5 and 6 received a lot of deposited sediment thought to be washed-in from the breach (particularly Site 6, see Chapter on sediments) and site 5 was also poorly drained in the first year (possibly trapped by the deposited sediment in front of this site). These sites had between just 1-3% vegetation ground cover in 2003, but have increased to a ground cover of 60% in 2006.

Transect D (Fig. 5.14) Sites 1-3 increased their ground cover from between 45% and 66% in 2003 to between 82% and 94% in 2006. Site 3 had lower ground cover in 2005 than 2004, as did Site 4, in this case largely due to poor drainage and standing water on the site in 2005, but cover has increased from 25% in 2003 to 39% in 2006. TD Site 5 increased from 37% in 2003 to 83% in 2006, but with lower ground cover (and some water) in 2005 than in 2004. Site 6 on Transect D has had poor drainage, and high sedimentation, but drainage had improved by 2006 and vegetation has started to colonise (7% ground cover).

The first vegetation estimates for Transect E (Fig. 5.15) were made in 2004, when these sites were established. Sites 1, 3, 4, 5,and 6 increased their ground cover from between 53% and 63% in 2004 to 61-88% in 2006, but with lower cover in 2005 compared with 2004 on sites 3, 5 and 6. Site 2 had the highest ground cover on this transect of 80% in 2004, which had increased to 91% in 2006.

Transect F (Fig. 5.16) Site 1 has been submerged by standing water several centimetres deep in all years and so has not developed any vegetation. Sites 2 and 3 have increased their ground cover from 8% and 24% in 2003 to 65% and 85% in 2006, respectively. Sites 4 to 6 have increased in ground cover from between 34% and 46% in 2003 to 90% in 2006. Sites 3, 4, 5 and 6 had lower cover in 2005 than in 2004. The reduced ground cover found at some transects in 2005 compared with 2004 was largely due to a decline in annual *Salicornia europaea* ground cover, and a reduction in size of the annual pioneer plants (discussed later).

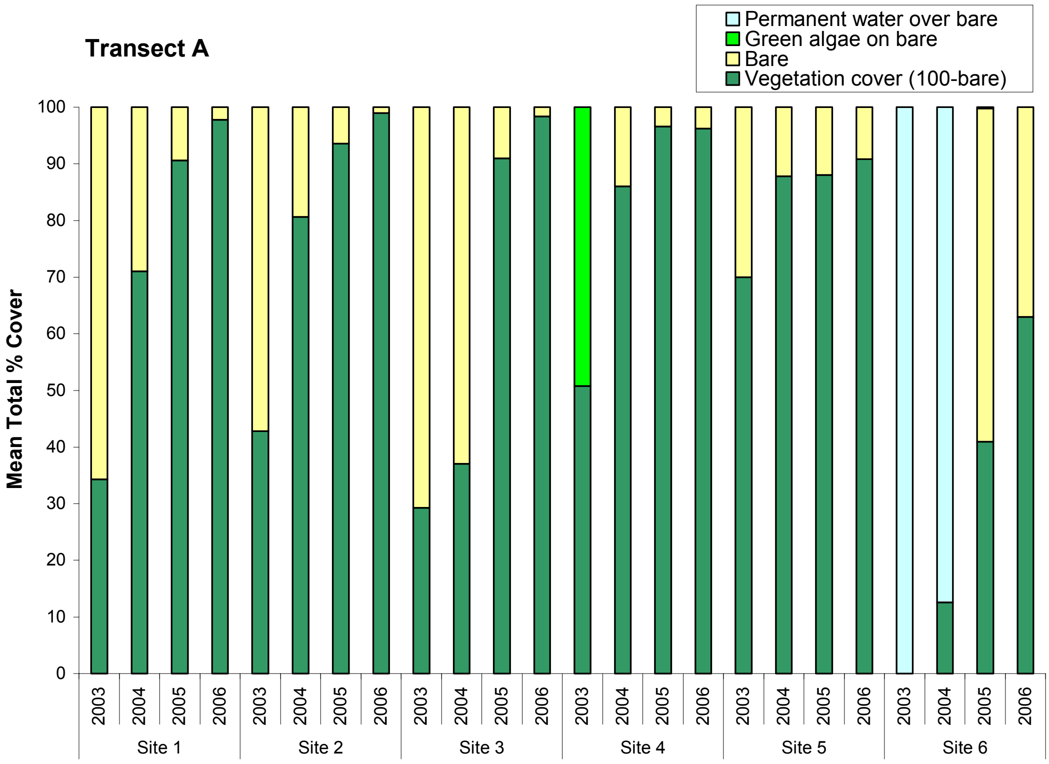


Fig. 5.11. Mean total percentage vegetation ground cover (100-% bare) on Transect A

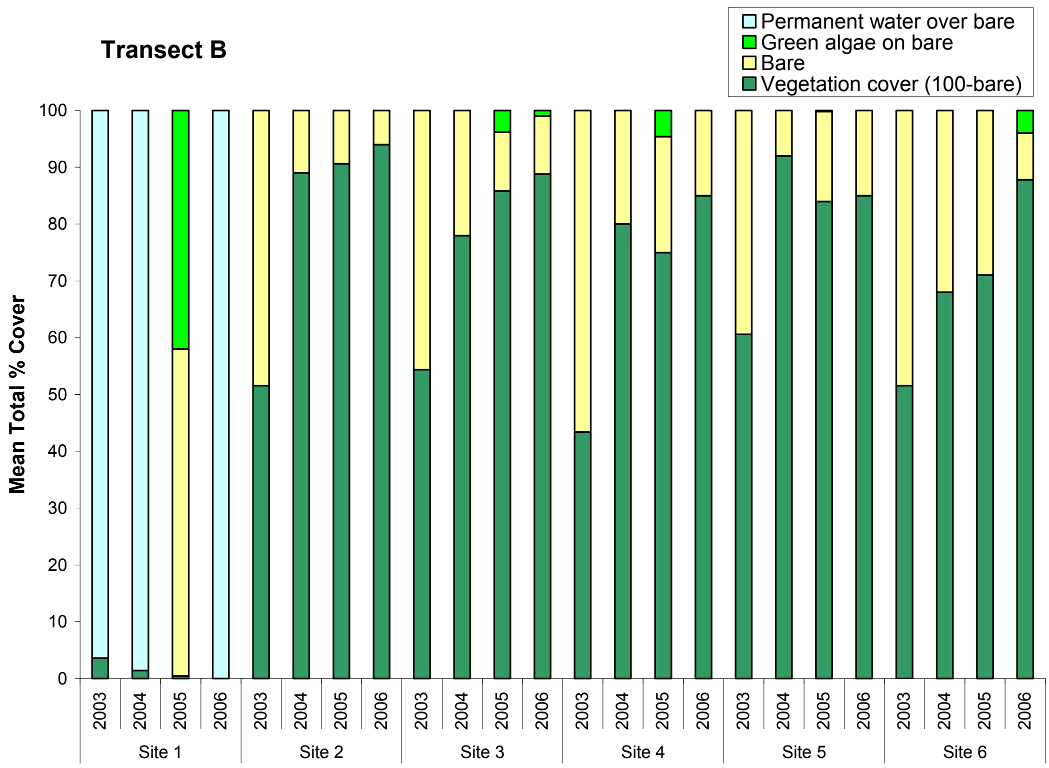


Fig. 5.12. Mean total percentage vegetation ground cover (100-% bare) on Transect B

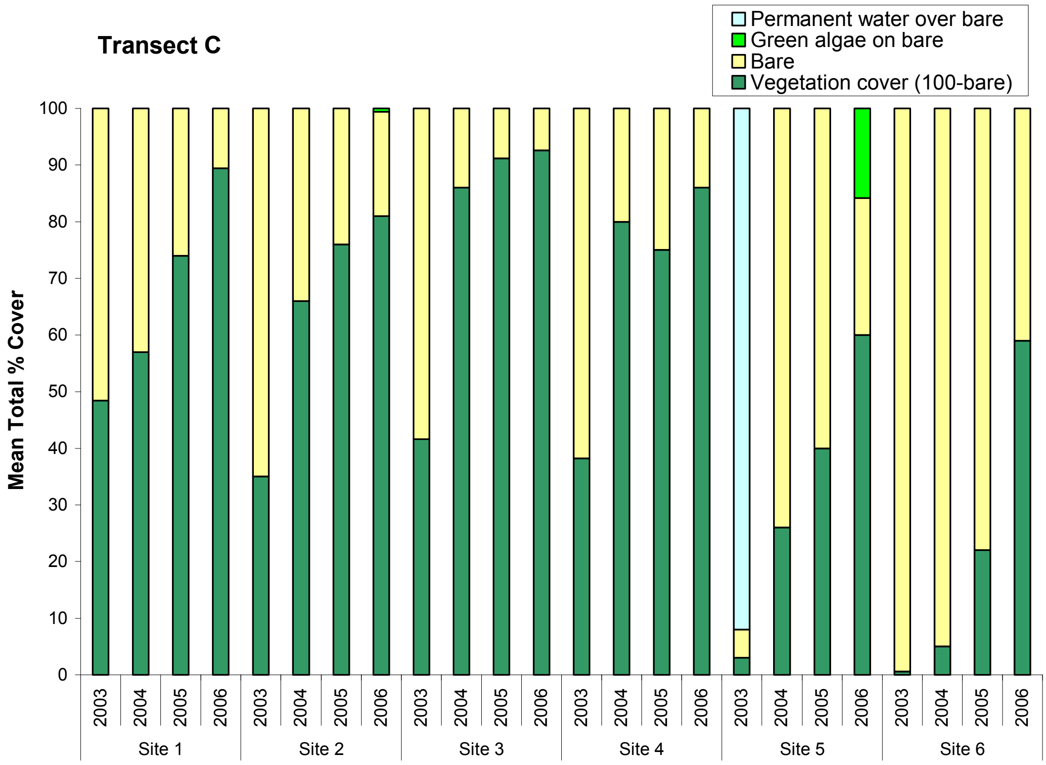


Fig. 5.13. Mean total percentage vegetation ground cover (100-% bare) on Transect C

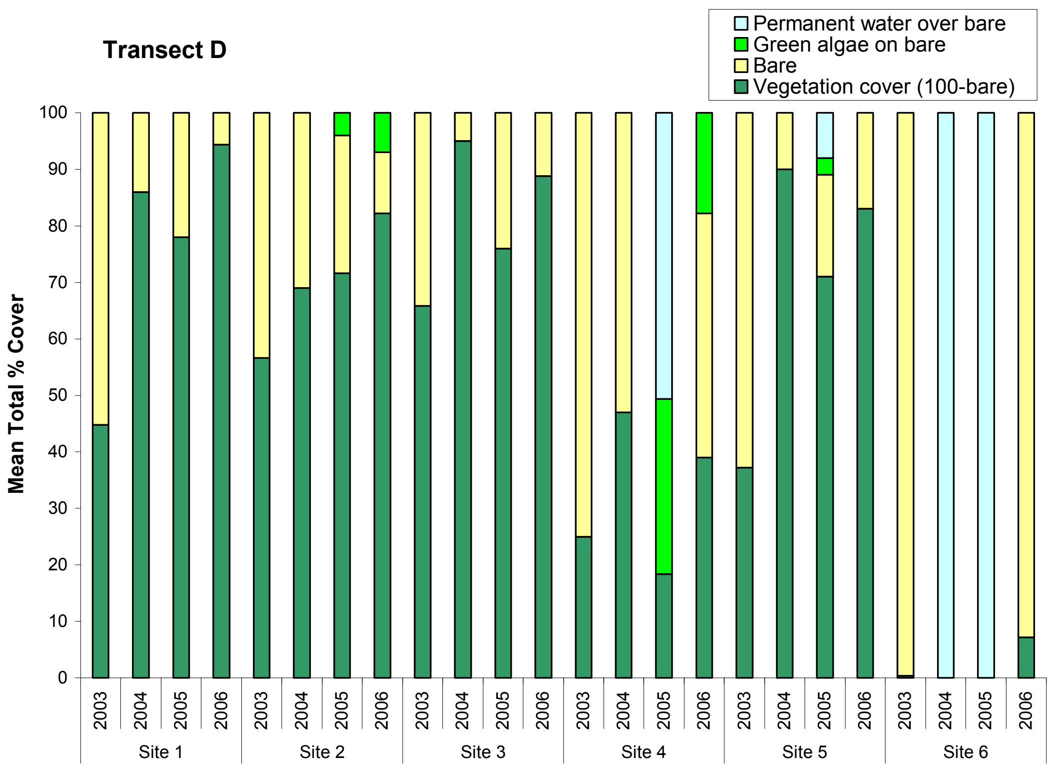


Fig. 5.14. Mean total percentage vegetation ground cover (100-% bare) on Transect D

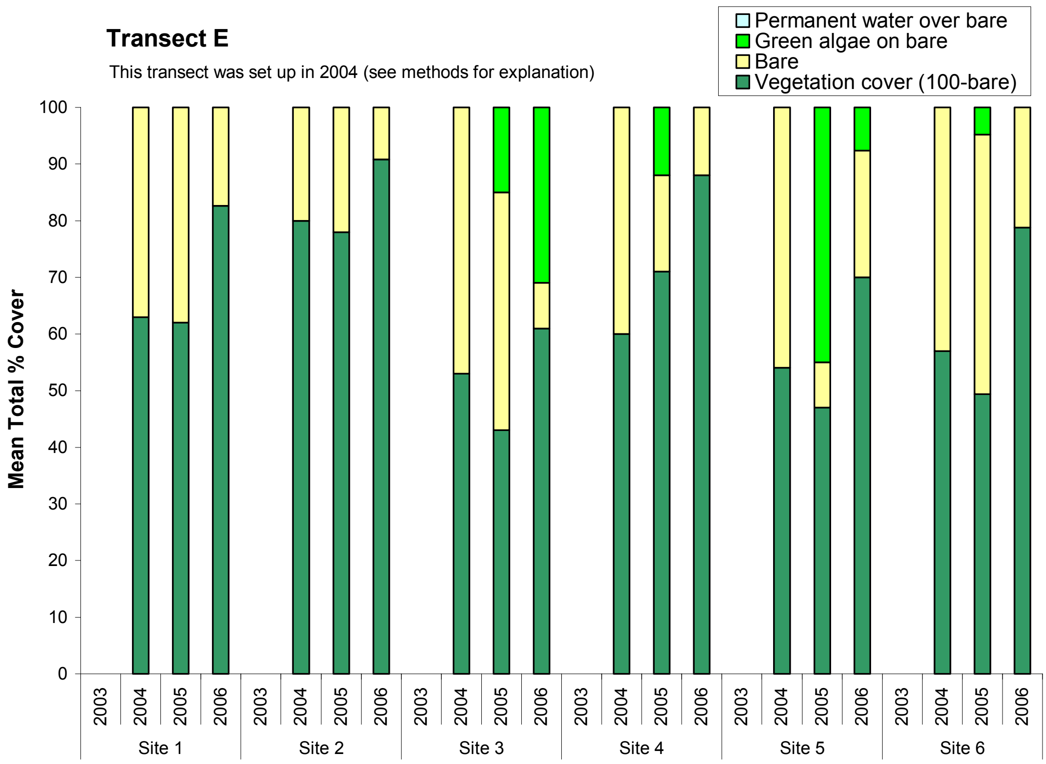


Fig. 5.15. Mean total percentage vegetation ground cover (100-% bare) on Transect E

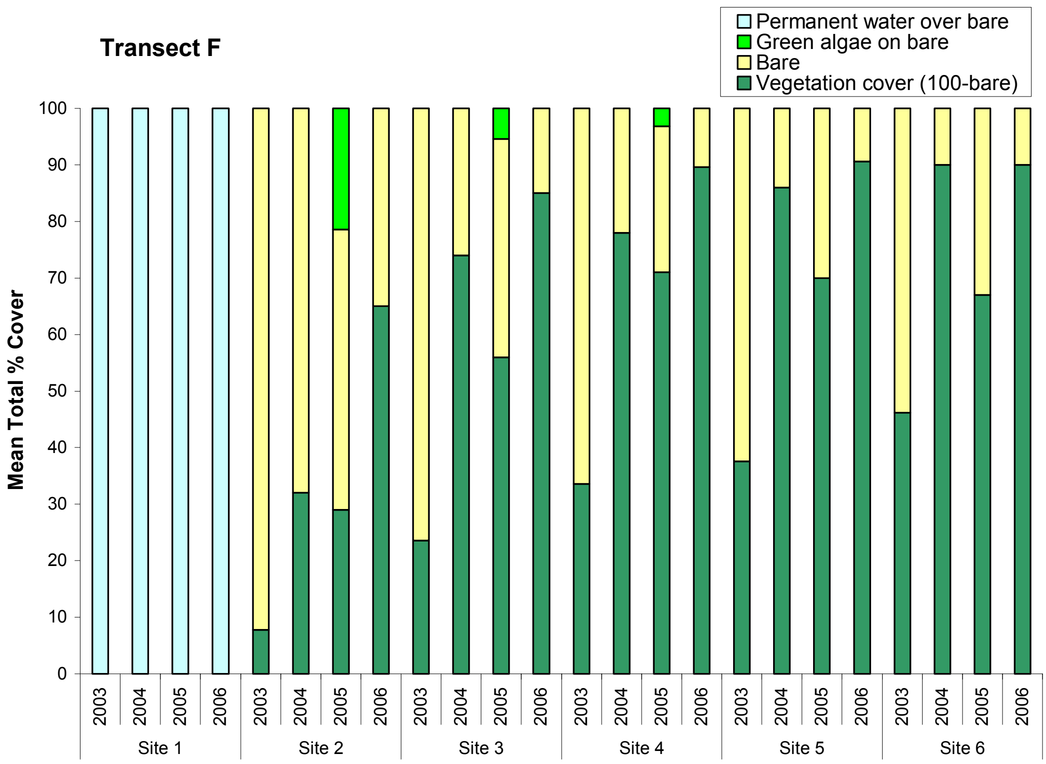


Fig. 5.16. Mean total percentage vegetation ground cover (100-% bare) on Transect F

5.4.3 5 x 1m² Quadrats: Comparison of summary observations on mean total vegetation cover inside and outside the realignment at the equivalent elevation range

Elevation is a key factor for vegetation establishment, and therefore is the most useful category for comparison of vegetation cover and species composition between the realignment site and the salt marsh outside. All of the realignment sites lie at an elevation suitable for salt marsh vegetation to grow, and the sampling sites are at elevations between 2.7 to 3.3mODN (as measured in 2005). Sites on transects outside the MR lie between approximately 2.1 and 3.3mODN. Later in this chapter, mean percentage total vegetation cover and mean percentage cover of the component species are compared by grouping the data into different elevation range categories within the overall range.

First, a summary comparison of mean total vegetation over the years of study between all sites inside the realignment, and sites outside in the same elevation range (i.e. 2.7-3.3mODN) is shown in Fig. 5.17. These data were compiled from mean total values calculated from the sum of species cover (explained previously).

The mean total vegetation cover of sites outside the realignment site (2.7-3.3mODN) varied between 95% and 97% over 5 years of monitoring. Mean total cover has increased inside the site from 35% in 2003 to 81% in 2006.

Fig 5.18 shows the same comparison but without the two sites in the realignment which have yet to develop any vegetation as they have been covered in standing water. Mean total cover has increased from 37% in 2003 to 86% in 2006.

If vegetation spread continues to increase at a rate similar to that observed between 2004 and 2006, a cover value close to that outside in the same elevation range is predicted to be reached between 2008 and 2010, excluding the flooded sites. However, it may take longer for the realignment site to reach equivalent vegetation community composition.

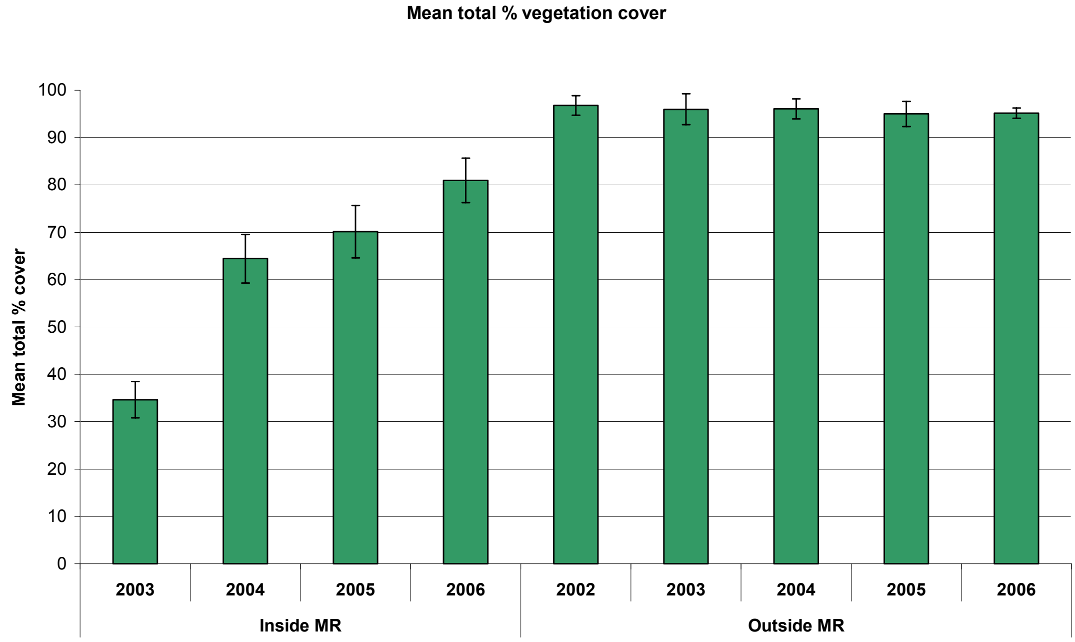


Fig. 5.17. Mean total percentage vegetation cover inside and outside the managed realignment site at the equivalent elevation range (2.7-3.3mODN) ±SE. No. of sites inside MR: 30 (2003) and 36 (2004-6). No. of sites outside MR: 26 (out of 38). Values are calculated from additions of individual species cover (i.e. not from 100%-bare)

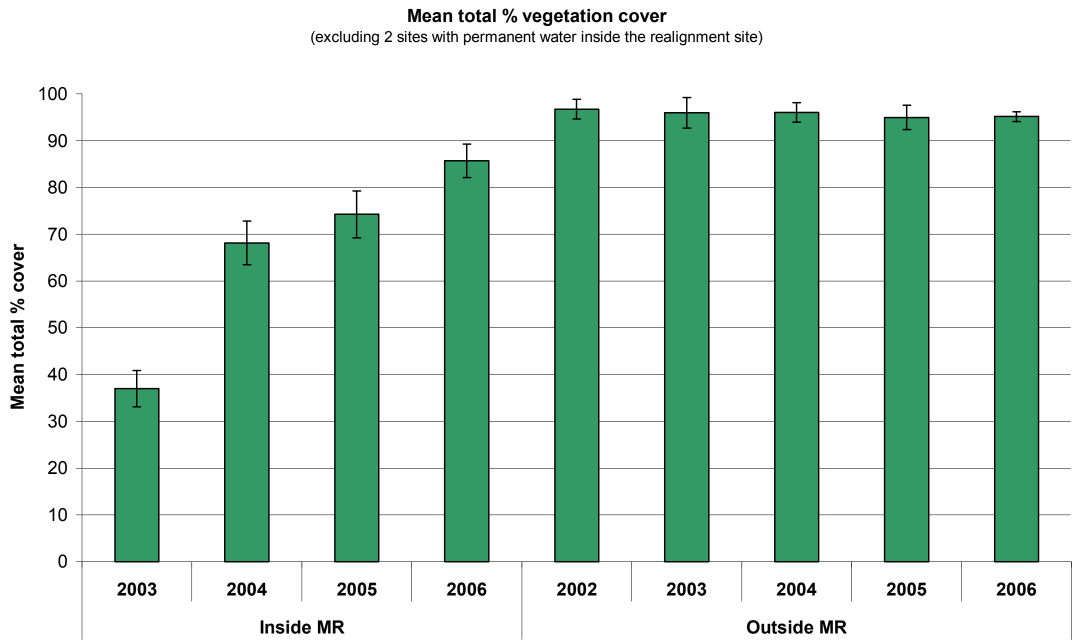


Fig. 5.18. Mean total percentage vegetation cover inside and outside the managed realignment site at the equivalent elevation range (2.7-3.3mODN) ±SE, excluding 2 sites in the realignment with permanent water cover (TBS1, TFS1). No. of sites inside MR: 28 (2003) and 34 (2004-6). No. of sites outside MR:

26 (out of 38). Values are calculated from additions of individual species cover (i.e. not from 100%-bare)

5.4.4 5 x 1m^2 Quadrats: Comparison of summary observations on mean total vegetation cover, inside and outside the realignment according to elevation range categories

Site elevations were divided into sub-categories within the total range in order to compare total vegetation cover inside and outside the realignment in more detail. The total vegetation cover was calculated from the sum of individual species cover. The summary means for the total vegetation cover in different categories are shown in Table 5.1, for the full range of the realignment site (2.7-3.3mODN); for this range split into two categories: 2.7-2.99mODN (<3mODN) and 3.0-3.3mODN; and also with the upper elevation range split into two sub categories: 3.0-3.15mODN and 3.16-3.3mODN. The sites were set up before the elevations could be measured, but they cover an even spread over the range (mean and median values were very close, shown in Fig. 5.19), and there was generally a very close agreement between mean and median elevations inside and outside the realignment. The largest difference was in the lower half of the elevation range at sites between 2.7-2.99mODN, where sites in the realignment have a mean elevation of 6cm higher (measured in 2005) than those in this range outside on the salt marsh. In higher elevation categories, the difference between means was just 1-2cm, and within the standard error of the means.

Fig. 5.20 shows the mean total percentage vegetation cover inside and outside the realignment (excluding standing water sites), divided into three category ranges. Mean values including the two standing water sites are also given in Table 5.1. As noted previously, there are no sites below 2.7mODN inside the realignment.

Outside on the pioneer salt marsh at <2.7mODN mean total vegetation cover has increased each year since the start of the programme, reaching 61% in 2006.

In the lower half of the elevation range inside the realignment (2.7-2.99mODN), the vegetation cover has increased to 72% in 2006, slightly higher than the value for the lowest category (<2.7mODN) outside, but still lower than the cover for the 2.7-2.99mODN elevation category outside, which was 93% in 2006. Including the flooded site at TFS1 in this elevation range, the mean total vegetation cover in 2006 was 66%.

Between 3.0-3.3mODN, mean total percentage vegetation cover inside the site had reached 92% by 2006 (89% including the flooded site at TBS1) compared with 97% outside on the salt marsh in this elevation range.

The higher category (3.0-3.3mODN) was sub-divided into two categories: 3.0-3.15mODN, and 3.16-3.3mODN, shown in Fig. 5.21 (4 category ranges). Between 3.0-3.15mODN, the mean total percentage vegetation cover inside the realignment had increased to 87% by 2006 (80% including flooded site TBS1), compared with 97% outside the realignment in this range. Vegetation spread inside the realignment was most rapid at the higher elevation category (3.16-3.3mODN), reaching a mean total percentage value of 98% by 2005 (and the same in 2006) which was the same value as cover outside on the salt marsh in this elevation range.

The mean total percentage vegetation data from inside the managed realignment is shown as a line plot in Fig. 5.22, for easier comparison of the rates of vegetation spread. This shows clearly the consistently highest rate of growth in the upper elevation category (3.16-3.3mODN), reaching 98% by 2005, followed by the middle (3.0-3.15mODN) then lower range (2.7-2.99mODN) categories. The mean total cover value for the middle category levelled off between 2004 and 2005, and decreased slightly in the lowest range. This was due mainly to a significant decrease in the annual *Salicornia europaea* cover between these two years, and the change in the size of these and *Suaeda maritima* plants (discussed later), but both range categories increased in vegetation cover again between 2005 and 2006.

Table 5.1. Summary means for total percentage vegetation cover in the 5x1m^2 quadrats, by elevation category

Category	No. of Sites ( )=sites in 2003*	ELEVATION (mODN) MEAN	MEDIAN	MEAN TOTAL % VEGETATION COVER (from sum of species cover) 2002	2003	2004	2005	2006
INSIDE MR:								
Whole range: 2.7-3.3mODN	36 (30)	3.067	3.080		34.6	64.4	70.1	80.9
2.7- <3.0mODN	12 (9)	2.920	2.935		22.9	51.5	48.1	65.7
3.0-3.3mODN	24 (21)	3.141	3.130		39.6	70.9	81.2	88.6
3.0-3.3mODN divided into 2 categories:								
3.0-3.15mODN	13 (11)	3.080	3.080		36.3	66.4	67.3	80.4
3.16-3.3mODN	11 (10)	3.213	3.210		43.3	76.2	97.5	98.2
Excluding 2 sites with standing water:								
Whole range: 2.7-3.3mODN, excluding TBS1, TFS1	34 (28)	3.069	3.080		37.0	68.1	74.2	85.7
2.7- <3.0mODN, excluding TFS1	11 (8)	2.916	2.930		25.8	56.1	52.5	71.7
3.0-3.3mODN, excluding TBS1	23 (20)	3.141	3.130		41.4	73.9	84.7	92.4
3.0-3.15mODN, excluding TBS1	12 (10)	3.076	3.080		39.6	71.8	72.9	87.1
OUTSIDE MR:								
2.7-3.3mODN (= range in MR)	26	3.010	2.990	96.8	95.9	96.0	95.0	95.2
<2.7mODN (no equivalent in MR)	12	2.483	2.550	33.8	32.5	40.2	42.4	60.9
2.7- <3.0mODN	13	2.859	2.830	90.6	88.2	89.7	88.0	93.4
3.0-3.3mODN	13	3.160	3.160	103.0	103.6	102.4	101.9	97.2
3.0-3.3mODN divided into 2 categories:								
3.0-3.15mODN	6	3.070	3.060	101.2	105.5	102.4	102.7	96.6
3.16-3.3mODN	7 (5,2006)†	3.237	3.260	104.5	102.0	102.4	101.3	97.9

Notes: * No. of sites: ( ) = before Transect E was established
† 2 sites outside MR damaged by cattle in 2006

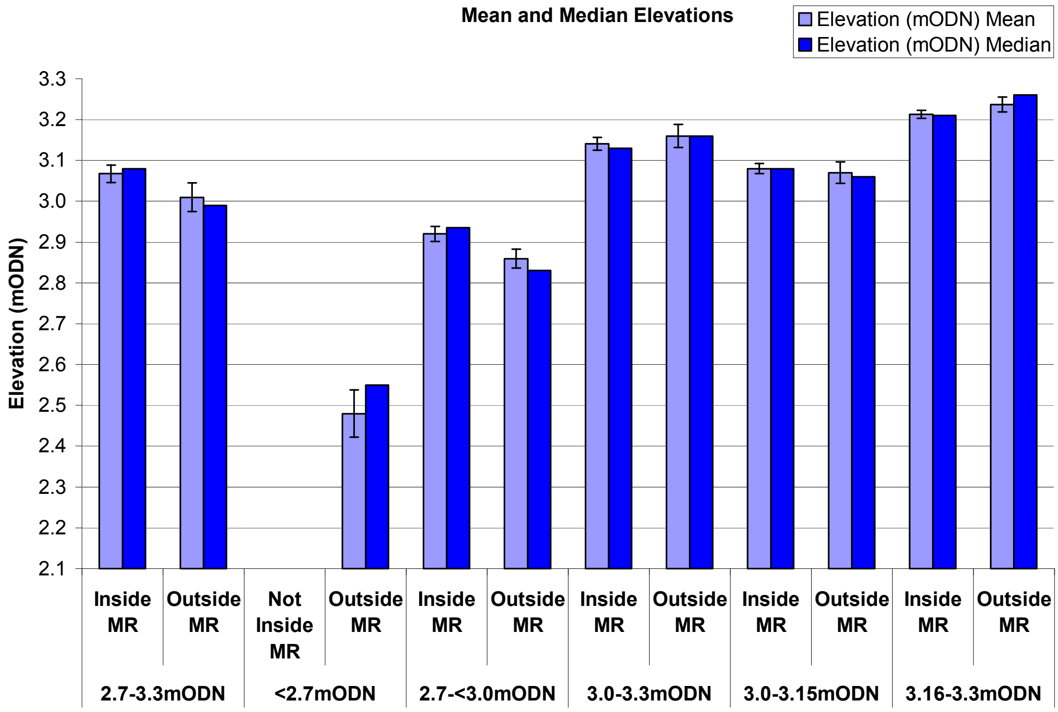


Fig. 5.19. Mean (±SE) and median elevations for different elevation categories inside and outside the managed realignment site

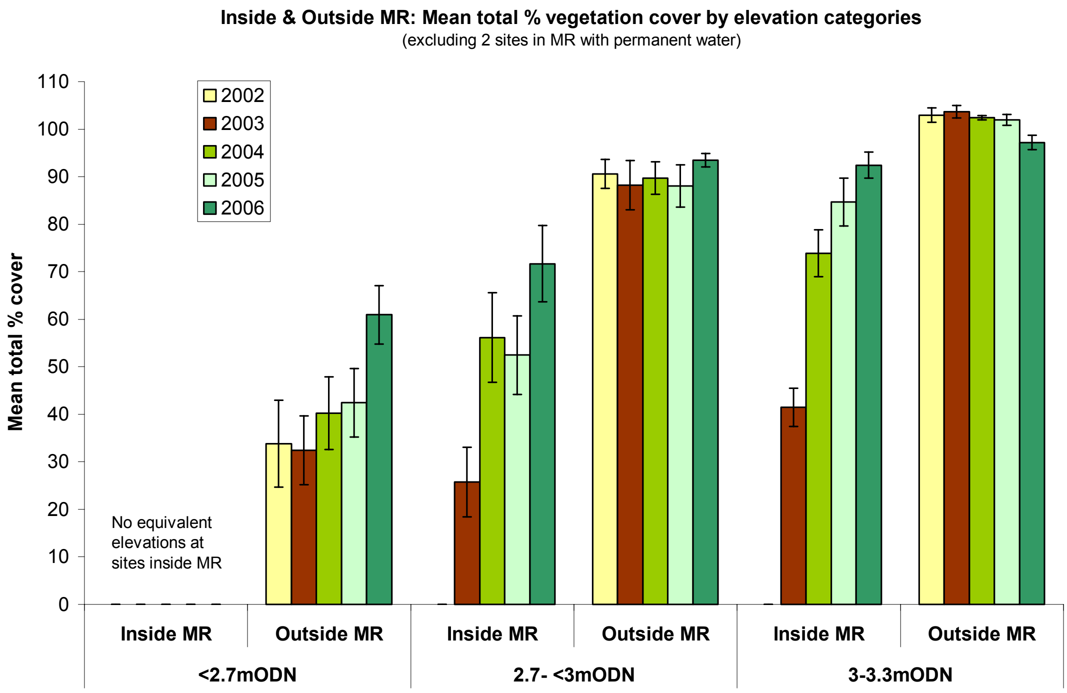


Fig. 5.20. Mean total percentage vegetation cover inside and outside the managed realignment site at different elevation ranges ±SE. Values are calculated from sum of individual species cover. No. of sites (n) inside MR: 2.7- <3mODN, n=12 (9 in 2003); 3-3.3mODN, n= 24 (21 in 2003); outside MR: <2.7mODN, n=12; 2.7- <3mODN, n= 13; 3-3.3mODN, n= 13.

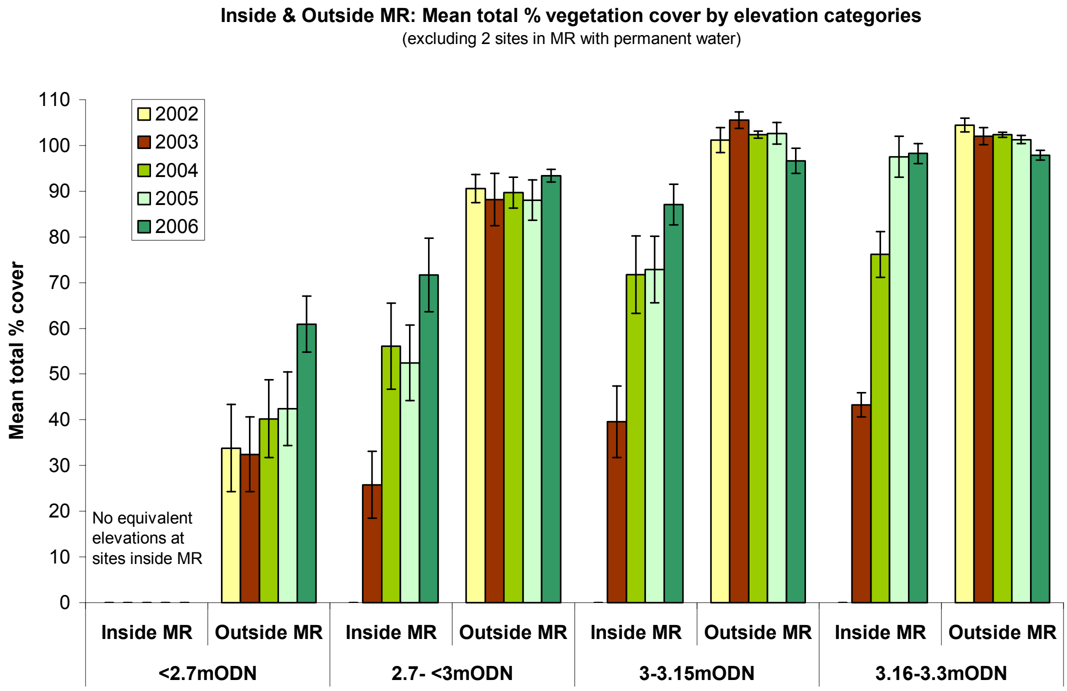


Fig. 5.21. Mean total percentage vegetation cover inside and outside the managed realignment site at different elevation ranges ±SE. Values are calculated from sum of individual species cover. No. of sites (n) inside MR: 2.7- <3mODN, n=12 (9 in 2003); 3-3.15mODN, n= 13 (11 in 2003); 3.16-3.3mODN, n=11 (10 in 2003); outside MR: <2.7mODN, n=12; 2.7- <3mODN, n= 13; 3-3.15mODN, n= 6; 3.16-3.3mODN, n= 7 (5 in 2006 due to cattle damage).

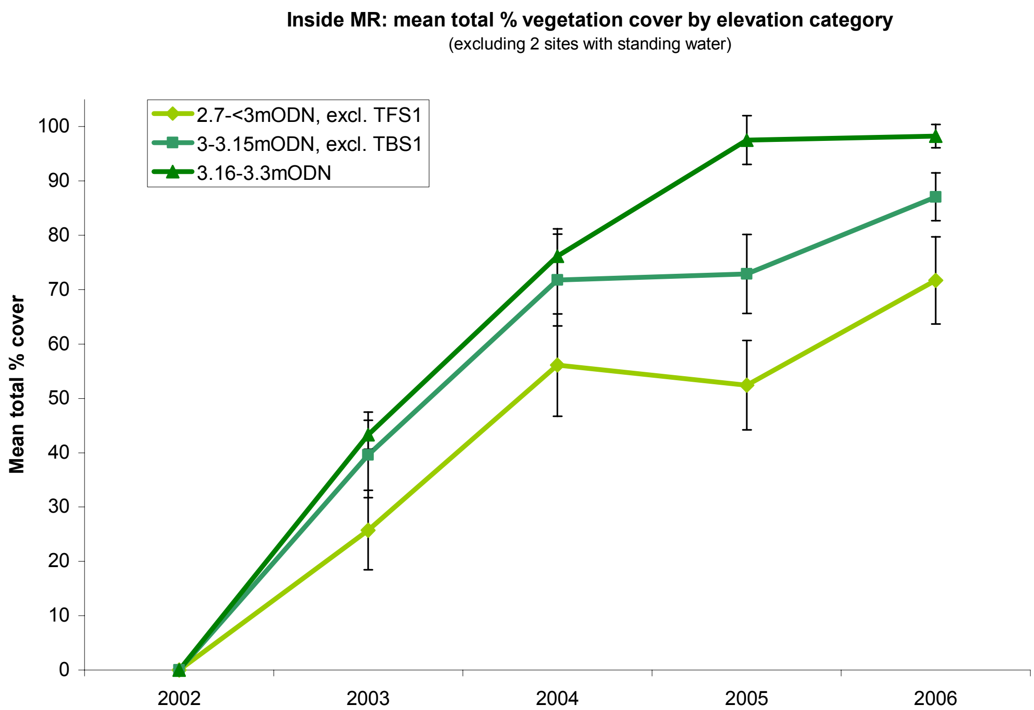


Fig. 5.22. Line plot of mean total percentage vegetation cover by elevation category inside the managed realignment site

5.4.5 5 x 1m^2 Quadrats: Number of species inside and outside the realignment according to elevation

The salt marshes around the Wash are relatively low in species diversity and the marshes have no gently sloping upper salt marsh transition zones, due to the truncation by high grassy embankments that provide flood defence.

All of the species found on the salt marsh adjacent and in front of the realignment site, except for one (*Triglochin maritima*) had been seen inside the realignment site by 2006. As absence of evidence is not evidence of absence, the unrecorded *T. maritima* may be present as a rare occurrence. All of the abundant species outside the realignment have been found inside the managed realignment monitoring quadrats. The most common were the annuals *Salicornia europaea* (Common Glasswort) and *Suaeda maritima* (Annual Sea-blite), important colonisers of the pioneer zone and which were the dominant species inside the realignment in the first year; the perennials *Puccinellia maritima* (Common Saltmarsh-grass), *Atriplex portulacoides* (Sea purslane) and *Spartina anglica* (Common Cord-grass), and the biennial (sometimes annual) *Aster tripolium* (Sea Aster), all found occasionally with low cover in 2003 and which have all increased in the realignment since. The grass *Elytrigia atherica* (Sea Couch) established in small amounts inside the realignment at the highest points in 2003 and has spread into a large patch near the northwestern end, with numerous smaller patches colonising the northwestern part of the site in 2005 and 2006. This grass is now more common inside the realignment site than outside, except on and at the base of the old breached embankment in front of the realignment site which is fenced off from cattle. It is not common at the base of the embankment north and south of the realignment site, presumably because of cattle trampling and grazing in these areas.

Species found less frequently on the Freiston salt marshes than the most abundant species listed above, but which have been monitored in the realignment site quadrats since 2003 include the Greater and Lesser Sea-spurreys *Spergularia media* and *Spergularia marina* (*S. marina* was not found in the quadrats after 2003, and is confined to upper patches of more open ground), and *Atriplex prostrata* (Spear-leaved Orache) found in two of the 5m x 5m quadrats, until 2004. *Cochlearia sp.* (Scurvy-grass) is common at the back of the realignment site between the upper quadrat sites (Sites 1 on each transect) and the back fence. Two species, *C. anglica* (English Scurvy-grass) and *C. officinalis* (Common Scurvy-grass) occur in this area of the Wash, although we have not distinguished between them in the surveys as small non-flowering specimens found sometimes under other vegetation were difficult to differentiate. *Sarcocornia perennis* was seen occasionally in the realignment site by 2006 and two specimens were found in the realignment site quadrats in 2006. *Plantago maritima* (Sea Plantain) and *Limonium vulgare* (Sea Lavender) occur occasionally on the outside salt marsh (locally common in places) and have also been found occasionally along the back of the realignment site between the upper quadrat sites and the back fence. Sea Wormwood (*Artemisia maritima*) occurs on an elevated mound between the embankment and Transect 1 Site 1 north of the realignment, and has also been found in the northwest corner below the car park on the embankment near the upper driftline of high spring tides which lies outside the realignment fence.

A total of 16 species have been recorded in the managed realignment (including the two species for *Cochlearia* and the *Artemisia maritima* just outside the fence in the northwest corner). The only other species found only rarely outside on the salt marsh here, but which has yet to be noted in the realignment site is *Triglochin maritima* (Sea Arrow-grass).

Festuca rubra (Red Fescue) is found in higher areas of salt marsh close to the zone occupied by other high marsh species such as *Elytrigia atherica* but this zone is generally truncated in this area of the Wash by the flood defence embankments. It may occur occasionally along a very narrow strip close to the embankment base, but if it does, it is not common at the back of the Freiston marsh (no patches of *F. rubra* found) and it has not been noted in the realignment site.

Up to eleven species were recorded in the quadrats inside the realignment site between 2003 and 2006, varying slightly between years (2003: 9 species, 2004: 8, 2005: 9; 2006: 10). *Spergularia marina* was only recorded in upper bare areas in 2003 in the realignment site and was not found subsequently. Nine species were recorded in the quadrats outside the realignment site in all years. Of the nine species, the seven most abundant species were common inside many of the MR quadrats: *Aster tripolium*, *Atriplex portulacoides*, *Puccinellia maritima*, *Salicornia europaea*, *Spartina anglica*, *Spergularia media* and *Suaeda maritima*.

The mean number of species (and range) found in the permanent quadrats outside and inside the realignment at different elevation range categories is shown in Table 5.2. This table gives the values inside the realignment for all quadrats, but also shows the values when the permanently flooded sites were excluded as these lower the mean values. The data are also shown graphically in Figures 5.23 to 5.27, for values excluding the flooded sites in the MR and are described for this condition.

The mean number of species (and range) found outside and inside the realignment at the elevation range of the realignment quadrats (2.7-3.3mODN) is shown in Fig. 5.23.

Outside the realignment site, between 2.7-3.3mODN the mean number of species recorded in the quadrats fluctuated between 5.46 and 5.77. Inside the realignment, mean species number has increased from 4.39 and 4.26 in 2003 and 2004 respectively to 5.71 in 2006, close to the mean value for the adjacent marsh. Therefore by 2006, the mean species number in the realignment site was equivalent to that outside (although the minimum and maximum range was still lower inside than outside). The lower value in 2006 outside the realignment (compared with 2004 and 2005) does not represent a real loss of species but was due to the loss of two sites at the upper part of the marsh to cattle damage.

Figures 5.24 to 5.27 show the comparison of mean species number inside the realignment and outside in sub-categories of the elevation range, to show where most species were found.

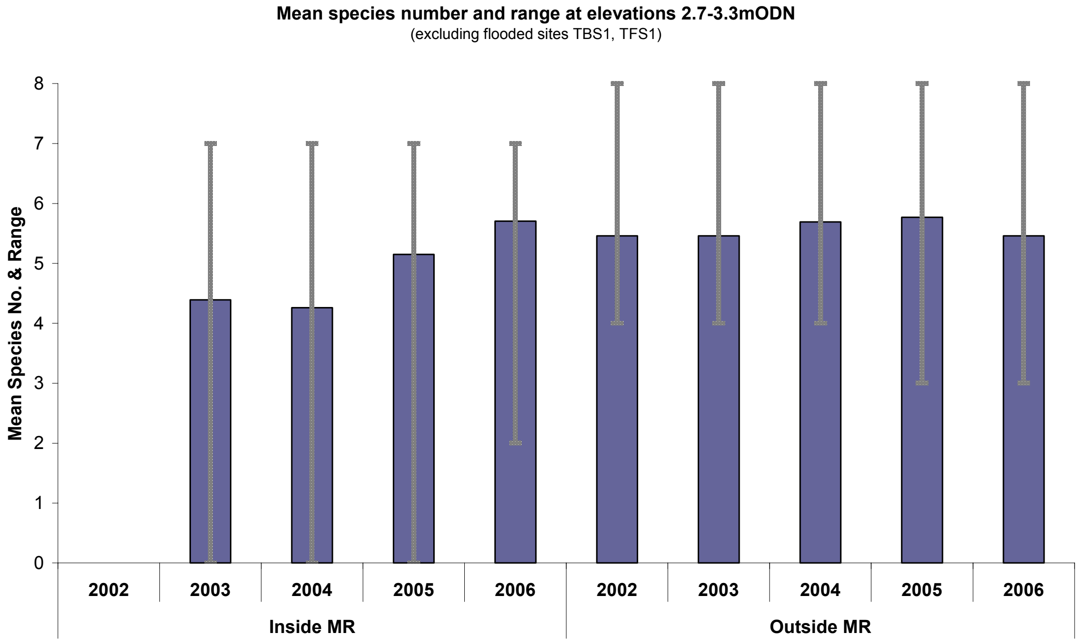


Fig.5.23. Mean species number in the realignment site and outside at the equivalent elevation range

Below 2.7mODN on the salt marsh front and pioneer zone (no equivalent in the realignment) where vegetation cover has increased over the five years of monitoring, the mean number of species has increased from 2.0 in 2002 to 4.42 in 2006 (Fig. 5.24).

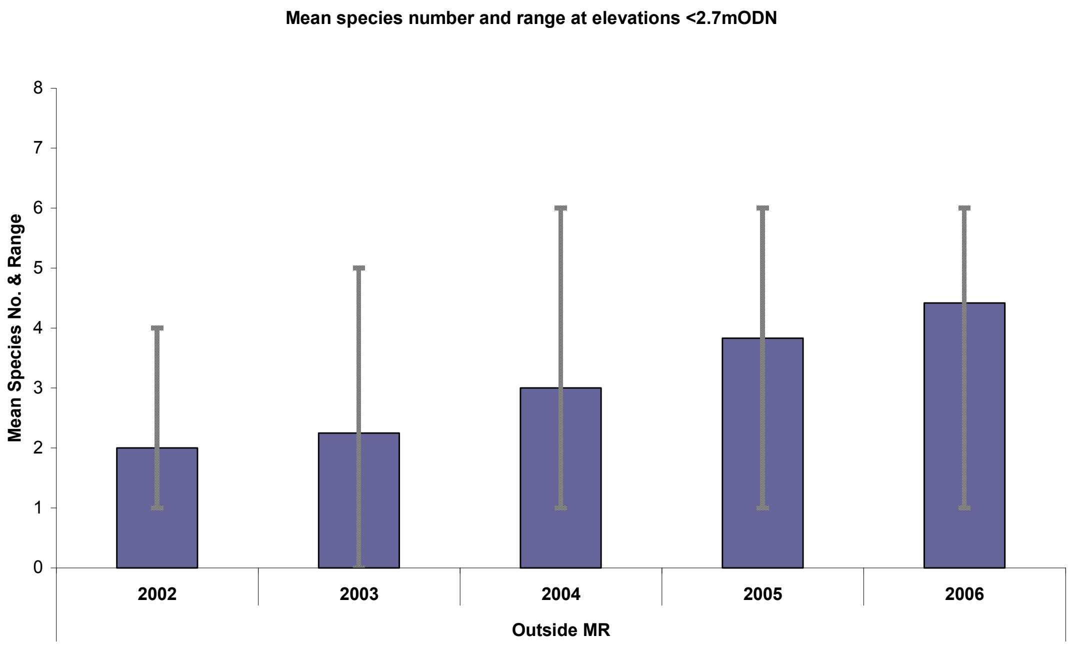


Fig. 5.24. Mean species number on the salt marsh outside the realignment at elevation <2.7mODN

Table 5.2. Mean plant species number according to elevation category

Mean vascular plant species number (and range) in different elevation categories

	OUTSIDE MR					**INSIDE MR**				**INSIDE MR, excluding flooded sites TBS1, TFS1**			
	2002	**2003**	**2004**	**2005**	**2006**	**2003**	**2004**	**2005**	**2006**	**2003**	**2004**	**2005**	**2006**
Elevation Range													
Full range in realignment: 2.7-3.3mODN	5.46 (4-8)	5.46 (4-8)	5.69 (4-8)	5.77 (3-8)	5.46 (3-8)	4.10 (0-7)	4.08 (0-7)	4.89 (0-7)	5.39 (0-7)	4.39 (0-7)	4.26 (0-7)	5.15 (0-7)	5.71 (2-7)
<2.7mODN	2.00 (1-4)	2.25 (0-5)	3.00 (1-6)	3.83 (1-6)	4.42 (1-6)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2.7-2.99mODN	5.31 (4-8)	5.38 (4-7)	5.77 (4-8)	6.15 (5-8)	6.00 (3-8)	2.56 (0-5)	2.58 (0-5)	3.67 (0-5)	4.67 (0-7)	2.88 (0-5)	2.82 (0-5)	4.00 (0-5)	5.09 (2-7)
3.0-3.3mODN	5.62 (4-7)	5.69 (4-8)	5.62 (3-8)	5.38 (3-8)	4.91 (3-7)	4.76 (1-7)	4.75 (2-7)	5.50 (1-7)	5.71 (0-7)	4.90 (1-7)	4.87 (2-7)	5.70 (4-7)	5.96 (5-7)
Upper range divided into 2 sub-categories:													
3.0-3.15mODN	5.83 (4-7)	5.67 (5-7)	5.83 (4-7)	5.50 (4-7)	5.50 (4-7)	3.91 (1-6)	4.15 (2-6)	5.00 (1-7)	5.38 (0-7)	4.10 (1-6)	4.33 (2-6)	5.33 (4-7)	5.83 (5-7)
3.16-3.3mODN	5.43 (4-7)	5.43 (4-8)	5.43 (3-8)	5.29 (3-8)	4.20 (3-6)	5.70 (4-7)	5.46 (4-7)	6.27 (5-8)	6.18 (5-7)	N/A	N/A	N/A	N/A

Note: The apparent decrease in mean species number and range outside the realignment in the highest elevation category (3.16-3.3) in 2006 is mainly due to the loss of 2 out of 7 of the sites from trampling by cattle. This also shows as a decrease in the wider elevation range categories that contain these sites, i.e. 3.0-3.3mODN and 2.7-3.3mODN.

At 2.7-2.99mODN (Fig. 5.25) on the salt marsh, mean species number increased from 5.31 in 2002 to 6.15 in 2005, 6.0 in 2006. Inside the realignment at this range (excluding flooded site TFS1) mean species number was 2.88 in 2003 and 2.82 in 2004, but increased to 5.09 in 2006.

Figures 5.26 and 5.27 show mean species number in two categories above 3mODN. At 3-3.15mODN (Fig. 5.26) the mean number of species outside the site varied between 5.50 and 5.83. Inside the site, excluding TBS1 with standing water, the mean species number increased from 4.10 in 2003 to 5.83 in 2006, the same mean value as outside in this range.

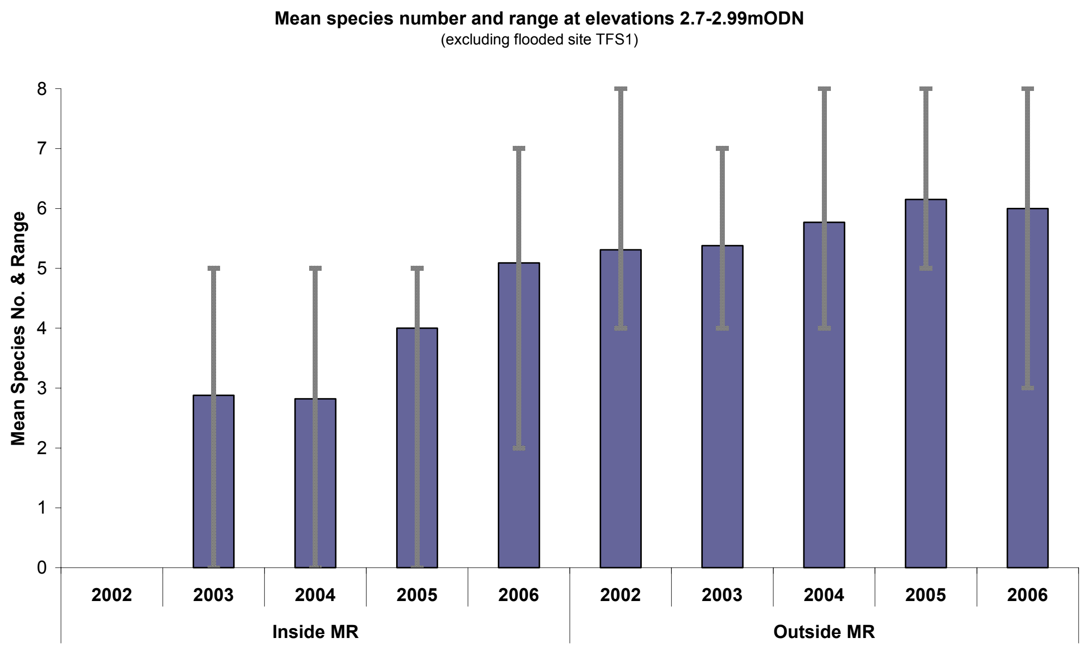


Fig. 5.25. Mean species number in the realignment site and outside at elevation range 2.7-2.99mODN

At the highest elevation sub-category (3.16-3.3mODN, Fig 5.27) mean plant species number on the salt marsh was between 5.3-5.43 in 2002-2005, apparently declining to 4.20 in 2006. However the decrease in species number was due to the loss of two relatively diverse sites because of cattle breaking the marker posts.

It was shown in the last section that the rate of increase in total vegetation cover inside the realignment was the greatest at the highest elevations. The 3.16-3.3mODN elevation range was also the most diverse in species composition from the outset, with mean species number consistently slightly higher than outside and fluctuating between 5.46 and 6.27.

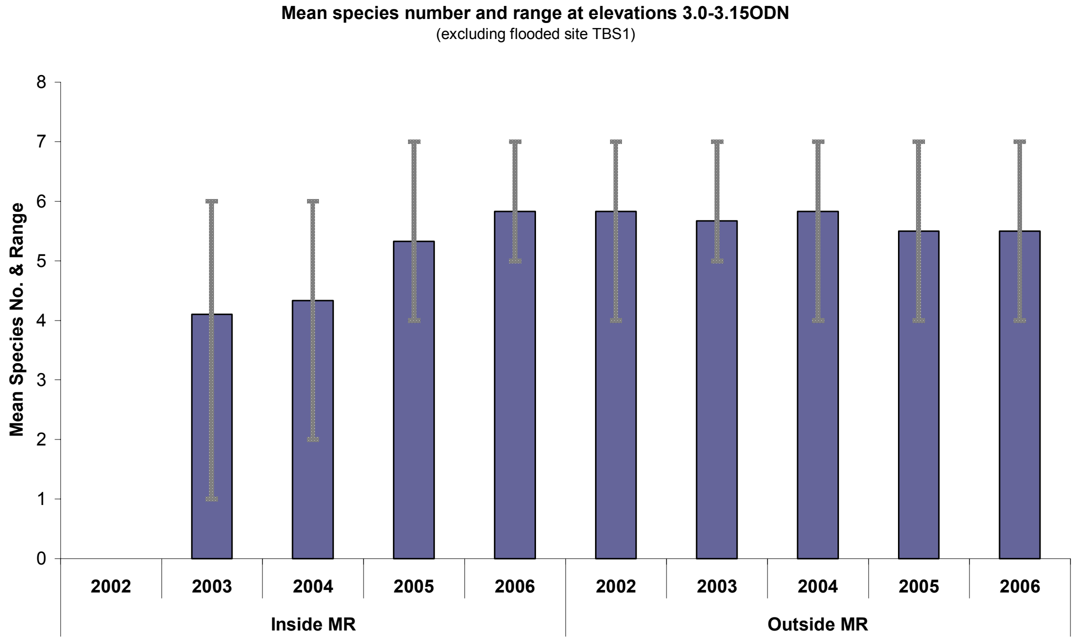


Fig. 5.26. Mean species number in the realignment site and outside at elevation range 3.0-3.15mODN

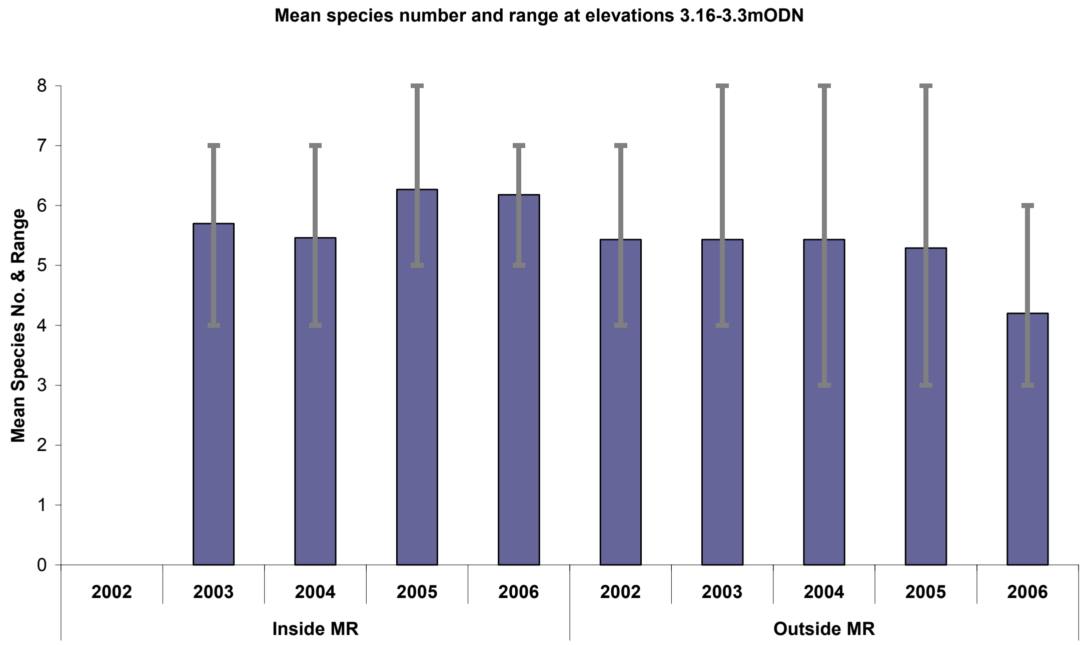


Fig. 5.27. Mean species number in the realignment site and outside at elevation range 3.16-3.3mODN

5.4.6 5 x 1m² Quadrats: Plant species inside and outside the realignment according to elevation

Plant species in the different elevation categories are listed in Table 5.3 in descending order of cover importance in 2006 (2005 for sites lost to cattle trampling). Species differences between outside and inside the realignment at the same elevation range are highlighted in colour. *Sarcocornia perennis* was recorded in some sites at all elevations outside the realignment site, and was first recorded (in two quadrats) in the realignment in 2006. *Spergularia media* was recorded outside at 2.7-2.99mODN but not in the realignment quadrats. *Limonium vulgare* was found outside at 3.16-3.3m (although only at one site, T6S1) but not in the realignment quadrats, although it was found occasionally near the back of the site. *Elytrigia atherica, Cochlearia sp*. and *Spergularia marina* were noted in some of the realignment quadrats in this highest elevation, but not outside in the quadrats, and *Spergularia marina* was only present in 2003 in the realignment quadrats. This species was seen in several places on open ground in higher areas at the back of the site during the first year, and it was also common on open areas at the base of the old (pre-breach) embankment where the ground was disturbed by trampling. It is generally annual or biennial, found on drier parts of salt marshes and seashores (Blamey and Grey-Wilson, 1989) and characteristic of disturbed situations such as upper marsh pans and along paths (Rodwell, 2000). Its decrease in frequency in the realignment site would be expected under competition with spreading perennial salt marsh vegetation. In 2003, a small specimen of *Elytigia atherica* was found in a quadrat at 3-3.15m in the Freiston site, but has since gone. However it has spread over the highest areas of the site.

Apart from these minor differences in occurrence of occasional species in the quadrats, all of the major species present on the salt marsh outside were found inside the realignment quadrats at equivalent elevations.

Table 5.3. Species in order of cover importance in quadrats outside and inside the realignment site, according to elevation category. (As species changed more rapidly inside the newly created site, the order of importance follows species composition recorded in 2005/2006)

Outside (OS) and inside MR (MR) at different elevation range categories (mODN)
Blue: species found outside in quadrats, not in MR quadrats.
Red: found inside MR in quadrats, not found outside in quadrats; [species] =gone after 2003
Note: This is in quadrats only. Species are present at low cover outside quadrats

OS <2.7	OS 2.7-2.99	MR 2.7-2.99	OS 3.0-3.15	MR 3.0-3.15	OS 3.16-3.3	MR 3.16-3.3
Salicornia	*Salicornia*	*Salicornia*	*Atrip. port*	*Puccinellia*	*Atrip.port*	*Puccinellia*
Suaeda m.	*Suaeda m.*	*Suaeda m.*	*Puccinellia*	*Salicornia*	*Puccinellia*	*Suaeda m.*
Spartina	*Aster*	*Puccinellia*	*Suaeda m.*	*Suaeda m.*	*Salicornia*	*Salicornia*
Aster	*Spartina*	*Atrip.port*	*Aster*	*Atrip.port*	*Suaeda m.*	*Atrip. port*
Sper.media	*Puccinellia*	*Spartina*	*Spartina*	*Spartina*	*Aster*	*Aster*
Puccinellia	*Atrip.port*	*Aster*	*Salicornia*	*Aster*	*Spartina*	*Sper.media*
	Sarc.peren	*Sarc.peren*	*Sarc.peren.*	*Sper.media*	*Sper.media*	*Spartina*
	Sper.media		*Sper.media*	[*Elytrigia*]	*Sarc.peren.*	*Sarc.peren*
					Limonium	*Elytrigia*
						Cochleria
						[*S.marina*]

5.4.7 5 x 1m^2 Quadrats: Comparison of plant species composition and cover inside and outside the realignment according to elevation

Plant species composition at each site outside the realignment is shown graphically in Appendix A5.3 and in Appendix A5.4 for inside the site. Species composition is summarised for different elevation categories outside and inside the realignment, shown in Figs 5.28-5.36 and described below.

The pioneer annuals were the first to colonise the realignment and *Salicornia europaea* and *Suaeda maritima* were the dominant species throughout the site in 2003, at all elevations. Between 2003 and 2006 other perennial species have established and spread, particularly at the higher elevations.

Outside MR, <2.7mODN (Fig. 5.28.)

In the pioneer zone, the dominant plant species were the annuals *Salicornia europaea* and *Suaeda maritima*. *Salicornia europaea* was recorded with a mean percentage species cover between 27% and 31% in 2002-2005 and 44% in 2006, and *Suaeda maritima* has increased in mean cover from 2% in 2002 to 11% in 2006. Remaining species occurred at less than 3% cover: *Spartina anglica*, increased from 1% mean cover in 2002 to 2.6% in 2006; *Aster tripolium* increased from 1% in 2002 up to 2.6% in 2006; *Spergularia media* was found with <0.02% mean cover in 2002 and increased to 0.59% in

2006; and sparse *Puccinellia maritima*, which was first recorded at this elevation range in 2004 (<0.02%) and increased to 0.1% mean cover in 2006.

In summary, at this elevation *Salicornia europaea* was still the dominant species in 2006, followed by *Suaeda maritima,* with remaining species contributing a mean percentage cover between <1 to 3%.

Outside MR, 2.7-2.99mODN (Fig 5.29)

At this elevation range, *Salicornia europaea* was still the species with the greatest recorded mean percentage cover in 2006, although it has decreased from 40% in 2002 to 27/28% in 2005/6, followed by *Suaeda maritima* which fluctuated between 19% and 24% mean cover. However, the remaining species at this elevation were found with higher cover values compared with the pioneer/marsh front. *Aster tripolium* cover fluctuated between 8.5% and 15%, *Spartina anglica* varied between 10% and 14% mean cover. *Puccinellia maritima* increased its mean cover from 2002 to 2004, from 7.0% to 14%, but had dropped back to 6.6% in 2006. *Spergularia media* was recorded with mean cover values between 1.4% and 4.3%. *Atriplex portulacoides* comes in at this elevation, and during the study period it has spread steadily from 0.3% up to 5.8% mean cover. *Sarcocornia perennis* was found in this range, but infrequently, with mean cover values between 0.2% and 0.8%.

In summary, *Salicornia europaea*, followed by *Suaeda maritima* were still the most abundant species by 2006. *Salicornia europaea* and *Puccinellia maritima* have decreased their cover over the survey period, while *Atriplex portulacoides*, which was rare in 2002, has increased to 6%. Other species (in descending order of cover importance): *Spartina anglica*, *Aster tripolium*, *Puccinellia maritima*, *Spergularia media*, and *Sarcocornia perennis* were recorded with mean cover values of 0.5-14% in 2006.

Inside MR, 2.7-2.99mODN (Fig.5.30)

In the first year (2003), *Salicornia erupoaea* and *Suaeda maritima* were the only species found with mean cover values greater than 1%, at 12% and 10% respectively, and they have remained the dominant species at this elevation range. *Salicornia europaea* was found at its highest mean cover of 44% in 2004, 31% in 2006. *Suaeda maritima* dropped from 10% mean cover in 2003 to approximately 6% in 2004 but increased to 21% in 2006. By 2006, both these species were found with similar mean cover values to sites on the salt marsh at this elevation. *Aster tripolium* and *Spartina anglica* were found in all years at low cover values, but both increased between 2003 and 2006 (*Aster*: <<0.1% increasing to 0.8%, *Spartina*: <0.1% increasing to 1.4%). *Puccinellia maritima* has spread steadily from 1% in 2003 to 8% in 2006. A tiny specimen of *Atriplex portulacoides* was found at one site in 2003, and although not recorded in the quadrats in 2004, it has increased in the last two years to 2.8% (found at 4 sites in 2006). A very small patch of *Sarcocornia perennis* was found in just one quadrat in 2006, at a mean cover of just 0.003% over all quadrats in this elevation range. The only species found in the quadrats outside at this elevation range which has not yet been recorded in the realignment quadrats was *Spergularia media*.

In summary, *Salicornia europaea* followed by *Suaeda maritima* were still the most abundant species in 2006, with fluctuating cover values but an overall increase in mean cover between 2003 and 2006. *Puccinellia maritima* increased in mean cover to 8%, and other species (in descending order of cover): *Atriplex portulacoides*, *Spartina anglica* and *Aster tripolium* have all increased since 2003 to between <1% and 3% in 2006.

Outside MR, 3.0-3.3mODN (Fig. 5.31)

Puccinellia maritima was the species with the greatest mean cover in 2002 and 2003 (44/45%) above 3mODN, but has declined since to 14% in 2006 and has been replaced by *Atriplex portulacoides* which increased from 39% to 70% and was the most abundant species by 2004. *Salicornia europaea* decreased from 11% mean cover in 2002 to 1% in 2006. At less than 10% cover, *Suaeda maritima* remained at a fairly steady value between 5.2% and 7.8%, *Aster tripolium* fluctuated between 1.5% and 4.6%, and *Sarcocornia perennis* between 0.2% and 0.8%. *Spartina anglica* increased from 0.7% in 2002 to 1.5% in 2006, and *Limonium vulgare* was present at just one site (0.02-0.1%).

In summary, *Atriplex portulacoides* has increased in cover and replaced *Puccinellia maritima* as the most abundant cover species in 2006. Both *Puccinellia maritima* and *Salicornia europaea* have declined since 2002, while *Suaeda maritima* has remained fairly steady. Other species present were found at low cover from <1% to approximately 2%.

Inside MR, 3.0-3.3mODN (Fig. 5.32)

The pioneer annuals, *Suaeda maritima* and *Salicornia europaea* were the dominant species in the first year (18% and 17%, respectively) and *Salicornia europaea* peaked in 2004 at 34%, but by 2005 both annuals had been overtaken by the expansion of *Puccinellia maritima*, which had spread rapidly from 2.9% in 2003 to 42% in 2005, remaining at this value in 2006. *Salicornia europaea* and *Suaeda maritima* were recorded with a mean cover of 18% and 15% in 2006, respectively. *Atriplex portulacoides* was found at just 0.2% cover in 2003 and has since increased to 9.3% in 2006, but cover was still much lower than the values for this species outside on the salt marsh. The cover value for *Puccinellia maritima* in 2006 was close to its maximum value found outside on the salt marsh in 2002-3 at this elevation range. It will be interesting to see if its cover abundance now begins to decline if *Atriplex portulacoides* starts to expand its cover rapidly. Other species found at low cover (<3%) but increasing between 2003 and 2006 were *Aster tripolium* (0.4% up to 2.2%) and *Spartina anglica* (<0.1% up to 1.4%). *Spergularia media* was recorded at <1% mean cover throughout. *Sarcocornia perennis* was first recorded at this elevation in 2006 and the two additional species not found in the quadrats outside, as noted in Table 5.3 above, were *Cochlearia sp.* and *Elytrigia atherica*, all <<0.1% mean cover. *Spergularia marina* was found in 2003 only (0.1% mean cover).

In summary, *Salicornia europaea* and *Suaeda maritima* were the most abundant species in 2003, and were found at similar cover values in 2006, while *Puccinellia maritima* increased rapidly to become the dominant species by 2005. *Atriplex portulacoides* has increased steadily each year. *Spartina anglica* and *Aster tripolium* have increased slowly, to 1-2%, and other species were recorded at <1% by 2006.

Sub-categories in 3.0-3.3mODN:

Outside MR, 3.0-3.15mODN (Fig. 5.33)

The pattern of succession is (unsurprisingly) similar to the description of the full range above 3m, but dividing the 3m and above range does show differences in dominance, particularly for the highest sub-category (>3.16mODN).

At 3-3.15mODN *Puccinellia maritima* had the highest mean species cover value from 2002 to 2004 (43-50%), peaking at 50% in 2003, but declining to 22% by 2006. *Atriplex portulacoides* expanded its cover from 30% in 2002 to 53% in 2006 and had taken over as the main cover species by 2005. *Salicornia europaea* decreased its cover from 16% in 2002 to just 0.5% in 2004 and 1.8% in 2006. *Suaeda maritima* increased in the 5 years, from 6.8% to 12%, and *Aster tripolium* varied between 2.5% and 7.6%. *Spartina anglica* was found between 1% and 2.8% and *Spergularia media* between <0.1% and 0.9%.

In summary, *Puccinellia maritima* was the dominant species in 2002, but has since declined along with *Salicornia europaea*, while *Atriplex portulacoides* has increased to become the most abundant species by 2005. *Suaeda maritima* has increased slowly and *Aster tripolium* cover has varied. Remaining species: *Sarcocornia perennis* and *Spergularia media* were recorded at <1% mean cover (in 2006).

Inside MR, 3.0-3.15mODN (Fig.5.34)

Salicornia europaea was the most abundant species in 2003 and 2004 (20% and 37%) followed by *Suaeda maritima* in 2003 (13%). *Salicornia* decreased to 17% in 2005, but increased again to 28% in 2006, and *Suaeda* has varied between 7.7% and 17% mean cover during the four years of monitoring in the realignment site. *Puccinellia maritima*, just 3% in the first year, had reached 21% mean cover in the second year and by 2005 and 2006 was recorded with 28% mean cover, similar to *Salicornia europaea* in 2006. From our observations of these two species, we would expect the cover of *Salicornia* *europaea* to decline in future concurrent with the expansion of cover by *Puccinellia maritima*, but with eventual decline of the latter as well and replacement by *Atriplex portulacoides*, if succession continues towards the relative species abundance found outside on the salt marsh in this elevation range. *Atriplex portulacoides* was just present in 2003 at 0.02% but has since increased steadily to 4.8%, *Spartina anglica* has increased slowly from 0.1% to 2.4%, and *Aster tripolium* has spread slightly from 0.2% to 1.3%. *Spergularia media* was first recorded in 2005 (<0.1% in 2005 and 2006). A small single plant of *Elytrigia atherica*, found in 2003 has not been recorded since, probably because the elevation is still a little too low for this upper marsh species to withstand the inundation regime. The only species found outside in the quadrats which has not yet been found inside the realignment at this elevation range was *Sarcocornia perennis*.

In summary, *Salicornia europaea* followed by *Suaeda maritima* were the most abundant species in 2003, fluctuating in cover since but generally increasing by 2006. *Puccinellia maritima* spread most rapidly between 2003 and 2005, remaining at a similar value in 2006, but just topping *Salicornia europaea* in mean percentage cover. *Atriplex portuacoides* has increased steadily to 5% in 2006, and *Aster tripolium* and *Spartina anglica* have increased slowly to 1-2%, with *Spergulara media* recorded more rarely at <<1%.

Outside MR, 3.16-3.3mODN (Fig.5.35)

Atriplex portulacoides has consistently been the most abundant species in this highest elevation category and has also increased its mean cover from 47% in 2002 to 65% in 2005 (and 90% in 2006, although this value was influenced by the loss of two sites with the lowest cover values for *Atriplex potulacoides*). At the same time, *Puccinellia maritima* decreased from 44% in 2002 to 24% in 2005. The apparent spurt in *Atriplex portulacoides* expansion by 2006, and marked decline in *Puccinellia maritima* to just 5% in 2006 was influenced greatly by the loss of two out of seven sites in this range to cattle damage. Coincidentally, these two sites had the lowest cover values for *Atriplex portulacoides* and the highest values for *Puccinellia maritima* in all years. *Salicornia europaea* mean cover varied between 4.1% and7.9% in 2002-2005, with no records in the 5 remaining sites in 2006, and *Suaeda maritima* was found at mean cover values between 2.8% and 7.3% over the monitoring period. Remaining species were found at <2% cover: *Aster tripolium* varied between 0.3-1.9%, *Spartina anglica* between 0.04-1.1%, and *Spergularia media* between 0.2-0.6% in the first 4 years, but with no records in the remaining 5 sites in 2006. The single site with *Limonium vulgare* (0.03-0.23% mean cover) was at this elevation range, and one very small patch of *Sarcocornia perennis* (<0.01% mean cover) was found at one site in 2003 only.

In summary, *Atriplex portulacoides* was the most abundant species in 2002, but followed closely by *Puccinellia maritima*. In the 5 years of surveying *Atriplex portulacoides* has increased steadily while *Puccinellia maritima* has decreased rapidly. *Suaeda maritima* and *Aster tripolium* were recorded in

2006 at <3% and <1% respectively, and *Spartina anglica* and *Limonium vulgare* were found rarely at <<1%. *Salicornia europaea* was not found in 2006 (although 2 out of the 7 sites in this elevation range were lost to cattle damage).

Inside MR, 3.16-3.3mODN (Fig. 5.36)

In the first year, the annual pioneer species were the most abundant, as they were at all elevations, although at this higher level *Suaeda maritima* was more prevalent (at 25% mean cover) than *Salicornia europaea* (14% mean cover). The best year for *Salicornia europaea* recruitment and establishment was 2004 (31%), but it had decreased to 8% in 2005 and 7% last year in 2006, and *Suaeda maritima* cover dropped to 14% in 2006. In 2003, *Puccinellia maritima* was recorded with a mean cover of 2.8% but it has spread rapidly at this elevation, to 58% by 2005 when it was the most abundant species (similar at 59% in 2006), with a mean cover value 15% higher than found outside at this elevation in 2002. The main difference between inside and outside at this elevation was the relative abundance of *Puccinellia maritima* and *Atriplex portulacoides*. However, as noted above, *Atriplex portulacoides* was already the dominant species outside in 2002. In recent years it has shown signs of rapid expansion beginning inside the site, having spread quickly from a mean cover value of just 0.4% in 2003 to 14% in 2006, and it is likely to replace *Puccinellia maritima* in future to become the most abundant plant species at this elevation, or may be itself replaced by *Elytrigia atherica* in time if the site remains fenced and inaccessible to cattle throughout the successional process. *Aster tripolium* has increased more slowly from 0.5% to 3.2% during the study. Less common species such as *Spergularia media* varied from 0.3% to 2%, with the rest still at <1% in 2006 including *Spartina anglica*, first recorded in 2004 and which has increased its cover each year but was still at <0.2% mean cover in 2006, and *Cochlearia sp.* (<0.1%, one site only); both of these were first recorded in 2004. *Elytrigia atherica* was found in two sites in 2003, but just one since (up to 0.04% mean cover). However it has become more common in the higher area of Transect A and is expected to be found with greater cover in future as numerous patches of this species had sprung up over this area of the realignment by 2006. *Sarcocornia perennis* was first recorded in one quadrat (0.8%cover) at this elevation in 2006, with a mean cover over all quadrats of just 0.07%. Only one species, *Limonium vulgare* (localised and uncommon) was found outside in the quadrats but not yet inside in the quadrats at this elevation range.

In summary, *Suaeda maritima* followed by *Salicornia europaea* were the most abundant species in the first year but both had declined in mean cover by 2006. *Puccinellia maritima* spread rapidly, particularly between 2004 and 2005 to become the dominant species by 2005, and with a similar cover value in 2006. *Atriplex portulacoides* has increased steadily each year to become the second most important cover species by 2006. *Aster tripolium* has increased, but more slowly. Other species: *Spartina anglica*, *Spergularia media*, *Cochlearia sp.*, *Elytrigia atherica*, and *Sarcocornia perennis* were recorded at <1% in 2006.

5.4.8 Summary of Vegetation Establishment and Succession

The expansion and decline of different species at different elevations appears quite complex when the percentages are described, therefore the main points about the vegetation establishment, spread and succession are described again.

The pioneer annuals were the first to colonise the realignment 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 have remained the most abundant species at lower elevations in the realignment, but other species have established and spread, particularly at the higher elevations, where the annuals have been replaced by the perennial *Puccinellia maritima* as the dominant species. The perennial *Atriplex portulacoides*, extremely abundant outside on the salt marsh at higher elevations has shown a steady increase at higher elevations in the MR, and by 2006 was the second most important cover species after *Puccinellia maritima* in the highest elevation range category (3.16-3.3mODN).

The main difference between the MR and outside at the lower elevation range (2.7-2.99mODN) was that outside, *Salicornia europaea* and *Puccinellia maritima* cover has decreased, and *Atriplex portulacoides* has increased. In the MR *Salicornia europaea* and *Puccinellia maritima* were still increasing in cover by 2006. *Atriplex portulacoides* has increased but to lower cover levels than outside.

The main difference at elevation range 3-3.15mODN was that outside, *Puccinellia maritima* was dominant in 2002 but has decreased along with *Salicornia europaea*, while *Atriplex portulacoides* increased to become the most abundant species by 2005. In the MR, *Puccinellia maritima* increased very rapidly between 2003 and 2005 to become the most abundant species at this elevation. *Atriplex portulacoides* has increased steadily but was still less than 5% cover by 2006.

The main difference at elevation range 3.16-3.3mODN was that *Atriplex portulacoides* was dominant in 2002 on the salt marsh outside and has increased steadily while *Puccinellia maritima* has decreased. Inside the MR, *Suaeda maritima*, followed by *Salicornia europaea* were the dominant species in 2003, but both have decreased in cover since. *Puccinellia maritima* increased rapidly to become the most abundant species by 2005. *Atriplex portulacoides* has increased steadily to become the second most important cover species by 2006, and may replace *Puccinellia maritima* as the dominant cover type in future.

The overall impression by 2006 was that succession of perennial species in the upper half of the elevation range of the site was occurring rapidly and to a rough approximation was one ‘elevation category’ behind the community composition outside the realignment.

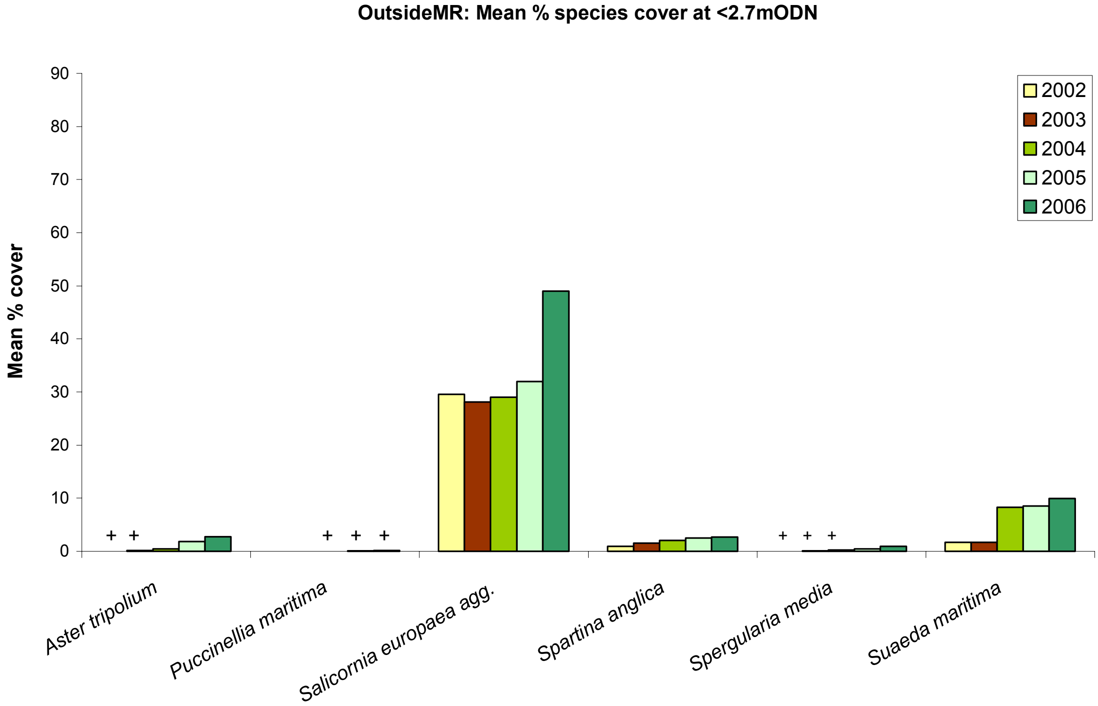


Fig. 5.28. Mean percentage species cover outside the realignment on the salt marsh at elevations <2.7mODN (no equivalent range inside MR). + = species present at <0.2% mean cover

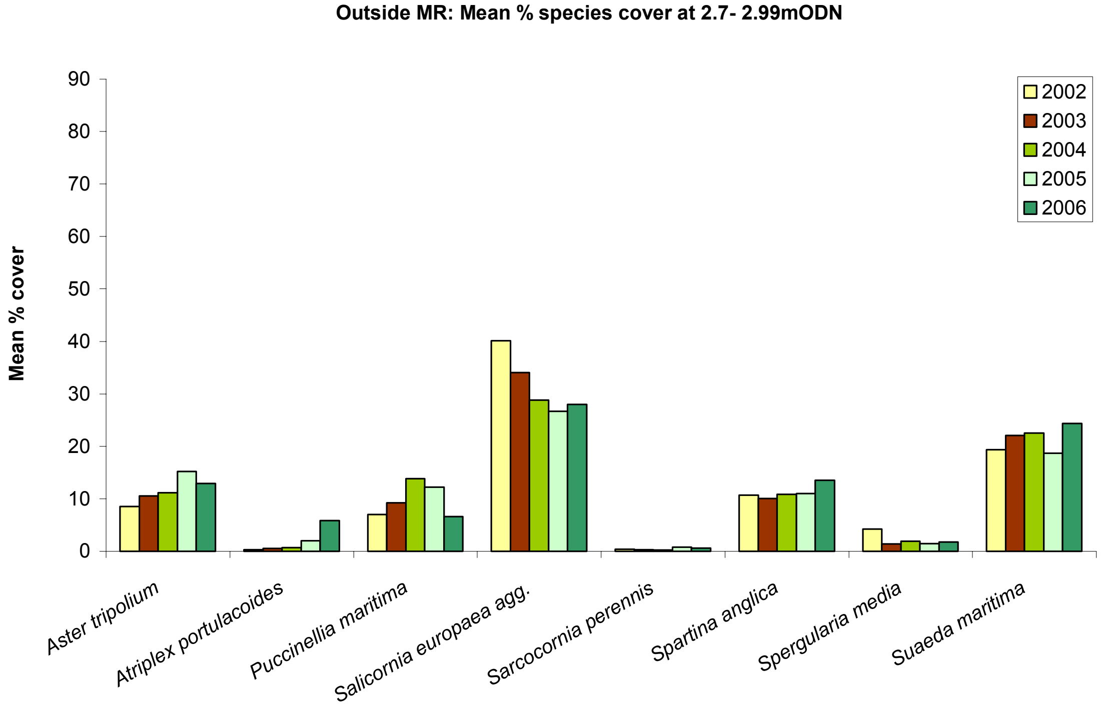


Fig. 5.29. Mean percentage species cover outside the realignment on the salt marsh at elevation range 2.7-2.99mODN

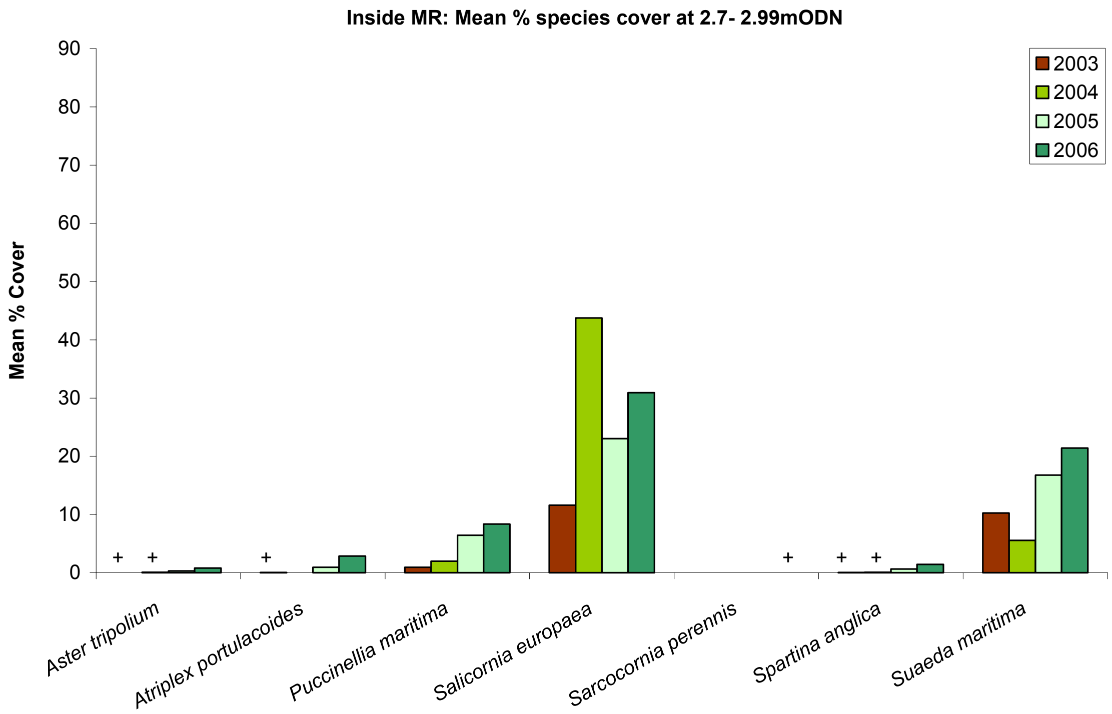


Fig. 5.30. Mean percentage species cover inside the realignment at elevation range 2.7-2.99mODN. + = species present at <0.2% mean cover.

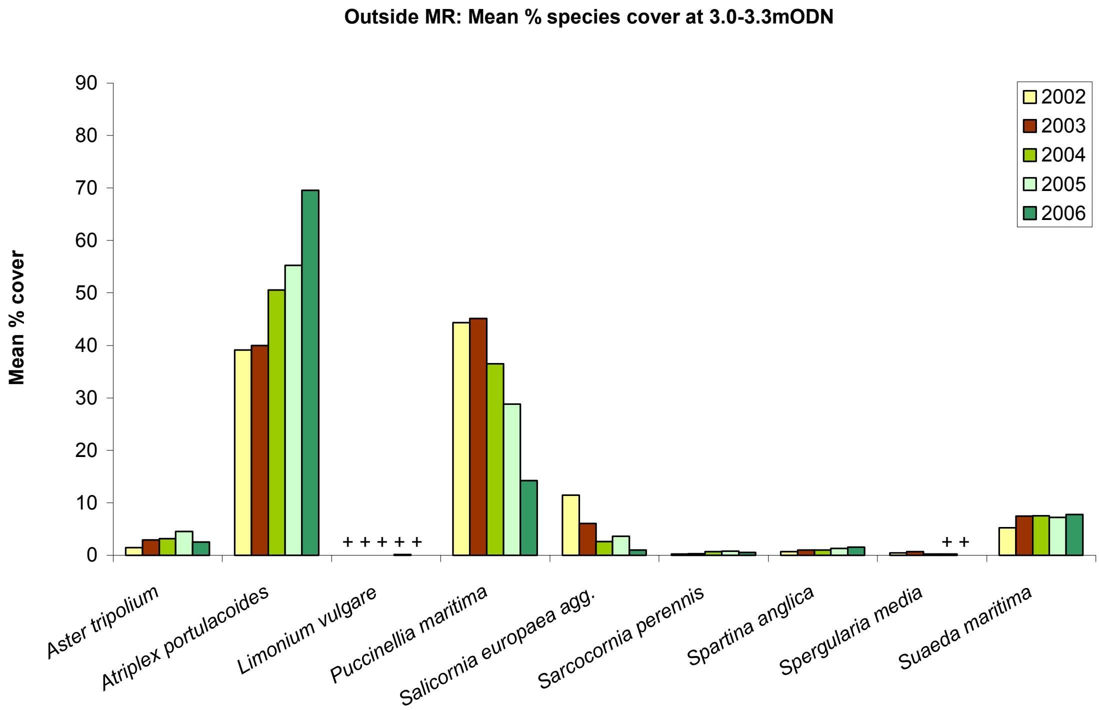


Fig. 5.31. Mean percentage species cover outside the realignment on the salt marsh at elevation range 3.0-3.3mODN. + = species present at <0.2% mean cover.

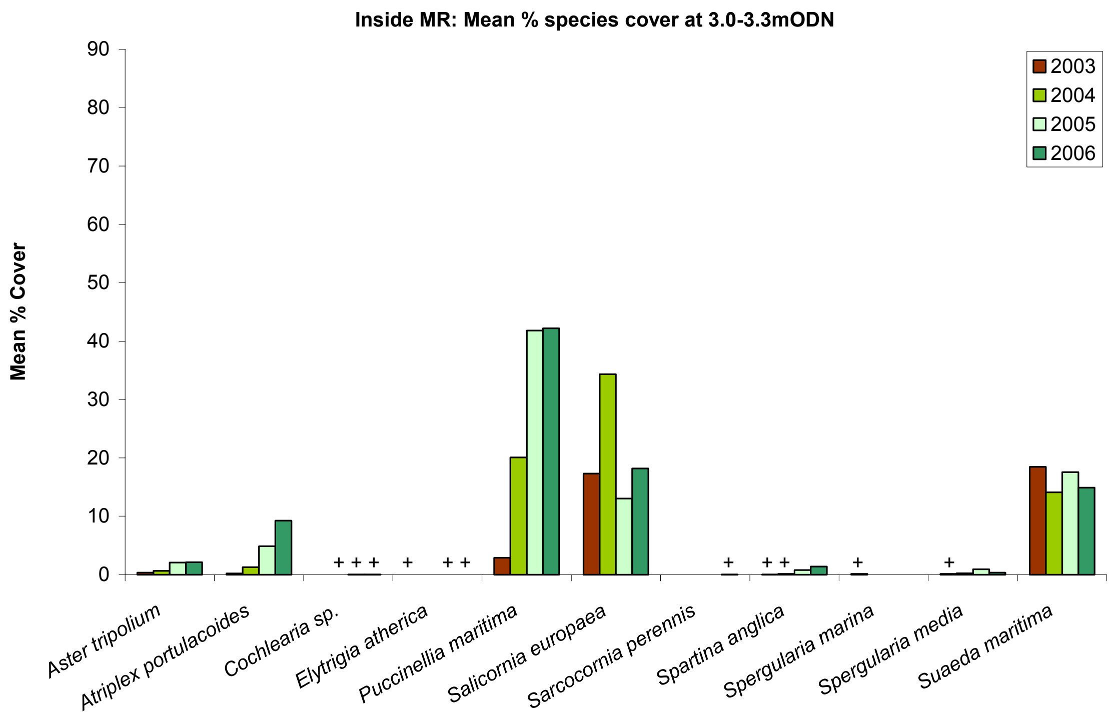


Fig. 5.32. Mean percentage species cover inside the realignment at elevation range 3.0-3.3mODN. + = species present at <0.2% mean cover.

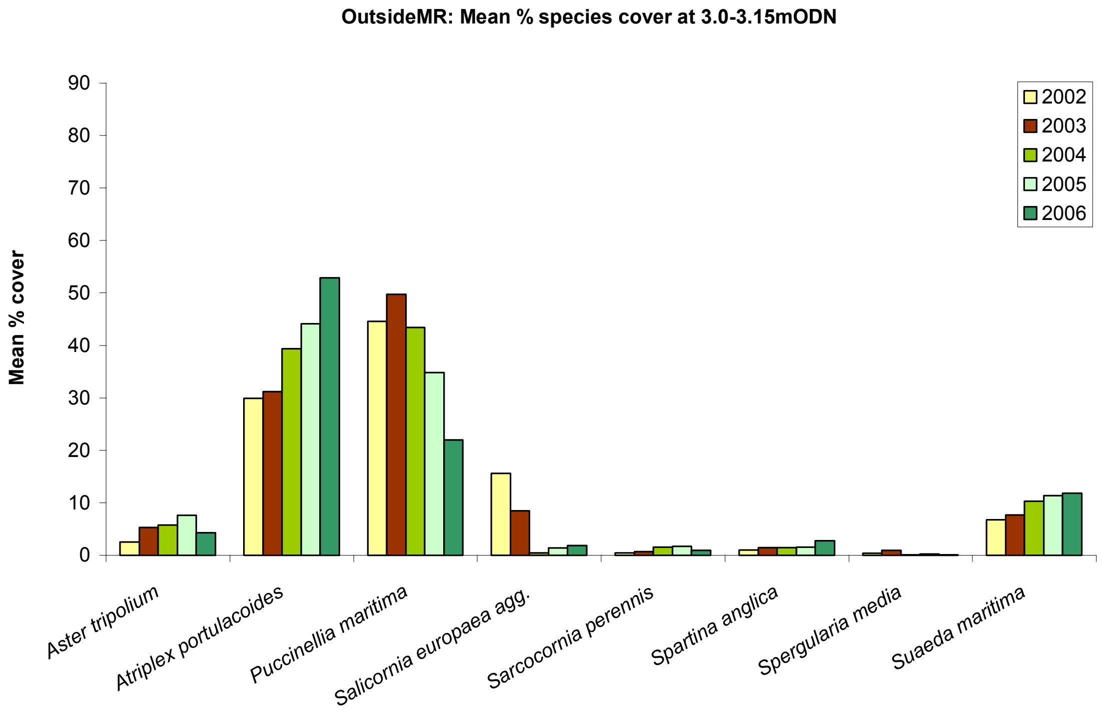


Fig. 5.33. Mean percentage species cover outside the realignment on the salt marsh at elevation range 3.0-3.15mODN

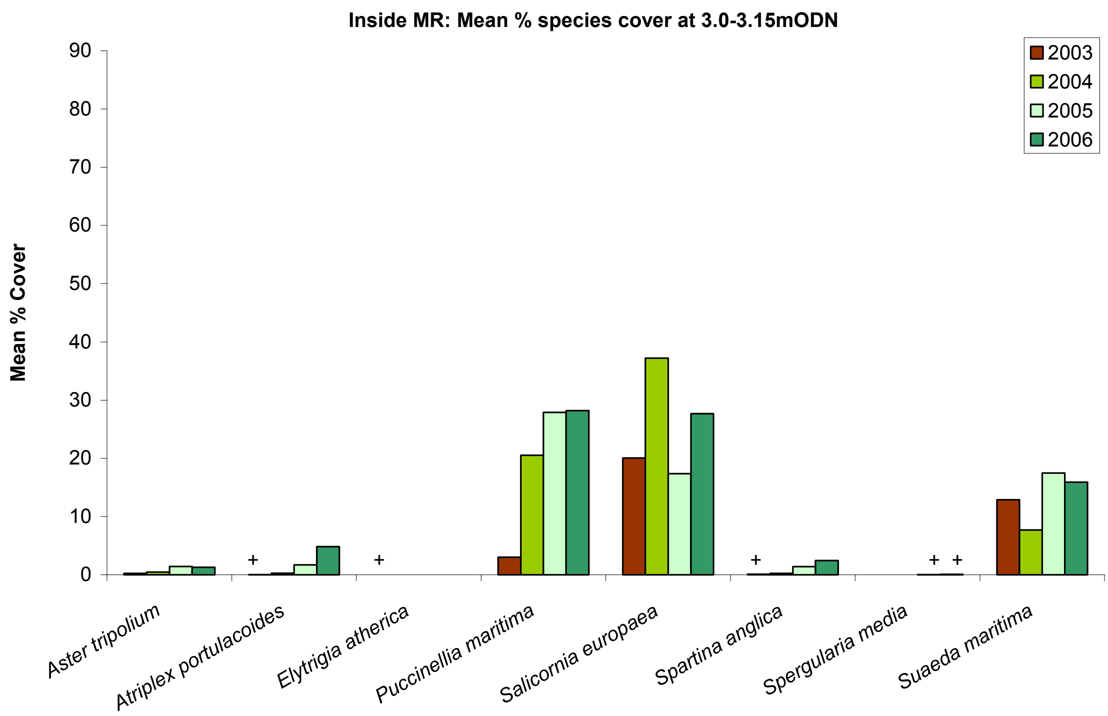


Fig. 5.34. Mean percentage species cover inside the realignment at elevation range 3.0-3.15mODN. + = species present at <0.2% mean cover.

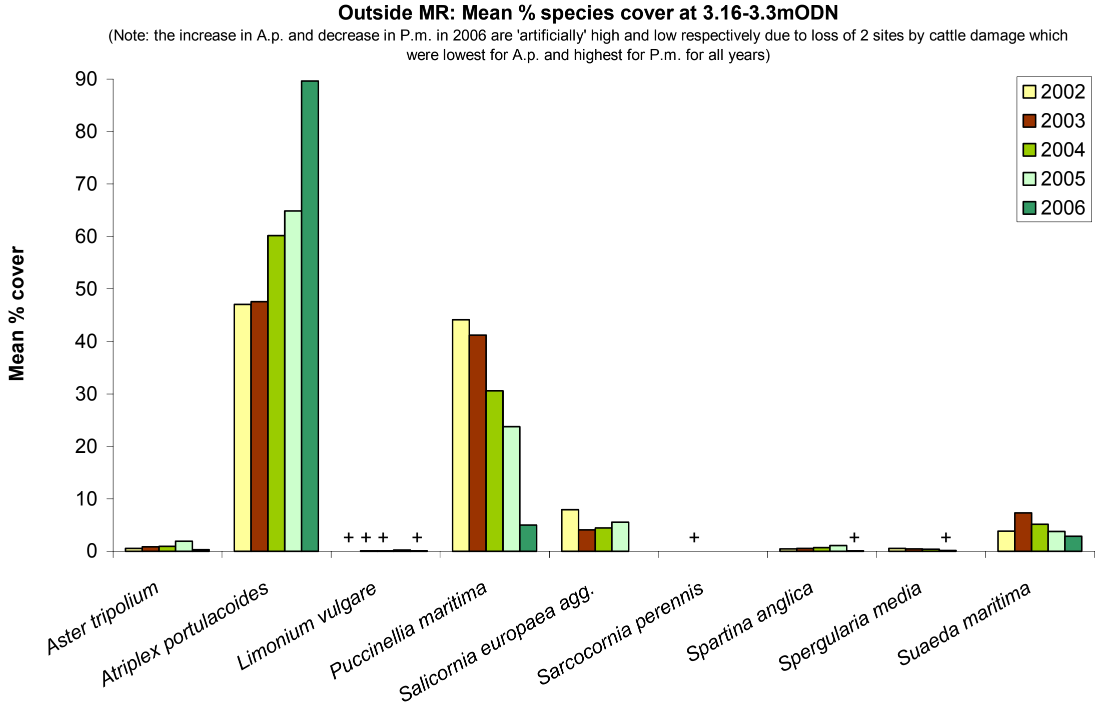


Fig. 5.35. Mean percentage species cover outside the realignment on the salt marsh at elevation range 3.16-3.3mODN. + = species present at <0.2% mean cover.

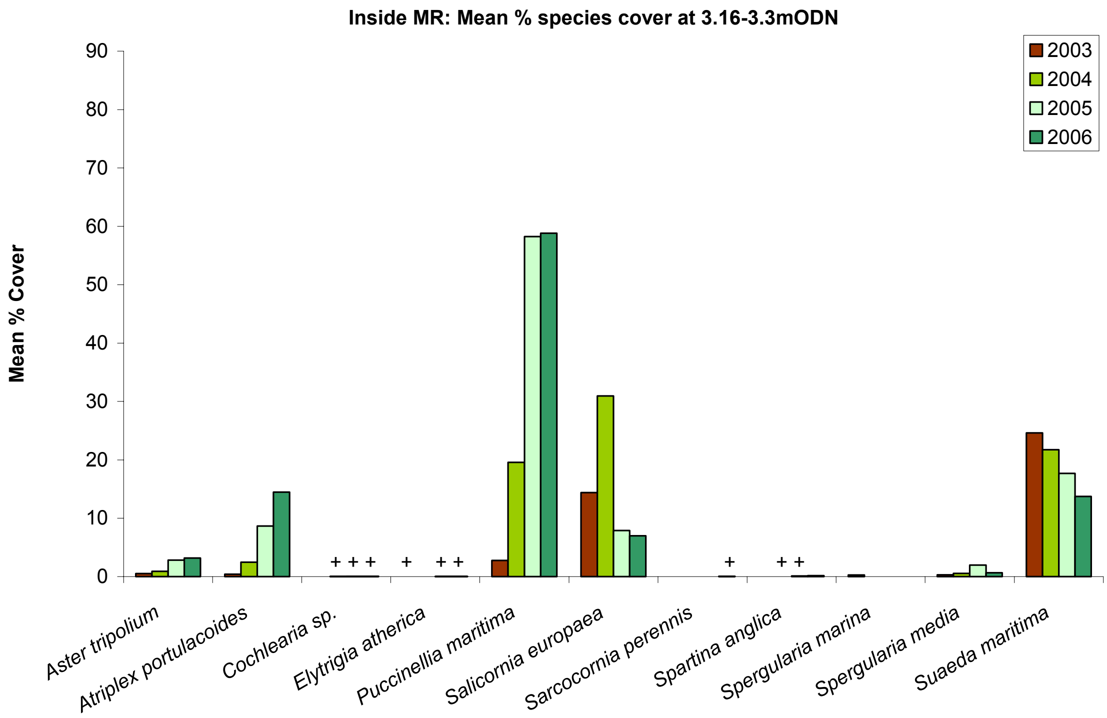


Fig. 5.36. Mean percentage species cover inside the realignment at elevation range 3.16-3.3mODN. + = species present at <0.2% mean cover.

5.4.9 Frequency distribution in 100 cells of the 1x1m quadrats in the realignment site

Frequency data give an indication of the distribution of species in the quadrat. These examples show the mean percentage frequency distribution at a small scale ($1m^2$ quadrats divided into 100 cells) in three elevation range categories. The frequency is compared with the percentage cover in the same quadrats.

The frequency distribution of the species generally follows a similar pattern to the mean percentage cover values, which is not surprising as plants colonise and spread over the quadrat area, but there were some differences in pattern between frequency and cover, particularly with the annual pioneer species, *Salicornia europaea* and *Suaeda maritima.* The differences were due to changes in their size and growth form over time as the sediment surface becomes increasingly vegetated and plants compete for light and nutrients.

2.7-2.99mODN (Fig. 5.37a; compare with mean percentage cover in Fig. 5.37b)

Puccinellia maritima showed a steep and steady increase in mean frequency of occurrence from 3% in 2003 to 50% of the cells by 2006 as small plantlets became established over the quadrat, while mean cover increased from 1.2% to 12% during this time (Fig. 5.37b). Percentage frequency of *Salicornia europaea* rose rapidly from 10% in 2003 to 65% in 2004. Mean cover for this species also increased between 2003 and 2004, from 12% to 46%, but dropped to half this value (23%) in 2005, when mean frequency only decreased from 71% to 63%. Both frequency and cover increased again in 2006. *Suaeda maritima* frequency increased steeply and steadily from 4.8% in 2003 to 59% in 2006, at a similar rate to *Puccinellia maritima*, but mean percentage cover dropped slightly from 10% in 2003 to 9% in 2004, before increasing again. In 2003, *Salicornia europaea* and *Suaeda maritima* in particular, were generally large specimens. For example, *Suaeda* plants were frequently approximately 30cms high or more, with side shoots, and *Salicornia* was approximately 20cm high and highly branched at many sites. In later years these annual species were less robust unbranched specimens and half their 2003 size, resulting in a lower cover value in spite of their increased frequency of occurrence.

3.0-3.15mODN (Fig. 5 38a; compare with mean percentage cover in Fig. 5.38b)

Puccinellia maritima frequency increased very steeply from 4.6% in 2003 to 65% in 2005, and 76% in 2006, as numerous tiny plants colonised many cells of the quadrats. Mean cover showed a similar pattern with the greatest increase from 2.8% in 2003 to 29% in 2005, increasing only slightly to 32% in 2006. Patterns for *Salicornia europaea* and *Suaeda maritima* were similar to those in the lower elevation category. *Suaeda maritima* increased in frequency year on year, with the largest increase between 2003 and 2004, from 6.1% to 29%, continuing to 43% and 52% in 2005 and 2006. Concurrent with the largest increase in frequency, *Suaeda maritima* decreased in mean percentage cover from 12% in

2003 to 10% in 2004 as individual plants were smaller. *Salicornia europaea* increased sharply in frequency between 2003 and 2004, from 17% to 80%, dropping to 67% in 2005 and rising again to 73% in 2006. Mean cover decreased at a greater rate between 2004 and 2005, by more than half from 40% to 18%, but increasing after to 30% in 2006.

3.16-3.3mODN (Fig. 5.39a). Compare with mean percentage cover in Fig. 5.39b

Both frequency (particularly) and cover of the perennial *Puccinellia maritima* increased most rapidly between 2004 and 2005, reaching 90% mean frequency and 62% mean cover. Perennial *Atriplex portulacoides* showed similar patterns of percentage cover and frequency, increasing each year, as did the generally biennial *Aster tripolium*. *Salicornia europaea* mean frequency increased most rapidly between 2003 and 2004, from 16% to 90%, dropping to approximately half this value (47%) in 2005, although frequency was still about three times higher than in the first year (2003). Mean percentage cover of *Salicornia europaea* increased from 14% in 2003 to 26% in 2004, but subsequently dropped to 6% in 2005 and 2006, less than a quarter of the 2004 value, and half of the mean cover recorded in the first year (2003), due to the reduction in plant size. Mean cover of *Suaeda maritima* decreased steadily from 25% in 2003, down to 14% in 2006, but mean percentage frequency rose sharply from 14% in 2003 to 49% in 2004, and remained around this level (45%, 2005, 53% 2006).

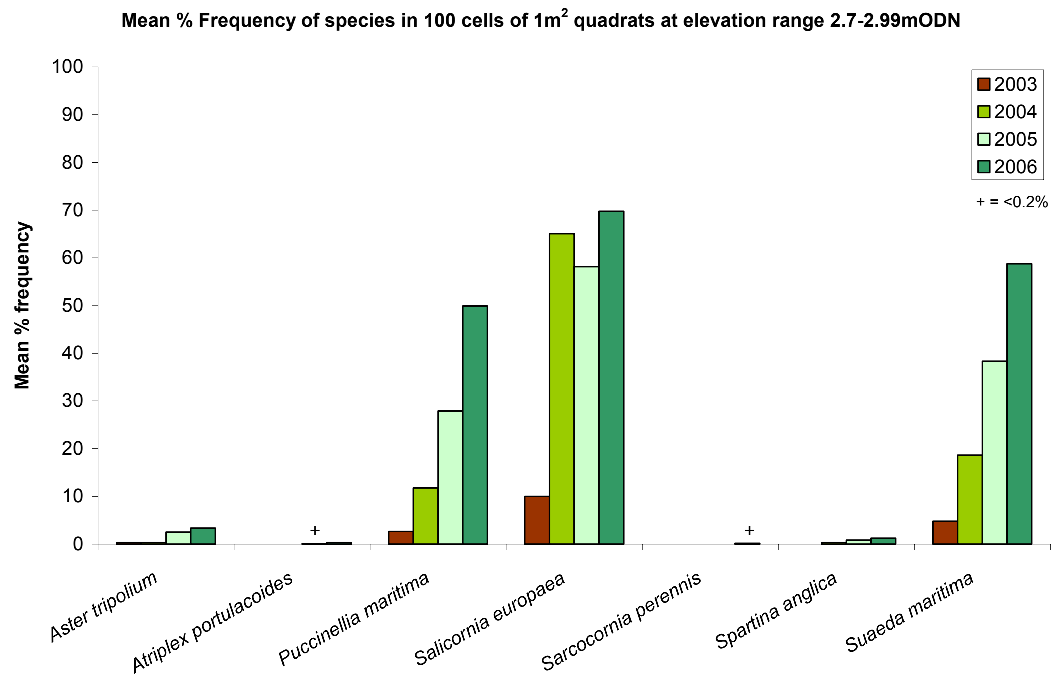


Fig. 5.37a. Mean percentage frequency of occurrence of species in 100 cells of 1m^2 quadrats inside the realignment site at elevation range 2.7-2.99mODN

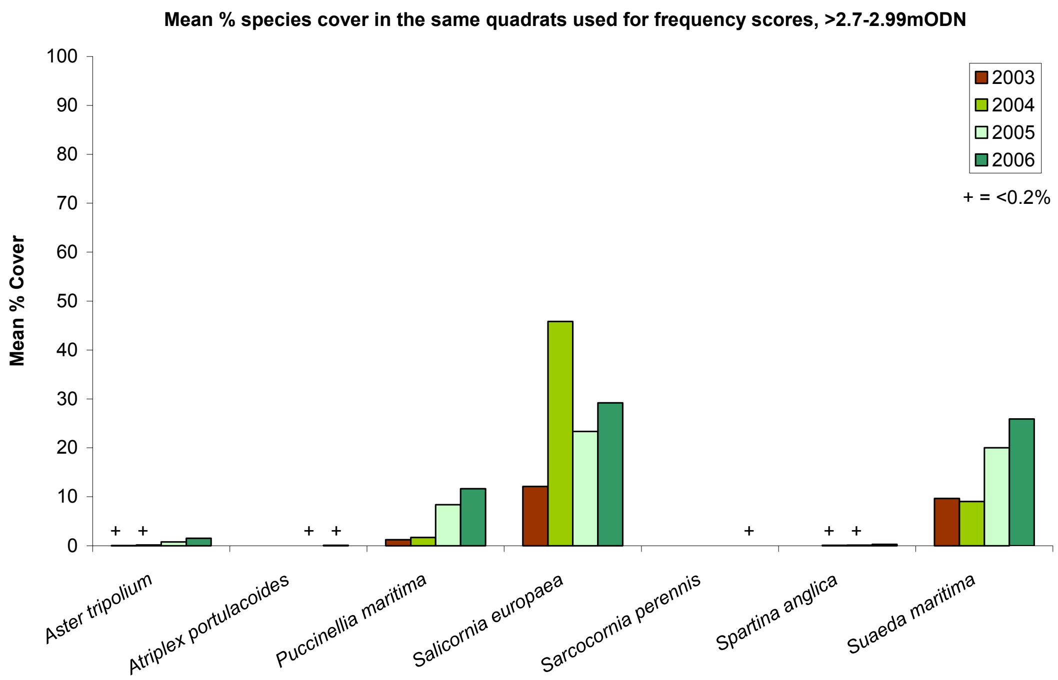


Fig. 5.37b. Mean percentage cover of species in the same quadrats as percentage frequency measurements above, at elevation range 2.7-2.99mODN

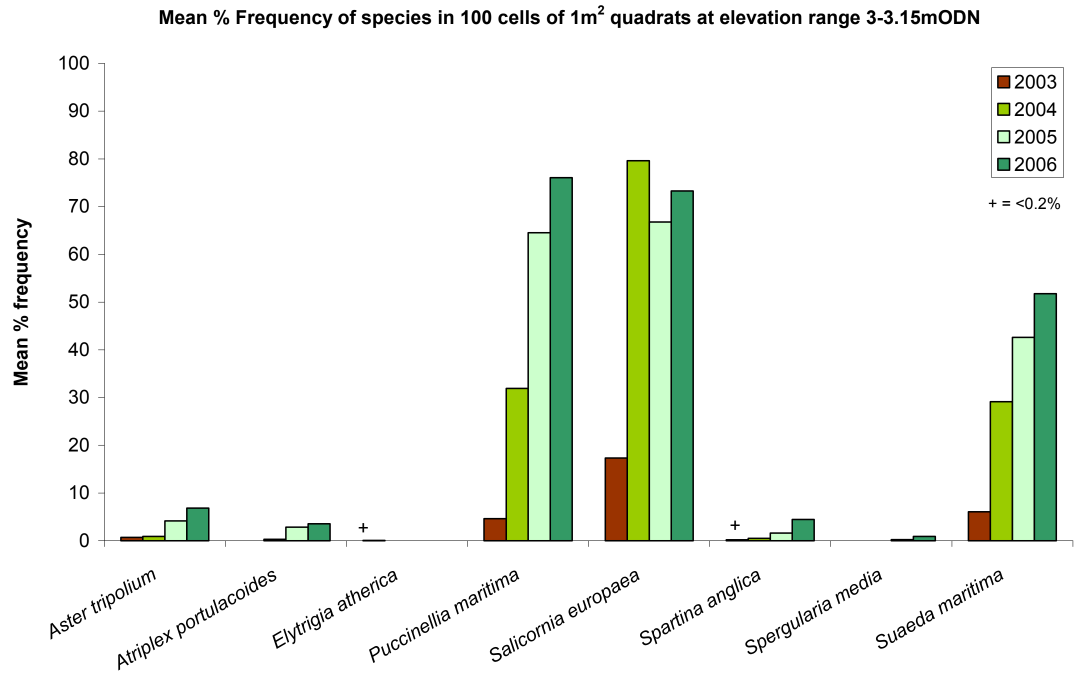


Fig. 5.38a. Mean percentage frequency of occurrence of species in 100 cells of 1m² quadrats inside the realignment site at elevation range 3.0-3.15mODN

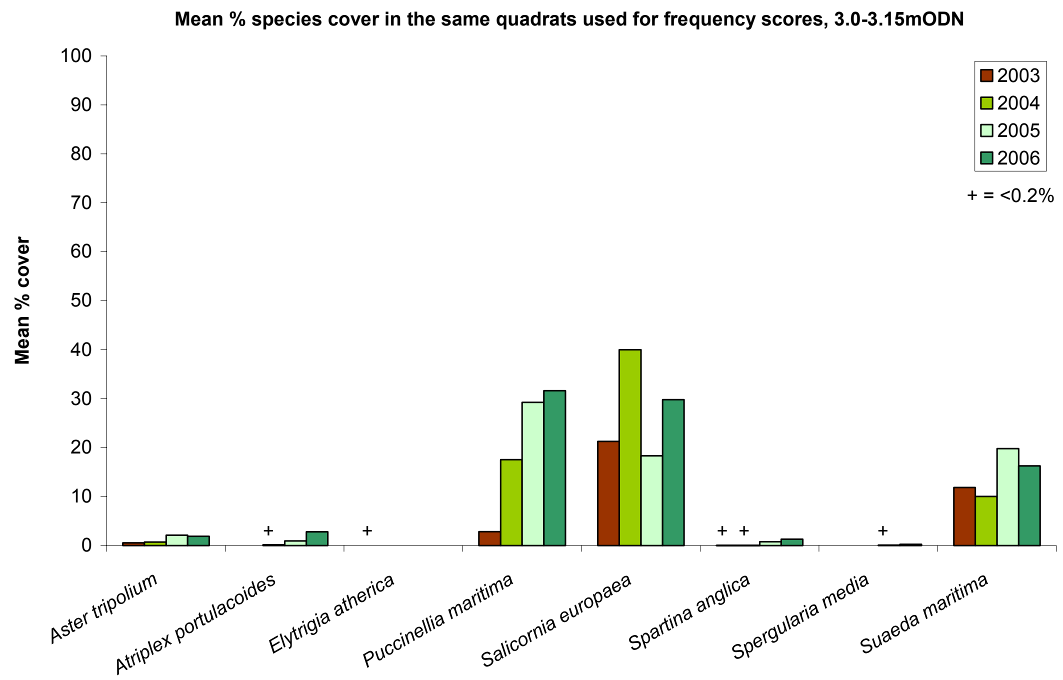


Fig. 5.38b. Mean percentage cover of species in the same quadrats as percentage frequency measurements above, at elevation range 3.0-3.15mODN

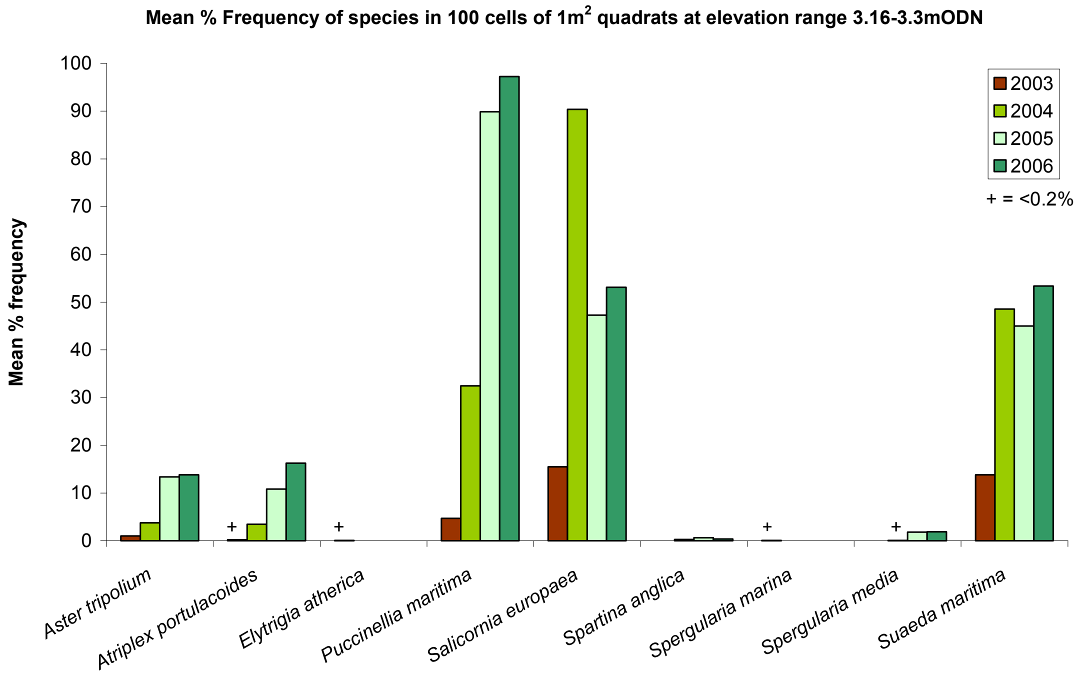


Fig. 5.39a. Mean percentage frequency of occurrence of species in 100 cells of 1m^2 quadrats inside the realignment site at elevation range 3.16-3.3mODN

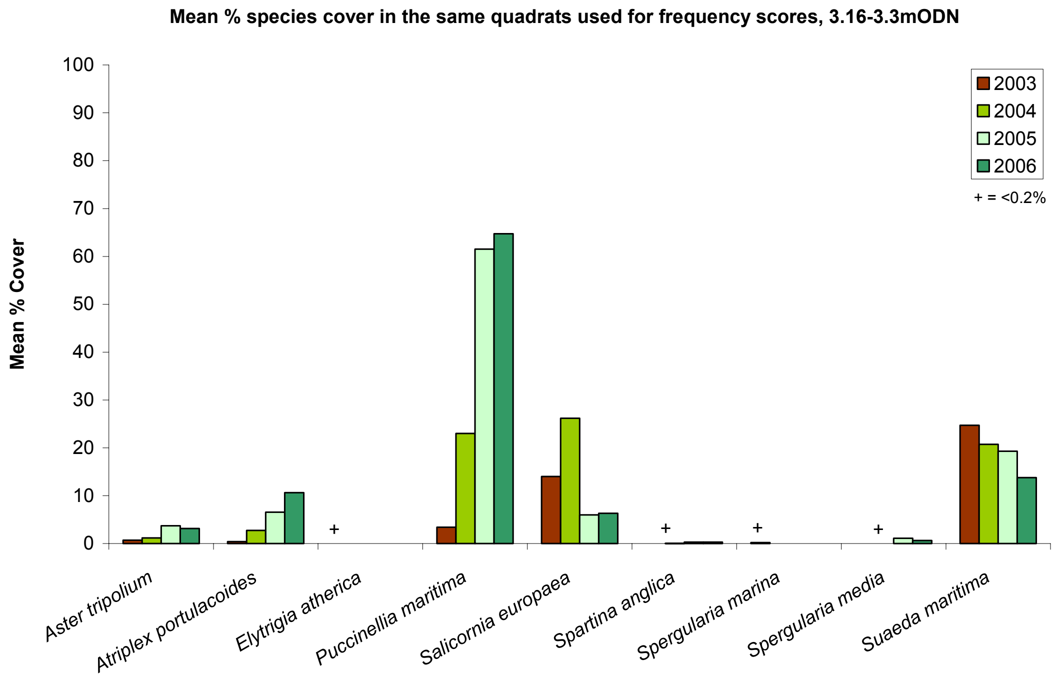


Fig. 5.39b. Mean percentage cover of species in the same quadrats as percentage frequency measurements above, at elevation range 3.16-3.3mODN

5.4.10 5 x 5m Quadrats inside the realignment site: Summary of plant species composition and percentage cover

The 5m x 5m quadrats were set up primarily as ground reference data for aerial remote sensing of the Freiston realignment and surrounding salt marsh (Thomson *et al*. 2003a & b, 2004), but the results for these larger quadrats inside the realignment are shown here to demonstrate that the changes in species composition show similar trends to those described for the smaller quadrats. The elevations are mean values of about 20 readings taken across each of the 5m x 5m quadrats.

The lowest of these large quadrats is just 6cm lower than 3mODN. The figures showing the data are grouped in the same elevation range as discussed above, and shown in order of ascending elevation. There are two additional quadrats which were at elevations just over 3.3mODN. Positions of the quadrats are shown in Fig. 2.2 (Transect and Site Establishment, Chapter 2). Quadrats A3, B2, C4, D3, and D5 are close to the sampling sites with this notation (e.g. A3, close to TAS3). Quadrats X1, X2, X4 (X3 was set up but markers had gone after the first year) are additional quadrats away from the transect sampling sites, selected to provide more ground reference information, including the patch of *Elytrigia atherica* (quadrat X4) at the back of the site at the northwestern end. A further quadrat was set up in 2005 at the back of the site at the southern end to represent an area predominantly covered by *Atriplex portulacoides* (quadrat Y1).

Because these data were used for ground reference, the sum of percentage species composition was adjusted in proportion for each species and bare ground to a total of 100%, rather than showing the individual species totals (as in the 5x1m^2 quadrats).

2.7-2.99mODN (Figs 5.40a, 5.40b; quadrats X2 & X1)

These two quadrats have a mean elevation of 2.94 and 2.99mODN, at the top of this elevation range. As seen previously in the 5x1m^2 quadrats, both X2 and X1 showed the initial dominance of the annual *Salicornia europaea*, which has continued over the four year monitoring period. Both also showed a decrease in *Salicornia europaea* cover between 2004 and 2005. In these lower elevation plots that were dominated by a single annual species such as *Salicornia europaea*, whose populations can fluctuate greatly from year to year, the changing abundance in *Salicornia europaea* was consequently reflected in the total vegetation cover (shown on the right hand side of the figures). The drop in annual *Salicornia europaea* colonisation between 2004 and 2005 (and decrease in individual plant size) was the main cause of the decrease in mean total percentage vegetation cover between these years in the 2.7-2.99mODN category, described earlier for the smaller quadrats and shown in Fig. 5.30. This decline continued in quadrat X2, although there was an increase again in X1 in 2006, seen in various 5x1m^2 quadrats (Appendix A5.4) at lower elevations where recruitment and establishment may have been better, and where there has been generally less competition from perennial species such as *Puccinellia maritima*. The other annual, *Suaeda maritima* has been the next most important component of the vegetation in most years. Other common species occurring in lower amounts at this elevation were *Puccinellia maritima*, *Spartina anglica*, and *Aster tripolium*. All these observations were consistent with the findings in the smaller 5x1m^2 quadrats at this elevation range.

3.0-3.3mODN (Figs. 5.41 a-e, quadrats D5, D3, C4, A3, B2)

Quadrat D5, just squeezes in to this category, with a mean elevation of 3.0mODN, but its range was 2.98-3.02mODN, with about half of the quadrat lying just below 3mODN. It differed from the other quadrats in this category in species dominance in 2005 and 2006. All elevation measurements taken in the other 4 quadrat sites were above 3.0mODN. In 2003, the main contribution to cover in all quadrats in this elevation range was annual *Suaeda maritima*, followed by annual *Salicornia europaea*, with small amounts of the other common species: *Puccinellia maritima, Spartina anglica* and *Aster tripolium*. In the lowest quadrat, D5, *Salicornia europaea* had a particularly good recruitment year in 2004 (with *Suaeda maritima* correspondingly diminished) but declined rapidly after 2004, and again *Suaeda maritima* took over as the dominant plant and has remained dominant up to 2006. *Puccinellia maritima* has increased steadily in this quadrat but was still a fraction of the cover of *Suaeda maritima* in 2006. Also in this lowest of the 5 quadrats, *Atriplex portulacoides* was not present until 2006.

The remaining 4 quadrats (mean elevations 3.18mODN to 3.25mODN) showed a similar pattern of species succession, in which *Puccinellia maritima* replaced the annuals as the dominant species by 2005. The rapid spread of *Puccinellia maritima* was particularly marked in the three highest quadrats (mean elevations 3.20-3.25mODN), reaching approximately 70% or greater by 2005. *Atriplex portulacoides* was found present in the 4 quadrats at 3.18mODN and above during the first year (2003) and had increased in all by 2006, although to no more than 8%. Other common species present at low cover in all quadrats were *Aster tripolium* (up to 5%) and *Spartina anglica* (up to 3%, but absent from the highest quadrat B2). *Spergularia media* was found in the three highest quadrats (3.20mODN and above) at low cover of <1%. *S. media* was found less frequently than the common species listed above, both on the salt marsh and in the realignment. It was recorded in several sites in the realignment 5 x 1m^2 quadrats, but only at elevations >3mODN and mainly (most records) in the 3.16-3.3mODN range category.

The pattern of species composition, plant establishment, spread, and vegetation succession in the large quadrats was again similar to those in the 5m x 1m^2 quadrats at this elevation range.

Quadrats X4 and Y1, mean elevation 3.39 & 3.40mODN (Figs. 5.42 a & b)

These two quadrats are at higher elevations than the accretion site-associated quadrats (5 x 1m^2) and were selected for their specific plant composition as reference data for remote sensing.

At X4, *Elytrigia atherica* had colonised in the first year (39% cover), along with the early pioneers *Suaeda maritima* (8%) and *Salicornia europaea* (20%), and it has been dominant throughout, reaching a cover of 89% in 2006. *Suaeda maritima* and *Salicornia europaea* declined dramatically after 2003, and by 2006 *Salicornia europaea* had gone and *Suaeda maritima* was reduced to just 0.5% cover. *Puccinellia maritima* increased from 1% to 6% between 2003 and 2004 but has decreased since to 3% in 2006. *Aster tripolium* was recorded with 0.5-5% cover and *Spergularia media* at 0.5% cover in all years. The only species that has extended its cover, in spite of the relatively dense *Elytrigia atherica,* was *Atriplex portulacoides* which increased its cover from 1% in 2003 to 6% in 2006. *Atriplex portulacoides* is frequently found mixed in with, and under, *Elytrigia atherica* in upper marsh zones except where the latter is too dense and long established.

Quadrat Y1 was set up in 2005 as an example of *Atriplex portulacoides* cover type. In two years, this species increased in cover from 75% to 90%. *Puccinellia maritima* was found at 5% cover in both years, *Suaeda maritima* dropped from 2% to 1%, and the remaining species: *Aster tripolium*, *Salicornia europaea*, *Spartina anglica* and *Spergularia media* were recorded at <1% cover. This quadrat lies just below a higher area which was covered with *Elytrigia atherica*. In time it is likely that *Elytrigia atherica* will invade this quadrat area which had a similar elevation to quadrat X4. Transition from *Atriplex portulacoides* to *Elytrigia athercia* is the usual progression on many east coast marshes near the upper limits of the tide. However, *Atriplex portulacoides* can persist for many years even with competition from dense *Elytrigia athercia* growth.

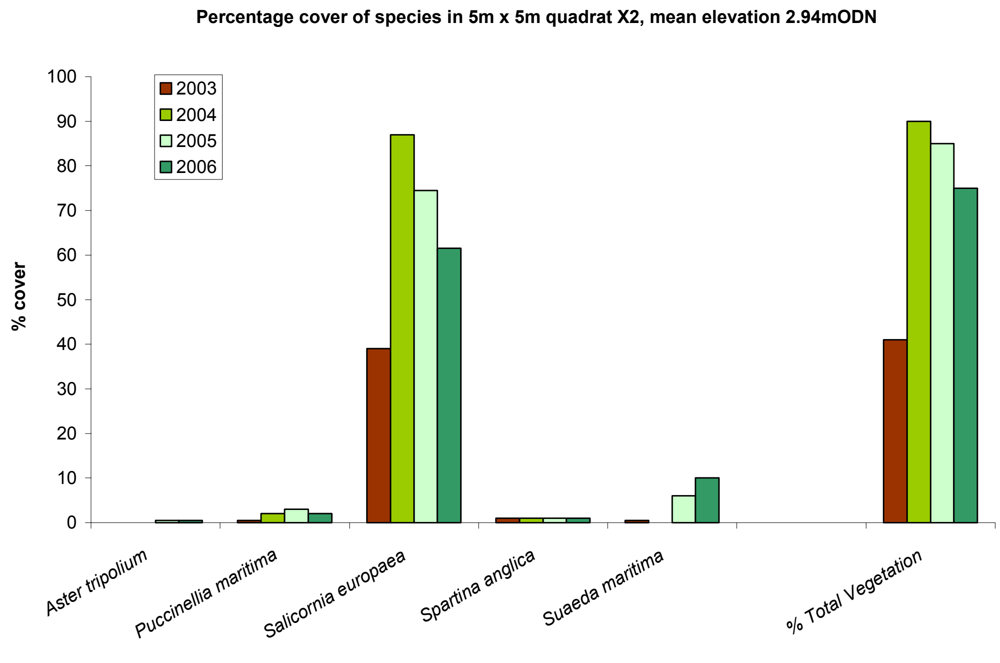


Fig. 5.40a. Mean percentage species cover in quadrat X2, mean elevation 2.94mODN

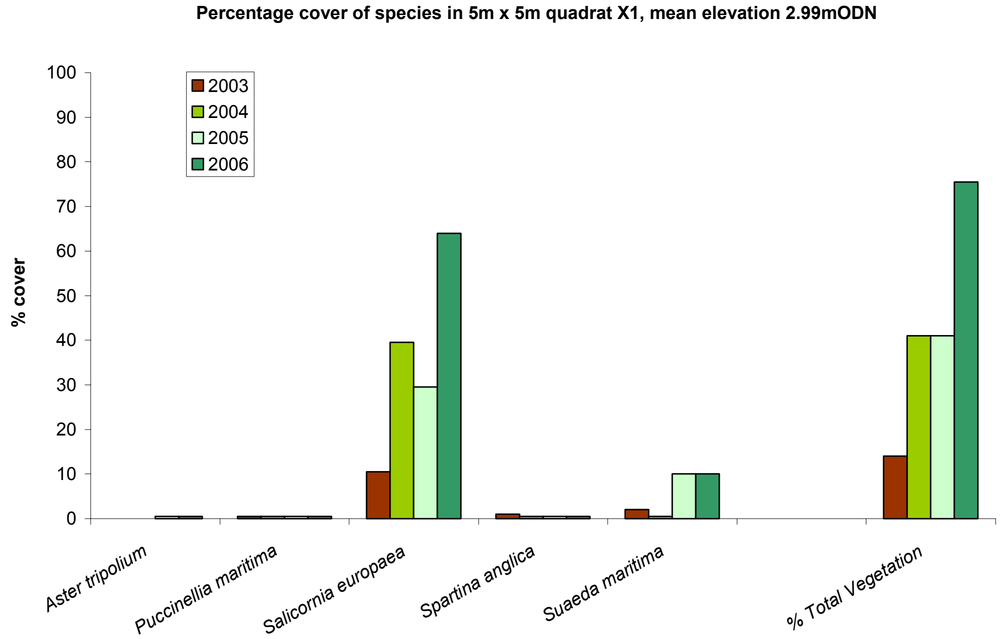


Fig. 5.40b. Mean percentage species cover in quadrat X1, mean elevation 2.99mODN

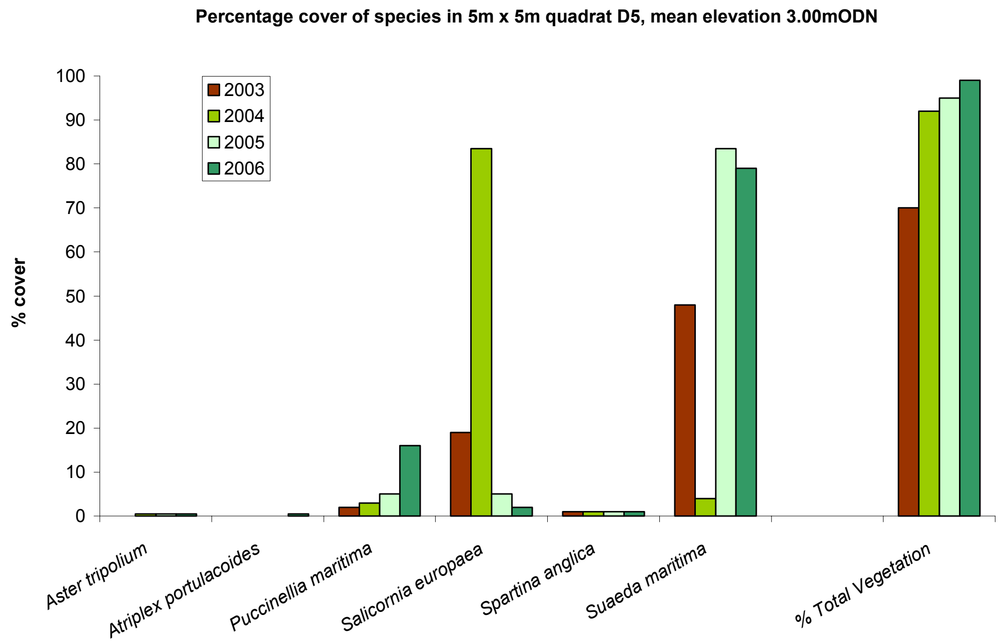


Fig. 5.41a. Mean percentage species cover in quadrat D5, mean elevation 3.00mODN

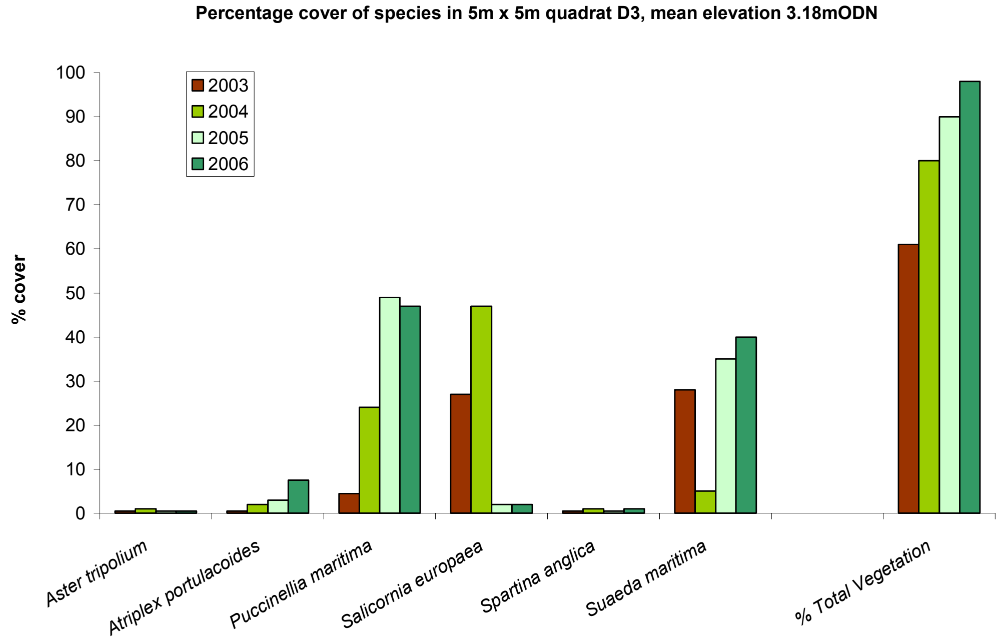


Fig. 5.41b. Mean percentage species cover in quadrat D3, mean elevation 3.18mODN

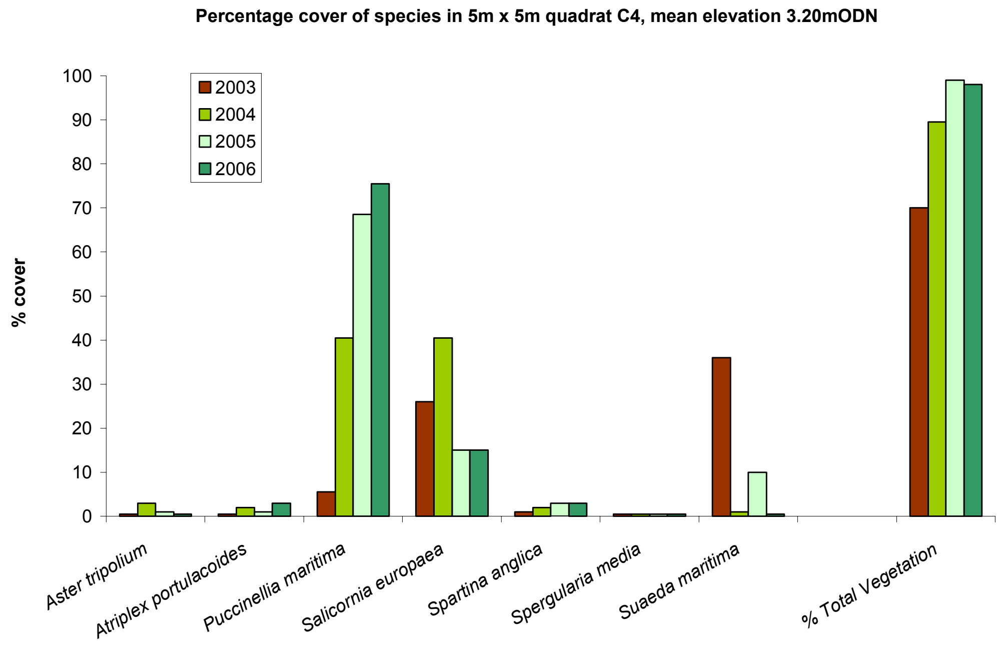


Fig. 5.41c. Mean percentage species cover in quadrat C4, mean elevation 3.20mODN

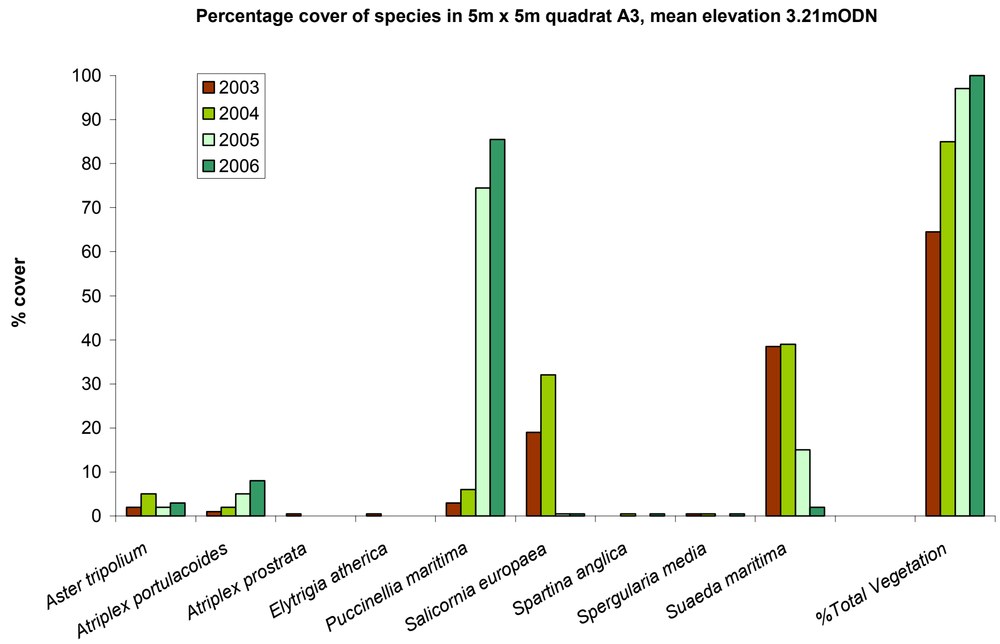


Fig. 5.41d. Mean percentage species cover in quadrat A3, mean elevation 3.21mODN

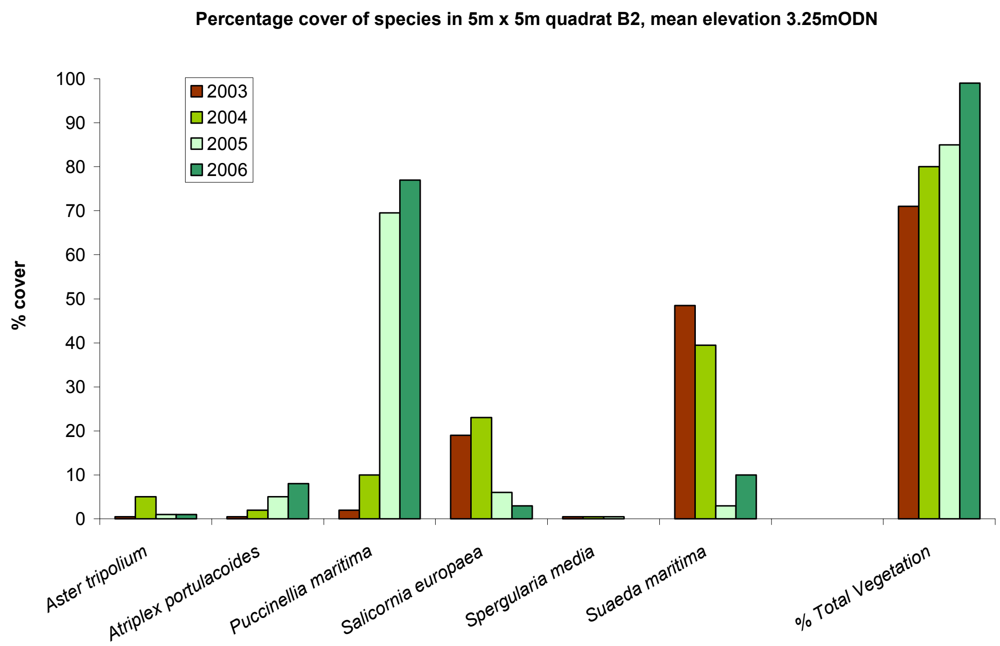


Fig. 5.41e. Mean percentage species cover in quadrat B2, mean elevation 3.25mODN

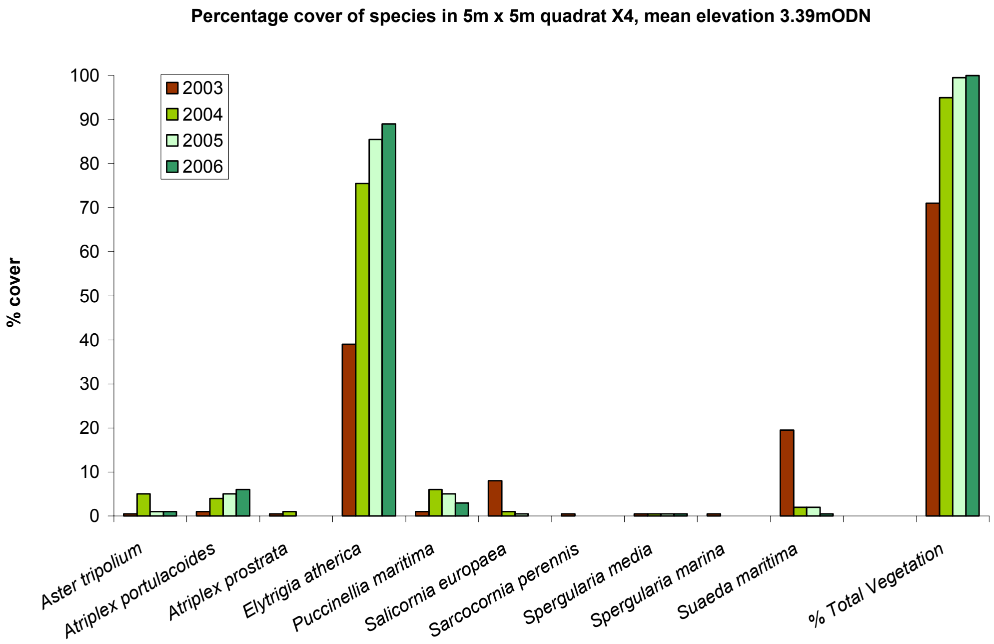


Fig. 5.42a. Mean percentage species cover in quadrat X4, mean elevation 3.39mODN

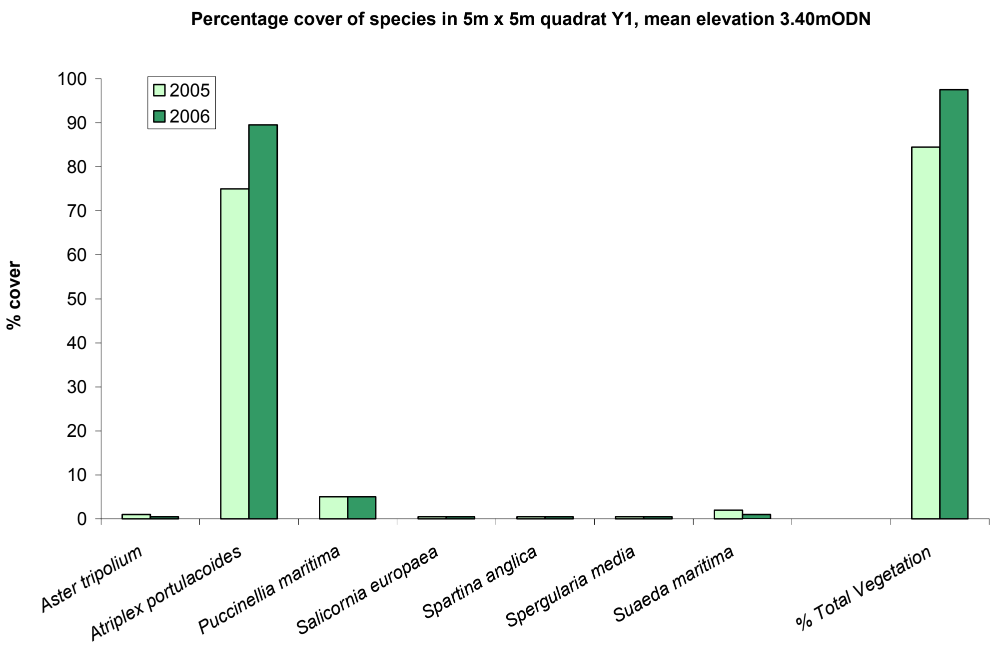


Fig. 5.42b. Mean percentage species cover in quadrat Y1, mean elevation 3.40mODN

5.4.11 Comparison of NVC Communities and order of species abundance inside and outside the realignment site

Descriptions of species composition and abundance have so far summarised the mean cover values in different elevation categories.

An attempt was made to match the 5 x 1m^2 2006 quadrat data at each individual site to NVC Communities (Rodwell 2000) using MATCH, a programme developed by the University of Lancaster. The data from 2005 were used for the two sites lost last year to cattle poaching: T5S1 and T6S2. Homogenous community types are needed for NVC analysis, but the managed realignment site is in rapid transition between community compositions, so the most abundant species (>10% cover) were also listed (in decreasing cover order) to make a comparison between the realignment and outside salt marsh.

The NVC community designations according to the best fit determined by MATCH are shown in Tables 5.4a-d for each survey site divided into the different elevation categories outside on the salt marsh and inside the realignment. The main species at each sampling site, in order of cover importance down to 10% mean cover, are also listed in the same tables.

3.16-3.30mODN, outside and inside the realignment site (Table 5.4a)
[Outside MR: 7 sites; inside MR: 11 sites]

In this higher elevation group, most of the salt marsh outside the realignment is covered predominantly by *Atriplex portulacoides*, sometimes with patches of dense *Puccinellia maritima* between the *Atriplex* stands, and most sites were matched, as expected, to SM14a: *Halimione (=Atriplex) portulacoides* salt marsh, *Halimione* sub-community.

Exceptions were T5S1 and T6S2. At T5S1, the quadrats lie across a patch of predominantly *Puccinellia maritima* with scattered *Atriplex portulacoides* bushes, for which the most closely matched NVC classifications were SM14a and also SM10 (Transitional low marsh vegetation). This site is relatively high in the tidal frame (and not transitional low marsh) and seems to be closer to SM13 (*Puccinellia maritima* salt marsh community) and the *Puccinellia maritima* is dense here, but this was not picked out in the list of probables produced by the MATCH programme (some species typical of this community are absent in the relatively low diversity on the salt marsh near Freiston). T6S2 is in an area of short *Puccinellia maritima* (that seems to be particularly favoured for grazing by wildfowl), interspersed with *Salicornia europaea*, *Aster tripolium*, *Spartina anglica*, *Suaeda maritima*, *Spergularia media*, and small *Atriplex portulacoides* plants. The MATCH programme identified this area as SM10.

In the realignment site, only the two highest sites matched the community designation SM14a, with the remainder identified by best fit in MATCH as SM10. The most prominent cover species in the remaining sites (except the lowest one) was *Puccinellia maritima*, some with *A. portulacoides* covering >10% of the quadrats, and others which still had a >10% contribution by the annuals *Suaeda* *maritima*, and/or *Salicornia europaea* in 2006. The lowest site in this elevation range (TES1) was still dominated by *Suaeda maritima*, followed by *Puccinellia maritima*, in 2006.

The main cover species outside the realignment site in this elevation range (*Atriplex portulacoides* and *Puccinellia maritima*) were important cover species in most of the sites in the realignment (*A. portulacoides* generally above 3.2mODN). However, *Atriplex portulacoides* still has to increase its cover in most of the realignment sites in this elevation group for the sites to be matched to equivalent salt marsh communities to those found outside.

3.0-3.15mODN, outside and inside the realignment site (Table 5.4b)
[Outside MR: 6 sites; inside MR: 13 sites, one with standing water]

Four out of the 6 sites on the salt marsh in this range were identified as SM14a, with *Atriplex portulacoides* or *Puccinellia maritima* as the main cover species. The remaining two sites were matched as SM10, and SM10/SM11 (SM11: *Aster tripolium* community) for the lowest site.

All sites in the realignment matched to SM10, except for one at the lower end of the elevation range (TES3), still dominated by *Salicornia europaea* in 2006 (other species present at <10%) which was identified as SM8 (Annual *Salicornia* saltmarsh community). Five out of the 12 vegetated realignment sites had *Puccinellia maritima* as the most abundant species, two of them with *Atriplex portulacoides* as a component with >10% cover. Five sites still had *Salicornia europaea* as their primary species in 2006, with or without *Puccinellia maritima* present at over 10% cover, and two contained *Suaeda maritima* as the most prominent species, with either more than 10% of *Puccinellia maritima* or *Atriplex portulacoides*.

The species mix between the realignment and outside was similar, although *Aster tripolium* was not yet present at > 10% inside the realignment (but it has been increasing). The main difference was the greater abundance of *Atriplex portulacoides* outside.

2.7-2.99mODN, outside and inside the realignment site (Table 5.4c)
[Outside MR: 13 sites; inside MR: 12 sites, one with permanent standing water]

The highest site outside the realignment in this elevation category had *Atriplex portulacoides* as its main species, with > 10% *Puccinellia maritima*, *Suaeda maritima* and *Aster tripolium*, and was classified as SM14a. The remainder came out as mainly SM10 or occasionally as *Aster tripolium* salt marsh community (SM11). *Aster tripolium* was the most abundant cover species at two sites, and present with more than 10% cover in four other sites (5 including the highest site, noted above). Nine out of twelve sites (excluding the *Spartina anglica* patch) had the annuals *Salicornia europaea* or *Suaeda maritima* as their dominant species. One site (T5S5), the largest *Spartina anglica* patch in the area, was selected specifically for ground reference data of this community and we included an accretion and vegetation monitoring site here. This was NVC classification SM6 (*Spartina anglica* salt marsh community).

Inside the realignment, 8 sites came out as SM10, two as SM8 (Annual *Salicornia*) and one as SM9 (Suaeda *maritima* salt marsh community). The annuals, either *Salicornia europaea* or *Suaeda maritima* were the most abundant species in all sites, with *Puccinellia maritima* present at >10% in 3 sites, and *Atriplex portulacoides* in one site. *Aster tripolium* was present at these elevations, but was not recorded at >10%. In general, the species mix inside and outside the realignment at lower elevations was similar (apart from the *Atriplex portulacoides* community in the highest site on the salt marsh within this elevation range).

<2.7mODN, outside the realignment only (Table 5.4d)
[12 sites]

In the pioneer zone and at the marsh front the dominant species on the six lowest sites (<2.55mODN) was *Salicornia europaea*, NVC community: SM8, annual *Salicornia* salt marsh. Above 2.55mODN, *Salicornia euopaea* was also the most abundant species at five out of six sites, with or without *Suaeda maritima* over 10% cover, and *Suaeda maritima* was the dominant plant at one site. Two sites came out of the NVC analysis with a best fit to SM9, *Suaeda maritima* salt marsh community, and three to SM10 (Transitional low marsh vegetation). One site with *Salicornia europaea*, followed by *Aster tipolium* and *Spartina anglica*, both over 10% cover, was most closely matched to SM6 (*Spartina anglica* salt marsh) or SM11 (*Aster tripolium var. discoides* salt marsh community).

Table 5. 4a. Main species in sites outside and inside the managed realignment at equivalent elevation ranges and NVC community types (determined by MATCH)
(a) 3.16-3.3mODN

Transect & Site	Elevation (mODN)	Elevation Range 3.16-3.3mODN Dominant/abundant species >10%mean cover	NVC Community
		OUTSIDE MR	
T6S1	3.29	*A.portulacoides, P.maritima*	SM 14a *A. portulacoides* salt marsh, *A.p.* sub-community
T2S2	3.28	*A.portulacoides*	SM 14a *A. portulacoides* salt marsh, *A.p.* sub-community
T5S1	3.26	*P.maritima, A.portulacoides*	SM10 Transitional low marsh vegetation / SM 14a
T5S2	3.26	*A.portulacoides*	SM 14a *A. portulacoides* salt marsh, *A.p.* sub-community
T5S3	3.21	*A.portulacoides*	SM 14a *A. portulacoides* salt marsh, *A.p.* sub-community
T6S2	3.20	*P.maritima, S.europaea*	SM10 Transitional low marsh vegetation
T1S1	3.16	*A.portulacoides*	SM 14a *A. portulacoides* salt marsh, *A.p.* sub-community
		INSIDE MR	
TAS2	3.26	*P.maritima*	SM14a *A.portulacoides* salt marsh, *A.p.* sub-community
TAS4	3.26	*A.portulacoides, P.maritima*	SM14a *A.portulacoides* salt marsh, *A.p.* sub-community
TAS1	3.24	*P.maritima*	SM10 Transitional low marsh vegetation
TCS1	3.24	*P.maritima, A.portulacoides, Su.maritima*	SM10 Transitional low marsh vegetation
TBS2	3.22	*P.maritima, A.portulacoides*	SM10 Transitional low marsh vegetation
TCS3	3.21	*P.maritima, S.europaea*	SM10 Transitional low marsh vegetation
TAS3	3.20	*P.maritima, A.portulacoides*	SM10 Transitional low marsh vegetation
TCS2	3.20	*P.maritima, S. europaea*	SM10 Transitional low marsh vegetation
TBS3	3.18	*P.maritima, S.europaea, Su.maritima*	SM10 Transitional low marsh vegetation
TDS1	3.17	*P.maritima, Su.maritima*	SM10 Transitional low marsh vegetation
TES1	3.16	*Su.maritima, P.maritima*	SM10 Transitional low marsh vegetation

Table 5. 4b. Main species in sites outside and inside the managed realignment at equivalent elevation ranges and NVC community types (determined by MATCH)
(b) 3.0-3.15mODN

Transect & Site	Elevation (mODN)	Elevation Range 3.0-3.15mODN Dominant/abundant species >10%mean cover	NVC Community
		OUTSIDE MR	
T2S1	3.15	*P.maritima, A.portulacoides, Su.maritima*	SM 14a *A. portulacoides* salt marsh, *A.p.* sub-community
T6S3	3.14	*A.portulacoides, P.maritima*	SM 14a *A. portulacoides* salt marsh, *A.p.* sub-community
T2S3	3.08	*A.portulacoides*	SM 14a *A. portulacoides* salt marsh, *A.p.* sub-community
T5S4	3.04	*P.maritima, S.anglica*	SM10 Transitional low marsh vegetation
T1S2	3.01	*A.portulacoides*	SM 14a *A. portulacoides* salt marsh, *A.p.* sub-community
T3S1	3.00	*Su.maritima, A.portulacoides, A.tripolium, P.maritima*	SM11 *A.tripolium var. discoides* salt marsh community /SM10 Transitional low marsh vegetation.
		INSIDE MR	
TBS1	3.13	Standing water, no vegetation	
TCS6	3.13	*S.europaea*	SM10 Transitional low marsh vegetation
TES2	3.13	*P.maritima, Su.maritima*	SM10 Transitional low marsh vegetation
TAS5	3.11	*P.maritima, A.portulacoides*	SM10 Transitional low marsh vegetation
TCS4	3.11	*P.maritima, S.europaea*	SM10 Transitional low marsh vegetation
TCS5	3.10	*S.europaea*	SM10 Transitional low marsh vegetation
TBS5	3.08	*S.europaea, P.maritima*	SM10 Transitional low marsh vegetation
TDS3	3.08	*P.maritima, S.europaea, Su.maritima, A.portulacoides*	SM10 Transitional low marsh vegetation
TBS4	3.06	*S.europaea, P.maritima*	SM10 Transitional low marsh vegetation
TDS2	3.06	*P.maritima, S.europaea*	SM10 Transitional low marsh vegetation
TFS3	3.04	*Su.maritima, P.maritima*	SM10 Transitional low marsh vegetation
TES3	3.01	*S.europaea*	SM 8 Annual *Salicornia* salt marsh community
TFS4	3.00	*Su.maritima, A.portulacoides*	SM10 Transitional low marsh vegetation

Table 5. 4c. Main species in sites outside and inside the managed realignment at equivalent elevation ranges and NVC community types (determined by MATCH). (c) 2.7-2.99mODN

Transect & Site	Elevation (mODN)	Elevation Range 2.7-2.99mODN Dominant/abundant species >10%mean cover	NVC Community
		OUTSIDE MR	
T2S4	2.98	*A.portulacoides, P.maritima, Su.maritima, A.tripolium*	SM 14a *A. portulacoides* salt marsh, *A.p.* sub-community
T1S3	2.97	*Su.maritima, P.maritima*	SM10 Transitional low marsh vegetation
T5S5	2.96	Large *S.anglica* patch – selected for this species type	SM 6 *Spartina anglica* salt marsh community
T6S4	2.92	*S.europaea, P.maritima, S.anglica, Su.maritima, A.tripolium*	SM11. *Aster tripolium var. discoides* salt marsh community *
T4S1	2.91	*Su.maritima, P.maritima, A.tripolium, A.portulacoides, S.anglica*	SM10 Transitional low marsh vegetation
T2S5	2.90	*A.tripolium, S.europaea*	SM10 Transitional low marsh vegetation
T3S2	2.83	*A.tripolium, S.europaea, Su.maritima*	SM10 Transitional low marsh vegetation
T3S3	2.82	*S.europaea, Su.maritima*	SM10 Transitional low marsh vegetation
T4S2	2.80	*S.europaea, A.tripolium, S.anglica*	SM11 *Aster tripolium var. discoides* salt marsh community *
T1S4	2.79	*Su.maritima, S.europaea, A.tripolium*	SM10 Transitional low marsh vegetation
T4S3	2.78	*Su.maritima, S.europaea*	SM10 Transitional low marsh vegetation
T6S5	2.78	*S.europaea, Su.maritima*	SM10 Transitional low marsh vegetation
T6S6	2.73	*S.europaea, S.anglica*	SM10 Transitional low marsh vegetation
		INSIDE MR	
TBS6	2.99	*S.europaea, P.maritima, Su.maritima*	SM10 Transitional low marsh vegetation
TFS2	2.97	*S.europaea, Su.maritima*	SM 9 *Suaeda maritima* salt marsh community
TES4	2.96	*S.europaea, Su.maritima*	SM10 Transitional low marsh vegetation
TFS1	2.96	Permanent standing water, no vegetation	
TFS5	2.95	*Su.maritima, A.portulacoides, p.maritima*	SM10 Transitional low marsh vegetation
TFS6	2.94	*Su.maritima, P.maritima*	SM10 Transitional low marsh vegetation
TDS4	2.93	*S.europaea*	SM 8 Annual *Salicornia* salt marsh community
TES5	2.92	*S.europaea*	SM10 Transitional low marsh vegetation
TDS5	2.91	*Su.maritima, S.europaea*	SM10 Transitional low marsh vegetation
TES6	2.88	*S.europaea, Su.maritima*	SM10 Transitional low marsh vegetation
TAS6	2.87	*S.europaea, Su.maritima*	SM10 Transitional low marsh vegetation
TDS6	2.76	*S.europaea* (7.2%)	SM 8 Annual *Salicornia* salt marsh community

Table 5. 4d. NVC community types and main species outside the managed realignment at elevation range <2.7mODN (no equivalent inside MR)

Transect & Site	Elevation (mODN)	Elevation Range <2.7mODN Dominant/abundant species >10%mean cover	NVC Community
		OUTSIDE MR	
T2S6	2.69	*S.europaea, A.tripolium, S.anglica*	SM 6 *S.anglica* salt marsh community /SM11 *A.tripolium var.discoideus* community*
T4S4	2.69	*S.europaea, Su.maritima*	SM9 *Suaeda maritima* salt marsh community
T3S4	2.68	*S.europaea*	SM10 Transitional low marsh vegetation
T5S6	2.68	*S.europaea, Su.maritima*	SM10 Transitional low marsh vegetation
T1S5	2.57	*S.europaea, Su.maritima*	SM10 Transitional low marsh vegetation
T2S7	2.56	*Su.maritima, S.europaea*	SM9 *Suaeda maritima* salt marsh community
T3S5	2.54	*S.europaea*	SM 8 Annual *Salicornia* salt marsh community
T1S6	2.38	*S.europaea*	SM 8 Annual *Salicornia* salt marsh community
T2S8	2.33	*S.europaea*	SM 8 Annual *Salicornia* salt marsh community
T6S7	2.30	*S.europaea*	SM 8 Annual *Salicornia* salt marsh community
T5S7	2.28	*S.europaea*	SM 8 Annual *Salicornia* salt marsh community
T4S5	2.09	*S.europaea*	SM 8 Annual *Salicornia* salt marsh community
		NO EQUIVALENT ELEVATION SITES INSIDE MR	

5.5 Discussion

The salt marshes around the Wash are relatively low in species number, and the marshes have no gently sloping upper salt marsh transition zones, due to the truncation by high grassy embankments that provide flood defence. The main species around the Freiston area (and generally in the Wash) are *Atriplex portulacoides* (Sea purslane) in the middle to upper parts and along creek levees; *Puccinellia maritima* (Common Saltmarsh-grass) and *Spergularia media* (Greater Sea-spurrey) from the upper part of the pioneer zone to upper areas; *Spartina anglica* (Common Cord-grass), the biennial (or sometimes annual) *Aster tripolium* (Sea Aster), and the annuals *Salicornia spp.* (mainly *europaea*, Common Glasswort) and *Suaeda maritima* (Annual Sea-blite), all concentrated in the pioneer zone and lower marsh, but scattered throughout. Smaller amounts of other species are found in this area of the Wash, including: *Sarcocornia perennis* (perennial Glasswort), *Cochlearia spp*. (*Cochlearia anglica* and *C.officinalis*, English and Common Scurvy-grass respectively), and occasional *Limonium vulgare* (Sea Lavender), *Triglochin maritima* (Sea Arrow-grass) and *Plantago maritima* (Sea Plantain). *Spergularia marina* (Lesser Sea-spurrey) is found occasionally in upper disturbed areas. *Festuca rubra* (Red Fescue) and *Glaux maritima* (Sea-milkwort) can be found in a narrow zone near the base of the defence embankments around the Wash, but *Glaux maritima* has not been noted in the Freiston area, and if *Festuca* occurs here, it is not common and was not found. *Elytrigia atherica* (Sea Couch) is a common species at higher levels near the tidal limit on salt marshes, including the Wash, although there is little at Freiston on the salt marsh itself, probably because the elevation is generally not high enough for this species, except for a narrow zone truncated by the defence embankments, some of which are regularly grazed and trampled by cattle which may prevent its spread. It is likely that cattle on the marsh would deter the growth of *Elytrigia atherica*, because poaching creates waterlogged holes. Cattle graze north of the realignment site but grazing ceased south of the realignment site at Freiston for a few years (from around the time that the realignment site was created). However, grazing cattle were re-introduced to the southern part of the salt marsh study area by 2006. *Elytrigia atherica* occurs at the base of the breached embankment in front of the realignment site in areas fenced off to cattle and it is common within the fenced realignment sites, around the margins and other higher areas of the site.

The Freiston realignment site has become vegetated very quickly, and all of the common species found outside on the salt marsh have been found in the realignment. Elevation is of key importance for the establishment and survival of salt marsh species and the entire Freiston site elevations are appropriate for all major vegetation community types found outside on the adjacent marshes. The distribution of the major species within the realignment coincides with their elevational niche outside, although the site has not yet had sufficient development time for species densities and relative abundance to become equivalent to outside.

Successful colonisation and establishment of salt marsh vegetation on a newly created site depends on a number of factors including the appropriate elevation, a good supply of propagules (seeds and tiller fragments), dispersal into the site primarily by the tides (but also other ways e.g. in mud on birds' feet) and deposition in suitable conditions (e.g. the appropriate elevation for the species, good surface drainage, sufficient shelter etc.). The establishment of annual pioneer species such as *Salicornia europaea* at the front of an open salt marsh depends on the young seedlings not being washed out by wave action before they have formed sufficient anchoring roots. Any storms during this crucial time can have a major effect on plant survival. The presence of the former embankment provides shelter from wave action for most of the realignment site except perhaps for areas immediately opposite the breaches. A considerable amount of standing water remains on parts of the site after the tide has receded as it is relatively flat. However, creeks have been forming rapidly to increase drainage after tidal inundation.

The Wash marshes are very extensive and can therefore provide abundant propagules to be washed into the realignment site, and the rapid colonisation by pioneer species in the first year after the breach is testament to this. Although less ubiquitous than *Salicornia europaea* and *Suaeda maritima*, there were also many small specimens of perennial species colonising the site in the first year, particularly at higher elevations.

Salicornia europaea had a very good year in 2004, when species frequency and cover increased dramatically. In the second year, there must have been an enormous abundance of seeds produced within the site, which was covered almost entirely by this species in the first year, plus an additional supply washing in from the adjacent marsh. There was also still a considerable amount of bare sediment for colonisation, in sheltered conditions.

Frequency of *Suaeda maritima* also increased most rapidly between 2003 and 2004 particularly at higher elevations. On pioneer salt marshes where *Suaeda mariitma* and *Salicornia europaea* occur together, *Suaeda maritima* tends to occur on slightly higher, better drained areas than *Salicornia europaea*. *Salicornia europaea* declined in frequency between 2004 and 2005, but the decrease in frequency was less marked than the decrease in mean cover. *Suaeda maritima* cover decreased each year at higher elevations in spite of maintaining similar frequencies. The main reason for the mis-match in cover and frequency was due to size changes in these annuals, from tall and branched specimens in the early years to much smaller single stemmed plants in later years. There was no competition from other species in the first year colonising the bare site, and the plants may have benefited from nutrient enrichment in the agricultural soil. In later years, particularly at the higher elevation sites where mean cover values for *Salicornia europaea* and *Suaeda maritima* showed the greatest decline, there has been increasing competition from the spread of perennial species, primarily *Puccinellia maritima* and *Atriplex portulacoides*.

Examination of the vegetation data according to elevation, a key environmental variable influencing salt marsh species distribution, has proved to be a useful approach to compare the vegetation establishment in the realignment site with the reference marsh outside, in order to assess the success of the habitat creation. Analysis of the data according to elevation category has helped to interpret the process and extent of species succession, which varies at different elevations. Many of the details would be masked if the entire realignment site was compared with the salt marsh, even if the outside salt marsh sites were restricted to the elevation range of the realignment.

As expected, the pioneer annuals were the first to colonise the realignment and *Salicornia europaea* and *Suaeda maritima* were the dominant species throughout the site in 2003, at all elevations. Between 2003 and 2006, the pioneer annuals remained the most abundant species at lower elevations in the realignment, but other species have established and spread, particularly at the higher elevations, where the annuals have been replaced by the perennial *Puccinellia maritima* as the dominant species. The perennial *Atriplex portulacoides*, most abundant outside on the salt marsh at higher elevations has shown a steady increase at higher elevations in the realignment, and by 2006 was the second most important cover species after *Puccinellia maritima* in the highest elevation range category (3.16-3.3mODN). There was a good agreement between the species present inside and outside at equivalent elevation ranges. The main difference was in the relative dominance of perennial species at higher elevations.

We attempted NVC analysis using MATCH software to compare the vegetation in the individual site quadrats in the realignment in 2006 with outside, although there are limitations, particularly for the realignment site. Homogenous community types are needed for NVC analysis, but many salt marsh areas are a mosaic of vegetation patches and because communities are zoned on a shallow gradient there are wide transition areas between typical NVC community zones. Some community designations appear to be very sensitive to the absence of a species that 'should be present' or to just a presence (very low cover) of a species that 'should not be there'. Furthermore, the managed realignment site is in a phase of relatively rapid transition from the first initial colonisation and dominance of pioneer annuals throughout, closely followed by a rapid increase in perennial *Puccinellia maritima* at mid and upper elevations, and *Atriplex portulacoides* which has been increasing steadily, particularly at the highest sites. Therefore these conditions are not ideal for NVC analysis, so we also compared the most abundant species in quadrats inside and outside in different elevation categories.

The comparisons re-enforced our findings from the mean cover values and showed that there was considerable agreement in species composition between the realignment and outside, and in several cases the same dominant species and equivalent NVC designations were found. The greatest similarities between the realignment and outside were in the lowest elevation category. This would be expected as the pioneer annuals are the dominant species at this level outside on the marsh and these plants were the first to colonise the site in abundance in the first year, and have increased their cover between 2003 and 2006 at the lower elevations.

Higher sites above 3mODN had a similar species mix to outside, but relative abundances of species were still different in 2006 and the sites were still undergoing succession towards the typical dominant perennial species and

NVC communities found outside. However, *Atriplex portulacoides* has increased sufficiently in the two highest sites in the realignment for the community type to be designated SM14a, *Atriplex portulacoides* salt marsh community, as found for five out of the seven sites outside in the highest elevation category.

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 to a rough approximation was one ‘elevation category’ behind the community composition outside the realignment by 2006. Accretion rates in the realignment site have been shown to be comparable (over most of the range) to the salt marsh outside (Chapter 3), so the underlying physical process that influences species composition and succession appears to be operating on a similar time scale. It remains to be seen how long it will take for the realignment sites to be indistinguishable, in terms of vegetation composition and relative species abundance to the adjacent salt marsh.

5.6 Conclusion

The vegetation colonisation of the Freiston site has been rapid, all common species found outside the site have been found inside, and were present at their expected elevations. Mean species number was comparable inside and outside on the salt marsh, and even greater inside at the highest elevation sites.

Perennial species have increased their cover year on year and have been replacing the annual pioneer plants as the most abundant species, particularly in the upper half of the elevation range, and some sites were approaching similar community compositions by 2006. Optimum elevations and a good supply of propagules will have been key factors in the rapid vegetation development at Freiston.

It is not surprising after only four years since the site was breached, that succession has not yet produced the equivalent community composition at all sites in terms of relative abundance of the different species as those found on the salt marsh outside the realignment site.

The observed rate of increase in mean total percentage vegetation cover, would suggest that equivalent cover to outside the site could be achieved in two to three years. It may take longer to reach equivalent species abundance and community types, and we have little experience from other sites, but if the major perennials continue to spread as they have in the last two years, the principal author would hazard an estimate that this could be achieved within about five more years.

In conclusion, vegetation establishment and spread within most of the Freiston realignment site has been highly successful (except in areas with poor drainage or creek erosion, see Overview Chapter 9). 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. Over most of the site there appears to be no reason or indication to suggest that it will not.

5.6.1 References

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5.7 Appendix 5

Percentage vegetation cover, species composition and frequency at individual sites; ground reference data for remote sensing; scientific and common names of plant species

Contents:

Appendix A5.1. Mean total percentage cover of vegetation on transects 1-6 outside the realignment site.
Totals are the sum of individual species cover which can exceed 100% in dense vegetation

Appendix A5.2. Mean total percentage cover of vegetation on transects A-F inside the realignment site.
Totals are the sum of individual species cover which can exceed 100% in dense vegetation

Appendix A5.3. Percentage cover of plant species in the 5 x 1m^2 quadrats outside the managed realignment site

Appendix A5.4. Percentage cover of plant species in the 5 x 1m^2 quadrats inside the managed realignment site

Appendix A5.5. Percentage frequency of occurrence of species in the 1x1m^2 quadrats inside the managed realignment site
The quadrats were divided into 100 10cm x 10cm cells.

Appendix A5.6a. Ground reference vegetation data (% cover) from 5x5m quadrats on Transects 1-6 on the salt marsh outside the realignment site
The quadrats were divided into 25 1m^2 cells. Frequency data is provided on an accompanying CD

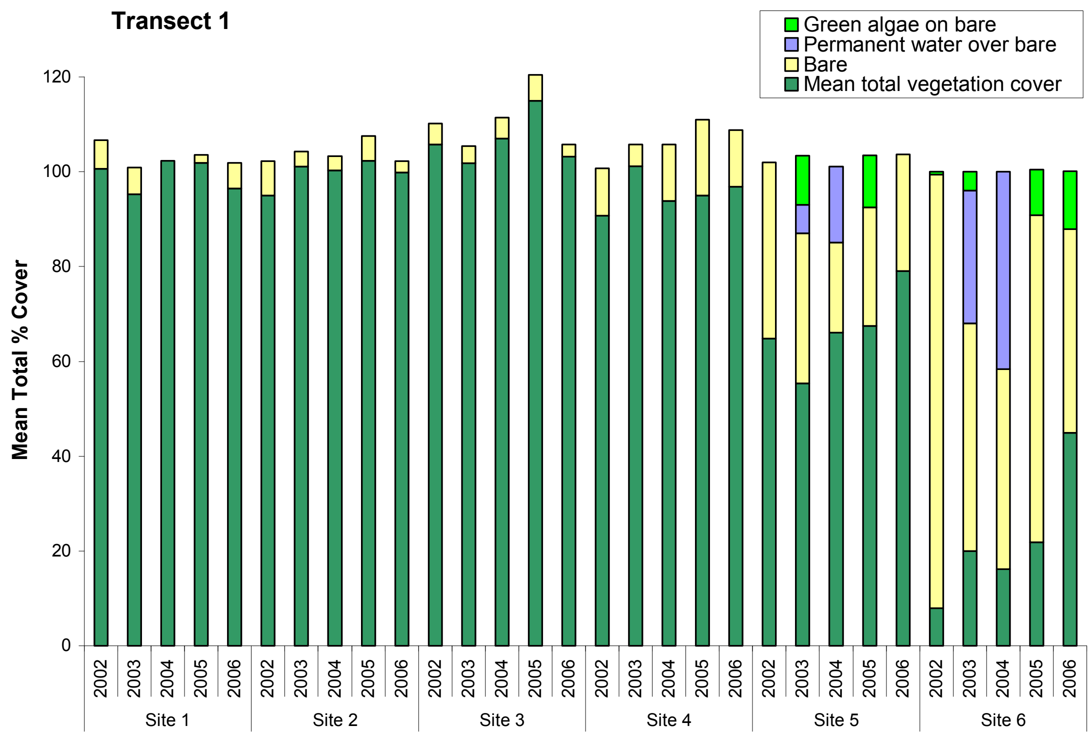
Appendix A5.6b. Ground reference vegetation data (% cover) from 5x5m quadrats inside the realignment site
Frequency data is provided on an accompanying CD

Appendix A5.6c. Notes on ground reference vegetation data from 5x5m quadrats outside and inside the realignment site

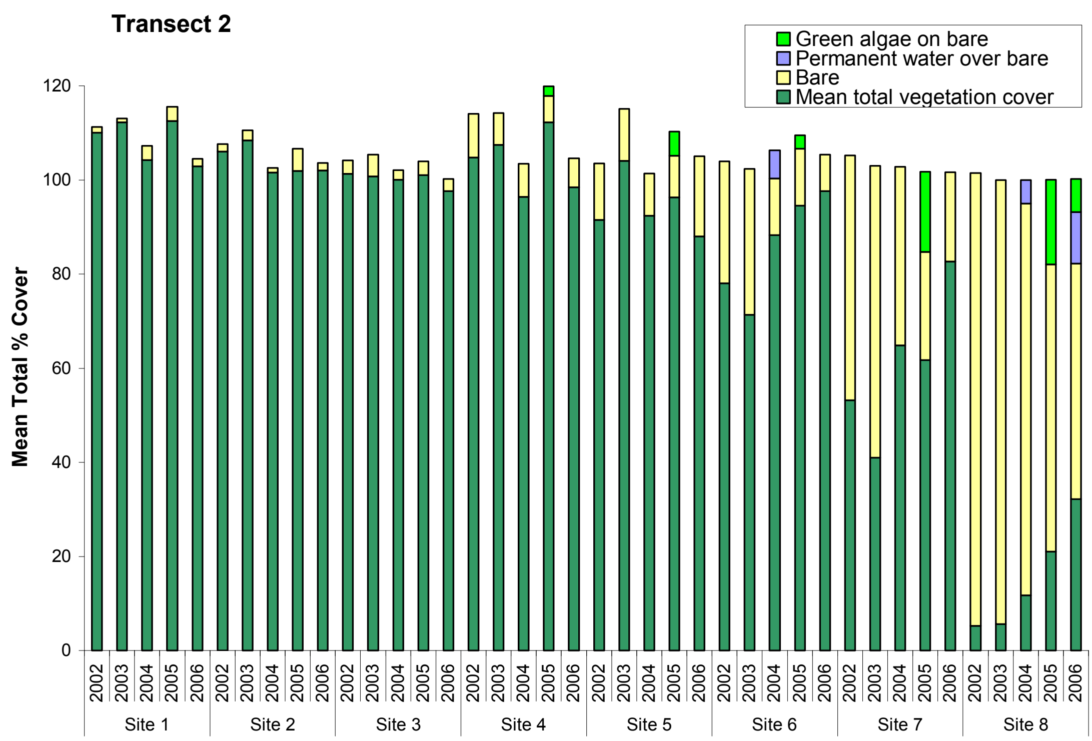
Appendix A5.7. Crude (first version) mosaic of three flightlines of Airborne Thematic Mapper Data taken by the NERC Airborne Research Survey Facility on 11th September 2006

Appendix A5.8. Scientific and common names of plants recorded in the realignment site and outside on the salt marsh around Freiston

Appendix A5.1. Mean total percentage cover of vegetation on transects 1-6 outside the realignment site.

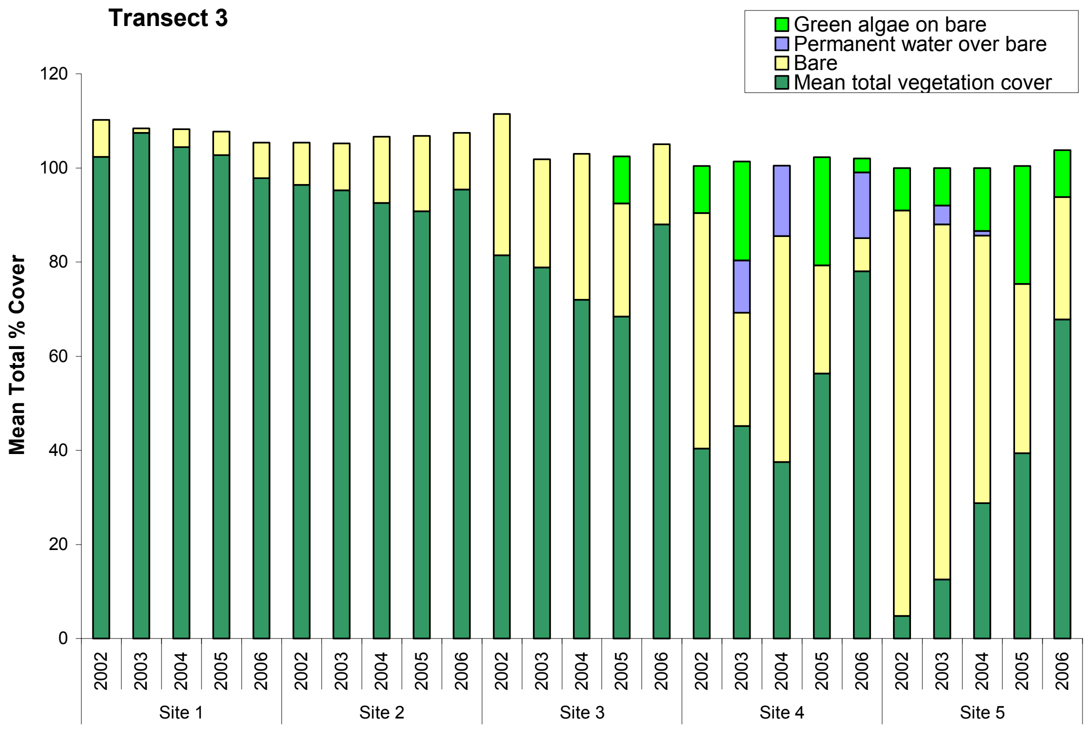


Mean total percentage vegetation cover on Transect 1

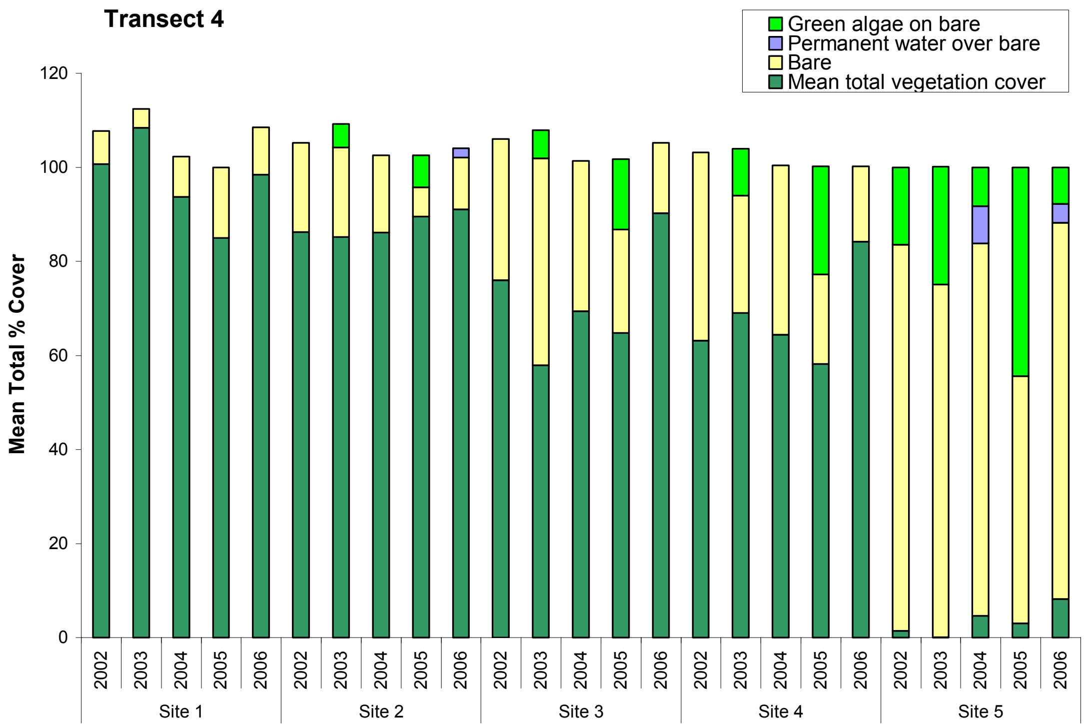


Mean total percentage vegetation cover on Transect 2

Appendix 5.1. Continued

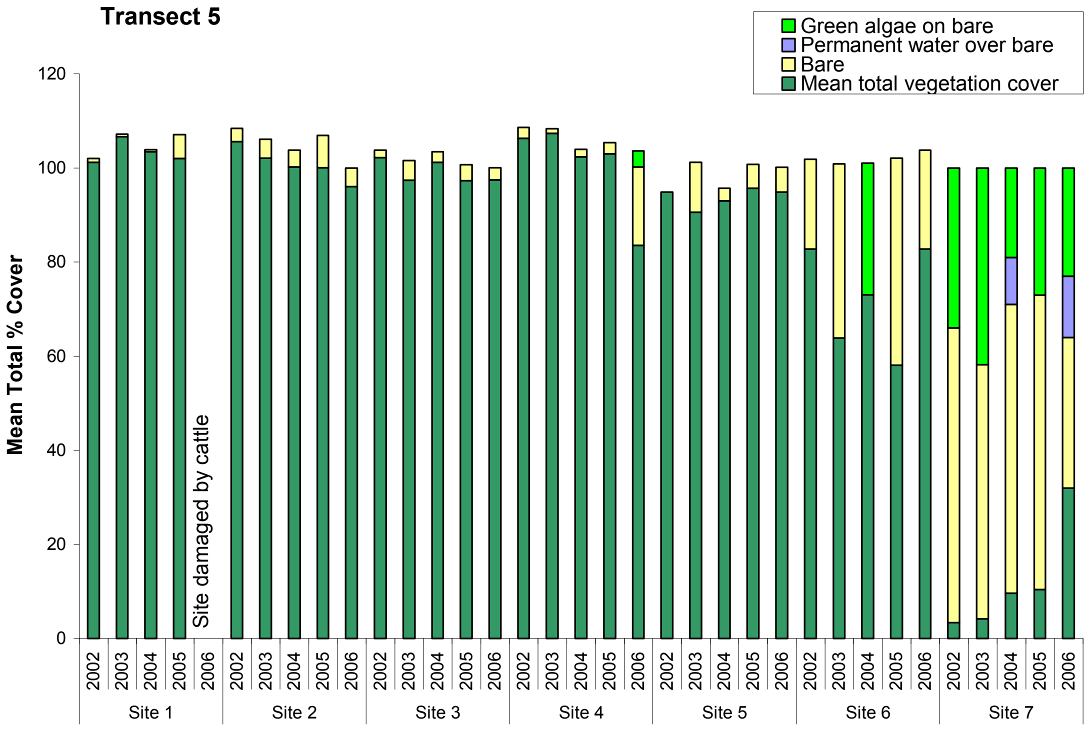


Mean total percentage vegetation cover on Transect 3

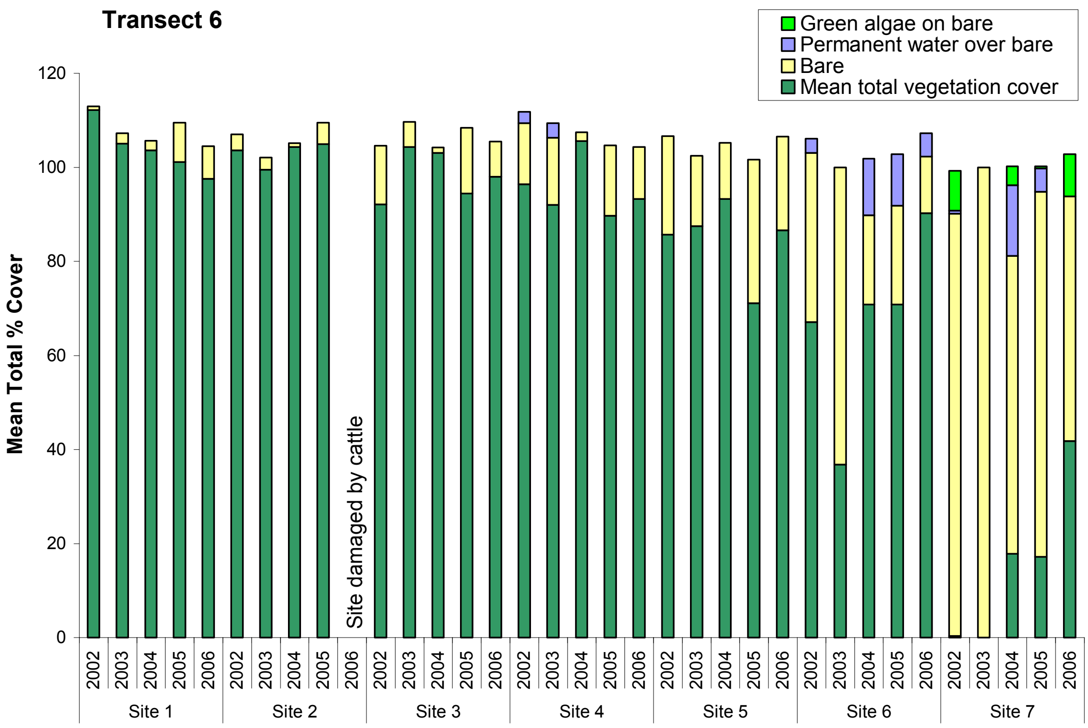


Mean total percentage vegetation cover on Transect 4

Appendix 5.1. Continued



Mean total percentage vegetation cover on Transect 5



Mean total percentage vegetation cover on Transect 6

Appendix A5.2. Mean total percentage cover of vegetation on transects A-F inside the realignment site.

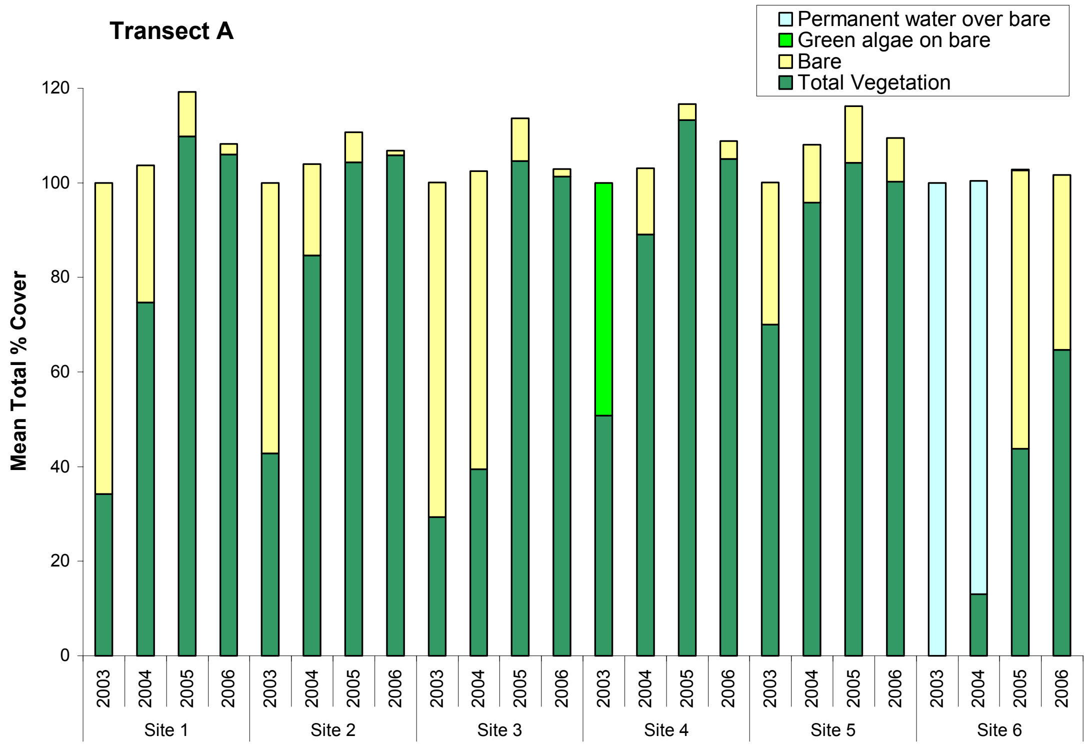


Fig. 5.17. Mean total percentage vegetation cover on Transect A

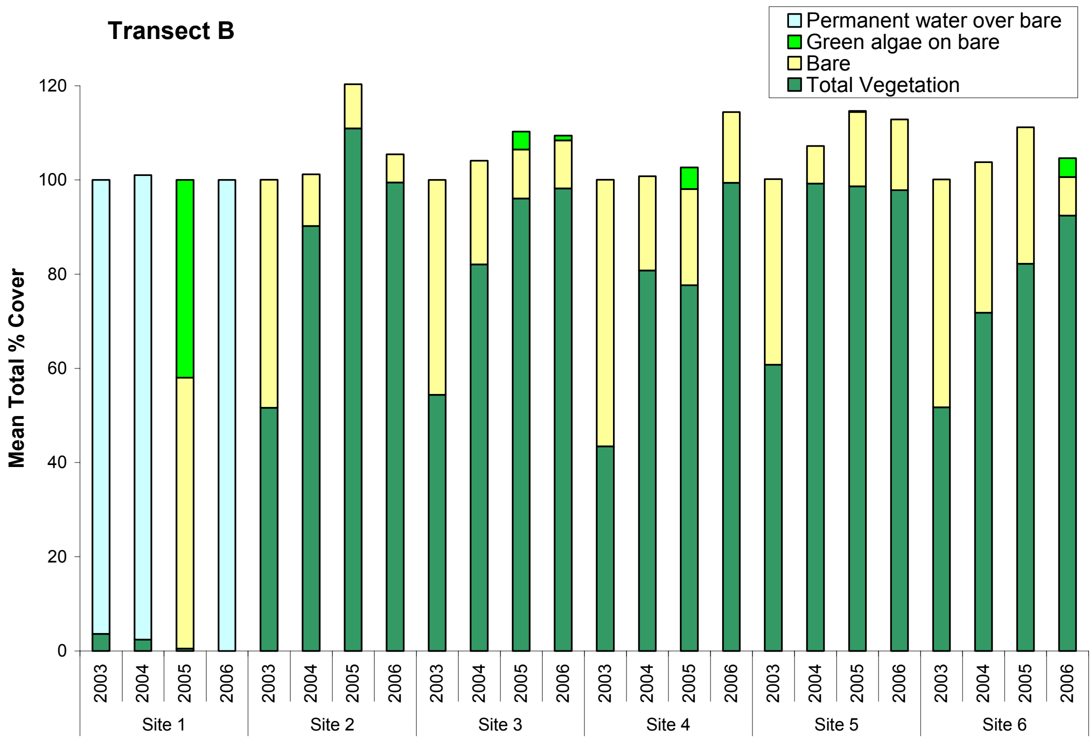


Fig. 5.18. Mean total percentage vegetation cover on Transect B

Appendix 5.2 Continued

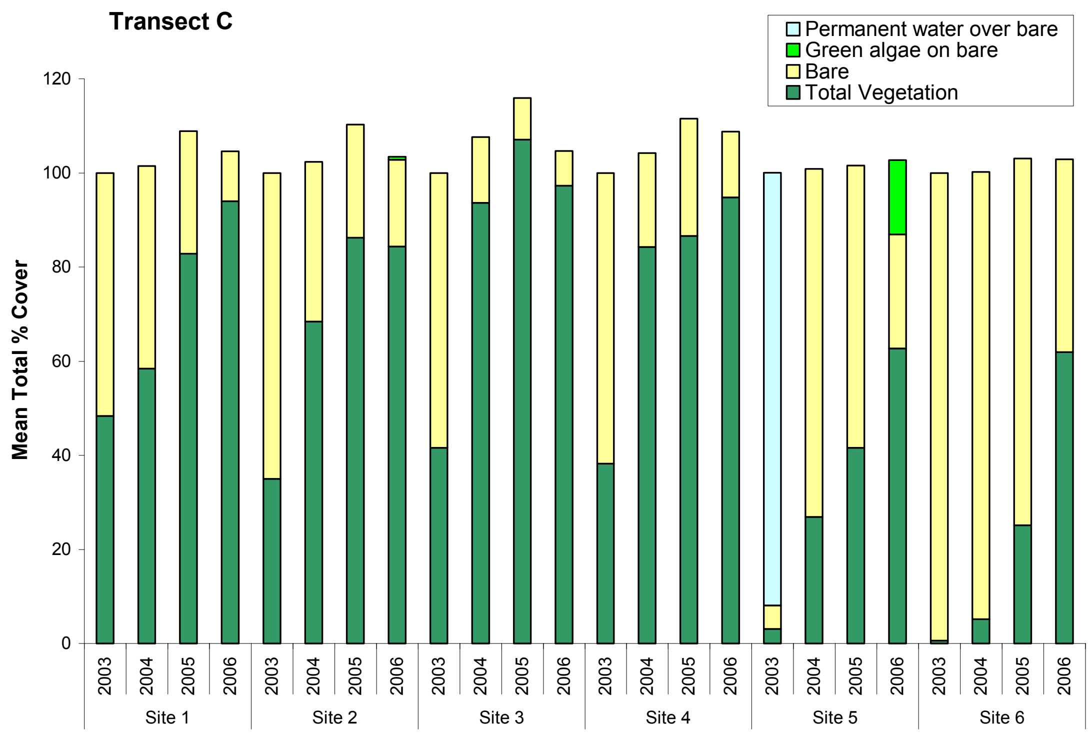


Fig. 5.19. Mean total percentage vegetation cover on Transect C

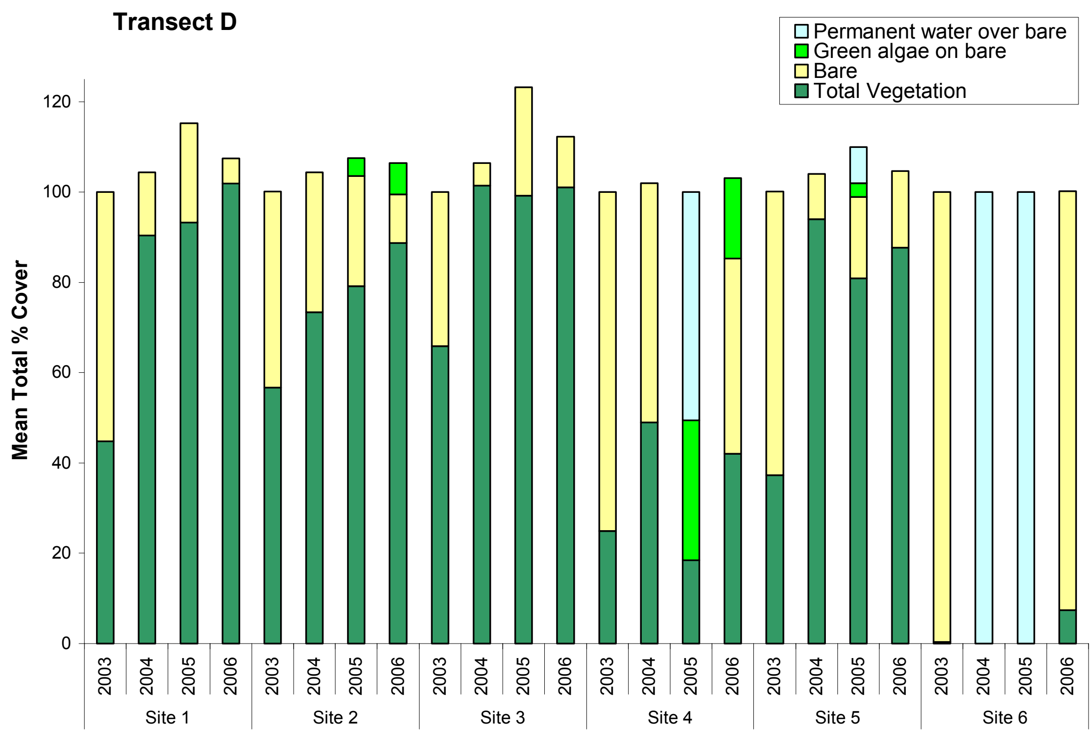


Fig. 5.20. Mean total percentage vegetation cover on Transect D

Appendix 5.2 Continued

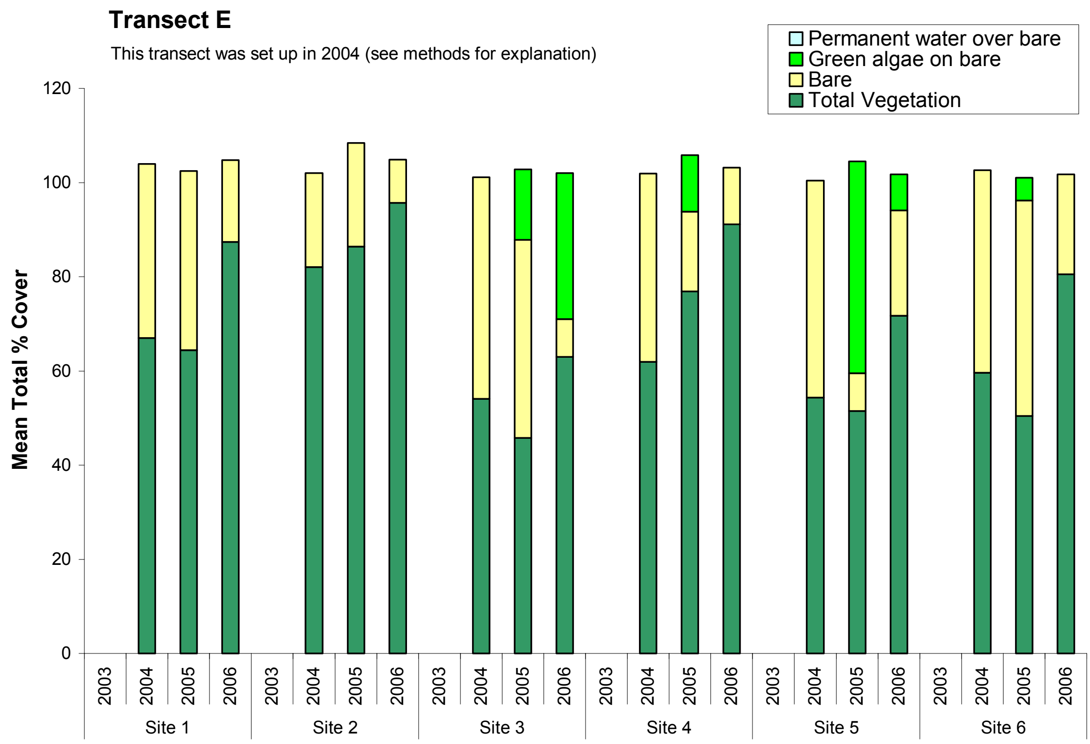


Fig. 5.21. Mean total percentage vegetation cover on Transect E

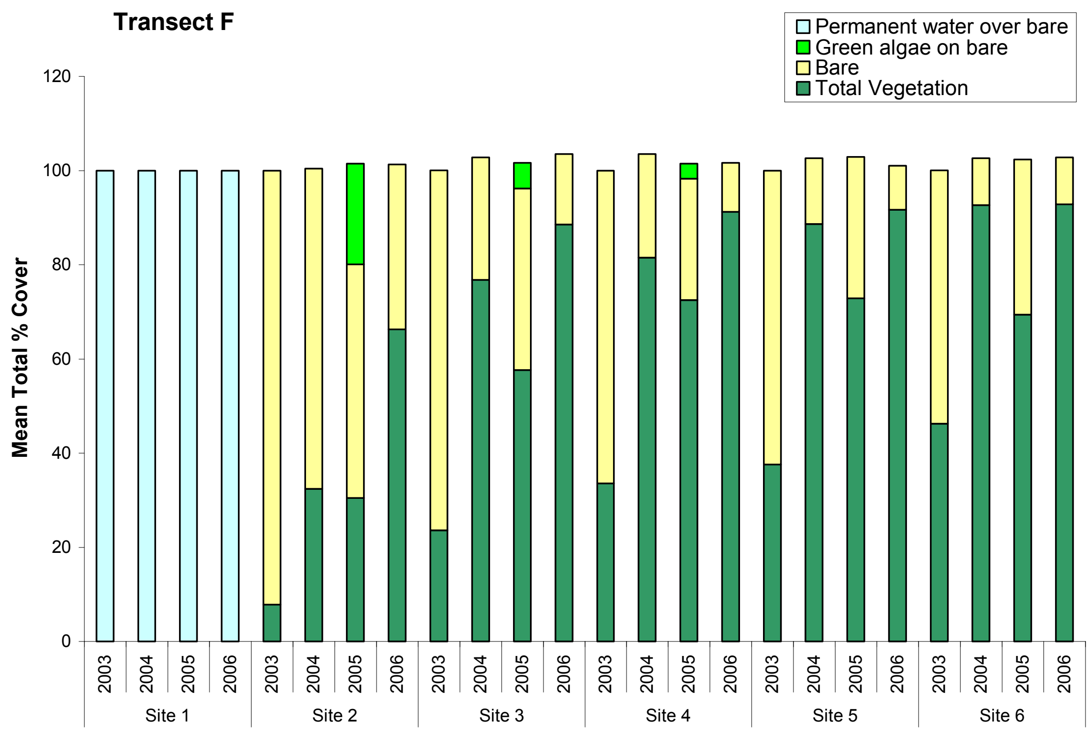
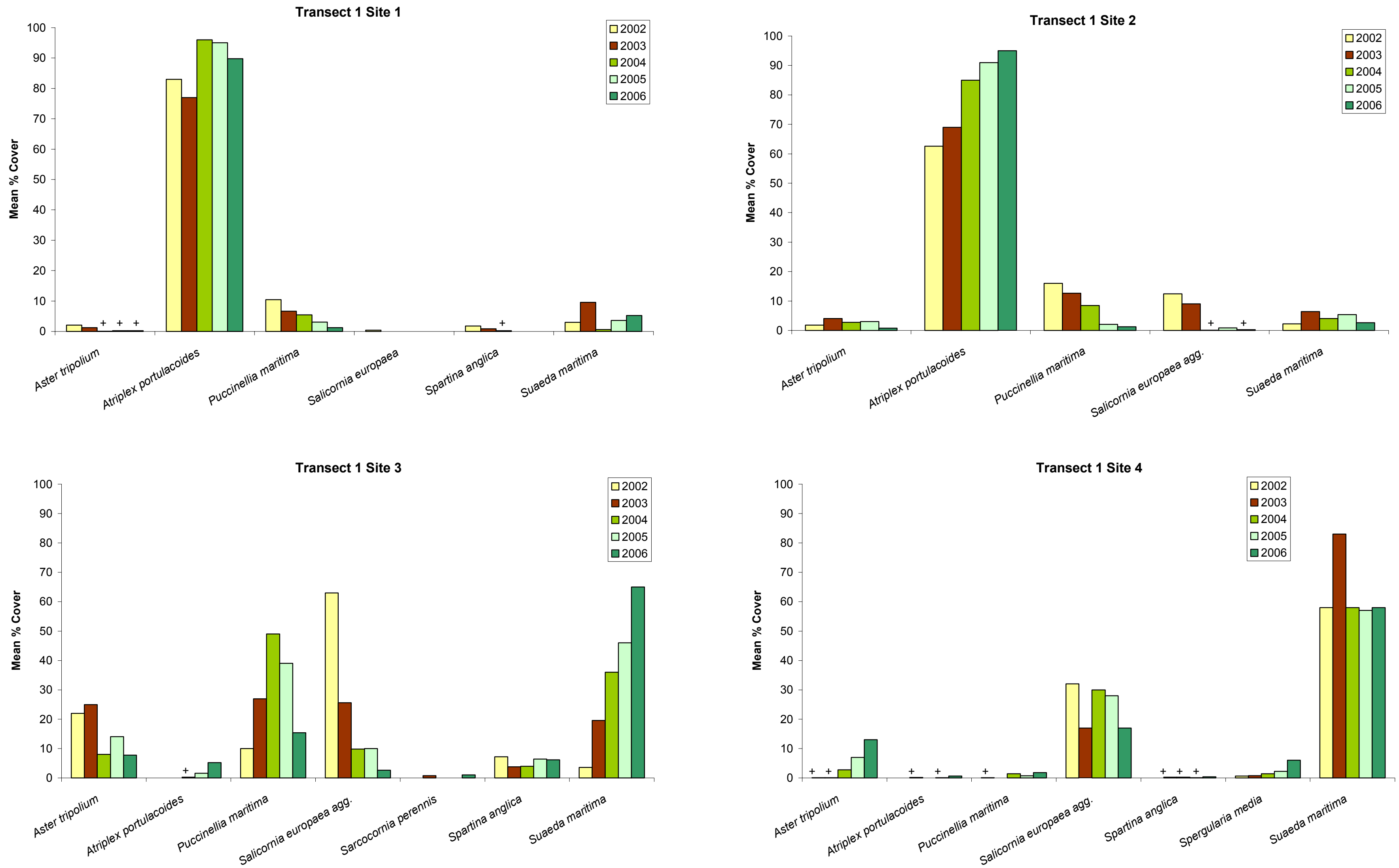
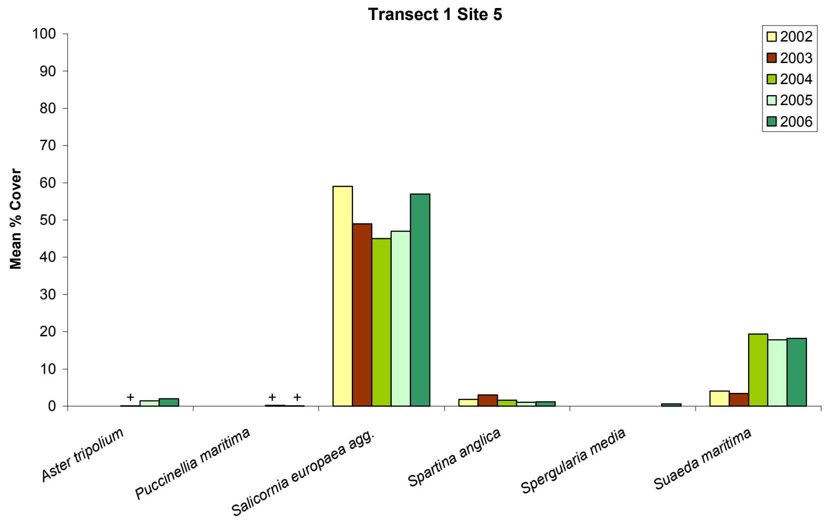
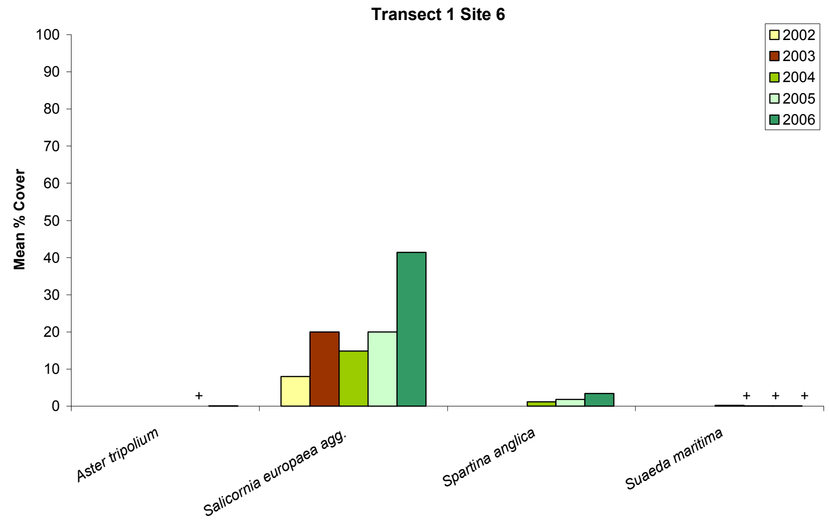


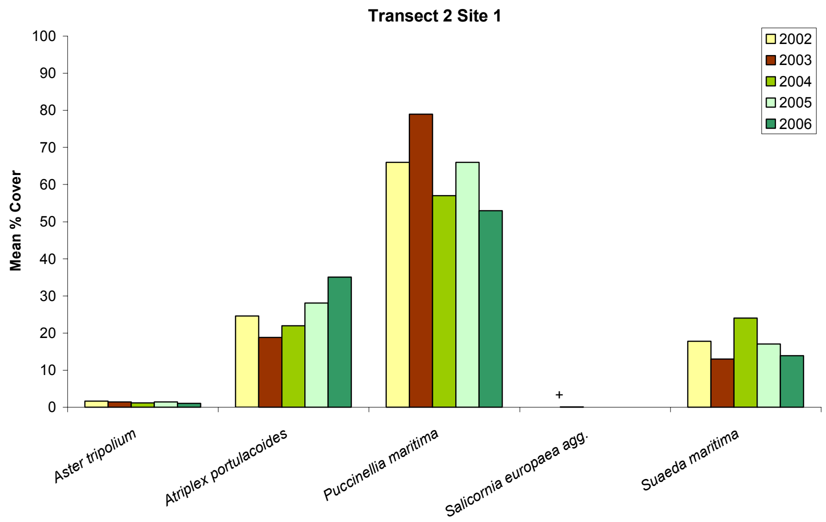
Fig. 5.22. Mean total percentage vegetation cover on Transect F

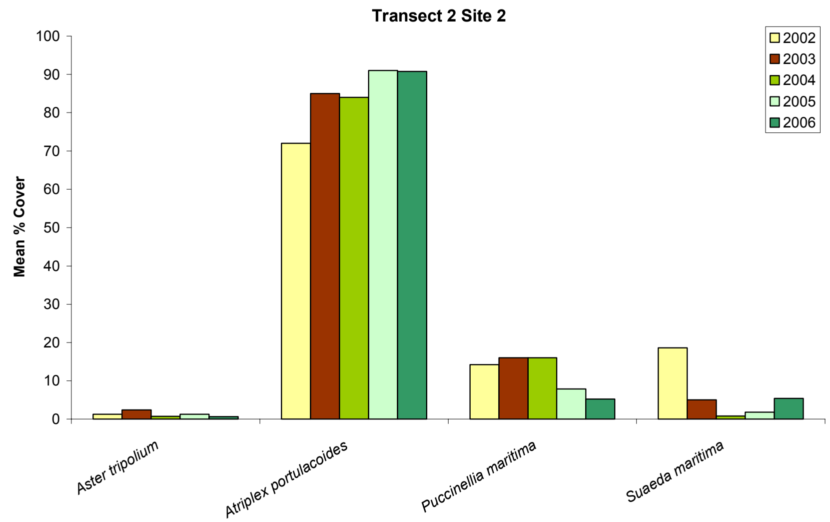


Appendix A5.3. Percentage cover of plant species in the 5 x 1m^2 quadrats on the salt marsh outside the managed realignment site









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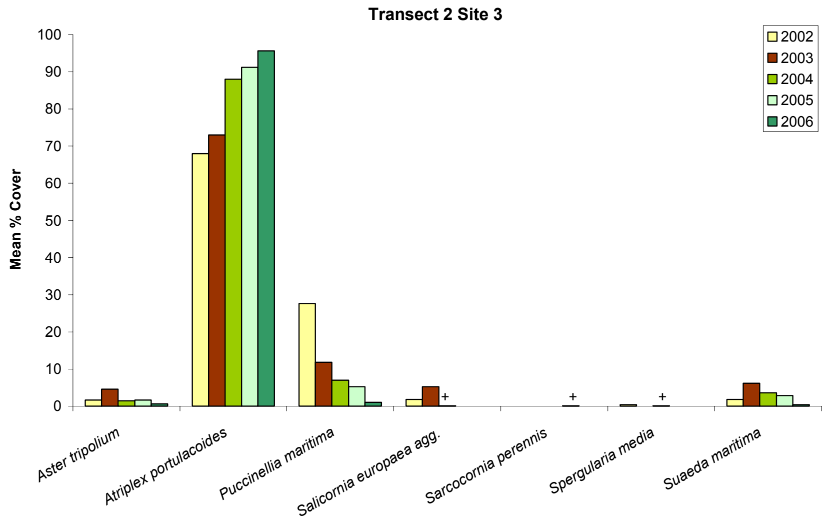

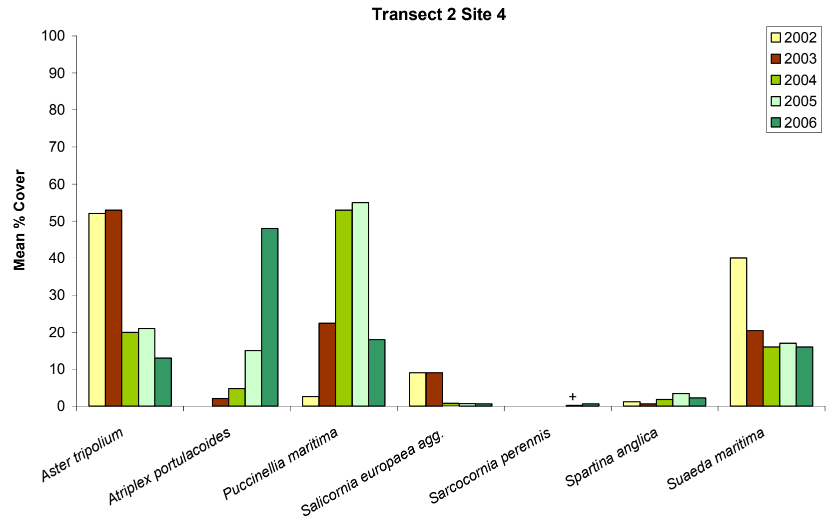

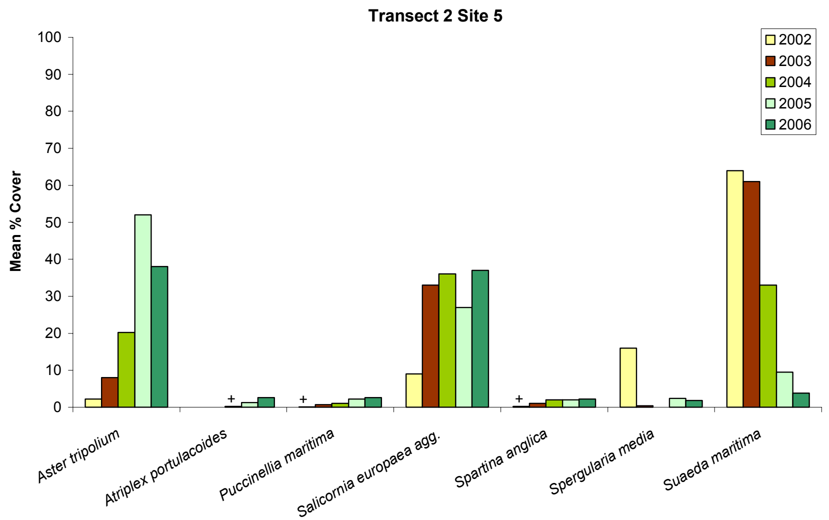

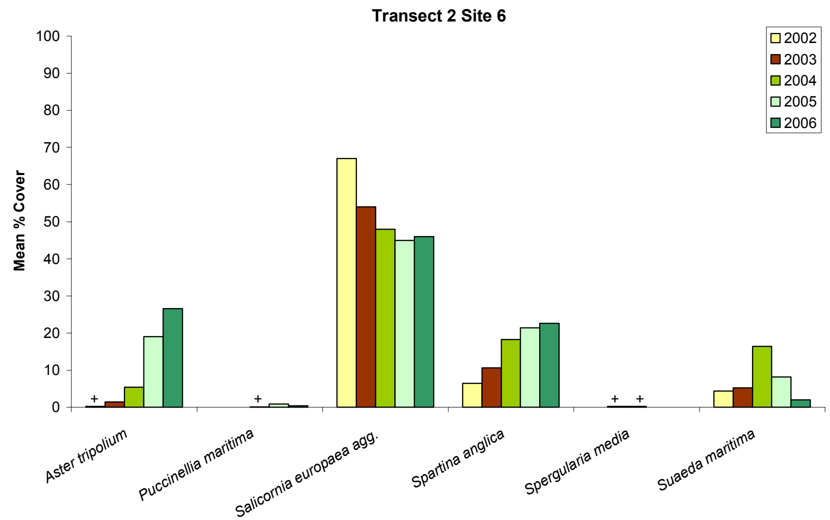

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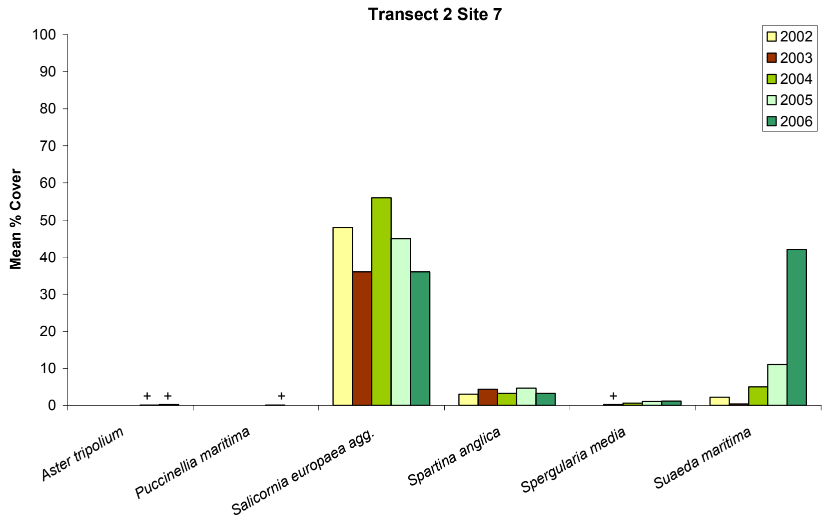

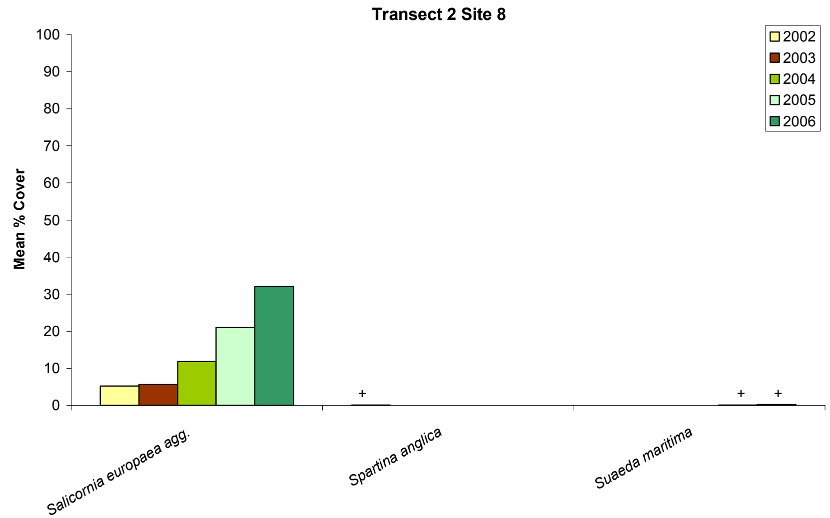

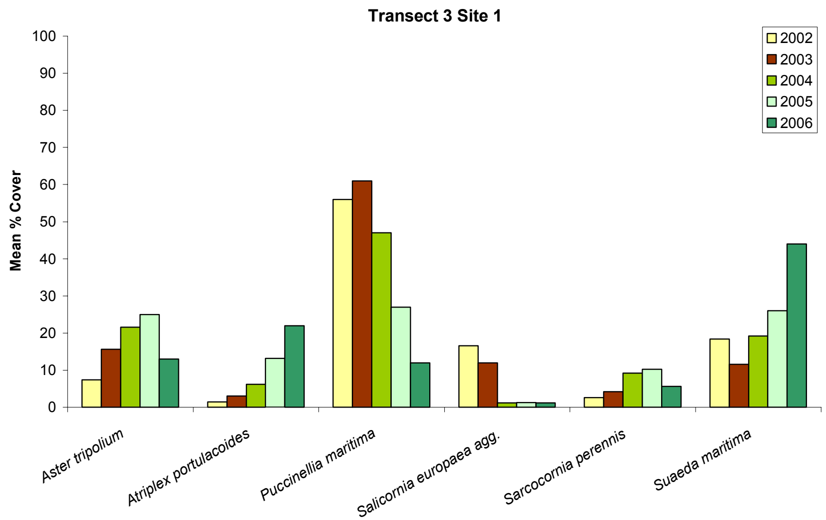

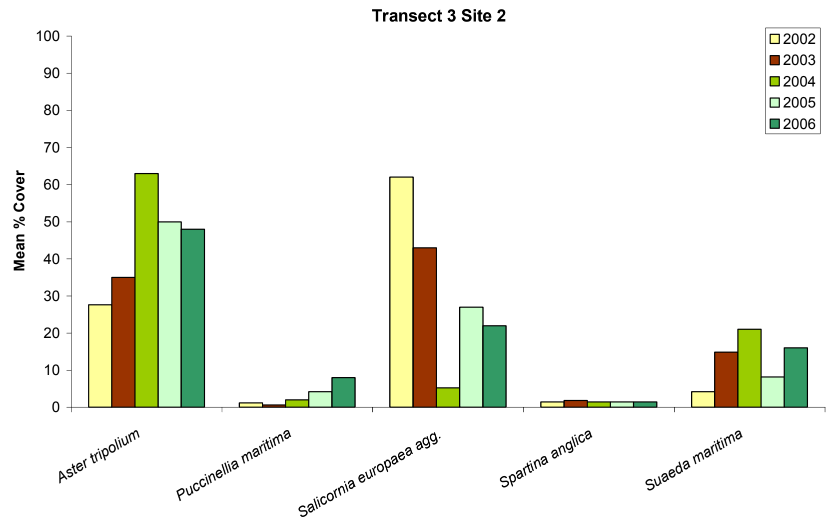

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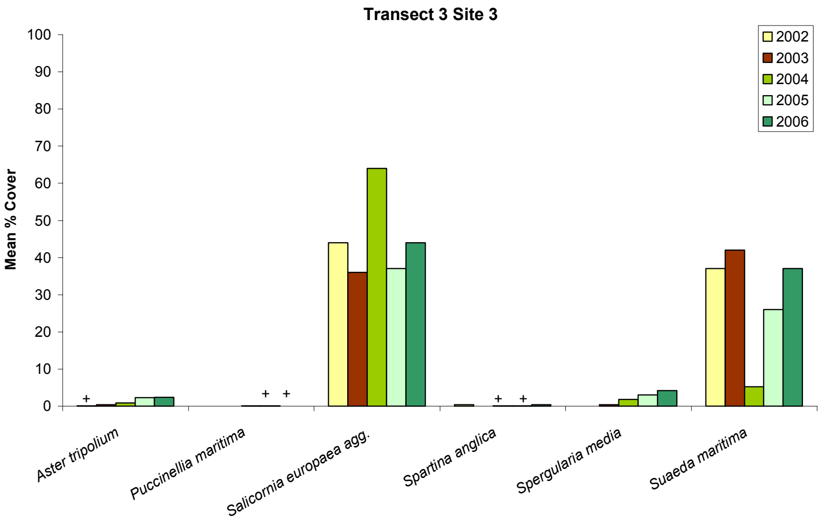

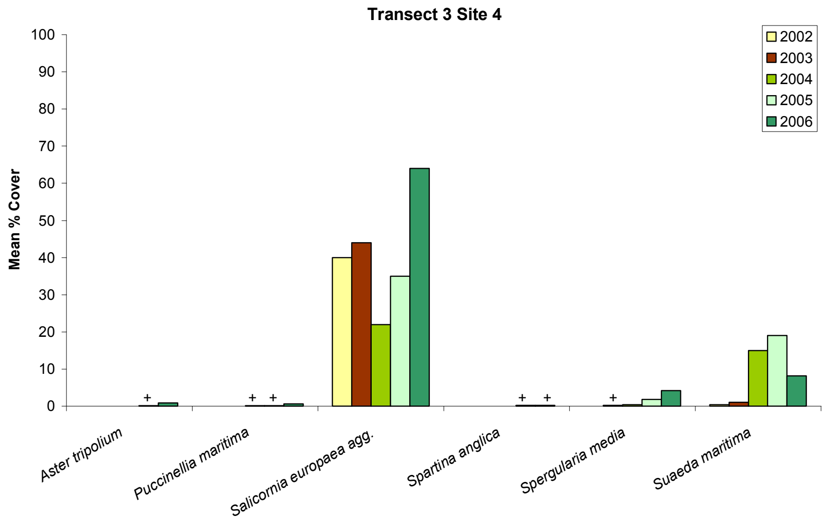

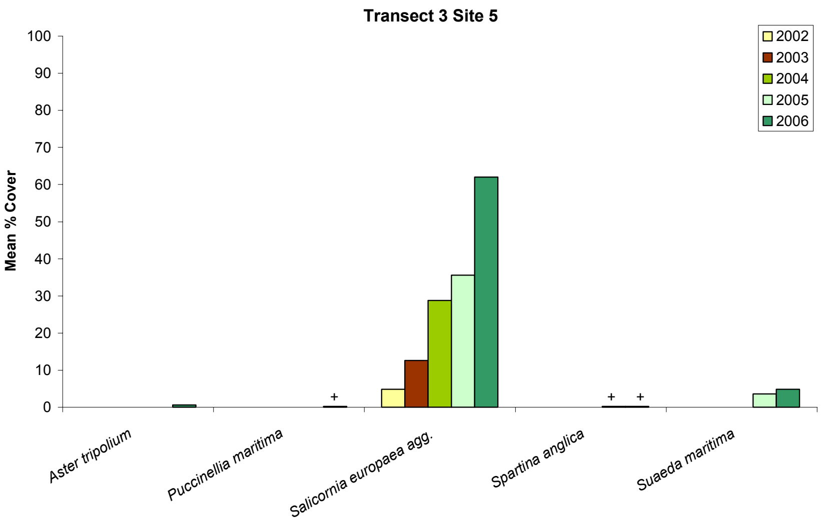

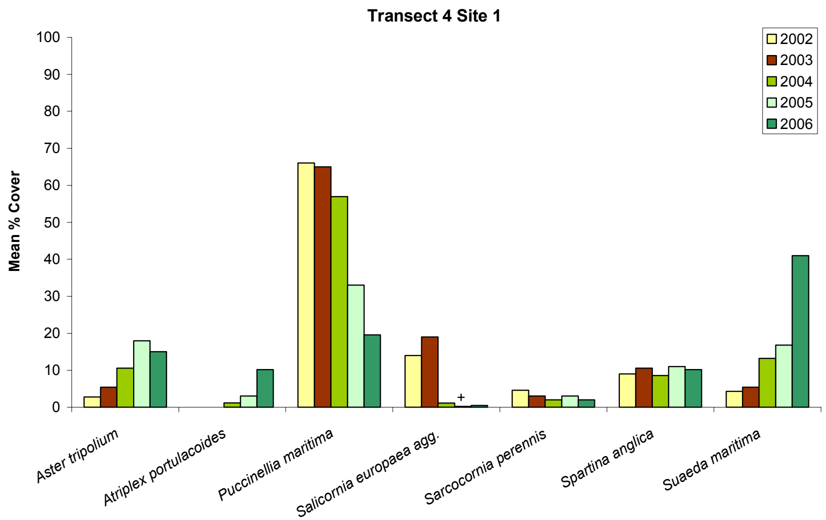

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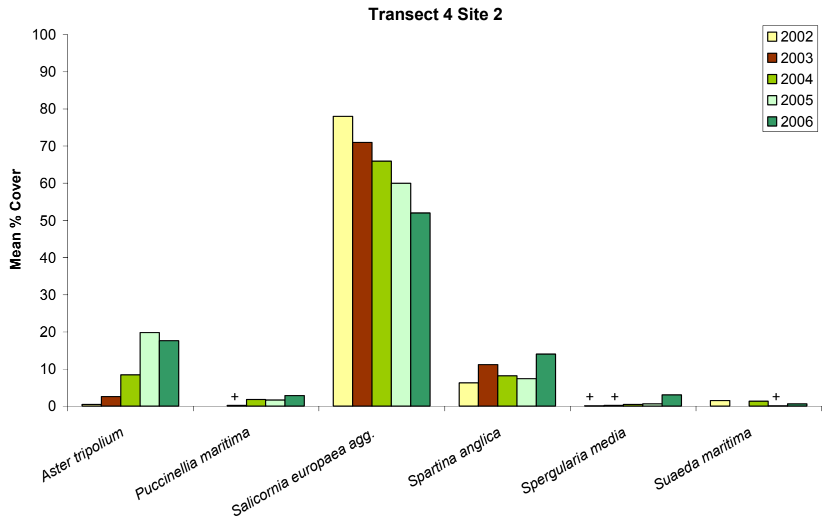

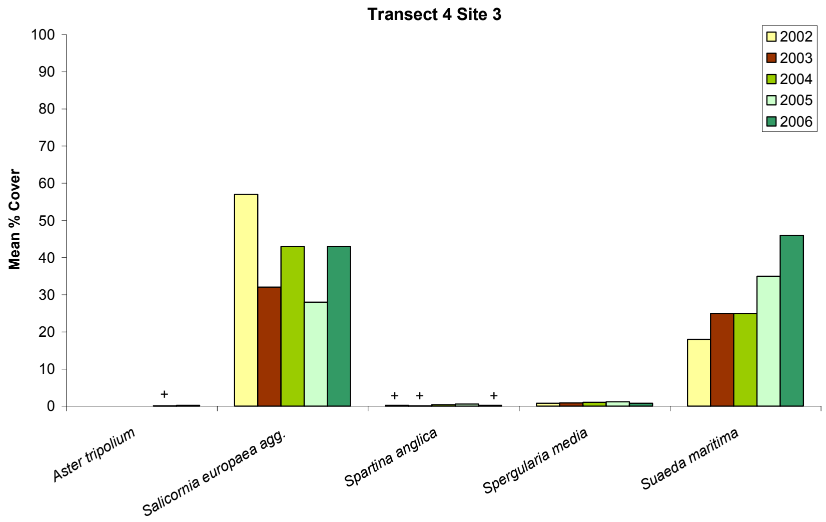

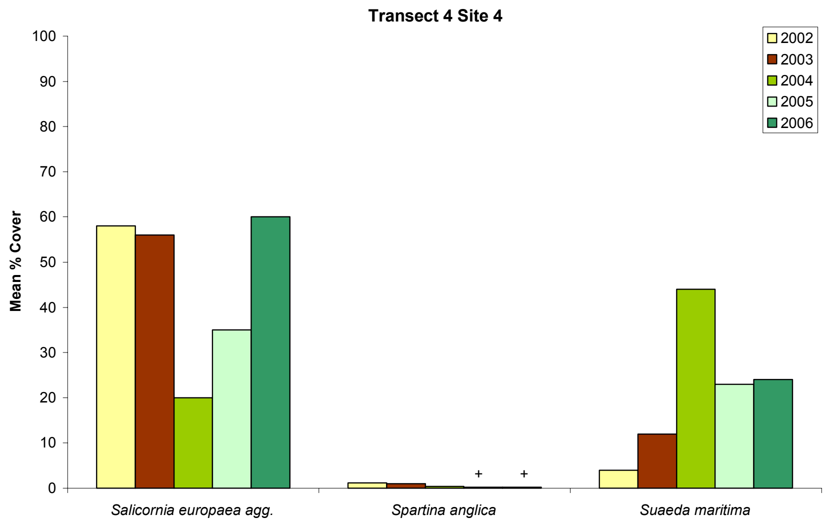

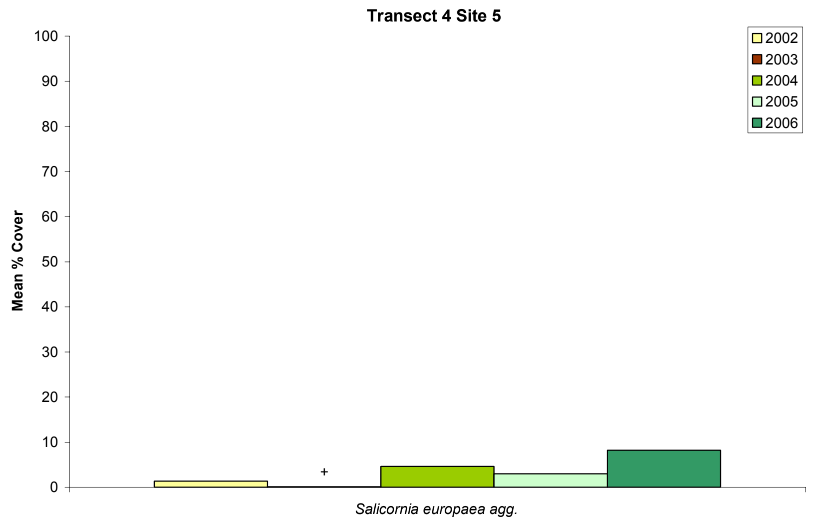

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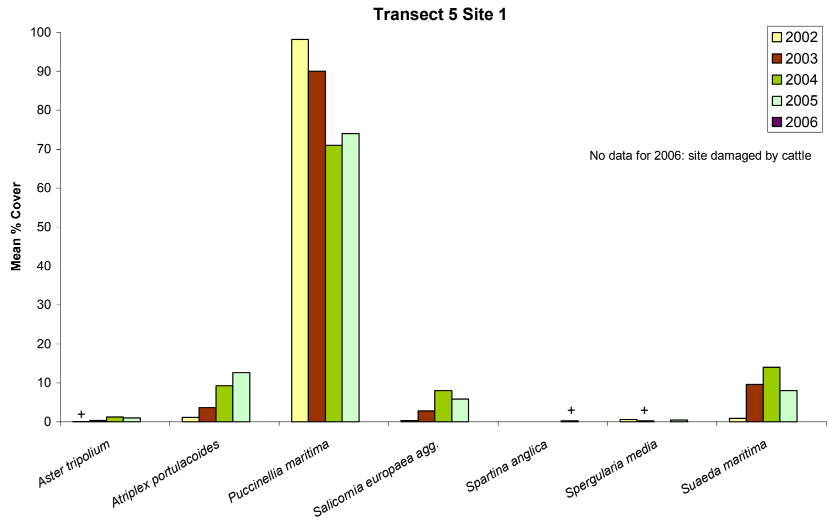

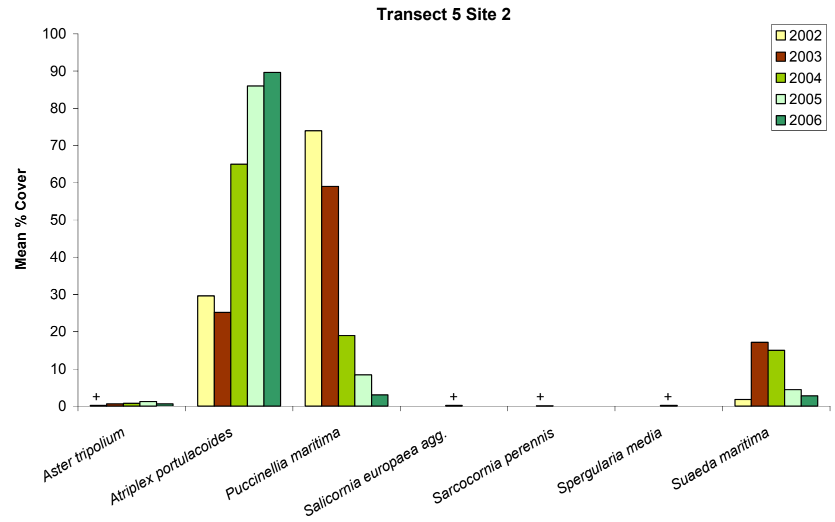

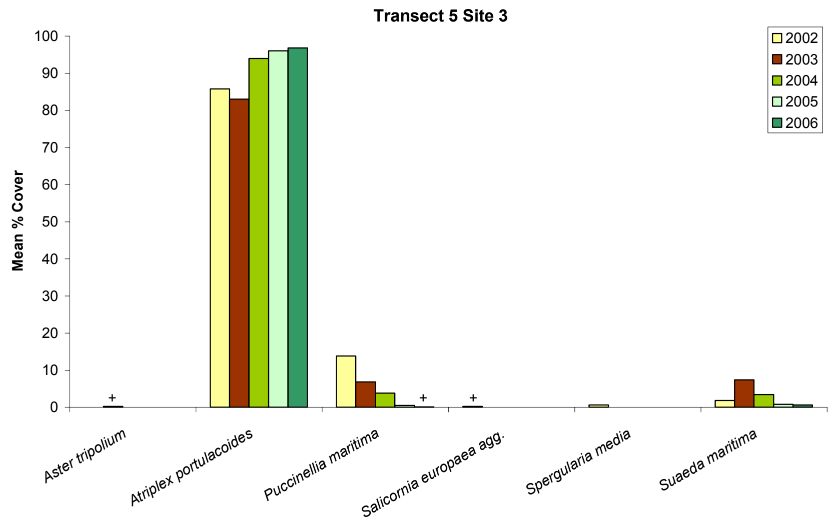

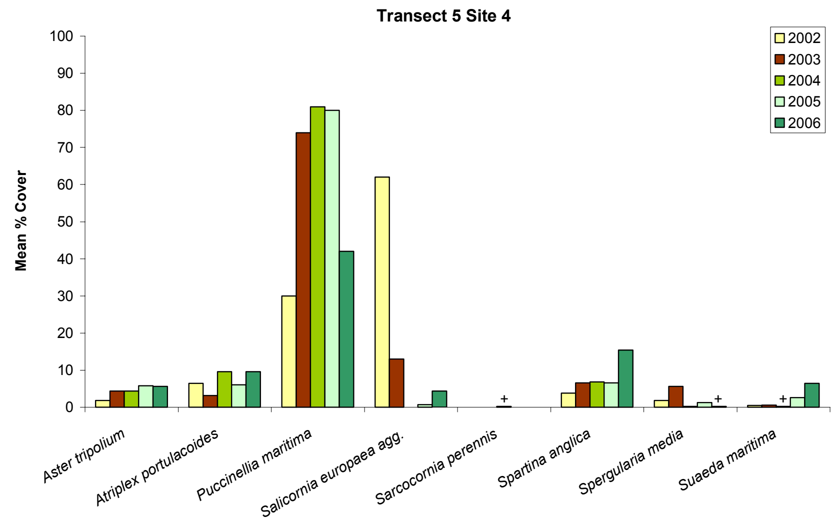

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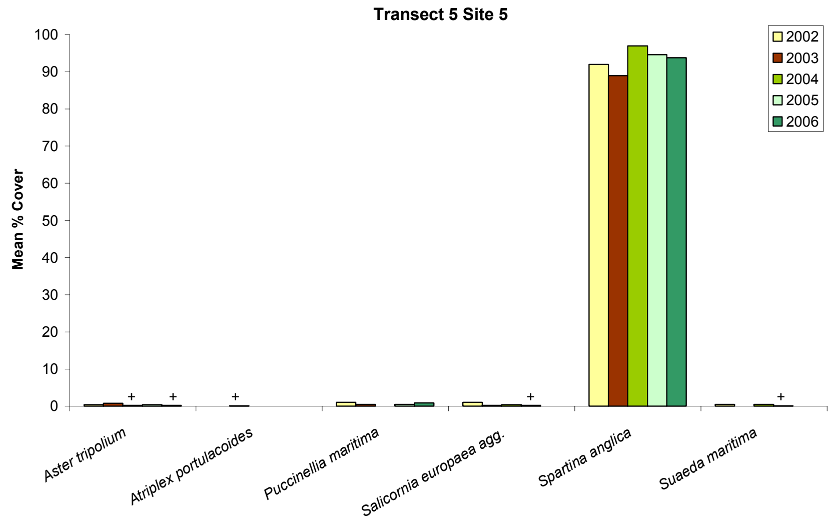

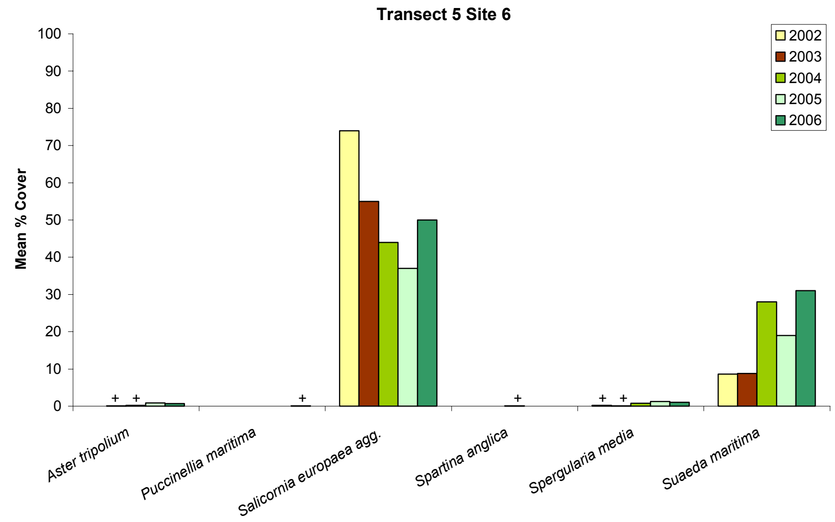

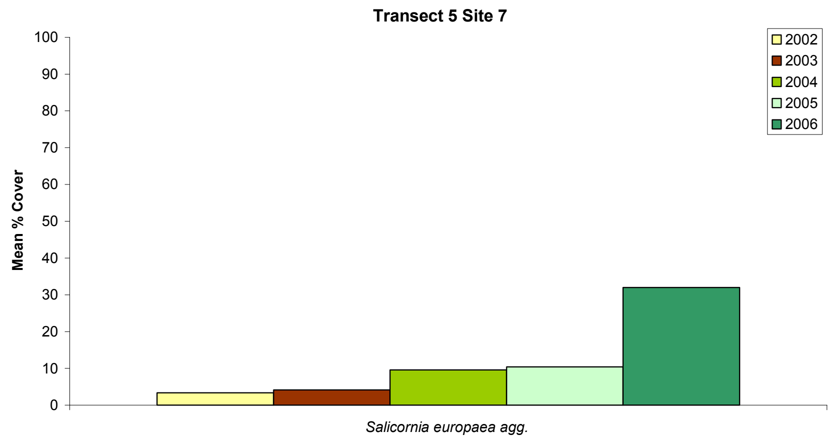

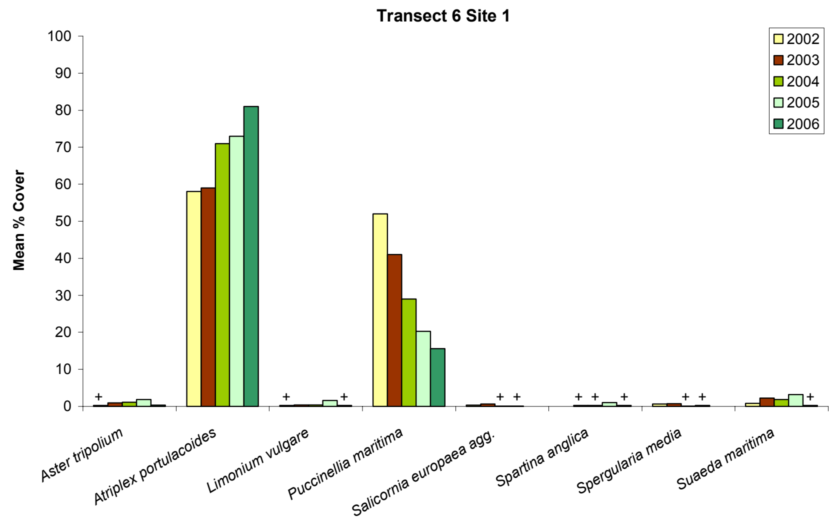

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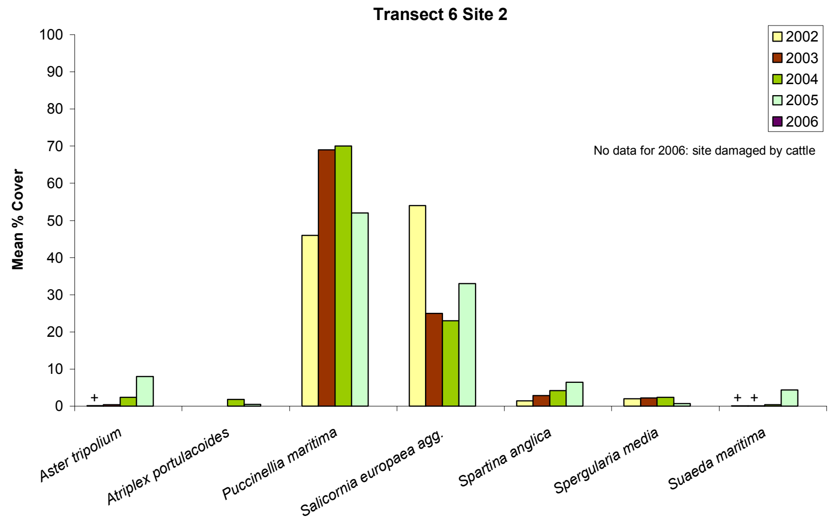

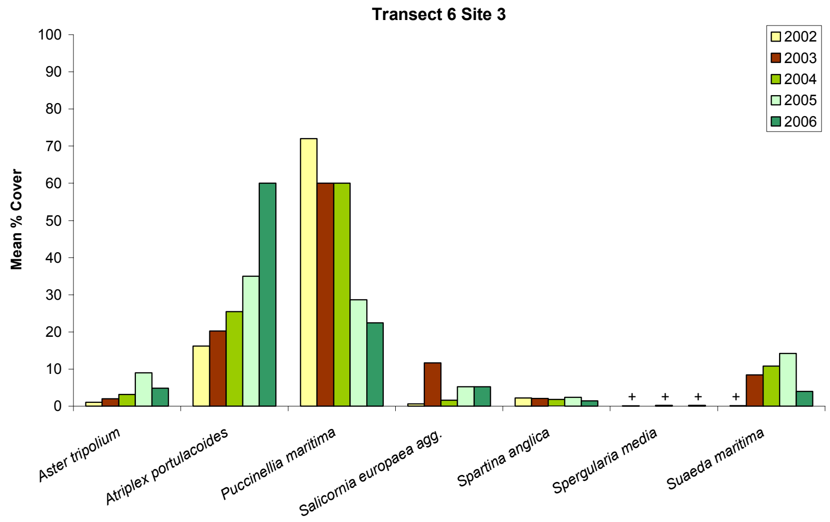

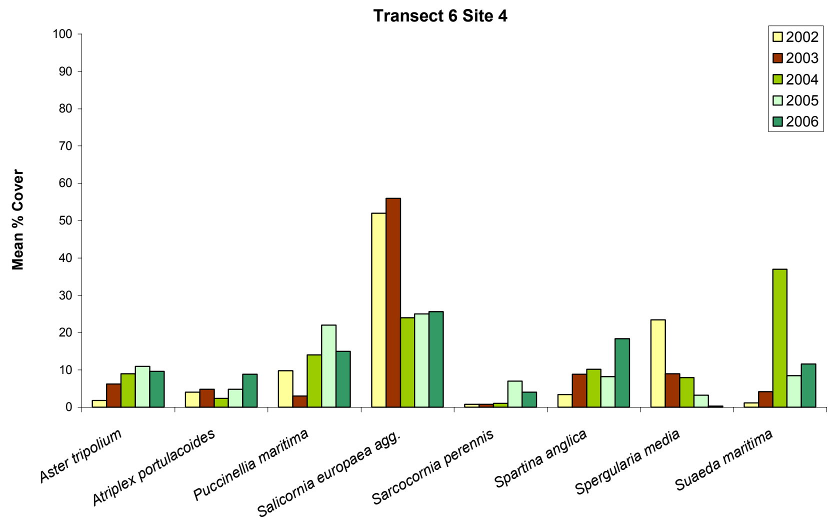

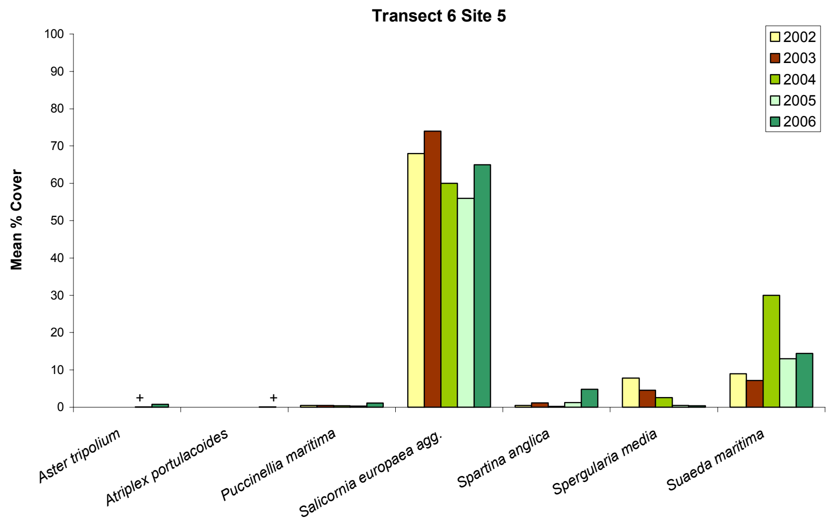

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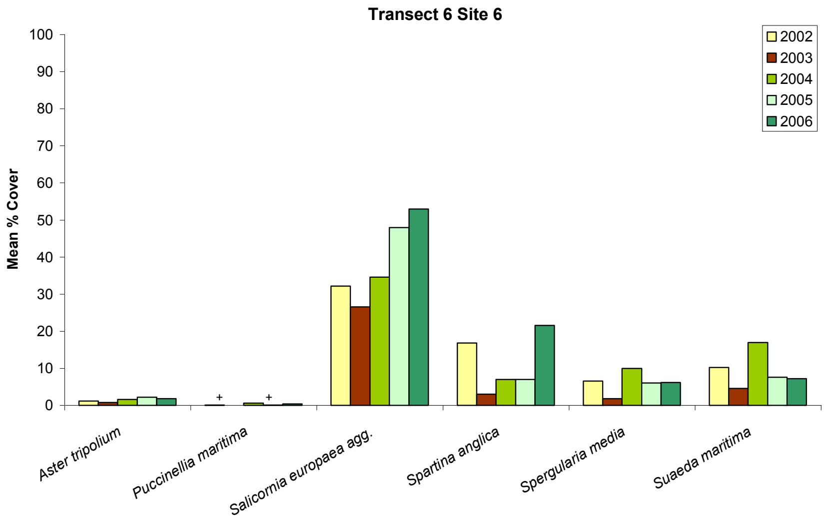

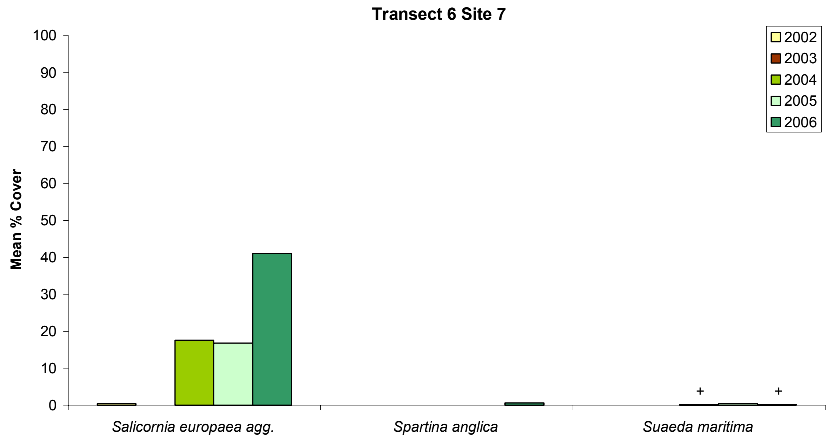

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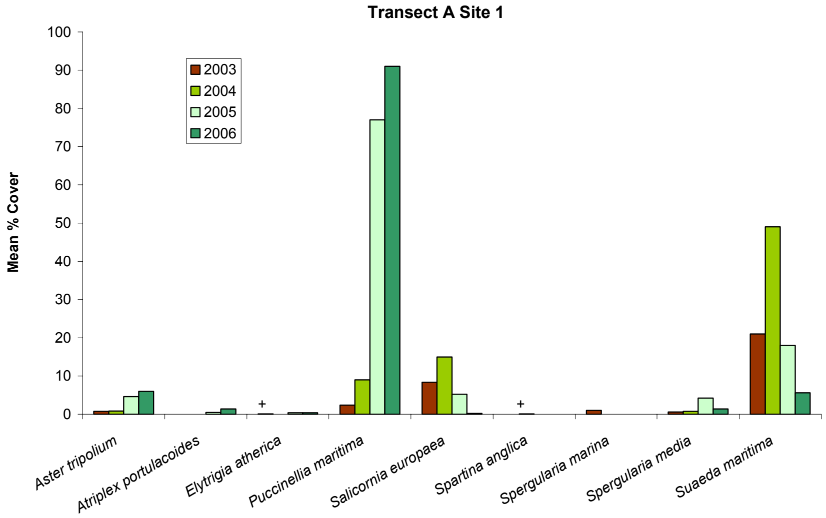
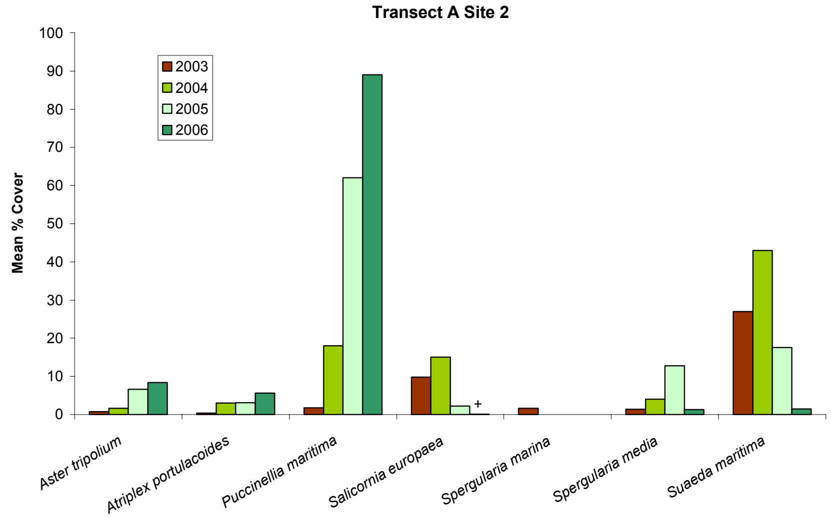
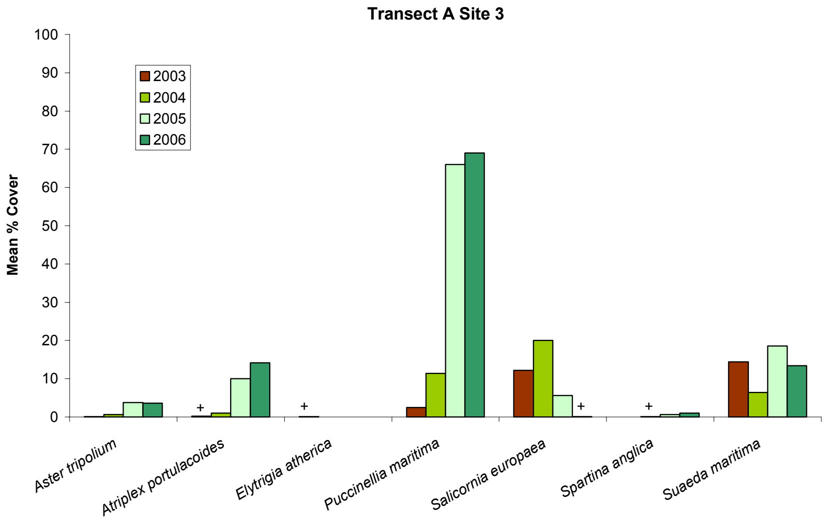
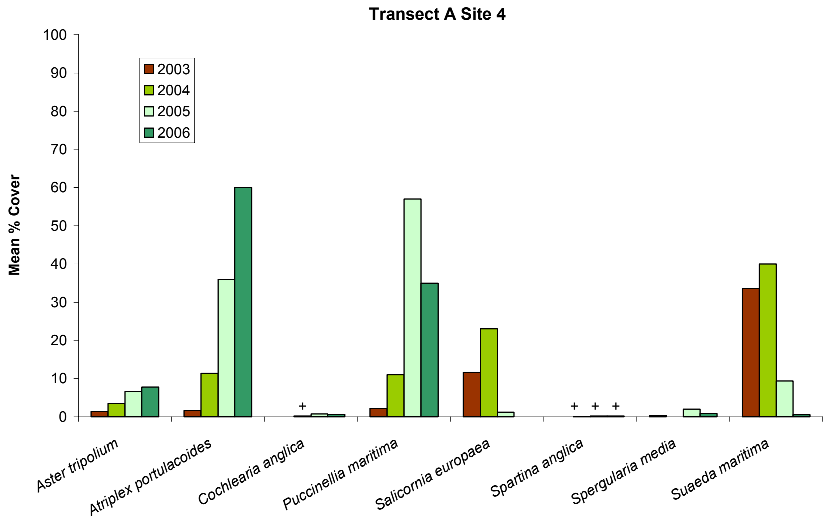
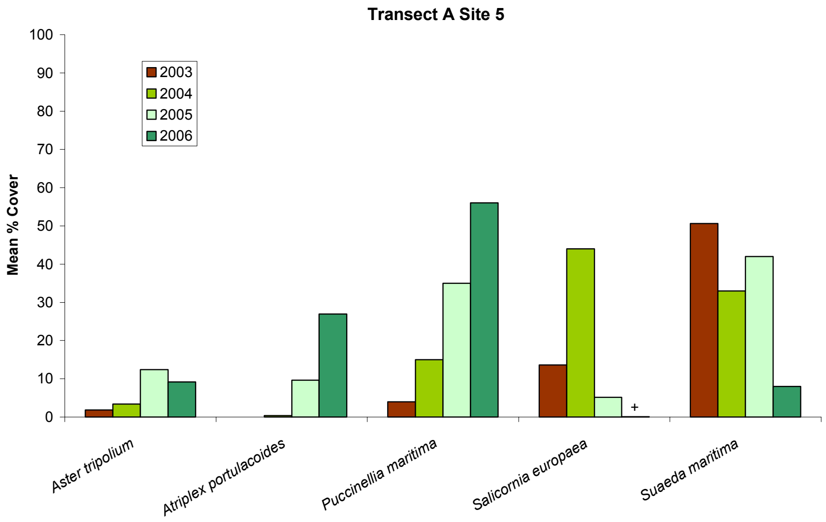


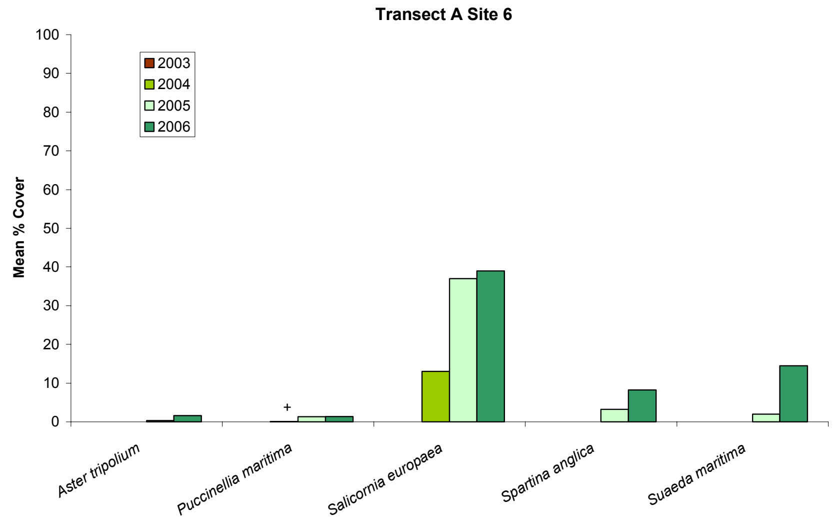


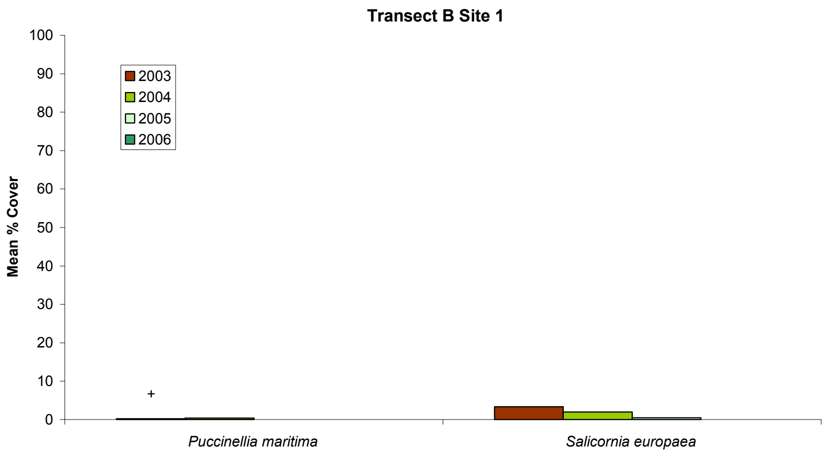


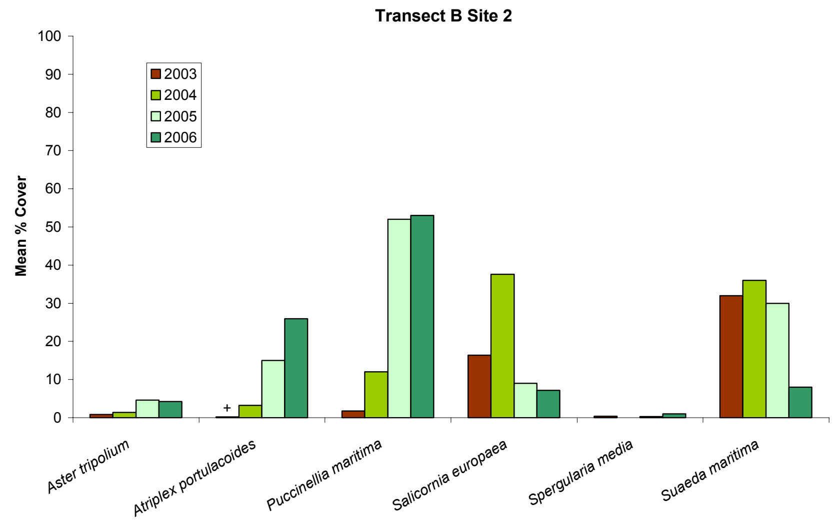


Appendix A5.4. Percentage cover of plant species in the 5 x 1m^2 quadrats inside the managed realignment site









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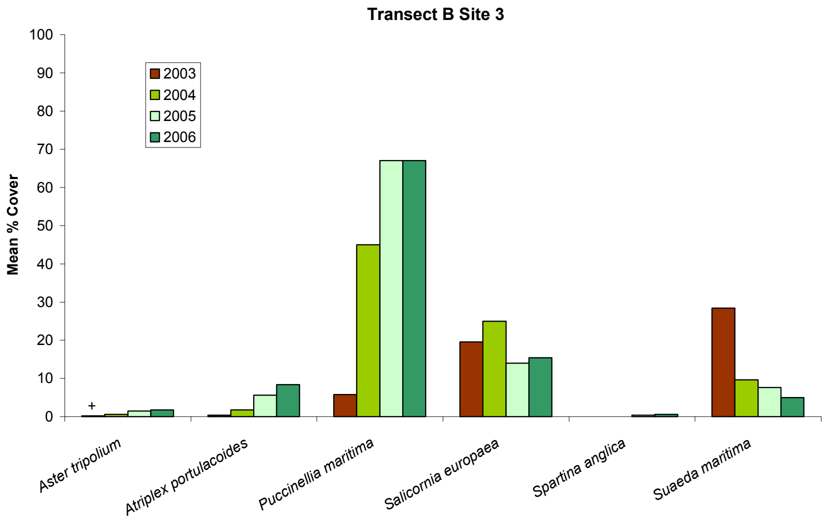

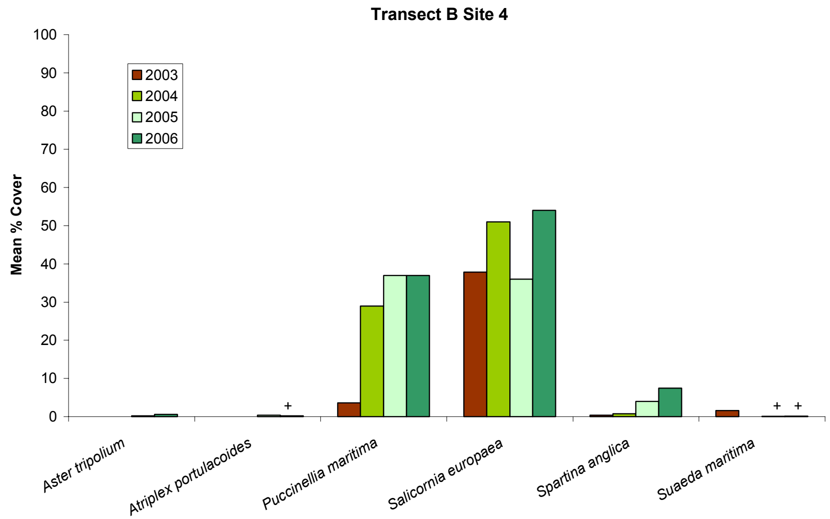

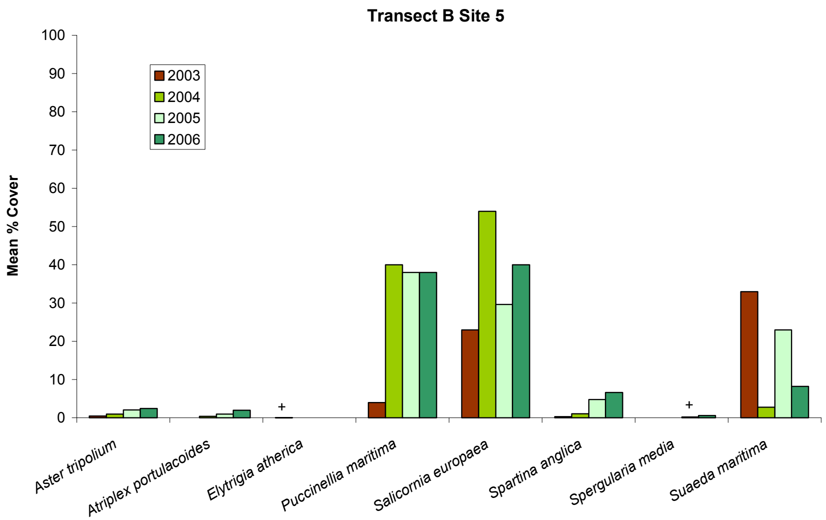

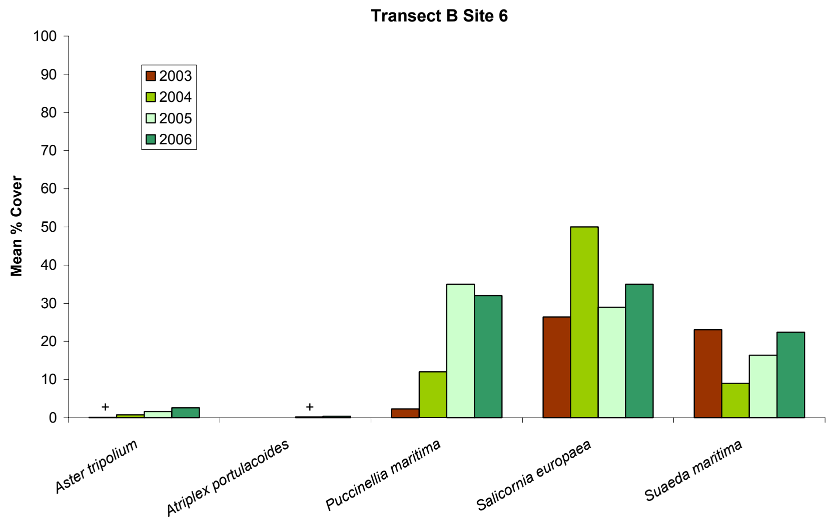

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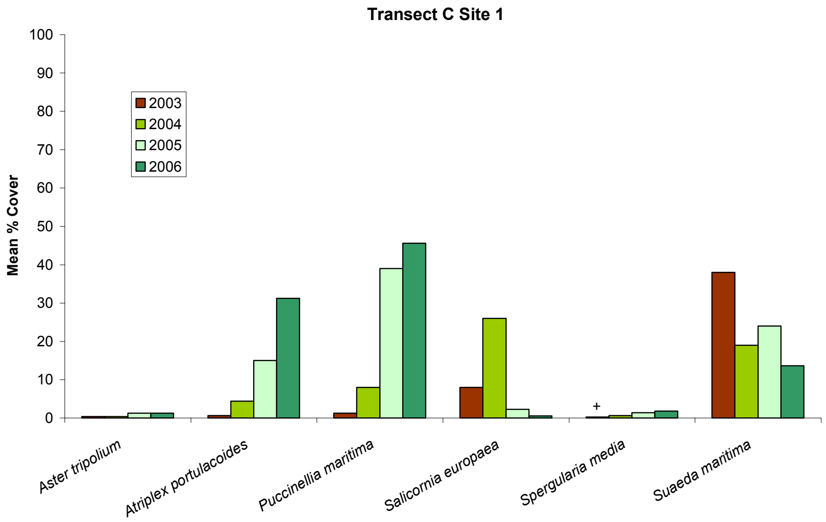
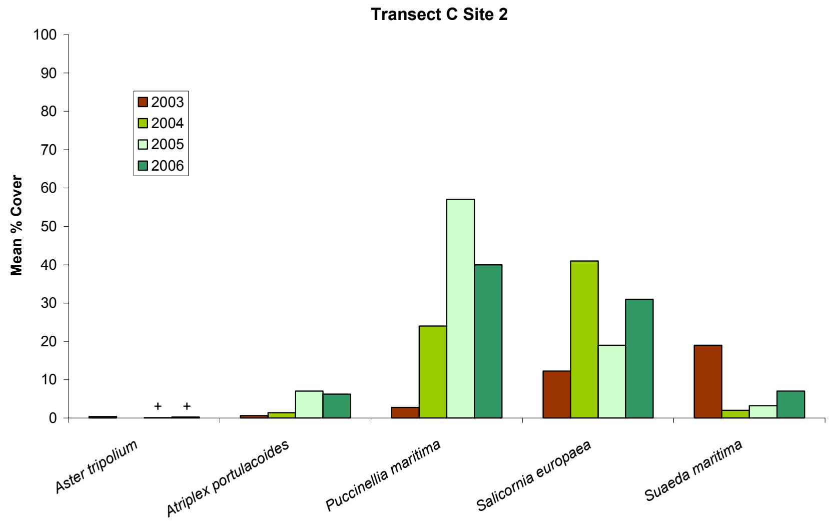
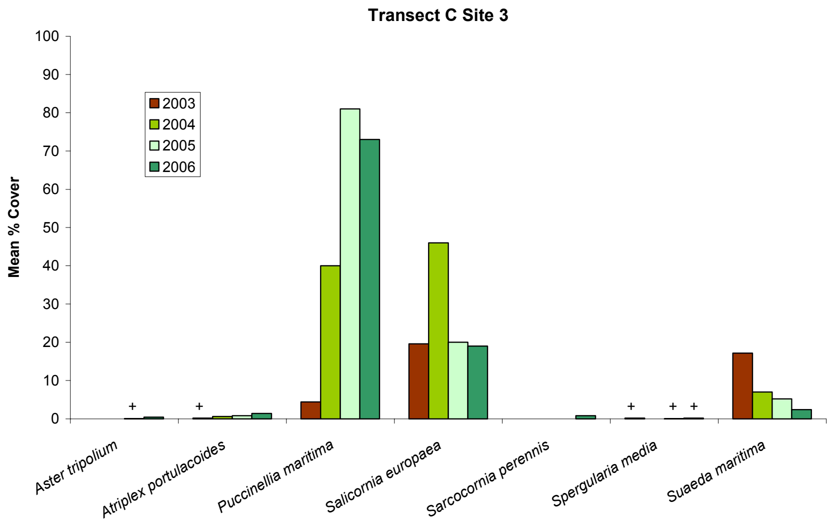
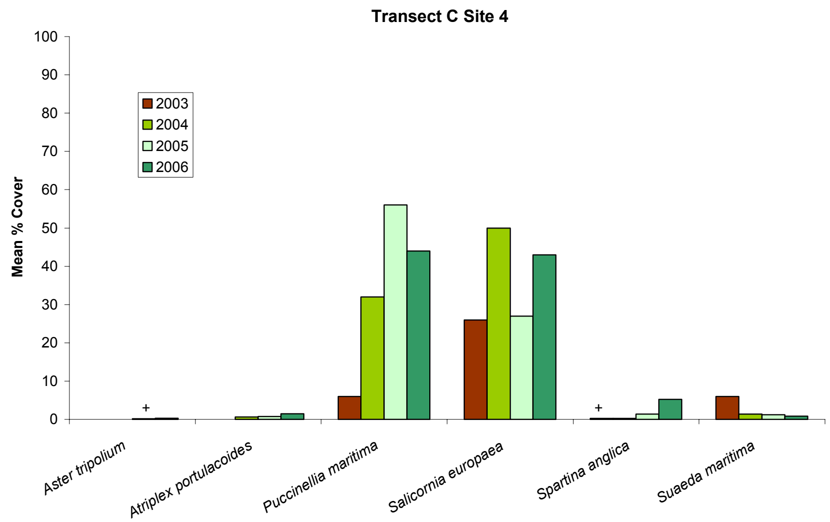
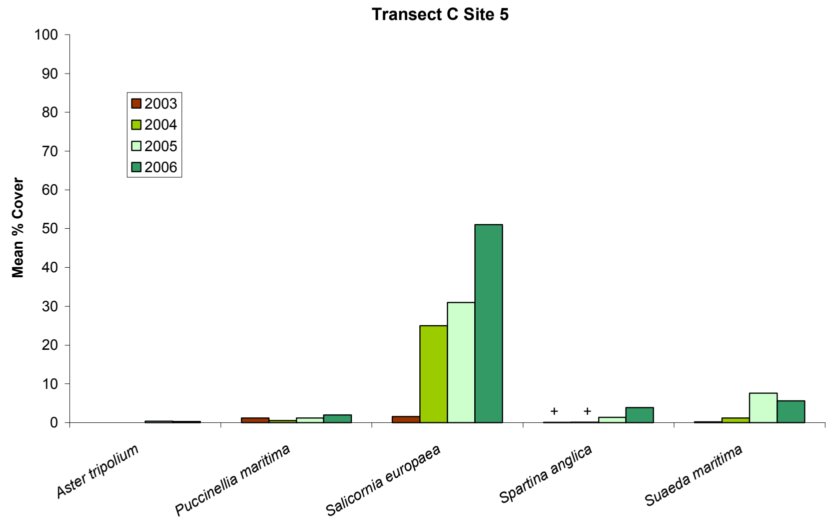


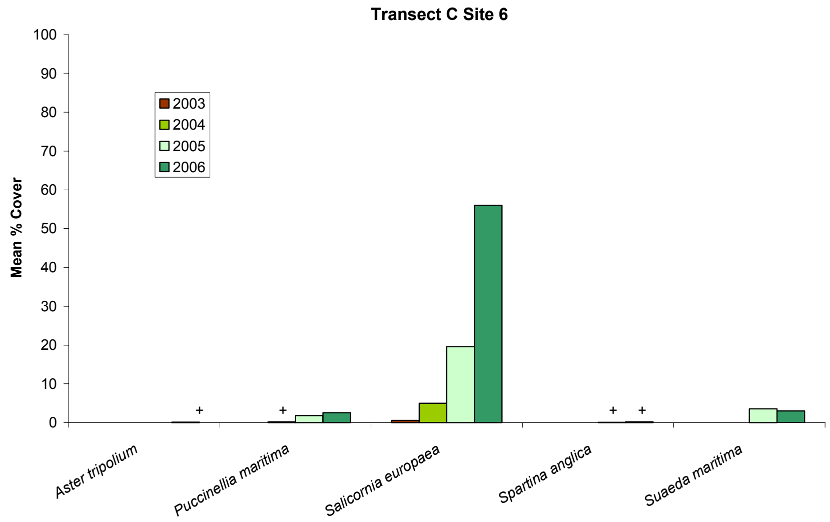


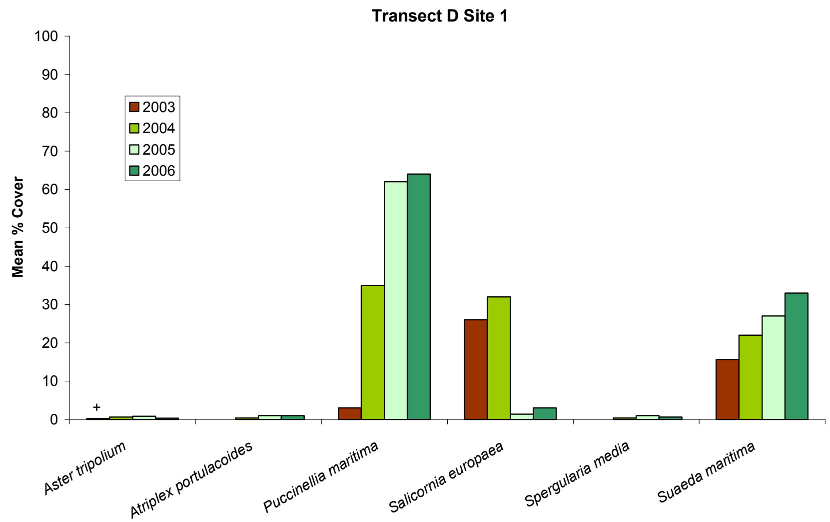


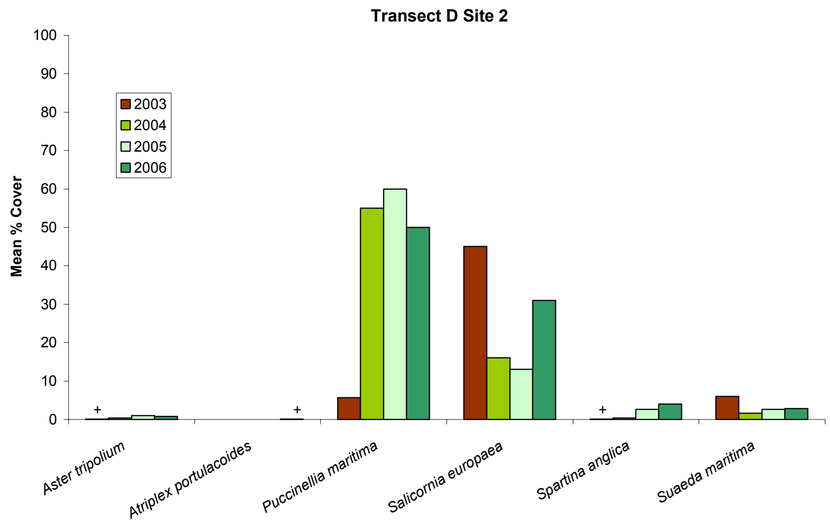


Appendix A5.4. continued









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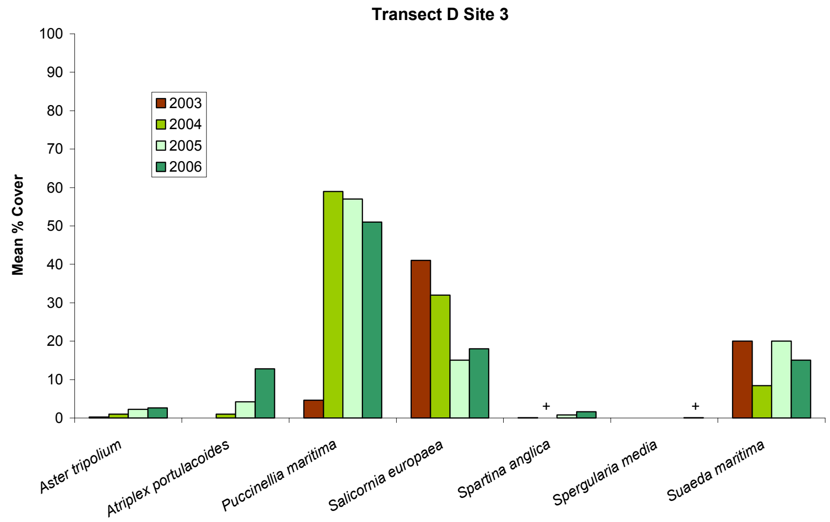

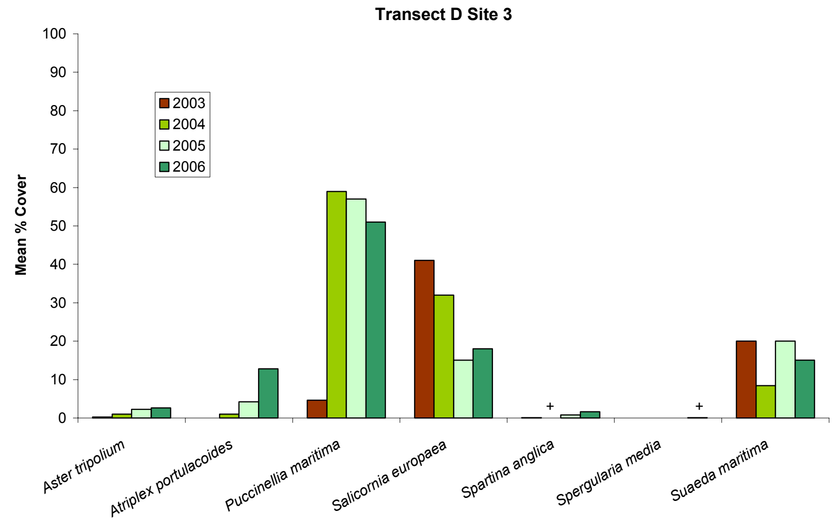

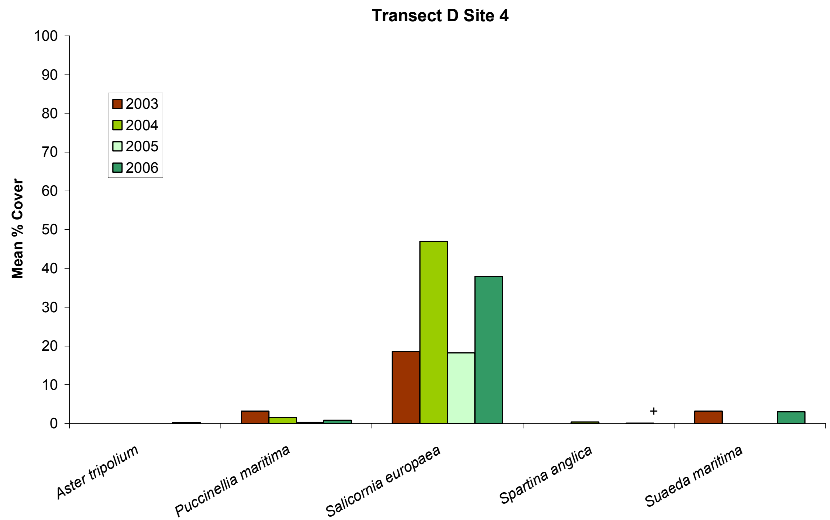

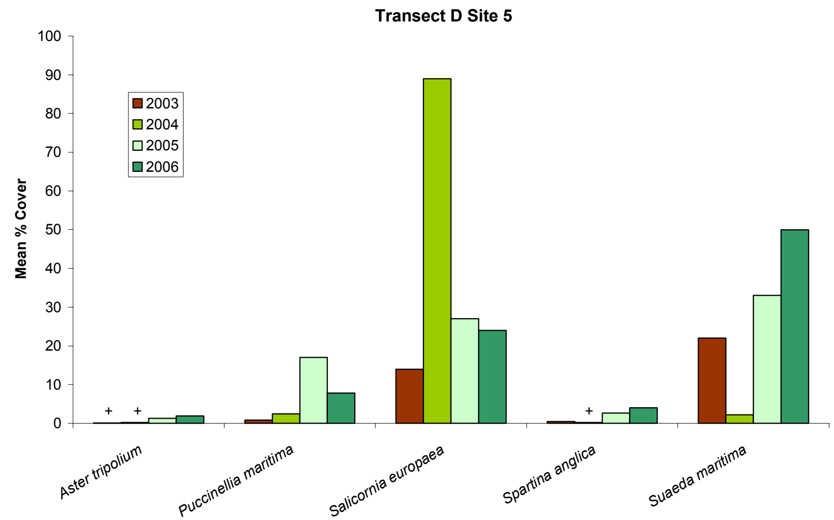

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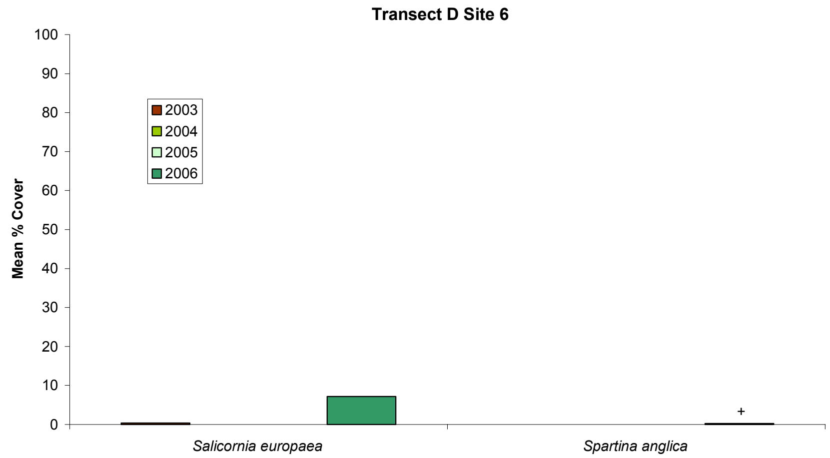
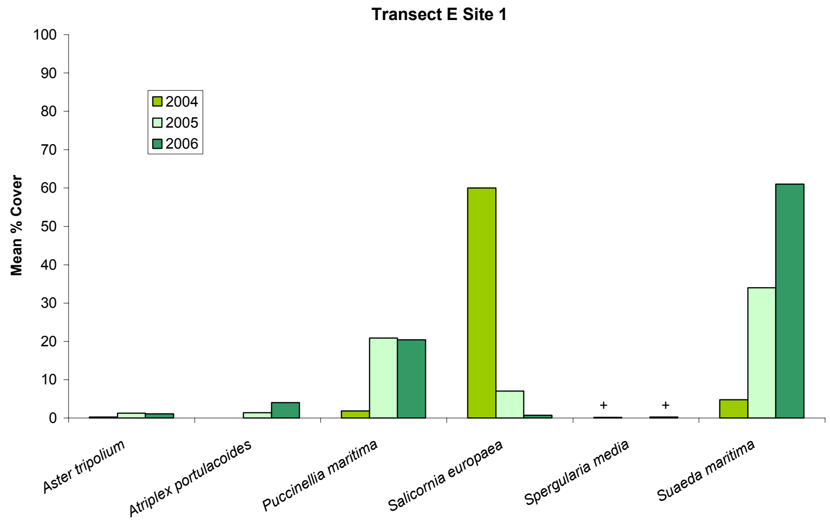
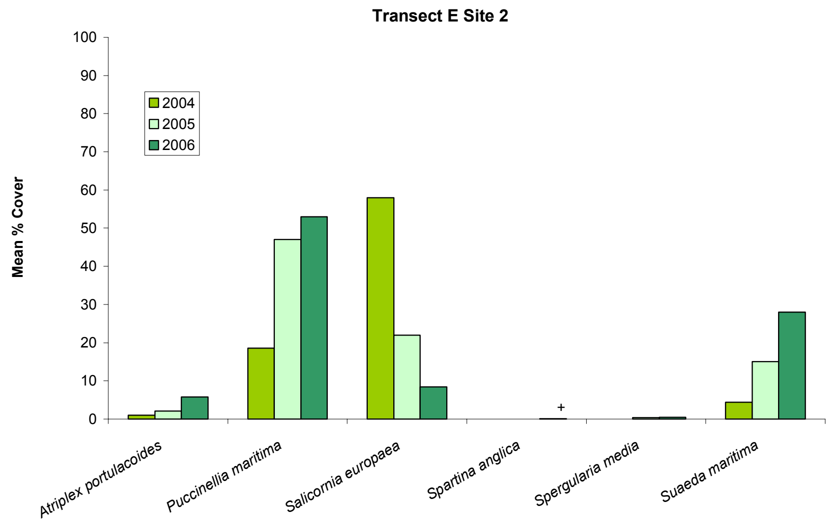
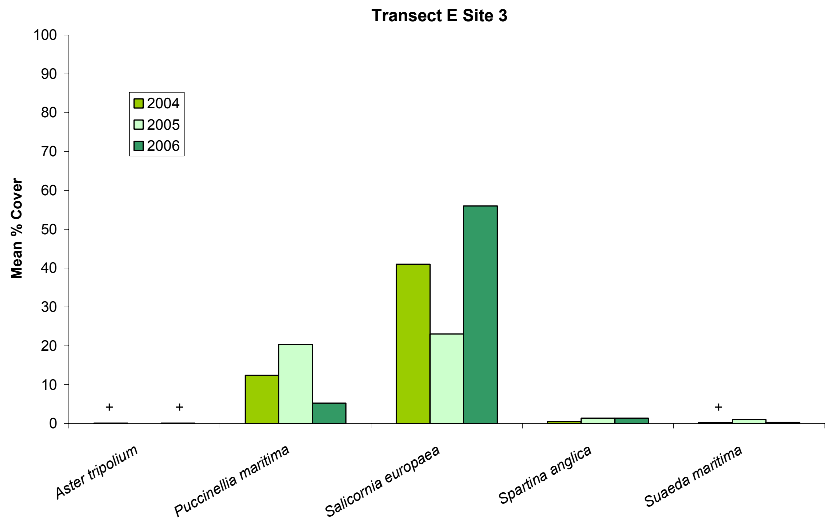
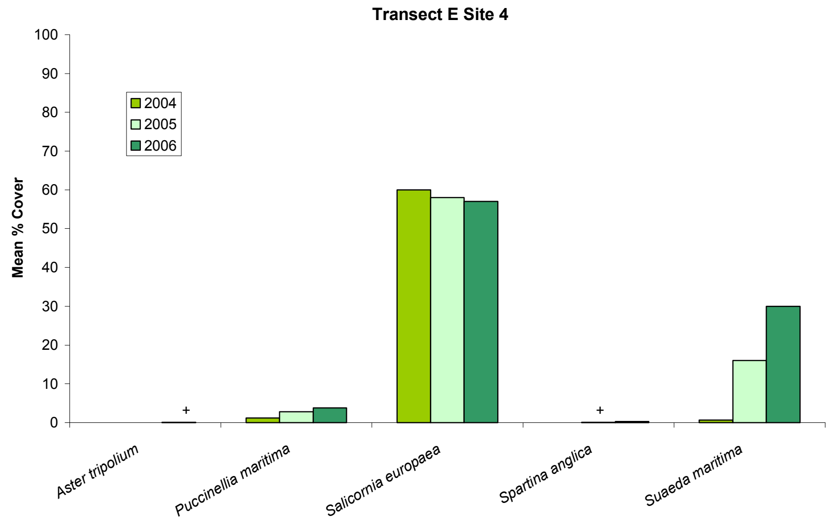


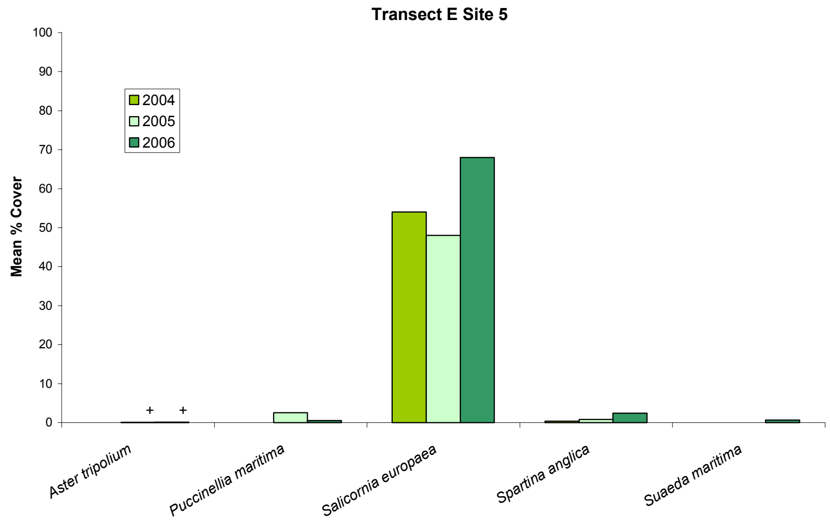


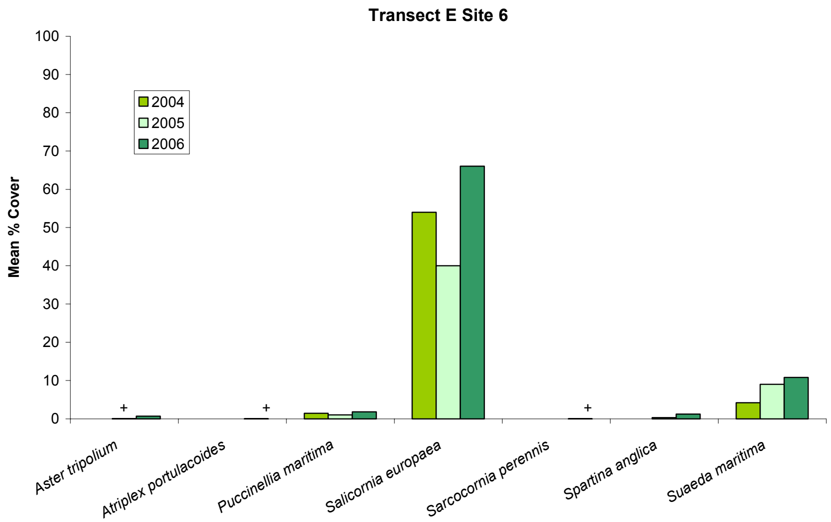


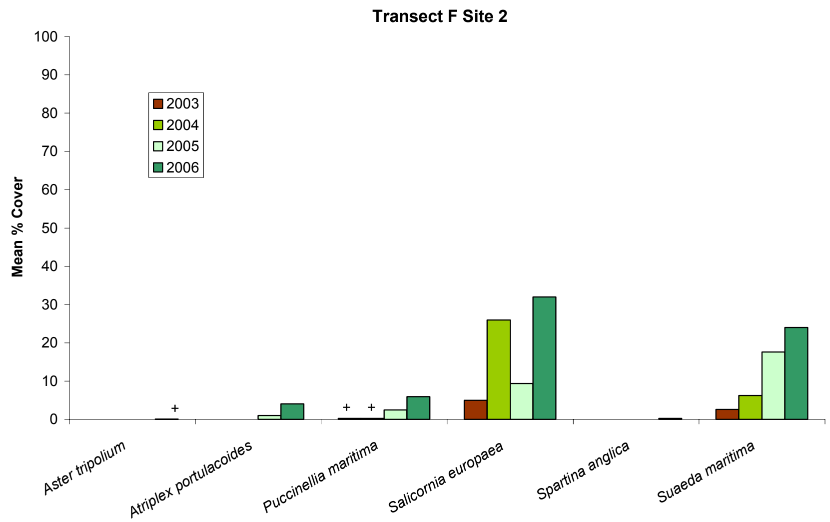


Appendix A5.4. continued

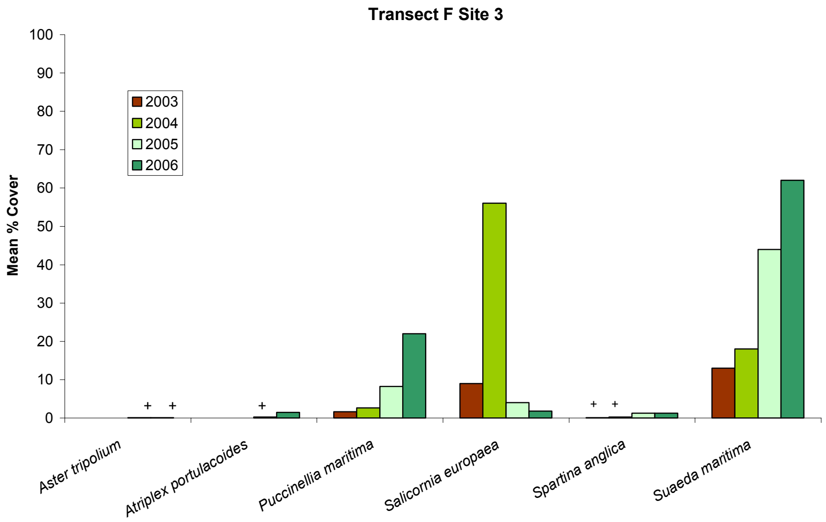


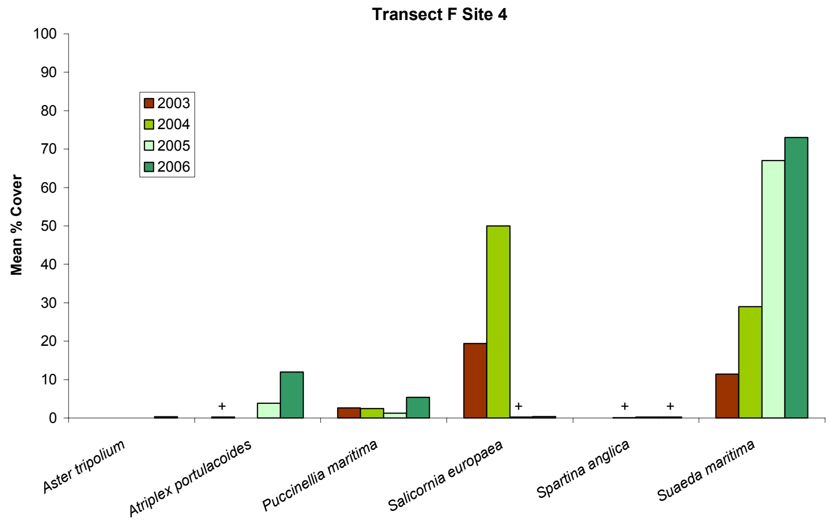


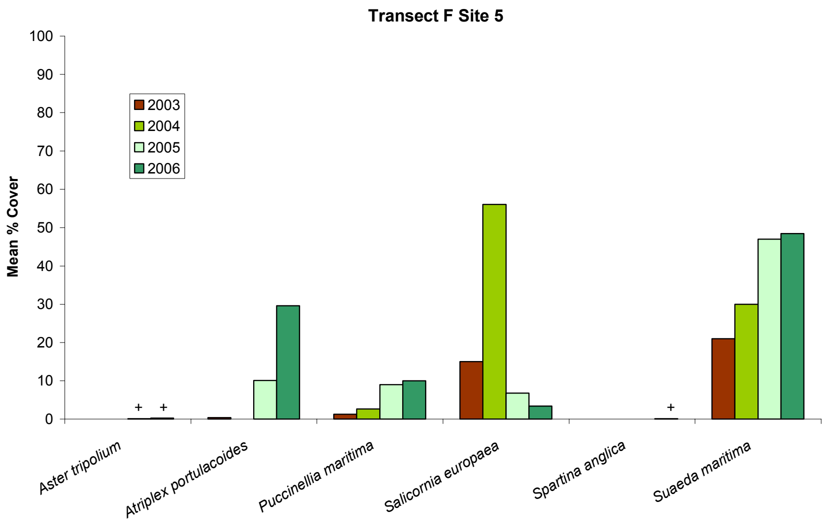


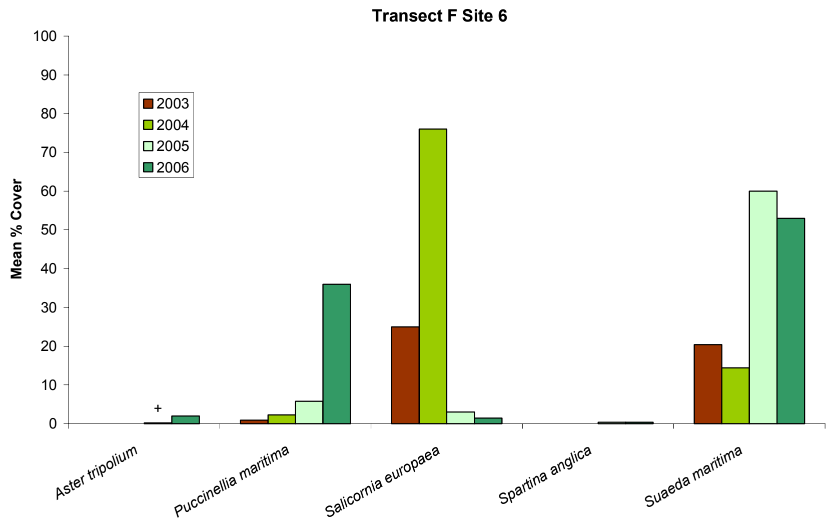


Appendix A5.4. continued [Note: Transect F Site 1: covered with permanent shallow water for all years; no vegetation]









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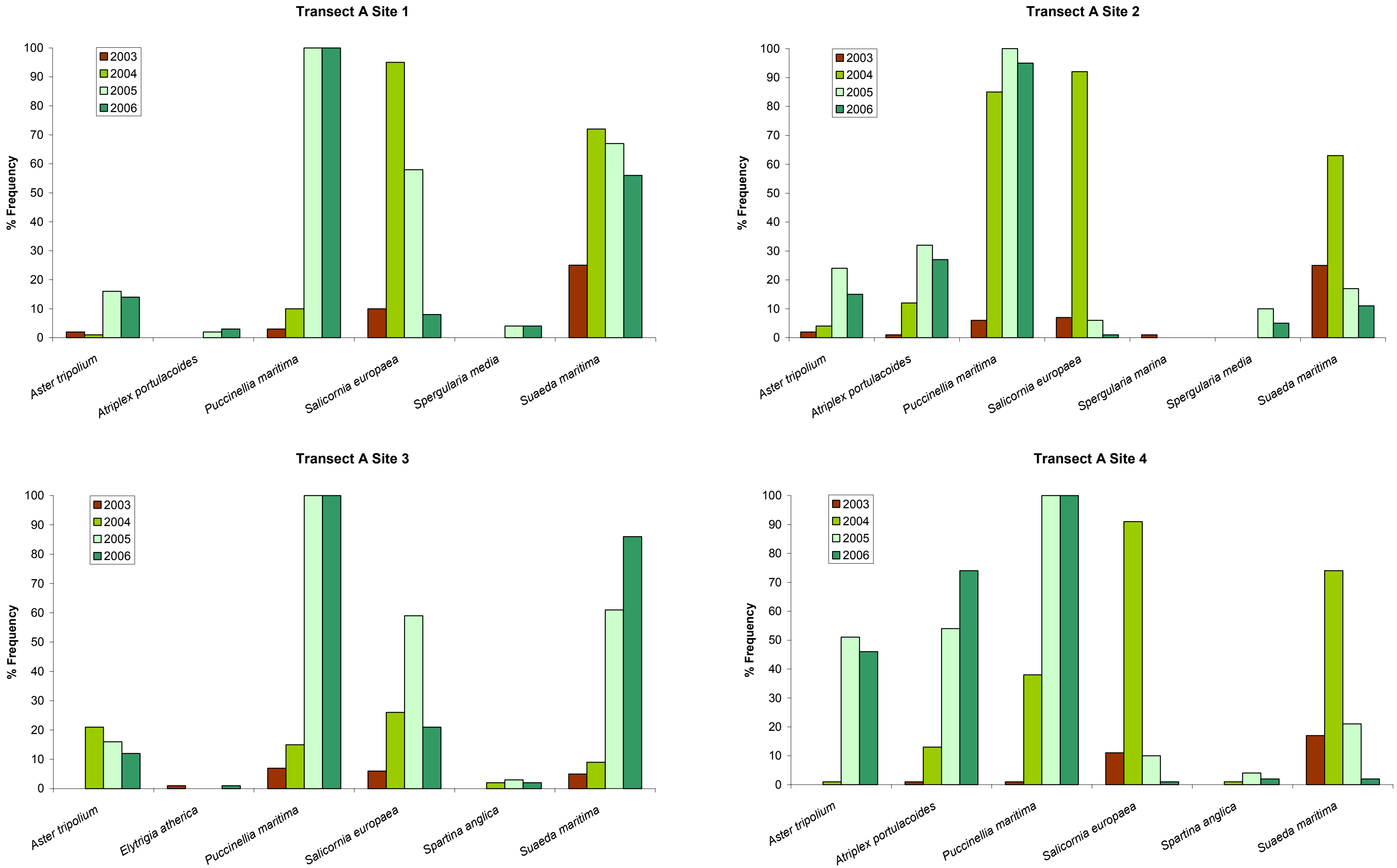
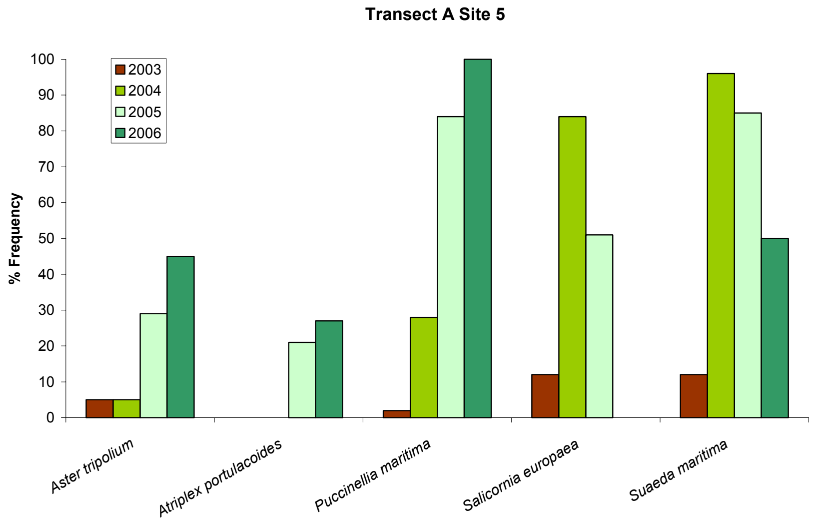
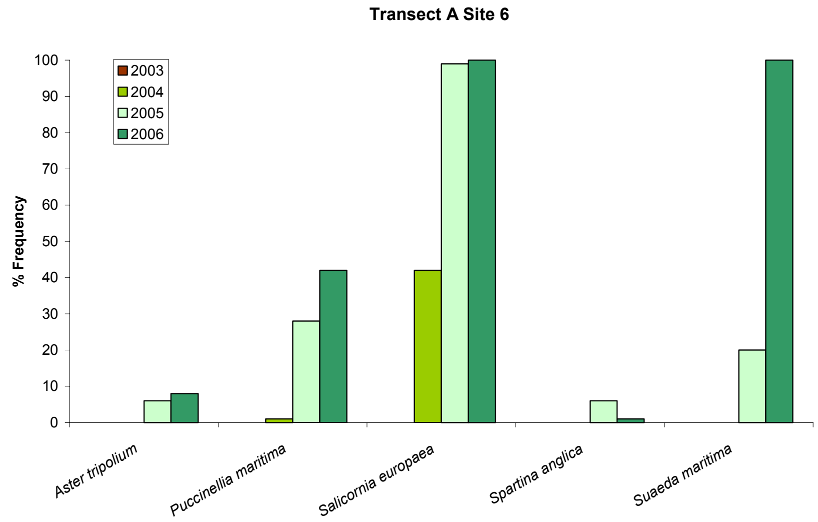
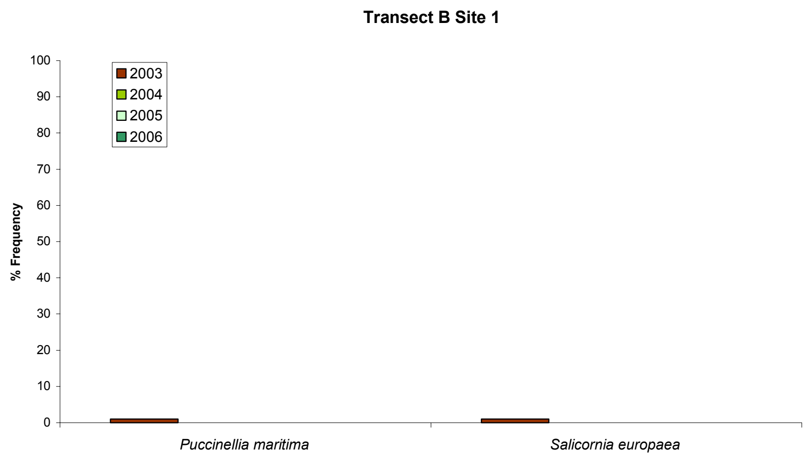
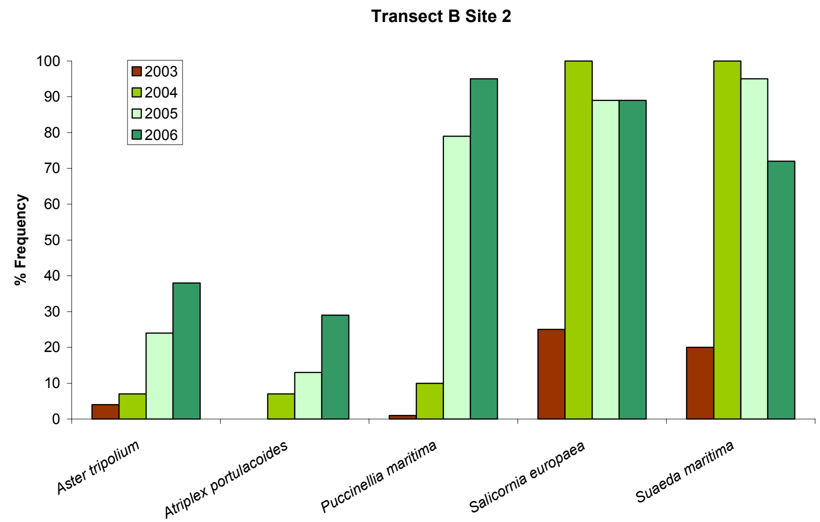


Appendix A5.5. Percentage frequency of occurrence of species in the 1 x 1m^2 quadrats inside the managed realignment site (100 cells)









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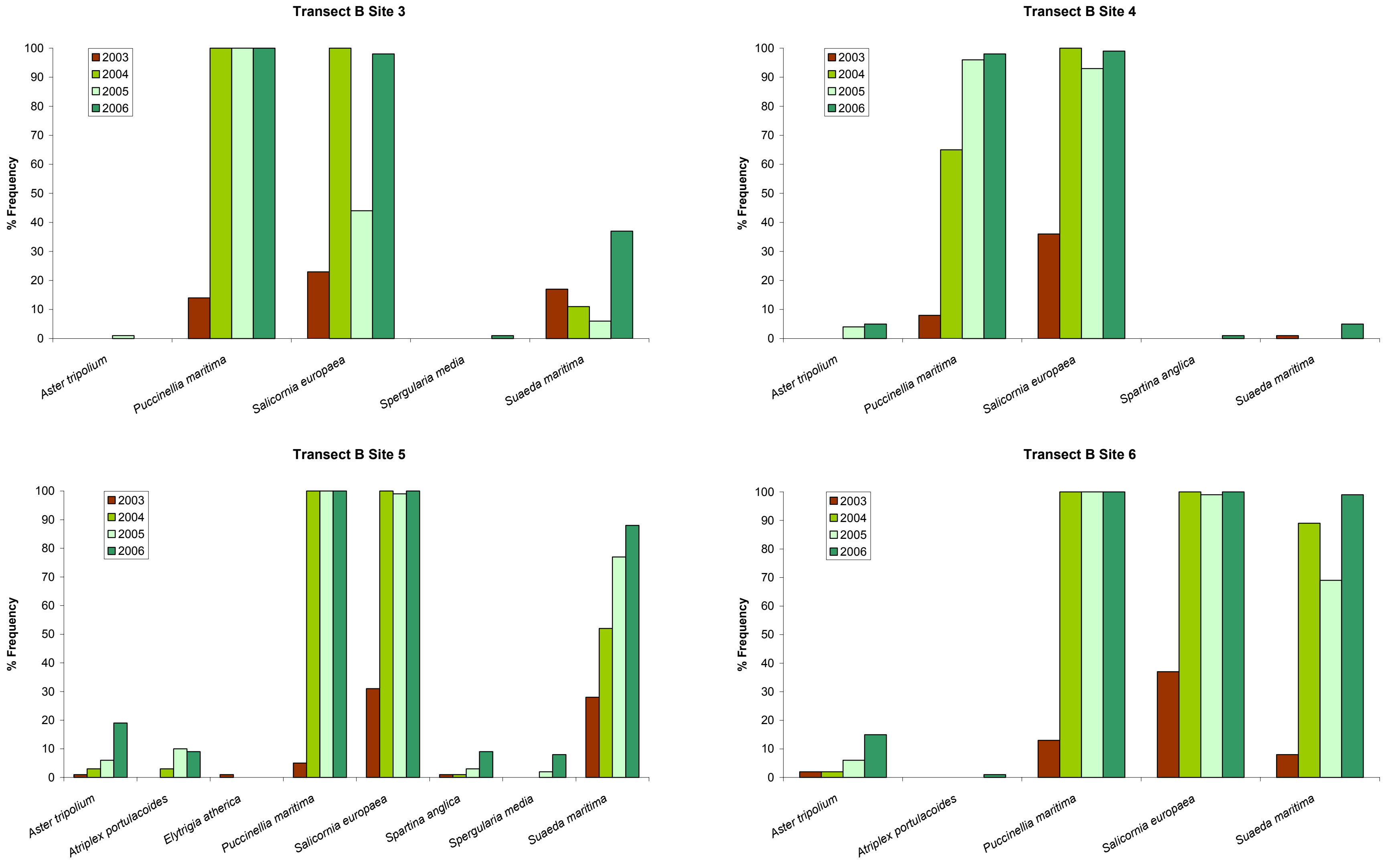

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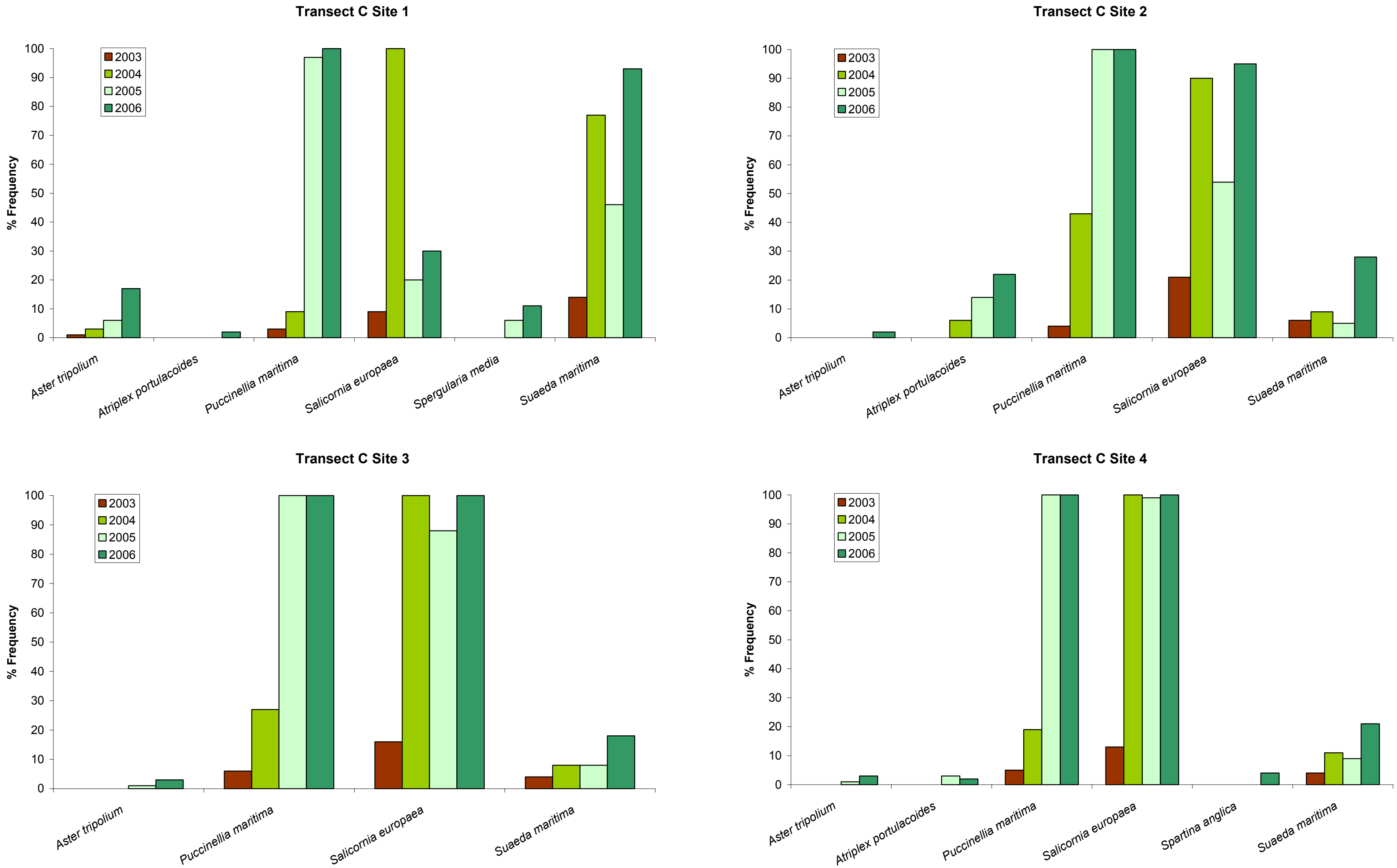
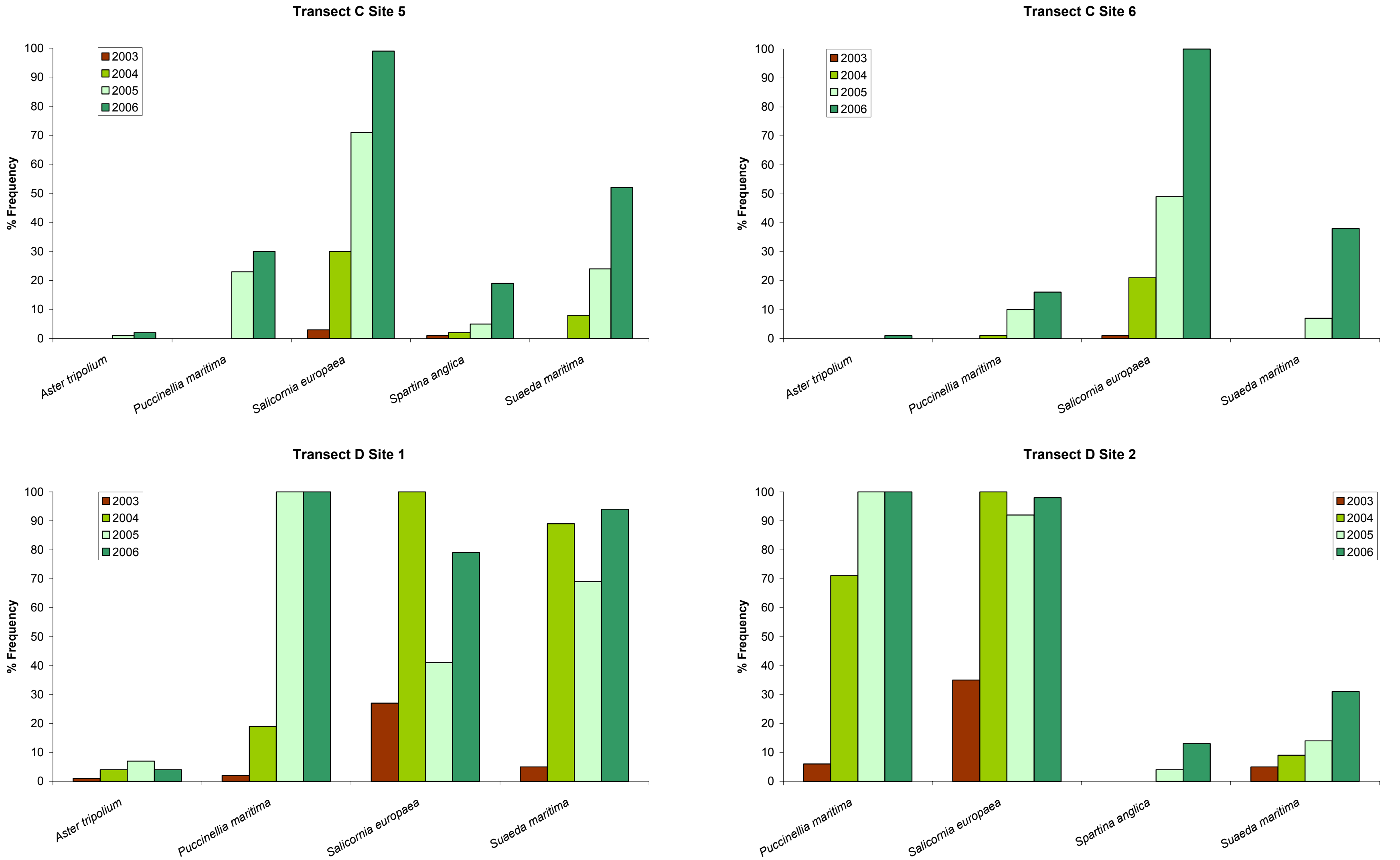


Appendix A5.5. continued



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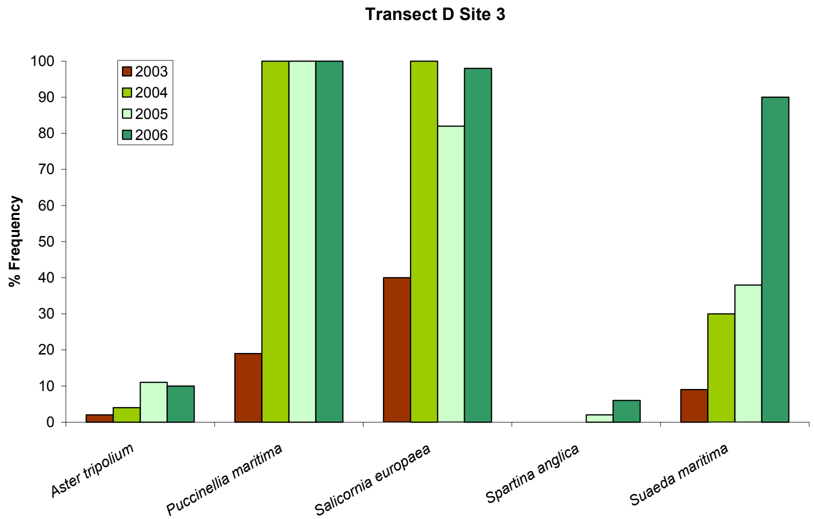
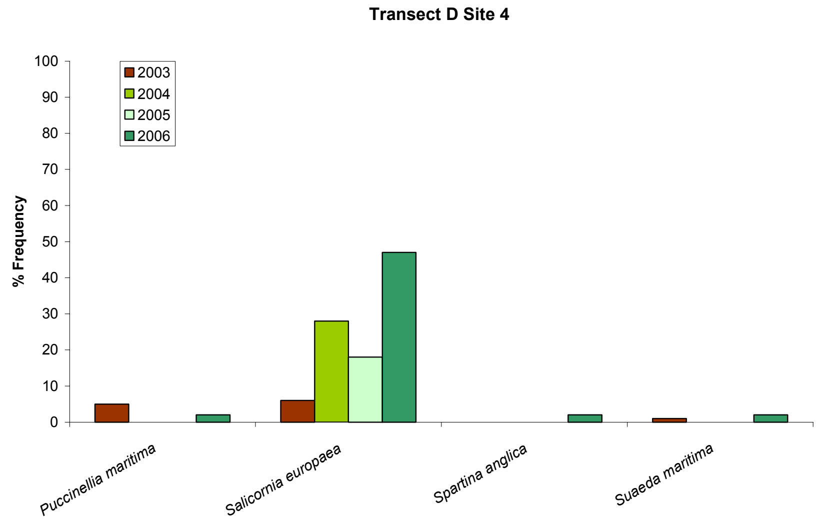
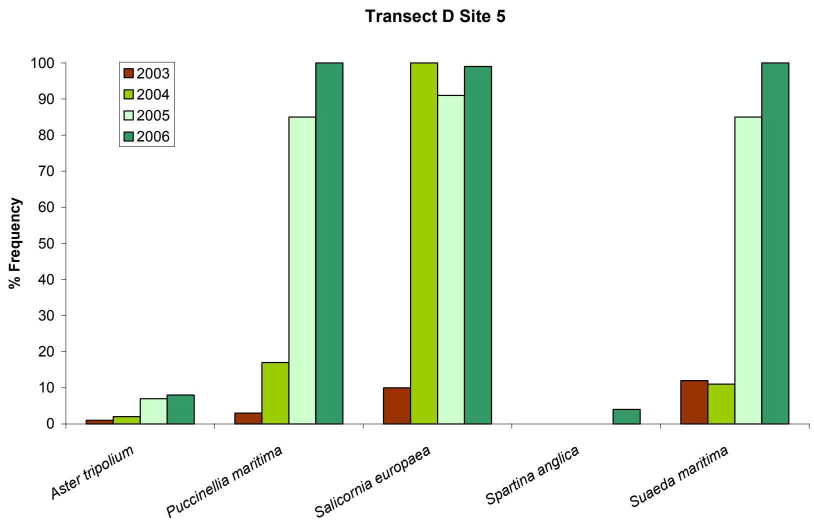
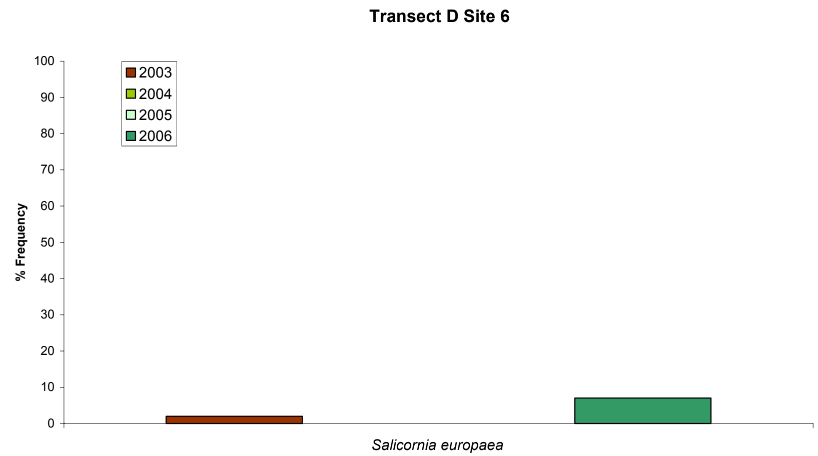


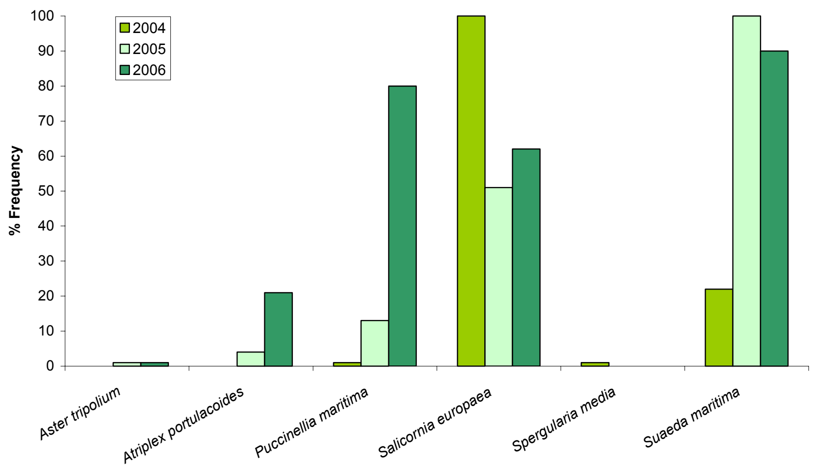




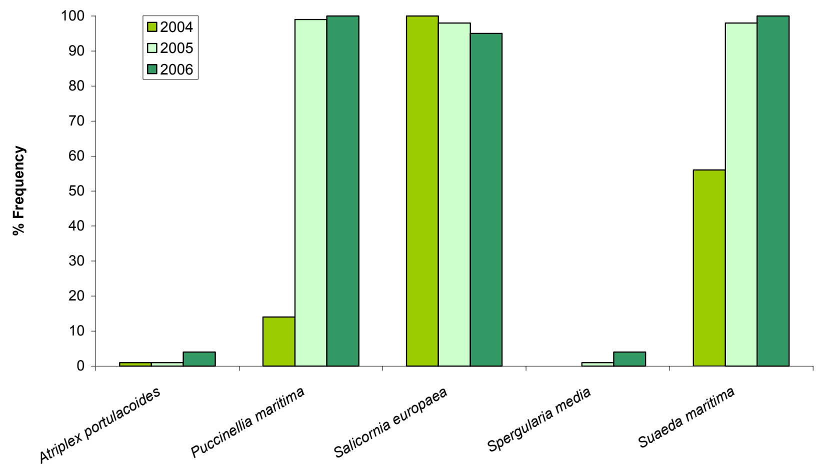


Appendix A5.5. continued

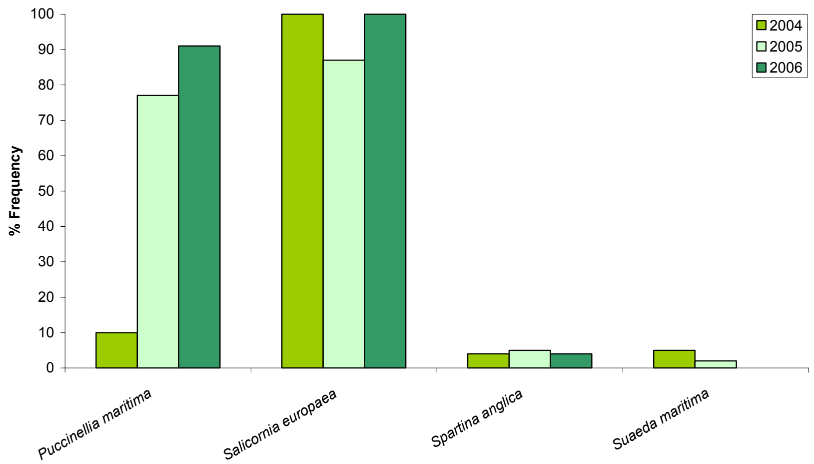
Transect E Site 1



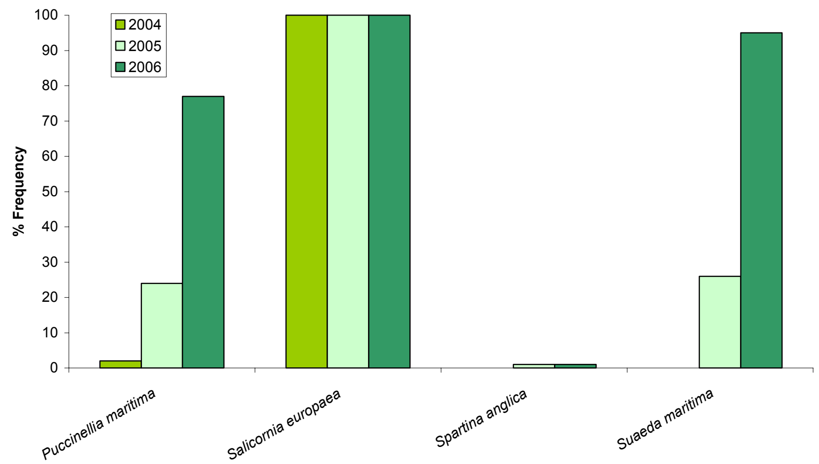
Transect E Site 2



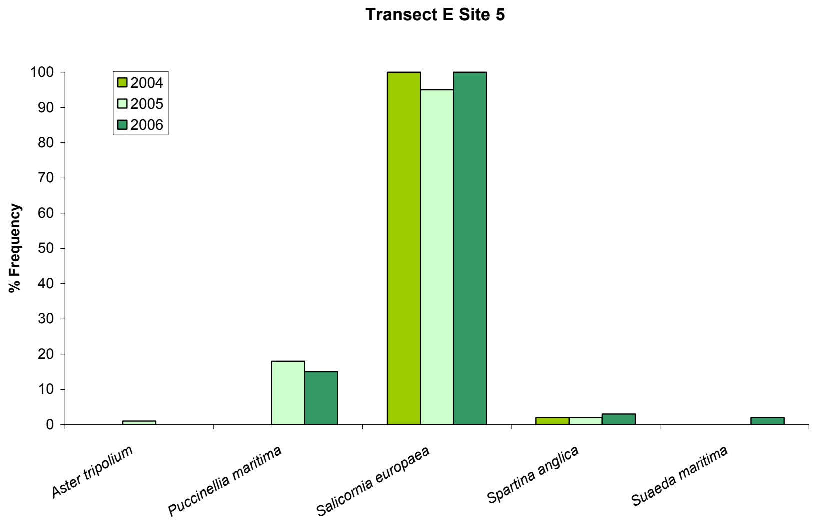
Transect E Site 3

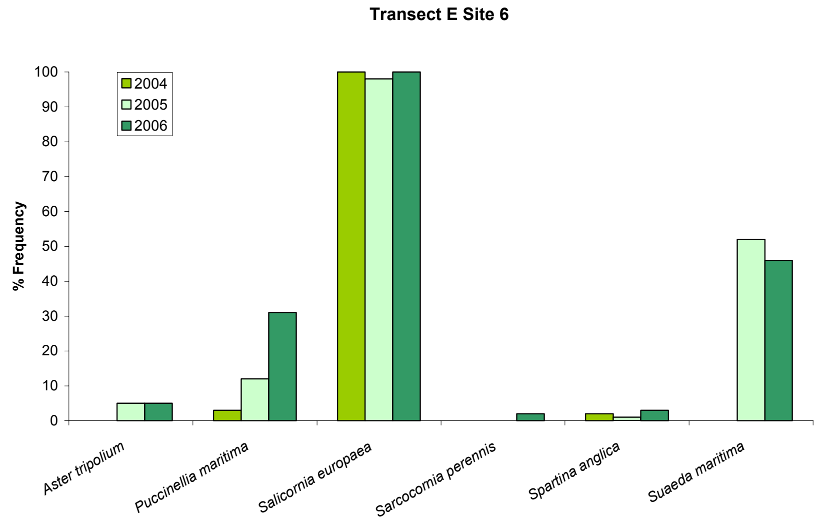


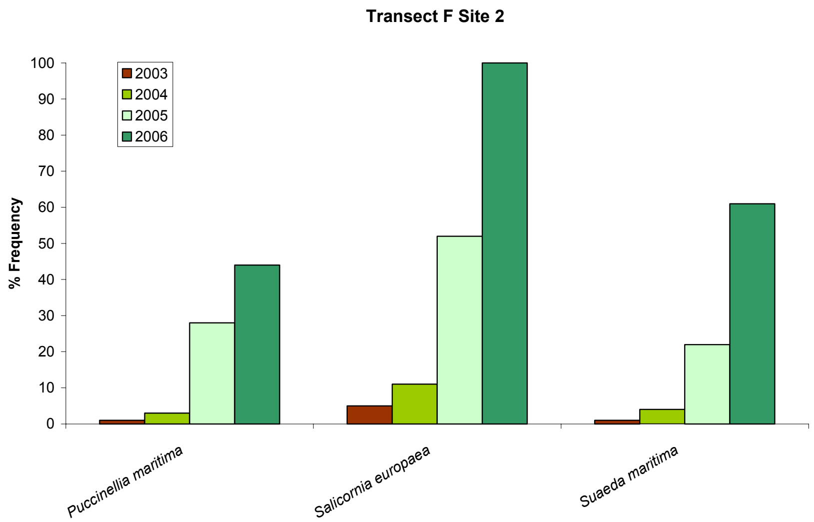
Transect E Site 4

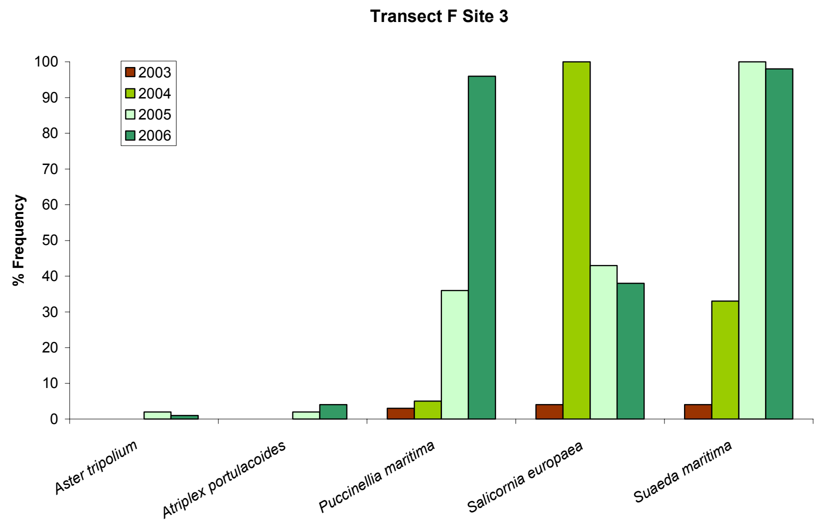


Appendix A5.5. continued

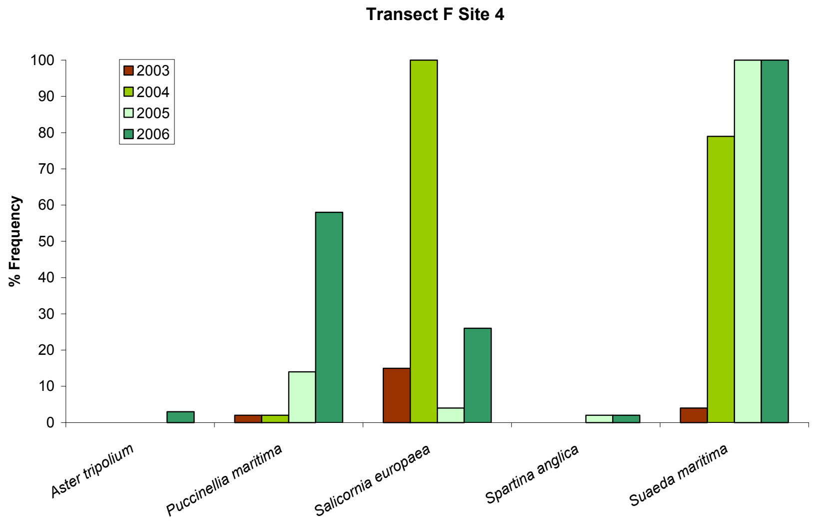


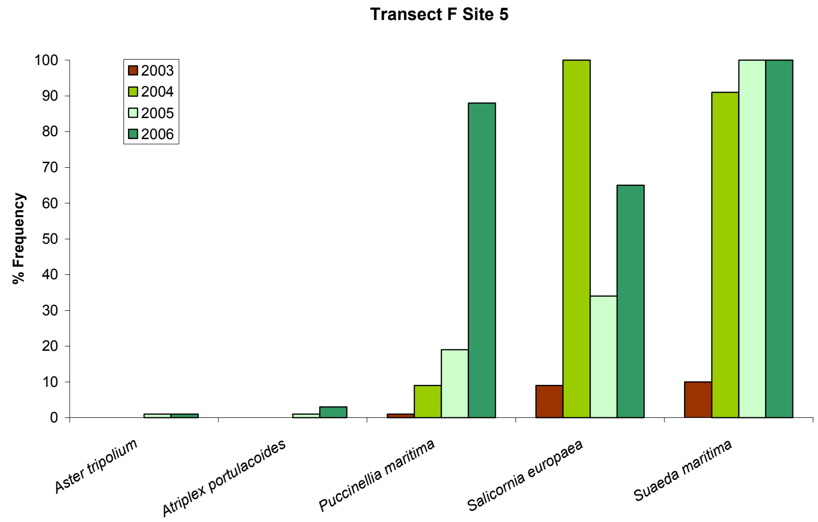


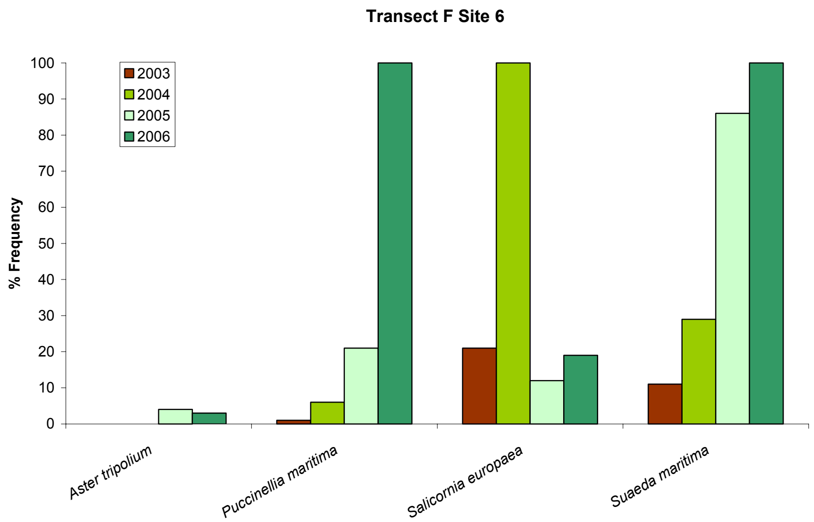




Appendix A5.5. continued (note: TFS1 underwater, no vegetation)

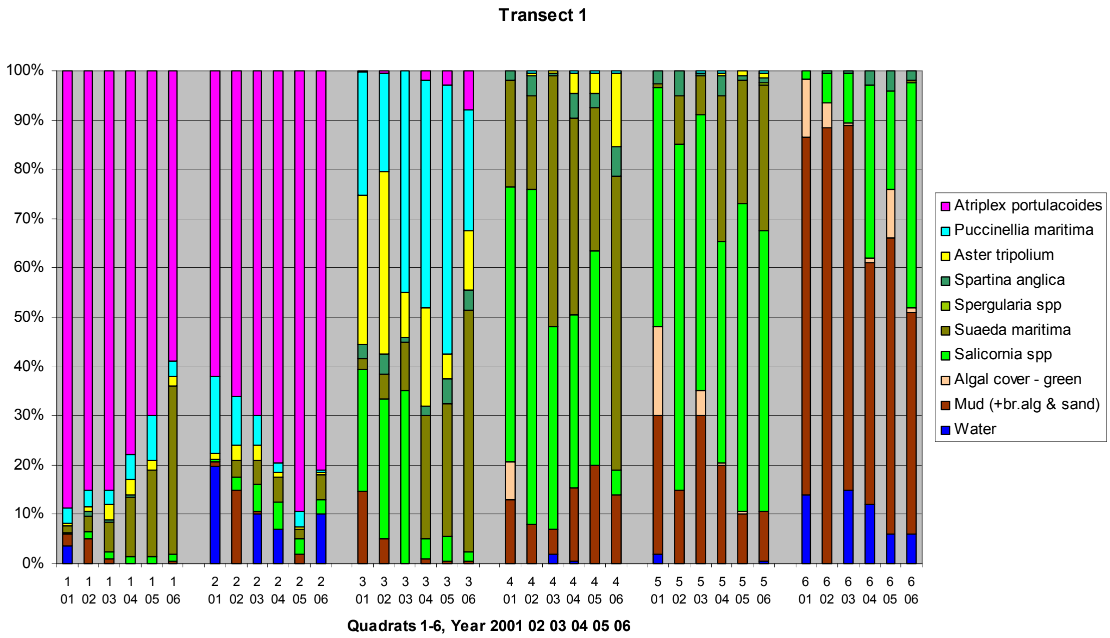


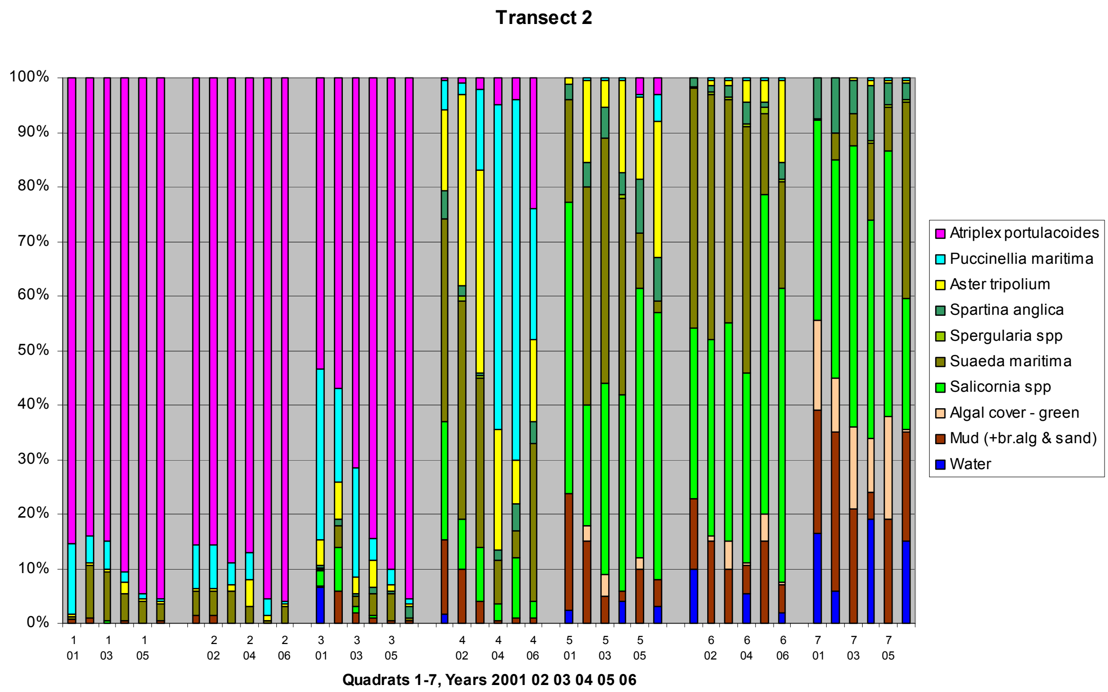




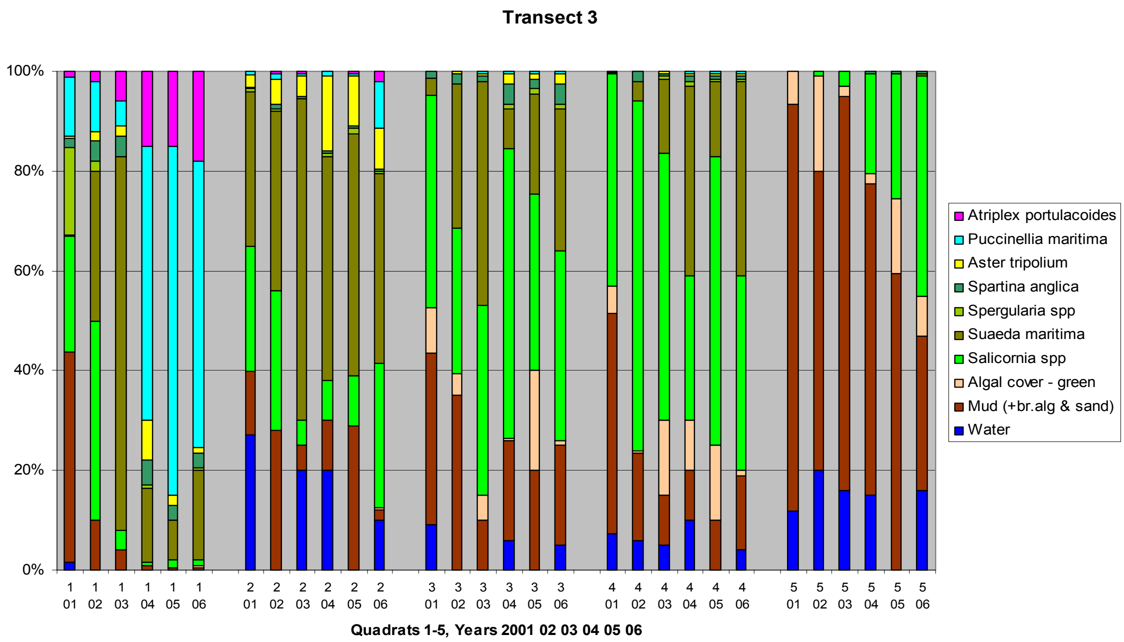
Appendix A5.5. continued

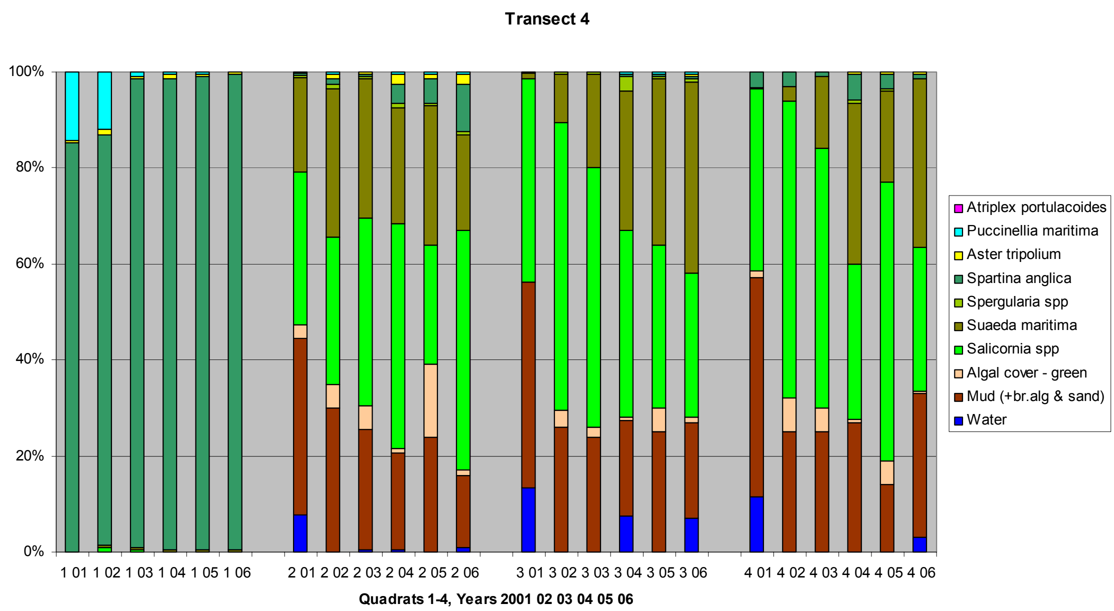
Appendix A5.6a. Ground reference vegetation data (% cover) for 5x5m quadrats on Transects 1-6 on the salt marsh outside the realignment site



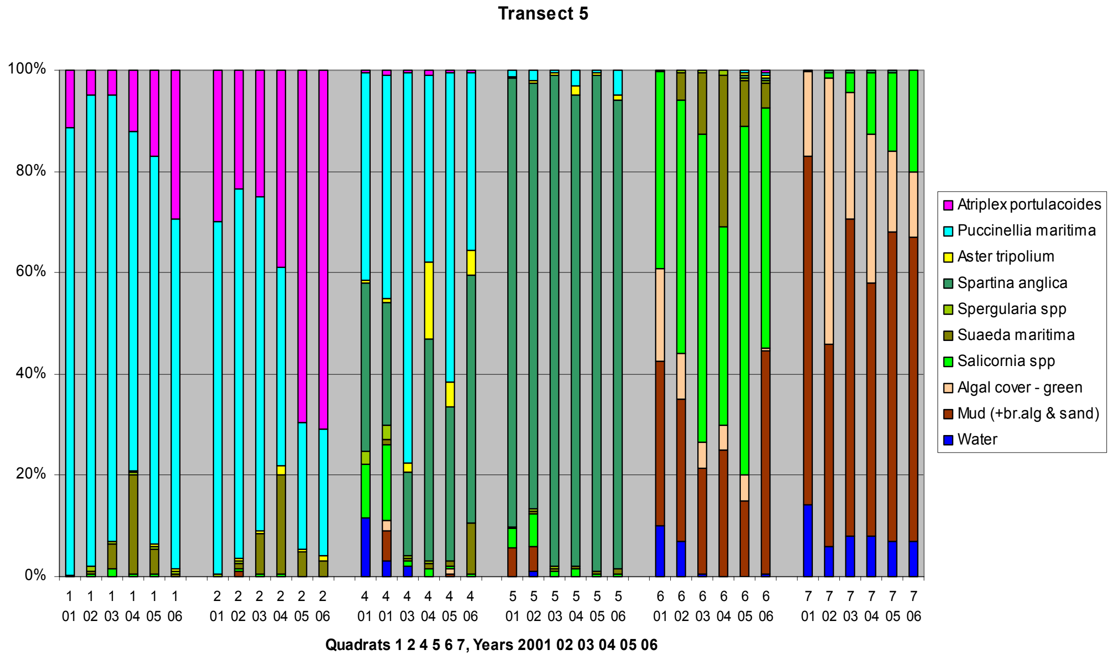


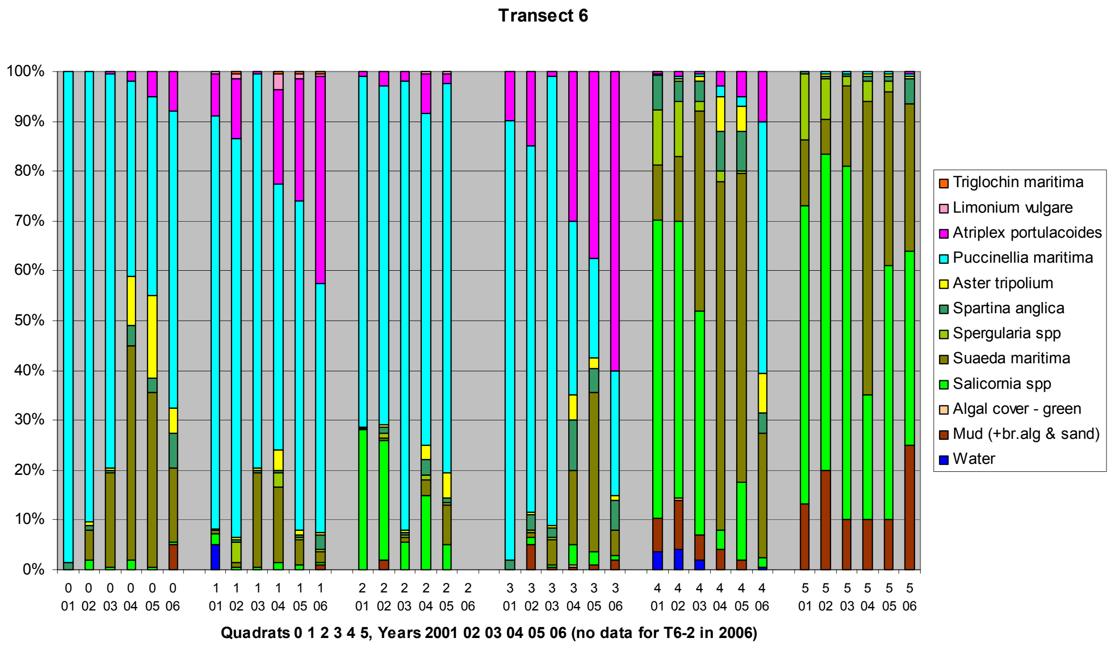
Appendix A5.6a. Continued



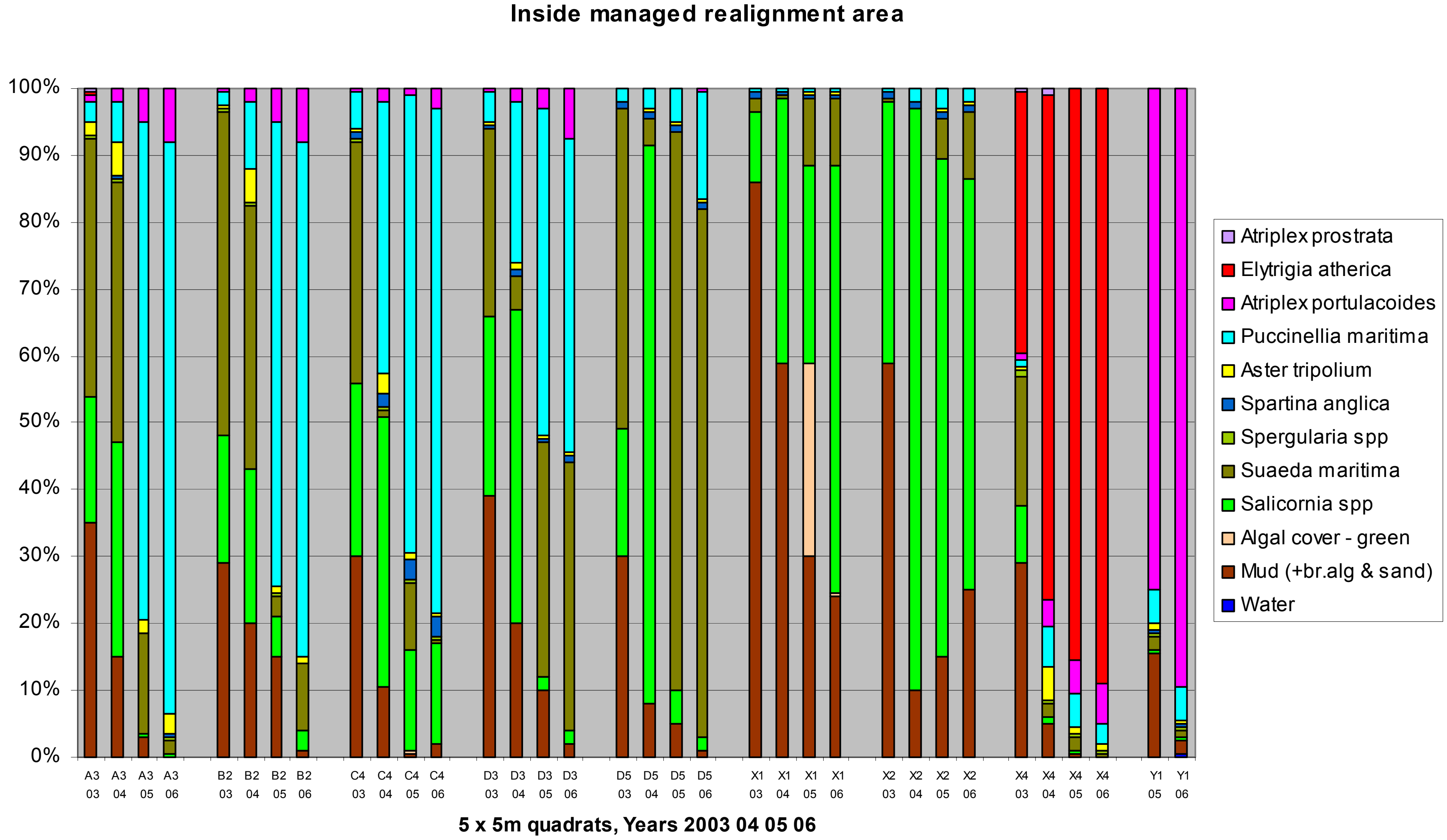


Appendix A5.6a. Continued





Appendix A5.6b. Ground reference vegetation data from 5x5m quadrats inside the realignment site



Appendix A5.6c. Notes on ground reference vegetation survey 2001-06

A.G. Thomson

The results of percentage estimated cover of species/cover types within the Freiston Macrovegetation Quadrats (5 x 5m) have been summarized in a series of charts showing results from October 2001, September 2002, September 2003, September 2004, September 2005 and September 2006.

The species/cover types are arranged to follow their approximate sequence down the shore profile and have been given a consistent colour code. Some species/cover types have been amalgamated, e.g. brown algae with mud, small amounts of *Sarcocornia (=Salicornia*: former name*) perennis* with *Salicornia europaea.*

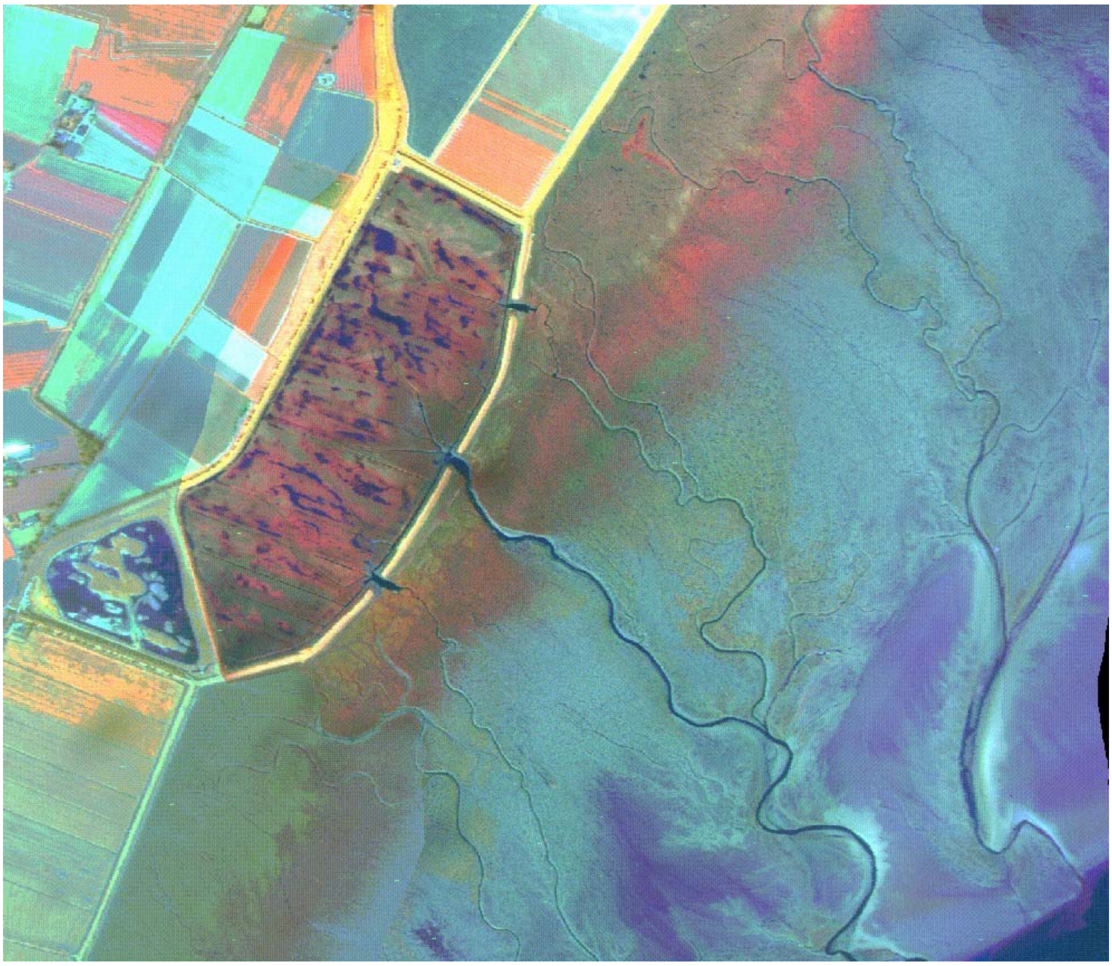
Data and charts have been supplied to show % frequency values of species/cover types (derived by multiplying the presence in 25 1 x 1 m cells within each quadrat by 4). This is a more objective measure than percentage estimated cover but is less sensitive to minor changes in species abundance.

Comments for 2006:

- For the first time since 2003, an overflight by the NERC Airborne Research Survey Facility has been carried out, and during the time of field recording. It took place on Monday 11 September 2006 between 15.20 and 15.50 BST under moderately clear sunny conditions; the weather had been completely clear until 15.00 but small amounts of patchy cloud were beginning to form.
- Fieldwork was carried out during the week 11-16 September 2006, i.e. *c.* two weeks earlier in the season than for 2005 but at a similar time for 2002, 2003 and 2004 (and much earlier than 2001). The field recording in 2005 & 2006 was undertaken by A G Thomson and D Freiss.
- Recording started after high spring tides hence more standing water was recorded than in neap tide conditions of the 2005 recording (standing water soon to drain off was ignored).
- Since last year, cattle have had access to the saltmarsh in the south of the study area, i.e. at the tops of Transects 5 and 6. Their trampling has destroyed some marker poles and the location of T6-2 has been lost completely. Erosion has removed some marker poles at the marsh front and T5-6 could not be relocated for survey with the rope quadrat but a photograph has shown that one marker has survived, a valid estimate of vegetation cover can be made and the quadrat can be reconstructed in future years with the aid of a photo from 2004.
- Outside the Managed Realignment area (i.e. in Transects 1–6), the salt marsh vegetation is relatively unchanged since 2005. There has been only localized occurrence of the previous apparent trend of increasing vegetation cover at the seaward ends of the transects this year; at T1-6, T3-5 and possibly T5-7 but not T2-7, T4-6 and T6-6. There have been variable changes in the relative % cover of *Atriplex portulacoides* and *Puccinellia* and *Salicornia* and *Suaeda* in different quadrats. Specific comments for each Transect are given below:

- Transect 1 (the northernmost transect). *Suaeda* has increased in cover in T1-1, T1-3 and T1-4 and *A.portulacoides* decreased in T1-1 (but is still predominant). The increase in *Salicornia* at T1-6 indicates an advancing marsh front at this point. [Note from S.B. : *Salicornia* is an annual and can show varied recruitment each year, although its steady increase does suggest that the marsh is advancing and other species e.g. *Spartina* has increased and *Aster* appeared in the smaller quadrats by 2006]
- Transect 2. *Atriplex portulacoides* continues to dominate T2-1, T2-2 and T2-3, and is increasing (with *Suaeda*) at the expense of *Puccinellia* at T2-4. The vegetation composition of the more seaward quadrats (T2-5, T2-6 and T2-7) is more stable. *Aster* is more prominent in T2-4, T2-5 and T2-6 (but this may be a seasonal effect of earlier recording) [Note from S.B.: Aster is a biennial, sometimes annual, and can vary between years].
- Transect 3 (in front of the Managed Realignment area). T3-1 has stabilized as a *Puccinellia*-dominated mid-marsh vegetation (originally pioneer saltmarsh). The pioneer salt marsh vegetation of T3-2, T3-3 and T3-4 is little changed (more *Salicornia* in -2, more *Suaeda* in -3 and -4) but all show a small increase in vegetated cover. Increasing *Salicornia* at T3-5 indicates another location for an advancing marsh front.
- Transect 4 (in front of the Managed Realignment area). The dense stand of *Spartina* is unchanged. All three other quadrats, T4-2, T4-3 and T4-4, contain pioneer salt marsh vegetation with very little change.
- Transect 5. The top of this Transect shows increased cover of *A.portulacoides*, it has taken over from *Puccinellia* in T5-2 (whereas T5-1 is still predominantly *Puccinellia*). *Spartina* has become predominant in T5-4 (and remains as a stable dense sward in T5-5). Of the two seaward quadrats, T5-6 shows a decrease in vegetation cover whereas T5-7 shows a slight increase (but this is an estimate from a photograph).
- Transect 6 (the southernmost transect). The top of this transect has been trampled by cattle; it is still predominantly dominated by *Puccinellia* but *A.portulacoides* has increased in T6-0, T6-1 and T6-3 (no record from T6-2). T6-1 is the most floristically diverse quadrat but the amount of *Triglochin* and *Limonium* has decreased. T6-4 shows considerable change, from *Suaeda* dominated pioneer marsh in 2005 to *Puccinellia* dominated marsh in 2006. The most seaward quadrat, T6-5 has changed little.
- Inside the Managed Realignment area (MR), there have been rapid successional changes of the vegetation. In much of the MR, the perennial species e.g. *Atriplex portulacoides* and *Puccinellia* are taking over from the annuals, *Salicornia* and *Suaeda,* this main change occurred after two years, between 2004 and 2005, but the trend is continuing. *Suaeda* is still dominant at the seaward end of Transect D and *Salicornia* still dominates X-1 and X-2. There has been a general increase in vegetation cover of previously bare ground but some bare ground and shallow pools remain. *Elytrigia atherica* has consolidated at X4 and *Atriplex portulacoides* has established good coverage at the south of the site (Y1).
- The main creeks draining the MR have continued to widen and deepen.

Appendix A5.7. Crude (first version) mosaic of three flightlines of Airborne Thematic Mapper Data taken by the NERC Airborne Research Survey Facility on 11th September 2006



The data has been passed to Dan Freiss, PhD student, Cambridge University Geography department

Appendix A5.8. Scientific and common names of plants recorded in quadrats or noted at Freiston.
Nomenclature follows Stace (1997)

Scientific Name	**Common Name**
Artemisia maritima	Sea Wormwood
Aster tripolium	Sea Aster
Atriplex portulacoides	Sea-purslane
Atriplex prostrata	Spear-leaved Orache
Cochlearia anglica	English Scurvygrass
Cochlearia officinalis	Common Scurvygrass
Elytrigia atherica	Sea Couch
*Festuca rubra**	Red Fescue
*Glaux maritima***	Sea-milkwort
Limonium vulgare	Sea Lavender
Plantago maritima	Sea Plantain
Puccinellia maritima	Common Saltmarsh-grass
Salicornia europaea	Common Glasswort
Sarcocornia perennis	Perennial Glasswort
Spartina anglica	Common Cord-grass
Spartina maritima ***	Small Cord-grass
Spergularia marina	Lesser Sea-spurrey
Spergularia media	Greater Sea-spurrey
Suaeda maritima	Annual Sea-blite
Triglochin maritima	Sea Arrow-grass

* *Festuca rubra* occurs occasionally in a narrow strip at the base of the embankment on this side of the Wash and may occur around Freiston, but it is has not been seen and is not common.
** *Glaux maritima* also occurs occasionally in a narrow strip at the base of the embankment on this side of the Wash, but it has not been seen at Freiston
*** One patch of *Spartina* closely resembling *Spartina maritima* (3-4m diameter) was found in the 1990s on Transect 6 just seaward of Site 2 (S.L. Brown's former LOIS transect) and was seen until recently, but it appears to have gone now. This plant has been recorded (post 1930) at two sites on this side of the Wash in Perring and Walters 1976.

6. Colonisation of the Freiston Managed Realignment site by intertidal invertebrates

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6.1 Summary

The data demonstrate that 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 it is possible they escaped detection and, even if real, their absence from the managed realignment 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 indicate 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 detected, and observations during the sampling periods indicate that these organisms are able to bury into the agricultural soil beneath the accumulating marine sediment, and so were not dependent on the latter for colonisation.

6.2 Introduction

The purpose of the invertebrate sampling was to monitor the arrival, and the establishment, of a community of littoral and salt marsh invertebrates within the managed realignment, after the sea wall was breached. The pre-existing salt marsh immediately adjacent outside the breached sea wall was also sampled to determine the local littoral and salt marsh invertebrate community structure. The invertebrate taxa detected at Freiston are listed in Appendix 6.3, with their taxonomic classification and their habitat preferences.

6.3 Methods

Invertebrates 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 old established saltmarsh outside the realignment. Appendices A6.1 and A6.2 show which sites were sampled inside and outside the MR each year, and which sampling methods were used.

Invertebrates were sampled by three methods:

1) **Pitfall Traps**

These were placed in the sediment (with the tops level with the surface) close to the transect sites, during neap tides. Since the traps were only set for three days and nights, two were placed at each site to increase the catch. At most sites one was placed one metre to the North of the marked out site with the second one metre to the North of that. At some sites, however, this position was still under standing water from the previous spring tides, so a position within 20 metres of this on higher ground was chosen. One centimetre depth of ethanediol was placed in each as a non-volatile killing and preserving agent. Crossed-wire lids were placed over the trap pots to prevent other animals taking the catch. At the end of the sampling period the traps were lifted and the wire lids replaced by impermeable screw caps for removal to the laboratory for counting. The depth of marine sediment which had been deposited at each site within the managed realignment was measured in the wall of the core hole made to insert the trap.

2) **Sediment Scrapes**

At each of the sites a sample of the marine sediment which had deposited was taken. These were located at random near the marked sites at but located to fit between the salt marsh plants present. The depth of this sediment varied according the local elevation and distance from the breaches. Higher up the shore this was often just a thin layer over the agricultural soil; but closer to the breaches this could be 20cm deep, or more. In each case the marine sediment enclosed by a 30cm x 30cm quadrat was lifted off with a spade down to a maximum of 10cm. In 2003, care was taken to minimise the straw laden agricultural soil taken as this was still very compacted and had not been colonised by marine invertebrates and so would have choked the sample.

Where the marine sediment was deeper than 10cm, 2 x 10cm cores were taken down to a maximum of 30cm. These were broken up on site to search for any deep burrowing marine worms. On the salt marsh outside the sea wall the scrapes were taken from non-vegetated patches close to the transect site.

The samples were washed on site in sea water in a 0.5mm mesh sieve to remove much of the fine sediment. What remained was placed in a plastic pot with a little sea water and concentrated formaldehyde solution was added to kill and fix any invertebrates present. These samples were transported to the laboratory for sorting.

3) Sweep nets

We took these from the saltmarsh vegetation at each sampling position in order to check for any invertebrates high up in the salt marsh vegetation and hence not collected by the other two collection methods. A custom- made sweep net was used which consisted of a nylon mesh bag, formerly used on a vacuum sampling machine, hooked to the Y-frame of a kite type butterfly net. This configuration avoided the need to transfer the invertebrates captured to other storage containers since after each sample was taken, it could be contained simply by tying the top of the bag. This was then placed into a polythene bag with the other bagged samples together with a cotton wool pad soaked in ethyl acetate killing fluid. Another empty mesh bag was then hooked onto the frame for the next sample. Each sample consisted of fifty sweeps performed across the vegetation while walking steadily forward. If there was a brisk wind on the day of sampling, care was taken to walk *into* the wind, otherwise the catch would have been blown back out of the net bag. Due to insufficient time being available, the taxa could not be identified to the level of species.

Differences between sampling periods in 2003-2006

2002 (28.10.02 -1.11.02)
Only pitfall samples were taken.

2003 (15.09.03-19.09.03)
Pitfall and scrape samples were taken.

2004 (07.09.04-09.09.04)
Salt marsh vegetation had grown vigorously inside the site, covering so much of the realignment site that it was difficult to find bare areas from which to take sediment scrape samples. This was most particularly so in transect A, so the scrape samples for that transect were taken from the low area containing semi-permanent water parallel to the transect to the North East, at shore levels equivalent to the sites on the transect. Where such areas were found the surface sediment had been so baked by the sun since the last inundation that the samples were intractable to sieve, especially where matted filamentous algae were also present.

Springtails were abundant, and so many fell into some of the traps that a sub-sampling method had to be used to estimate the catch. This comprised rinsing them into a large measuring cylinder, making sure they were suspended evenly in the water using a perforated piston and then pouring half away, topping the cylinder back up with clean water. This was repeated until the springtails remaining were few enough to be counted approximately and the original number estimated by multiplying by the number of dilutions.

This year, sweep net samples were taken from the salt marsh vegetation at each sampling position in order to check for any invertebrates high up in the salt marsh vegetation and hence not collected by the other two collection methods. The catch is necessarily dependant on the weather conditions at the time, and fortunately the day of sampling was fine and dry.

2005 (28.09.05-29.09.05)
Within the realignment site an extra (sixth) transect had been set up in the large gap between the fourth transect and the fifth one. This new one was designated as transect E, the last one being changed to F and all previous data and records adjusted accordingly. Outside the sea wall the same number of sites as last year was sampled, but the actual ones sampled were varied to provide a uniform spread of actual elevations, determined by surveying.

Springtails were again this year taken in enormous numbers in many of the pitfall traps situated within the site. Again, in several cases, when they filled the traps completely it was impracticable to count them individually but as it had been found difficult to suspend them evenly in the measuring cylinder in the progressive dilution method last year, this year each whole sample was spread with the minimum of liquid as evenly as possible over the surface of a large plastic sorting tray, and then a known fraction of the area was counted and multiplied up to estimated the total in the sample.

2006 (11.09.06-16.09.06)
Pitfall traps were processed as in 2005.

6.4 Results And Discussion

6.4.1 Changes in diversity and distribution observed year by year

2002 (Appendix A6.4.Pitfalls)
Inside the managed realignment the littoral species *Carcinus maenas* (shore crab), *Lekanesphaera rugicauda* (pillbug) and *Talitrus saltator* (sandhopper) were found along two, one and three of the five transects, respectively. Springtails (also littoral) were found along all of the transects within the managed realignment. No additional littoral or salt marsh species were detected on the marsh outside the managed realignment and, here, *Lekanesphaera rugicauda* (pillbug) was not found.

2003 (Appendix A6.5.Pitfalls, A6.6.Scrapes)
In addition to the invertebrates found in 2002, pitfall samples taken within the managed realignment contained the littoral species *Psammotettix putoni* (plant bug/hopper), *Saldula pallipes/palustris* (true bug) and the salt marsh beetles, *Dicheirotrichus gustavi* and *Pogonus chalceus*, along one, three, three and four transects, respectively. *Carcinus maenas* (shore crab) was found along each transect. Each of these taxa was also detected on the marsh outside the managed realignment, along with an additional two salt marsh species of beetle (*Bledius spectabilis* and *Heterocerus obsoletus*). Scrape samples revealed the presence of the littoral oligochaete worms, *Hediste diversicolor* and *Capitella* sp., along one and three transects, respectively, within the managed realignment. On the marsh outside the managed realignment, these and three other littoral oligochaete worm species were detected: *Eteone longa*, *Spio martinensis* and a *Tharyx* sp. The bivalve mollusc, *Mytilus edulis* was found both inside (only one individual) and outside the managed realignment, but four other bivalve mollusc species typical of intertidal mudflat (*Cerastoderma edule*, *Macoma balthica*, *Abra alba* and *Scrobicularia plana*) were found only outside.
The small littoral snail, *Hydrobia ulvae,* was present over much of the managed realignment (along all five transects) and the marsh outside.

2004 (Appendix A6.7.Pitfalls, A6.8.Scrapes, A6.9.Sweeps)
Within the managed realignment, all of the littoral/salt marsh species found in pitfall catches in 2003 were also caught in 2004, with no evidence that additional species had colonised the site. The pitfall catch of springtails was remarkably high, probably due to the early sampling date and the favourable weather conditions. Numbers were greatest on Transect D. There was also a large increase in the catch of *Carcinus maenas* (shore crab) across the managed realignment, but particularly in the traps on Transect B. *Psammotettix putoni*, *Saldula pallipes/palustris* were more widely distributed than in 2003, having been detected in pitfall traps at four and five transects, respectively. The two salt marsh beetle species, *Dicheirotrichus gustavi* and *Pogonus chalceus*, had also spread across the managed realignment, being found along each transect this year. However, three salt marsh beetle species (*Bembidion laterale*, *Bledius spectabilis* and *Heterocerus obsoletus*) found on the marsh outside the managed realignment were not detected inside. Scrape samples

revealed that the oligochaete worm, *Hediste diversicolor*, appeared to have increased its distribution and was this year found along four transects, and that the site had also been colonised by four other species of oligochaete worms (*Eteone longa*, *Nephtys hombergii*, *Pygospio elegans*, *Spio martinensis* and *Tharyx* sp.), most notably along transect A. In contrast, on the salt marsh outside the managed realignment neither *Pygospio elegans*, *Spio martinensis*, *Tharyx* sp. nor *Capitella* sp. were detected. *Mytilus edulis* was not found (only a single individual had been noted in 2003) but three other bivalve mollusc species (*Macoma balthica*, *Abra alba* and *Scrobicularia plana*) were collected within the managed realignment for the first time, all at transect A. On the salt marsh outside the sea wall *Mytilus edulis* was found, as were *Macoma balthica* and *Scrobicularia plana*, but *Abra alba* was not. As last year, *Cerastoderma edule* was detected outside the site only. *Hydrobia ulvae* formed most of the catch of the sediment scrape samples, both inside and outside the managed realignment, this year being also found at transect F.

Prominent among the sweep net catch were various plant bugs/hoppers. The catch confirmed that the planthopper *Psammotettix putoni* had spread across the managed realignment, and was found at four transects.

2005 (Appendix A6.10.Pitfalls, A6.11.Scrapes, A6.12.Sweeps)
Within the managed realignment, all of the littoral/salt marsh species found in pitfall catches in 2004 were also detected in 2005, with no evidence that additional species had colonised the site. Springtails were again this year taken in enormous numbers in many of the pitfall traps and *Carcinus maenas* remained widespread across the site, albeit in lower numbers than in 2004. As last year, only two salt marsh beetle species (*Dicheirotrichus gustavi* and *Pogonus chalceus*) were found inside the managed realignment, widely distributed across the six transects. No additional beetle species were detected outside the site. The scrape samples contained more filamentous algae than the previous years which may have contributed to a huge increase in the numbers of unidentified oligochaete worms which were distributed evenly across all the transects both within and outside the managed realignment site and at all levels on the shore. Only three of the six identified species found within the site in 2004 (*Hediste diversicolor*, *Eteone longa* and *Pygospio elegans*) were also found in 2005. *Hydrobia ulvae* was again the commonest invertebrate collected, being taken evenly over all of the transects and elevations both inside and outside the site. The most notable change since 2004 was the almost total disappearance of bivalve molluscs from the sample sites both inside and outside the managed realignment; only two specimens of *Scrobicularia plana* were collected (both from outside the site) and none of the other species detected in previous years were found.

2006 (Appendix A6.13.Pitfalls, A6.14.Scrapes, A6.15.Sweeps)
In the pitfall, scrape and sweep net samples, all the littoral and salt marsh invertebrate species (except *Pygospio elegans*) found inside the managed realignment in 2005 were found there again in 2006. Three additional littoral and salt marsh species were detected inside the managed realignment in 2006: *Crangon crangon* (brown shrimp) at transect E only; the salt marsh beetle,

Heterocerus obsoletus, at transect C only; and larvae of *Psychidae* sp. (bagmoth) at transects A and B only.

6.4.2 Final (2006) distribution of littoral and salt marsh invertebrate taxa

Between 2002 and 2006 the total number of littoral and salt marsh invertebrate species detected within the managed realignment had increased from four to 24, compared with three to 29 on the salt marsh outside the sea wall (Table 6.11). The paucity of taxa found in 2002 may have been due partly to the lower number of samples collected in 2002 (30 inside, 24 outside) than in 2006 (108 inside, 48 outside, Appendix A6.1.). Only in 2005 were the number of sampling sites and the number of samples collected the same as in 2006. Even so, the data demonstrates that 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 littoral and salt marsh species which were not detected inside the managed realignment were the oligochaete worm *Spiophanes bombyx*, the snails *Leucophytia bidentata* and *Retusa obtusa*, and the beetles *Bembidion laterale* and *Heterocerus obsoletus*. But each of these species was only found infrequently from 2002-2006, in very low numbers (one, seven, nine, and three individuals, respectively) and they were not widely distributed (each was found at only one transect), so their absence from the managed realignment may be neither real, nor significant.

By 2006, nine littoral and salt marsh invertebrate taxa had been found at all six transects within the managed realignment site. These were: *Hediste diversicolor*, *Hydrobia ulvae*, *Carcinus maenas*, *Lekanesphaera rugicauda*, *Talitrus saltator*, Springtails, *Saldula pallipes/palustris*, *Dicheirotrichus gustavi*, and *Pogonus chalceus* (Table 6.11). These taxa were also found at least three of the four transects on the salt marsh outside the breached sea wall. Only the oligochaete worm *Eteone longa* was found at every transect outside on the salt marsh, but not at every transect within the managed realignment; it was not detected at transects B and F.

To determine if there was a relationship between elevation and the distribution of invertebrate taxa, the number of each taxon collected at 2.7-3.0mODN and at >3.0-3.3mODN using the different sampling methods was recorded each year both inside and outside the managed realignment (See Appendices A6.16-A6.27 for data according to elevation). These results are summarised in Table 6.12. Inside the managed realignment the invertebrate taxa that were found in much greater numbers within the lower elevation range were nematodes, *Capitella* sp., *Carcinus maenas*, mites and springtails, but only on 1-3 sampling occasions. *Capitella* sp. and springtails were also more common within the lower elevation range on the marsh outside the realignment, where, in some years, the bivalve molluscs *Cerastoderma edule*, *Macoma balthica*, *Abra alba* and *Scrobicularia plana*, the snail *Hydrobia ulvae,* aphids, Hymenoptera (other than ants and bees), the beetles *Dicheirotrichus gustavi* and *Pogonus chalceus,* and flies were also more common, but not inside the managed realignment. In the realignment other Hymenoptera, *Dicheirotrichus gustavi* and *Pogonus chalceus* were more common at higher elevations. *Talitrus saltator*, spiders, plant bugs/hoppers, *Psychidae* sp. and flies were more common at higher elevations both within and outside the managed realignment. Only *Talitrus saltator* (inside), spiders (outside) and aphids (inside) were found more within the higher elevation range each year that they were collected.

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

6.4.3 Abundance of invertebrate taxa inside and outside the managed realignment site

The total number of each invertebrate taxon caught in pitfall traps each year is displayed in Table 6.1. Changes in mean catches of two taxa (*Carcinus maenas* and *Talitrus saltator*) during the period 2002-2006 are displayed in Fig. 6.1 and 6.2. Within the managed realignment all the taxa found in pitfall traps in significant numbers (>10 individuals) increased in total numbers caught between 2002 and 2006 and mean numbers caught per site increased also (Table 6.4). The same was true of the salt marsh outside the breached sea wall except that here the mean number of springtails decreased greatly from 42000 to 3.31 and the mean number of spiders decreased slightly from 2.67 to 1.88 (Tables 6.1 and 6.5). For most taxa, in most years, there was a high degree of variation between the numbers of individuals collected at different sites, as indicated by the high Standard Error (SE) values and the wide range in numbers (eg 0-1800000 springtails collected in pitfall traps inside the managed realignment in 2005 (Table 6.4). Springtails were the most numerous invertebrates detected, peaking at an estimated total of approx. 10,000,000 inside the managed realignment in 2005 (Table 6.1.). Other taxa that were noticeably abundant in these samples within the managed realignment were *Carcinus maenas*, spiders, the beetles *Dicheirotrichus gustavi* and *Pogonus chalceus*, and flies. These taxa were also abundant on the marsh outside the breached sea wall. Only the sandhopper *Talitrus saltator* was more common here than inside the managed realignment.

The total number of each invertebrate taxon detected in scrape samples each year is displayed in Table 6.2. Changes in mean catches of *Hydrobia ulvae* during the period 2002-2006 are displayed in Fig. 6.3. Within the managed realignment all the taxa found in scrape samples in significant numbers (>10 individuals) increased in total numbers caught between 2003 and 2006 and mean numbers caught per site increased also (Table 6.6), except in the case of the oligochaete worm *Capitella* sp., which decreased from 75 individuals collected in 2004 to zero individuals in either 2005 or 2006. The same was true of the salt marsh outside the breached sea wall, except for the bivalve molluscs *Cerastoderma edule* and *Macoma balthica* (which were also not detected in scrape samples after 2004). For most taxa, in most years, there was a high degree of variation between the numbers of individuals collected at different sites, as indicated by the high Standard Error (SE) values and the wide range in numbers (e.g. 0-2906 *Hydrobia ulvae* collected in scrapes outside the managed realignment in 2004 (Table 6.7). Unidentified oligochaete worms were the most abundant taxon found in scrape samples, peaking at a total of 13153 individuals collected inside the managed realignment in 2005 (Table 6.b). Other taxa that were noticeably abundant in scrape samples within the managed realignment were the snail *Hydrobia ulvae*, the oligochaete worm *Hediste diversicolor* and fly larvae. Unidentified oligochaete worms, the snail *Hydrobia ulvae* and fly larvae were also abundant on the marsh outside. Only nematodes and *Hydrobia ulvae* were more common here than inside the managed realignment.

The total number of each invertebrate taxon caught in sweep net samples from 2004 to 2006 is displayed in Table 6.3. Due to insufficient time, none of the taxa were identified to the level of species. Within the managed realignment all the taxa found in sweep net samples in significant numbers (>10 individuals) increased in total numbers caught between 2004 and 2006 and mean numbers caught per site increased also (Table 6.8). The same was true of the salt marsh outside the breached sea wall, except for aphids. For most taxa, in most years, there was a high degree of variation between the numbers of individuals collected at different sites, as indicated by the high Standard Error (SE) values and the wide range in numbers (eg 0-56 aphids collected in scrapes outside the managed realignment in 2005 (Table 6.9). Plant bugs/hoppers were the most abundant taxon detected in sweep net samples, peaking at a total of 762 individuals collected inside the managed realignment in 2006 (Table 6.3). Other taxa that were noticeably abundant in sweep net samples within the managed realignment were butterfly and moth larvae and flies. Plant bugs/hoppers, butterfly and moth larvae and flies were also abundant on the marsh outside the breached sea wall. Only aphids were more common here than inside the managed realignment, although not in 2006 (Table 6.3).

In summary, mean numbers of the different invertebrate taxa collected inside and outside the managed realignment were broadly similar. Notable exceptions were springtails, the oligochaete worm *Hediste diversicolor* (both more common inside) and the sandhopper *Talitrus saltator*, nematodes, aphids and the snail *Hydrobia ulvae* (all more common outside). Several littoral and salt marsh species appear to have increased in abundance inside the site between 2002 and 2006, these are *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.

6.4.4 Effect of marine sediment deposition on colonisation by burrowing invertebrates

In the early years of colonisation of the sediment at the Tollesbury managed realignment it was thought that the hard structure of the agricultural soil was unsuitable for colonisation by burrowing invertebrates (Boorman *et al*. 1997).

Therefore, it was considered that the accumulation of marine sediment might also be a limiting factor in the colonisation of the Freiston managed realignment by these organisms. To assess whether this was the case, marine sediment depth was measured at each sample site where scrape samples were taken (Table 6.10).

Between 2003 and 2004, the mean sediment depth at the scrape sites in the lower elevation range (2.7-3.0ODN) increased from 3.23cm (range 0-10cm) to 5.8cm (range 1-15cm) (Table 6.10). There was still little marine sediment deposition on the upper shore sites within the managed realignment, but more had accreted in any concave areas lower down the shore profile. In scrape samples collected inside the managed realignment in 2004, there was a significant increase in the numbers of the oligochaete worm, *Hediste diversicolor* and five more species of oligochaete worm (*Eteone longa*, *Nephtys hombergii*, *Pygospio elegans*, *Spio martinensis* and *Tharyx* sp.) had colonised the site (Table 6.2). At the time of sampling in 2004 it was noted that *Hediste diversicolor* had penetrated down into the underlying arable soil, unlike the previous year, when it was present only in the surface deposited marine sediment. However, numbers of *Capitella* sp. and unidentified oligochaete worms collected had decreased. Numbers of the snail *Hydrobia ulvae* collected increased dramatically from 404 to 6268 individuals (Table 6.10); the trend was toward larger catches at lower elevations and towards the outer Transects, A and F (Appendix Tables A6.8.Scrapes and A6.20.Sc/E). A few individuals of the bivalve molluscs, *Macoma balthica*, *Abra alba* and *Scrobicularia plana* were also detected in the managed realignment for the first time this year (Table 6.b).

Between 2004 and 2005 the mean sediment depth in the lower elevation range (2.7-3.0ODN) increased from 5.8cm (range 1-15cm) to 8.1cm (range 1-17cm) (Table 6.10). However, whilst the numbers of unidentified oligochaete worms collected had increased significantly (from 27 to 13153 individuals), this had been attributed at the time of sampling to a significant increase in the amount of filamentous algae in the marine sediment in 2005, and five of the six identified species of oligochaete worm detected in 2004 had decreased in abundance in the catch in 2005 or were not detected at all (Table 6.2), despite the increase in the number of sites sampled (from 30 to 36). Mean numbers of the snail *Hydrobia ulvae* collected per site decreased from 209 to 178 individuals and no bivalve molluscs were collected in the scrapes (Table 6.6).

Between 2005 and 2006 the mean sediment depth in the lower elevation range (2.7-3.0mODN) decreased from 8.1cm (range 1-17cm) to 5.9cm (range 0.5-10cm, Table 6.10). The numbers of unidentified oligochaete worms collected had also decreased significantly (from 13153 to 2175 individuals), and the number of individuals of *Hediste diversicolor* collected actually increased from 38 to 124 (Table 6.2). The number of sites sampled in 2005 and 2006 was the same (36). Numbers of the snail *Hydrobia ulvae* collected decreased from 6401 to 5085 individuals and (as the previous year) no bivalve molluscs were collected in the scrapes (Table 6.2).

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

6.4.5 Reference

Boorman, L.A. *et al*., 1997. *Large Scale Experimental Managed Realignment at Tollesbury, Essex.* Institute of Terrestrial Ecology, Final Report to MAFF. [for first phase of monitoring at Tollesbury]

Table 6.1. Total number of each invertebrate taxon detected in pitfall traps each year, inside and outside the Managed Realignment

Key: 1)Numbers in parenthesis indicate the number of sites sampled each year. 2) indet. = not identified to the level of species
3) Other Hymenoptera = Hymenoptera other than ants and bees. These are parasites (eg Ichneumon flies) or gall-formers (eg Cynipoidea).

Taxa	Total no. of individuals detected INSIDE MR					Total no. of individuals detected OUTSIDE MR				
	2002 (30)	2003 (30)	2004 (30)	2005 (36)	2006 (36)	2002 (24)	2003 (12)	2004 (15)	2005 (16)	2006 (16)
Nematodes				8						
Hydrobia ulvae			1	5	33		6	3	6	11
Leucophytia bidentata							1	3	3	
ALL Snails and Slugs			1	5	33		7	6	9	11
Carcinus maenas	2	78	926	110	290	11	180	66	47	74
Lekanesphaera rugicauda	1	1	3	2	3		28	14	6	14
Talitrus saltator	9	8	14	3	26	20	301	213	66	133
Pardosa agricola					26					1
Spiders indet.	19	2	33	66	43	64	28	73	52	30
ALL Spiders	19	2	33	66	69	64	28	73	52	31
Mites		13	102	2	21	12	74	15	6	15
Springtails	405	26145	1130466	10034040	85515	1000994	852	278	200	53
Aphrodes bicinctus									1	
Psammotettix putoni		1	9	8	5		9	4	2	
ALL Plant bugs/hoppers		1	9	8	5		9	4	3	
Aphids		277					34		1	
Saldula pallipes / palustris		4	33	6	12		24	6		3

Taxa	Total no. of individuals detected INSIDE MR					Total no. of individuals detected OUTSIDE MR				
	2002 (30)	**2003 (30)**	**2004 (30)**	**2005 (36)**	**2006 (36)**	**2002 (24)**	**2003 (12)**	**2004 (15)**	**2005 (16)**	**2006 (16)**
Plagiognathus chrysanthemi		2	1							
ALL True bugs		6	34	6	12	1	24	6		3
Ants	1					2				
Bees					1					
Other Hymenoptera	3	5								
Bembidion laterale								1		
Dicheirotrichus gustavi		6	30	66	310		57	60	12	34
Pogonus chalceus		5	77	57	58		4	36	51	21
Proteinus macropterus		1								
Anotylus rugosus		2					2			
Bledius spectabilis							1	2		2
Atheta sp.							2			
Glischrochilus 4-punctatus							1			
Heterocerus obsoletus					1		1	2		
Cortinicara gibbosa		1	1							
ALL Beetles	1	15	108	123	369		68	101	63	57
Beetle larvae			1			2		1	46	1
Booklice	2									
Psychidea spp.					3					1
Flies	2	64	86	244	95	86	38	30	103	20
Fly larvae	1	1			15	1		3	1	

Table 6.2. Total number of each invertebrate taxon detected in scrape samples each year, inside and outside the Managed Realignment

Key: 1)Numbers in parenthesis indicate the number of sites sampled each year. 2) indet. = not identified to the level of species

Taxa	**Total no. of individuals detected INSIDE MR**					**Total no. of individuals detected OUTSIDE MR**				
	2002 (0)	**2003 (30)**	**2004 (30)**	**2005 (36)**	**2006 (36)**	**2002 (0)**	**2003 (11)**	**2004 (15)**	**2005 (16)**	**2006 (16)**
Nematodes		3	2	65	81		11	66	262	548
Oligochaete worms indet		94	27	13153	2175		636	1250	4552	4226
Eteone longa			4	5	5		13	8	15	5
Hediste diversicolor		1	166	38	124		5	14	8	8
Nephtys hombergii			1					3		
Pygospio elegans			42	5						1
Spio martinensis			5				3			
Spiophanes bombyx										1
Tharyx sp.			2				1		2	
Capitella sp.		75	3				87			8
ALL Oligochaete worms		170	250	13201	2304		745	1275	4577	4249
Cerastoderma edule							27	32		
Mytilus edulis		1					2	1		
Macoma balthica			2				58	29		
Abra alba			4				8			
Scrobicularia plana			1				1	88	2	9
ALL Bivalve molluscs		1	7				96	150	2	9
Hydrobia ulvae		404	6268	6401	5085		10962	17595	14375	5248
Leucophytia bidentata										1
Retusa obtusa							9			
ALL Snails and Slugs		404	6268	6401	5085		10971	17595	14375	5249
Carcinus maenas			4		2		2	1		4

Taxa	Total no. of individuals detected INSIDE MR					Total no. of individuals detected OUTSIDE MR				
	2002 (0)	**2003 (30)**	**2004 (30)**	**2005 (36)**	**2006 (36)**	**2002 (0)**	**2003 (11)**	**2004 (15)**	**2005 (16)**	**2006 (16)**
Crangon crangon					1			1		2
Lekanesphaera rugicauda				2	2			1	4	1
Talitrus saltator								1	3	
Mites		1		1	1					
Anurida maritima				3						
ALL Springtails		1		3	1					
Aphids		3		2	1					
Saldula pallipes /palustris		1								
Beetles								1		
Flies				1						
Fly larvae		57	26	88	51		8	17	22	54

Table 6.3. Total number of each invertebrate taxon detected in sweep nets each year, inside and outside the Managed Realignment

Key: 1)Numbers in parenthesis indicate the number of sites sampled each year. 2) indet. = not identified to the level of species
3) Other Hymenoptera = Hymenoptera other than ants and bees. These are parasites (eg Ichneumon flies) or gall-formers (eg Cynipoidea).

Taxa	Total no. of individuals detected INSIDE MR					Total no. of individuals detected OUTSIDE MR				
	2002 (0)	2003 (0)	2004 (30)	2005 (36)	2006 (36)	2002 (0)	2003 (0)	2004 (15)	2005 (16)	2006 (16)
Snails and Slugs			1	16	45			10	10	4
Spiders			6	1	45			1		2
Mites					3					
Plant bugs/hoppers			63	70	762			11	5	13
Aphids			16	43	38			89	92	8
True bugs			25	12	36			8	1	6
Ants								1		
Other Hymenoptera			9	21	27			11	11	13
Beetles			4	2	23			2	3	8
Booklice					1					
Butterflies and Moths				1				1		2
Butterfly and Moth larvae			3	122	341			27	23	59
Flies			308	175	157			68	59	92
Fly larvae					9				1	
Thrips					1					1

Table 6.4. Pitfalls: means Inside

Taxa	2002 (30)		2003 (30)		2004 (30)		2005 (36)		2006 (36)	
	Mean (SE)	Range	Mean (SE)	Range	Mean (SE)	Range	Mean (SE)	Range	Mean (SE)	Range
Nematodes							0.22 (0.16)	0-5		
Hydrobia ulvae					0.03 (0.03)	0-1	0.14 (0.07)	0-2	0.92 (0.52)	0-18
Leucophytia bidentata										
ALL Snails and Slugs					0.03 (0.03)	0-1	0.14 (0.07)	0-2	0.92 (0.52)	0-18
Carcinus maenas	0.07 (0.05)	0-1	2.60 (0.51)	0-10	31 (6.96)	0-158	3.14 (0.56)	0-11	8.06 (1.63)	0-42
Lekanesphaera rugicauda	0.03 (0.03)	0-1	0.03 (0.03)	0-1	0.10 (0.07)	0-2	0.06 (0.06)	0-2	0.08 (0.05)	0-1
Talitrus saltator	0.30 (0.12)	0-2	0.27 (0.11)	0-2	0.47 (0.16)	0-4	0.08 (0.05)	0-1	0.72 (0.27)	0-8
Pardosa agricola									0.72 (0.25)	0-6
Spiders indet.									1.19 (0.21)	0-6
ALL Spiders	0.63 (0.13)	0-2	0.07 (0.05)	0-1	1.10 (0.32)	0-6	1.83 (0.57)	0-15	1.92 (0.35)	0-10
Mites			0.43 (0.18)	0-4	3.40 (2.21)	0-59	0.06 (0.06)	0-2	0.58 (0.29)	0-10
Springtails	14 (2.96)	0-80	872 (299)	1-9K	38K (23K)	0-554K	279K(75K)	0-1800K	2375 (2375)	0-66K
Aphrodes bicinctus										
Psammotettix putoni			0.03 (0.03)	0-1	0.30 (0.13)	0-3	0.22 (0.11)	0-3	0.14 (0.06)	0-1
ALL Plant bugs/hoppers			0.03 (0.03)	0-1	0.30 (0.13)	0-3	0.22 (0.11)	0-3	0.14 (0.06)	0-1
Aphids			9.23 (2.81)	0-68						
Saldula pallipes / palustris			0.13 (0.08)	0-2	1.10 (0.40)	0-12	0.17 (0.08)	0-2	0.33 (0.10)	0-2
Plagiognathus chrysanthemi			0.07 (0.07)	0-2	0.03 (0.03)	0-1				

Taxa	2002 (30)		2003 (30)		2004 (30)		2005 (36)		2006 (36)	
	Mean (SE)	**Range**	**Mean (SE)**	**Range**	**Mean (SE)**	**Range**	**Mean (SE)**	**Range**	**Mean (SE)**	**Range**
ALL True bugs			0.20 (0.10)	0-2	1.13 (0.40)	0-12	0.17 (0.08)	0-2	0.33 (0.10)	0-2
Ants	0.03 (0.03)	0-1								
Bees									0.03 (0.03)	0-1
Other Hymenoptera	0.10 (0.06)	0-1	0.17 (0.08)	0-2						
Bembidion laterale										
Dicheirotrichus gustavi			0.20 (0.11)	0-3	1.00 (0.29)	0-5	1.83 (0.36)	0-6	8.61 (2.66)	0-85
Pogonus chalceus			0.17 (0.08)	0-2	2.57 (0.85)	0-22	1.58 (0.41)	0-11	1.61 (0.91)	0-31
Proteinus macropterus			0.03 (0.03)	0-1						
Anotylus rugosus			0.07 (0.05)	0-1						
Bledius spectabilis										
Atheta sp.										
Glischrochilus 4-punctatus										
Heterocerus obsoletus									0.03 (0.03)	0-1
Cortinicara gibbosa			0.03 (0.03)	0-1	0.03 (0.03)	0-1				
ALL Beetles	0.03 (0.03)	0-1	0.50 (0.18)	0-3	3.60 (0.92)	0-22	3.42 (0.67)	0-17	10 (3.51)	0-116
Beetle larvae					0.03 (0.03)	0-1				
Booklice	0.07 (0.05)	0-1								
Psychidea spp.									0.08 (0.06)	0-2
Flies	0.07 (0.05)	0-1	2.13 (0.35)	0-9	2.87 (0.64)	0-17	6.78 (1.67)	0-37	2.64 (0.50)	0-11
Fly larvae	0.03 (0.03)	0-1	0.03 (0.03)	0-1					0.42 (0.36)	0-13

Table 6.5. Pitfalls: means Outside

Taxa	2002 (24)		2003 (12)		2004 (15)		2005 (16)		2006 (16)	
	Mean (SE)	Range	Mean (SE)	Range	Mean (SE)	Range	Mean (SE)	Range	Mean (SE)	Range
Nematodes										
Hydrobia ulvae			0.50 (0.23)	0-2	0.20 (0.14)	0-2	0.38 (0.26)	0-4	0.69 (0.69)	0-11
Leucophytia bidentata			0.08 (0.08)	0-1	0.20 (0.20)	0-3	0.19 (0.19)	0-3		
ALL Snails and Slugs			0.58 (0.29)	0-3	0.40 (0.24)	0-3	0.56 (0.30)	0-4	0.69 (0.69)	0-11
Carcinus maenas	0.46 (0.13)	0-2	15.0 (9.12)	0-114	4.40 (1.28)	0-19	2.94 (0.59)	0-7	4.63 (0.99)	0-14
Lekanesphaera rugicauda			2.33 (1.54)	0-16	0.93 (0.56)	0-8	0.38 (0.15)	0-2	0.88 (0.75)	0-12
Talitrus saltator	0.83 (0.42)	0-8	25.1 (13.13)	0-136	14.2 (13.1)	0-197	4.13 (2.23)	0-36	8.31 (5.80)	0-94
Pardosa agricola									0.06 (0.06)	0-1
Spiders indet.	2.67 (0.92)	0-18	2.33 (1.03)	0-12	4.87 (3.29)	0-50	3.25 (2.59)	0-42	1.88 (1.28)	0-21
ALL Spiders	2.67 (0.92)	0-18	2.33 (1.03)	0-12	4.87 (3.29)	0-50	3.25 (2.59)	0-42	1.94 (1.28)	0-21
Mites	0.50 (0.34)	0-8	6.17 (2.19)	0-22	1.00 (0.52)	0-7	0.38 (0.18)	0-2	0.94 (0.46)	0-6
Springtails	42K (42K)	0-1000K	71.0 (56.51)	0-690	18.5 (15.4)	0-230	12.5 (6.86)	0-100	3.31 (1.97)	0-30
Aphrodes bicinctus							0.06 (0.06)	0-1		
Psammotettix putoni			0.75 (0.28)	0-2	0.27 (0.12)	0-1	0.13 (0.13)	0-2		
ALL Plant bugs/hoppers			0.75 (0.28)	0-2	0.27 (0.12)	0-1	0.19 (0.14)	0-2		
Aphids			2.83 (1.58)	0-19			0.06 (0.06)	0-1		
Saldula pallipes / palustris			2.00 (0.78)	0-8	0.40 (0.19)	0-2			0.19 (0.10)	0-1
Plagiognathus chrysanthemi										

Taxa	2002 (24)		2003 (12)		2004 (15)		2005 (16)		2006 (16)	
	Mean (SE)	**Range**	**Mean (SE)**	**Range**	**Mean (SE)**	**Range**	**Mean (SE)**	**Range**	**Mean (SE)**	**Range**
ALL True bugs	0.04 (0.04)	0-1	2.00 (0.78)	0-8	0.40 (0.19)	0-2			0.19 (0.10)	0-1
Ants	0.08 (0.08)	0-2								
Bees										
Other Hymenoptera										
Bembidion laterale					0.07 (0.07)	0-1				
Dicheirotrichus gustavi			4.75 (3.13)	0-36	4.00 (1.01)	0-12	0.75 (0.32)	0-4	2.13 (0.74)	0-10
Pogonus chalceus			0.33 (0.19)	0-2	2.40 (1.06)	0-14	3.19 (2.47)	0-40	1.31 (0.51)	0-6
Proteinus macropterus										
Anotylus rugosus			0.17 (0.11)	0-1						
Bledius spectabilis			0.08 (0.08)	0-1	0.13 (0.09)	0-1			0.13 (0.09)	0-1
Atheta sp.			0.17 (0.11)	0-1						
Glischrochilus 4-punctatus			0.08 (0.08)	0-1						
Heterocerus obsoletus			0.08 (0.08)	0-1	0.13 (0.13)	0-2				
Cortinicara gibbosa										
ALL Beetles			5.67 (3.21)	0-39	6.73 (1.95)	0-26	3.94 (2.59)	0-42	3.56 (0.88)	0-11
Beetle larvae	0.08 (0.06)	0-1			0.07 (0.07)	0-1	2.88 (2.88)	0-46	0.06 (0.06)	0-1
Booklice										
Psychidea spp.									0.06 (0.06)	0-1
Flies	3.58 (1.23)	0-19	3.17 (0.60)	0-8	2.00 (0.85)	0-13	6.44 (1.97)	0-24	1.25 (0.37)	0-4
Fly larvae	0.04 (0.04)	0-1			0.20 (0.20)	0-3	0.06 (0.06)	0-1		

Table 6.6. Scrapes: means Inside

Taxa	2003 (30)			2004 (30)			2005 (36)			2006 (36)		
	Mean	(SE)	Range	Mean	(SE)	Range	Mean	(SE)	Range	Mean	(SE)	Range
Nematodes	0.10	(0.10)	0-3	0.07	(0.07)	0-2	1.81	(0.87)	0-29	2.25	(1.39)	0-49
Oligochaete worms indet	3.13	(1.75)	0-47	0.90	(0.28)	0-6	365	(126)	0-4120	60.4	(21.1)	0-644
Eteone longa				0.13	(0.10)	0-3	0.14	(0.07)	0-2	0.14	(0.08)	0-2
Hediste diversicolor	0.03	(0.03)	0-1	5.53	(1.91)	0-35	1.06	(0.50)	0-14	3.44	(1.18)	0-34
Nephtys hombergii				0.03	(0.03)	0-1						
Pygospio elegans				1.40	(0.90)	0-26	0.14	(0.08)	0-2			
Spio martinensis				0.17	(0.11)	0-3						
Spiophanes bombyx												
Tharyx sp.				0.07	(0.05)	0-1						
Capitella sp.	2.50	(1.39)	0-40	0.10	(0.10)	0-3						
ALL Oligochaete worms	5.67	(2.11)	0-47	8.33	(2.75)	0-66	367	(126)	0-4120	64.0	(21.2)	0-647
Cerastoderma edule												
Mytilus edulis	0.03	(0.03)	0-1									
Macoma balthica				0.07	(0.05)	0-1						
Abra alba				0.13	(0.13)	0-4						
Scrobicularia plana				0.03	(0.03)	0-1						
ALL Bivalve molluscs	0.03	(0.03	0-1	0.23	(0.15)	0-4						
Hydrobia ulvae	13.5	(3.76)	0-78	209	(59.0)	0-1340	178	(28.8)	1-432	141	(30.5)	0-861
Leucophytia bidentata												
Retusa obtusa												
ALL Snails and Slugs	13.5	(3.76)	0-78	209	(59.0)	0-1340	178	(28.8)	1-432	141	(30.5)	0-861
Carcinus maenas				0.13	(0.08)	0-2				0.06	(0.06)	0-2
Crangon crangon										0.03	(0.03)	0-1
Lekanesphaera rugicauda							0.06	(0.04)	0-1	0.06	(0.04)	0-1
Talitrus saltator												

Taxa	2003 (30)			2004 (30)			2005 (36)			2006 (36)		
	Mean	**(SE)**	**Range**	**Mean**	**(SE)**	**Range**	**Mean**	**(SE)**	**Range**	**Mean**	**(SE)**	**Range**
Mites	0.03	(0.03)	0-1				0.03	(0.03)	0-1	0.03	(0.03)	0-1
Anurida maritima							0.08	(0.05)	0-1			
ALL Springtails	0.03	(0.03)	0-1				0.08	(0.05)	0-1	0.03	(0.03)	0-1
Aphids	0.10	(0.06)	0-1				0.06	(0.06)	0-2	0.03	(0.03)	0-1
Saldula pallipes /palustris	0.03	(0.03)	0-1									
Beetles												
Flies							0.03	(0.03)	0-1			
Fly larvae	1.90	(0.49)	0-12	0.87	(0.42)	0-9	2.44	(0.77)	0-25	1.42	(0.44)	0-12

Table 6.7. Scrapes: means Outside

Taxa	2003 (11)			2004 (15)			2005 (16)			2006 (16)		
	Mean	(SE)	Range	Mean	(SE)	Range	Mean	(SE)	Range	Mean	(SE)	Range
Nematodes	1.00	(0.66)	0-7	4.40	(3.20)	0-48	16.4	(5.66)	0-76	34.3	(11.6)	0-140
Oligochaete worms indet	57.8	(57)	0-628	83.3	(45.16)	0-594	284	(128)	0-1909	264	(136)	0-2016
Eteone longa	1.18	(0.81)	0-9	0.53	(0.32)	0-4	0.94	(0.32)	0-5	0.31	(0.15)	0-2
Hediste diversicolor	0.45	(0.31)	0-3	0.93	(0.48)	0-6	0.50	(0.22)	0-3	0.50	(0.22)	0-3
Nephtys hombergii				0.20	(0.20)	0-3						
Pygospio elegans										0.06	(0.06)	0-1
Spio martinensis	0.27	(0.27)	0-3									
Spiophanes bombyx										0.06	(0.06)	0-1
Tharyx sp.	0.09	(0.09)	0-1				0.13	(0.13)	0-2			
Capitella sp.	7.91	(7.04)	0-78							0.50	(0.33)	0-5
ALL Oligochaete worms	67.7	(57)	0-643	85.00	(45.1)	0-594	286	(128)	0-1909	266	(136)	0-2016
Cerastoderma edule	2.45	(2.45)	0-27	2.13	(1.93)	0-29						
Mytilus edulis	0.18	(0.18)	0-2	0.07	(0.07)	0-1						
Macoma balthica	5.27	(4.98)	0-55	1.93	(1.15)	0-15						
Abra alba	0.73	(0.56)	0-6									
Scrobicularia plana	0.09	(0.09)	0-1	5.87	(5.32)	0-80	0.13	(0.13)	0-2	0.56	(0.56)	0-9
ALL Bivalve molluscs	8.73	(8.13)	0-90	9.93	(7.97)	0-119	0.13	(0.13)	0-2	0.56	(0.56)	0-9
Hydrobia ulvae	997	(240)	0-2240	1173	(401)	0-2906	898	(252)	0-2992	328	(159)	0-2050
Leucophytia bidentata										0.06	(0.06)	0-1
Retusa obtusa	0.82	(0.82)	0-9									
ALL Snails and Slugs	997	(241)	0-2240	1173	(401)	0-2906	898	(252)		328	(159)	0-2050
Carcinus maenas	0.18	(0.12)	0-1	0.07	(0.07)	0-1				0.25	(0.14)	0-2
Crangon crangon				0.07	(0.07)	0-1				0.13	(0.09)	0-1
Lekanesphaera rugicauda				0.07	(0.07)	0-1	0.25	(0.19)	0-3	0.06	(0.06)	0-1
Talitrus saltator				0.07	(0.07)	0-1	0.19	(0.14)	0-2			
Mites												

Taxa	2003 (11)			2004 (15)			2005 (16)			2006 (16)		
	Mean	**(SE)**	**Range**	**Mean**	**(SE)**	**Range**	**Mean**	**(SE)**	**Range**	**Mean**	**(SE)**	**Range**
Anurida maritima												
ALL Springtails												
Aphids												
Saldula pallipes /palustris												
Beetles				0.07	(0.07)	0-1						
Flies												
Fly larvae	0.73	(0.30)	0-3	1.13	(0.57)	0-7	1.38	(0.45)	0-5	3.38	(2.65)	0-43

Table 6.8. Sweeps: means Inside

Taxa	2004 (30) Mean	(SE)	Range	2005 (36) Mean	(SE)	Range	2006 (36) Mean	(SE)	Range
Snails and Slugs	0.03	(0.03)	0-1	0.44	(0.13)	0-3	1.25	(0.48)	0-15
Spiders	0.20	(0.09)	0-2	0.03	(0.03)	0-1	1.25	(0.23)	0-4
Mites							0.08	(0.05)	0-1
Plant bugs/hoppers	2.10	(0.58)	0-13	1.94	(0.53)	0-13	21.3	(4.92)	0-132
Aphids	0.53	(0.22)	0-5	1.19	(0.51)	0-17	1.06	(0.24)	0-6
True bugs	0.83	(0.24)	0-5	0.33	(0.10)	0-2	1.00	(0.20)	0-4
Ants									
Other Hymenoptera	0.30	(0.11)	0-1	0.58	(0.31)	0-10	0.75	(0.21)	0-6
Beetles	0.13	(0.06)	0-1	0.06	(0.04)	0-1	0.64	(0.17)	0-3
Booklice							0.03	(0.03)	0-1
Butterflies and Moths				0.03	(0.03)	0-1			
Butterfly and Moth larvae	0.10	(0.06)	0-1	3.39	(1.60)	0-57	9.47	(1.46)	0-35
Flies	10.3	(1.86)	0-54	4.86	(0.39)	0-10	4.36	(0.68)	0-19
Fly larvae							0.25	(0.09)	0-2
Thrips							0.03	(0.03)	0-1

Table 6.9. Sweeps: means Outside

Taxa	2004 (30) Mean	(SE)	Range	2005 (36) Mean	(SE)	Range	2006 (36) Mean	(SE)	Range
Snails and Slugs	0.67	(0.60)	0-9	0.63	(0.33)	0-5	0.25	(0.14)	0-2
Spiders	0.07	(0.07)	0-1				0.13	(0.09)	0-1
Mites									
Plant bugs/hoppers	0.73	(0.38)	0-5	0.31	(0.22)	0-3	0.81	(0.34)	0-5
Aphids	5.93	(3.39)	0-40	5.75	(3.49)	0-56	0.50	(0.32)	0-1
True bugs	0.53	(0.19)	0-2	0.06	(0.06)	0-1	0.38	(0.18)	0-2
Ants	0.07	(0.07)	0-1						
Other Hymenoptera	0.73	(0.28)	0-3	0.69	(0.44)	0-6	0.81	(0.32)	0-4
Beetles	0.13	(0.09)		0.19	(0.10)	0-1	0.50	(0.20)	0-3
Booklice									
Butterflies and Moths	0.07	(0.07)	0-1				0.13	(0.09)	0-1
Butterfly and Moth larvae	1.80	(1.24)	0-15	1.44	(0.90)	0-14	3.69	(1.56)	0-20
Flies	4.53	(0.79)	0-9	3.69	(0.79)	0-10	5.75	(0.99)	0-13
Fly larvae				0.06	(0.06)	0-1			
Thrips							0.06	(0.06)	0-1

Key (Tables X.d-i) –
1. Numbers in parenthesis indicate the number of sites sampled each year
2. SE = Standard Error
3. K = 1000 (numbers > 10000)
3. indet. = not identified to the level of species
4. Other Hymenoptera = Hymenoptera other than ants and bees. These are parasites (eg Ichneumon flies) or gall-formers (eg Cynipoidea).

Table 6.10. Sediment depth (cm) measured at scrape sample location at each site within the managed realignment (2003-2006)

2003	A	B	C	D	E	F
1	0	0	0.4	0.8		**1.3**
2	1.5	0.1	0.5	0.5		**1.3**
3	0.7	0.5	0.5	0.6		**0.3**
4	0.6	0.8	5	**0.1**		0.8
5	2	2	3.5	**5.5**		**0**
6	**7.5**	**5**	4	**10**		**1.3**

2004	A	B	C	D	E	F
1	5	1	1	1		**1**
2	3	1.5	1	3		**1**
3	0.5	1	1	3		1
4	3	2	2	**6**		**2**
5	3	7	14	**5**		**1**
6	**10**	**6**	20	**15**		**13**

2005	A	B	C	D	E	F
1	1	0.5	1	0.5	0.5	**0.7**
2	1.5	1	0.5	1	0.5	**1**
3	2	0.7	1	1	0.4	1
4	1	2	4	**6**	**10**	**1**
5	3	2	15	**10**	**12**	**2**
6	**17**	**1**	20	**14**	**7**	**1.5**

2006	A	B	C	D	E	F
1	2	0.5	0.5	1	1	**0.5**
2	1	0.5	0.5	8	2	**2**
3	1.5	2	2	6	2	5
4	0.5	0.5	5	**10**	**10**	**10**
5	1	1.5	12	**8**	**5**	**4**
6	2	**3**	13	**6**	**0.6**	**3**

Key
Sites located at 2.7-3.0mODN are indicated in bold type

Table 6.11. Number of years each littoral/salt marsh invertebrate taxon was detected within each transect, inside and outside the Managed Realignment

		Transects Inside MR						Transects Outside MR			
Group	**Species**	**A**	**B**	**C**	**D**	**E[1]**	**F**	**2[2]**	**3**	**4**	**5**
Oligochaete worms	*Eteone longa*	1		**2**	**3**	**2**		1	**4**	**4**	**2**
	Hediste diversicolor	**3**	**3**	**1**	**4**	**2**	**2**	**1**	**3**	**3**	**3**
	Nephtys hombergii				1					1	
	Pygospio elegans	2		1	1	1					**1**
	Spio martinensis	1								1	
	Spiophanes bombyx										**1**
	Tharyx sp.	1								2	
	Capitella sp.	1	1		1		1		1	**2**	**1**
Bivalve molluscs	*Cerastoderma edule*								1	2	
	Mytilus edulis				1				1	2	
	Macoma balthica	1			1				2	2	
	Abra alba	1								1	
	Scrobicularia plana	1							2	1	**2**
Snails and Slugs	*Hydrobia ulvae*	**4**	**4**	**4**	**4**	**2**	**3**	**2**	**4**	**4**	**4**
	Leucophytia bidentata										**4**
	Retusa obtusa									1	
Shore crab	*Carcinus maenas*	**4**	**5**	**5**	**4**	**2**	**4**	**3**	**5**	**5**	**5**
Brown shrimp	*Crangon crangon*					**1**			**1**	1	**1**
Pillbugs	*Lekanesphaera rugicauda*	**1**	3	1	1	1	**2**		3	**4**	**4**
Sandhoppers	*Talitrus saltator*	**4**	**5**	**4**	**4**	**2**	2	**3**	2		**3**
Springtails	Springtails indet.	**5**	**5**	**5**	**5**	**3**	**5**	**3**	**5**	**5**	3
Plant bugs/hoppers	*Psammotettix putoni*	**3**	**3**	**3**	3	**1**		1	2		2
True bugs	*Saldula pallipes/palustris*	1	**3**	**4**	1	2	**4**	**1**	2	**3**	**3**
Beetles	*Bembidion laterale*									1	

Group	Species	Transects Inside MR						Transects Outside MR			
		A	B	C	D	E[1]	F	2[2]	3	4	5
Beetles (cont.)	*Dicheirotrichus gustavi*	3	**4**	**4**	3	**3**	**4**	**2**	**4**	**4**	**4**
	Pogonus chalceus	3	2	2	**4**	**3**	**4**	1	**4**	**4**	**3**
	Bledius spectabilis								**2**	**2**	1
	Heterocerus obsoletus			**1**					2		
Bagmoth larvae	*Psychidae* sp.	**1**	**1**								

Key
Bold typeface indicates that taxon was detected in 2006
[1] = sampled 2005-6 only
[2] = sampled 2002, 2005-6 only

Table 6.I2. Invertebrate taxa which were detected in greater numbers within either the higher or the lower elevation range

	2.7-3.0mODN		>3.0-3.3mODN	
Taxon	**INSIDE**	**OUTSIDE**	**INSIDE**	**OUTSIDE**
Nematodes	6			
Oligochaete worms indet.			5,6	
Hediste diversicolor			5,6	
Capitella sp.	3	4,6		
Cerastoderma edule		4		
Macoma balthica		4		
Abra alba		4		
Scrobicularia plana		4,6		
Hydrobia ulvae		4,5,6		
Snails and Slugs indet.				4
Carcinus maenas	6			
Lekanesphaera rugicauda				
Talitrus saltator			4,6	2,3,4,5,6
Spiders indet.			2,3,4,5,6	4,5,6
Mites	4	6		2
Springtails	4,5,6	2,4,5		3
Plant bugs/hoppers			4,5,6	6
Aphids		4,5	3,4,5,6	
Saldula pallipes/palustris			4	
Other Hymenoptera		6	4,5,6	
Dicheirotrichus gustavi		4	4,5,6	3
Pogonus chalceus		4,5,6	4,5	
Beetles indet.		6	6	
Psychidae sp.			6	4,6
Flies		2,4,5,6	4,5,6	
Fly larvae			6	6

Key
2 = 2002, etc

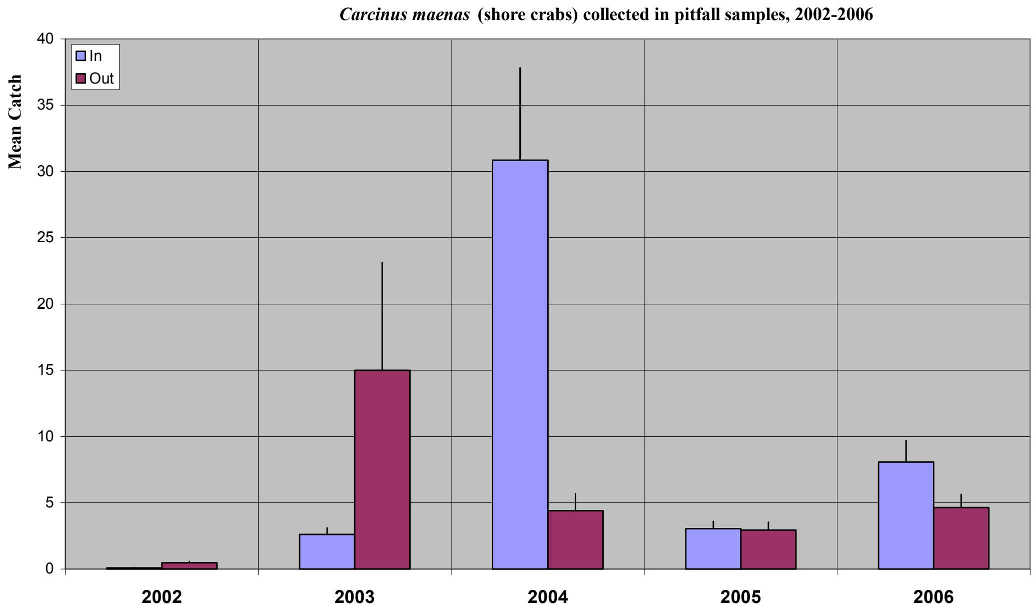

Fig. 6.1. Mean catches of *Carcinus maenas* (shore crab) inside and outside the managed realignment, 2002-2006

Fig. 6.2. Mean catches of *Talitrus saltator* (sandhopper) inside and outside the managed realignment, 2002-2006

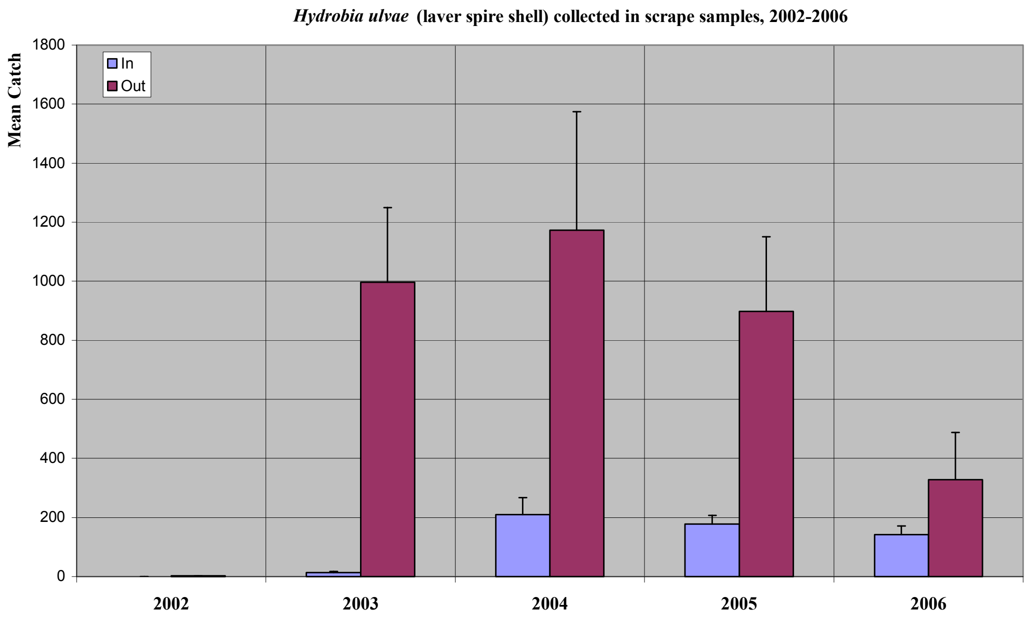

Fig. 6.3. Mean catches of *Hydrobia ulvae* (laver spire shell) inside and outside the managed realignment, 2002-2006

6.5 Appendix 6

6.5.1 Sites sampled, invertebrate taxa and data by collection method and year, and by elevation category

Appendix A6.1. Sites within the managed realignment sampled for invertebrates 2002-2006

Site	2002	2003	2004	2005	2006
A1	P	P S	P S N	P S N	P S N
A2	P	P S	P S N	P S N	P S N
A3	P	P S	P S N	P S N	P S N
A4	P	P S	P S N	P S N	P S N
A5	P	P S	P S N	P S N	P S N
A6	P	P S	P S N	P S N	P S N
B1	P	P S	P S N	P S N	P S N
B2	P	P S	P S N	P S N	P S N
B3	P	P S	P S N	P S N	P S N
B4	P	P S	P S N	P S N	P S N
B5	P	P S	P S N	P S N	P S N
B6	P	P S	P S N	P S N	P S N
C1	P	P S	P S N	P S N	P S N
C2	P	P S	P S N	P S N	P S N
C3	P	P S	P S N	P S N	P S N
C4	P	P S	P S N	P S N	P S N
C5	P	P S	P S N	P S N	P S N
C6	P	P S	P S N	P S N	P S N
D1	P	P S	P S N	P S N	P S N
D2	P	P S	P S N	P S N	P S N
D3	P	P S	P S N	P S N	P S N
D4	P	P S	P S N	P S N	P S N
D5	P	P S	P S N	P S N	P S N
D6	P	P S	P S N	P S N	P S N
E1				P S N	P S N
E2				P S N	P S N
E3				P S N	P S N
E4				P S N	P S N
E5				P S N	P S N
E6				P S N	P S N
F1	P	P S	P S N	P S N	P S N
F2	P	P S	P S N	P S N	P S N
F3	P	P S	P S N	P S N	P S N
F4	P	P S	P S N	P S N	P S N
F5	P	P S	P S N	P S N	P S N
F6	P	P S	P S N	P S N	P S N

Key
A1, A2 etc = site 1 on transect A, site 2 on transect A etc
P = pitfall trap samples
S = scrape samples
N = sweep net samples

Appendix A6.2. Sites outside the managed realignment sampled for invertebrates 2002-2006

Site	2002	2003	2004	2005	2006
1.1	P	P S			
1.2	P	P S			
1.3	P	P S			
1.4	P	P S			
2.1	P			P S N	P S N
2.2	P			P S N	P S N
2.3	P			P S N	P S N
2.4	P			P S N	P S N
2.5				P S N	P S N
3.1	P	P S	P S N	P S N	P S N
3.2	P	P S	P S N	P S N	P S N
3.3	P	P S	P S N		P S N
3.4	P	P S	P S N	P S N	
3.5			P S N		
4.1	P	P S	P S N	P S N	P S N
4.2	P	P S	P S N	P S N	P S N
4.3	P	P S	P S N	P S N	P S N
4.4	P	P S	P S N		
4.5			P S N		
5.1	P	P S	P S N	P S N	P S N
5.2	P	P S	P S N	P S N	P S N
5.3	P	P S	P S N	P S N	P S N
5.4	P	P S	P S N	P S N	P S N
5.5			P S N	P S N	P S N
6.1	P				
6.2	P				
6.3	P				
6.4	P				

Key
1.1, 1.2 etc = site 1 on transect 1, site 2 on transect 1 etc
P = pitfall trap samples
S = scrape samples
N = sweep net samples

Appendix A6.3. Invertebrate taxa detected at Freiston, classification and habitat preferences

Group	Classification	Species	Common name	Habitat
Nematodes	**Phylum NEMATODA**	Indet.		Ubiquitous
Oligochaete worms	**Phylum ANNELIDA**			
	Class Oligochaeta	Indet.		Ubiquitous
	Class Polychaeta			
	PHYLLODOCIDAE	*Eteone longa*		Littoral
	NEREIDAE	*Hediste diversicolor*	ragworm	Littoral
	NEPTHTYIDAE	*Nephtys hombergii*	catworm	Littoral
	SPIONIDAE	*Pygospio elegans*		Littoral
	SPIONIDAE	*Spio martinensis*		Littoral
	SPIONIDAE	*Spiophanes bombyx*		Littoral
	CIRRHATULIDAE	*Tharyx* sp.		Littoral
	CAPITELLIDAE	*Capitella* sp.		Littoral
	Phylum MOLLUSCA			
Bivalve molluscs	**Class Pelecypoda**			
	CARDIIDAE	*Cerastoderma edule*	common cockle	Littoral
	MYTILIDAE	*Mytilus edulis*	common mussel	Littoral
	TELLINIDAE	*Macoma balthica*	baltic tellin	Littoral
	SEMELLIDAE	*Abra alba*		Littoral
	SEMELLIDAE	*Scrobicularia plana*	peppery furrow shell	Littoral
		Indet.	other cockles	Littoral
Snails and Slugs	**Class Gastropoda**			
	Caenogastropoda	*Hydrobia ulvae*	laver spire shell	Littoral
	Archaeopulmonata	*Leucophytia bidentata*		Salt marsh
	Opisthobranchia	*Retusa obtusa*		Littoral

Group	Classification	Species	Common name	Habitat
Snails and Slugs (cont.)	**Class Gastropoda** (cont.)	Indet.		
	Phylum ARTHROPODA Class CRUSTACEA			
Crabs	Decapoda	*Carcinus maenas*	shore crab	Littoral
		Crangon crangon	brown shrimp	Littoral
Pillbugs	Isopoda	*Lekanesphaera rugicauda*		Salt marsh
Sandhoppers	Amphipoda	*Talitrus saltator*		Littoral
Spiders	Araneae	*Pardosa agricola*		Ubiquitous[1]
		Indet.		Ubiquitous
Mites	Subclass Acari	Indet.		Ubiquitous
	Class INSECTA			
Springtails	Collembola	*Anurida maritima*		Littoral
		Indet.		
Plant bugs/hoppers	Hemiptera	*Aphrodes bicinctus*		Ubiquitous[1]
		Psammotettix putoni		Salt marsh
Aphids	Hemiptera, Homoptera, Sternorrhyncha	Indet.		Ubiquitous
True bugs	Hemiptera (suborder Heteroptera)	*Saldula pallipes/palustris*		Salt marsh
		Plagiognathus chrysanthemi		Ubiquitous
		Indet.		
Ants	Hymenoptera	Indet		Terrestrial
Bees	Hymenoptera	Indet		Ubiquitous
Beetles	CARABIDAE	*Bembidion laterale*		Salt marsh
	CARABIDAE	*Dicheirotrichus gustavi*		Salt marsh
	CARABIDAE	*Pogonus chalceus*		Salt marsh
	STAPHYLINIDAE	*Proteinus macropterus*		Ubiquitous

Group	Classification	Species	Common name	Habitat
	STAPHYLINIDAE	*Anotylus rugosus*		Terrestrial
Beetles (cont.)	STAPHYLINIDAE	*Bledius spectabilis*		Salt marsh
	STAPHYLINIDAE	*Atheta* sp.		Ubiquitous
		Glischrochilus 4-punctatus		Ubiquitous
	HETEROCERIDAE	*Heterocerus obsoletus*		Salt marsh
	LATHRIDIIDAE	*Cortinicara gibbosa*		Ubiquitous
		Indet.		
Beetle larvae	Coleoptera	Indet.		
Booklice	Psocoptera	Indet.		Terrestrial
Butterflies and Moths	Lepidoptera	Indet.		Ubiquitous
Butterfly and Moth larvae	Lepidoptera	*Psychidae* sp.	bagmoth	Salt marsh
	Lepidoptera	Indet.		Ubiquitous
Flies	Diptera	Indet.		Ubiquitous
Fly larvae	Diptera	Indet.		Ubiquitous
Thrips	Thysanoptera	Indet.		Ubiquitous

Key
[1] = taxon is ubiquitous but particularly associated with salt marshes

Appendix Table A6.4.Pitfalls. Number of each invertebrate taxon detected in 2002 in pitfall traps within each transect, inside and outside the Managed Realignment

	Transects INSIDE MR						Transects OUTSIDE MR						
Taxa	**A (6)**	**B (6)**	**C (6)**	**D (6)**	**F (6)**	**Total**	**1 (4)**	**2 (4)**	**3 (4)**	**4 (4)**	**5 (4)**	**6 (4)**	**Total**
Carcinus maenas		1	1			2	1	1	1	3	2	3	11
Lekanesphaera rugicauda		1				1							
Talitrus saltator		2		4	3	9		15	3		2		20
Spiders	5	5	4	1	4	19	1	4	1	5	23	30	64
Mites									1		10	1	12
Springtails	81	211	51	48	14	405	1000 K	586	98	222	20	6	1000 K
True bugs										1			1
Ants		1				1			2				2
Other Hymenoptera	2	1				3							
Beetles				1		1							
Beetle larvae									2				2
Booklice		2				2							
Flies			1	1		2	3		25	53	4	1	86
Fly larvae			1			1				1			1

Appendix Table A6.5.Pitfalls. Number of each invertebrate taxon detected in 2003 in pitfall traps within each transect, inside and outside the Managed Realignment

	Transects INSIDE MR						Transects OUTSIDE MR				
Taxa	**A (6)**	**B (6)**	**C (6)**	**D (6)**	**F (6)**	**Total**	**1 (4)**	**3 (2)**	**4 (2)**	**5 (4)**	**Total**
Hydrobia ulvae								1	2	3	6
Leucophytia bidentata										1	1
ALL Snails and Slugs											
Carcinus maenas	10	22	14	18	14	78	21	9	22	128	180
Lekanesphaera rugicauda				1		1		1	16	11	28
Talitrus saltator	1	3	1	3		8	147	2		152	301
Spiders		1			1	2	3	8	4	13	28
Mites	3		2	6	2	13	19	16	24	15	74
Springtails	3120	4130	627	7776	10492	26145	56	15	30	751	852
Psammotettix putoni				1		1	4	2		3	9
Aphids	49	78	85	19	46	277	29	2	2	1	34
Saldula pallipes / palustris		1	1		2	4	3	4	9	8	24
Plagiognathus chrysanthemi			2			2					
ALL True bugs		1	3		2	6	3	4	9	8	24
Other Hymenoptera	1	1		2	1	5					
Dicheirotrichus gustavi		2	3		1	6	53	2	1	1	57
Pogonus chalceus	1	2		1	1	5	1	2	1		4
Proteinus macropterus		1				1					
Anotylus rugosus			1		1	2	1	1			2
Bledius spectabilis									1		1
Atheta sp.							1		1		2
Glischrochilus 4-punctatus									1		1
Heterocerus obsoletus								1			1
Cortinicara gibbosa				1		1					
ALL Beetles	1	5	4	2	3	15	56	6	5	1	68
Flies	22	13	8	7	14	64	13	9	6	10	38
Fly larvae					1	1					

Appendix Table A6. 6.Scrapes. Number of each invertebrate taxon detected in 2003 in scrape samples within each transect, inside and outside the Managed Realignment

	Transects INSIDE MR						Transects OUTSIDE MR			
Taxa	**A (6)**	**B (6)**	**C (6)**	**D (6)**	**F (6)**	**Total**	**3 (5)**	**4 (5)**	**5 (1)**	**Total**
Nematodes	3					3	11			11
Oligochaete worms indet.	36	5	51	2		94		636		636
Eteone longa							2	11		13
Hediste diversicolor				1		1		5		5
Pygospio elegans										
Spio martinensis								3		3
Tharyx sp.								1		1
Capitella sp.		16		53	6	75	86	1		87
ALL Oligochaete worms	36	21	51	56	6	170	88	657		745
Cerastoderma edule <5mm								2		2
Cerastoderma edule 6-10mm								3		3
Cerastoderma edule 11-15mm								4		4
Cerastoderma edule 16-20mm								10		10
Cerastoderma edule 21-25mm								8		8
All *Cerastoderma edule*								27		27
Mytilus edulis <5mm				1		1				
Mytilus edulis 16-20mm								2		2
All *Mytilus edulis*				1		1		2		2
Macoma balthica <5mm								1		1
Macoma balthica 6-10mm							1	45		46
Macoma balthica 11-15mm								8		8
Macoma balthica 16-20mm								3		3
All *Macoma balthica*							1	57		58
Abra alba 11-15 mm								8		8
ALL Bivalve molluscs				1		1	2	94		96

Taxa	Transects INSIDE MR						Transects OUTSIDE MR			
	A (6)	B (6)	C (6)	D (6)	F (6)	Total	3 (5)	4 (5)	5 (1)	Total
Hydrobia ulvae <3mm	1		4			5	49	4055		4104
Hydrobia ulvae >3mm	46	35	152	154	12	399	4860	1998		6858
All *Hydrobia ulvae*	47	35	156	154	12	404	4909	6053		10962
Retusa obtusa <3mm								9		9
ALL Snails and Slugs	47	35	156	154	12	404	4909	6062		10971
Carcinus maenas								2		2
Mites				1		1				
Springtails		1				1				
Aphids		1		1	1	3				
Saldula pallipes /palustris					1	1				
Fly larvae	3	10	8	26	10	57	6	2		8

Appendix Table A6.7.Pitfalls. Number of each invertebrate taxon detected in 2004 in pitfall traps within each transect, inside and outside the Managed Realignment

	Transects INSIDE MR						Transects OUTSIDE MR			
Taxa	**A (6)**	**B (6)**	**C (6)**	**D (6)**	**F (6)**	**Total**	**3 (5)**	**4 (5)**	**5 (5)**	**Total**
Hydrobia ulvae				1		1		3		3
Leucophytia bidentata									3	3
ALL Snails and Slugs				1		1		3	3	6
Carcinus maenas	32	555	121	154	64	926	40	16	10	66
Lekanesphaera rugicauda		1	2			3	11	1	2	14
Talitrus saltator	5	2	3	3	1	14	2		211	213
Spiders	13	3	15	2		33	7		66	73
Mites				1	101	102	4	8	3	15
Springtails	433K	21	2000	559K	137K	1131K	230	48		278
Psammotettix putoni	2	2	1	4		9	1		3	4
Saldula pallipes /palustris	5	4	19	3	2	33	3	1	2	6
Plagiognathus chrysanthemi	1					1				
ALL True bugs	6	4	19	3	2	34	3	1	2	6
Bembidion laterale								1		1
Dicheirotrichus gustavi	13	5	6	5	1	30	33	16	11	60
Pogonus chalceus	27	12	16	4	18	77	24	10	2	36
Bledius spectabilis							1		1	2
Heterocerus obsoletus							2			2
Cortinicara gibbosa			1			1				
All Beetles	40	17	23	9	19	108	60	27	14	101
Beetle larvae			1			1		1		1
Flies	16	12	14	33	11	86	22	5	3	30
Fly larvae								3		3

Appendix Table A6.8.Scrapes. Number of each invertebrate taxon detected in 2004 in scrape samples within each transect, inside and outside the Managed Realignment

	Transects INSIDE MR						Transects OUTSIDE MR			
Taxa	**A (6)**	**B (6)**	**C (6)**	**D (6)**	**F (6)**	**Total**	**3 (5)**	**4 (5)**	**5 (5)**	**Total**
Nematodes	2					2	11	2	53	66
Oligochaete worms indet.	3	1	8	9	6	27	556	50	644	1250
Eteone longa	1			3		4	7	1		8
Hediste diversicolor	92	10		56	8	166	4	3	7	14
Nephtys hombergii				1		1		3		3
Pygospio elegans	39		2	1		42				
Spio martinensis	5					5				
Tharyx sp.	2					2				
Capitella sp.	3					3				
ALL Oligochaete worms	145	11	10	70	14	250	567	57	651	1275
Cerastoderma edule <5mm							12			12
Cerastoderma edule 6-10mm							6	1		7
Cerastoderma edule 11-15mm							9	1		10
Cerastoderma edule 16-20mm							1	1		2
Cerastoderma edule 21-25mm							1			1
All *Cerastoderma edule*							29	3		32
Mytilus edulis <5mm								1		1
Macoma balthica <5mm							1	1		2
Macoma balthica 6-10mm				1		1	2	4		6
Macoma balthica 11-15mm							3	10		13
Macoma balthica 16-20mm	1					1	5	3		8
All *Macoma balthica*	1			1		2	11	18		29
Abra alba 11-15 mm	4					4				
Scrobicularia plana <5mm	1					1	48	7		55
Scrobicularia plana >5mm							33			33
All *Scrobicularia plana*	1					1	81	7		88

	Transects INSIDE MR						Transects OUTSIDE MR			
Taxa	**A (6)**	**B (6)**	**C (6)**	**D (6)**	**F (6)**	**Total**	**3 (5)**	**4 (5)**	**5 (5)**	**Total**
ALL Bivalve molluscs	6			1		7	121	28		149
Hydrobia ulvae <3mm	814	428	45	346	2111	3744	5718	6959	1392	14069
Hydrobia ulvae >3mm	215	692	92	441	1084	2524	832	2629	65	3526
All *Hydrobia ulvae*	1029	1120	137	787	3195	6268	6550	9588	1457	17595
ALL Snails and Slugs	1029	1120	137	787	3195	6268	6550	9588	1457	17595
Carcinus maenas	2	1		1		4		1		1
Crangon crangon								1		1
Lekanesphaera rugicauda							1			1
Talitrus saltator									1	1
Beetles									1	1
Fly larvae	5	1	8		12	26	2	7	8	17

Appendix Table A6.9.Sweeps. Number of each invertebrate taxon detected in 2004 in sweep nets within each transect, inside and outside the Managed Realignment

	Transects INSIDE MR						Transects OUTSIDE MR			
Taxa	**A (6)**	**B (6)**	**C (6)**	**D (6)**	**F (6)**	**Total**	**3 (5)**	**4 (5)**	**5 (5)**	**Total**
Snails and Slugs	1					1	1		9	10
Spiders	1	2		3		6	1			1
Plant bugs/hoppers	14	2	31	16		63		2	9	11
Aphids	5	4	6		1	16	79	6	4	89
True bugs	12	3	3	2	5	25	5		3	8
Ants									1	1
Other Hymenoptera	3	1		5		9	3	3	5	11
Beetles	1		1	2		4	1		1	2
Butterflies and Moths							1			1
Butterfly and Moth larvae	2	1				3			27	27
Flies	86	33	38	72	79	308	29	22	17	68

Appendix Table A6.10.Pitfalls. Number of each invertebrate taxon detected in 2005 in pitfall traps within each transect, inside and outside the Managed Realignment

	Transects INSIDE MR							Transects OUTSIDE MR				
Taxa	**A (6)**	**B (6)**	**C (6)**	**D (6)**	**E (6)**	**F (6)**	**Total**	**2 (5)**	**3 (3)**	**4 (3)**	**5 (5)**	**Total**
Nematodes		8					8					
Hydrobia ulvae		2		1	1	1	5		1	4	1	6
Leucophytia bidentata											3	3
ALL Snails and Slugs		2		1	1	1	5		1	4	4	9
Carcinus maenas	5	40	8	22	20	15	110	17	11	3	16	47
Lekanesphaera rugicauda		2					2		3	1	2	6
Talitrus saltator	1	1	1				3	51			15	66
Spiders	10	1	40	9	3	3	66	1	5	1	45	52
Mites		2					2		2	1	3	6
Springtails	410K	3752K	2520	2068K	1621K	2180K	10034 K	30	100	20	50	200
Aphrodes bicinctus								1				1
Psammotettix putoni	2	1	4	1			8	2				2
All Plant bugs/hoppers	2	1	4	1			8	3				3
Aphids										1		1
Saldula pallipes /palustris			5			1	6					
Dicheirotrichus gustavi	9	3	11	12	9	22	66	4	2	5	1	12
Pogonus chalceus	5		19	16	4	13	57	2	44	4	1	51
All Beetles	14	3	30	28	13	35	123	6	46	9	2	63
Beetle larvae								46				46
Flies	104	18	60	34	9	19	244	31	36	6	30	103
Fly larvae								1				1

Appendix Table A6.11.Scrapes. Number of each invertebrate taxon detected in 2005 in sediment scrapes within each transect, inside and outside the Managed Realignment

	Transects INSIDE MR							Transects OUTSIDE MR				
Taxa	**A (6)**	**B (6)**	**C (6)**	**D (6)**	**E (6)**	**F (6)**	**Total**	**2 (5)**	**3 (3)**	**4 (3)**	**5 (5)**	**Total**
Nematodes	8			35	21	1	65	65	83	40	74	262
Oligochaete worms indet.	578	7779	963	1732	1516	585	13153	772	2813	8	959	4552
Eteone longa			2	1	2		5	2	2	8	3	15
Hediste diversicolor	34	1		1	2		38		2	3	3	8
Pygospio elegans	3				2		5					
Tharyx sp.										2		2
ALL Oligochaete worms	615	7780	965	1734	1522	585	13201	774	2817	21	965	4577
Scrobicularia plana											2	2
ALL Bivalve molluscs											2	2
Hydrobia ulvae <3mm	656	233	166	651	440	1353	3499	1997	4929	3433	3362	13721
Hydrobia ulvae >3mm	186	916	493	438	340	529	2902	51	127	220	256	654
All *Hydrobia ulvae*	842	1149	659	1089	780	1882	6401	2048	5056	3653	3618	14375
ALL Snails and Slugs	842	1149	659	1089	780	1882	6401	2048	5056	3653	3618	14375
Lekanesphaera rugicauda					1	1	2		3		1	4
Talitrus saltator								3				3
Mites			1				1					
Anurida maritima	1				1	1	3					
Aphids	2						2					
Flies						1	1					
Fly larvae	24	5	7	10	25	17	88	9	6	6	1	22

Appendix Table A6.12.Sweeps. Number of each invertebrate taxon detected in 2005 in sweep nets within each transect, inside and outside the Managed Realignment

	Transects INSIDE MR							Transects OUTSIDE MR				
Taxa	**A (6)**	**B (6)**	**C (6)**	**D (6)**	**E (6)**	**F (6)**	**Total**	**2 (5)**	**3 (3)**	**4 (3)**	**5 (5)**	**Total**
Snails and Slugs		1	1	3	4	7	16	8			2	10
Spiders						1	1					
Plant bugs/hoppers	8	7	34	14	7		70	3	2			5
Aphids	9	1	1	5	26	1	43	68	1	10	13	92
True bugs		2	3	5	1	1	12				1	1
Other Hymenoptera	18			2	1		21	1	6		4	11
Beetles	1				1		2		2		1	3
Butterflies and Moths						1	1					
Butterfly and Moth larvae	3	6	11	67	18	17	122	9	14			23
Flies	21	32	34	27	28	33	175	15	18	6	20	59
Fly larvae									1			1

Appendix Table A6.13.Pitfalls. Number of each invertebrate taxon detected in 2006 in pitfall traps within each transect, inside and outside the Managed Realignment

	Transects INSIDE MR							Transects OUTSIDE MR				
Taxa	**A (6)**	**B (6)**	**C (6)**	**D (6)**	**E (6)**	**F (6)**	**Total**	**2 (5)**	**3 (3)**	**4 (3)**	**5 (5)**	**Total**
Hydrobia ulvae	6	20	2	4		1	33	11				11
ALL Snails and Slugs												
Carcinus maenas	51	57	16	52	54	60	290	25	8	12	29	74
Lekanesphaera rugicauda	1					2	3			1	13	14
Talitrus saltator	13	1	5	2	5		26	104			29	133
Pardosa agricola	10	2	9	5			26	1				1
Spiders indet.	3		17	9	8	6	43	3	2	1	24	30
ALL Spiders	13	2	26	14	8	6	69	4	2	1	24	31
Mites	14		1		3	3	21		5	10		15
Springtails	40	195	60	66K	20	19K	86K	40	3	10		53
Psammotettix putoni	2	1	1		1		5					
Aphids												
Saldula pallipes /palustris		1	3		2	6	12	1		1	1	3
Bees			1				1					
Dicheirotrichus gustavi	15	12	45	134	24	80	310	7	6	4	17	34
Pogonus chalceus				47	1	10	58		15	4	2	21
Bledius spectabilis									1	1		2
Heterocerus obsoletus			1				1					
All Beetles	15	12	46	181	25	90	369	7	22	9	19	57
Beetle Larvae								1				1
Psychidea spp.	1	2					3				1	1
Flies	15	7	10	2	25	36	95	9	4	2	5	20
Fly larvae		1	13	1			15					

Appendix Table A6.14.Scrapes. Number of each invertebrate taxon detected in 2006 in sediment scrapes within each transect, inside and outside the Managed Realignment

	Transects INSIDE MR							Transects OUTSIDE MR				
Taxa	**A (6)**	**B (6)**	**C (6)**	**D (6)**	**E (6)**	**F (6)**	**Total**	**2 (5)**	**3 (3)**	**4 (3)**	**5 (5)**	**Total**
Nematodes	2	1		8	53	17	81	243	64	42	199	548
Oligochaete worms indet.	1073	100	346	44	419	193	2175	1382	88	58	2698	4226
Eteone longa			1	2	2		5		3	1	1	5
Hediste diversicolor	11	43	43	15	7	5	124	1	3	2	2	8
Pygospio elegans											1	1
Spiophanes bombyx											1	1
Tharyx sp.												
Capitella sp.										6	2	8
ALL Oligochaete worms	1084	143	390	61	428	198	2304	1383	94	67	2705	4249
Scrobicularia plana											9	9
ALL Bivalve molluscs											9	9
Hydrobia ulvae <3mm	304	401	400	783	170	804	2862	1769	591	2427	373	5160
Hydrobia ulvae >3mm	15	589	481	840	259	39	2223	7	24	14	43	88
All *Hydrobia ulvae*	319	990	881	1623	429	843	5085	1776	615	2441	416	5248
Leucophytia bidentata											1	1
ALL Snails and Slugs	319	990	881	1623	429	843	5085	1776	615	2441	417	5249
Carcinus maenas					2		2	1	1		2	4
Crangon crangon					1		1		1		1	2
Lekanesphaera rugicauda						2	2			1		1
Talitrus saltator												
Mites		1					1					
Springtails				1			1					
Aphids						1	1					
Flies												
Fly larvae	11		2	12	15	11	51	4	5		45	54

Appendix Table A6.15.Sweeps. Number of each invertebrate taxon detected in 2006 in sweep nets within each transect, inside and outside the Managed Realignment

	Transects INSIDE MR							Transects OUTSIDE MR				
Taxa	**A (6)**	**B (6)**	**C (6)**	**D (6)**	**E (6)**	**F (6)**	**Total**	**2 (5)**	**3 (3)**	**4 (3)**	**5 (5)**	**Total**
Snails and Slugs	16	7	2	5	7	8	45	1	2		1	4
Spiders	11	7	11	6	3	7	45	2				2
Mites	1	1		1			3					
Plant bugs/hoppers	150	320	118	116	51	7	762	5		1	7	13
Aphids	3	6	3	10	15	1	38	1	1	1	5	8
True bugs	9	6	5	7	1	8	36		1	1	4	6
Other Hymenoptera	4	6	7	2	6	2	27	6	4	1	2	13
Beetles	12		6	2		3	23	2	3		3	8
Booklice			1				1					
Butterflies and Moths									1		1	2
Butterfly and Moth larvae	77	78	61	52	36	37	341	3		15	41	59
Flies	44	24	21	19	21	28	157	38	25	19	10	92
Fly larvae		5	3			1	9					
Thrips		1					1				1	1

Key
1. Numbers in parenthesis indicate the number of sites sampled each year.
2. indet. = not identified to the level of species
3. Other Hymenoptera = Hymenoptera other than ants and bees. These are parasites (eg Ichneumon flies) or gall-formers (eg Cynipoidea).
4. K = 1000 (numbers > 10000)

APPENDIX TABLES OF DATA ACCORDING TO ELEVATION CATEGORY

Notation: A6.No.Sampling method(P or Sc or Sw)/E

P=Pitfalls, Sc=Scrapes, Sw=Sweeps

Table A6.16.P/E Number of each invertebrate taxon detected in 2002 in pitfall traps within each elevation range, inside and outside the Managed Realignment

	Totals for each elevation range - INSIDE			Totals for each elevation range - OUTSIDE		
Taxa	**2.7-3.0mODN (10 sites)**	**>3.0-3.3mODN (20 sites)**	**TOTAL IN**	**2.7-3.0mODN (12 sites)**	**>3.0-3.3mODN (12 sites)**	**TOTAL OUT**
Carcinus maenas	0	2	2	5	6	11
Lekanesphaera rugicauda	0	1	1	0	0	0
Talitrus saltator	6	3	9	3	17	20
Spiders	5	14	19	22	42	64
Mites	0	0	0	1	11	12
Springtails	99	306	405	1000876	118	1000994
True bugs	0	0	0	1	0	1
Ants	0	1	1	2	0	2
Other Hymenoptera	0	3	3	0	0	0
Beetles	0	1	1	0	0	0
Beetle larvae	0	0	0	2	0	2
Booklice	1	1	2	0	0	0
Flies	0	2	2	79	7	86
Fly larvae	0	1	1	1	0	1

Table A6.17.P/E Number of each invertebrate taxon detected in 2003 in pitfall traps within each elevation range, inside and outside the Managed Realignment

Taxa	Totals for each elevation range - INSIDE			Totals for each elevation range - OUTSIDE		
	2.7-3.0mODN (10 sites)	>3.0-3.3mODN (20 sites)	TOTAL IN	2.7-3.0mODN (6 sites)	>3.0-3.3mODN (6 sites)	TOTAL OUT
Hydrobia ulvae	0	0	0	3	3	6
Leucophytia bidentata	0	0	0	0	1	1
ALL Snails and Slugs	0	0	0	3	4	7
Carcinus maenas	22	56	78	50	130	180
Lekanesphaera rugicauda	1	0	1	17	11	28
Talitrus saltator	0	8	8	14	287	301
Spiders	1	1	2	12	16	28
Mites	11	2	13	43	31	74
Springtails	16315	9830	26145	90	762	852
Psammotettix putoni	0	1	1	2	7	9
Aphids	40	237	277	11	23	34
Saldula pallipes / palustris	2	2	4	14	10	24
Plagiognathus chrysanthemi	0	2	2	0	0	0
ALL True bugs	2	4	6	14	10	24
Other Hymenoptera	1	4	5	0	0	0
Dicheirotrichus gustavi	1	5	6	4	53	57
Pogonus chalceus	1	4	5	3	1	4
Proteinus macropterus	0	1	1	0	0	0
Anotylus rugosus	0	2	2	1	1	2
Bledius spectabilis	0	0	0	1	0	1
Atheta sp.	0	0	0	2	0	2
Glischrochilus 4-punctatus	0	0	0	1	0	1

Taxa	Totals for each elevation range - INSIDE			Totals for each elevation range - INSIDE		
	2.7-3.0mODN (10 sites)	>3.0-3.3mODN (20 sites)	TOTAL IN	2.7-3.0mODN (6 sites)	>3.0-3.3mODN (6 sites)	TOTAL OUT
Heterocerus obsoletus	0	0	0	1	0	1
Cortinicara gibbosa	0	1	1	0	0	0
ALL Beetles	2	13	15	13	55	68
Flies	25	39	64	23	15	38
Fly larvae	1	0	1	0	0	0

Table A6.18.Sc/E **Number of each invertebrate taxon detected in 2003 in scrape samples within each elevation range, inside and outside the Managed Realignment**

Taxa	Totals for each elevation range - INSIDE			Totals for each elevation range - OUTSIDE		
	2.7-3.0mODN (10 sites)	>3.0-3.3mODN (20 sites)	TOTAL IN	2.7-3.0mODN (10 sites)	>3.0-3.3mODN (1 site)	TOTAL OUT
Nematodes	3	0	3	11	0	11
Oligochaete worms indet.	25	69	94	636	0	636
Eteone longa	0	0	0	13	0	13
Hediste diversicolor	0	1	1	5	0	5
Pygospio elegans	0	0	0	0	0	0
Spio martinensis	0	0	0	3	0	3
Tharyx sp.	0	0	0	1	0	1
Capitella sp.	70	5	75	87	0	87
ALL Oligochaete worms	95	75	170	745	0	745
Cerastoderma edule <5mm	0	0	0	2	0	2
Cerastoderma edule 6-10mm	0	0	0	3	0	3
Cerastoderma edule 11-15mm	0	0	0	4	0	4
Cerastoderma edule 16-20mm	0	0	0	10	0	10
Cerastoderma edule 21-25mm	0	0	0	8	0	8
All *Cerastoderma edule*	0	0	0	27	0	27
Mytilus edulis <5mm	1	0	1	0	0	0
Mytilus edulis 16-20mm	0	0	0	2	0	2
All *Mytilus edulis*	1	0	1	2	0	2
Macoma balthica <5mm	0	0	0	1	0	1

Taxa	Totals for each elevation range - INSIDE			Totals for each elevation range - OUTSIDE		
	2.7-3.0mODN (10 sites)	>3.0-3.3mODN (20 sites)	TOTAL IN	2.7-3.0mODN (10 sites)	>3.0-3.3mODN (1 site)	TOTAL OUT
Macoma balthica 6-10mm	0	0	0	46	0	46
Macoma balthica 11-15mm	0	0	0	8	0	8
Macoma balthica 16-20mm	0	0	0	3	0	3
All *Macoma balthica*	0	0	0	58	0	58
Abra alba 11-15 mm	0	0	0	8	0	8
Scrobicularia plana	0	0	0	1	0	1
ALL Bivalve molluscs	1	0	1	96	0	96
Hydrobia ulvae <3mm	0	5	5	4104	0	4104
Hydrobia ulvae >3mm	131	268	399	6858	0	6858
All *Hydrobia ulvae*	131	273	404	10962	0	10962
Retusa obtusa <3mm	0	0	0	9	0	9
ALL Snails and Slugs	131	273	404	10971	0	10971
Carcinus maenas	0	0	0	2	0	2
Mites	0	1	1	0	0	0
Springtails	0	1	1	0	0	0
Aphids	1	2	3	0	0	0
Saldula pallipes /palustris	1	0	1	0	0	0
Fly larvae	37	20	57	8	0	8

Table A6.19.P/E Number of each invertebrate taxon detected in 2004 in pitfall traps within each elevation range, inside and outside the Managed Realignment

	Totals for each elevation range - INSIDE			Totals for each elevation range - OUTSIDE		
Taxa	**2.7-3.0mODN (10 sites)**	**>3.0-3.3mODN (20 sites)**	**TOTAL IN**	**2.7-3.0mODN (11 sites)**	**>3.0-3.3mODN (4 sites)**	**TOTAL OUT**
Hydrobia ulvae	1	0	1	3	0	3
Leucophytia bidentata	0	0	0	0	3	3
ALL Snails and Slugs	1	0	1	3	3	6
Carcinus maenas	216	710	926	58	8	66
Lekanesphaera rugicauda	0	3	3	12	2	14
Talitrus saltator	1	13	14	2	211	213
Spiders	0	33	33	7	66	73
Mites	99	3	102	12	3	15
Springtails	1126420	4046	1130466	278	0	278
Psammotettix putoni	0	9	9	1	3	4
Saldula pallipes /palustris	2	31	33	4	2	6
Plagiognathus chrysanthemi	0	1	1	0	0	0
ALL True bugs	2	32	34	4	2	6
Bembidion laterale	0	0	0	1	0	1
Dicheirotrichus gustavi	1	29	30	54	6	60
Pogonus chalceus	11	66	77	36	0	36
Bledius spectabilis	0	0	0	2	0	2
Heterocerus obsoletus	0	0	0	2	0	2
Cortinicara gibbosa	0	1	1	0	0	0
All Beetles	12	96	108	95	6	101
Beetle larvae	0	1	1	1	0	1
Flies	34	52	86	28	2	30
Fly larvae	0	0	0	3	0	3

Table A6.20.Sc/E **Number of each invertebrate taxon detected in 2004 in scrape samples within each elevation range, inside and outside the Managed Realignment**

	Totals for each elevation range - INSIDE			Totals for each elevation range - OUTSIDE		
Taxa	**2.7-3.0mODN (10 sites)**	**>3.0-3.3mODN (20 sites)**	**TOTAL IN**	**2.7-3.0mODN (11 sites)**	**>3.0-3.3mODN (4 sites)**	**TOTAL OUT**
Nematodes	0	2	2	16	50	66
Oligochaete worms indet.	11	16	27	609	641	1250
Eteone longa	3	1	4	8	0	8
Hediste diversicolor	67	99	166	7	7	14
Nephtys hombergii	1	0	1	3	0	3
Pygospio elegans	27	15	42	0	0	0
Spio martinensis	1	4	5	0	0	0
Tharyx sp.	1	1	2	0	0	0
Capitella sp.	3	0	3	0	0	0
ALL Oligochaete worms	114	136	250	627	648	1275
Cerastoderma edule <5mm	0	0	0	12	0	12
Cerastoderma edule 6-10mm	0	0	0	7	0	7
Cerastoderma edule 11-15mm	0	0	0	10	0	10
Cerastoderma edule 16-20mm	0	0	0	2	0	2
Cerastoderma edule 21-25mm	0	0	0	1	0	1
All *Cerastoderma edule*	0	0	0	32	0	32
Mytilus edulis <5mm	0	0	0	1	0	1
Macoma balthica <5mm	0	0	0	2	0	2
Macoma balthica 6-10mm	1	0	1	6	0	6
Macoma balthica 11-15mm	0	0	0	13	0	13

Taxa	Totals for each elevation range - INSIDE			Totals for each elevation range - OUTSIDE		
	2.7-3.0mODN (10 sites)	>3.0-3.3mODN (20 sites)	TOTAL IN	2.7-3.0mODN (11 sites)	>3.0-3.3mODN (4 sites)	TOTAL OUT
Macoma balthica 16-20mm	1	0	1	8	0	8
All *Macoma balthica*	2	0	2	29	0	29
Abra alba 11-15 mm	0	4	4	0	0	0
Scrobicularia plana <5mm	1	0	1	55	0	55
Scrobicularia plana >5mm	0	0	0	33	0	33
All *Scrobicularia plana*	1	0	1	88	0	88
ALL Bivalve molluscs	3	4	7	149	0	149
Hydrobia ulvae <3mm	2724	1020	3744	13993	76	14069
Hydrobia ulvae >3mm	1105	1419	2524	3518	8	3526
All *Hydrobia ulvae*	3829	2439	6268	17511	84	17595
ALL Snails and Slugs	3829	2439	6268	17511	84	17595
Carcinus maenas	0	4	4	1	0	1
Crangon crangon	0	0	0	1	0	1
Lekanesphaera rugicauda	0	0	0	1	0	1
Talitrus saltator	0	0	0	0	1	1
Beetles	0	0	0	0	1	1
Fly larvae	12	14	26	14	3	17

Table A6.21.Sw/E   Number of each invertebrate taxon detected in 2004 in sweep nets within each elevation range, inside and outside the Managed Realignment

Taxa	Totals for each elevation range - INSIDE			Totals for each elevation range - OUTSIDE		
	2.7-3.0mODN (10 sites)	>3.0-3.3mODN (20 sites)	TOTAL IN	2.7-3.0mODN (11 sites)	>3.0-3.3mODN (4 sites)	TOTAL OUT
Snails and Slugs	0	1	1	1	9	10
Spiders	0	6	6	1	0	1
Plant bugs/hoppers	0	63	63	2	9	11
Aphids	2	14	16	85	4	89
True bugs	4	21	25	5	3	8
Ants	0	0	0	0	1	1
Other Hymenoptera	1	8	9	6	5	11
Beetles	2	2	4	1	1	2
Butterflies and Moths	0	0	0	1	0	1
Butterfly and Moth larvae	0	3	3	0	27	27
Flies	101	207	308	58	10	68

Table A6.22.P/E Number of each invertebrate taxon detected in 2005 in pitfall traps within each elevation range, inside and outside the Managed Realignment

	Totals for each elevation range - INSIDE			Totals for each elevation range - OUTSIDE		
Taxa	**2.7-3.0mODN (13 sites)**	**>3.0-3.3mODN (23 sites)**	**TOTAL IN**	**2.7-3.0mODN (9 sites)**	**>3.0-3.3mODN (7 sites)**	**TOTAL OUT**
Nematodes	0	8	8	0	0	0
Hydrobia ulvae	1	4	5	5	1	6
Leucophytia bidentata	0	0	0	0	3	3
ALL Snails and Slugs	1	4	5	5	4	9
Carcinus maenas	53	57	110	26	21	47
Lekanesphaera rugicauda	0	2	2	5	1	6
Talitrus saltator	1	2	3	5	61	66
Spiders	2	64	66	6	46	52
Mites	0	2	2	4	2	6
Springtails	7263420	2770620	10034040	200	0	200
Aphrodes bicinctus	0	0	0	0	1	1
Psammotettix putoni	0	8	8	2	0	2
All Plant bugs/hoppers	0	8	8	2	1	3
Aphids	0	0	0	1	0	1
Saldula pallipes /palustris	1	5	6	0	0	0
Dicheirotrichus gustavi	18	48	66	7	5	12
Pogonus chalceus	10	47	57	49	2	51
All Beetles	28	95	123	56	7	63
Beetle larvae	0	0	0	0	46	46
Flies	10	234	244	67	36	103
Fly larvae	0	0	0	0	1	1

Table A6.23.Sc/E Number of each invertebrate taxon detected in 2005 in scrape samples within each elevation range, inside and outside the Managed Realignment

Taxa	Totals for each elevation range - INSIDE			Totals for each elevation range - OUTSIDE		
	2.7-3.0mODN (13 sites)	>3.0-3.3mODN (23 sites)	TOTAL IN	2.7-3.0mODN (9 sites)	>3.0-3.3mODN (7 sites)	TOTAL OUT
Nematodes	55	10	65	142	120	262
Oligochaete worms indet.	1514	11639	13153	3317	1235	4552
Eteone longa	1	4	5	11	4	15
Hediste diversicolor	5	33	38	6	2	8
Pygospio elegans	2	3	5	0	0	0
Tharyx sp.	0	0	0	2	0	2
ALL Oligochaete worms	1522	11679	13201	3336	1241	4577
Scrobicularia plana	0	0	0	2	0	2
ALL Bivalve molluscs	0	0	0	2	0	2
Hydrobia ulvae <3mm	2141	1358	3499	13266	455	13721
Hydrobia ulvae >3mm	1212	1690	2902	636	18	654
All *Hydrobia ulvae*	3353	3048	6401	13902	473	14375
ALL Snails and Slugs	3353	3048	6401	13902	473	14375
Lekanesphaera rugicauda	1	1	2	3	1	4
Talitrus saltator	0	0	0	0	3	3
Mites	0	1	1	0	0	0
Anurida maritima	1	2	3	0	0	0
Aphids	2	0	2	0	0	0
Flies	1	0	1	0	0	0
Fly larvae	59	29	88	13	9	22

Table A6.24.Sw/E Number of each invertebrate taxon detected in 2005 in sweep nets within each elevation range, inside and outside the Managed Realignment Sweep

Taxa	Totals for each elevation range - INSIDE			Totals for each elevation range - OUTSIDE		
	2.7-3.0mODN (13 sites)	>3.0-3.3mODN (23 sites)	TOTAL IN	2.7-3.0mODN (9 sites)	>3.0-3.3mODN (7 sites)	TOTAL OUT
Snails and Slugs	9	7	16	6	4	10
Spiders	1	0	1	0	0	0
Plant bugs/hoppers	2	68	70	2	3	5
Aphids	3	40	43	83	9	92
True bugs	3	9	12	1	0	1
Other Hymenoptera	0	21	21	6	5	11
Beetles	1	1	2	2	1	3
Butterflies and Moths	1	0	1	0	0	0
Butterfly and Moth larvae	69	53	122	15	8	23
Flies	54	121	175	42	17	59
Fly larvae	0	0	0	1	0	1

Table A6.25.P/E Number of each invertebrate taxon detected in 2006 in pitfall traps within each elevation range, inside and outside the Managed Realignment

Taxa	Totals for each elevation range - INSIDE			Totals for each elevation range - OUTSIDE		
	2.7-3.0mODN (13 sites)	>3.0-3.3mODN (23 sites)	TOTAL IN	2.7-3.0mODN (9 sites)	>3.0-3.3mODN (7 sites)	TOTAL OUT
Hydrobia ulvae	23	10	33	11	0	11
ALL Snails and Slugs	23	10	33	11	0	11
Carcinus maenas	205	85	290	54	20	74
Lekanesphaera rugicauda	2	1	3	2	12	14
Talitrus saltator	2	24	26	0	133	133
Pardosa agricola	0	26	26	0	1	1
Spiders indet.	13	30	43	4	26	30
ALL Spiders	13	56	69	4	27	31
Mites	7	14	21	15	0	15
Springtails	85350	165	85515	23	30	53
Psammotettix putoni	0	5	5	0	0	0
Saldula pallipes /palustris	6	6	12	1	2	3
Bees	0	1	1	0	0	0
Dicheirotrichus gustavi	81	229	310	14	20	34
Pogonus chalceus	20	38	58	20	1	21
Bledius spectabilis	0	0	0	2	0	2
Heterocerus obsoletus	0	1	1	0	0	0
All Beetles	101	268	369	36	21	57
Beetle Larvae	0	0	0	0	1	1
Psychidea spp.	0	3	3	0	1	1
Flies	57	38	95	10	10	20
Fly larvae	0	15	15	0	0	0

Table A6.26.Sc/E Number of each invertebrate taxon detected in 2006 in scrape samples within each elevation range, inside and outside the Managed Realignment

Taxa	Totals for each elevation range - INSIDE			Totals for each elevation range - OUTSIDE		
	2.7-3.0mODN (13 sites)	>3.0-3.3mODN (23 sites)	TOTAL IN	2.7-3.0mODN (9 sites)	>3.0-3.3mODN (7 sites)	TOTAL OUT
Nematodes	72	9	81	231	317	548
Oligochaete worms indet.	231	1944	2175	1435	2791	4226
Eteone longa	2	3	5	5	0	5
Hediste diversicolor	16	108	124	6	2	8
Pygospio elegans	0	0	0	1	0	1
Spiophanes bombyx	0	0	0	1	0	1
Capitella sp.	0	0	0	8	0	8
ALL Oligochaete worms	249	2055	2304	1456	2793	4249
Scrobicularia plana	0	0	0	9	0	9
ALL Bivalve molluscs	0	0	0	9	0	9
Hydrobia ulvae <3mm	1529	1333	2862	5028	132	5160
Hydrobia ulvae >3mm	323	1900	2223	79	9	88
All *Hydrobia ulvae*	1852	3233	5085	5107	141	5248
Leucophytia bidentata	0	0	0	0	1	1
ALL Snails and Slugs	1852	3233	5085	5107	142	5249
Carcinus maenas	2	0	2	3	1	4
Crangon crangon	0	1	1	2	0	2
Lekanesphaera rugicauda	2	0	2	1	0	1
Mites	1	0	1	0	0	0
Springtails	1	0	1	0	0	0
Aphids	0	1	1	0	0	0
Fly larvae	21	30	51	6	48	54

Table A6.27.Sw/E Number of each invertebrate taxon detected in 2006 in sweep nets within each elevation range, inside and outside the Managed Realignment

Taxa	Totals for each elevation range - INSIDE			Totals for each elevation range - OUTSIDE		
	2.7-3.0mODN (13 sites)	>3.0-3.3mODN (23 sites)	TOTAL IN	2.7-3.0mODN (9 sites)	>3.0-3.3mODN (7 sites)	TOTAL OUT
Snails and Slugs	10	35	45	3	1	4
Spiders	11	34	45	1	1	2
Mites	2	1	3	0	0	0
Plant bugs/hoppers	14	748	762	2	11	13
Aphids	7	31	38	2	6	8
True bugs	11	25	36	2	4	6
Other Hymenoptera	3	24	27	10	3	13
Beetles	2	21	23	4	4	8
Booklice	0	1	1	0	0	0
Butterflies and Moths	0	0	0	1	1	2
Butterfly and Moth larvae	54	287	341	16	43	59
Flies	41	116	157	66	26	92
Fly larvae	0	9	9	0	0	0
Thrips	1	0	1	0	1	1

Key

1. Numbers in parenthesis indicate the number of sites sampled each year.
2. indet. = not identified to the level of species
3. Other Hymenoptera = Hymenoptera other than ants and bees. These are parasites (eg Ichneumon flies) or gall-formers (eg Cynipoidea).

7. Fish utilisation of the Freiston Shore realignment site, 2003 – 2006 surveys

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7.1 Summary

1. 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.

2. Using micromesh seine and fyke nets, a total of 11570 individuals of 12 species have been 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 consisted of a mix of both sprat and herring. Further analysis of these samples to species level can be provided if required. A selection of all of the samples was preserved for both length and dietary analysis.

3. 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.

4. 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, continued to act as an important nursery zone for 0+ fishes, during periods of non-connectivity with the sea.

5. 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.

6. 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 most likely a result of sporadic linkage via the sluice (wheel pool), which provides limited periods of connectivity with the adjacent wetland.

7. 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 that 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.

8. The results from these surveys suggest that the creation of additional ponded areas within the 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.

7.2 Introduction

It is well recognised that inter-tidal zones provide important nursery and rich feeding areas for young-of-the-year fishes, including many species of commercial value. During such a crucial stage in the life history of fishes (i.e. early development), the availability of such habitats play an important role in early growth and survival of some species, and thus play an important role in the recruitment process. In order to identify those species utilising the managed retreat 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. Results from the initial survey in 2003 survey raised the question: do fish only enter and leave the site on high spring tides, or do some species reside within the permanently flooded channels of the site during neap tides, when the tidal range is not sufficient to allow connectivity between the site and the sea? To address this question, the 2004 survey was designed in two parts: (1) to repeat the 2003 survey, by sampling during spring tides on the 4th, 5th and 6th of August, incorporating both the realignment site and the adjacent established salt marsh for comparative purposes, and (2) a further visit to the realignment site on the 9th and 10th of August, to assess which species reside within the residual water of the permanently flooded channels of the realignment site, when the tidal range does not allow access to and from the neighbouring Wash embayment. This survey design revealed that the permanently flooded channels of the site do provide nursery habitats for juvenile fish between spring tides and within this report, we also present preliminary data from the gut contents of a selection of fishes captured over a range of tides during the 2004 survey.

7.3 Summary Of Survey Results

Over the course of the four year study period, 12 species have been caught to date. Of this total, 11 have been caught inside the newly flooded realignment area, with only six species caught outside the breached walls, on the natural saltmarsh. Sand goby (mainly) and Common goby, *Pomatoschistus minutus* and *P.microps* have dominated the catch in all years, both within and outside the realignment. Although a number of species were poorly represented, with only single specimens caught in some years, some species of commercial interest, such as bass, *Dicentrarchus labrax*, sprat, *Sprattus sprattus* and herring *Clupea harengus* have been captured on a regular basis, albeit in varying numbers. Despite being very common within the realignment during 2003, three-spined stickleback, *Gasterosteus aculeatus* have demonstrated a marked reduction in number. A summary of species composition between years is presented in Table 7.1.

Table 7.1. Species caught between 2003 and 2006.

Common name	Scientific name	Total number caught in 2003	Total number caught in 2004	Total number caught in 2005	Total number caught in 2006
Sand goby/ Common goby	*Pomatoschistus minutus/ P.microps*	835	3240	3742	1767
Three-spined stickleback	*Gasterosteus aculeatus*	697	45	16	165
Sprat	*Sprattus sprattus*	99	413	169	158
Herring	*Clupea harengus*				
Smelt	*Osmerus eperlanus*	4			5
Flounder	*Platichthys flesus*	3	49	1	
Bass	*Dicentrarchus labrax*	1	84	20	21
Poor cod	*Trisopterus minutus*	1			
Sand smelt	*Atherina presbyter*	1	1		
Mullet	*Mugilidae sp.*		1	1	
Eel	*Anguilla anguilla*		1		
Nilssons Pipe fish	*Syngnathus rostellatus*			2	28

7.4 2003 Survey

7.4.1 Methods

Samples of fish were collected both within and outside the realignment site between 27 and 29 August 2003 (Fig 7.1). Samples were taken over a range of states of tide, using several sampling methods. The majority of samples were collected using a micromesh beach seine (10 x 2 metres) deployed either by wading or set using a small inflatable boat and retrieved to the shoreline. Dip nets were also used around the margins, in order to catch small fish that had been located visually. Outside the realignment area a fyke net with leading wings was set across one of the main creeks and left in position for one hour while the creek drained.

Where large numbers of fish were caught, the catch was carefully inspected for unusual species and then an estimated proportion of the catch was sub sampled for further analysis with the remainder of the catch returned alive. Fish retained were first anaesthetised using 2-Phenoxyethanol to prevent stress-induced evacuation of the gut and preserved in 4% formaldehyde solution. Back at the laboratory all fish were identified to species level, counted and measured (fork length). All samples have been archived for possible future analysis of diet spectrum.

Figure 7.1. Aerial image of southern end of Freiston Shore realignment, showing location of the 17 samples conducted during the 2003 fish survey.

7.4.2 Results

During the 2003 survey a total of nine species and 1641 individuals (Table 7.1) were captured and retained for length analysis and possible future investigation of diet utilisation. Only three species were caught outside the realignment area, on the adjacent established marsh and only one of these species, a single poor cod, differed from the species captured within the realignment area.

Sample 1: Marginal dip net samples outside the realignment area

Date: 27/8/03	**Sampling Method:** Dip net
Time: 16:15	**State of tide:** Approx 1.75 hours before high water

Young gobies were observed all along the shallow margins of the shore line and were also abundant in all puddles still holding water from the previous tide. A sample of these fish was caught using a standard dip net and retained for length analysis.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Goby	18	13	32	21.22	1.49

Sample 2: Seine net sample at the top of main south channel, within the realignment area.

Date: 27/8/03	**Sampling Method:** Micromesh seine net
Time: 16:45	**State of tide:** Approx 1.25 hours before high water

This sample was taken at the top end of the main south channel, within the realignment area. The channel at this point was approximately eight metres wide and two metres deep. A micromesh seine (10 x 2m) was set parallel with the north bank, deployed in an arc and beached adjacent to the sluice gate. This produced a huge number of fish, crabs, prawns and one small jellyfish. Only approximately 10% of the fish were preserved for further analysis with the remainder of the catch returned alive.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Goby	197	15	49	26.81	1.26
3-spined stickleback	332	24	50	30.73	0.98
Sprat/Herring	28	44	58	51.67	0.67
Flounder	3	64	85	71.93	6.59

Sample 3: Seine net sample on the vegetated margins outside the realignment area.

Date: 28/8/03	**Sampling Method:** Micromesh seine net
Time: 07:15	**State of tide:** Turning, flood to ebb

Seine net sample deployed in an arc 10 metres from the shore line outside the realignment area. The area sampled was densely vegetated with depths not exceeding 50 cm.

Only one goby was caught and this was returned unprocessed.

Sample 4: Seine net sample over shallow vegetation within the realignment area

Date: 28/8/03	**Sampling Method:** Micromesh seine net
Time: 07:40	**State of tide:** Turning, flood to ebb

A seine net was trawled 10 – 20 metres out from west bank for a distance of 50 metres and eventually drawn in at the west shore. Depths did not exceed 60 cm with a 70% density of submerged macrophyte cover. The entire catch was retained and consisted of 232 goby, one stickleback and one Clupeidae.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Goby	232	14	31	23.03	0.80
3-spined stickleback	1			50	
Sprat/Herring	1			46	

Sample 5: Fyke net, main creek outside the southern end of the realignment area

Date: 28/8/03	**Sampling Method:** Fyke
Time: 08:00 – 09:00	**State of tide:** Ebb

A fyke net with leading wings was set across the entire creek at 8:00hrs and left *in situ* for one hour. Although many gobies were seen within the creek, the total catch was very disappointing with only a few larger specimens retained in the coarser mesh of the net along with one sprat and one poor cod.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Goby	21	25	38	30.62	0.63
Poor cod	1			62	
Sprat/Herring	1			51	

Sample 6: Seine net sample at the top of the main south channel, within the realignment area (same site as sample 2).

Date: 28/8/03	**Sampling Method:** Seine
Time: 10:45	**State of tide:** Ebb

This sample was carried out in the same way as sample 2 only on a higher tide. Large numbers of three-spined sticklebacks were caught along with some sprat and gobies.

Only 50% of the sample was retained with the remainder being released.

		Fork Length			
Species	No.	Min	Max	Mean	SE
3-spined stickleback	351	22	38	28.2	0.73
Sprat/Herring	15	49	64	54	1.04
Goby	20	17	31	23.55	0.82

Sample 7: Seine net sample within the mouth of the south breach

Date: 28/8/03	**Sampling Method:** Seine
Time: 11: 05	**State of tide:** Ebb

At the time of this survey, the southern most breach of the sea wall was not functioning properly, with the majority of water entering and leaving the site through the other two breaches. With the exception of the very top of the tide, this resulted in the south breach holding slack water for the majority of the tide.

A seine net was set adjacent to the North bank of this breach and pulled across to the south bank. Possibly due to the very deep water (depth unknown but > two metres, i.e. depth of seine net) only one goby was captured as the net was drawn into the margins.
This sample was not retained.

Sample 8: Seine net sample in the main south channel, just inside the mouth of the south breach

Date: 28/8/03	**Sampling Method:** Seine
Time: 11: 15	**State of tide:** Ebb

Again a seine net was set against the west bank and pulled in on the east bank. Although the catch only produced a few gobies, one sand smelt, a new species to the survey was also captured.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Goby	15	22	45	29.13	1.76
Sand smelt	1			44	

Sample 9: Seine net sample in the main south channel, 50 metres south of the south breach

Date: 28/8/03	**Sampling Method:** Seine
Time: 11: 30	**State of tide:** Ebb

This sample was a carried out in the same way as sample 8 and again just returned a small number of gobies. The catch from this sample was not retained and returned to the water immediately.

Sample 10: Seine net sample at the top end of creek 2, running adjacent to the south channel.

Date: 28/8/03	**Sampling Method:** Seine
Time: 11:50	**State of tide:** Ebb

This sample involved trawling a seine net along the western 25 metres of this creek, with the net being beached at the end of this ditch. Large numbers of fish were captured but after an inspection of the catch revealed no new species to the study, all fish and crustaceans were released alive. This catch consisted of approximately 500 three-spined stickleback, 100 goby and a single sprat/herring.

Sample 11: Seine net sample at the elbow in the main south channel, in the south east corner of the realignment site.

Date: 28/8/03	**Sampling Method:** Seine
Time: 11:15	**State of tide:** Ebb

For this sample, the seine net was deployed in the same way as samples 8 and 9. Sprat and goby were caught along with a single bass, another new species to the study.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Goby	98	21	41	29.25	0.94
Sprat/Herring	22	45	60	52.06	0.91
Bass	1			30	

Sample 12: Seine net sample at the elbow in the main south channel, in the south east corner of the realignment site.

Date: 29/8/03	**Sampling Method:** Seine
Time: 08:40	**State of tide:** Ebb (still very high)

This sample incorporated both the main channel and areas of flooded salt marsh outside the banks of the channel. The Clupeidae caught in this sample were a smaller size class than previously caught.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Goby	4	20	32	24.0	2.68
Sprat/Herring	13	27	38	34.7	0.87

Sample 13: Seine net sample in the main south channel, between creeks running perpendicular to the main channel.

Date: 29/8/03	**Sampling Method:** Seine
Time: 08:55	**State of tide:** Ebb (still very high)

This sample was carried out in the same way as sample 12, incorporating both the main channel and areas of flooded salt marsh outside the banks of the channel. Again a smaller cohort of sprat was captured along with a larger size class. Mean lengths of each size cohort are given below.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Sprat/Herring (small)	4	31	37	35.4	1.61
Sprat/Herring (large)	3	51	53	52	0.5

Sample 14: Seine net trawl sample across the flooded vegetation

Date: 29/8/03	**Sampling Method:** Seine
Time: 09:30	**State of tide:** Ebb (still very high)

This sample had to be abandoned due to the net snagging on barbed wire.

Sample 15: Seine net sample across the flooded vegetation against the west bank.

Date: 29/8/03	**Sampling Method:** Seine
Time: 09:50	**State of tide:** Ebb (still very high)

Seine net sample deployed in an arc 10 metres from west shoreline inside realignment area. Depths were variable, between 10 and 50 cm. The catch was dominated with gobies along with a small number of sprat/herring and a single stickleback.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Sprat/Herring	12	48	57	52.36	0.78
Goby	103	14	39	27.09	1.15
3-spined stickleback	1	30	30	30	

Sample 16: Seine net sample across the flooded vegetation against the west bank, 100 metres north of sample 15 and opposite the south breach.

Date: 29/8/03	**Sampling Method:** Seine
Time: 10:10	**State of tide:** Ebb (still high)

Seine net sample deployed in the same way, and over similar habitat to sample 15. Again gobies dominated the catch with some sticklebacks also present.

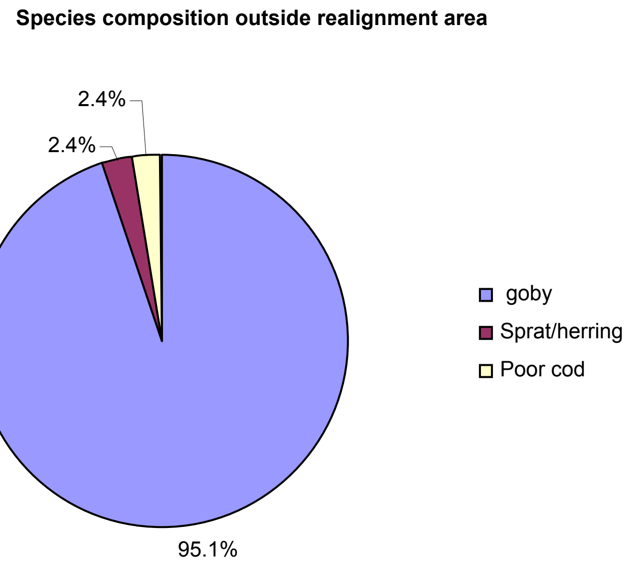
		Fork Length			
Species	No.	Min	Max	Mean	SE
Goby	127	20	38	25.85	0.86
3-spined stickleback	13	24	33	26.79	0.66

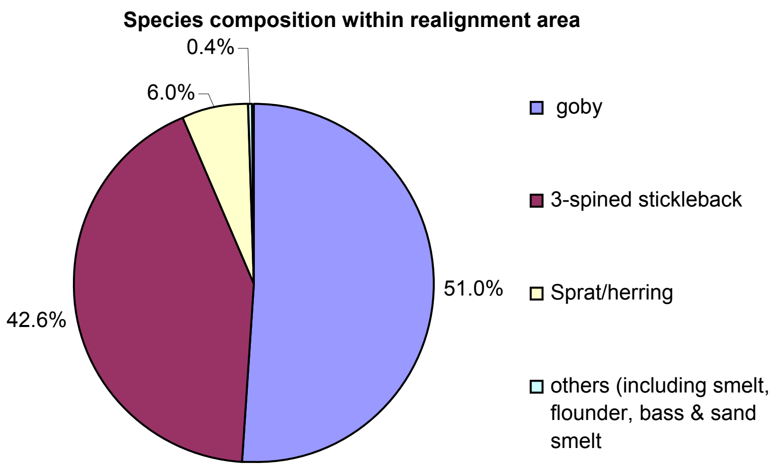
Sample 17: Seine net sample at the top of the main south channel, within the realignment area.

Date: 29/8/03	**Sampling Method:** Seine
Time: 10:30	**State of tide:** Ebb (still high)

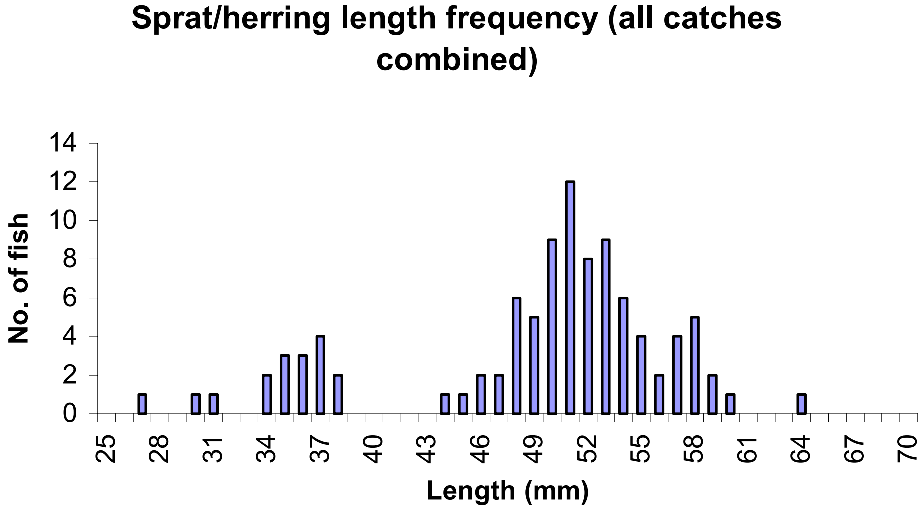
This sample was carried out as a replicate of sample 2. The catch returned large numbers of stickleback, a few gobies and a single sprat/herring. Because large numbers of these species had already been collected, the entire catch was returned alive.

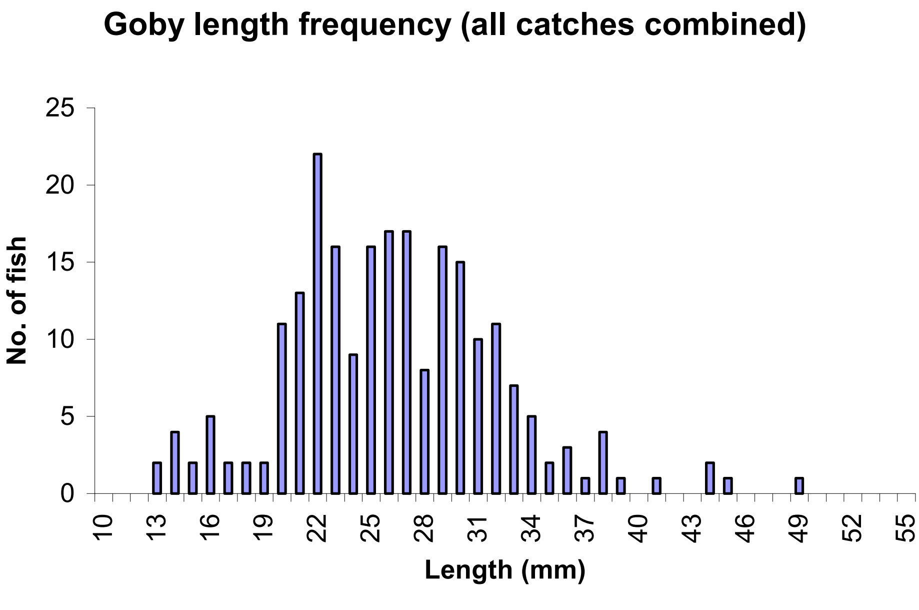
Comparison of relative species composition, both within and outside realignment area



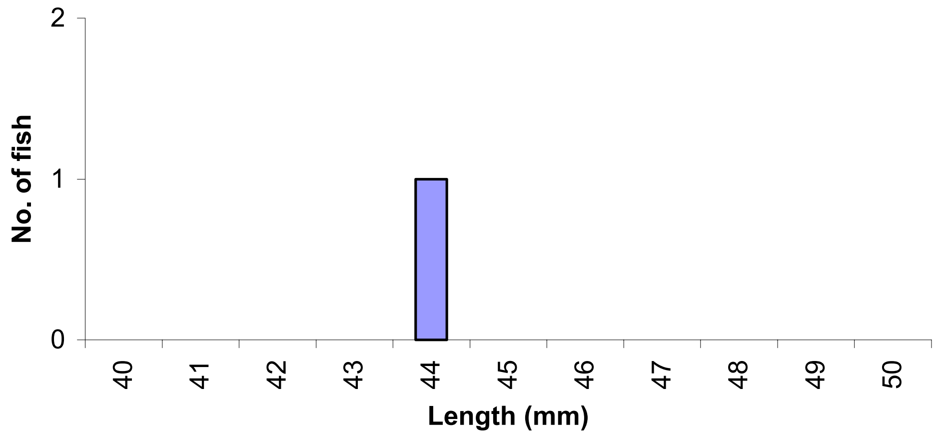


LENGTH FREQUENCY HISTOGRAMS

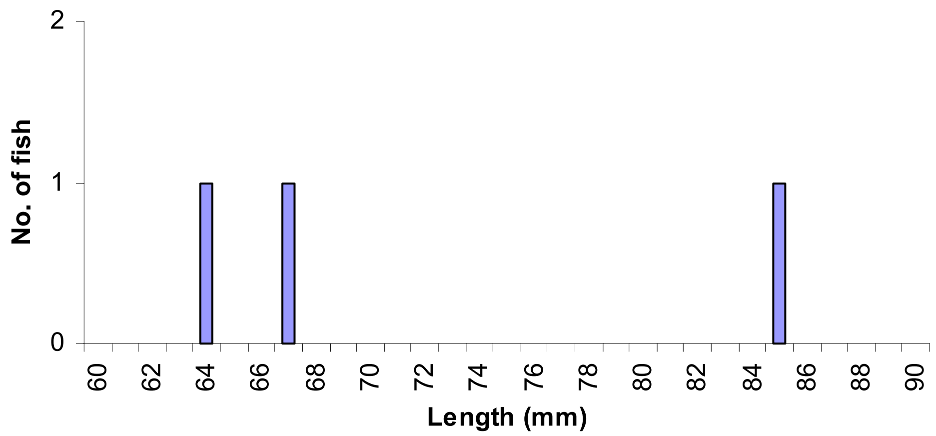




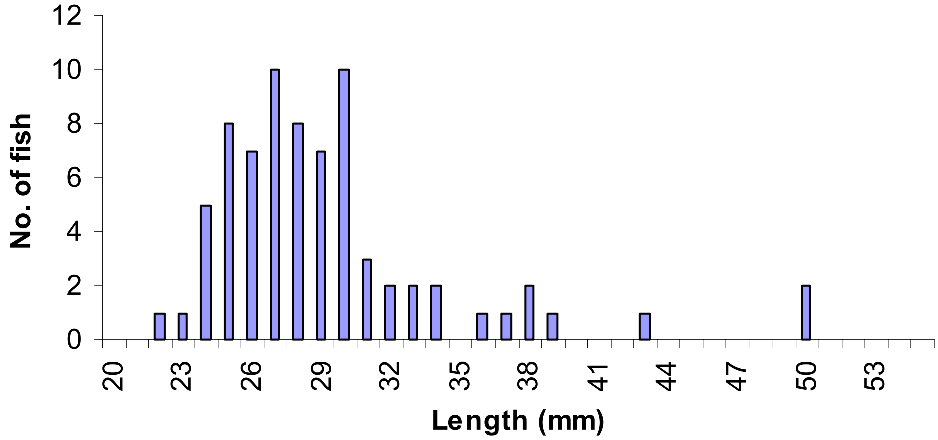
Sand smelt length frequency (all catches combined)



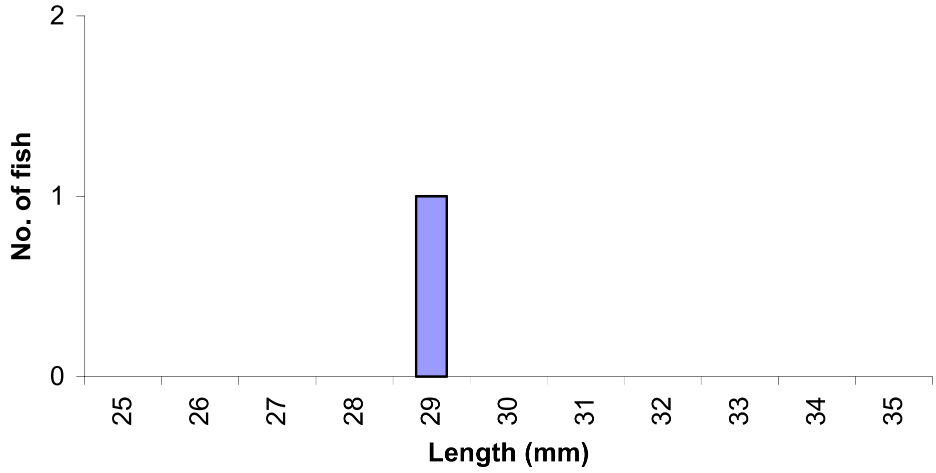
Flounder length frequency (all catches combined)



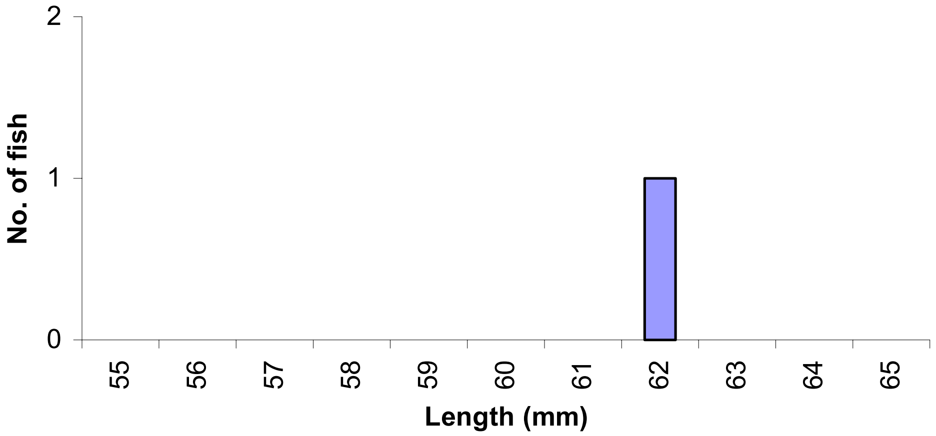
Three-spined stickleback length frequency (all catches combined)



Bass length frequency (all catches combined)



Poor cod length frequency (all catches combined)



7.5 2004 Survey

7.5.1 Methods

Samples of fish were collected both within and outside the realignment site between 4 and 6 August 2004 over the peak of the spring tides. Further samples were collected from the residual water within the realignment area on 9 and 10 August when the tides were not sufficiently high to enter the site. Over the spring tide period, samples were taken over a range of states of tide, using two main sampling methods. The majority of samples were collected using micromesh beach seines (10 x 2 metres and 20 x 1 metres), deployed either by wading or positioned using a small inflatable boat before retrieving to the shoreline. A fyke net with leading wings was also deployed across creeks both in and outside the realignment in order to catch fishes entering and leaving the salt marsh.

Where large numbers of fish were caught, the catch was carefully inspected for unusual species and then an estimated proportion of the catch was sub sampled for further analysis, with the remainder of the catch returned alive. Fish retained were first anaesthetised using 2-Phenoxyethanol to prevent stress-induced evacuation of the gut and preserved in 4% formaldehyde solution. In the laboratory all fish were identified to species level, counted and measured (fork length) using a pair of Mahr digital callipers.

Dietary analysis

Fish from 2004 were used for the gut analysis due to the fish numbers available and the comparisons that could be made according to various states of the tide. The species used for analysis were restricted to bass and mixed Clupeidae (i.e. sprat/herring) due to their commercial importance, unlike sand goby which have consistently been numerically dominant in most samples.

Guts were removed from individual fish and the length recorded (fork length). Gut fullness (%) was then visually estimated before the contents were mounted on glass slides using ‘Hydramount’, prior to examination using a binocular microscope.
Prey types were identified to broad categories and identification to species level was not undertaken.

Three comparisons of diet composition were made:

(1) Fish that had recently fed within the new intertidal area (sample 8, 2004).
(2) Fish captured entering the site but prior to inundation of vegetated land of the newly developing marsh area (sample 11).
(3) Fish captured in permanently flooded channels during neap tides. (These individuals have no access to either the sea or the vegetated land of the realignment during this part of the tidal cycle sample 13).

Figure 7.2. Aerial image of southern end of Freiston Shore realignment, showing location of the 16 samples conducted during the 2004 fish survey.

7.5.2 Results

During the 2004 survey, a total of nine species and 3833 individuals (Table 7.1) were captured and retained for length analysis. Six species were caught outside the realignment area, on the adjacent established marsh and only one of these species, a single sand smelt, differed from the species captured within the realignment area.

Sample 1: South breach.

Date: 04/08/04	**Sampling Method:** Micromesh seine net
Time: 15:30	**State of tide:** Low water

At the time of this survey, the southern most breach of the sea wall was not functioning properly, with the majority of water entering and leaving the site through the other two breaches. With the exception of the very top of the tide, this resulted in the south breach holding slack water for the majority of the tide.

A seine net was set adjacent to the north bank of this breach and pulled across to the south bank. This was repeated a second time and the catches combined.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Goby	29	15.9	41.1	23.0	0.975
Sprat/Herring	118	25.6	39.2	31.64	0.556
3-spined stickleback	1			17.4	

Samples 2 & 3: Seine net samples, south of the south breach.

Date: 04/08/04	**Sampling Method:** Micromesh seine net
Time: 16:00	**State of tide:** Low water

Two seine nets were deployed across the main creek just south of the southerly most breach. The channel at this point is approximately five metres wide and 50 cm deep. Because of the close proximity of these samples to one another, both catches were combined.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Goby	68	14.2	34.4	22.7	0.789
Bass	4	24.4	29.6	25.9	1.236
Sprat/Herring	21	31.5	64.7	37.6	1.747
Flounder	1			42.2	

Sample 4: Seine net along creek.

Date: 04/08/04	**Sampling Method:** Micromesh seine net
Time: 16:30	**State of tide:** Low water

A seine net was trawled along 50 metres of a small creek running adjacent to the main perimeter channel. At the time of sampling, this creek was approximately 2 m wide and 50 cm deep. The catch consisted of a few bass and large numbers of gobies. Consequently, only 50 percent of the catch was retained.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Bass	4	22.2	29.6	24.4	1.774
Goby	706	16.9	39.2	23.3	1.126

Sample 5: Fyke net, main creek outside the southern end of the realignment area.

Date: 5/8/04	**Sampling Method:** Fyke
Time: 08:50-09:10	**State of tide:** Flooding

A fyke net with leading wings was set across the entire creek at 8:50hrs and left in situ for 20 minutes while the creek flooded. Although many gobies were seen within the creek, the total catch was very disappointing with only one sprat caught. This was not retained and returned alive.

Sample 6: Seine net outside old southern sea wall.

Date: 5/8/04	**Sampling Method:** 20 x 1m seine
Time: 10:00	**State of tide:** High slack water

A longer seine net of 20 x 1m was deployed over a partially vegetated (30%) area not exceeding 50 cm in depth, outside the realignment area. The catch consisted largely of sprat/herring with a single bass and a few goby.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Goby	5	23.4	28.7	25.2	0.914
Bass	1			25.5	
Sprat/Herring	32	28.9	39.5	33.7	0.389

Sample 7: Seine net outside old southern sea wall.

Date: 5/8/04	**Sampling Method:** 20 x 1m seine
Time: 10:20	**State of tide:** High slack water

This sample was carried out in the same way as sample 6 but over a more densely vegetated (80%) and deeper area of water. The catch was again dominated by sprat/herring, although gobies, a single sand smelt and a three-spined stickleback were also captured.

		Fork Length			
Species	No.	Min	Max	Mean	SE
3-spined stickleback	1			28.9	
Sprat/Herring	132	27.3	42.5	34.8	0.584
Goby	15	16.6	29.2	21.9	1.032
Sand smelt	1			41.3	

Sample 8: Seine net sample inside the south wall of the realignment wall

Date: 5/8/04	**Sampling Method:** 10 x 2m seine
Time: 10:40	**State of tide:** High slack water

Seine net deployed over flooded land and beached inside southern sea wall.
This sample covered an area with approximately 30% submerged vegetation and a fairly uniform depth of 1m.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Sprat/Herring	44	26.2	45.6	32.8	0.658
3-spined stickleback	6	26.0	54.2	40.0	3.908
Bass	12	22.0	31.6	27.9	0.877
Goby	20	18.0	41.8	25.7	1.176

Sample 9: Seine net trawl along the west bank, inside the realignment area.

Date: 5/8/04	**Sampling Method:** 20 x 1m seine
Time: 11:00	**State of tide:** High slack water

Working about 20 metres from the west bank, a 20 metre seine net was trawled 60 metres through open water, over flooded land. This encompassed an area with 50% submerged vegetation of 1metre average depth and a surface area of approximately 780 m^2. The catch was dominated by goby, with a single bass and a few sprat/herring also present.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Goby	92	17.2	35.4	24.0	0.360
Sprat/Herring	17	27.7	36.5	32.0	0.561
Bass	1			30.1	

Sample 10: Seine net sample in the middle breach.

Date: 5/8/04	**Sampling Method:** 10 x 1m seine
Time: 13:45	**State of tide:** Ebb

The seine net was set from the boat on a dropping tide and retrieved quickly to the South shore. The depth of this breach was not known but was greater than the 2 metre depth of the net used and consequently will have only been sampled semi efficiently. With the exception of one large flounder (25cm) the rest of the catch was retained for analysis. A further sample was taken at the same location, returning the same species in similar proportions to the first catch. This second sample was discarded with the fish returned alive.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Goby	203	16.5	35.5	23.1	0.849
Flounder	3	44.3	59.6	52.6	4.480
Bass	2	28.6	29.8	29.2	0.605
Sprat/Herring	5	34.2	40.6	36.4	1.158

Sample 11: Fyke net across channel near the middle breach.

Date: 6/8/04	**Sampling Method:** Fyke
Time: 09:10 – 09:40	**State of tide:** Flooding

A fyke net was set across the channel to intercept all fish as they entered the realignment area on the flooding tide. The net was set while the channel was still dry and recovered just as the banks began to overtop and inundate the surrounding land. With the exception of one large flounder (30cm), the rest of the catch, consisting largely of bass and goby, was retained.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Goby	39	25.9	43.6	34.5	0.775
Bass	28	25.6	36.1	29.3	0.405
Flounder	3	37.7	83.3	53.9	14.725

Sample 12: Seine net at the top of the main south channel, within realignment area.

Date: 6/8/04	**Sampling Method:** 10 x 2m seine
Time: 10:10	**State of tide:** High slack water

This sample was taken at the top end of the main south channel, within the realignment area. The channel at this point is approximately eight metres wide and two metres deep. The seine (10 x 2m) was set parallel with the north bank, deployed in an arc and beached adjacent to the sluice gate. Although a sample carried out in the same way during the 2003 survey produced large numbers of goby and three-spined stickleback, the catch this year was disappointing, with only a few gobies and a single flounder caught.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Goby	44	17.3	36.5	22.1	0.787
Flounder	1			62.0	

Sample 13: Seine net sample through the south breach.

Date: 9/8/04	**Sampling Method:** 10 x 2m seine
Time: 15:30	**State of tide:** Neap tides not entering site

Sample taken by running a seine along the length of the south breach.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Sprat/Herring	36	23.3	54.5	31.3	1.129
Goby	86	16.7	32.2	23.1	0.629
Flounder	1			59.1	
Bass	1			31.9	
3-spined stickleback	1			26.8	

Sample 14: Seine net sample, south of the south breach.

Date: 9/8/04	**Sampling Method:** 10 x 2m seine
Time: 16:00	**State of tide:** Neap tides not entering site

A seine net was deployed across the main creek at the same location as sample 2, just south of the southerly most breach. The width of the wetted channel was approximately five metres wide and 30 cm deep during this state of the tide.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Goby	347	15.7	44.2	24.6	1.296
Flounder	8	32.9	76.6	58.7	5.208
Bass	5	18.0	33.9	24.4	2.634

Sample 15: Seine net along creek.

Date: 9/8/04	**Sampling Method:** 10 x 2m seine
Time: 16:30	**State of tide:** Neap tides not entering site

This sample was a repeat of sample 4, with the seine net trawled along 50 metres of a small creek running perpendicular to the main perimeter channel. At the time of sampling, this creek was approximately 2 m wide and 50 cm deep. The catch consisted mainly of goby with a few bass and flounder also present.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Goby	65	18.7	39.4	27.7	1.209
Bass	4	28.3	29.4	28.7	0.255
Flounder	2	44.9	70.0	57.5	12.515

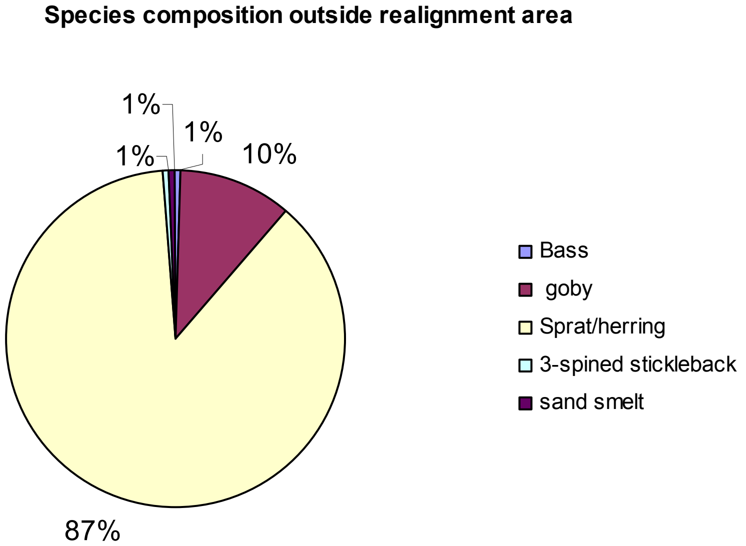
Sample 16: Seine net at top of the main south channel, within realignment area.

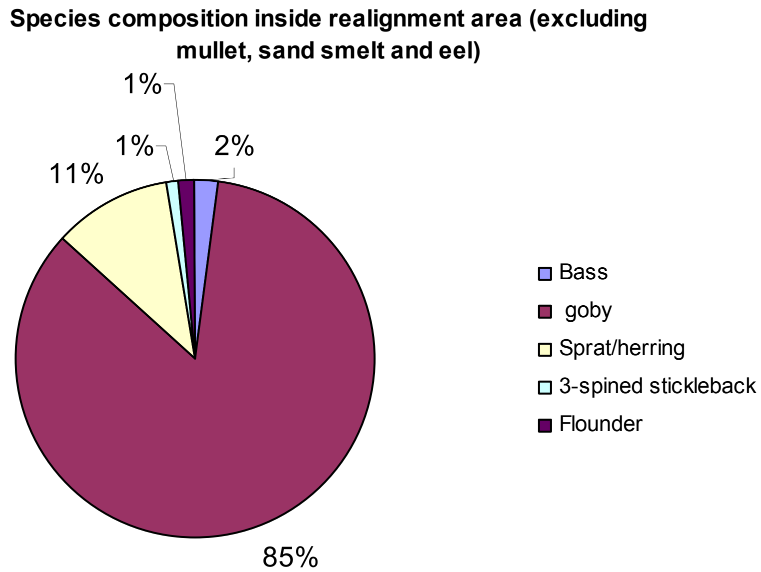
Date: 10/8/04	**Sampling Method:** 10 x 2m seine
Time: 09:30	**State of tide:** Neap tides not entering site

This sample was carried out as a replicate of sample 12. At the time of sampling the depth was no greater than 40 cm. The catch returned two new species to the survey, with single specimens of eel *Anguilla anguilla* and mullet *Mugilidae sp.*

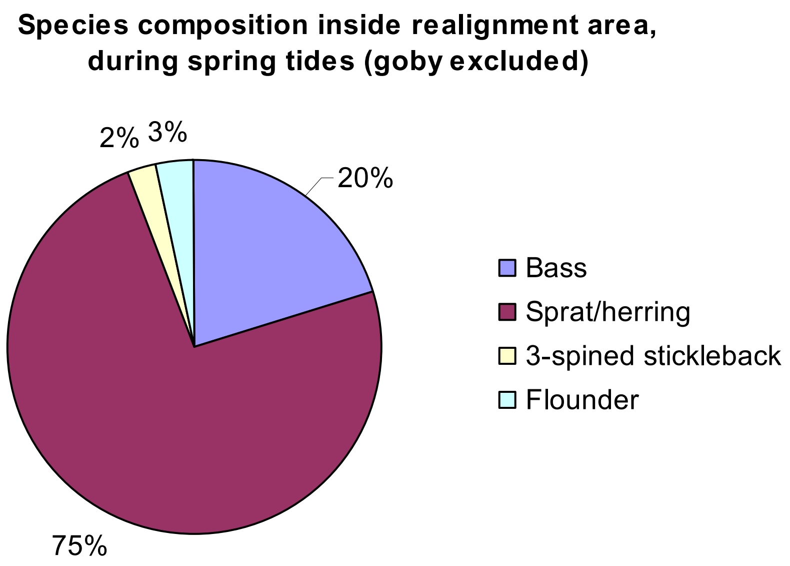
		Fork Length			
Species	No.	Min	Max	Mean	SE
Goby	812	16.6	45.8	25.6	1.261
3-spined stickleback	36	23.2	56.1	33.3	1.058
Bass	18	18.6	39.7	27.9	1.401
Flounder	30	19.5	56.1	29.9	1.621
Mullet	1			48.5	
Eel	1			180.0	

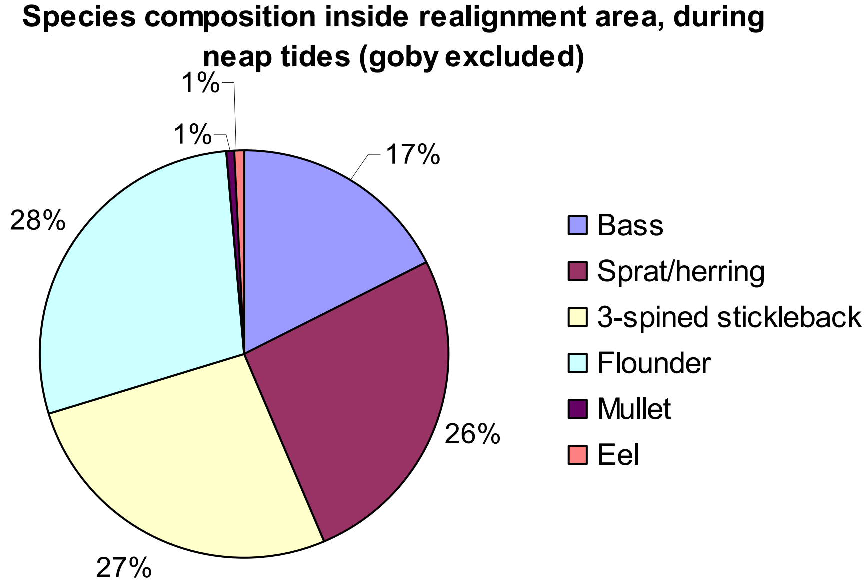
Comparison of relative species composition, both within and outside realignment area





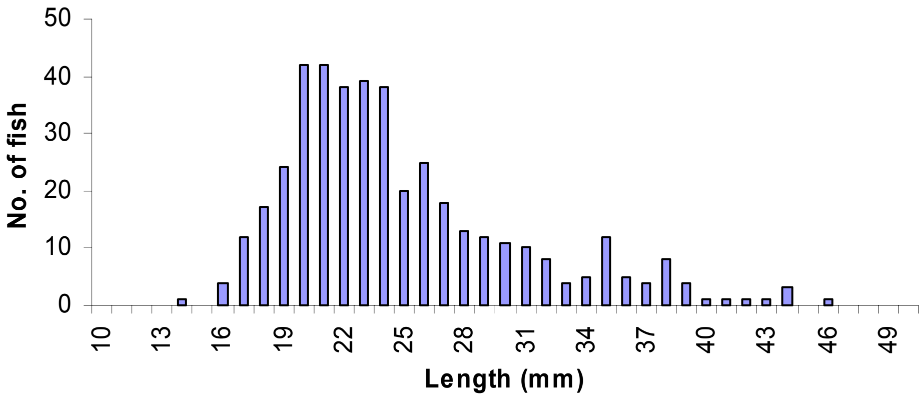
Comparison of relative species composition, between spring and neap tides, within realignment area
(goby excluded from analysis)



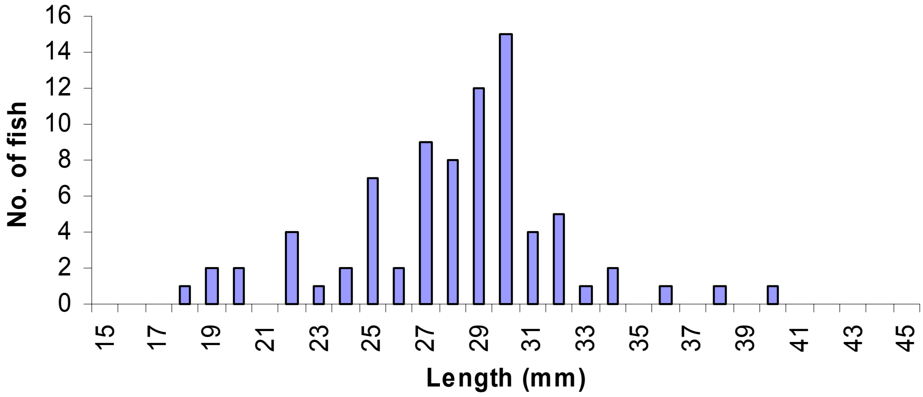


LENGTH FREQUENCY HISTOGRAMS

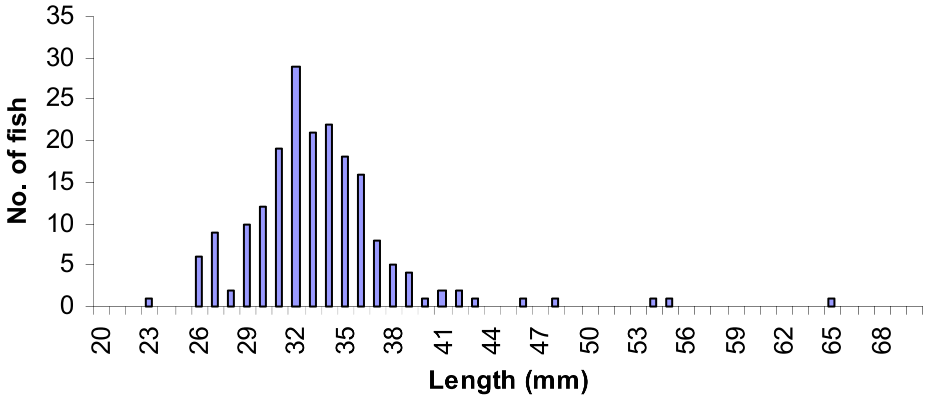
Goby length frequency (all catches combined)



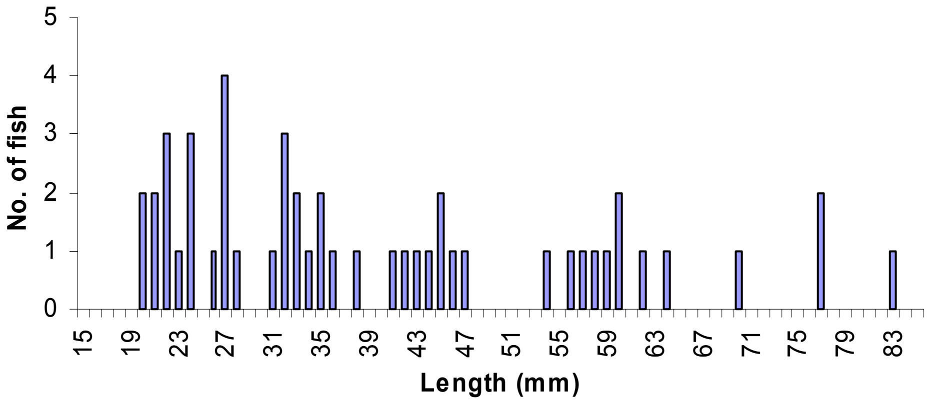
Bass length frequency (all catches combined)



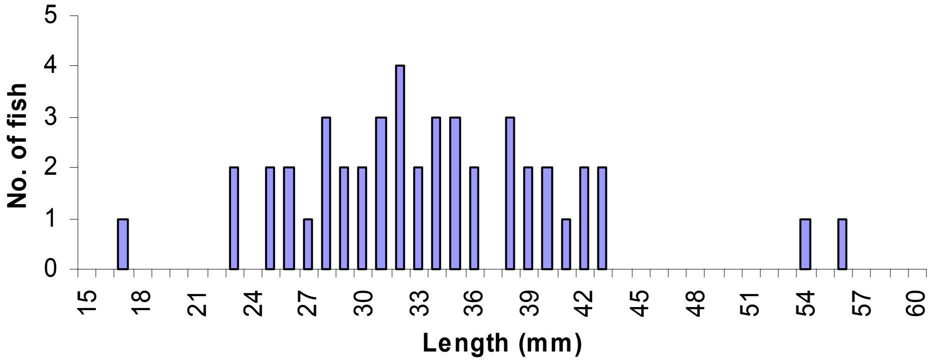
Sprat/herring length frequency (all catches combined)



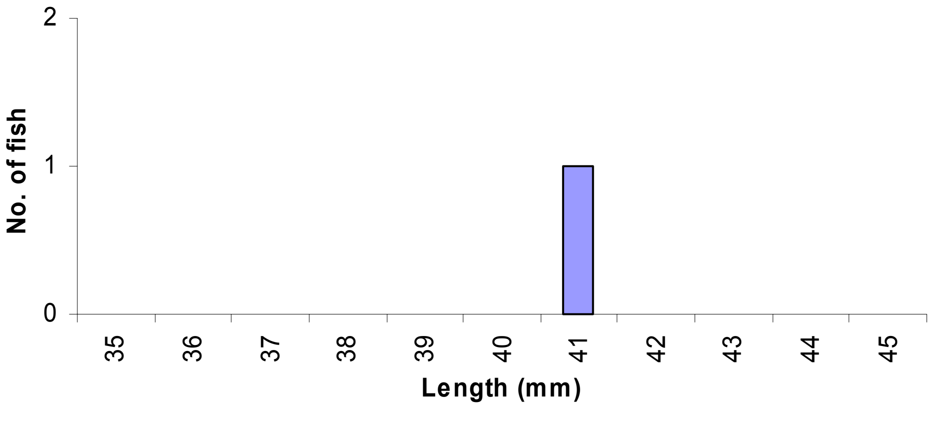
Flounder length frequency (all catches combined)



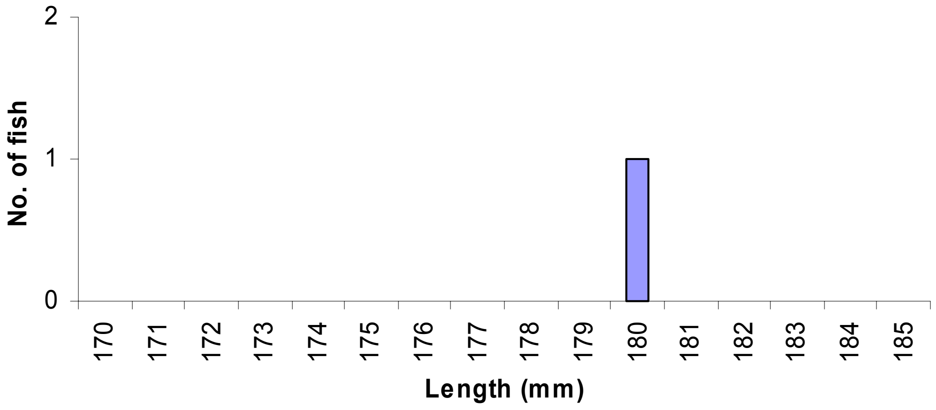
Three-spined stickleback length frequency (all catches combined)



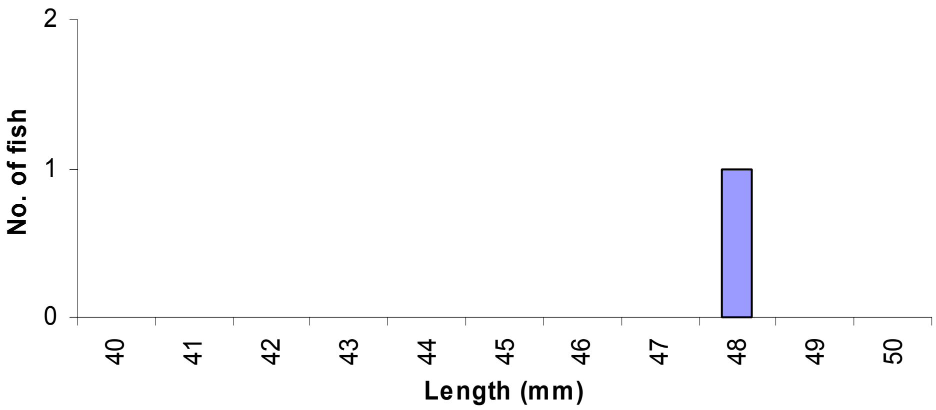
Sand smelt length frequency (all catches combined)



Eel length frequency (all catches combined)



Mullet length frequency (all catches combined)



Dietary analysis

Summary of the 2004 samples used for dietary analysis:

Sample 8: Seine net sample inside the south wall of realignment wall. GPS: TF40165 42795.

Date: 5/8/04	**Sampling Method:** 10 x 2m seine
Time: 10:40	**State of tide:** High slack water

A seine net was deployed over flooded land and beached inside southern sea wall. This sample covered an area with approximately 30% submerged vegetation and a fairly uniform depth of 1m.

Sample 11: Fyke net across channel near the middle breach. GPS: TF40700 43223.

Date: 6/8/04	**Sampling Method:** Fyke
Time: 09:10 – 09:40	**State of tide:** Flooding

A fyke net was set across the channel to intercept all fish as they entered the realignment area on the flooding tide. The net was set while the channel was still dry and it was recovered just as the banks began to overtop and inundate the surrounding land.

Sample 13: Seine net sample through the south breach. GPS: TF40608 49893.

Date: 9/8/04	**Sampling Method:** 10 x 2m seine
Time: 15:30	**State of tide:** Neap tides not entering site

The sample was taken by running a seine along the length of the south breach.

Sprat/herring

The Clupeidae fed mainly on copepods (Table 7.2) with mean numbers exceeding 100 per fish. Ten fish were examined from sample 8, which was taken at the top of the spring tide, thus allowing access to forage the temporarily flooded vegetation of the realignment. Gut fullness was high in these individuals (mean 93%), with high variability between the numbers of copepods in individual fish (130-440, mean 255.5).

The low spring tide (sample 11) failed to yield sprats.

The neap tide sample (sample 13) was taken from the permanently flooded south breach during the few days which excluded access to either the sea or the realignment due to the limited tidal range. The guts of 5 fish were examined from this sample which contained 30-410 copepods (mean 132.2). Gut fullness was lower than those examined during spring tides, ranging between 50-100%, mean 75%) and three of the five fish also contained one or two crab larvae.

Table 7.2: Dietary analysis of Sprat/Herring

Sample No	Fork Length	Gut fullness %	Copepoda	Crab larvae	Ostracod	Sponge fragments	Oligo. fragments
8	33	100	182		6		
8	32	100	190	2			
8	33	80	291		2		
8	32	100	219			present	
8	32	100	130				
8	35	100	440				
8	34	75	173				
8	33	75	213				
8	32	100	398				
8	30	100	319				
	MEAN	**93**	**255.5**	**0.2**			
13	34	100	410	2			
13	27	50	30	2			
13	30	100	157	1			
13	27	50	24				1
13	28	75	40				1
	MEAN	**75**	**132.2**	**1**			

Bass

Bass displayed great variability in gut fullness and contained a wider range of gut contents that sprat captured at the same time. In the majority of fish, copepods were the dominant food resource with crab larvae (2-3mm) being the second most abundant item. Five bass were examined from sample 8, when access to forage the flooded vegetation of the realignment was available. In these five individuals, gut fullness was very variable (5-100%, mean 58%), only one fish had more than 20 copepods (255), one fish contained 4 crab larvae and two contained single (goby) prey items. Two fish had also ingested individual mites.

The gut contents of ten individual bass were examined from sample 11 as they entered the flooding realignment but prior to them gaining access to the flooding vegetated land. Only three of these individuals had gut fullness equal to or exceeding 70%, with copepods abundant in just two fish. Three fish contained one or two crab larvae and another two fish had taken a large mysid shrimp.

The neap tide sample (sample 13) was taken from the permanently flooded south breach during the few days were excluded access either to the sea or the realignment due to the limited tidal range. Only four bass were captured in this sample. Mean gut fullness was 80% and all four fish contained copepods (4-40, mean 15.2). Three fish contained crab larvae, 1-33, mean 11.0) and insect remains were also evident in three individuals.

Table 7.3: Dietary analysis of bass

Sample No	Fork Length	Gut fullness %	Copepoda	Crab larvae	Shrimp larvae	Fish	Mysid	Terr. mite	Terr. insect
8	24	5	5					1	
8	27	100	0			1			
8	23	10	20					1	
8	24	100	255						
8	32	75	2	4		1			
	MEAN	**58**	**56.5**	**0.8**					
11	30	70					1		
11	29	20		2					
11	31	0							
11	29	10			1				
11	28	0							
11	28	70	58						
11	26	0							
11	28	100					1		
11	27	50	69	1					
11	33	50	16		1				
	MEAN	**39**	**14.3**	**0.4**					
13	27	70	12	10					1
13	28	80	5						1
13	28	70	40	1					
13	28	100	4	33					1
	MEAN	**80**	**15.2**	**11**					

7.6 2005 Survey

7.6.1 Methods

Samples of fish were collected both within and outside the realignment site between 19 and 22 August 2005 over the peak of the spring tides. Samples were taken over a range of states of tide, using two main sampling methods. The majority of samples were collected using micromesh beach seines (10 x 2 metres and 20 x 1 metres), deployed either by wading or positioned using a small inflatable boat before retrieving to the shoreline. A fyke net with leading wings was also deployed across creeks both in and outside the realignment in order to catch fishes entering and leaving the salt marsh. Where larval/juvenile fishes could be easily seen in smaller bodies of standing water, a small number of samples were also collected using a targeted approach with a standard dip net.

Where large numbers of fish were caught, the catch was carefully inspected for unusual species and then an estimated proportion of the catch was sub sampled for further analysis, with the remainder of the catch returned alive. Fish retained were first anaesthetised using 2-Phenoxyethanol to prevent stress-induced evacuation of the gut and preserved in 4% formaldehyde solution. In the laboratory all fish were identified to species level, counted and measured (fork length) using a pair of Mahr digital callipers. All samples have been archived for possible future analysis of diet spectrum.

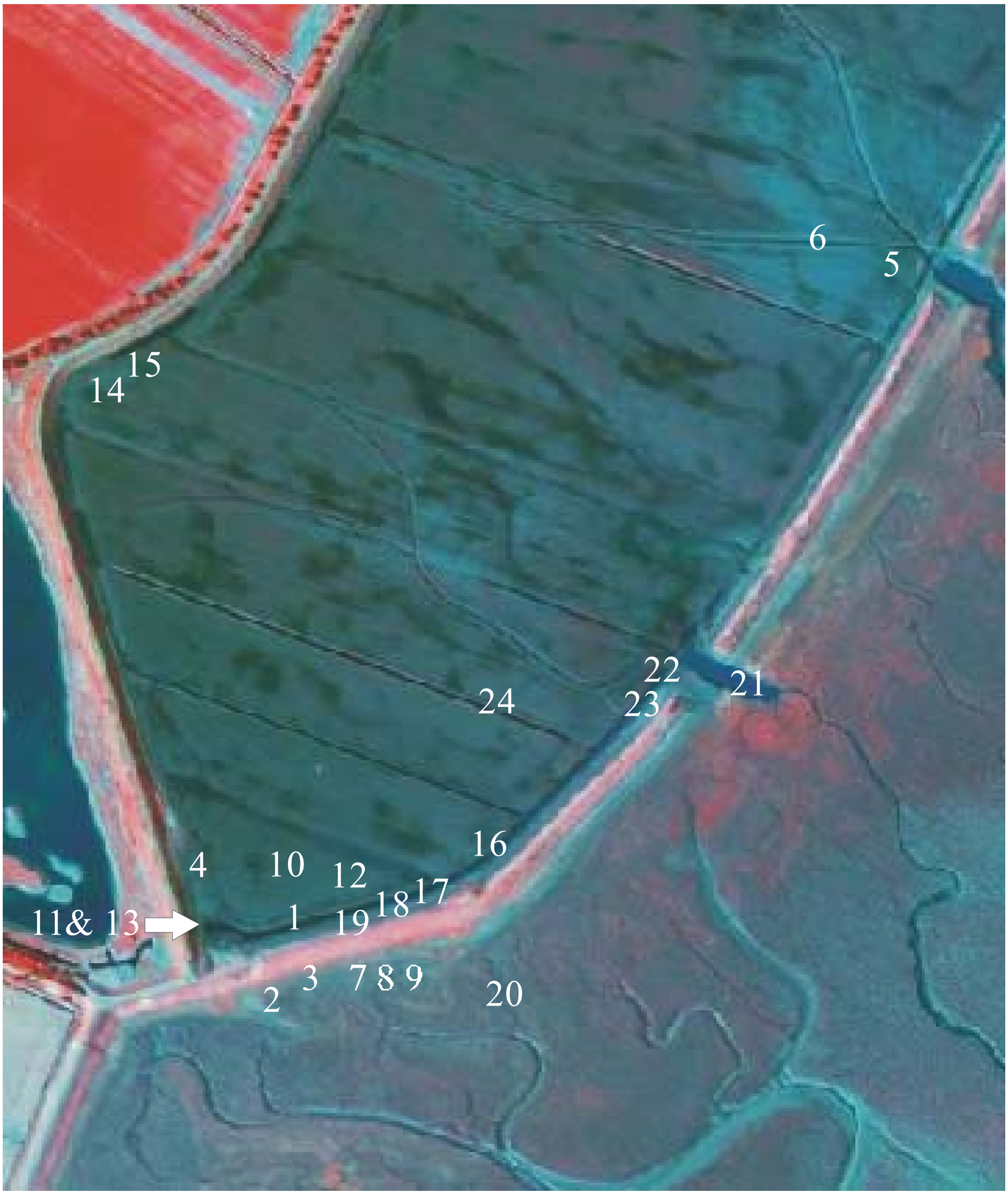


Figure 7.3. Aerial image of southern end of Freiston Shore realignment, showing location of the 24 samples conducted during the 2005 fish survey.

7.6.2 Results

During the 2005 survey, a total of eight species and 3951 individuals (Table 7.1) were captured and retained for length analysis and possible future investigation if diet spectrum. Only two/three species, goby and sprat/herring were caught outside the realignment area, on the adjacent established marsh. These species were also captured within the realignment area. Nilsson's pipe fish *Syngnathus rostellatus* were captured for the first time this year, with two individuals caught in sample 11. This brings the species tally to 12 over the three years that surveys have been carried out.

During the 2005 survey, a total of eight species and 3951 individuals (Table 7.1) were captured and retained for length analysis and possible future investigation if diet spectrum. Only two/three species, goby and sprat/herring were caught outside the realignment area, on the adjacent established marsh. These species were also captured within the realignment area. Nilsson's pipe fish *Syngnathus rostellatus* were captured for the first time this year, with two individuals caught in sample 11. This brings the species tally to 12 over the three years that surveys have been carried out.

Sample 1: South channel.

A fyke net was set across the main south channel at low water and left in place to sample the first 20 minutes of the flooding tide. Due to a disappointing catch, all fish were counted and returned alive.

Date: 19/8/05	**Sampling Method:** Fyke net
Time: 17:40	**State of tide:** Early flood

		Fork Length			
Species	No.	Min	Max	Mean	SE
Bass	1				
Goby	6				
Flounder	1			250	

Samples 2: Seine net sample taken over established marsh outside the realignment.

Date: 20/8/05	**Sampling Method:** Seine (20 x 1m)
Time: 07:00	**State of tide:** High water

A seine net was deployed in an arc across flooded vegetation outside realignment. Maximum depth of water was approximately 75 cm and macrophyte cover was approximately 40%. Only 12 gobies were caught in this sample and all were returned alive.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Goby	12				

Sample 3: Seine net sample taken over established marsh outside the realignment.

Date: 20/8/05	**Sampling Method:** Seine (20 x 1m)
Time: 7:15	**State of tide:** High water

The seine net was deployed in the same manner as sample 2, but a further 50 metres north. Only gobies were caught and the entire catch was preserved for length analysis.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Goby	91	17	29	21.7	0.602

Sample 4: Seine net trawl taken along the west bank, inside realignment area.

Date: 20/8/05	**Sampling Method:** Seine (20 x 1m)
Time: 07:45	**State of tide:** High water

Working about 20 metres from the west bank, a 20 metre seine net was trawled 60 metres through open water, over flooded land. This encompassed an area with 50% submerged vegetation of 1metre average depth and a surface area of approximately 780 m^2. The catch was dominated by goby, with two larval Clupeidae also present.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Goby	20	11	30	19.8	0.942
Sprat/herring	2	23	26	24.5	1.50

Sample 5: Seine net set as a trap across draining land near the middle breach.

Date: 20/8/05	**Sampling Method:** Seine (10 x 2)
Time: 08:30	**State of tide:** Ebb

A shorter seine net of 10 x 2m was held across an area carrying the majority of the flow from a large area of draining land. This blocked access to the sea acting as a trap to fish leaving the realignment area. After 5 minutes the net was inspected and revealed a small catch of gobies and one sprat/herring. This sample was returned alive.

Sample 6: Fyke net set across channel near the middle breach. GPS: TF40700 43223.

Date: 20/8/05	**Sampling Method:** Fyke
Time: 06:15 – 06:45	**State of tide:** Flooding

A fyke net was set across the channel to intercept all fish as they entered the realignment area on the flooding tide. The net was set while the channel was still dry and recovered just as the banks began to overtop and inundate the surrounding land.

Despite the net fishing the channel very efficiently, only one juvenile bass was caught, the rest of the catch consisting of large numbers of gobies. 50% of the sample was retained with the remainder returned alive.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Bass	1			34	
Goby	117	17	45	32.56	1.175

Samples 7, 8 & 9: Three seine net samples were taken at 50 metre intervals along the shore of the established marsh at the southern end of the realignment.

Sample 7: Seine net samples taken over established marsh outside realignment.

Date: 21/8/05	**Sampling Method:** Seine (20 x 1m)
Time: 08:20	**State of tide:** High slack water

The seine net was deployed in an arc across flooded land, along the margins of the established marsh at the southern end of the realignment site. The maximum depth of water was approximately 75 cm and macrophyte cover was approximately 40%.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Sprat/herring	1			42	
Goby	273	12	36	24.33	0.939

Sample 8: Seine net sample, taken 50 metres north of sample 7.

Date: 21/8/05	**Sampling Method:** Seine (20 x 1m)
Time: 08:30	**State of tide:** High slack water

Same methodology employed as sample 7 (50 metres north of sample 7). The maximum depth of water was approximately 60 cm and macrophyte cover was approximately 60%.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Sprat/herring	10	35	52	41.9	1.649
Goby	147	11	33	23.37	0.930

Sample 9: Seine net sample, taken 50 metres north of sample 8.

Date: 21/8/05	**Sampling Method:** Seine (20 x 1m)
Time: 08:45	**State of tide:** High slack water

Same methodology employed as samples 7 & 8, a further 50 metres north of sample 8. The maximum depth of water was approximately 70 cm and macrophyte cover was approximately 50%.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Sprat/herring	38	34	57	42.2	0.724
Goby	191	14	38	22.1	0.772

Sample 10: Seine net sample taken over flooded land, inside realignment.

Date: 21/8/05	**Sampling Method:** Seine net (10 x 2m)
Time: 09:20	**State of tide:** Ebbing

A seine net was set from the boat, deployed in a circle and retrieved back into the boat. Only one goby was caught and this was returned alive.

Sample 11: Seine net at top of main south channel, within the realignment area.

Date: 21/8/05	**Sampling Method:** Seine net (10 x 2m)
Time: 10:20	**State of tide:** Ebbing

This sample was taken at the top end of the main south channel, within the realignment area. The channel at this point was approximately eight metres wide and two metres deep. The seine (10 x 2m) was set parallel with the north bank, deployed in an arc and beached adjacent to the sluice gate. At this point of the tide, the water was just dropping within the banks of the channel. This produced four species including two Nilsson's pipe fish, *Syngnathus rostellatus*, a new addition to the species tally at Freiston Shore.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Goby	55	15	32	23.9	0.724
3-spined stickleback	8	26	35	30.25	1.048
Pipe fish	2	43	51	47.0	4.0
Mullet	1			74	

Sample 12: Fyke net set across draining land within the realignment.

Date: 21/8/05	**Sampling Method:** Fyke net
Time: 08:00 – 10:30	**State of tide:** Ebbing

The fyke net with the leading wings set to provide an entrance 25 metres wide was set at 8 am, prior to the site being flooded. The net was then left in place to sample the entire ebb between 08:00 and 10:30 hours, as the site drained. The catch was disappointing with only a few gobies and large numbers of crabs caught. The entire catch was returned alive.

Sample 13: Repeat of sample 11. Seine net set at top of the main south channel, within the realignment area.

Date: 21/8/05	**Sampling Method:** Seine net (10 x 2m)
Time: 11:00	**State of tide:** Standing water in drained channel

This sample was taken at the top end of the main south channel, within the realignment area and was a repeat of sample 11 at a later state of the tide. The majority of water had already drained from the channel and the maximum water depth was only 60 cm.

This time large numbers of goby were caught along with three juvenile bass and a single stickleback. Only 25% of the gobies were retained, with the remainder released unharmed.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Goby	520	15	40	23.76	1.016
Bass	3	31	35	33	1.155
3-spined stickleback	1			16	

Sample 14: Dip net sample targeting surface swimming larvae

Date: 21/8/05	**Sampling Method:** Dip net
Time: 11:45	**State of tide:** Low tide

Several areas of impounded water remain in the realignment site at low tide. Samples 14 & 15 were carried out in a channel running along the west fence. Larvae could be easily seen swimming near the surface and these were captured using a standard dip net. These larvae were found to be young gobies and were incorporated into sample 15 which sampled the channel more extensively with the use of a seine net.

Sample 15: Seine net sample of impounded channel.

Date: 21/8/05	**Sampling Method:** Seine net (10 x 2m)
Time: 12:00	**State of tide:** Low tide

Large numbers of fish were caught using a 10 x 2 metre seine net in the same area sampled for sample 14. Maximum depth was only 60 cm and only 20% of the sample was retained, with the remaining 80% released unharmed.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Goby	862	13	41	25.2	1.266
Bass	1			36	
Sprat/herring	43	23	57	35.36	1.187

Sample 16: Fyke net in flooding south channel, within the realignment.

Date: 22/8/05	**Sampling Method:** Fyke net
Time: 06:50 – 07:00	**State of tide:** Flooding

A fyke net was positioned within the main south channel before the flooding tide had entered the realignment area. Although the water velocity was rapid with the water level also increasing quickly, the net fished the rising tide effectively and remained in place for the first 10 minutes of the flood before being retrieved. The catch consisted of goby and stickleback, with the latter being heavily infested with blackspot.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Goby	957	13	44	28.23	1.317
3-spined stickleback	5	22	35	29.8	2.154

Sample 17: Seine net along margins of southern defence within the realignment

Date: 22/8/05	**Sampling Method:** Seine net (10 x 2m)
Time: 07:50	**State of tide:** Flooding

A seine net was trawled 20 metres along rapidly flooding land adjacent to the southern wall of the realignment. The maximum depth of water during this sample was approximately 50 cm and the substratum was covered with dense Samphire (Annual Glasswort, *Salicornia europaea*).

		Fork Length			
Species	No.	Min	Max	Mean	SE
Goby	3	18	22	19.66	1.202
Sprat/herring	3	25	40	33.33	4.409

Sample 18 & 19: Combined seine net catches along margins of southern defence within the realignment.

Date: 22/8/05	**Sampling Method:** Seine net (10 x 2m)
Time: 08:00 – 08:15	**State of tide:** Flooding

Samples 18 and 19 were carried out in the same manner as sample 17 with the net trawled over dense Samphire as the tide continued to rise. The maximum depth of water was approximately 75 cm. As these samples were taken in close proximity of one another, the catches were combined.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Goby	26	16	30	22.46	0.673
Bass	1			22	
3-spined stickleback	1			30	
Sprat/herring	23	27	52	38.86	1.542

Sample 20: Fyke net set in creek on established marsh outside the realignment

Date: 22/8/05	**Sampling Method:** Fyke net
Time: 10:40	**State of tide:** Ebbing

A fyke net was set at low tide prior to the marsh flooding, to sample the ebb. The net was positioned in one of the smaller channels outside the realignment area and recovered after the tide had subsided. Although the net stayed in position and fished effectively there was no catch from this sample.

Sample 21: Seine net in the south breach

Date: 22/8/05	**Sampling Method:** Seine net (10 x 2m)
Time: 15:30	**State of tide:** Low tide

The south breach was sampled with a 10 x 2 metre seine net after the site had drained. The catch returned a small number of gobies, which were promptly released. Due to consistently disappointing catches from this area it had been assumed that the water in the breach was deeper than the 2 metre seine. On this occasion the depth was checked with the use of a fishing rod and plumb line. This revealed the true depth of the south breach to be seven metres at low tide and thus impossible to sample effectively with the use of seine nets.

Sample 22: Seine net in pool just south of the south breach

Date: 22/8/05	**Sampling Method:** Seine net (10 x 2m)
Time: 15:40	**State of tide:** Low tide

The seine net was set pulled through an impounded pool of standing water, where the depth did not exceed 50 cm. The catch was dominated by goby with two sprat/herring and a single bass also captured.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Goby	24	16	36	24.083	0.947
Bass	1			38	
Sprat/herring	2	33	35	34	1.0

Sample 23: Seine net in pool just south of sample 22.

Date: 22/8/05	**Sampling Method:** Seine net (10 x 2m)
Time: 15:45	**State of tide:** Low tide

This sample was carried out in the same manner as sample 22 but in the next pool immediately south of the last sample. This time, large numbers of goby were captured, along with good numbers of sprat/herring, a few bass and a single stickleback.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Goby	306	15	38	24.23	1.017
Bass	13	17	43	30.23	2.131
Sprat/herring	47	34	71	51.06	2.100
3-spined stickleback	1			28	

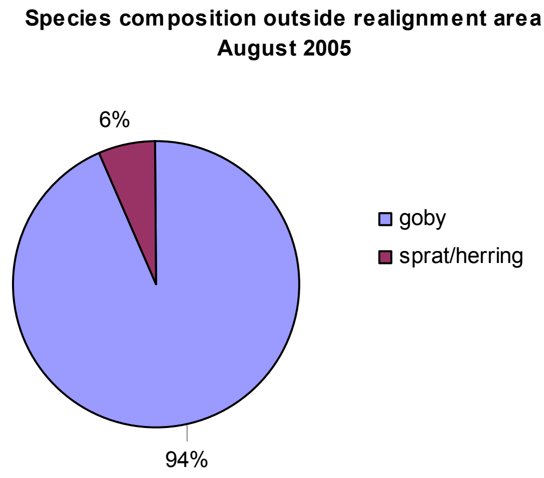
Sample 24: Seine net trawled up partially flooded ditch within the realignment.

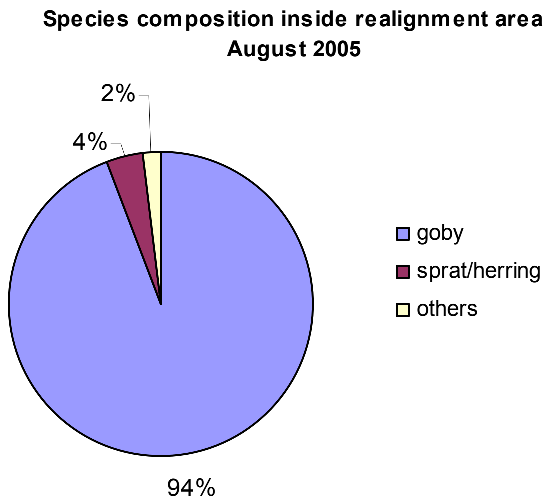
Date: 22/8/05	**Sampling Method:** Seine net (10 x 2m)
Time: 16:00	**State of tide:** Low tide

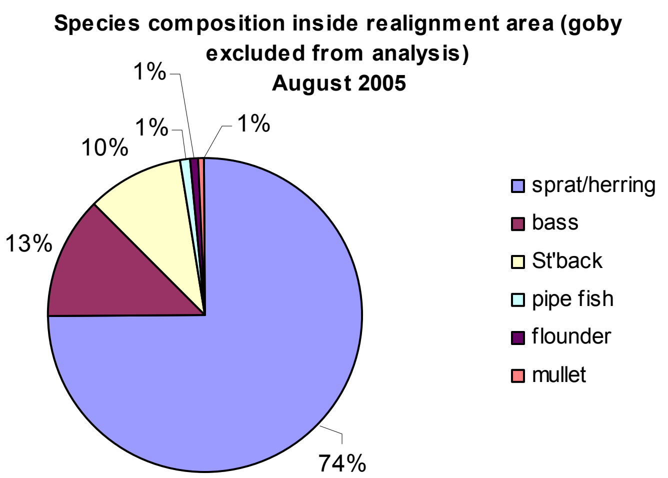
A seine net was trawled along 50 metres of a small creek running perpendicular to the main perimeter channel. At the time of sampling, this creek was approximately 2 m wide and 50 cm deep. The catch consisted of goby with a single flounder also present.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Goby	124	14	42	25.13	1.304
Flounder	1			72	

Comparison of relative species composition, both within and outside realignment area

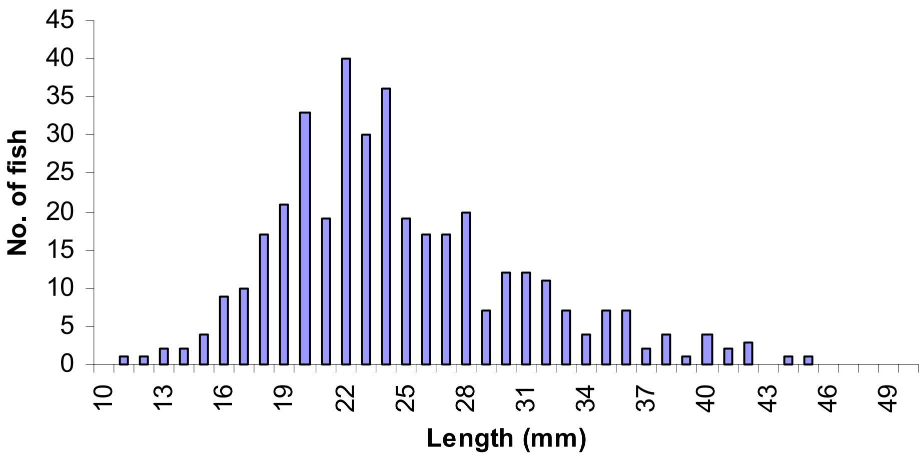




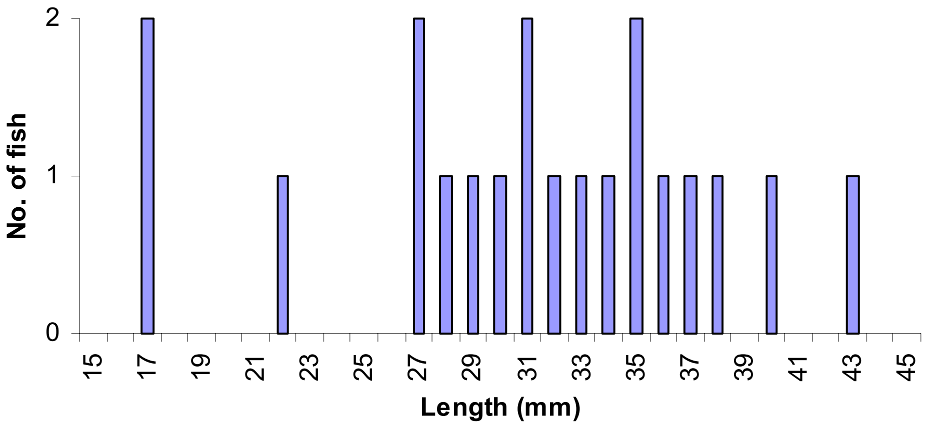


LENGTH FREQUENCY HISTOGRAMS

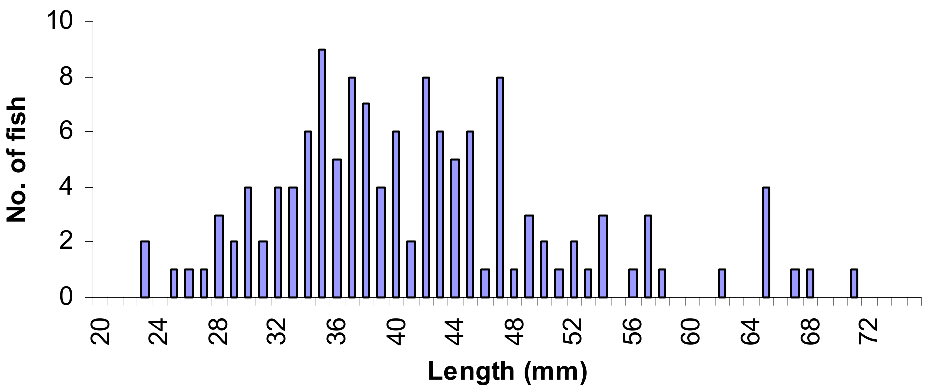
Goby length frequency (all catches combined)



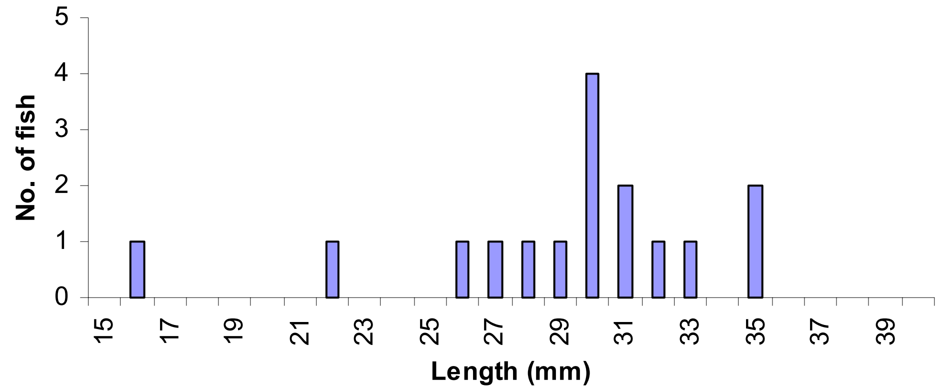
Bass length frequency (all catches combined)



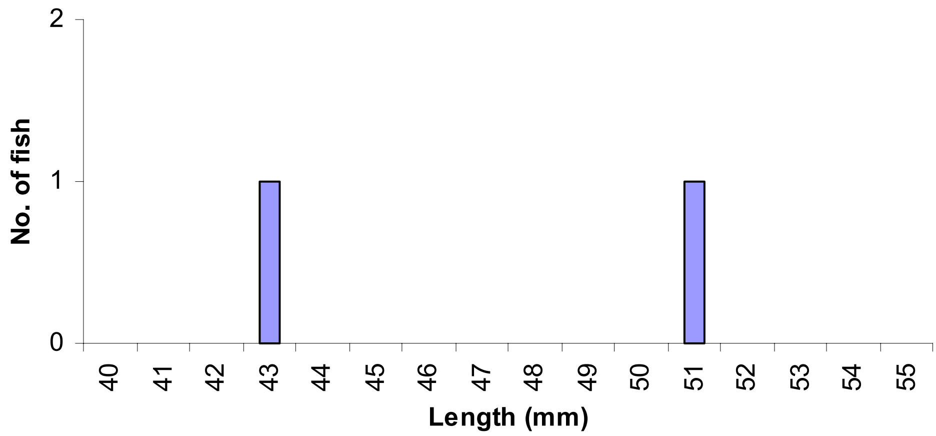
Sprat/herring length frequency (all catches combined)



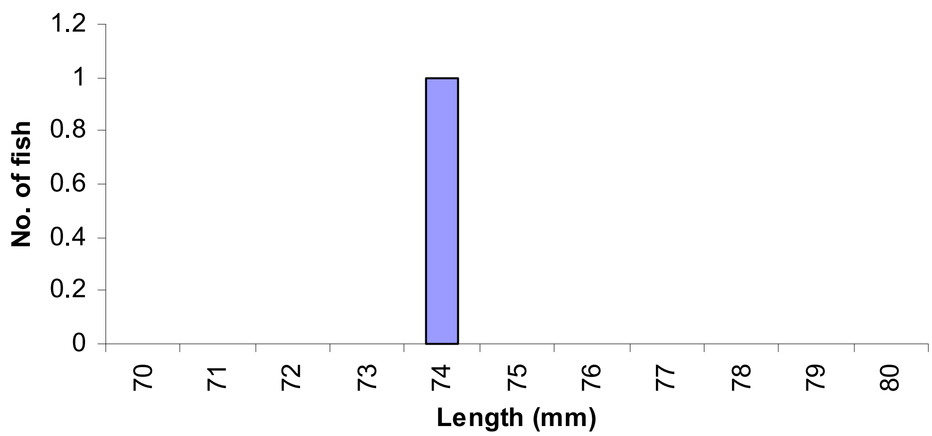
Three-spined stickleback length frequency (all catches combined)



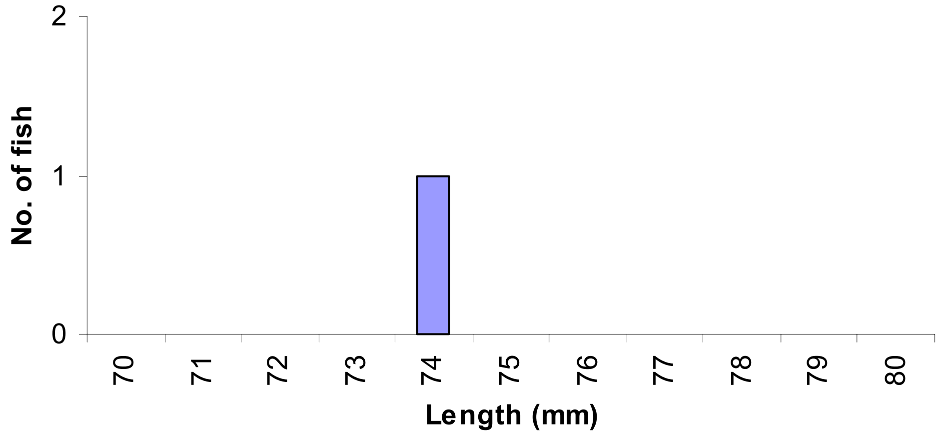
Pipe fish length frequency (all catches combined)



Flounder length frequency (all catches combined)



Mullet length frequency (all catches combined)



7.7 2006 Survey

7.7.1 Methods

Samples of fish were collected both within and outside the realignment site between 13 and 15 August 2006 (Fig 7.1). Samples were taken over a range of states of tide, using several sampling methods. The majority of samples were collected using micromesh beach seines (10 x 2 & 25 x 2.5metres), deployed either by wading, or set using a small inflatable boat and retrieved to the shoreline. Fyke nets were also used to catch fishes both entering and leaving the creeks at a variety of locations within the realignment. These were either set at low tide to collect fish entering the site, or pegged out at low tide, in a manner that would allow the rising water to flow around the traps and then sample fish leaving the site on the ebbing tide later in the day. Where fish larvae were observed in margins and ponded areas, these were targeted with the use of a dip net.

Where large numbers of fish were caught, the catch was carefully inspected for unusual species and then an estimated proportion of the catch was sub sampled for further analysis with the remainder of the catch returned alive. Fish retained were first anaesthetised using 2-Phenoxyethanol to prevent stress-induced evacuation of the gut and preserved in 4% formaldehyde solution. Back at the laboratory all fish were identified to species level, counted and measured (fork length). All samples have been archived for possible future analysis of diet spectrum.

Figure 7.4. Aerial image of southern end of Freiston Shore realignment, showing location of the 24 samples conducted during the 2006 fish survey.

7.7.2 Results

Sample 1: Wheel Pool, at top of the main South channel. GPS: TF4293 42222

Date: 13/8/06	**Sampling Method:** Seine net (10 x 2m)
Time: 13:00	**State of tide:** Low

With the site draining, only a narrow channel remained below the wheel pool, with a small area of deeper water (<40cm) adjacent to the sluice gate. The seine was pursed in the deeper area and returned a large number of goby and three-spined stickleback.
Only 20% of the sample was retained with the rest returned alive.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Goby	1200	12.3	38.6	25.84	1.339
3-Spined stickleback	45	26.4	32.5	29.2	0.665

Sample 2: Flooded pond on the western side of the realignment. GPS: TF40297 42754

Date: 13/8/06	**Sampling Method:** Dip net
Time: 13:20	**State of tide:** Low

Flooded pond near western inner wall. Large numbers of small juveniles were observed swimming near the surface and were targeted with a pond net.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Goby	6	9.4	11.9	10.9	0.388

Sample 3. Seine net sample in the same pond as sample 2. GPS: TF40268 42742

Date: 13/8/06	**Sampling Method:** Seine net (10 x 2m)
Time: 13:30	**State of tide:** Low

Flooded pond near the western inner wall: thousands of gobies of all size classes were observed in this pond while the net was being dragged through the water. Due to the high density of this species only 10% of goby were retained. A single sprat/herring and Nilsson's pipefish were also caught in this sample.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Goby	300	17.6	43.9	30.6	1.234
Sprat/herring	1			27.3	
Pipe fish	1			53.5	

Sample 4. Seine net sample in adjacent pond to the North of samples 2 & 3.
GPS: TF40349 42823

Date: 13/8/06	**Sampling Method:** Seine net (10 x 2m)
Time: 13:50	**State of tide:** Low

Flooded pond near the western inner wall: using a 10 x 2 metre seine, the net was trolled for a distance of 10 metres through a water depth of approximately 50 cm. Again, large numbers of goby were present in this pond along with small numbers of bass, sprat/herring and stickleback. Only 10% of goby and stickleback were retained.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Goby	250	13.8	40.6	28.3	1.382
3-Spined stickleback	120	27.7	38.5	32.9	0.864
Sprat/herring	2	27.4	30.2	28.8	1.425
Bass	2	38.1	38.6	38.4	0.27

Sample 5. Fyke net set in channel near the South breach. GPS: TF40637 42434

Date: 14/8/06	**Sampling Method:** Fyke net
Time: 08:00-14:10	**State of tide:** Set at low tide to sample the next ebb

The net was set at low tide and secured in place to sample the next ebb. The net was retrieved at 14:10 with the catch consisting of sprat/herring, smelt, pipe fish, bass and goby.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Goby	1			25.7	
Smelt	5	59.9	78.7	66.5	4.370
Sprat/herring	84	30.6	71.6	45.5	1.812
Bass	7	33.2	50.6	41.9	2.558
Pipe fish	27	41.5	88.3	60.5	2.705

Sample 6. Wheel Pool, top of the main South channel. GPS: TF4293 42222

Date: 14/8/06	**Sampling Method:** Seine net (10 x 2m)
Time: 08:40	**State of tide:** Rising (still within channel banks)

At the time of sampling the water depth was approximately 1.25 metres. Despite the seine net fishing well through the pool, the catch was very poor, with just a few goby and a single stickleback returned alive.

Sample 7. Outside the southern wall of the realignment. GPS: TF40374 42171

Date: 14/8/06	**Sampling Method:** Seine net (25 x 2.5m)
Time: 09:40	**State of tide:** High water

The large seine net was set over dry land, parallel and approximately 50 metres on the Wash side of the outer defence wall. As the tide rose the net was held in place until the densely vegetated land was inundated to a depth of approximately 0.75 metres. The net was then drawn in an arc to the sea wall. The catch consisted of just a few sprat/herring.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Sprat/herring	7	26.1	49.5	31.0	3.11

Sample 8. Outside southern wall of the realignment. GPS: TF40386 42199

Date: 14/8/06	**Sampling Method:** Seine net (10 x 2m)
Time: 09:50	**State of tide:** High water

At the peak of high tide a 10 x 2 metre seine was trawled for a distance of 10 metres parallel with the south bank. The ground here was very densely vegetated, and mean water depth was approximately 0.75 metres. The catch consisted of large sprat/herring, 2 goby and 2 bass.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Sprat/herring	8	47.3	55.3	50.4	0.296
Goby	2	21.9	34.2	28.1	6.105
Bass	2	33.0	51.7	42.3	9.335

Sample 9. Outside southern wall of the realignment. GPS: TF40386 42199

Date: 14/8/06	**Sampling Method:** Seine net (10 x 2m)
Time: 10:00	**State of tide:** High water

This sample was carried out over the same habitat type and in the same manner as sample 8, although slightly further north along the sea wall. The catch consisted of large sprat/herring, 2 goby and 2 bass.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Sprat/herring	24	28.6	56.8	41.5	1.801
Goby	2	32.5	58.5	29.3	3.285
Bass	2	45.3	46.4	45.8	0.545

Sample 10. Flooded land on the West side of site GPS: TF40262 42338

Date: 14/8/06	**Sampling Method:** Seine net (10 x 2m)
Time: 10:30	**State of tide:** High water

This sample taken over flooded land, 200 metres north of wheel pool. The seine net was set from the boat approximately 20 from an area of dry land onto which the net was retrieved. The water depth was approximately 50-75 cm deep and the area was densely vegetated. Species captured included bass, sprat/herring and goby.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Sprat/herring	6	32.4	57.7	47.5	3.412
Goby	2	11.4	31.3	21.3	9.950
Bass	2	36.1	50.4	43.3	7.115

Sample 11. South wall GPS: TF40503 42253

Date: 14/8/06	**Sampling Method:** Seine net (10 x 2m)
Time: 10:50	**State of tide:** High water

A seine net was set from the boat to fish across the main south channel and surrounding flooded land. The net was retrieved to the south bank after being pulled through water of varying depths (<3 m) with bare mud substrate within the confines of the channel, with dense vegetation on the flooded land. Only sprat/herring and goby were caught.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Sprat/herring	21	20.8	43.8	34.1	1.349
Goby	3	15.9	37.9	29.6	6.918

Sample 12. South wall GPS: TF40538 42259

Date: 14/8/06	**Sampling Method:** Seine net (10 x 2m)
Time: 11:05	**State of tide:** High water (beginning to ebb)

A repeat of sample 11, slightly further east toward the southern breach. Bass, sprat and goby were caught.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Bass	3	41.5	46.3	43.4	1.394
Sprat/herring	5	35.2	51.4	43.2	3.120
Goby	1			29.8	

Sample 13 & 14. South channel near the south breach GPS: TF40694 42442

Date: 14/8/06	**Sampling Method:** Seine net (10 x 2m)
Time: 15:00	**State of tide:** Low water

Two seine net samples with catches combined at the bottom end of the south channel near the south breach. The first attempt to pull the seine through a deeper pool resulted in the net snagging and so, was repeated a second time. A large number of goby were captured and returned alive. A single bass was retained for possible future dietary analysis.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Bass	1			50.8	

Sample 15. South channel GPS: TF40668 42409

Date: 14/8/06	**Sampling Method:** Seine net (10 x 2m)
Time: 15:10	**State of tide:** Low water

Seine net across South channel. Only goby and shrimp caught. All catch returned.

Sample 16. South channel GPS: TF40503 42255

Date: 15/8/06	**Sampling Method:** Fyke net
Time: 09:10-09:20	**State of tide:** Flooding

A fyke net was set across the South channel just prior to the sea entering the site. Within 10 minutes the depth had increased from 0 to 1.25 metres and the net was retrieved to dry land. Only goby were captured and all were released alive.

Sample 17. Inside South wall GPS: TF40423 42226

Date: 15/8/06	**Sampling Method:** Seine net (10 x 2m)
Time: 10:20	**State of tide:** Flooding

The sample was taken over flooding land within minutes of inundation. The substrate was covered with dense macrophytes and water depth did not exceed 30 cm. Although gobies were seen in the area the sample returned no catch.

Sample 18. Inside South wall GPS: TF40423 42226

Date: 15/8/06	**Sampling Method:** Seine net (10 x 2m)
Time: 10:40	**State of tide:** Flooding

This sample was taken in the same location as sample 17 although depth had increased to 45 cm. Again, no fish were captured.

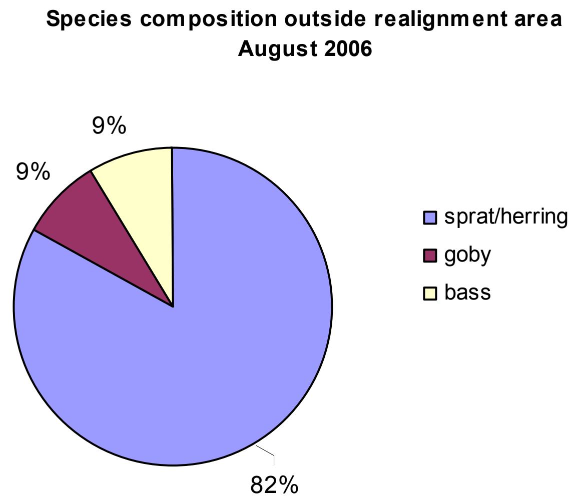
Sample 19. Inside South wall GPS: TF40423 42226

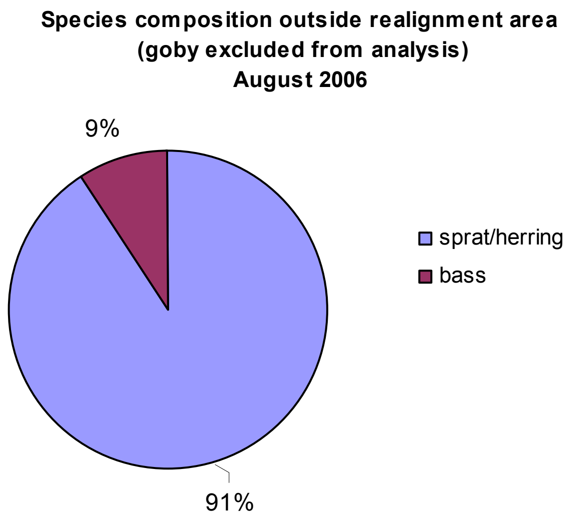
Date: 15/8/06	**Sampling Method:** Seine net (10 x 2m)
Time: 11:00	**State of tide:** Peak of high tide

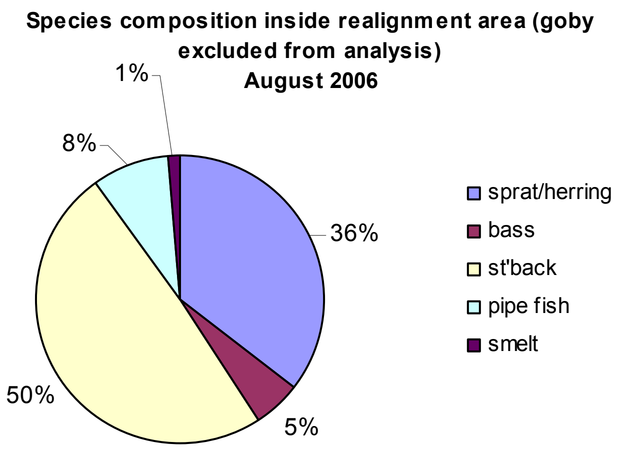
Another repeat of samples 17 and 18 when the water had reached its maximum depth of 60 cm. This time 2 bass were captured and retained for possible future dietary analysis.

		Fork Length			
Species	No.	Min	Max	Mean	SE
Bass	1	19.8	41.3	30.6	10.745

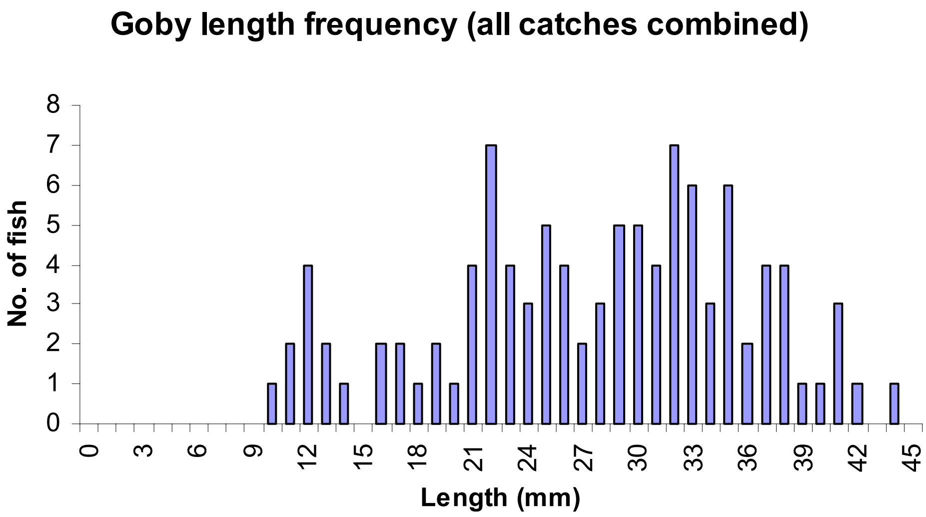
Comparison of relative species composition, both within and outside realignment area

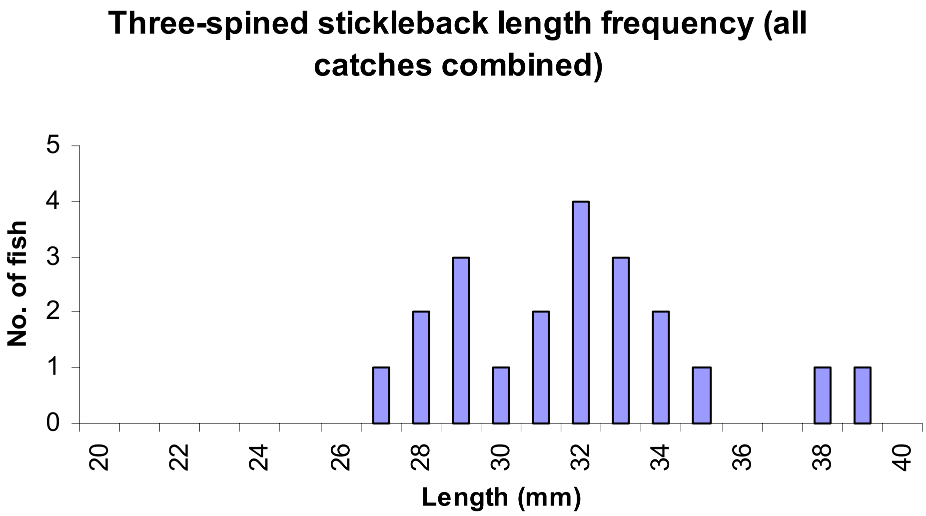


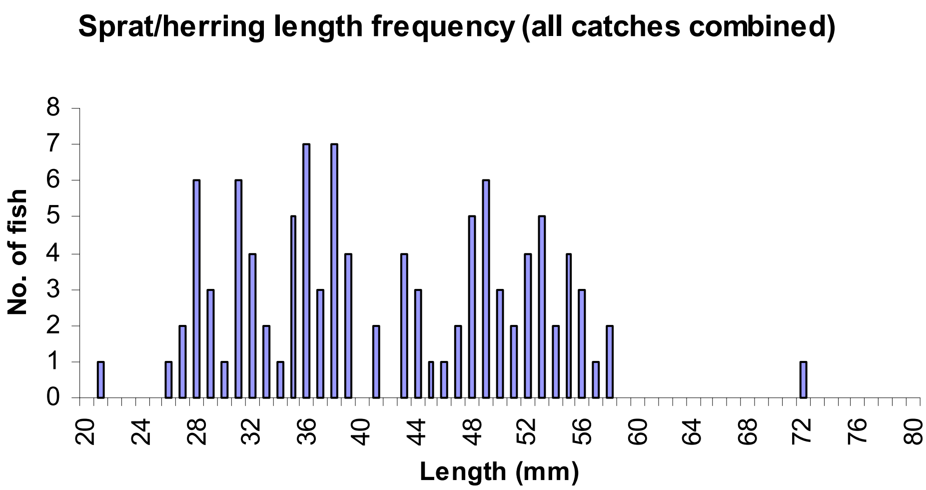




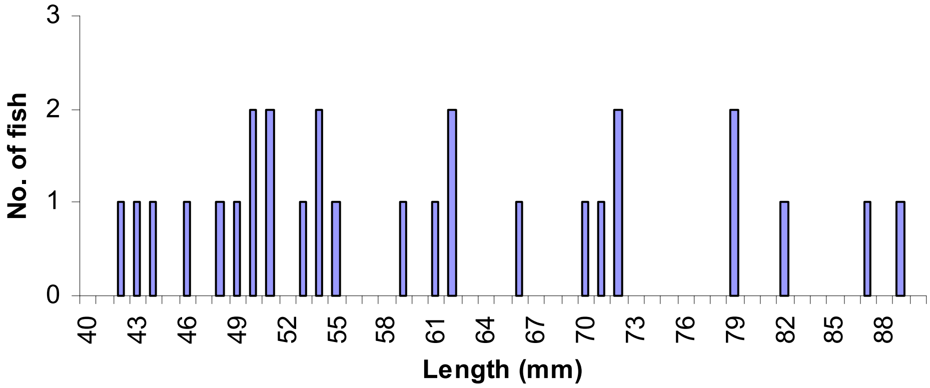
LENGTH FREQUENCY HISTOGRAMS



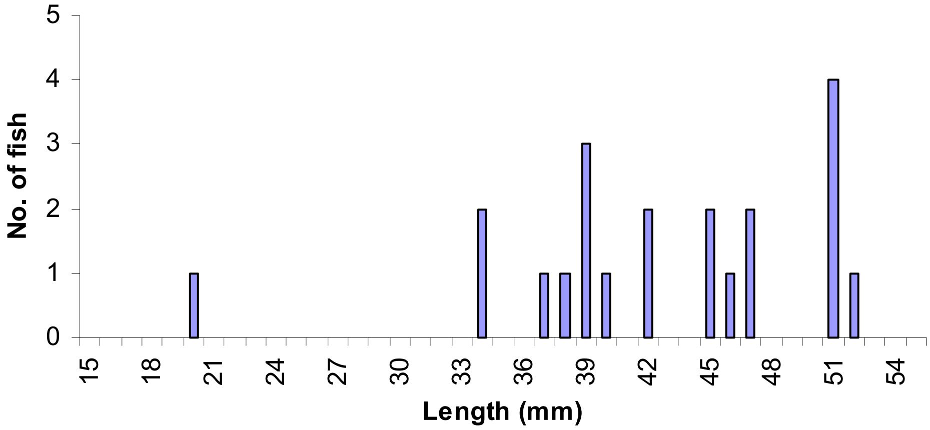




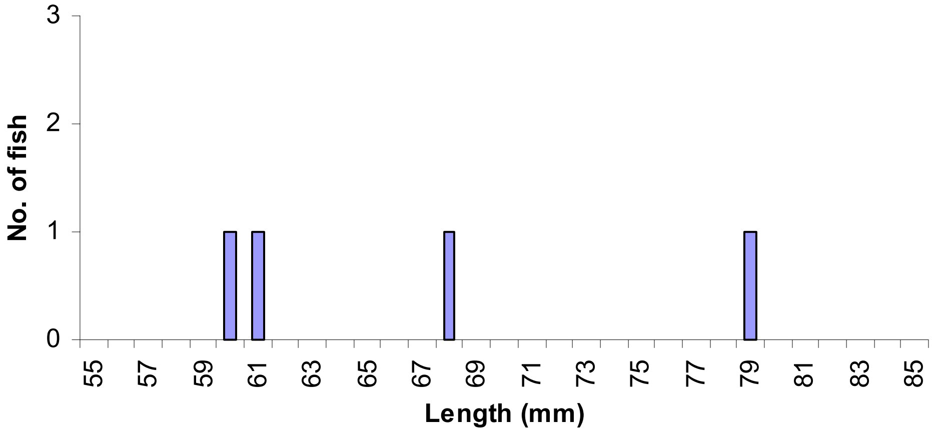
Nilsson's pipe fish length frequency (all catches combined)



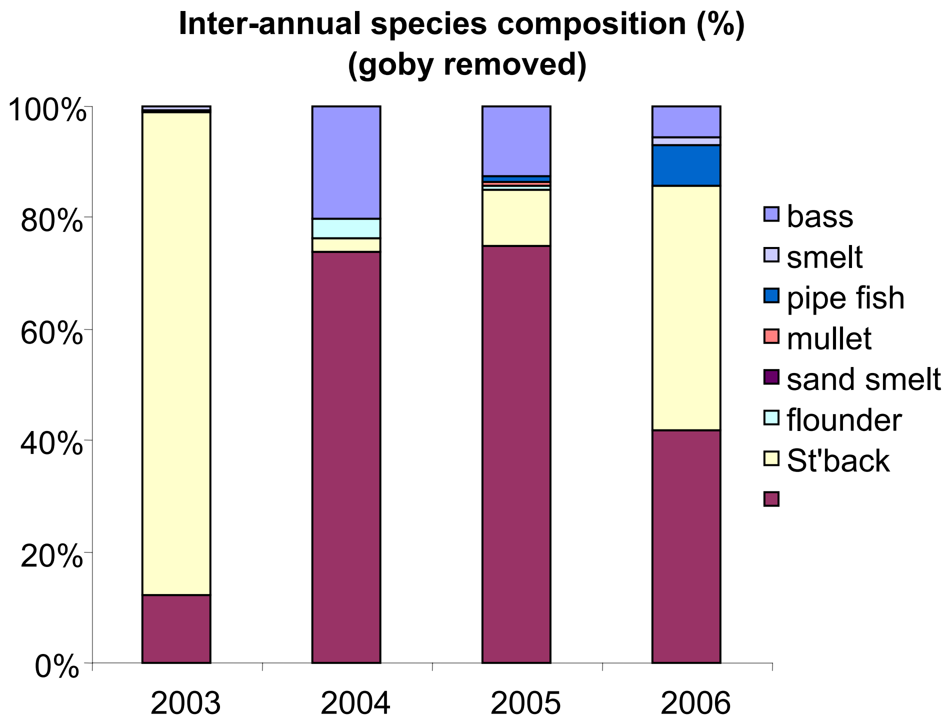
Bass length frequency (all catches combined)



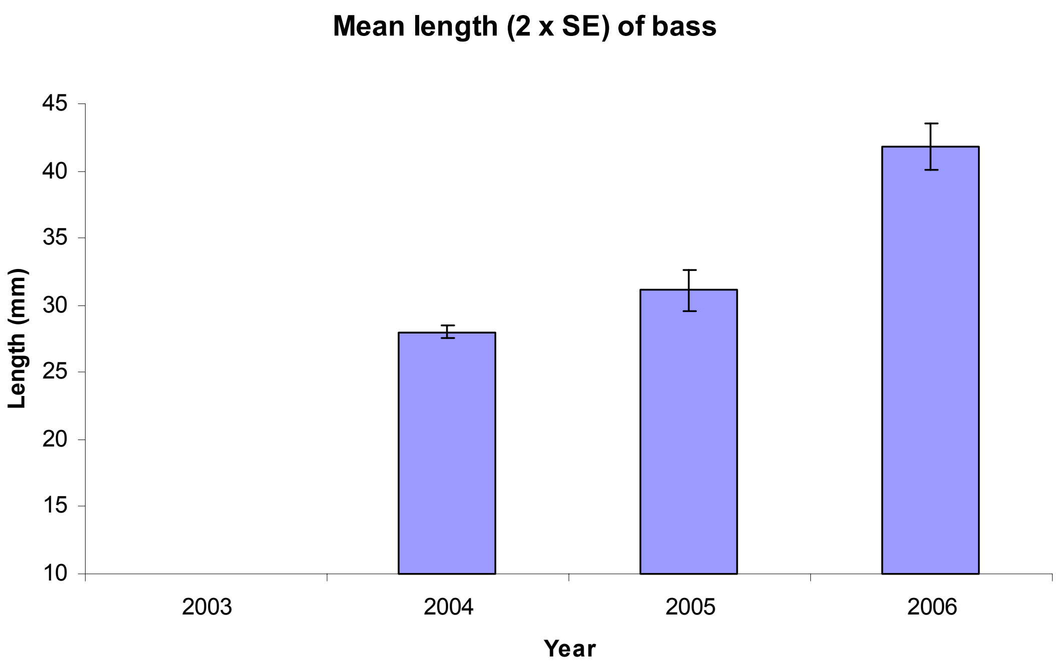
Smelt length frequency (all catches combined)

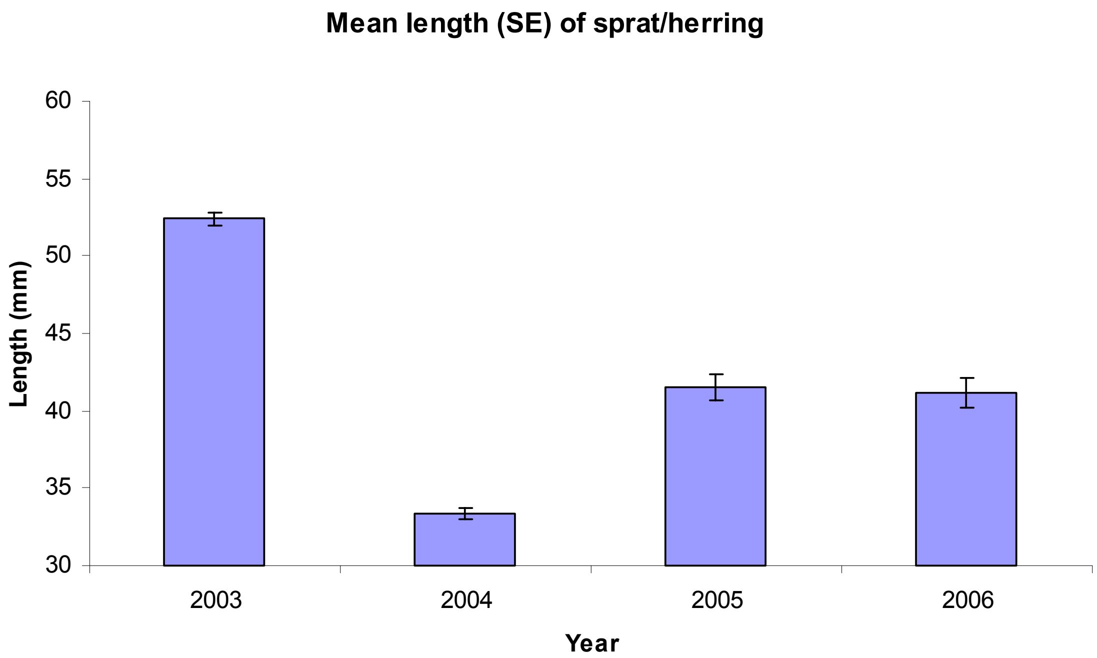


INTER-ANNUAL COMPARISONS



GROWTH COMPARISONS




Mean length (SE) of sprat/herring
Length (mm)
60
55
50
45
40
35
30
2003
2004
2005
2006
Year

7.8 Discussion and Conclusions

Of the 12 species caught to date, 11 have been captured within the newly breached site, with only six species, caught on the established marsh. The fact that fewer species have been caught on the established area has been consistent between years and can be attributed to the difficulties associated with sampling this large area. Obtaining samples from the established marsh, outside the realignment, was restricted around the shore margins, to a period of approximately 30 minutes, either side of the top of the tide. The time window for obtaining further samples using fyke nets in the filling and draining creeks was extended, but still limited to approximately two to three hours around high tide. This method of sampling, however, has not proved to be very productive on the established marsh area. Conversely, within the realignment site, fishes that had potentially been using the inundated land, tended to become concentrated in the main channels, which remained wetted during all states of the tide and thus facilitated sampling to take place throughout the day. Despite a much extended time window for sampling the realignment, the speed at which the site fills and drains has increased dramatically since being breached in 2003. This is due to a combination of the hydrological formation of new creeks on the establishing marsh and the continuous erosion of the breaches themselves. The depth of these breaches in 2003 was not known, however, the south breach was measured at 7 metres deep at low tide in 2005. Although gobies were caught in relatively low numbers on the established marsh, this was not a true reflection of their total abundance as they were physically observed in large numbers both around the shore margins and in all creeks and puddles inspected at low tide. If the same sampling effort could be applied to the natural salt marsh then it is likely that all the species caught within the realignment area would also be captured on the natural marsh area.

The addition of a second survey over neap tides during 2004, revealed that the permanently flooded network of channels on the retreat site, continue to act as an important nursery zone for 0+ fishes during periods of non-connectivity with the sea. When comparing relative abundance of species between spring and neap tides, sprat/herring, flounder and three-spined stickleback showed significant differences, with flounder and stickleback increasing from 3-28% and 2-27% respectively, and sprat/herring decreasing from 75-26%. The reduced water depth at this time could explain the increase in numbers of flounder captured as shallow water will increase the efficiency of the seine nets in sampling benthic habitats. The significant decrease in numbers of sprat using the site, over neap tides however, may indicate that this species is more transient, with large numbers entering and leaving the retreat site with the tide.

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, and significantly reduced numbers between 2003 and 2006, 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 most likely a result of sporadic linkage via the sluice (wheel pool), which provides limited periods of connectivity with the adjacent wetland.

Heavy infestation levels of Diplostomiasis (commonly known as ‘black spot’) have been evident in a large proportion of sticklebacks captured at this site since 2003. This is caused by the resting metacerial stage of a digenean trematode and known to be transmitted by piscivorous birds. This would suggest that until the realignment was breached in 2003, this species represented an important component in the diet of piscivorous birds utilising the pre-breach, freshwater channels in this area. Although no longer a viable food source for birds, this species is likely to be present in high numbers in the brackish lagoon area behind the site.

Due to the limited scope, in terms of time and man-power restrictions invested in these surveys, it is difficult to associate robust inter-annual differences in terms of both species composition and growth. Although sprat and herring have been grouped into the family Clupeidae, these were represented as smaller year classes in 2004, which could be due to many factors, including temperature, time of spawning, food availability etc. It is also possible that sampling the spring tides either side of this survey may have produced a larger cohort of these species, more comparable with other years. Again if sampling were to be carried out over a period of weeks, then those species represented by only single specimens in some years, may be shown to feature more prominently in the total species composition. In order to further investigate size cohorts of both sprat and herring as individual species, additional time would be required to carry out the more detailed identification required to separate these species during these early stages of development.

The dietary analysis focussed on samples collected during the 2004 survey. Although still very limited in the scope of this study, using the samples from 2004 facilitated a greater range of comparisons due to the numbers of bass and sprat/herring captured over a wider range of the tidal cycle.

In summary, the Clupeidae had fuller guts on spring tides than neap tides. Their prey was dominated by copepods and included no evidence of terrestrial organisms. Bass were individually more variable in gut-fullness, prey type and prey number, with copepods more numerous in those individuals that had access to the flooded vegetated areas of the realignment. Bass appear to be more opportunistic in their dietary requirements with terrestrial mites and insects also represented in the diet of some specimens. These items are possibly captured from the surface film and derived from the developing saltmarsh vegetation on adjacent land. When confined to the flooded channels during neap tides, bass also demonstrated a switch from copepods to crab larvae.

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 the Freiston Shore realignment site has shown that 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. This suggests that the creation of additional ponded areas within the 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.

7.9 Appendix

Photographs

Image 7.1: Setting the fyke to sample a rising tide.

Image 7.2: Ten minutes later as the channel begins to flood. The net was retrieved before inundation of the surrounding land.

Image 7.3: Setting the fyke at high tide to sample the ebb.

Image 7.4: The above sample 2 hours 30 minutes later just prior to removal of the net.

Image 7.5: Using the fyke to sample a rising tide in the main south channel.

Image 7.6: A close up of the above sample (note the stakes holding the net in place against the imminent strong tidal flow). Within 15 minutes of this photo being taken, the water level had overtopped the banks and was flooding the land

Image 7.7: Impounded areas of permanently flooded land within the realignment.

Image 7.8: Plumbing the depth of the south breach at low tide. At the time this photograph was taken, the water depth was 7 metres, too deep to sample effectively using current sampling methods.

Image 7.9: The wheel pool at the top of the south channel.

Image 7.10: Sampling the above pool with a seine net on a higher tide.

8. Pilot study of SEDIMENT PROPERTIES: GRAIN SIZE, TOTAL Nitrogen AND ORGANIC MATTER, MOISTURE CONTENT

Dr S.L. Brown, CEH Dorset

8.1 Summary

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 was the influence of vegetation (above and below ground production) which increased 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 is suggested that this may be due to additional inputs from 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 was just 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 was encouraging to find that the sediment properties (particularly organic matter content and total nitrogen) 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.

8.2 Introduction

The measurement of sediment properties has not been a main component of the Freiston monitoring programme. The author is not a specialist in salt marsh sediment properties but considered that it would be useful to take a quick look at some basic sediment attributes in the realignment site for comparison with sediments outside on the salt marsh and with the agricultural soil underlying the newly accreted salt marsh sediment in the site. Properties investigated were: grain size, organic matter and total Nitrogen, and sediment moisture content.

Productivity in salt marshes (and other coastal seawater ecosystems) is generally considered to be nitrogen limited, although inputs of nitrates from fertiliser run-off from agricultural land which lies behind most areas of salt marsh on the east coast, or from sewage outlets, can produce eutrophic conditions. Measurements of total nitrogen in sediments make no distinction between organic and inorganic forms or of the levels of available nitrogen for plant uptake; or of dissolved forms available for nutrient exchange and so on, but it was considered that measurements of the total nitrogen and organic matter in the sediments might give some insights into the nitrogen and organic matter status of the sediments in the realignment site and how they are developing compared with the reference marsh outside. It has been suggested that low soil organic matter content is associated with low nutrient concentrations and a lower functional value of created marshes (e.g. Broome *et al.* 2000) compared with mature reference marshes.

8.3 Methods

Sediment samples were collected in September 2005, from the monitoring sites along four transects outside the realignment: Transects 2, 3, 4 and 5 (the four closest to the realignment: two in front, one north and one south), and four transects chosen randomly inside the site (Transects A, B, D, E). Three sediment cores (to a depth of about 10cm) were taken around each monitoring site on the salt marsh, and sealed in airtight bags. Deeper cores (to about 15cm depth) were taken inside the site and they were extruded onto a tray. It was possible to see the change between newly accreted marine sediment and the agricultural soil underneath. The cores were divided into marine sediment and agricultural soil (discarding the zone of transition). More than 3 cores were taken at sites inside the realignment, until sufficient material (post-breach accreted sediment and agricultural soil) had been collected for analysis. At the upper realignment sites, such as TAS1-4, where there have been only low amounts of sediment accretion, we took surface scrapes to supplement the cores, until enough material had been collected for analysis. At one site, TDS6 which has accreted a high level of new sediment, our cores did not reach the agricultural soil surface. There were insufficient resources to analyse separate replicate samples for this brief investigation, therefore the sediment samples were well mixed before analysis.

Total Nitrogen, organic matter and moisture content analyses were carried out by Anglian Soil Analysis in Boston. As this is close to the realignment site, the samples were delivered as soon as possible after collection. Total N in the sample was converted to ammonium-nitrogen by digestion with sulphuric acid and a potassium sulphate and copper (II) sulphate catalyst. 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 of a sub-sample of the surface marine sediment collected was carried out using a Coulter Counter at CEH Dorset.

8.4 Results

The results are shown graphically according to the elevation at each sampling site.

8.4.1 Inside the managed realignment: underlying agricultural soil OM, total N and moisture content

The values for total nitrogen, organic matter and moisture content of the underlying agricultural soil in the realignment are shown in Fig. 8.1. Moisture content varied between 20% and 25%, total N varied between 1.12 and 2.80 g Kg^{-1}, and organic matter varied between 5.6% and 11.8% dry weight of sample.

There was no relationship between elevation and organic matter or moisture content. This result would be expected in well mixed agricultural soil. Pearson correlations were as follows: Moisture %: P.corr. =0.009, p=0.969; OM %: P.corr. = -0.178, p=0.415. A very slight increase in total N was observed at higher elevations, which was found to be significant, P.corr = 0.631, p=0.001.

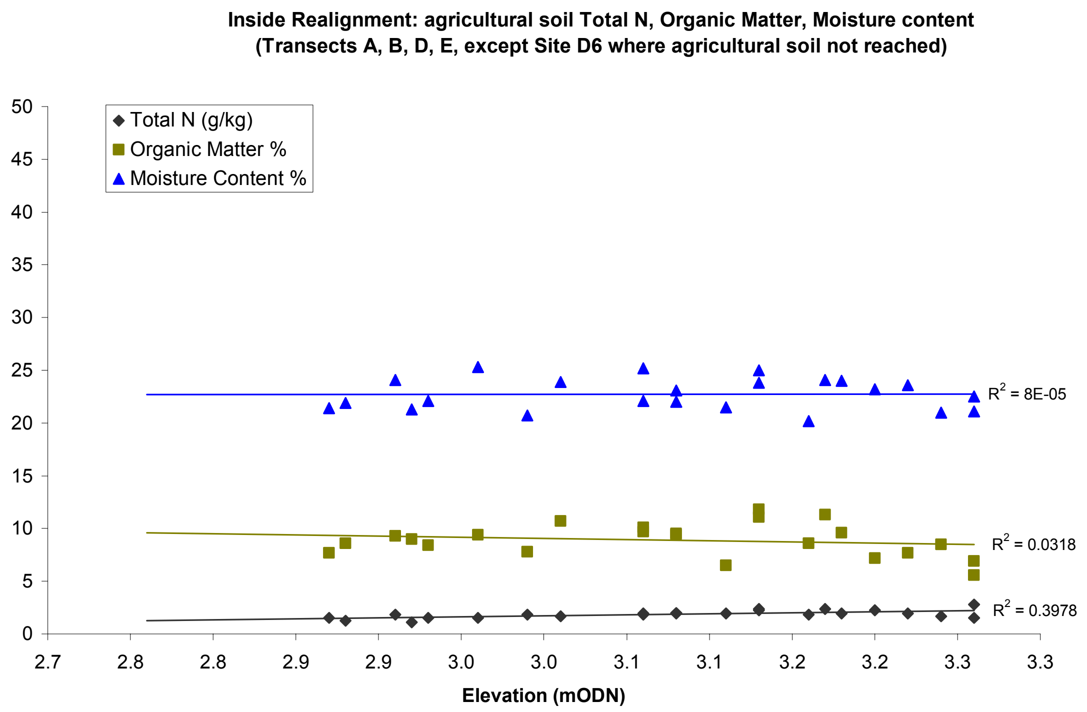


Fig. 8.1. Inside MR: Total N, Organic Matter and Moisture content in agricultural soil underlying the accreted salt marsh sediments.

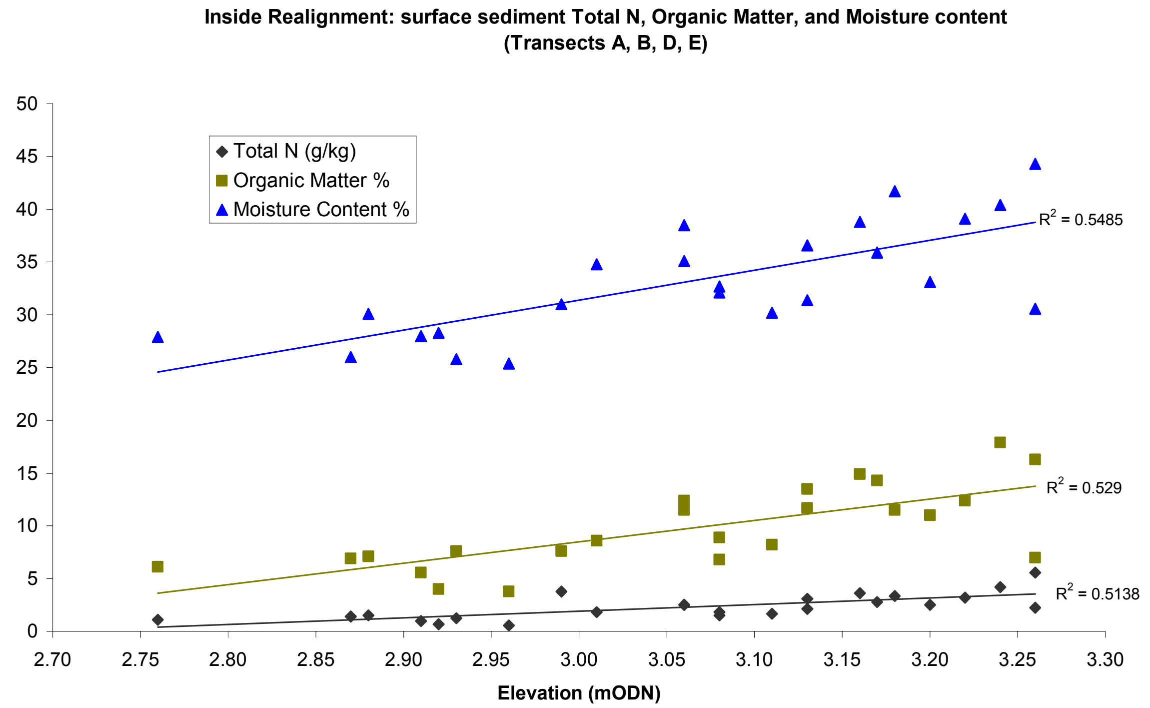


Fig. 8.2. Inside MR: Total N, Organic Matter and Moisture content in accreted sediments

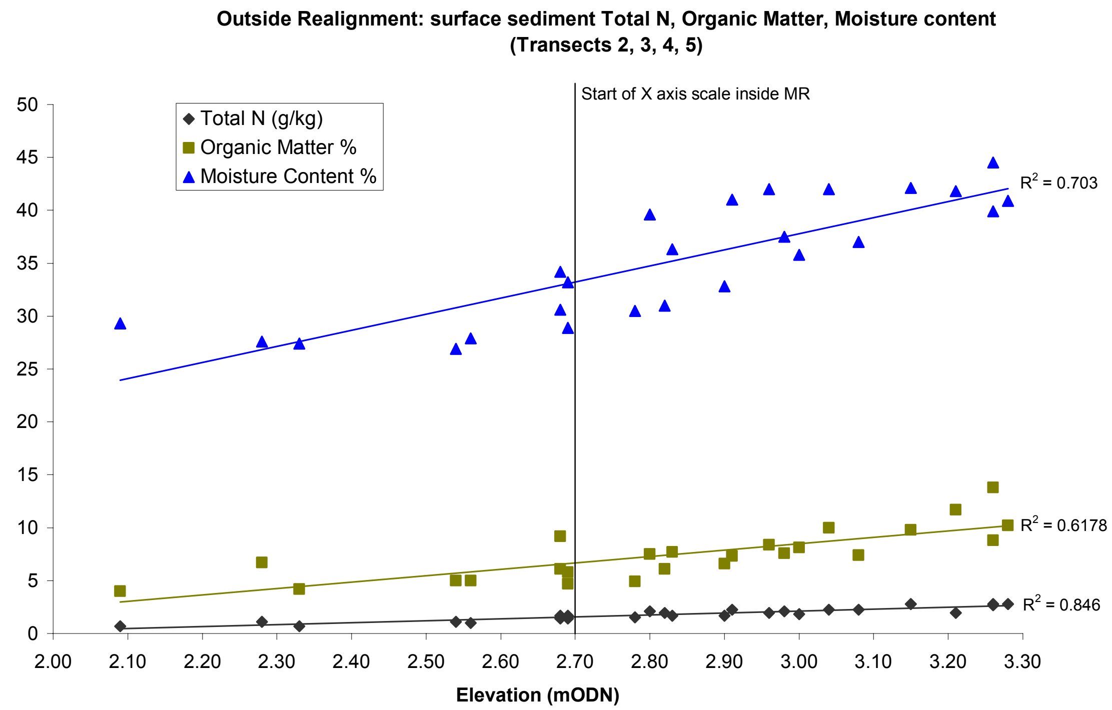


Fig. 8.3. Outside MR: Total N, Organic Matter and Moisture content in salt marsh sediments

8.4.2 Inside the managed realignment: accreted marine sediment OM, total N and moisture content

The data for the sites on the four selected transects are shown in Fig. 8.2. Moisture content varied between 25% and 44%, total N between 0.56 and 5.6g Kg^{-1}, and organic matter between 3.8% and 18% and all showed a highly significant increasing trend with elevation. Moisture %: P.corr. = 0.741, p=0.000; total N: P.corr. = 0.717, p=0.000; OM%: P.corr. =0.727, p=0.000. The range of values for organic matter, total N and moisture content was greater in the accreted marine sediment than in the underlying agricultural soil. At lower elevations in the realignment, organic matter and total N content were less than the agricultural soil, but they were greater than the underlying soil at upper elevations in the realignment site.

8.4.3 Outside the managed realignment: marine sediment OM, total N and moisture content

The data are shown in Fig. 8.3. Moisture content varied between 27% and 45%, similar values to inside the realignment, and showed a highly significant correlation with elevation (P.corr. = 0.838, p=0.000). Total N varied between 0.70-2.8g Kg^{-1} and organic matter ranged between 4.0-14%, and both were found to have a highly significant relationship with elevation (Total N: P.corr. = 0.921, p=0.000; OM%: P.corr. =0.786, p=0.000). The range of values for organic content and total N on the salt marsh were generally similar to those for the agricultural soil in the realignment site although they were lower in the sparsely vegetated pioneer zone and mudflat sites below 2.7mODN.

Data for the selected transects outside the realignment site are shown split into the elevation range found in the realignment (2.7m-3.3mODN, Fig. 8.4) and for the sites on the selected transects below 2.7mODN (Fig. 8.5).

At 2.7-3.3mODN (Fig. 8.4), moisture content varied from 31-45%, total N from 1.54-2.8g Kg^{-1}, and organic matter from 4.9-13.8%. As for the full range, all were correlated highly significantly with elevation (Moisture%: P.corr. =0.668, p=0.005; Total N: P.corr. =0.7989, p=0.000; OM%: P.corr. = 0.809, p=0.000). The minimum values for total N and organic matter were higher outside than inside the realignment site but the maximum values for total N and organic matter (at the upper end of the elevation range) were lower than inside the realignment site.

Below 2.7mODN (Fig.8.5), moisture content was 27-34%, total N 0.7-1.68g Kg^{-1}, and organic matter 4.0-9.2%. There were only 5 sites sampled between 2.09mODN and 2.56mODN, but the limited data suggest that there was no tendency for moisture to increase at all with elevation at these lower sites outside the realignment. Correlations for moisture and organic matter with elevation were not significant below 2.7mODN (Moisture %: P.corr. = 0.497, p=0.172; OM%: P.corr. =0.424, p=0.255). However, Total N, although increasing very slightly, was found to be significantly correlated with elevation (P.corr. =0.831, p=0.006). The range of values for organic matter and total N were lower in the pioneer zone and mudflat sites below 2.7mODN than in the salt marsh sites above 2.7mODN.

8.4.4 Inside the realignment: Mean and median grain size and percentage mud and clay

Particle size data is shown in Fig. 8.6. The mean grain size for 23 out of 24 samples ranged between 15.2μm and 33.3μm. One sample (TDS5) had a mean grain size of 40.7μm. Median grain size range was close to the means, from 14.7μm to 35μm, except for TDS5 which had a median value more than twice the maximum of the other samples, at 74μm. Percentage mud (portion <63μm) ranged from 61-80%, with the exception of TDS5 which was just 42%. The data was widely scattered with no clear relationship to elevation and correlations were not significant (Mean: P.corr. =-0.025, p=0.907; Median: P.corr. =-0.322, p=0.125, % mud: P.corr. =0.311, p=0.140). Percentage clay (<2μm) ranged from just 4.5-9.0% and showed no relationship with elevation (P.corr. = -0.127, p=0.554)

8.4.5 Outside the realignment: Mean and median grain size and percentage mud and clay

Fig. 8.7 shows the particle size data for sites outside the realignment. Mean grain size varied between 12.2-45μm, median grain size was similar and ranged between 10.8-43μm, and percentage mud (<63μm) and clay (<2μm) varied between 56-84% and 5.5-10.8%, respectively. The data were widely scattered with no clear relationship to elevation (Mean: P.corr. =0.325, p=0.113; Median: P.corr. =0.030, p=0.888; % mud: P.corr. =-0.123, p=0.559; % clay: P.corr. =-0.212, p=0.308). Therefore at outside elevations comparable with the range in the realignment (2.7-3.3mODN) the results for this selection were little different to those for all of the outside sites. Mean grain size at 2.7-3.3mODN ranged from 12.9-45μm and median grain size from 11.8-43μm, very close to the ranges for these parameters inside the site. Percentage mud ranged between 56-84%, identical to the range found inside the realignment, and percentage clay ranged between 5.5-9.7%, a similar range to inside.

8.4.6 Vegetation ground cover in 2005 according to sampling site elevations

The results of this pilot study are discussed in the following section. The increase in organic matter, total nitrogen and moisture content with elevation in the accreted sediments is likely to be influenced by inputs from vegetation *in situ* (from root biomass and litter from above ground vegetation). The relationship between vegetation cover in 2005 and elevation both inside and outside the realignment is shown in Fig. 8.8.

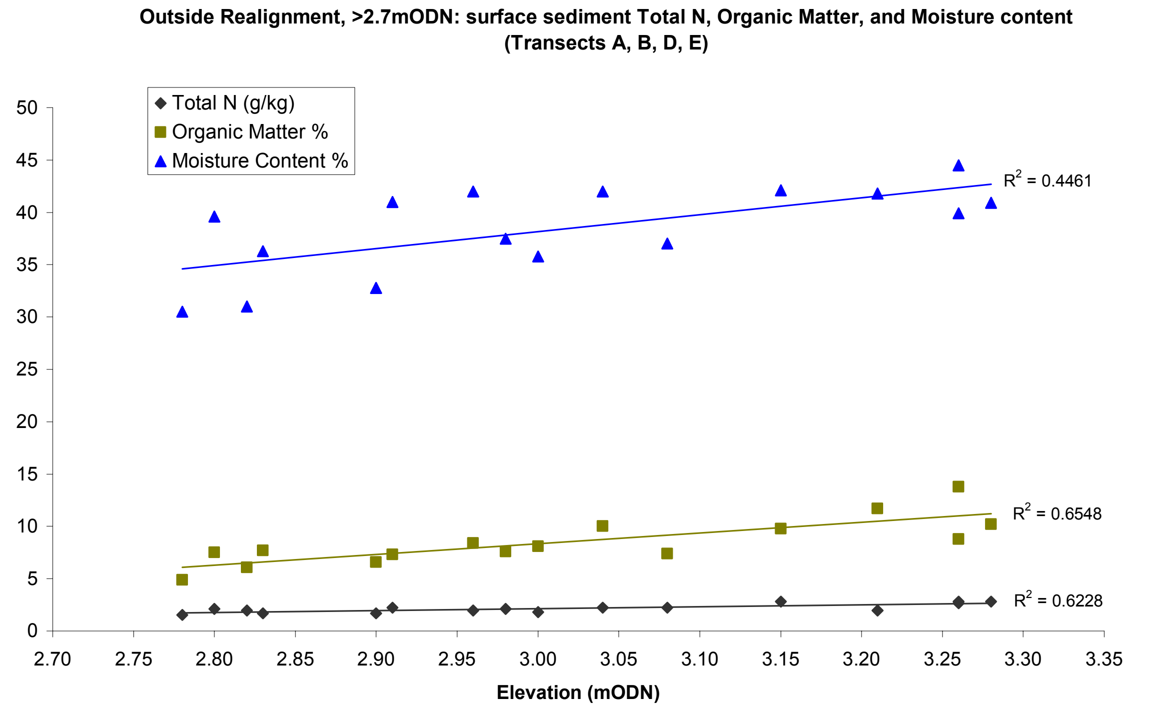


Fig. 8.4. Outside MR: Total N, Organic Matter and Moisture content in salt marsh sediments at equivalent elevations to sites in the realignment.

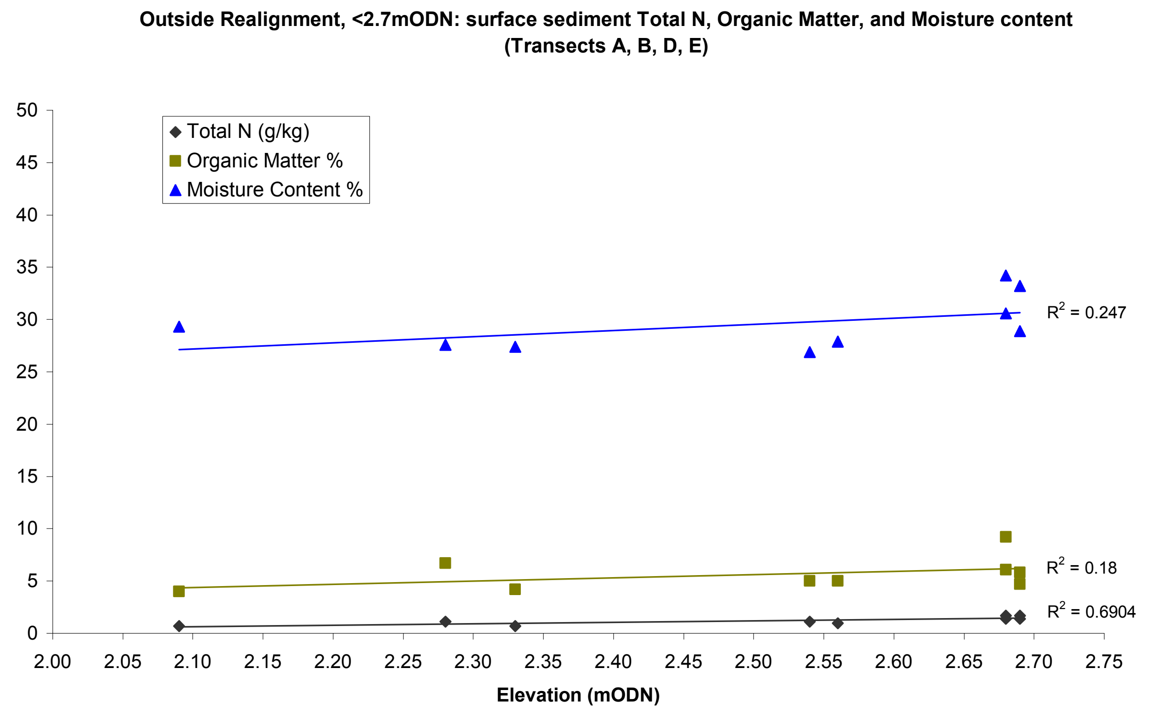


Fig. 8.5. Outside MR: Total N, Organic Matter and Moisture content in salt marsh sediments at pioneer zones sites <2.7mODN.

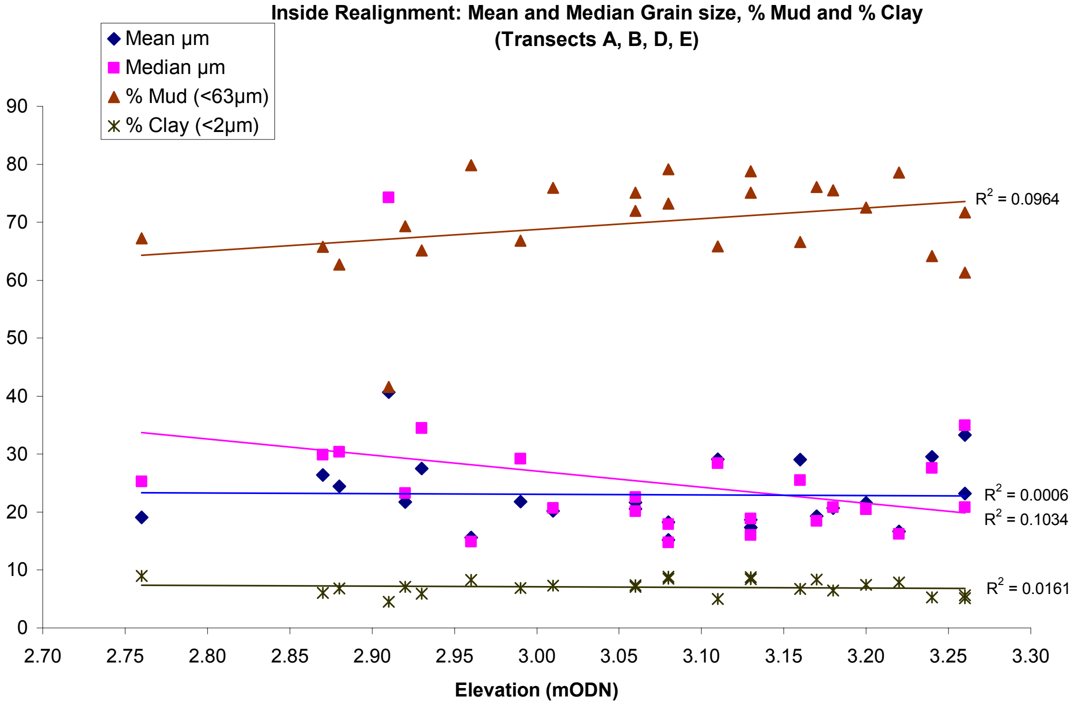


Fig. 8.6. Inside MR: Mean and Median Grain size, and percentage Mud (<63µm) and Clay (<2µm)

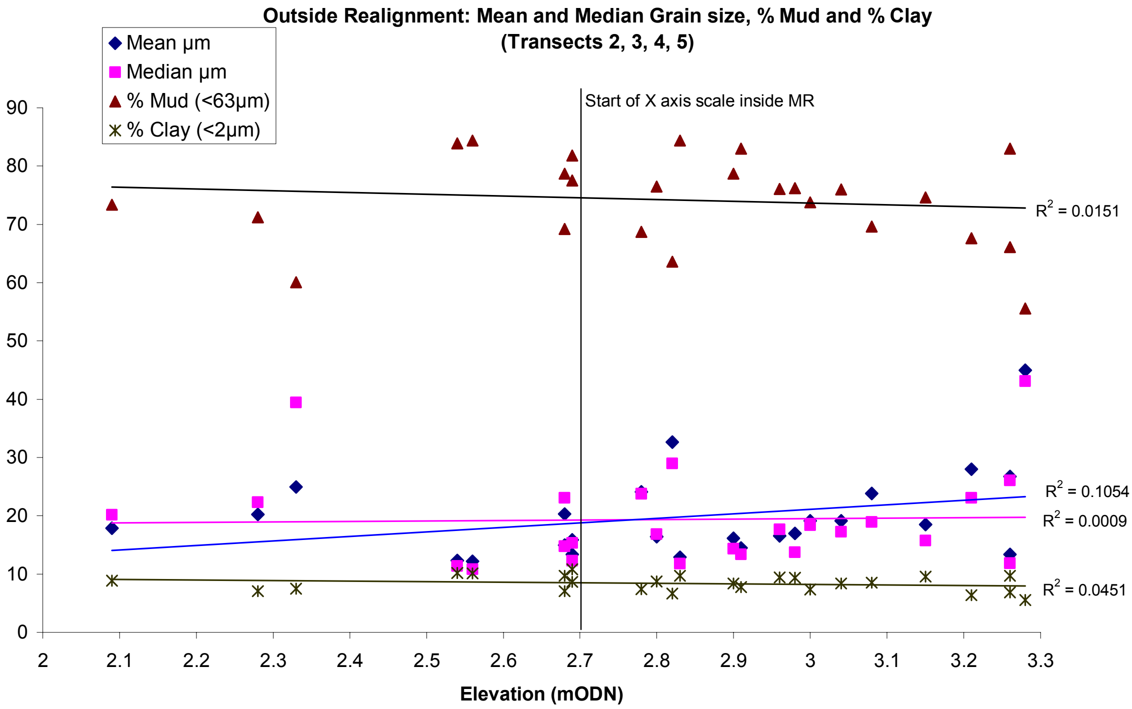


Fig. 8.7. Outside MR: Mean and Median Grain size and percentage Mud (<63µm) and Clay (<2µm)

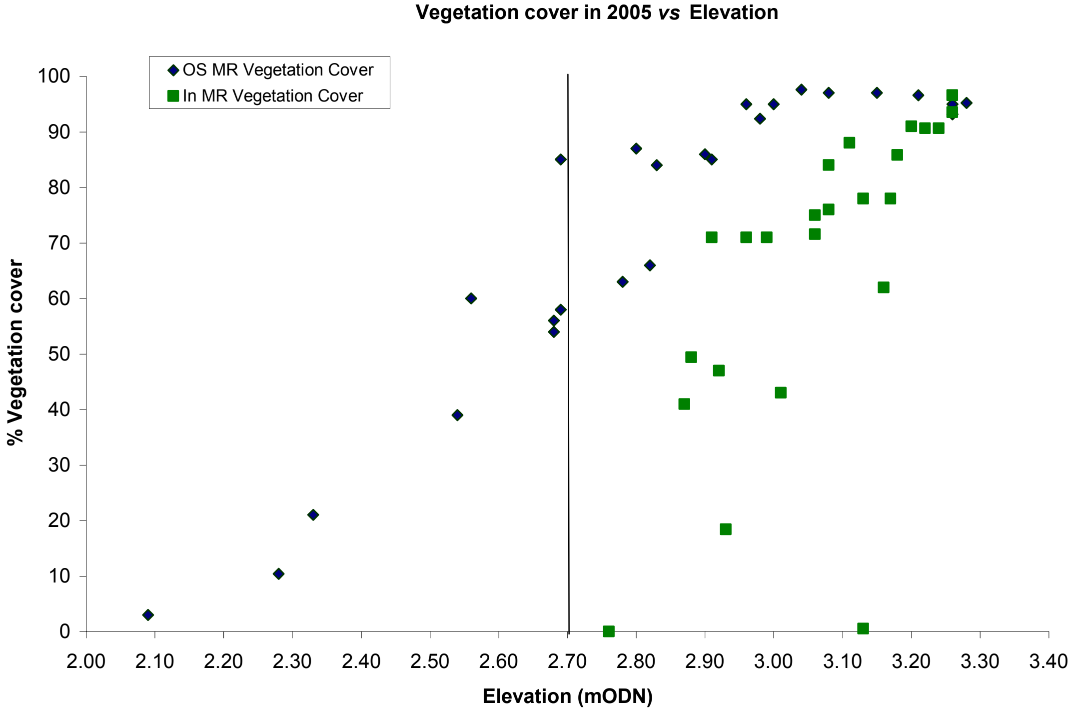


Fig. 8.8. Total vegetation ground cover in 2005, inside and outside the realignment site according to sampling site elevations

8.5 Discussion

Due to time constraints for the pilot study, we were unable to analyse replicate samples for each site and so cannot draw detailed conclusions. However, there were some clear and comparable trends in the accreted sediment inside the site and outside on the salt marsh. Organic matter, total nitrogen and moisture content all increased with increasing elevation. Possible explanations for the observed results are offered in this short discussion.

Organic matter has been reported to increase with elevation (Packham and Liddle 1970, Gray and Bunce 1972) under increasing plant cover. An increasing trend in total nitrogen from bare mud to upper marsh was measured by Ranwell (1964). Organic matter and nitrogen inputs to salt marshes come from tidal flooding by seawater and deposition of suspended sediments and tide-borne plant detritus, and *in situ* salt marsh vegetation (above and below ground production), algae, microalgae and decomposers. Therefore an increase would be expected with increasing density of plant cover which increases with elevation. Nitrogen is also added from atmospheric deposition/precipitation.

There are various well established relationships between sediment parameters, for example, organic matter content and microbial biomass in marine sediments are associated with small particle size. Soil moisture retention is increased in sediments with high organic matter and clay content. If we had found a decrease in grain size with elevation this may have accounted (at least in part) for the observed increase in organic matter, total N and moisture content. However, no relationship was found between grain size (and related mud and clay content) with elevation, suggesting that the increase in organic matter, total N and moisture is due to additional inputs such as vegetation debris, plant roots *in situ*, and drift litter. The shading effect of the vegetation will also prevent the underlying sediment from drying out so much between tidal inundations.

Comparison of the measured parameters inside the realignment site and outside at equivalent elevations showed that the range of values for organic content, total N and moisture content overlapped. However, at the lower end of this elevation range values for these three variables were lower inside the realignment site and vegetation cover was also less in the lower part of the elevation range in the realignment site compared with outside (Fig. 8.8). At the upper end of the elevation range, organic matter and total N content were higher inside the realignment than outside on the salt marsh. One possible explanation for this is the presence of dead and decaying terrestrial vegetation trapped in the shallow layer of accreted sediment at upper elevations. At lower elevations the accreted sediment was much deeper so the layer of dead terrestrial vegetation would not have been incorporated in the surface sediment samples.

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. As there has only been a few mm of sediment accretion at higher elevations the underlying agricultural soil is close to the surface. Total N content here may be influenced by various factors including atmospheric inputs, the higher values of total N in the overlying surface marine sediment at upper elevations, 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).

Although we cannot draw detailed conclusions from this limited study, it was encouraging to find that the sediment organic matter and total nitrogen content showed similarities to the adjacent reference marsh. This may be a good indication that processes in the sediments may also be comparable. 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.

8.5.1 References

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9. An overview of Freiston, lessons learned and recommendations

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9.1 Introduction

This final chapter summarises the key findings, observations and lessons learned from the Freiston monitoring programme. Important factors for salt marsh establishment are discussed, with some comparisons with two other managed realignment sites. This chapter also makes recommendations for future work and aspects of managed realignment to be considered for future schemes.

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.

The success of the newly created salt marsh habitat and the brackish lagoon established behind the realignment site for birds has been assessed by RSPB, and wave activity and tide heights were monitored for a year after the site was breached by the University of Southampton Oceanography Centre.

The main driver for the creation of the Freiston realignment site was to find a cost effective solution to problems of wave attack and erosion to the toe of sea defence embankment in this area. Managed realignment was selected as the preferred cost-effective option in the long term (rather than maintaining the line of defence) and this option has associated environmental enhancements. Schemes which incorporate nature conservation benefits meet Defra's high level target of no net loss for capital schemes and are given priority in Defra's funding criteria for flood and coastal defence works.

Several managed realignment schemes are underway on different areas of the coast, with some aimed specifically at providing compensation habitat (salt marsh and/or mudflat) for that lost by flood defence schemes and urgent works in an area (e.g. Paull Holme Strays and Welwick in the Humber Estuary) and/or to address losses from expected relative sea level rise over the lifetime of sea defence works. The objectives of schemes providing compensation for habitat losses are closely linked to the requirements of the Habitats Directive (European Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild fauna and Flora) and the UK Biodiversity Action Plan (BAP) targets for salt marsh and mudflats for which the Environment Agency is the lead organisation (Rawson *et al.* 2004). The salt marsh Habitat Action Plan aims to achieve no further net loss of salt marsh (100ha predicted to be lost annually) and to restore an additional 600ha of salt marsh by 2014 to make up for losses between 1992 and 1998. In total, this means a commitment to create or restore 2100ha of salt marsh by 2014, and must be addressed in coastal management plans (e.g. Shoreline Management Plans (SMPs) and Coastal Habitat Management Plans (CHaMPs).

Several realignment schemes have been initiated since the 1990s and some have been monitored. Nevertheless, experience is still relatively limited and many sites that were breached with the intention to produce salt marsh are still developing and have yet to produce salt marsh habitat or vegetation communities that are equivalent to adjacent salt marsh. Sites differ in initial conditions and in many cases sites were initially too low in the tidal frame to develop salt marsh until the site had warped up to appropriate levels. Managed realignment sites lie in different locations (e.g. in upper and lower reaches of estuaries, such as the Essex and Humber realignments, or on more open coasts, such as Freiston in the Wash Embayment) and experience differences in tidal range and suspended sediment loads. It is therefore important to continue to monitor realignment sites and to learn from experience in order to optimize starting conditions and site design for future schemes if BAP targets are to be met.

The desirable outcome of habitat creation (or restoration) of salt marshes and/or mudflats by managed realignment is to achieve sustainable biodiversity and ecosystem function (rates and processes), comparable with that of natural ecosystems. This leads to a number of questions about how to quantify the success of restoration schemes. Research on developing success criteria for restored and created habitats is receiving attention in wetland and salt marsh restoration ecology, particularly in the United States (e.g. Short et al. 2000, Zedler 2000, Zedler and Lindig-Cisneros 2000). What characteristics are important to measure function and how can they be measured economically? What structural attributes provide the best indicators of restoration success? What time frame is needed for sites to achieve structural and functional equivalence? These questions need attention in the UK, particularly where schemes are required to provide compensation for habitat losses. It is important to set out the objectives of a scheme and targets to be achieved in order that the success of the scheme can be assessed.

Salt marshes have many functions and achieving ‘functional equivalence’ is a complex issue, with different processes operating on different time scales. Some may be attainable and some may not, depending upon conditions at proposed sites for salt marsh creation. Many functional attributes of salt marshes (e.g. primary and secondary production, nutrient cycling and fluxes between adjacent ecosystems, food web support etc.) would need more resources and intensity of study to make a detailed comparison of created salt marshes with reference habitats than a standard monitoring programme could support. More UK research on these ecosystem characteristics would benefit the evaluation of restoration and habitat creation schemes. Some functions such as sediment trapping and rates of accretion can be measured at reasonable cost, but often various structural attributes are the only pragmatic option for comparison between restored or created salt marshes, such as vegetation cover and species composition at a point in time, faunal abundance etc. Nevertheless, when these measurements are made over several points in time useful information can be learned about the development and establishment of newly created salt marshes and the rates of change towards achieving a habitat comparable with natural marshes in the area.

9.2 Sediment accretion

Sediment accretion is highly dependant on available suspended sediment load and also the elevation of the site as this determines the number of tidal submergences carrying suspended sediment experienced at different levels on a salt marsh. Other factors such as proximity to creeks affect the sediment load deposited, and vegetation density can influence water flow and deposition, but perhaps more importantly vegetation has a stabilising effect, binding the sediments and protecting against erosion, and reducing the amount of resuspension of recently deposited sediment on the ebb tide (e.g. Randerson 1979, Brown 1998). Overall there is generally an inverse relationship between accretion and elevation on wide gently sloping salt marshes once the zone of continuous vegetation cover is reached, as found in this study. In front of this zone in sparse annual vegetation and on the bare mudflats sediment levels are more dynamic (e.g. Brown *et al.* 1998) and can be influenced by the biota which may stabilise the sediment (e.g. filamentous algae and diatoms which bind the sediments with the help of mucopolysaccharide secretions) or destabilise the sediment surface (e.g. bioturbating benthic organisms, Widdows *et al.* 2000).

Results of the accretion surveys in the Freiston realignment site and outside were very encouraging and indicated that the realignment site has been accreting sediment with a close overall similarity to accretion rates outside the site at the same elevation range. On first analysis, it was found difficult to compare mean accretion rates inside and outside the site, because a few sites near the central breach had accreted anomalously high levels of new sediment, particularly in the first two years. This was thought to be due to washed in material from the breach area, reworking of sediments moved during the breach excavations, and transport and deposition of material released from the rapid creek widening and headward extension in this zone. These few high deposition sites had a major affect on the calculations of annual accretion rates, but removing these showed that mean annual accretion rates were similar inside and outside the site at the equivalent elevation range, at approximately 7mm per year, sufficient to offset predicted rates of sea level rise. A significant inverse relationship between accretion and elevation was found inside the site (when the outliers were removed) and outside at elevations with continuous vegetation. Because of the marked effects of the few very high accretion sites on mean values, the median accretion values (mid values of the inside and outside data sets) were found to be a useful representative measure of the data set and showed a very close agreement inside and outside (7.4mm and 7.3mm per year, respectively).

In the upper half of the elevation range mean and median annual accretion rates were similar (between 4-5mm) inside and outside the realignment, but accretion rates were higher in the lower half of the range inside the more sheltered conditions of the site compared with the adjacent salt marsh (median annual accretion was 13.6mm inside the site compared with approximately 9mm outside).

A similar observation was found at the Paull Holme Strays managed realignment site in the Humber Estuary, where annual accretion rates overlapped between elevations of approximately 2.8-3.3mODN, but at lower elevations accretion was significantly higher inside the more sheltered realignment than on the salt marsh and mudflat outside. There was an inverse relationship between accretion and elevation on the area of mudflat inside the Paull realignment as well as on the salt marsh, which is not found on exposed natural mudflats fronting salt marshes (Brown and Brown 2006, Brown *et al.* 2005, Brown *et al.* 1998). It was initially anticipated (Halcrow Ltd) that the Paull Holme Strays site would ultimately create 45ha of mudflat and 35ha of salt marsh to meet targets for compensatory habitat. However, by 2006 it was apparent that the lower areas of 'mudflat' in the site were continuing to act as a settling tank and accreting sediment at a rapid rate, presumably because the site is not exposed enough for much resuspension of deposited sediment to occur. By summer 2006 large areas of mudflat had built up to a level at which pioneer plants (mainly *Spartina anglica*) were beginning to colonise much of the mudflat area, and we predicted that most of the Paull site, except for the area facing the breaches, would eventually become salt marsh (Brown and Brown 2006). This raises the need to consider full embankment removal for areas where creation of mudflat is required. A new realignment site created by ABP (Associated British Ports) further down the Humber Estuary at Welwick has a wider breach that those at Paull and it will be interesting to see if this creates a balance between deposition and resuspension and erosion to prevent the area warping up to salt marsh levels, and whether the required compensatory mudflat (as well as a proportion of salt marsh) will be created and maintained in the long term (Brown and Brown 2006).

At Freiston, the site elevations were suitable for salt marsh establishment and the shelter afforded by the former seawalls was undoubtedly helpful for plant establishment. Plant cover has been less developed in the more exposed area in the vicinity of the middle breach, seen in aerial photographs (Photos 9.1 and 9.2) and shown in the data. The photographs also show how the creek leading out from the central breach (in particular) has eroded and widened; presumably most of the tidal water leaves through this breach with considerable erosive force.

We could not make a detailed comparison of the data from the CEH sediment plates with the CCRU SET sites without the elevations for the SET sites to put the data in context with elevation. Furthermore there were considerable spatial variations in accretion at plate sites close to the central breach (lower half of Transects C and D). However, some of the CCRU sites are close to the CEH sites, and these showed good agreement in overall accretion between autumn 2002 and 2006. Both methods of accretion measurement found a seasonal variation in net accretion at many sites in most years, where accretion was greater during the winter period than the summer months.

CCRU highlighted two SET sites (one close to, and north, of the central breach and a site in the northwest corner of the realignment) which have shown minimal surface elevation change since April 2005 and they suggested that sediment supply to the northern half of the site may have changed adversely. The first of these sites is now in an area that is eroding due to the formation of a creek (by 2005-6), and although there are no CEH plate sites close to this, sites on the lower half of the transects either side (Transects B and C) have continued to accrete sediment. Accretion rates on the lower half of Transect C have settled down since the early years of high deposition (discussed above), but subsequent accretion rates were comparable with sites on other transects at similar elevations. The second of these SET sites is in the northwest section close to Transect A, Sites 1 and 2. The first four sites on Transect A are relatively high (over 3.2mODN) and have therefore accreted less sediment than sites in the realignment at lower elevations, but all have shown continued accretion. Therefore there does not appear to be any additional evidence from these CEH sites to indicate any problem with sediment supply. However, observations across the site suggest that there may be areas where the surface level may be lowering (where drainage is not channelled), and rapid erosion of creeks has been occurring in places (cutting back and widening by collapse of creek edges) which may potentially be a problem, and is discussed later.

Continued accretion within the realignment and outside on the salt marsh is important to maintain managed realignment sites and existing salt marsh in the context of rising relative sea level. CCRU noted that the real value of the SET technique comes from long (>5 year) records of surface elevation change, which filter out short term variability. This also applies to other methods of accretion measurements, such as the CEH sediment plates and levelled canes; it can take several years of measurements to be able to determine reliable accretion rates at different elevations over the long-term because the ‘noise’ of inter-annual variations in accretion can be considerable (Brown *et al*. 1998). The value of the sediment plate method (or levelled canes) is that they are inexpensive to install and therefore can be used to cover a wide area of the site under study and account for spatial as well as temporal variability. We therefore recommend that monitoring both the SET stations and the accretion plates at Freiston should be continued for a further five years if possible. It may be prudent to install a small number of additional sites if problem areas are detected, or to survey such area at intervals with an RTK GPS system which can measure elevation to approximately ± 1 or 2cm accuracy.

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 (Photos 9.3 and 9.4), 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. We understand that morphological change is being monitored by LIDAR flights every 3 years (Rawson *et al.* 2004), and the wider impact of the realignment site, including changes in creek widths is part of a PhD study by Dan Freiss at CCRU.

9.3 Vegetation colonisation and development of salt marsh

Elevation in relation to the tidal frame is the single most important key factor for establishment and survival of salt marsh vegetation. In general, the lower limit of salt marsh vegetation is approximately at the level of Mean High Water Neap tides (MHWN) and extends upwards to ≈ Mean High Water Springs (MHWS).

Photo 9.1. Freiston realignment site, viewed from the southern end. Note the sparsely vegetated area inside the site opposite the central breach. Photo: Environment Agency

Photo 9.2. Freiston realignment site viewed from the north end. Note marked widening of the creek from the central breach, through the fronting salt marsh
Photo: Environment Agency

Photo 9.3. Creek from central breach looking towards realignment site
Photo: Sue Brown

Photo 9.4. Creek draining central breach looking seawards. Photo: Sue Brown

Elevation also determines which species will be present at each level. Salt marsh plant species occur in overlapping zones and the generally accepted although simplified view is that the lower vertical limit is set primarily by tolerance to tide related factors and exposure, while biotic factors such as interspecific competition are more important at the upper limits (Pielou and Routledge 1976, Bertness 1991a & b, Gray 1992, Clarke and Brown 2002).

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 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. Many other sites of salt marsh creation (either deliberate or resulting from accidental breaches) have not reached equivalent community composition after many years or even decades (Burd 1994), but initial starting conditions (e.g. low-lying flat agricultural land) were often very different from neighbouring mature salt marshes. The Tollesbury site in Essex was breached in 1995 but was initially low in the tidal frame and just 6ha out of 21ha were colonised by vegetation after 6 years. In the overview of the Tollesbury monitoring programme, Gray suggested that probably more than 10 further years of accretion at the average rate of 23mm $year^{-1}$ measured in the site would be needed for salt marsh to develop over most of the site (in Reading *et al.* 2002). Since 2002, the average annual accretion rate at Tollesbury has reduced to 10.9mm $year^{-1}$ (Garbutt, in Reading *et al.*2005). The extent of salt marsh cover over the site by 2005 is not given in the 2005 Tollesbury report, but presumably an even longer period will be needed for vegetation to spread throughout the site if accretion rates are slowing down.

The Paull Holme Strays realignment site in the Humber estuary was breached in 2003, but 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 quadrats 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 Lincolnshire 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. Between 2.6-3.5mODN the most abundant plant in the first year at Paull was *Atriplex prostrata* (Spear-leaved Orache), a species found in coastal habitats and in mid to upper zones of salt marshes, but which is also a weed of arable land, roadsides, gardens and waste places (Blamey and Grey-Wilson 1989). This widespread species has since been declining as perennial salt marsh species have colonised and spread. There have been no studies of seed dispersal into the Paull Holme Strays realignment site, but it seems likely that lack of seed availability and predominantly localised dispersal were important factors limiting plant colonisation in the first year or two after the site was breached. Research elsewhere has indicated that these are important factors limiting plant abundance within marsh zones (Bakker 1985, Rand 2000, Wolters *et.al.* 2005). Once vegetation has developed in the site, the rate of establishment would be expected to increase as propagules are produced *in situ* as well as those brought in by the tide, although the relative species compositions may be biased by the abundance of the most successful colonisers in the early years. Therefore it may take some time (as yet undetermined) for species communities in some realignment sites to match those outside.

The rapid establishment of salt marsh plants at Freiston (both pioneer and mid to upper marsh species) indicates that there has been no shortage of propagules dispersed into this realignment site. All species except for one found only rarely outside on the adjacent marsh (*Triglochin maritima*) had been noted inside the site by 2006, and even an upper marsh species (*Artemisia* *maritima*, Sea Wormwood) found only in one high area outside on the salt marsh north of the realignment has appeared at high levels on the site behind the northwest corner fence. The results of the monitoring survey 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.

9.4 Invertebrates

Many realignment sites encompass areas of mudflat, either deliberately (e.g. at Paull Holme Strays, Humber Estuary, although it was noted above that the mudflat level is building up rapidly), or because the realignment site was initially too low in the tidal frame to develop salt marsh throughout (e.g. Tollesbury). Several realignment sites with mudflat areas have been monitored for their colonisation and abundance of intertidal invertebrates (mudflat benthos such as bivalve molluscs and oligochaete and polychaete worms, found generally below MHWN and the level of vegetation) and have shown increasing numbers of typical intertidal benthos with time. Although their distribution can be patchy, annual autumn monitoring (usually around October) by sediment cores is sufficient to show trends in colonisation and establishment provided enough samples are taken over a wide area (e.g. see Reading *et al*. 2002 for results at Tollesbury, and reports by the University of Hull Institute for Estuarine and Coastal Studies (IECS) for benthos colonisation at Paull Holme Strays). Overview reports for Paull Holme Strays which encompass the summary reports from CEH on accretion and vegetation monitoring, and IECS on benthic invertebrates are produced annually by Halcrow Ltd. for the Environment Agency (see Environment Agency 2006 for the latest report).

At the time of writing the tender, the elevations of the Freiston site were not known, but on learning that the site would be appropriate for vegetation colonisation the sampling methods were changed to pick up mobile fauna moving over the sediments during neaps when the site is uncovered by the tide (pitfall traps), infauna inhabiting near surface sediments (sediment scrapes), and invertebrates associated with the development of vegetation (sweep nets). We attempted initially to sample vegetation by vacuum sampling but this proved very difficult in wet weather. 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 with established reference marsh could be an attribute for assessing success of salt marsh creation or restoration. However, the diversity of fauna and weather-dependant activity of some of the organisms presents considerable problems for the resources of a monitoring programme. We were only available to sample annually over a few days during neap tides and therefore we were effectively looking at just small snapshots in time. The activities of many mobile organisms associated with vegetated salt marsh are seasonal and also highly dependant on the temperature and weather conditions at the time of sampling. Also some very small species showed enormous variability in numbers. As with all such studies the major effort is in the identification of the organisms. The greater diversity of small invertebrates (terrestrial and littoral) associated with vegetated zones compared with intertidal mudflat benthos meant that not all of the invertebrates could be identified to species level. Under these constraints it was difficult to determine trends in time and to make quantitative comparisons between the realignment site and the adjacent salt marsh. This type of investigation would be suited to a more intensive study (at different times of year and under a range of weather conditions) such as a PhD or post-doctoral research project.

Nevertheless, several species of invertebrates were found to generally increase in diversity, abundance and distribution across the realignment site between 2002 and 2006, including the Shore Crab (*Carcinus maenus*), a gastropod mollusc (Laver Spire shell, (*Hydrobia ulvae*), Ragworm (*Hediste diversicolor*), two beetle species (*Dicheirotrichus gustavi* and *Pogonus chalceus*), Springtails, plant bugs/hoppers, nematodes, flies and various oligochaete worms.

9.5 Fish

Salt marshes are known to provide a nursery function (for food and refuge) for juvenile fishes, including commercially important species, but there have been few studies on fish utilisation of salt marshes in North West Europe compared with the United States. This may be in part due to sampling difficulties in areas with large tidal ranges (Colclough *et al*. 2005 and references in this paper) although there have been a number of studies in the macrotidal Mont Saint Michel Bay (e.g. Laffaille *et al.* 2001, and work by the French group led by E. Feunteun in the European EUROSAM (EUROpean SAlt Marsh Modelling) programme (Brown and Cox 2001, Brown *et a*l. 2003).

The fish surveys at Freiston were carried out each year from 2003, but over just two to three days over spring tides in August, with an additional study over neap tides inside the realignment in August 2004 in the permanently flooded channels and soke dykes. Comparisons between the realignment site and outside on the marsh were difficult to make because of time limitations at the top of the tide, particularly outside the realignment so it was not possible to standardise the catch effort to trap fish by the different methods. Also, factors such as water depth can affect the number of individuals caught, for example more benthic fish such as flounder are likely to be caught in shallow water. Investigations into fish utilisation of managed realignment sites would also be well suited to a more intensive post-graduate or other research project in which sampling could be carried out over weeks, and at different times of year to show seasonality in abundance. A more comprehensive study might also show increased usage of salt marsh managed realignment sites as the vegetation canopy develops and spreads (providing refuge and organic matter with associated developing food webs). The Abbotts Hall realignment was found to be beneficial to fish fry, found in close association with vegetation stands (Colclough *et al*. 2005).

Nevertheless, during the brief annual surveys in this monitoring programme, eleven of the twelve species caught were found in the realignment site, of which the most abundant were sand gobies. These and other species found were similar to those found by Colclough *et al*. (2005) who have studied fish utilisation of five salt marsh sites in south east England (including the managed realignment sites at Abbotts Hall and Orplands). The species caught included the commercially important juvenile bass, sprat and herring, as well as sand-smelt, smelt, flounder, three spined stickleback, mullet and eel.

Our fish survey team found a sharp decline in three spined sticklebacks caught between 2003 and 2005 (but increasing again in 2006) and suggested that these may have been a relic freshwater/brackish population living in the field drains before the breach and maintained by sporadic linkage to the brackish lagoon behind via the sluice. According to the Field Guide to the Water Life of Britain (Reader's Digest 1984) three-spined sticklebacks live in ditches, ponds, lakes and rivers, but also in estuaries and seashore pools. There are three distinct races with different but overlapping distributions that may be accounted for by temperature and salinity preferences: a freshwater form, a migratory form spawning in rivers and overwintering in the sea, and an intermediate less common form living in brackish water, especially along the east coast. Colclough *et al.* (2005) found very abundant three-spined stickleback (as well as gobies) in the Abbotts Hall managed realignment site and described it as 'a euryhaline species, explaining its abundance and potentially pioneering role within the restored salt marsh'.

Neap tide samples from permanent water bodies in the realignment site disconnected from the sea showed that the realignment site continues to provide nursery habitat for juvenile fishes (less than 1 year old) throughout the entire tidal cycle. Dietary analysis and estimates of gut fullness of some samples of commercial species (sprat, herring and bass) showed that these young fish were feeding in the realignment site.

It was recommended by our fish survey team that additional ponded areas (deeper than the areas of standing shallow water that remain at low tide) could be created in managed realignment sites to enhance the quality of habitat to juvenile fishes, by increasing the available habitat and food resources outside the period of spring tide inundation. Colclough *et al*. (2005), Simenstad *et al.* (2000) and Desmond *et al.* (2000) have highlighted factors such as creek configuration, order, density and complexity, channel depth and bank slope (cross-sectional profile) amongst other attributes that increase habitat and topographic heterogeneity. Factors that have been found to be beneficial to juvenile fish could be incorporated into realignment schemes to optimise this functional role of salt marshes as important fish nursery areas.

Studies at Freiston have confirmed that the newly created salt marsh is functioning as a refuge and nursery area for juvenile fish including economic species, although more detailed comparisons with the adjacent marsh could not be made in this study. In view of the economic importance of some juvenile species utilising salt marshes as nursery grounds, and the relatively few studies in Europe, research on fish feeding behaviour, habitat use and requirements, and salt marsh food webs, would merit further attention to enhance the fisheries resource quality of future realignment sites if this is to be one of the aims.

9.6 Sediment properties: organic matter accumulation, total Nitrogen, grain size and moisture content

The brief pilot study carried out in 2005 showed generally similar values (overlapping range of values) inside the realignment site and outside on the adjacent and fronting salt marsh for the sediment properties investigated. This is perhaps not surprising as the newly accreted marine sediment would be expected to be similar to that accreting on the adjacent marsh, at least for the organic matter and nitrogen brought in with the deposited sediments. The levels of organic matter and total nitrogen were also shown to increase significantly with increasing elevation inside and outside the realignment site. This relationship was not related to grain size parameters as these showed no correlation with elevation, and it is likely that the observed increases in organic matter content, total nitrogen and moisture content with elevation were due to accumulation of below-ground biomass (plant roots) and additions of detritus from above-ground vegetation which is denser at higher elevations (vegetation cover in the realignment was close to cover values outside by 2005 at >3.16mODN). Other additions to the organic and nitrogen content of the sediments at higher elevations may come from material washed up by the tide and possibly the decaying layer of terrestrial vegetation trapped in the newly accreted sediments. Although we cannot draw detailed conclusions, the results indicate that organic matter accumulation in the new salt marsh is similar to the adjacent marsh, and therefore sediment processes may be comparable.

9.7 Drainage and creeks

Although not part of our monitoring programme, it may be useful to include some observations on site drainage and creek development in this overview.

Site drainage characteristics govern the time that tidal water remains standing on the marsh surface, sediment stability, and the velocities of currents across the marsh and through the breaches, and are determined by sediment grain size, slope and creek systems. Early development of an efficient drainage system seems to be critical for the success of salt marsh creation. 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. Good drainage increases sediment stability and reduces waterlogging which is detrimental to plant colonisation and survival. Also the creek network provides access to the marsh surface for juvenile fish.

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 and decrease the duration of the ebb tide to produce a similar tidal curve to that measured outside the site (Rawson *et al.* 2004).

Although the site in general drains between each spring tide, the gradient of the realignment site is less than the salt marsh adjacent and in front of the site, and there is a considerable amount of standing water left on the site between tidal inundations and over neap periods (Photo 9.2). This feature may be beneficial to birds (J.Badley, RSPB Freiston Reserve, pers. comm.), but is detrimental to sediment stability and vegetation establishment. As expected, vegetation is absent in areas covered by standing water after the tide has receded at Freiston, and areas covered in permanent water, such as Site 1 on Transect F have not continued to accrete sediment since it has become permanently waterlogged with several centimetres of standing water. The sediment level was difficult to measure accurately at TFS1 as it had such high water content, but the results indicate that the sediment level has decreased over the last three years. Presumably the highly fluid and unstable sediment at this site goes into suspension at each tidal flooding.

An estimate of the extent of standing water remaining on the site after the tide has receded was made from a preliminary composite Airborne Thematic Mapper (ATM) image compiled from data acquired by the NERC ARSF (Airborne Research and Survey Facility) in 2006. The total area estimate for the managed realignment measured from the base of the seawalls was approximately 68ha, of which 5.6ha (8.2%) was occupied by standing water at low tide (A. Thomson, pers. comm.). The data had not yet undergone full georegistration when this estimate was made and therefore should be regarded as an approximation. As noted previously, some salt marsh has been lost in front of the site due to extensive enlargement of the cross sectional areas of creeks. This process started initially near low water and has cut back to the realignment site breaches (Rawson *et al.* 2004). A similar process with the formation of deep wide creeks has occurred on the mudflats opposite the two breaches at the Paull Holmes Strays realignment site. By 2006 at Paull Holme Strays a deep channel had cut down and back through the narrower southern breach (Brown and Brown 2006) and by April 2007 it had connected to the end of a drain crossing the site to the breach (S.L. Brown, pers. observation).

At Freiston, the loss of some external salt marsh to creek widening combined with the extent of standing water in the site may potentially have implications for meeting the requirements for net salt marsh creation, depending upon the definition of salt marsh in this respect (e.g. if it is vegetated and creek area only). Although we do not have an estimate for the loss of marsh in front of the realignment, net salt marsh area created by the Freiston realignment so far would appear to be closer to 60ha or less, rather than the 66ha estimated initially.

Some creeks were excavated at Freiston to join up with the breaches. Since the site was breached, many of these creeks have widened and several new creeks have been forming on the realignment site.

At Tollesbury, Watts (2002, in Reading *et al.* 2002) found that embryo creeks only formed in the newly accreted sediments once a critical depth (20-30cm) was reached, and subsequently the banks drained faster than the surrounding sediments and showed an increase in sediment stability and shear strength. *Salicornia europaea* colonised the edges of the embryo creeks, but not the adjacent sediments with higher water content. In general the accreting sediments at Tollesbury had poor drainage, low bulk density and low resistance to resuspension and erosion, and were slow to develop a system of drainage creeks. This was thought to be due in part to the formation of an unconsolidated horizon with low hydraulic conductivity on the reclaimed agricultural soil, forming an aquaclude or barrier to water (Crooks *et al*. 2002). The extent to which creek development is limited to newly accreted marine sediments probably depends on several factors, including site history (time since reclamation that influences elevation and soil properties) soil type, grain size, compaction and consolidation, and physical and chemical changes in the agricultural soil that may be irreversible (Hazelden and Boorman 2001). The observations at Tollesbury suggested that creeks would not develop in the underlying agricultural soil.

At Freiston, many drainage creeks have developed in areas where there has been considerable deposition of mobile sediment (e.g. around the lower ends of Transects C and D, opposite the central breach) and where vegetation cover is sparse (largely annual species). The excavated creek leading to the central breach has widened considerably as large blocks of agricultural soil have collapsed along the sides, and side creeks have been forming off this (Photo 9.5). Unlike Tollesbury the agricultural soil at Freiston does not form a barrier to creek formation. Numerous deep creeks have been developing down through the agricultural soil at many areas on the site, particularly along the seaward section where the water drains off into the soke dyke behind the old embankment (Photos 9.6 and 9.7). Side creeks have also been cutting back from the edges of the excavated creeks further into the site (Photo 9.8) with large blocks of soil collapsing into the creeks even where the surface is well vegetated.

The sediments on this side of the Wash are relatively sandy compared with the muds within the Humber Estuary or those fronting the Essex salt marshes, such as in the Tollesbury area. It is only just over 20 years since the Freiston site was reclaimed from salt marsh and the soil under the newly accreted sediment appears quite loosely consolidated. Although creek development inside the site will improve drainage and increase transport of suspended sediment to the marsh surface and access for fish to upper areas of the site, the rapid erosion of some creek sides and headward extension of some new creeks inside the site, particularly those draining to the central breach (Photos 9.5, 9.9 – 9.12) could be a setback if several large creeks develop close to each other and the marsh between collapses. One possible area of concern is an area between Transect C and D where there has been a lot of standing water with little vegetation and where channels have been developing over a wide area (Photos 9.13 and 9.14). This area drains towards a creek that has been cutting back, shown in Photos 9.9 -9.12. To date, the sites along Transect D closest to this area have accreted sediment since the site was breached, although the surface level dropped slightly at the upper four sites on Transect C and upper two sites on Transect D during the summer of 2006, and levelled off on Transect C Site 5 and Transect D Site 3. Whether this is just part of the seasonal variation in accretion (winter *vs* summer) observed at many sites inside and outside the realignment, or whether it is the beginning of a general lowering of this part of the site as water drains off and erodes the surface remains to be seen and would need further monitoring to determine the trends in accretion / erosion in this area of the site.

Prior to the breaching it was recommended that the realignment area was ploughed and then levelled by raking to remove furrows and prevent channelling of water and consequent erosion (RSPB 2005). However, furrows that channel water are still visible in some areas, and it is questionable whether ploughing to loosen the soil further is a good option for all soil types and consistencies.

As the slope of the realignment site is more gradual than the adjacent marsh and has several flat areas that do not drain, there are large areas of standing water which will affect the stability and erosion potential of the underlying sediment. It may be worth considering pre-breach contouring of sites that lie on relatively flat agricultural land to provide a gradient that will facilitate better drainage. Increasing the slope of a potential realignment site will also increase the diversity of plant communities that inhabit different elevation zones and improve the conservation value of the site. At Freiston, for example, there are few areas outside the realignment that are even high enough for upper marsh species such as *Elytrigia atherica* to grow. This vegetation type provides nesting areas for birds. It would also be possible to grade the site landward to the defence embankment to create elevations appropriate for transitional plant communities to establish. This would add greatly to the conservation value of a site as these communities are rare on many east coast marshes that have been truncated by flood defence embankments after reclamation. However, because they are rare there may be an insufficient supply of propagules of transition zone plants for such a zone to develop naturally.

It is recommended that a detailed topographic survey is carried out on sites selected for future realignment schemes, either by a ground-based RTK GPS survey or by remote sensing using LIDAR which has improved in accuracy in recent years (providing that terrestrial vegetation is cut down before any remote sensing elevation surveys). A pre-breach detailed topographic survey of elevations to produce a contour map 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. Although a topographic survey and any necessary contouring of the site and excavation of drainage creeks will increase initial costs, they are worth considering in cases where there may be potential problems with drainage that can not be easily remedied post-breach.

According to Harvey *et al* (1983) and Haltiner and Williams (1987), drainage networks should be designed so that no point on the marsh surface is further than approximately 30m from a channel and should meander in a pattern similar to local natural systems. This represents a much greater density and complexity of drainage creeks than was constructed at Freiston, and to create this artificially would incur additional costs.

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 further. 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, creek profiles, creek densities and design. 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 the Humber Estuary.

9.8 Summary

In conclusion, the results of the ecological monitoring programme have shown that during the first four years most areas of the Freiston site have accreted sediment at a rate similar to the adjacent salt marsh 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. Organic matter and total nitrogen content in the newly accreted sediments were shown to be generally similar to the adjacent marsh although still somewhat lower at lower elevations. 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 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 species, and how optimum conditions could be encouraged by site design (pre-treatment) or management techniques.

Photo 9.5 Creek side erosion of excavated creek inside MR, looking towards central breach. Photo: Sue Brown, April 2007

Photo 9. 6. New creek running into soke dyke behind the old embankment, looking towards central breach. Photo: Sue Brown, October 2005

Photo 9. 7.. New side creek cutting back by SET Site 7. Photo: Sue Brown, April 2007

Photo 9.8. Formation of side creek and headward erosion inside MR. Photo: Sue Brown, April 2007


Photo 9.9. New creek (shown in 9.6) cutting back towards TDS6, looking away from central breach. Photo: Sue Brown, October 2005


Photo 9.10. New creek shown in 9.9. looking towards the central breach. Photo: Sue Brown, October 2005

Photo 9.11. New creek shown in 9.10 cutting back further from the central breach. Photo: Sue Brown, April 2007

Photo 9.12. Headward extension of new creek (shown in Photos 9.9-9.11) now close to TDS6 (figure standing at TDS6). Photo: Sue Brown, April 2007

Photo. 9.13. Wide drainage area near Transect D with shallow runnels forming, looking landward towards new embankment. Photo: Sue Brown, April 2007

Photo. 9.14. Sparsely vegetated wide drainage area on Transect D (taken near TDS3) looking seawards towards former sea wall. Photo: Sue Brown, April 2007

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