From: dave-hickling
Sent: 30 July 2012 11:37
To:
Cc: Able Marine Energy Park
Subject: Able Marine Energy Park

Follow Up Flag: Follow up
Flag Status: Red

I enclose a copy of an independent report by Roger Morris of Bright Angel Coastal Consultants regarding the proposed compensation site at Cherry Cobb Sands on behalf of Mr Stephen Kirkwood.

This report is referred to in the earlier submission made on Mr Kirkwood's behalf and will be used as part of his submissions to the Issue Specific Hearing on 11th September

My unique reference number is

David Hickling.
Hickling Gray Associates.

Evaluation of the proposed AMEP compensation site at Cherry Cobb Sands

For

Mr Stephen Kirkwood
Sands Farm

By

Roger Morris
Bright Angel Coastal Consultants Ltd

29 July 2012

Contract title: **Evaluation of the proposed AMEP compensation at Cherry Cobb Sands**

Client: Mr Stephen Kirkwood
D J Kirkwood & Son
Sands House
Cherry Cobb Sands Road
Burstwick
Hull
North Humberside
HU12 9JX

Prepared by Roger Morris

Bright Angel Coastal Consultants Ltd.
7 Vine Street
Stamford
Lincolnshire
PE9 1QE
01780-753419
brightangel.coastal@googlemail.com
www.bacoastal.co.uk

Executive Summary

1. This analysis compares the mudflat at the proposed AMEP development site with examples of managed realignment used to compensate for other port developments. It is extensively illustrated with photographs of the relevant features and with diagrams that help to explain the key issues. Evidence is also presented from a variety of other realignments which form an important body of experience on the performance of realignment in creating mudflat.

2. **The report concludes that the compensation site at Cherry Cobb Sands will not deliver comparable functionality to the mudflatst that will be lost on the AMEP frontage**.

3. This conclusion is reached by examining the ways in which managed realignment sites evolve. The theory behind coastal evolution is discussed, together with its relevance to the use of managed realignment as a conservation management tool. The report is laid out sequentially to explain the following key points:

   - There are specific reasons for adopting managed realignment as a tool for offsetting loss of habitat within sites designated as Special Areas of Conservation, Special Protection Areas and Ramsar Sites. The linkage is directly related to the need to maintain of coherence of the Natura 2000 series by offsetting loss of extent and functionality.

   - Case law has generated a series of metrics for compensatory measures that might be interpreted as having a strictly numerical foundation. In fact, each package has been developed to address specific issues of functionality and as such there is no reason to believe that a package of offsetting measures can always be agreed or delivered. The closest analogue to this proposal is Dibden Bay where there remained outstanding issues about the viability of the offsetting measures at the onset of the Public Inquiry. In that case the failure to find a functionally viable solution was a significant factor in the decision not to grant consent.

   - There are obvious and profound differences in the form and function of a linear strip of estuarine mudflat and the habitat provided by realigning sea walls. **These differences are especially important when considering the implications for specialist waterbirds such as Black-tailed Godwits**.

   - The evidence shows that managed realignment sites can be expected to evolve into saltmarsh over time. The time-period involved will vary according to the geometry of the site, the suspended sediment loads in the estuary concerned and the degree to which the site is exposed to wave action. **In the Humber there is very good evidence that saltmash will develop very quickly regardless of where the realignment is sited or of its breach geometry.**

   - Managed realignment sites create inter-tidal habitat at the upper end of the tidal frame. As such they only offer a small proportion of the functional contribution made by mudflats that are exposed to the full range of tidal and wave energy influences.

   - Black and Veatch's own analysis highlights two important design criteria for constructing managed realignment with longer-term sustainability as mudflat. Firstly the realignment should be orientated towards the highest level of wave energy so as to minimise sedimentation rates. Secondly, where saltmarsh exists in front of a realignment site both the old sea wall and the saltmarsh should be removed. Neither of these criteria has been met in the favoured design reported in the supporting documentation.

- Breach design will at best provide a temporary influence over sedimentation rates. The ultimate outcome will be the evolution of a site with a relatively flat topography composed of saltmarsh and mudflats that are exposed to tidal influences over a most of the tidal cycle. One of the best examples for the Humber (at Chowderness) was created in 2006 and is now effectively dry over the neap part of the spring-neap cycle. This is despite fitting the design criteria highlighted by Black & Veatch

- Managed realignment has been a useful tool in providing compensatory measures where the migratory waterbird populations affected are not dominated by specialist long-billed feeders such as Black-tailed Godwits. It cannot be assumed that this mechanism of habitat creation is appropriate in all cases, or that previous multipliers used to determine the necessary extent of offsets can be used in all cases.

4. This analysis is a new contribution to the arguments about the use of habitat creation to offset losses of inter-tidal habitat. It suggests that there is an urgent need to re-appraise the assumptions that have been made to date about the use of realignment to offset loss of waterbird feeding habitat. In particular it suggests that compensation sites may have been far too small and that there are governing factors that require a significant change in the approach to their design. In particular much more attention needs to be paid to the topography of the lost site as well as that of the compensation site.

5. The analysis suggests that there are circumstances where it will not be possible to compensate for loss of habitat or functionality. In the case of the Humber Estuary it is clear that its high sediment load gives it immense resilience in terms of the potential for realignment to develop saltmarsh and to provide improved flood defences. This strength brings with it the drawback that creation of mudflat habitats is largely impossible at the scale of intervention proposed to date.

6. Bearing in mind that the key issue facing the competent authorities is whether the coherence of the Natura 2000 sites can be maintained, **this analysis argues that the proposed compensation will not achieve this objective**. As such, the legal basis for granting consent for the AMEP project is in doubt because it is not possible to attach any confidence to the likely effectiveness of compensatory habitat creation.

7. If managed realignment is to remain a means of compensating for major losses due to incursions onto mudflats, there is an urgent need for the statutory nature conservation bodies to re-examine design criteria and to provide clear guidance on what is suitable and where.

Contents

	Chapter	Pages
1	Preamble – experience	1
2	Understanding of the proposals	2-3
3	Characteristics of the AMEP site (foreshore)	4-6
4	The proposed compensation site at Cherry Cobb Sands	7-8
5	Comparison with other major port developments	9-10
6	Previous compensation sites and other relevant analogues	11
7	How does managed realignment work and why does it behave in a predictable manner?	12-17
8	Predicted evolution of realignment site at Cherry Cobb Sands	18-20
9	Assessing the potential of the proposed Cherry Cobb Sands managed realignment as a compensatory measure	21-23
	Glossary	24 - 25
	References	26 - 27
	Appendices – photographs	28
	A1.1. – A1.6. AMEP site	33-35
	A2.1. – A2.4. Cherry Cobb Sands compensation site	36-37
	A2.1. – A3.8. Chowderness	38-41
	A4.1. – A4.8. Paull Holme Strays	42-45
	A5.1. – A5.2. ABP Welwick	46
	A6.1. – A6.6. Freiston Shore	47-49
	A7.1. – A7.2. Tollesbury	50

Figure 1.	The foreshore at the proposed Able Marine Energy Park.	1
Figure 2.	Location of the AMEP compensation site at Cherry Cobb Sands	7
Figure 3.	Simplified depiction of mudflat and saltmarsh evolution.	13
Figure 4.	The sea wall at Cherry Cobb Sands immediately west of the proposed realignment site.	14
Figure 5.	Rates of saltmarsh development within Paull Holme Strays, 2003-2008.	19

Figure 6.	The relative positions of the realignment site and mudflat whose loss it is intended to compensate for.	22
Figure 7.	The relative positions of the realignment site after sedimentation and mudflat whose loss it is intended to compensate for.	22
Table 1.	Data available on relevant analogues.	16
Photograph 1.	The foreshore at the proposed Able Marine Energy Park.	4
Photograph 2.	Foreshore at the Immingham end.	5
Photograph 3.	Saltmarsh at the Humber Sea Terminals end of the site.	6
Photograph 4.	Arable at Cherry Cobb Sands within the proposed compensation site.	8
Photograph 5.	Stone Creek, Humber Estuary.	13
Photograph 6.	Tollesbury realignment, Blackwater Estuary.	17

1. **Preamble – experience**

1.1. This analysis was prepared by Roger Morris on behalf of Mr Stephen Kirkwood, a registered objector to the proposed managed realignment at Cherry Cobb Sands (part of the application for a Development Consent Order for Able UK's proposed Marine Energy Park).

1.2. Roger Morris is Principal at Bright Angel Coastal Consultants Ltd. He holds an Honours Degree in Zoology with Applied Zoology from the UCNW Bangor (1980), is a Chartered Environmentalist, a Fellow of the Institute of Ecology & Environmental Management, a Fellow of the Royal Entomological Society and an Associate Member of the Institute of Civil Engineers. He has published on a wide variety of coastal management issues and specialises in the use of analogues to explore the issues arising from engineering interventions.

1.3. Roger Morris worked for the Nature Conservancy Council and its successors English Nature and Natural England from 1988 to 2009. During this time, Roger was, *inter alia*, 'Conservation Officer' for the south side of the Humber Estuary (1994-1998) and 'Head of Estuaries Conservation' (1998 - 2006) for English Nature.

1.4. During the period 1992 to 2009 Roger was involved in marine and coastal conservation issues in the Medway Estuary (1992-1994), Humber Estuary (1994-1998) and all English estuaries (1998-2009). He was responsible for designating North Killingholme Haven Pits SSSI and for the early stages of revising the Humber Flats, Marshes & Coast SPA and Ramsar Site. He was also closely involved in the early stages of the development of the Humber Estuary Flood Risk Management Strategy, the Humber Estuary Management Strategy and most of the major port development cases in England from 1998-2009. This experience included negotiation of compensatory measures at Dibden Bay, Bathside Bay, London Gateway and Bristol Container port.

1.5. In addition, Roger was a member of the steering group for the Wallasea Island managed realignment site which was compensation for port developments at Fagbury Flats and Lappel Bank. He was also a member of the Quality Review Panel for TE2100 (the Flood Risk Management Strategy for the Thames Estuary).

1.6. This experience is closely linked to interpretation of the Habitats Regulations (1994) (now updated and revised in the Habitats & Species Regulations 2010). Part of this experience also derives from involvement in several European studies into the application of the Habitats Directive in relation to port development (e.g. Paralia Nature and NEW!Delta).

2. Understanding of the proposals

2.1. Able UK proposes to build a marine energy park (AMEP), including a deep water quay occupying land and foreshore between North Killingholme Haven and the oil transfer jetty east of ABP's Humber International Terminal at the port of Immingham. The proposal is expected to lead to the following losses and changes within the inter-tidal environment:

	Saltmarsh (Ha)	**Inter-tidal mudflat (Ha)**	**Sub-tidal mudflats (Ha)**
Direct Loss	0	-31.5	-13.5
Indirect loss		-10.35	-9.83
Indirect gain	12.3	7.88	
Temporary functional loss	N/A	-6	N/A
Total area lost	**12.3**	**-39.97**	**-23.33***

*Note – loss of sub-tidal habitat involves partial loss and partial changes in functionality

2.2. The inter-tidal environment within the affected area is designated as a Special Protection Area (SPA), Special Conservation Area (SAC) and Ramsar Site. This means that Regulations 61 and 62 of the Conservation of Habitats & Species Regulations (2010) apply. There is common agreement that these changes and losses mean that it is not possible to conclude no adverse affect[1] on the integrity of the Humber Estuary. This means that Regulation 66 will apply.

2.3. Regulation 66 of the Habitats & Species Regulations states that:

'*Where in accordance with regulation 62 (considerations of overriding public interest)—*

(a) a plan or project is agreed to, notwithstanding a negative assessment of the implications for a European site or a European offshore marine site, or

(b) a decision, or a consent, permission or other authorisation, is affirmed on review, notwithstanding such an assessment,

the appropriate authority must secure that any necessary compensatory measures are taken to ensure that the overall coherence of Natura 2000 is protected.'

2.4. The Environmental Statement and supporting documentation for the Able Marine Energy Park recognises the need to incorporate compensatory measures and describes a managed realignment as one component of the proposals for offsetting impacts on nature conservation assets.

[1] Note, the use of the double negative is deliberate and relates to the application of the precautionary principle within the Habitats Regulations.

2.5. This analysis therefore focuses upon the proposed package of compensatory measures and the degree to which the 'appropriate authority' can be confident that the overall coherence of Natura 2000 is protected. It focuses specifically upon issues relating to the Humber Estuary Special Protection Area but also touches on the issues relating to the Special Area of Conservation and Ramsar Site.

2.6. The affected inter-tidal foreshore is known to support most, but not all, of the waterbird species that contribute to the key features of the Humber Estuary SPA. Many of the migratory waterbirds affected are the same species affected by other development proposals that have been consented on the Humber Estuary and elsewhere. Therefore, in theory, similar approaches for compensatory measures might be expected to apply. A description of past cases is provided in Morris & Gibson (2007).

2.7. There is one exception: Black-tailed Godwit, *Limosa limosa* (*islandica* race), which occurs in exceptionally large numbers on the affected foreshore (2566 birds forming 66% of the population within the Humber Estuary). The only previous case of a development affecting a particularly important population of waterbirds was the London Gateway project in which a population of 1300 Avocet, *Recurvirostra avosetta*, was expected to be displaced by functional changes to the mudflats at Mucking Flats (changes in level through accretion and saltmarsh development).

2.8. The issues and proposals also involve terrestrial impacts and loss of roosting/loafing areas on arable land that are an important but separate matter that is not addressed in this analysis.

3. Characteristics of the AMEP site (foreshore)

3.1. This is a linear section of foreshore approximately 2.6 km long (Figure 1; Photograph 1) (also see photographs in Appendix A1.1.-A1.6). It varies in width from around 100 metres to around 300 metres. It is primarily composed of fine muds that are inundated on all tides. However, there is a narrow strip of foreshore close to the sea wall at the Immingham end where there was some evidence of cracking on 15 July 2012. The date of the visit coincided with low tide on a neap tide, which suggests that this area is not subject to tidal influences for part of the spring-neap cycle (i.e. its elevation is raised above tidal inundation for part of the spring-neap cycle).

Figure 1. The foreshore at the proposed Able Marine Energy Park. Based on Google Earth photograph downloaded 15 July 2012.

1 – Creek
2 – Vegetating foreshore (Immingham end)
3 – Saltmarsh (Humber Sea Terminals End)

Photograph 1. The foreshore at the proposed Able Marine Energy Park. This illustrates the gently sloping open mudflats that are favoured by Black-tailed Godwits. 11/07/2012.

3.2. The majority of the mudflats grade up to a rubble-strewn section below the concrete sea wall, but there are odd places where remnants of former saltmarsh can be seen as consolidated clays lying slightly proud of the surface. In places, where the sea wall is set further back there is a narrow vegetated strip.

3.3. The mudflat surface is composed of relatively poorly consolidated sediments overlying layers of increasingly coherent material (clays), although there are places where some drying appears to have taken place.

3.4. About half way down the site a gravity drain from the adjacent farmland forms a deep creek through the mudflats (see photograph in the appendices). This creek is highly sinuous and exhibits localised slumping which suggests that the adjacent sediments are weakly consolidated.

3.5. At the Immingham (eastern) end of the site, there is evidence of vegetation spreading over the mudflats. This is in the lee of Humber International terminal. Note, there has been foreshore progradation (Photograph 2) around Humber International Terminal, which was argued by ABP at the time to offer a measure of offset for the loss of the foreshore which was incorporated into the port development (two phases, one opened in 2000 and the other in 2006).

Photograph 2. Foreshore at the Immingham end with scattered vegetation development. 11/07/2012.

3.6. At the Humber Sea Terminals (western) end of the site, there is an area of saltmarsh that has clearly undergone a period of recession followed by advancement (Photograph 3). The author is familiar with this section having regularly visited it since 1994. Saltmarsh has been advancing for several years and shows evidence of terracing, which is a feature normally associated with hypertidal estuaries such as the Severn and Solway. In this respect, foreshore evolution of this form is a matter of scientific interest in its own right.

Photograph 3. Saltmarsh at the Humber Sea Terminals end of the site. 11/07/2012. Point 1 marks the location of the original saltmarsh cliff. Point 2 marks the position of secordary cliffing at the outer limits of saltmarsh advance. These combined features are weak but direct parallels to saltmarsh terraces than can be seen on the Seven Estuary.

4. The proposed compensation site at Cherry Cobb Sands

4.1. The application for a Development Consent Order for the AMEP proposal recognises that there will be a sufficiently large loss of inter-tidal habitat that compensatory measures will be necessary in order to comply with the provisions of the Habitats Directive. This is correct. It appears that a site at Cherry Cobb Sands is favoured (See photographs in Appendix A2).

4.2. There is no absolute metric for determining the extent of compensatory measures, as discussed in chapter 5. However, it is important to recognise that straightforward 1:1 ratios are rarely possible because there are uncertainties about the likely effectiveness of such measures. Furthermore, there is almost inevitably a time-lag between habitat creation and its developing any functional contribution to the Natura 2000 series.

4.3. At the time of writing (mid-July 2012) it appears that the proposed dimensions and design of the compensation site have yet to be finalised. However, it is understood that the preferred site is located on the north bank of the Humber directly opposite the proposed AMEP development.

4.4. This site (photograph 4) is largely or wholly occupied by Mr Stephen Kirkwood (depending on the configuration) as a tenant of the Crown Estate Commissioners. It is situated west of Stone Creek and lies behind a part of the Humber Estuary that is currently accreting. It is also in close proximity to both the Paull Holme Strays managed realignment site and the ABP Welwick compensation site (figure 2).

Figure 2. Location of the AMEP compensation site at Cherry Cobb Sands (2) in relation to nearby managed realignment sites at Paull Holme Strays (1) and ABP Welwick (3). Map downloaded from Google Earth on 16 July 2012.

4.5. The proposed site lies within the middle part of the Humber Estuary according to the boundaries set by the Humber Estuary Flood Risk Management Strategy (Environment Agency, 2000). This section of the Humber is believed to behave in a different manner to the outer estuary, which includes the mudflats and sandflats between Hawkins Point and Spurn.

Photograph 4. Arable at Cherry Cobb Sands within the proposed compensation site. 11/07/2012.

5. Comparison with other major port developments

5.1. There is a growing number of UK port development projects that have been consented on Imperative Reasons of Over-Riding Public Interest (IROPI) and that have included compensatory measures. Five are particularly relevant:

- Harwich Haven channel deepening
- Bathside Bay
- Bristol container port
- Immingham Outer Harbour
- London Gateway

5.2. In each of the above cases a package of compensation involving managed realignment was incorporated as part of the package of offsetting measures (some of which were deemed mitigation). No standard formula was applied to the agreement on the relationship between habitat lost and new habitat created. For example, compensatory habitat creation at Trimley (for Harwich Haven channel deepening) involved 4.5 ha to offset direct losses (4.5 ha) and a further 12 ha to act as a precaution against failure of a sediment feeding agreement (4 years at 2.5 Ha per year). Immingham Outer Harbour, by comparison (around 25 ha lost) was consented together with compensatory measures at Welwick and Chowderness of over 60ha that cumulatively amounted to around 2:1 (measures included offsetting for Hull Quay 2005).

5.3. It should also be borne in mind that apart from the Bristol container port proposals, all of the other cases relate to port development affecting habitat designated primarily for its migratory waterfowl in relation to designation as a Special Protection Area. The AMEP project therefore draws attention to aspects of compensatory habitat provision that have hitherto only been addressed on one occasion (a package that considered functionality and used much higher ratios of replacement to loss).

5.4. London Gateway largely focussed on offsetting functional changes rather than loss, and included further measures to offset loss of newly created habitat under ESA agreement. The compensation site for Bristol container port nominally looks like a ratio of 5:1 but in fact includes measures specifically designed to offset functionality rather than direct losses. Bathside Bay, meanwhile, largely focussed on the loss of a waterbird feeding area and the creation of habitat in a similar position in an adjacent SPA, and therefore illustrates how efforts have been madeto replicate the features lost in a manner that is most likely to deliver the desired outcomes.

5.5. It must also be borne in mind that the Wallasea Island realignment site has been developed to act as compensation for two port developments in the early 1990s in which the Secretary of State was required to provide new habitat because of a failure in the regulatory system. Wallasea Island provides compensation for habitat loss at Fagbury Flats (Port of Felixstowe) and Lappel Bank (Port of Sheerness). In this case, the habitat had been lost a decade or more previously and the offsetting was undertaken in a location some distance from the affected Special Protection Areas (Stour & Orwell Estuary, and Medway Estuary).

5.6. In addition, Dibden Bay, the ABP proposal for a container port in Southampton Water, provides a useful analogue even though it did not gain consent. This is useful for two reasons, firstly in the (in)adequacy of the offsetting proposals; and secondly in the nature of the proposals which involved functional changes as well as a creek which was an innovative concept.

5.7. The cases outlined above clearly show that the process of designing offsetting measures has focussed very carefully upon functionality as well as upon the loss of extent, with greater areas involved where there were uncertainties about changes in functionality.

5.8. The Able UK proposal for offsetting at the time at which this analysis was written (mid-July 2012) appears to be incomplete. It is noted that Natural England have outlined in their submission that certain critical information has not been supplied to them and it seems that a precise design, including extent and location, has yet to be completely defined. This offers an immediate parallel with Dibden Bay, where negotiations relating to the overall package of compensatory measures carried on during the Public Inquiry. New measures developed during this process were ruled inadmissible to the process by the Inspector.

5.9. It is also noteworthy that unlike other port development proposals that were consented on grounds of IROPI this proposal involves a compensatory package that appears not to have been agreed and which is not accompanied by a Compensation, Mitigation and Monitoring Agreement (CMMA) as has happened elsewhere. The presence of such an agreement has been a critical factor in the consenting process for most of the major port developments in the past ten years and as such it is an indicator of the degree to which the applicant has taken account of the concerns of the statutory agencies and the NGOs. This is pertinent because agreement with the NGOs and statutory agencies provides the Secretary of State with reassurance that the package is sufficiently robust to maintain coherence of the Natura 2000 series. If no agreement is reached, then there remains the risk that the decision will be challenged in the European courts.

6. Previous compensation sites and other relevant analogues

6.1. Out of the five compensation packages listed in section 4.1., only two have been completed and provide useful information on performance.

6.2. The Trimley realignment in the Orwell Estuary has performed well and meets its design parameters. It is slowly becoming saltmarsh but retains some mudflats. This site was designed to offset loss of extent at extreme low water and was not required to accommodate a particular assemblage of waterbirds.

6.3. ABP completed two realignments on the Humber Estuary to compensate for loss of mudflats at Immingham Outer Harbour and Quay 2005 (Hull). These mudflats were very similar to those that will be lost if the AMEP project is consented. They therefore offer an insight into the likely effectiveness of the AMEP proposals. In each case, sedimentation has been extremely rapid and has been accompanied by development of saltmarsh vegetation. Neither appears to attract significant numbers of feeding Black-tailed Godwits.

6.4. There are, however, numerous other realignment sites to draw upon for supporting information. Data are available through ABPmer's *Online Managed Realignment Guide*[2]. Six additional examples have been selected. The rationale for these choices was that each provides a different scenario: sites within estuaries with low levels of suspended sediments; sites in sediment laden environments; sites with differing starting elevations and positions in relation to fronting saltmarsh (see Table1.) .

- Chowderness (Humber Estuary)
- Freiston Shore (The Wash SPA)
- Paull Home Strays (Humber Estuary)
- Tollesbury (Blackwater Estuary SPA)
- Trimley (Stour & Orwell Estuaries SPA)
- Wallasea Island (Crouch & Roach Estuary SPA) (see Dixon *et al*., 2008)

6.5. In addition, examination of the geometry of the shoreline on the Humber Estuary itself can be used to demonstrate how foreshores have behaved in recent decades. It is noteworthy that where there are inland kinks in sea walls saltmarsh almost invariably resides. This can be seen at Cherry Cobb Sands and elsewhere.

6.6. The critical point about of each of these analogues is that they are located in east coast estuaries where suspended sediment loads are relatively high (compared to south and west coast estuaries). They vary in age and therefore offer an insight into site performance over a period of up to 15 years.

[2] http://www.abpmer.net/omreg/search_database.aspx

7. How does managed realignment work and why does it behave in a predictable manner?

7.1. Managed realignments sites are almost without exception[3] former saltmarsh that has been enwalled for human occupancy and agricultural reasons. Consequently it is important to recognise the processes of coastal evolution that have occurred over the 10,000 or so years since the end of the last ice-age (the Holocene). These processes have been driven by a suite of critical factors:

- Relative sea level rise
- Sediment sources (both fluvial and marine)
- Foreshore geometry
- The direction of prevailing winds

7.2. Saltmarsh evolution is a function of low energy environments in which fine sediment carried in suspension is deposited subtidally and on the foreshore. As water depths decrease, the wave climate is attenuated by friction. Waves are primarily responsible for sediment re-mobilisation in shallow water and especially in inter-tidal waters (currents play their part in certain circumstances but must not be looked upon as the primary force). Aspects of this relationship were investigated in modelling studies by HR Wallingford for the DECC Severn Tidal Barrage investigations and are also discussed by Morris (2012a.).

7.3. Thus, where there are substantial sources of suspended sediments and sufficient shallow waters to provide a sink, sediment will be deposited and **provided the wave climate is suitably attenuated** mudflats and saltmarshes will develop. The deposition zone is often referred to as '**accommodation space**'. ***This is fundamental to understanding saltmarsh and mudflat evolution***.

7.4. As mudflats gain elevation they ultimately reach the point where they are exposed for a sufficient number of tides to support halophytic plants; the first colonisers of saltmarshes. They are primarily within the genera *Salicornia* and *Sueda* in high salinity environments but also include the recently evolved *Spartina anglica*.

7.5. This colonisation sets in train an ongoing evolution through a series of zones that support different plant communities as the saltmarsh gains elevation. The plants themselves absorb wave energy and allow more sediment deposition. Under certain circumstances that can happen very rapidly, as is often the case where *Spartina anglica* occurs. Saltmarsh zonation is a classic aspect of plant ecology and arises because different plants have differing abilities to tolerate immersion in salt water and water-logging. Thus, over time the seaward extent of saltmarsh will increase in lateral extent until it reaches the point where a combination of wave and tidal energy limits further accretion.

[3] Northey Island is different because it started off at naturally dry land that would have been affected by sea level rise had it not been defended.

7.6. It must be borne in mind that as mudflats and saltmarshes gain elevation they will be submerged for more limited periods and consequently the potential for sedimentation diminishes (figure 3). This means that accretion rates within realignment sites inevitably decline. However, mudflat and saltmarsh resilience also increases once they are exposed to wind and sun – desiccation and de-watering promotes sediment cohesiveness and thus improves is shear strength.

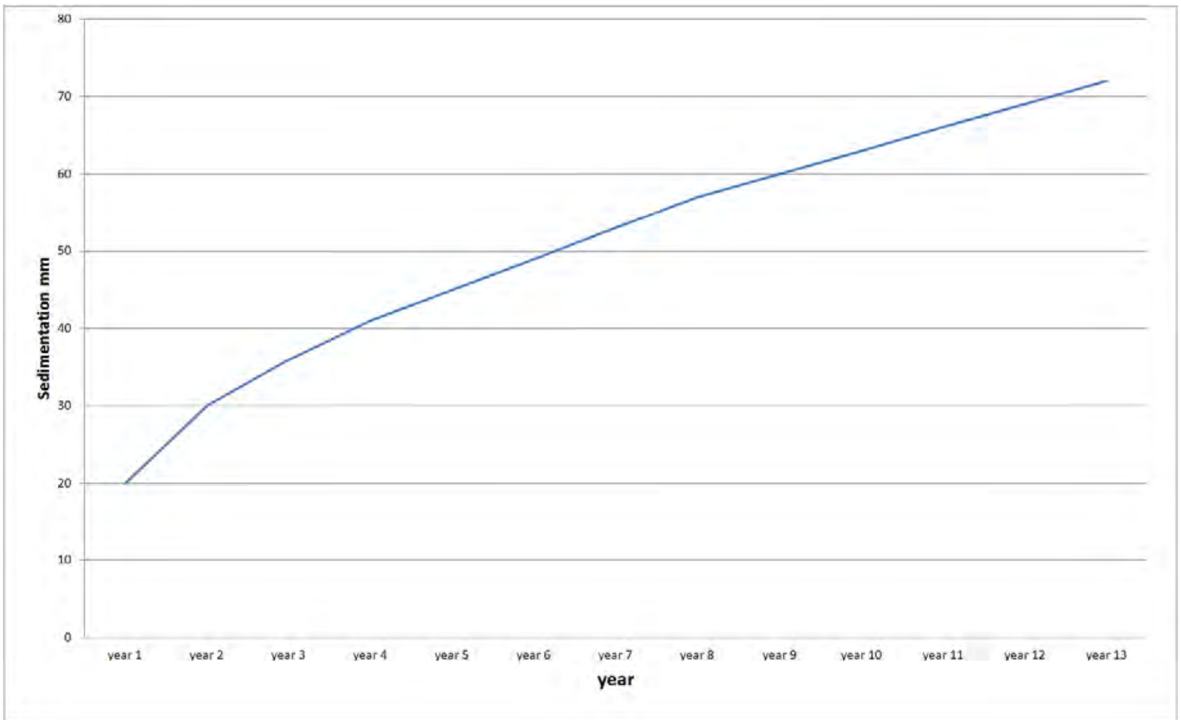


Figure 3. Simplified depiction of mudflat and saltmarsh evolution in which sedimentation rates decline as mudflat/saltmarsh elevation rises.

7.7. In such accreting environments it is noticeable that the gradation between saltmarsh and mudflat is uniform, with no cliffing. Where the energy environment has changed and involves more wave energy, foreshore erosion will lead to saltmarsh cliffing and recession of saltmarsh (see photograph 5).

Photograph 5. Stone Creek, Humber Estuary. 11/07/2012. Location 1 shows saltmarsh cliffing – erosion points where the wave climate causes mudflats to lower and cliffs to form in better consolidated sediments. Location 2 shows the gradual interface between mudflat and saltmarsh where the wave climate is countered by appropriate foreshore geometry. The cliffing process at this point is unusual because it illustrates a period of erosion followed by accretion that has led to the development of a saltmarsh terrace – a feature best illustrated in the Severn Estuary and other hypertidal estuaries such as the Solway.

7.8. Over the last thousand years (although in some places back as far as Roman influences or even earlier) walls have been created to restrict tidal influence to improve grazing for livestock and latterly arable. That process continued until the late 1970s. It has led to our modern estuarine landscape changing from extensive saltmarshes to effectively canalised estuaries with limited saltmarsh. In the case of the Humber, this process has been extreme and the estuary exhibits a comparative paucity of saltmarsh (e.g. see Cave *et al*., 2003; Morris *et al*., 2004).

7.9. This decline in saltmarsh extent has flood risk management implications as well as nature conservation impacts. Several accounts have described the engineering consequences (Brampton, 1992; Empson et al., 1997; Morris, 2012b). Thus, in the case of the Humber, accommodation space has been largely lost, whilst the estuary itself contains huge volumes of sediment that might be expected to lead to sedimentation in remaining inter-tidal. The fact that this does not happen, except where sea walls unexpectedly kink landwards, indicates that inadequate accommodation space remains. An example of saltmarsh development in a sea wall kink is actually present at Cherry Cobb Sands (Figure 4). However, where new accommodation space is created the conditions are suitable for rapid sedimentation and saltmarsh development.

Figure 4. The sea wall at Cherry Cobb Sands immediately west of the proposed realignment site (hatched red). This illustrates the degree to which changes in sea wall orientation can affect saltmarsh development. Based on Google Earth photograph downloaded 14 July 2012.

7.10. The land behind sea walls is already at the position in the tidal frame where it is likely to turn to saltmarsh. The degree to which its elevation varies from modern levels depends upon the interval between the land being claimed from the sea and the time when defences are realigned and the old ones are breached. Former saltmarsh behind sea walls invariably lies below modern saltmarsh elevations. There are several reasons for this:

- Sea level rise means that remaining saltmarshes and mudflats have continued to gain new sediment. The degree to which gains in saltmarsh and mudflat elevation keep pace with sea level rise is a function of sediment availability and the wave energy climate.

- Enwalled land has de-watered and has therefore shrunk. This process will also have included oxidation of organic matter (mudflats and saltmarshes are important carbon sinks).

- The land will have been re-profiled as it is ploughed flat. This will mean that some elevation is lost to fill in former creeks.

7.11. Rates of sedimentation within realignments depend upon a variety of factors linked to sediment availability and to internal wave energy generation. There are three basic scenarios:

- Suspended sediment loads are sufficiently high to permit rapid accumulation of fine sediment. In such cases the realignment site will rapidly vegetate (e.g. Humber realignments, Freiston Shore).

- Suspended sediment loads permit early deposition in the lowest energy areas within a realignment site, thus eliminating evidence of vehicle tracks etc over a series of seasons. However, once a particular threshold is reached sedimentation rates diminish and a long lag occurs before mudflats start to turn to saltmarsh (e.g. Tollesbury, Trimley and Wallasea Island).

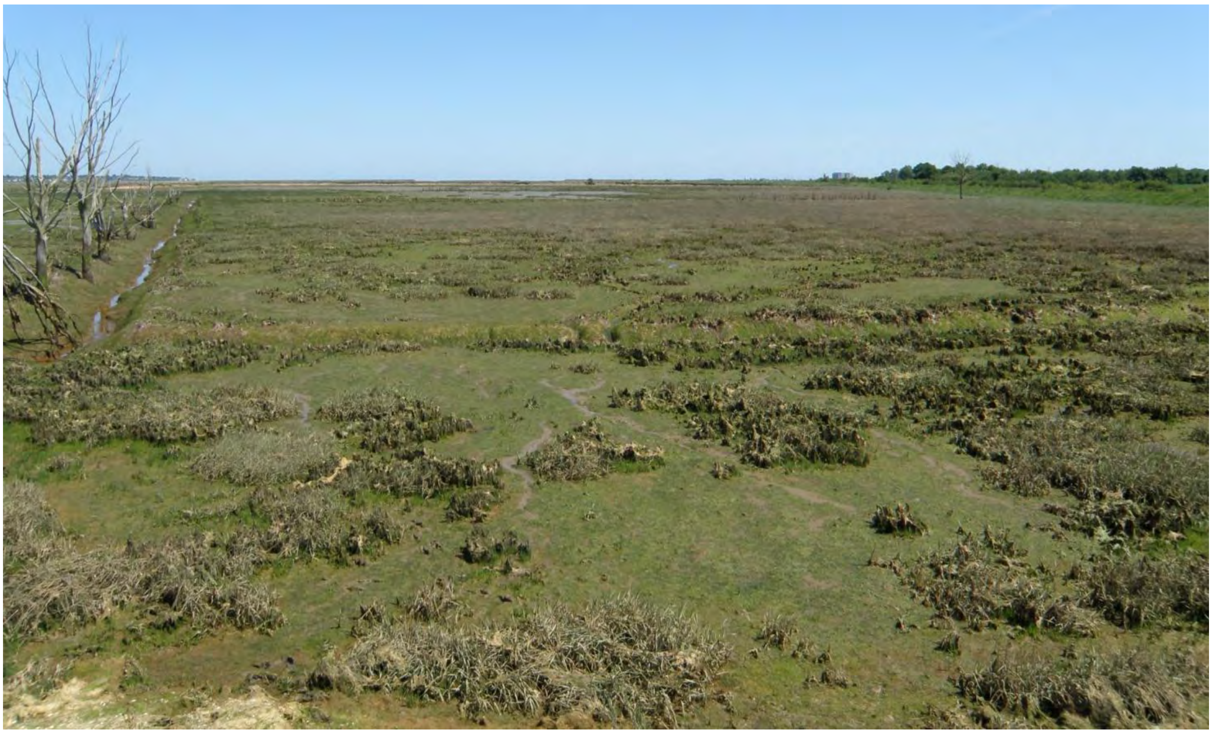
- Suspended sediment loads are insufficient to replace losses during extreme storm events and a dynamic equilibrium develops in which saltmarsh fails to develop but mudflats occur in a dynamic form. This is an unusual situation that can be found in a small number of estuaries with very peculiar geometry – the Blyth, Alder-Ore and Breydon water in East Anglia. A conceptual model for this process is described by Morris (2012b). In some ways, this is the situation that obtains on those parts of estuary shorelines that are composed of mud and not saltmarsh.

7.12. Details relating the evolution of realignment sites on the Humber Estuary, and elsewhere, might be expected to be available, but as Table 1 shows, publicly available information appears to be incomplete. It does however confirm that the behaviour of accreting sediment follows the conceptual profile illustrated in Figure 1.

Locality	Size (Ha)	Elevation	Year of breach	Foreshore in front of realignment	Breach type	Sedimentation rates	Notes
Chowderness	12.2	1.6-4.5m OD	2006	Small area of green foreshore, most of sea wall exposed	Mainly bank removal – two breaches one about 60% of bank length	Around 9cm in year 1. No data for subsequent years.	Site now lies almost entirely above high water neaps.
Freiston Shore	66	2.76-3.26m OD	2002	Saltmarsh in front of sea wall - accreting	Three breaches	Year 1: 7.9mm Year 2: 5.4mm Year 3: 5.8mm Year 4: 7.3mm	
Paull Holme Strays	80	~1.5m OD	2003	Eroding, and toe exposed – wall unsustainable.	Two breaches	28.5-40 cm over the first four years.	Elevation given in OMREG looks wrong (5.1-6.7 OD)
Tollesbury	21	0.9-3 OD (average - 0.6-1.5 MHWN)	1995	Eroding saltmarsh	Single breach	2006/07 (9.6mm) 2005/06 (11.2mm).	Since 1996 there has been a steady decline in the annual rate of sediment accretion of 1.6mm (0.6-2.1mm)
Trimley	16.5	1.5-3.5 OD (at least 70% of site, rest slightly higher)	2000	Little/no saltmarsh in front of sea wall.	Single breach	Unknown	Some dredged sediment placed in site to accelerate development.
Wallasea Island	115	1-3 OD	2007	Partial areas of saltmarsh but heavily degrading and eroding.	Six breaches	Year 1: 10cm Year 2: 5cm Year 3: 5cm Year 4: 3cm	Site composed of three discrete sections
Welwick	54	1.75-4 OD	2006	Fronted by saltmarsh	Two breaches	No details given but highest rate of accretion in year 1.	Bank removed but saltmarsh retained in front i.e. effectively a sea wall!

Table 1. Data available on relevant analogues (note that the main sources are ABPmer Online Managed Realignment Guide (OMREG); Black & Veatch, 2011; CEH, 2008; and Hemmingway *et al*., 2008)

7.13. It is noteworthy that whereas in the Humber where accretion rates within realignment sites have been rapid, rates elsewhere have been much slower. The Tollesbury site exemplifies this and led to controversy over reasons for the slow rate of saltmarsh evolution. One school of thought (Hughes & Paramor, 2004) argued that bioturbation by the ragworm *Hediste diversicolor* might be the reason. An alternative geomorphological explanation was given by Morris *et al*., 2004) in which the rate of accretion was linked to suspended sediment supplies. Additional supporting analysis was provided by Wolters *et al*. (2005). Within two years of the controversy the site greened up and now supports extensive *Salicornia* saltmarsh (see photograph 6).



Photograph 6. Tollesbury realignment, Blackwater Estuary. 02/06/2009. The saltmarsh vegetation extends extensively across a largely uniform foreshore profile. Remaining mud is covered with algal mats, reducing its suitability for foraging waterbirds.

7.14. Past experience can therefore be drawn upon to predict how the proposed realignment at Cherry Cobb Sands will behave. Such predictions will be subject to local variations that will influence rates of sedimentation, but there can be no doubt about the final outcome. Equally, some engineering designs may have a short-term bearing on the sedimentation process, but they are unlikely to affect the final outcome.

8. Predicted evolution of realignment site at Cherry Cobb Sands

8.1. The Cherry Cobb Sands site is reported (Black & Veatch, 2011) to lie fairly uniformly at 2.5m OD. This report provides a helpful overview of the realignments that have previously taken place in the Humber and their implications for a realignment site at Cherry Cobb Sands[4]. The actual elevation of the site will ultimately depend upon the degree to which the current surface is modified by removal of material for use in flood bank construction.

8.2. It has been demonstrated that there is a relationship between the degree of wave exposure a managed realignment site receives and the rate of sedimentation. This is described by Black and Veatch (2011b) who postulate in their analysis of the Cherry Cobb Sands site that this is why the Chowderness site has not accreted at the same rate as other sites within the Humber Estuary[5]. Similar observations have been made for the un-managed realignment at Burgh Castle in Breydon Water (Morris 2012b) and for the unusual estuary forms of the Blyth Estuary, Breydon Water and the Alder-Ore Estuary (Morris, 2012b).

8.3. This observation, together with those made by Black & Veatch on the influence of the saltmarsh in front of the Welwick site on sedimentation, clearly highlights the need to find a location where the realignment can be designed to be exposed to higher levels of wave energy. However, it appears as though the favoured site and design fulfils neither criterion.

8.3.1. The site is fronted by saltmarsh and is long and narrow, making it very difficult to remove a sufficient length of sea wall to expose the site to the wave climate in the estuary.

8.3.2. The design is for a breach at the southern end of the site (Black & Veatch, 2011a), =, This design limits the potential for the site to be exposed to significant fetch and wind-driven wave action that would suppress sedimentation within the site. This in turn means that the design follows the conventional approach of breaches of the order of 250 metres width.

8.4. Bearing in mind the performance of other realignment sites in the Humber Estuary, there can be considerable confidence that the majority of the site will evolve into saltmarsh over a relatively short period; probably in less than ten years. This will depend to some extent upon the degree to which surface materials are removed and used for construction of flood banks. Evidence for this prediction is provided by photographs of the Welwick, Paull Holme Strays and Chowderness realignments in the appendix to this report.

8.5. It must also be noted that even in estuaries where suspended sediment concentrations are much lower, saltmarsh evolution is relatively rapid. Tollesbury in the Blackwater

[4] It also provides a valuable correction to the data given on ABPmer's Online Managed Realignment Guide.

[5] It should be noted, however, that Chowderness is almost entirely at an elevation above high water neaps and that the mudflats are extensively cracked and dried (see photos dated 15 July 2012). It therefore ceases to make any functional contribution to the original objectives set when it was breached in 2006 (6 years ago).

Estuary has been studied in detail. This 21 ha site accreted sufficiently to support 13 ha of saltmarsh vegetation in the 12 years from 1995 to 2007 – i.e. 61.9% of the overall area of the site (CEH, 2008),

8.6. The Cherry Cobb Sands site is orientated broadly in the same way to that at Paull Holme Strays and Welwick and may therefore be expected to experience similar patterns of internally generated wave action and incoming wave activity through the breach. Thus, the wave climate is unlikely to result in any big difference in the rate of sediment remobilisation and so similar rates of sedimentation may be expected. Using data presented in Black & Veatch's own analysis (2011b) it might be expected that if the current land levels were to be maintained (i.e. around 2.5m OD) then between 34.2% and 76.8% of the site would have become saltmarsh over the first five years (Figure 5).

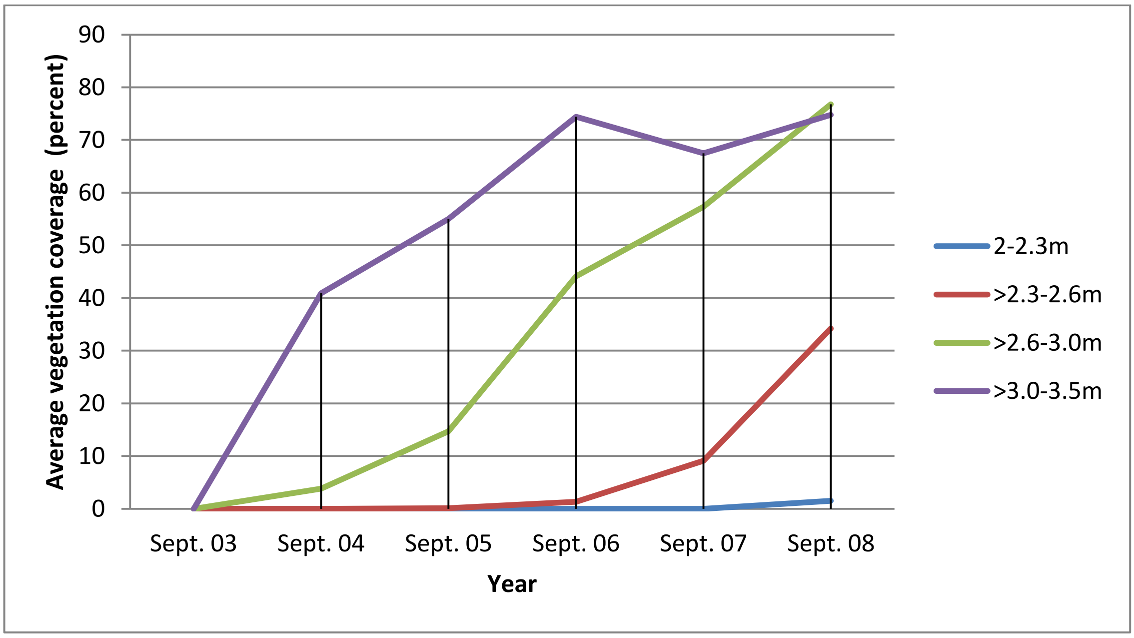


Figure 5. Rates of saltmarsh development within Paull Holme Strays, 2003-2008 according to the topography of the site (based on mudflat elevation in 2005).

8.7. The site is fronted with a growing saltmarsh, suggesting that the local wave climate is sufficiently benign to facilitate mudflat and saltmarsh evolution. If it was more aggressive there would be evidence of foreshore lowering and the need to defend the toe of the flood defences. This does not appear to be the case at any point within the proposed site. This suggests that the site is highly suited to a realignment that will accrete rapidly.

8.8. The proposed breach is intended to minimise disruption of Cherry Cobb Sands Creek and to minimise saltmarsh loss in the area fronting the realignment site. Opting for such a breach in a position at the narrowest end of the site will minimise incoming wave energy. This in turn means that the site can be expected to fill with sediment at a rate commensurate to that at Paull Holme Strays, although a deep channel may evolve within the breach unless it is heavily armoured.

8.9. A further characteristic of managed realignment sites is their overall topography, which also has a bearing on their ultimate form. Unlike mudflats fully exposed to tidal and wave energy, realignments lie at the upper end of the tidal frame. They might experience a tidal range of perhaps two metres at most and also undergo several hours of desiccation whilst fully exposed to the air. This means that sediment consolidates more effectively and consequently over time it gains resilience to most wave conditions. On many realignment sites in the Humber this is illustrated by superficial cracking (see photographs of Chowderness in the Appendix) that shows how the muds have been exposed for a period of days rather than hours, usually on neap tides. This consolidation process also means that most areas apart from the main channels within the site will gain elevation and sedimentation will be ongoing.

8.10. In the case of the Humber, where the tidal range at Immingham is in the order of 6.9 metres, mudflats such as those affected by the AMEP project are exposed to a constant variation in exposure to wind-driven waves and to changing water levels. Provided there is sufficient sediment to maintain that profile, erosion or sediment mobilisation is offset by deposition during subsequent periods of submersion. Rough weather acts as a brake on accretion and hence the foreshore profile reflects the energy regime throughout the tides. This energy environment is completely different from conditions experienced within realignment sites and is the governing process behind the sediment composition and ultimately its ecology.

9. Assessing the potential of the proposed Cherry Cobb Sands managed realignment as a compensatory measure

9.1. This argument is based on the analysis in section 7, and on a comparison between managed realignment sites and the form of the mudflats they are intended to replace. It contends that the following factors should be borne in mind when assessing the likely efficacy of the proposed compensatory habitat for the AMEP project:

9.1.1. An open mudflat that extends from the drying zone above high water neaps down to extreme low water (Figure 6) will be replaced by an enclosed body of tidally inundated sediment. Open sightlines will be replaced by impeded sight lines, and the mudflats that are created will be exposed for the greater part of the tidal cycle, allowing them to de-water, consolidate and change in nature.

9.1.2. Managed realignment sites undergo a period of rapid evolution in which the early stages of sedimentation create sloppy relatively unconsolidated muds (which are favoured by some waterbirds). The animals that first colonise such sites will form prey items for some waterbirds and it has been shown that waterbird numbers do increase over time.

9.1.3. As sedimentation progresses the mudflats gain elevation within the tidal frame and therefore undergo dewatering and consolidation. This process gradually changes the structure of the mud, and whilst larger prey items will become available, mud consistency will not be comparable to that on exposed 'natural' foreshores.

9.1.4. As vegetation develops, there will be a diminution in the levels of wave energy within the site. This in turn will help to stabilise sediments and will also assist sedimentation. In addition, vegetation will start to impede sight lines and make the site increasingly constrained and unsuitable for waterbirds that favour open expanses of mudflats.

9.1.5. The processes of sedimentation will generally be slower in bigger sites and consequently the size and geometry of the site is an important determinant of the site's relative resilience to sedimentation.

9.1.6. Managed realignment sites develop a relatively flat topography that supports organisms that favour the upper end of tidal influences (Figure 7). This topography and its benthos may be suitable for generalist waterfowl with short to medium beak lengths but it will be less appropriate for species such as Curlew, *Numenius arquata*, or Black-tailed Godwit whose bills are designed to seek prey deeper within the mud.

9.2. This means that whilst managed realignment has been used effectively to provide compensatory habitat for many migratory waterfowl displaced by some earlier port developments, the concept and its relevance to specific assemblages of waterfowl needs to be re-examined. This is a debate that requires serious attention from the statutory conservation bodies because the evidence points to weaknesses in the argument explored by Morris *et al*. (2006). Whilst early successional stages in inter-tidal environments are re-creatable using realignment, the extent of realignment required to generate stable and sustainable mudflats is clearly far greater than was first thought.

9.3. The proposed compensation for the AMEP scheme on the north bank of the Humber is arguably the first occasion where a proposal can be seen to affect a significant population of specialist waterfowl by displacement through direct habitat loss. This differs from other schemes in so far as the issues at London Gateway, where a major Avocet population was affected, involved anticipated functional changes and precautionary measures to resolve concerns about the birds' feeding grounds.

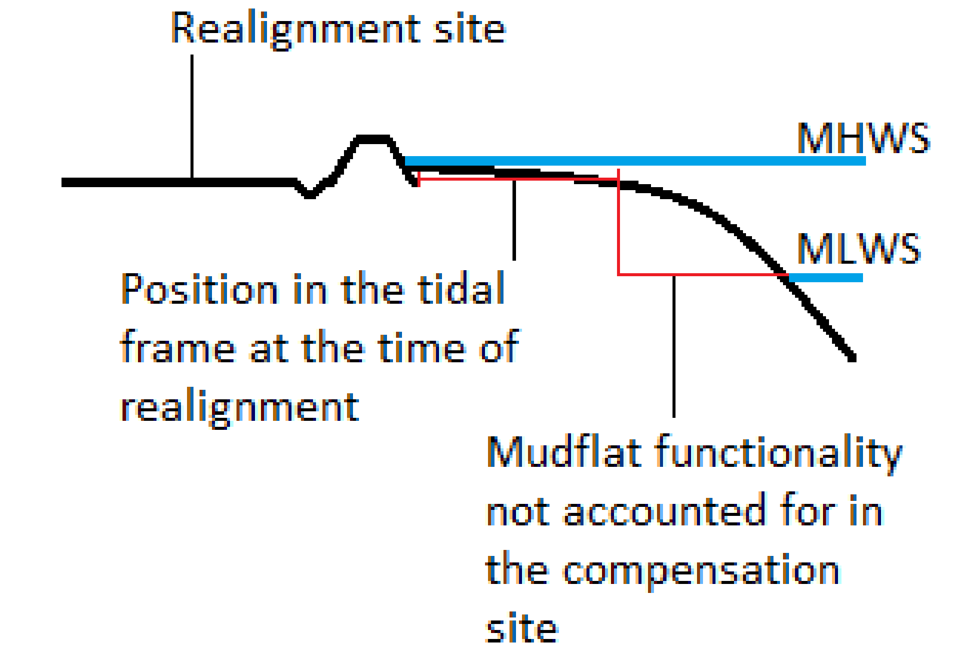


Figure 6. The relative positions of the realignment site and mudflat whose loss it is intended to compensate for. Note that only the uppermost sections will be offset at the time of realignment and the important loafing/feeding areas (see photographs A1.3. to A1.5x in Appendix 1.) will be lost.

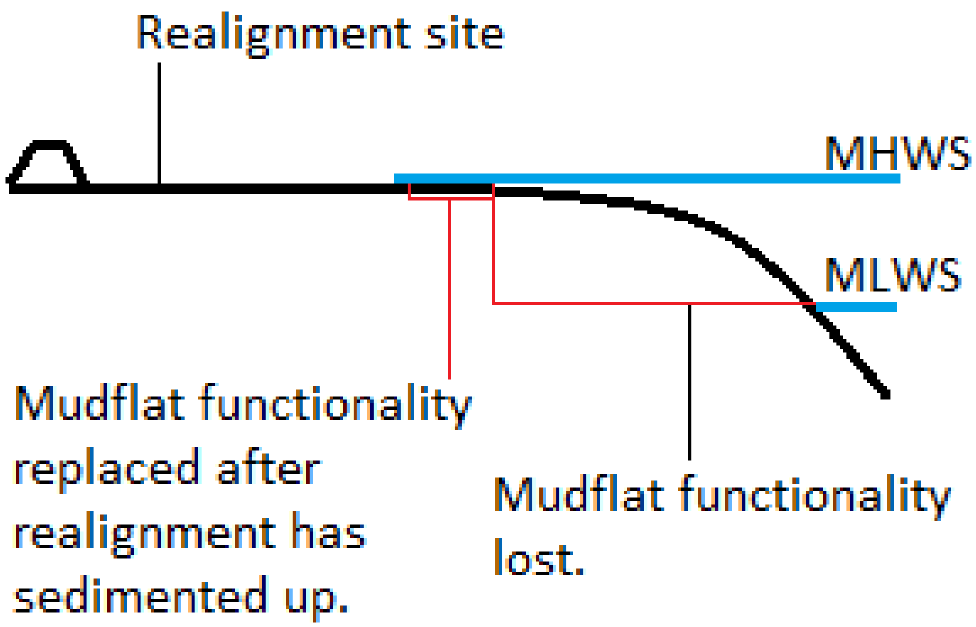


Figure 7. The relative positions of the realignment site after sedimentation and mudflat whose loss it is intended to compensate for. Note that the part of the foreshore that it replicates is much narrower and far greater functional losses will have happened.

9.4. So far, there is no evidence that managed realignment sites on the Humber Estuary have created habitat that would be favoured by Black-tailed Godwits. A brief visual comparison of these sites to the AMEP foreshore (see photographs in Appendix) offers immediate clues as to why this should be. Such sites bear little visual comparison to the favoured feeding grounds of Black-tailed Godwit. Managed realignment and open foreshore have very few features in common. And, as it is clear that Black-tailed Godwits do not make use of realignment sites out of preference it is clear that such sites are not a direct functional replacement.

9.5. There is low-level usage of the Paull Holme Strays site by feeding Black-tailed Godwit, but its value primarily appears to be as a high tide roost. Given that Paull Holme Strays is demonstrably not of the quality required to attract the Godwits away from their favoured feeding grounds it seems unlikely that a further site at a similar point in the tidal frame just a few kilometres to the east will offer any greater potential for supporting these birds.

9.6. The consequences of this analysis are that **it would be extremely unwise to consider the proposed realignment at Cherry Cobb Sands as a viable measure to offset the loss of feeding grounds used by 66% of the internationally important population of Black-tailed Godwit that visit the Humber Estuary each year**. This in turn means that there can be no confidence placed on the viability of the proposals as a means of maintaining the coherence of the Humber Estuary SPA. Consequently, **the proposed AMEP project should not be consented until a viable offsetting measure is developed that has the design parameters required to address the issues in this report**.

9.7. At the moment, the available evidence indicates that that it is not possible to create compensatory habitat within the Humber Estuary that would be adequate for the needs of the Black-tailed Godwits. So far, compensation packages have been geared to a ratio of around 2:1 replacement. This analysis suggests that the areas involved need to be far greater and designs need to incorporate higher levels of wind-driven wave activity. This is needed in order to slow the rate of accretion and to generate greater extents of fine sediment at lower points in the tidal frame.

9.8. This issue is an area of research that requires the urgent attention of the statutory nature conservation bodies because managed realignment has been looked upon as the solution to compensation for port development proposals that affect populations of migratory waterfowl. That argument still obtains under certain circumstances, but as can be seen from this analysis there are situations where it is not possible.

9.9. In addition to matters relating to feeding migratory waterbirds, it also needs to be borne in mind that there will be functional changes to the extent and the geometry of mudflats within the Humber Estuary SAC. The changes have largely been rehearsed above, but it should be recognised that a mudflat occupying the full tidal range of around 6.9 metres will be replaced by saltmarsh and high level drying mudflats of a different consistency to the present. **This means that there is also a case for arguing that the functional coherence of the features within the SAC will also not be maintained**.

Glossary

Accommodation space	Peripheral areas around the coast which lie at or around the high water level and provide room for tidal waters at their highest elevation. This space is primarily the vegetated foreshore and its wetland hinterlands, which will be inundated for limited periods of time. It has largely been lost in most British estuaries and this loss is the main factor behind problems with 'coastal squeeze'.
Bioturbation	The influences of animals such as bivalves and polychaete worms on sediments. As they move around sediment is mobilised and pushed into different places, in part through the creation of casts on the surface.
Breach	Specifically in relation to managed realignment – points where the old sea wall is removed to allow ingress of tidal waters.
Cliffing	Specifically refers to saltmarshes in this case. Here, saltmarsh erosion forms a vertical face that separates the saltmarsh from adjacent mudflats.
Compensatory measures	A specific term in the application of the Habitats Regulations. Compensation is required after the residual effects that cannot be resolved by changes in working practice or layout of the proposal. In the case of Natura 2000 compensatory measures lie outside the boundaries of the designated site and are expected to reach a similar level of functionality so that the site boundary can be extended to incorporate them: hence maintenance of coherence.
Ha	Hectares
Hypertidal	Estuaries with a tidal range of more than 8 metres. This is a somewhat arbitrary definition and the term is not recognised by some geomorphologists. Three other classes are normally recognised: Micro tidal (<2m); Meso-tidal (>2m to 4m); and Macro-tidal (above 4m)
Managed realignment	The process of creating a new sea defence to the rear of an existing defence before breaching existing defences to allow tidal influences to extend over former agricultural land.
Mitigation	Changes to project design, operating procedures or timing that minimise the impacts of a proposal. This may also include direct measures such as sediment feeding where changes to functionality can be addressed by measures within the site.
Mudflat	A habitat composed of fine sediments that is exposed at low tide and which is unvegetated.
Natura 2000	Habitat designated either as a Special Area pf Conservation or Special

	Protection Area under the EC Birds and Habitats Directives.
Neap tide	The lowest tides of the tidal cycle, which coincide with the waxing and waning moons.
OD	Ordnance Datum. Defined as the Mean Sea Level at Newlyn in Cornwall between 1915 and 1921
Offsetting measures	The combination of compensation and mitigation associated with a development proposal.
Progradation	The processes whereby foreshores grow outward towards the sea under accreting conditions.
Ramsar site	A wetland site designated under commitments as a signatory to the Ramsar Convention on the conservation of wetlands of international importance.
Saltmarsh	Vegetated land that is subjected to inundation by saline tidal waters.
Shear strength	The point at which sediment starts to disaggregate before being remobilised.
Spring tide	The biggest tides, which coincide with the full moon.
Tidal frame	The inter-tidal area lying within tidal influences.

References

Black & Veatch, 2011a. Cherry Cobb Sands Compensation Site Breach Design Report Annex 32.3. Environmental Statement for Able Marine Energy Park. Annex 32.3. 32pp.

Black & Veatch, 2011b. Cherry Cobb Sands Compensation Site Sedimentation, Erosion and Saltmarsh Growth. Environmental Statement for Able Marine Energy Park. Annex 32.5. 23pp.

Boyes, S., Mazik, K., 2004. Paull Holme Strays – Accretion/Erosion Monitoring. Report to Halcrow Group Ltd. Institute of Estuarine and Coastal Studies, University of Hull, UK. 27pp. http://www.hull.ac.uk/coastalobs/media/pdf/phs2.pdf

Brampton, A.H., 1992. Engineering significance of British saltmarshes. *In* Allen, J.R.L. & Pye, K. (Eds) Saltmarshes: Morphodynamics, Conservation and Engineering significance. Cambridge University Press, Cambridge. pp 115-122.

Cave, R.R., Ledoux, L., Turner, K., Jickells, T., Andrews, J.E. & Davies, H., 2003. The Humber catchment and its coastal area: from UK to European perspectives. The Science of the Total Environment 314 –316, 31–52.

CEH, 2008. Managed realignment at Tollesbury. Project Code FD 1922, Report to Defra. 9pp. http://www.google.co.uk/search?q=Tollesbury%20realignment%20sedimentation%20rates&ie=utf-8&oe=utf-8&aq=t&rls=org.mozilla:en-US:official&client=firefox-a&source=hp&channel=np

Dixon, M., Morris, R., Scott, C., Birchenough, A. & Colclough, S., 2008. Managed realignment: experiences at Wallasea Island. *Maritime Engineering* **161**: 61-71.

Empson, B., Collins, T., Leafe and Lowe, J. 1997. Sustainable flood defence and habitat conservation in estuaries – a strategic framework. Proceedings of 32nd MAFF Conference of River and Coastal Engineers 1997, F2.1-F2.12.

Environment Agency, 2000. Planning for the Rising Tides: the Humber Estuary Shoreline Management Plan. http://www.hull.ac.uk/coastalobs/media/pdf/hesmp.pdf

Hemingway, K.L., Cutts, N.C. & R. Pérez-Dominguez., 2008. *Managed Realignment in the Humber Estuary, UK*. Institute of Estuarine & Coastal Studies (IECS), University of Hull, UK. Report produced as part of the European Interreg IIIB HARBASINS project. 44pp.

Hughes, R.G. & Paramor, O.L.A., 2004. The effects of bioturbation and herbivory by the polychaete *Nereis diversicolor* on loss of saltmarsh in south-east England. Journal of Applied Ecology **41**: 440–448.

Morris, R.K.A., 2012a. Geomorphological analogues for large estuarine engineering projects: A case study of barrages, causeways and tidal energy projects. *Ocean & Coastal Management* (in press, available online)

Morris, R.K.A., 2012b. Managed realignment: A sediment management perspective . *Ocean & Coastal Management* (in press, available online)

Morris, R.K.A.& Gibson, C., 2007. Port development and nature conservation – experiences in England between 1994 and 2005. *Ocean & Coastal Management* **50**: 443-462.

Morris, R.K.A., Alonso, I., Kirby, K.J. & Jefferson, R., 2006. The creation of compensatory habitat – can it secure sustainable development? *Journal for Nature Conservation*. **14**(2): 106-116.

Morris, R.K.A., Reach, I.S., Duffy, M.J., Collins, T.S. & Leafe, R.N., 2004. Forum: On the loss of saltmarshes in south-east England and the relationship with *Nereis diversicolor*. Journal of Applied Ecology 41: 787-791.

Wolters, M., Bakker, J. P., Bertness, M. D., Jefferies R. L. & Möller, I., 2005. Saltmarsh erosion and restoration in south-east England: squeezing the evidence requires realignment. *Journal of Applied Ecology*, **42**: 844–851.

Appendices

Appendix 1. A1 – AMEP foreshore.
Appendix 2. A2 – Cherry Cobb Sands compensation site
Appendix 3. A3 - ABP Chowderness
Appendix 4. A4 – Paull Holme Strays
Appendix 5. A5 - ABP Welwick
Appendix 6. A6 - Freiston Shore
Appendix 7. A7 - Tollesbury

The following photographs provide a partial history of the evolution of several managed realignment sites drawn from the photographic archives of Bight Angel Coastal Consultants Ltd. All are copyright Roger Morris. Many are poor quality because they were taken into the sun (owing to the orientation of the site and the degree to which it was possible to reach suitable photographic vantage points).

The important points to derive from these photographs:

- The open vistas within the AMEP site. Sight lines are unimpeded and the sediment is obviously inundated on every tide including neap tides.
- The presence of a substantial number of Black-tailed Godwit on the AMEP site on 15 July 2012 – between 350 and 400 birds at a rough count with a reported 100 further birds at North Killingholme Haven Pits.
- The presence of a substantial freshwater flow across the AMEP site. Such freshwater situations are known to be important in extreme weather in some estuaries.
- The flat topography of the realignment sites with comparatively little difference in the elevation of mudflats and adjacent saltmarshes.
- The deep narrow channels that carry tidal waters. Many of these were either former ditches or specifically excavated to facilitate water movement.
- The lack of freshwater inputs and deep sharply defined channels in realignment sites.
- Changing extent of vegetation over time. It is important to bear in mind that the vegetation cover is also augmented by deposits of green algae and that algal mats are a not infrequent feature of realignments that have an additional influence over their functional contribution to the ecology of the estuary.
- The way in which vegetation cover extends from the sea wall outwards, but that it may also occur in isolated patches that gradually coalesce.
- Extensive mud cracking across the majority of the site at Chowderness, which confirms that, the site has gained sufficient elevation not to be inundated on neap tides.

A1.1. AMEP site. 15/07/2012. Looking west towards Humber Sea Terminal.

A1.2. AMEP site. 15/07/2012. Looking north showing wet mud with evidence of bird footprints and runnels.

A1.3. AMEP site. 15/07/2012. Photograph taken at 10.30am – around the bottom of the tide (neap). Roosting/loafing Black-tailed Godwits part-way up the shoreline – flock of between 350 and 400 birds.

A1.4. AMEP site. 15/07/2012. Part of the flock of Black-tailed Godwits shown in the photograph above. Note, most birds appear to be sleeping but there is the occasional feeding bird.

A1.5. AMEP site 15/07/2012. Black-tailed Godwit flock at 11 am. Note it has moved close to the water line – presumably in response to the turning tide.

A1.6. AMEP site 15/07/2012. Freshwater outfall across mudflats. Note the morphology of the channel through wet mud. Here the channel has sloping sides with slumps and a sinuosity associated with a relatively short fall (~ 4 metres at the bottom of the channel).

A2.1. Cherry Cobb Sands compensation site. 11/07/2012. Looking east towards Stone Creek. Note that the sea wall is fronted by saltmarsh.

A2.2. Cherry Cobb Sands compensation site. 11/07/2012. Looking east towards Stone Creek. Note that the saltmarsh in front of the sea wall is extensive – suggesting that this is a very low-energy environment.

A2.3. Cherry Cobb Sands compensation site. 11/07/2012. Looking west towards Paull Holme Strays. Note the extent of saltmarsh, which reflects the slight inland kink in the sea wall at this point.

A2.4. Cherry Cobb Sands compensation site. 11/07/2012. Looking south-east towards Immingham. Note the green foreshore appears to be growing out seawards and is accreting not eroding.

A3.1. ABP Chowderness compensation site. 14/09/2007. Looking west towards South Ferriby.

A3.2. ABP Chowderness compensation site. 14/09/2007. Looking east towards the Humber Bridge.

A3.3. ABP Chowderness compensation site. 22/09/2011. Looking east towards the Humber Bridge.

A3.4. ABP Chowderness compensation site. 22/09/2011. Looking south-west.

A3.5. ABP Chowderness compensation site. 15/07/2012. Looking west towards South Ferriby. Neap tide.

A3.6. ABP Chowderness compensation site. 15/07/2012. Looking south towards new counter-wall. Neap tide. Note extensive cracking of the mud, which suggests that this has been exposed to the air for several tides. This cracking covers most of the site.

A3.7. ABP Chowderness compensation site. 15/07/2012. Looking east towards the Humber Bridge. Neap tide. This photograph was taken from the middle of the site – demonstrating that even the surface layers had de-watered sufficiently to take the weight of a 16 stone man!

A3.8. ABP Chowderness compensation site. 15/07/2012. Looking west towards South Ferriby. Neap tide. Taken from near the middle of the site; mud cracking is evident.

A4.1. Paull Holme Strays. 14/09/2007. *L*ooking towards Saltend. 14/09/2007

A4.2. Paull Holme Strays. 14/09/2007. *L*ooking towards Killingholme.

A4.3. Paull Holme Strays. 25/06/2009. Looking towards Immingham.

A4.4. Paull Holme Strays. 28/04/2011. Looking East from Paull Fort

A4.5. Paull Holme Strays. 11/07/2012. Looking west towards Saltend.

A4.6. Paull Holme Strays. 11/07/2012. Looking east towards Immingham.

A4.7. Paull Holme Strays. 11/07/2012. Looking west towards Paull Fort.

A4.8. Paull Holme Strays. 11/07/2012. Looking south towards the western breach.

A5.1. ABP Welwick compensation site. 11/07/2012.

A5.2. ABP Welwick compensation site. 11/07/2012.

A6.1. Freiston Shore. 08/04/2011.

A6.1. Freiston Shore. 08/04/2011.

A6.3. Freiston Shore. 15/07/2012. Western end furthest from the western breach. Note limited freshwater outfall.

A6.4. Freiston Shore. 15/07/2012. Note the sharply defined channel through consolidated sediment with limited if any sloppy fine sediment.

A6.5. Freiston Shore. 15/07/2012. Channel carring tidal water. Note it looks very much like a terrestrial land drain and carries little wet sloppy sediment.

A6.6. Freiston Shore. 15/07/2012. Western breach. Note water ponded here because the outlet channels have become blocked.

A7.1. Tollesbury. 13/09/2007. Note strong *Salicornia* growth.

A7.2. Tollesbury. 02/06/2009. Looking north-east towards the breach. The dead trees were killed when the site was first flooded. They were not felled at the onset but should have been as they provide a vantage point for raptors.