Estuarine and coastal managed realignment sites in England

A comparison of predictions with monitoring results for selected case studies

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Allfleet's Marsh (Defra site) on Wallasea Island North Shore

1. Executive Summary

Managed realignment is a relatively new soft engineering strategy undertaken to provide sustainable coastal defences, re-create intertidal habitats or a combination of these two aims. More than fifty managed realignment sites have been created since the first in 1991.

This study (performed originally for a MSc project) describes the comparison of predictions made about individual managed realignment sites with the results from monitoring programmes at each. The intention was to evaluate whether current practice is getting full benefit from previous monitoring effort and to see whether the monitoring effort had been appropriate. Six managed realignment sites on the East coast of England were chosen for study. Results of the comparisons are presented on an individual site basis, showing that quantitative predictions were rarely accurate over the timescale of the monitoring.

A variety of stakeholders in managed realignment were identified and contacted to notify them of the project and its aims and to request help in identifying pertinent documents. Documentary sources were compiled and the data and information regarding predictions and monitoring results extracted from them. These data and information were integrated and interrogated to provide results from the comparison. Further refinement of this study is intended and more comments from the managed realignment community are very welcome.

At the oldest sites, there was a mismatch of predictions and monitoring results, which reflected the lack of knowledge to predict development, but predictions became more detailed and more parameters were monitored in sites implemented subsequently. Monitoring programmes were rarely of sufficient timescale to validate predictions. Full monitoring results from the most recent sites were not yet available.

Rates of sediment accretion tended to be faster initially than predicted and has resulted in refinement of modelling techniques. Colonisation rates by flora and fauna varied between sites. No site attained the diversity of flora species observed in nearby natural salt marsh by the cessation of monitoring. Abundances of fish and birds using the new intertidal areas were generally higher than predicted. Predictions regarding invertebrates tended to be limited to 'colonisation expected'. Monitoring of invertebrate colonisation showed wide variation between sites in terms of how abundance, diversity and biomass developed.

In all cases, more area of salt marsh developed than predicted and other authors have observed that in the Humber, once sufficient elevation of accreting sediments is reached, salt marsh will develop. Alternative methods may need to be developed to produce stable intertidal mudflat areas. Salt marsh may provide more ecological services than are currently considered within managed realignment benefits. Despite some sites being developed primarily for sustainable flood defence, discussions regarding degree of success centre only on natural environmental benefit.

Four recommendations are given:

- Understanding of the ecological functionality of the sites would benefit from longer term monitoring or revisiting to establish the medium and long term behaviour of managed realignment areas;
- Success criteria should be explicitly defined prior to site development;
- Key performance indices of sustainability should be developed, included in predictions and thereafter monitored to provide evidence that managed realignment meets economic, social and environmental sustainability; and,
- This study would be considerably more robust and valuable if it were further expanded to consider more sites from more geographically diverse areas.

2. Introduction

Managed realignment is a relatively new ‘soft’ engineering technique (French, 2004) involving designing new intertidal areas, created from formerly flood defended areas of coastal land in order to provide sustainable flood defences, new intertidal habitats or a combination of these. Existing ‘hard’ defences such as concrete walls and embankments are often expensive to maintain and have been identified as a contributing factor to the erosion and subsequent loss of salt marshes and mudflats around the coastline, through ‘coastal squeeze’ (Doody, 2004). In a natural undefended coastline, marshlands would react to changes in sea level or erosion by shifting position to a more suitable location in the tidal range, but this is constrained where such migration is impeded by flood defence structures. This erosion has been discovered to not just be a loss of intertidal habitat, but also of serious consequence to flood defence engineering, as salt marshes reduce the erosive force and overtopping potential on flood defence structures (Brampton, 1992).

The emergence of understanding with respect to salt marsh and mudflat importance to sustainable flood defence and European legislation regarding biodiversity safeguarding (Habitats Directive 1992(Council Directive 92/43/EEC) and Birds Directive 2009 (Council Directive 2009/147/EC)) have led to restoration projects with the purpose of recreating saltmarsh and mudflats. Some accidental breaches of flood defences had previously led to development of salt marshes and mudflats in newly tidally inundated areas, although not in all cases (Burd, 1992). This gave rise to the idea that this could be a managed process. Sites could be designed using criteria identified from the accidental breach scenarios which promoted the desired intertidal area development (French, 1999).

In the UK, the first deliberate managed realignment site was an area of 0.8 hectares at Northey Island in the Blackwater Estuary, Essex, which was flooded in 1991 (Dagley, 1995). This was done by breaching an existing embankment and was chosen as a demonstration project for habitat creation. Subsequently, approximately fifty different sites have been completed and more are planned, with the most recent ongoing project at the time of the investigation being Wallasea Island Wild Coast (distinct from Affleet’s Marsh or Wallasea Island North Coast), launched in September 2012, situated adjacent to Rivers Crouch and Roach in Essex[1]. Since these projects were designed, they had predictions for the type of habitat that was expected and many were monitored through time to observe the changes. Comparison of the actual results of monitoring with original predictions is a gap in the project development cycle and therefore this investigation is intended to address this. Examining the assumptions made to produce the predictions compared to the real world development of sites should:

- give direction to the successful design and execution of future sites,
- provide information to target resources into effective monitoring programmes, and
- enhance our understanding of the processes which affect site development.

It was considered timely to examine this, as there had been twenty years of managed realignment and many of the monitoring programmes associated with individual sites had ended and results were available, whilst managed realignment continues to be promoted for habitat compensation schemes, habitat restoration projects and sustainable flood defence purposes. Costs of flood defence in England are coming under close scrutiny by the government Department of Environment, Food and Rural Affairs (DEFRA), who provide the funding for such. Understanding the processes which lead to successful intertidal habitat re-creation and sustainable cost-effective flood defence can lead to an improvement in the probability that future managed realignment sites will successfully meet their aims and objectives. Guidelines to suitability criteria were

[1] http://www.rspb.org.uk/reserves/guide/w/wallaseaisland/

produced by DEFRA (Parker et al, 2004) and an analysis of best practice monitoring exists (IECS, 2008). However, the original predictions for sites have not been compared with monitoring results and examining this gap may provide further insights to assist with design and implementation of future managed realignment.

The aim was to compare predictions of managed realignment site development with the results of monitoring programmes to evaluate whether current practice is getting full benefit from the monitoring effort.

The objectives were to:

- add to the knowledge base about managed realignment site development, and
- to provide recommendations with respect to future predictions and monitoring programmes.

The study focussed on the following questions:

- How did timescales, hydrodynamic and ecological predictions compare to those observed in the monitoring?
- Was the monitoring designed appropriately, or were some changes observed which could have benefitted from being monitored specifically?
- Were unanticipated changes predictable with further knowledge and experience?
- If changes were unpredictable, has enough knowledge been amassed from investigations into the changes to include them in future predictions, or have hypotheses been developed?

There are multiple drivers for managed realignment (Ledoux et al, 2003; Elliott et al, 2007), as follows:

- To provide sustainable and effective flood and coastal defence
- Long term strategy for coping with sea level rise (from both isostatic rebound and climate change effects), looking in terms of centuries
- To provide environmental benefits in terms of habitat creation
- To compensate for habitats lost elsewhere as required by Habitats Regulations
- To reduce costs of flood and coastal defence
- To control breaching proactively, rather than deal with accidental breaching reactively

A mixture of these drivers may exist for any single scheme, and thus objectives for each site are site specific. If schemes are required as compensatory habitats, the predictions for that site will have been produced in published Environmental Statements (ES) documenting an Impact Assessment process or Appropriate Assessments (AA), as required by the European Union Habitats Directive (Council Directive 92/43/EEC) legislation, which is transposed into UK legislation. Such schemes are also liable to monitoring conditions as part of their licensing conditions – however, there is no compulsion for comparisons to be made between the monitoring results and the predictions and the result of such comparisons published. Due to the cost and resource implications of undertaking this last step, this is frequently an area which is neglected. Similarly, those schemes which have been undertaken by governmental organisations, such as the Environment Agency and DEFRA, have an obligation as statutory bodies to provide transparency in their costs and thus have to set out their intentions for sites and publish any monitoring campaigns. However, there is no resource made available to them to review their monitoring in light of the original aims and objectives.

The managed realignment approach to flood defence, habitat creation and habitat compensation has the potential to provide more benefits to a wider range of stakeholders than previous approaches, due to it satisfying more than singular drivers when adequately carried out. There is a need to understand and thus set rigorous success criteria and/or objectives (Elliott et al, 2007). Efforts have been made to learn lessons from previous experiences (Cooper et al, 2001, Atkinson et al, 2004, Wolters et al, 2005, Dixon et al, 2008). Lack of pre-defined precise and quantitative targets have been discussed (Wolters et al, 2005), but little effort made towards looking at the more nebulous qualitative aims that were expressed during the design phases of the schemes. Instead, many monitoring schemes have chosen to develop other measurements of success, such as comparing created and natural marsh (Edwards and Proffitt, 2003). Flood defence engineers would consider a particular width of marsh in front of new embankments a success (French 2004).

The contribution towards Water Framework Directive Biological Quality Elements is mentioned by the Environment Agency (Environment Agency, 2010) as evidence of success. Usage of the new intertidal area by other species have also been suggested as success criteria (Atkinson et al, 2001). Where sites have been promoted to provide habitat in response to conservation legislation, it may be appropriate to use these latter success criteria. Explicit aims of the legislation can be adopted, for example Good Ecological Status for the Water Framework Directive or Favourable Conservation Status for the Habitats Directive or Birds Directive (Council Directive 2009/147/EC). These will necessarily be of a qualitative nature, but have links to the current UK government vision for the marine environment, stated as “clean, healthy, safe, productive and biologically diverse oceans and seas” (HM Government, 2009)

There has been a significant policy and funding shift in Government that has facilitated managed realignment projects, recognising that this technique has considerable long-term potential to address sea level rises and continuing economic coastal activities such as the vital ports sector, whilst maintaining ecological functionality of the estuarine and coastal zone by ensuring the survival of important intertidal habitats (Dixon et al, 2008). There are also commitments to restoration of lost priority habitats through the EU Convention on Biological Diversity and UKBAP targets. Considerable effort has been expended by government departments and agencies, such as DEFRA and the Environment Agency, non-governmental organisations such as the Royal Society for the Protection of Birds and The Wildlife Trusts, the commercial sector through their environmental consultancies and engaging with academics to get to this position. This very large cross sectoral commitment is liable to extend into the future and taken together, the existing realignment projects have created hundreds (if not thousands) of hectares of new mudflat and saltmarsh habitat, and will create many more hundreds of hectares over the next decade or so.

The outcomes may have had some limitations and the suggestion that managed realignment sites do not satisfy the requirements of the EU Habitats Directive (Mossman et al, 2012; Morris, 2013) has provoked discussion about the circumstances under which realignment is being promoted. Although the rate of loss of saltmarsh seems to have slowed in the last decade or so, the recently revised Shoreline Management Plans indicate that the rate of loss in the medium to long term could be substantial because the rate of sea level rise is predicted to increase. Monitoring and evaluation has an important role to play in helping to ensure that future projects provide the best outcome for nature conservation and flood defence and therefore this project is relevant in examining whether the predictions and subsequent outcomes are vulnerable to attack due to weakness of evidence.

3. Study Locations

There are too many managed realignment sites for all of them to be examined within the scope of this project particularly and therefore the project concentrated on only a few case studies on the East Coast of England. The web database site Online Managed Realignment Guide (OMREG) was used to identify a selection.

A selection of six sites was made, with consideration to when they were implemented and what information could be gathered about them, as follows:

- two older schemes with lots of monitoring information, but which were designed at the earliest stage of the approach, so predictions were not based on experience;
- two intermediate schemes which were designed after more experience and research was available to inform the design, with subsequent extensive monitoring
- two recent projects whose design should have been informed by previous lessons and who are still undertaking monitoring, but have preliminary results to look at.

This resulted in the identification of the following sites:

- Orplands Farm and Tollesbury;
- Paull Holme Strays and Abbotts Hall 2;
- Chowder Ness and Wallasea Island North Shore (also now referred to as Allfleet's Marsh to distinguish it from the wider Wallasea Island Wild Coast project).

The geographic location of these selected sites are shown in Figure 1.

These were concentrated in two areas, the Humber Estuary and the wider Thames Estuary. Both of these areas are where managed realignment have been promoted most often and studied most closely. Managed realignment is considered to be most appropriate on flat low lying land, and especially in estuaries sheltered from the more severe coastal conditions experienced on the open coast (DEFRA/Environment Agency 2002). Despite being located closely, these sites were considered to still provide an adequate selection for the purpose of this study, due to the data and information available for inspection. It is acknowledged that a broader geographic spread of sites may have led to increased robustness in generalising findings and recommendations for all English managed realignment sites.

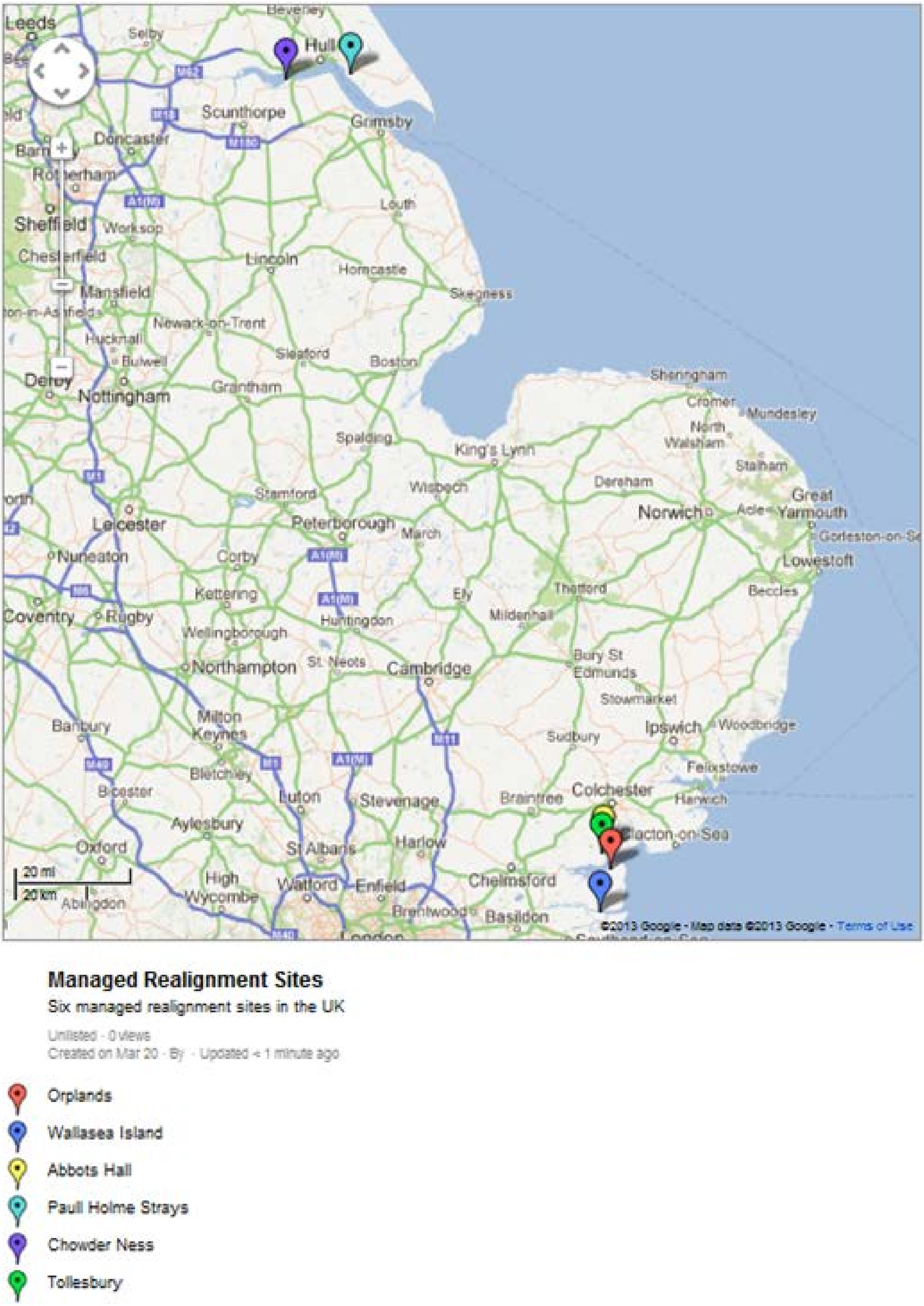

Figure 1: Location of chosen Managed Realignment Sites within England.

Source: Google Maps ©2013 Google

4. Methods

The documentary sources were sorted so that each was identified as belonging to one of the case studies and a table constructed summarising:

- the site names, the reason for their promotion and the year of their construction;
- predictions contained in the documentary sources; and
- monitoring contained in the documentary sources.

This is presented in Table 1.

Further tables were constructed for each site (see Tables 2 – 7), with a more detailed description of the predictions, and monitoring results and observations, subdivided into physical aspects (hydrodynamics, morphodynamics, timescales) and biological aspects (flora, invertebrates, fish, birds).

Table 1: <Insert Table Title>

Site information	Predictions	Monitoring
Orplands Experimental sustainable flood defence Constructed 1995	30 ha saltmarsh to develop 10 ha mudflat to develop No success criteria set, as it was an experimental site, so monitoring was intended to be observational. Patterns of sediment deposition and erosion predicted through computer modelling, no changes to the surrounding environment expected.	Accretion/erosion on site: accretion/erosion off site; physico-chemical parameters of sediments; vegetation; benthic invertebrates; fish and birds. 3 years of monitoring – further academic studies subsequently
Tollesbury Experimental sustainable flood defence Constructed 1995	6 ha saltmarsh to develop 15 ha mudflat to develop No success criteria set, as it was an experimental site, so monitoring was intended to be observational. Patterns of sediment deposition and erosion predicted through computer modelling, changes to tidal prism and creek formation expected.	Accretion/erosion on site: accretion/erosion off site; physico-chemical parameters of sediments; vegetation; invertebrates; birds. Initially 5 years, extended to 12 years
Paull Holme Strays Sustainable flood defence Compensatory habitat creation Constructed 2003	Upper Saltmarsh 3 ha Middle Saltmarsh 25 ha Lower Saltmarsh 15 ha Mudflat 32 ha. The mudflat created to support an invertebrate assemblage of similar species, population abundance and biomass to reference sites in the middle estuary. At least 30 species of feeding wintering waterbirds :	Hydrographic mapping; topographic surveying; water quality; accretion/erosion; sediments; vegetation; invertebrates; fish; birds. 5 years of monitoring – further academic studies subsequently

Site information	Predictions	Monitoring
	Redshank, Dunlin, Shelduck and Curlew to be present and 3000 individual birds. At least 12 species of roosting wintering waterbirds: Golden Plover to be present.	
Abbots Hall 2 Sustainable flood defence Demonstration of creation of a variety of habitats Constructed 2002	Intertidal mudflat, saltmarsh, transitional grassland and grazing marsh to develop.	Accretion/erosion on site (altimetry); accretion/erosion off site; scour; bathymetry (one off); tidal levels and velocities; suspended solids off site; salinity off site; invertebrates off site (one off); vegetation; birds; fish; amphibians/reptiles 5 years of monitoring
Chowder Ness Compensatory habitat creation Constructed 2006.	0.8 ha of saltmarsh to develop, 10.5 ha of intertidal mudflat to develop, 2 ha of grassland to develop. Patterns of sediment deposition and erosion predicted through computer modelling	Bathymetric and topographic survey of the realignment area and adjacent shoreline to assess changes in erosion and deposition of sediment; Ecological surveys of the newly created habitats to monitor their development and quality; Ecological surveys to monitor the continued health of existing habitats in the vicinity of the realignment scheme; Surveys of waterfowl to assess their usage of the realignment area and any changes in usage of existing areas. 10 years of monitoring
Wallasea Island North Shore (Allfleet's Marsh) Compensatory habitat creation Restoration of natural shoreline Sustainable flood defence Constructed 2006.	60 ha of intertidal mudflat to develop, 25 ha of saltmarsh to develop, 20 ha of saline lagoons to develop and 10 ha of transitional habitat to develop. Patterns of sediment deposition and erosion predicted through computer modelling	Accretion/erosion on site; accretion/erosion off site; estuary subtidal bathymetry; estuary & breach flow velocities; invertebrates (marine & freshwater); vegetation; birds (overwintering & breeding) 5 years of monitoring

4.1.1. Orplands

Table 2: Comparison of predictions and targets with monitoring results at Orplands managed realignment site

Physical predictions	Monitoring results
No significant effect on overall hydrodynamic regime of River Blackwater	Not located
Current speeds changed in a very localised area outside the site	Not located
Some accretion expected	Accretion of 50mm of sediment in 2 years post inundation
No prediction on chemical quality located	An anoxic zone in the sediment developed, possibly due to the terrestrial vegetation decomposition. Calcium, magnesium and sodium concentrations in the soils were increased following inundation. Iron concentrations reduced.
Biological predictions	**Monitoring results**
No direct predictions located. However, the site was experimental and intended to give more information with respect to the ecological development, whilst providing a more sustainable coastal defence.	Saltmarsh vegetation had developed on the higher elevations of the sites and was dominated by pioneer Salicornia spp. communities by 2000.
	Benthic invertebrate colonisation took place beginning in the first year of monitoring, with diversity increasing through the monitoring period.
	Eel, bass, common goby and sand smelt captured inside site
	Bird usage of the site was low in the first year after the breach, but gained through the years.

Photograph 1: Orplands Managed Realignment Site

Source: Google Maps ©2013 Google ©2013 DigitalGlobe, Getmapping plc, Infoterra Ltd & Bluesky

4.1.2. Tollesbury

Table 3: Comparison of predictions and targets with monitoring results at Tollesbury managed realignment site

Physical predictions	Monitoring results
Creek network to develop naturally within the site. Furrows may erode out faster.	Creeks formed following 20-30 cm accretion of new erodible sediments. Underlying previous soils too compacted for creek formation
Minor morphologic changes to Tollesbury Creek, outside the site, due to changes in tidal flows	Main channel pathway altered, moving to a previously less dominant channel.
Improvement to water quality	Not monitored
Accretion expected within the site	Around 21mm on average per year up to 2003, rate of accretion subsequently slowed.
Biological predictions	**Monitoring results**
Low marsh vegetation on 3.2 ha Pioneer species on 1.5 ha	13 ha of vegetation by 2007, less diverse than surrounding marshes
Some losses of marsh outside site	No losses seen, vegetation composition somewhat changed
Invertebrate species to colonise inundated area	Invertebrate diversity within site surpassed that outside
Upper estuarine fish species to move in; named species of eel, flounder, pipefish, mullet and goby	Juvenile bass and herring numerous.
Wildfowl and waders to use site for feeding and roosting	Slow in the first year, but rapidly increased subsequent to invertebrate (food source) colonisation.

Photograph 2: Tollesbury Managed Realignment Site

Source: Google Maps ©2013 Google ©2013 DigitalGlobe, Getmapping plc, Infoterra Ltd & Bluesky

4.1.3. Paull Holme Strays

Table 4: Comparison of predictions and targets with monitoring results at Paull Holme Strays managed realignment site

Physical predictions	Monitoring results
Upper Saltmarsh 3 ha Middle Saltmarsh 25 ha Lower Saltmarsh 15 ha Mudflat 32 ha	Accretion to the north of the site much stronger than expected and after five years of development, it was forecast that saltmarsh will develop over most of the site
Physical target	
13.01 ha of intertidal habitat required for compensation purpose	Sufficient intertidal developed during the three year monitoring programme
Biological predictions	**Monitoring results**
Upper saltmarsh limited to proximity of seawall, middle saltmarsh areas most extensive and low saltmarsh expected to be limited	Upper saltmarsh dominant in areas of marsh which developed. Little middle saltmarsh evident, low saltmarsh developed in some areas.
Biological targets	
Mid and lower salt marsh habitat will be lost from the site fronting the existing embankment, through direct losses and coastal squeeze. The salt marsh habitat created at PHS should replace these losses	Salt marsh habitat did develop and was regarded as having met this target, although very little middle marsh was developed by the end of monitoring, so this success may be overstated. However, saltmarsh was continuing to develop, so more middle marsh may have developed with time.
The mudflat created must support an invertebrate assemblage of similar species, population abundance and biomass to reference sites in the middle estuary.	Not met by the end of the monitoring in terms of abundance, although diversity and biomass were met. There were indications that the invertebrate assemblage was still developing by the end of the monitoring.
At least 30 feeding wintering waterbirds : Redshank, Dunlin, Shelduck and Curlew must be present. At least 12 roosting wintering waterbirds: Golden Plover must be present.	Bird usage of site high by 2003, all species named were observed, along with other wildfowl and wading species. However, densities were not considered similar to the densities previously recorded on the areas of saltmarsh which were lost

Photograph 3: Paull Holme Strays Managed Realignment Site

Source: Google Maps ©2013 Google ©2013 DigitalGlobe, Getmapping plc, Infoterra Ltd & Bluesky

4.1.4. Abbotts Hall Farm Stage 2

Table 5: Comparison of predictions and targets with monitoring results at Abbotts Hall Farm managed realignment site

Physical targets	**Monitoring results**
Sustainable coastal defence protection enhanced	Not mentioned in results, but judged to be cost effective
Increased current speeds outside site in the vicinity	Increased current speeds noted, but less severe than predicted, considered to be favourable
Accretion expected	Accretion took place and the site was demonstrated to be a net sediment sink, after challenge from oyster fisherman worried that sediment eroded from the site were impacting the shellfish beds.
Salcott Creek to remain stable	No significant increase in erosion was observed
Biological predictions	**Monitoring results**
40 ha saltmarsh, 9 ha mudflats and 35 ha coastal grassland	No estimates of areas given. Some saline lagoons developed in previous freshwater borrow pits
Re-created habitats to be utilised by fish	Juvenile bass, sand-smelt, smelt, flounder, common and sand goby, eel, herring, three spined stickleback and thick and thin lipped mullet were recorded from the site.
Re-created habitats to be utilised by birds	Bird usage of mosaic of habitats higher than usage of the area pre-inundation
Biological targets	**Monitoring results**
Create nationally important habitat and provide a significant contribution to the national Biodiversity Action Plan (BAP) targets for saltmarsh creation	Considered “successful”

Photograph 4: Abbotts Hall Managed Realignment Site

Source: Google Maps ©2013 Google ©2013 DigitalGlobe, Getmapping plc, Infoterra Ltd & Bluesky

4.1.5. Chowder Ness

Table 6: Comparison of predictions and targets with monitoring results at Chowder Ness managed realignment site

Physical predictions	Monitoring results
Potential for minor bed level change in vicinity of site, in outer area	LiDAR technique was being used to measure changes in topography. No results have yet been published
Greater coastal defence protection – designed to a 1 in 50 year life specification.	Nothing available
Site altered by less than 1 m other than in the area of seawall removal	Nothing yet published
Accretion rates to be of the order of 0-20 cm per year initially, declining over time	Rapid change in the first two years, accretion slowing, but difficult to discriminate exact rates, as LiDAR accuracy in the field tends to be around ±10 cm. Appropriate over longer term monitoring, but will not discriminate quantitatively on an annual basis
Biological predictions	**Monitoring results**
Net gain of 0.8 ha of saltmarsh	Peripheral saltmarsh had developed by 2009. Estimates of area not made.
Creation of 10.5 ha of mudflat	Mudflat evident within site; estimates of area not yet made
Newly re-created intertidal area will be used by fish	No result published yet
Newly re-created intertidal area will be used by birds. Species of interest expected – golden plover, lapwing, dunlin, redshank, ringed plover, curlew and black tailed godwit.	Bird species observed so far include shelduck, golden plover, lapwing, dunlin, curlew, black headed gull and common gull.

Photograph 5: Chowder Ness Managed Realignment Site

Source: Google Maps ©2013 Google ©2013 DigitalGlobe, Getmapping plc, Infoterra Ltd & Bluesky

4.1.6. Wallasea Island North Shore (Allfleet's Marsh)

Table 7: Comparison of predictions and targets with monitoring results at Wallasea Island managed realignment site

Physical predictions	Monitoring results
Stable creeks to form at breach site	The breach channels have remained very stable mainly because the breaches were made deep and over-wide to fully accommodate flows.
No effect on local shoreline	No effect has been identified
Accretion limited to the order of 1-3 cm per year, with a maximum of 3.5 cm in a year.	Accretion of 18 cm over four years
Better coastal defence protection	Not yet published
Biological predictions	**Monitoring results**
Shallow sublittoral 0.75 ha, Mudflat 84.66 ha, saltmarsh 20.74 ha, grassland 1.07 ha.	No area estimates yet published
Newly re-created intertidal area will be used by fish	Abundant fish fry using the area, including fry of bass, flounder and herring
Newly re-created habitats will be used by brids	Thirty-eight species of bird have been observed, with the most numerous being Brent goose, shelduck, teal, mallard, ringed plver, golden plover, lapwing, dunlin and redshank
Invertebrate assemblages will develop within the newly re-created intertidal area	Assemblages variable, but abundances are good, whilst stability and diversity are improving.

Photograph 6: Wallasea Island Managed Realignment Site

Source: Google Maps ©2013 Google ©2013 DigitalGlobe, Getmapping plc, Infoterra Ltd & Bluesky

Consideration was then given to the processes governing the development of the sites. Accretion of material at the sites was one of the most frequently quantitatively predicted physical parameters, although rates shown by the monitoring rarely matched the predictions. A multiple cause diagram of accretion was constructed to illustrate the different factors involved in accretion, shown in Figure 2.

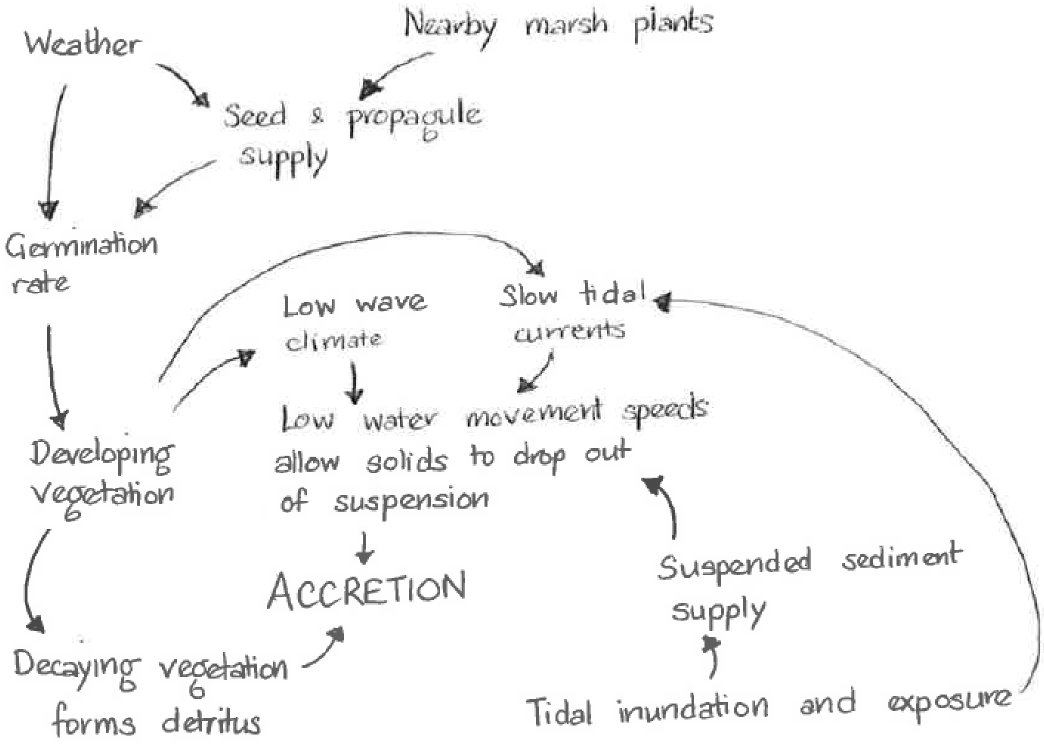

Figure 2: Multiple cause diagram exploring the factors affecting accretion rates

The complexity of accretion processes is unlikely to have been fully accounted for in computer modelling, with some necessary assumptions having taken averages of inputs. Additionally, computing calculation power is a limiting factor on modelling complexity. This combination can explain the discrepancies from predictions to monitoring. Accretion tended to be rapid in the first years of monitoring, gradually slowing through time.

Invertebrate colonisation was a main structuring parameter for the use of the site by fauna, as benthic invertebrates act as a food source to attract fish and birds. A multiple cause diagram of the factors affecting benthic invertebrate colonisation was constructed, shown in Figure 3.

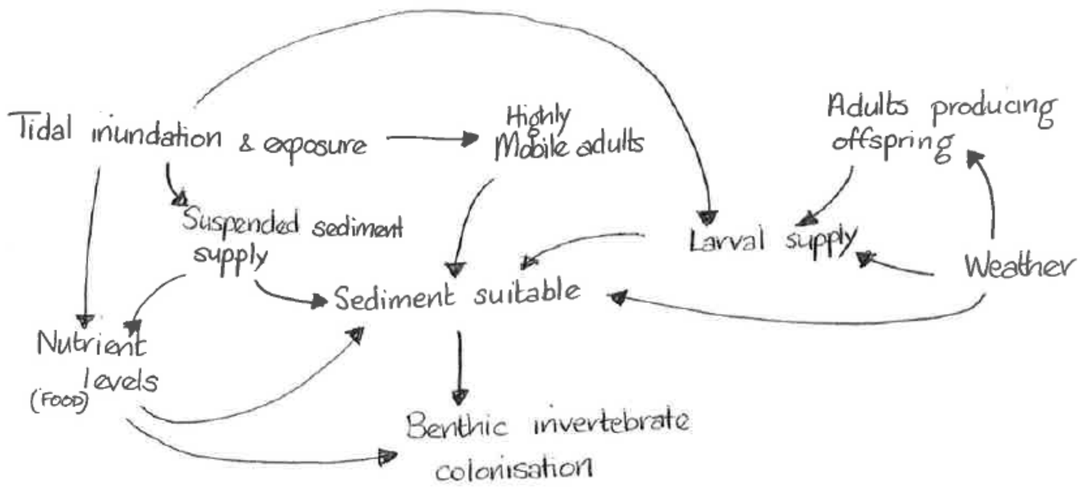

Figure 3: Multiple cause diagram exploring the factors affecting benthic invertebrate colonisation

It can again be seen that there is a high level of complexity structuring colonisation, mainly through the availability of suitable sediment (Garbutt et al, 2006). Quantitative predictions were not given as the level of understanding and prediction of the factors is insufficient to do so and liable to remain so. Qualitative targets related to similar assemblages developing to those external to the sites were appropriate.

5. Findings

5.1. Orplands

No original environmental impact assessment was located for Orplands and thus predictions which are presented are only those which could be gleaned from other sources. However any predictions were made with only what had happened during historic accidental breaches of sea defences and coastal process knowledge amassed from studies of physical changes and other anthropogenic activities within estuarine environments.

The aim to provide sustainable flood defence was promoted by the National Rivers Authority (later to become the Environment Agency) who were a government body charged with maintaining sea defences for the coastline of England and Wales, looking for economic efficiencies. The site was expected to have benefits of assisting the estuary system to adjust to changes in sea level and creating an improved natural habitat at the expense of a modest loss of low-grade agricultural land (HR Wallingford, 1994).

Negligible effects on the overall hydrodynamic regime of the Blackwater Estuary were predicted, but the monitoring results for this were not located, so no comparison could be made. There was a prediction that the site would need to drain completely during each tidal cycle in order for a stable morphology to establish (HR Wallingford, 1994). The site was high in elevation and it was therefore not expected that much sediment would accrete above the extant levels, however, monitoring showed 50mm of accretion in two years. This was more rapid than predicted.

Pioneer saltmarsh vegetation was sparsely covering the site two years later (Paramor & Hughes, 2005) although no measurements of area were located to compare to predictions. Biological predictions were not located, but monitoring showed the establishment of benthic invertebrates and usage of the area by fish and birds.

Despite the monitoring that was funded by the proponents of the scheme being only short-term (3 years) and fragmented among many different bodies, the experimental nature of the site meant that it was used by many researchers for study, yielding more information, for example, the fish usage of the created area (Colclough et al, 2005), the effects of invertebrates on flora (Paramor & Hughes, 2005) and long-term changes of the physicochemical properties of the sediment (Spencer et al, 2008).

5.2. Tollesbury

Tollesbury was also an experimental site, with similar aims to those at Orplands. Changes to the hydrodynamics of the outer creeks were predicted, with water exchange expected to increase and the creeks expected to be wider and deeper. This change in the creeks was expected to happen at the expense of existing saltmarsh. The monitoring showed that creeks did change, but no additional erosion of the existing salt marsh was observed. Accretion took place faster than anticipated, initially and was more extensive, particularly in the east of the site (Reading et al, 2008; Spearman, 2011).

Metal contamination in the sediments were monitored, despite no prediction of changes to sediment quality, however information on geochemical processes was sought (Chang et al, 2001).

Low marsh vegetation was expected to develop on approximately 3.2ha of the site, with a further 1.5ha which may be suitable for the pioneer species such as *Salicornia* and *Aster* (IECS, 1994). There was transition from mudflat, through pioneer to low and mid marsh vegetation within the site, dominated by

Spartina (Reading et al, 2008). Thirteen hectares of saltmarsh were recorded by 2007, leaving only 8 ha of intertidal mudflat (Reading et al, 2008). Plant communities within the site were lower in diversity than the surrounding saltmarsh, despite the more extensive coverage than predicted.

Intertidal species were expected to colonise the area, including fish species such as sticklebacks. Invertebrate monitoring was not included initially, but was added in the expanded monitoring programme and showed that diversity within the site was enhanced and that abundances increased rapidly at first, but appeared to plateau by the end of the monitoring period (Reading et al, 2008). An increase in tidal mudflat was expected to be utilised by wildfowl and wading birds and fish. Birds and fish were observed throughout the newly created intertidal area.

5.3. Paull Holme Strays

Paull Holme Strays was promoted by the Environment Agency, partly to meet their need for sustainable flood defence (primary driver) and partly to provide compensatory habitat for other flood defence schemes within the Humber where habitat was to be lost (secondary). The need for compensatory habitat meant that some quantitative aims for biological parameters were provided (Edwards and Winn, 2006, Environment Agency 2006), although predictions for these were not given.

Accretion was found to be greater than anticipated with 300mm over three years (Environment Agency, 2007) and higher than outside the site. Salt marsh flora were less diverse and contained a higher percentage of pioneer species than mature saltmarshes, with *Atriplex prostrata* being most frequently recorded and were colonising the mudflat area by 2007 (Environment Agency, 2007). A variety of habitats developed, with more area of upper saltmarsh and less middle marsh than expected in the ES, intertidal mudflat and saline lagoons being identified (Robertson, 2004). Invertebrate occurrence across the site was similarly patchy, with the highest diversity and biomass occurring in a central area. Waterfowl usage of the area was extensive, with most target species observed during the monitoring, consistently above the target numbers.

5.4. Abbotts Hall Stage 2

Abbotts Hall site is owned and managed by the Essex Wildlife Trust and the managed realignment was carried out in partnership with the Environment Agency and English Nature (now Natural England), to provide sustainable flood defence and to provide a publicly accessible demonstration habitat creation scheme. The habitats to be created were intertidal mudflat, saltmarsh, transitional grassland, grazing marsh and new freshwater habitat (replacing that inundated by the realignment).

There was a prediction of no change to the tidal regime, such as upstream tidal levels or direction of tidal flows, although some localised current speed increases may occur.

Tidal regime monitoring confirmed the predictions, with the exception of the current speed increases which were more modest than anticipated (ABPmer, 2011a). Sediment deposition and accretion were in line with predictions.

Vegetation colonisation was faster than anticipated, as it was more accelerated than that observed at the previous Blackwater sites at Tollesbury and Orplands. Fish fry were found in particularly high numbers (Colclough et al, 2005), associated with vegetation stands and it was postulated that timing of breach and regulated tidal exchange helped promote vegetation colonisation and thus fish diversity. Use of the area by birds has been extensive and the Essex Wildlife Trust promotes the area to visitors through the overwintering populations which roost and forage in the site, as well as skylarks, warblers, ducks and little egrets all year round.

5.5. Chowder Ness

Chowder Ness was promoted by Associated British Ports as compensatory habitat for that lost during port development schemes at Immingham and Hull. It was predicted to have an insignificant effect on tidal regime and hydromorphology and early results show the accretion of sediments to be following the trends expected, with rapid initial accretion, with gradual levelling off (ABPmer, 2011b).

A net gain of saltmarsh was predicted and the fringing areas of the site have shown some marsh development with pioneer saltmarsh flora species recorded.

The creation of 10.5 ha of intertidal mudflat was expected to provide a net gain of benthic invertebrates, which would provide an increased food resource for fish, waders and wildfowl, as well as new habitat for these biological parameters. The new intertidal area has been colonised by benthic invertebrates, with similar species composition to the pre-existing mudflat and slightly increased abundance. Sixteen species of birds have been observed on the site, including some of conservation interest for the area.

5.6. Wallasea Island North Shore (Allfleet's Marsh)

Wallasea Island North Shore Realignment was organised by Defra following losses of habitat at Lappel Bank (in the Medway Estuary) and Fagbury Flats (in the Orwell Estuary) following port developments.

Changes in the tidal prism were anticipated by allowing an additional volume of water moving into and out of the Crouch Estuary. No erosion was forecast in the surrounding estuary. The site was at an elevation which was suitable for mudflat development but it was necessary for Defra to also create saltmarsh quickly rather than wait for natural sediment accretion. Therefore to achieve this, the site was raised by 2m using imported silt material from dredging. This was deposited within the site (constrained by the new sea wall and a clay bund), to provide a suitable level and substrate for faster saltmarsh development and vegetation colonisation. Additionally, a careful landscaping design was employed, with channels, islands and lagoons included, to provide maximum habitat availability immediately after construction. Other areas were left low lying to encourage intertidal mudflat development.

Five years of monitoring were being undertaken and although this had finished at time of writing, the full results have not yet been published. Interim results showed that the mudflat has accreted sediment, saltmarsh has begun to develop with pioneering *Salicornia* plants dominant, sheltered areas are being utilised as nursery grounds by fish species and high abundances of birds were observed and using the site for roosting. Benthic invertebrates have rapidly colonised the mudflat areas, although assemblages are still widely variable (Defra, 2011). Additionally a website was set up where live information from the site was available via webcam for any member of the public wishing to watch the development of the site[2].

[2] http://www.carnyx.tv/CarnyxWild/WallaseaIsland/WallaseaLiveCamera.aspx

6. Discussion

6.1. Discussion of data analysis

Limited sites were studied, selected from the larger group of UK managed realignment sites, partially due to the information accessibility and availability. This could provide a source of bias within the study, as they may not represent practice across all of England. This may be exacerbated by the fact that those which were chosen were in only two main locations on the east coast. The study could be widened in future in order to either challenge or confirm the observations provided in this study.

Predictions from the Environmental Statements did not include much in the way of quantitative predictions, although each provided quantitative estimates of areas of habitat expected to develop and many provided quantitative estimates of sediment accretion. Targets were occasionally expressed, such as in the case of Paull Holme Strays. Most predictions were qualitative, with respect to the potential for both positive and negative impacts at each site and in the surrounding environment. This is usual in Environmental Impact Assessment, as the aim is to first consider the worst-case potential and to then design mitigation measures for the negative impacts to be incorporated in the construction and operation methodologies. In the case of Appropriate Assessment, if no suitable mitigation measures can be identified, compensation arrangements are then developed.

6.2. Research questions

6.2.1. How did timescales, hydrodynamic and ecological predictions compare to those observed in the monitoring?

The predictions of the schemes altered with a progression through the schemes; it was noticeable that predictions became more detailed in the later realignment environmental statements and appropriate assessments, reflecting that experience had led to a higher understanding and improvements in modelling tools such that there was higher confidence in making the predictions. Predictions of timescales were consistently conservative with respect to the sedimentary regime changes, with most sites accreting material more rapidly initially than expected. Accretion rates were observed to gradually slow subsequent to the initial two years, but none of the monitoring was sufficiently long term to establish whether sites achieved an equilibrium, suggested to be in the order of twenty years at Tollesbury by improved modelling (Spearman 2011).

Predictions of development of the site in terms of sedimentary levels and patterns of accretion/erosion were particularly inaccurate in the early sites, but improved through time. Computer modelling has been improved through refinement of assumptions, changes to the conceptual modelling approach and access to higher processing power machines (HR Wallingford, 2001; HR Wallingford, 2004; Spearman, 2011). In the Humber, it has been discovered that as soon as mudflats attain a certain elevation in the tidal exposure, pioneer flora will quickly convert the mud to saltmarsh, thus the proportions of saltmarsh to intertidal mudflat have mostly altered in sites which were relying on natural processes to restructure the intertidal environment (Mazik et al, 2010; Morris, 2013). Abbots Hall and Wallasea Island were designed more fully and engineered according to levels required prior to allowing the areas to be flooded. This included building up levels at Wallasea Island (Allfleet's Marsh) by placing dredged material from Felixtowe at the site (Dixon et al, 2008). They have achieved their habitat proportions more easily initially. However, the timescale involved is probably insufficient to determine whether the habitat proportions will remain stable in future.

Ecological predictions were necessarily qualitative, although some efforts were made to predict particular species which would be expected to colonise the sites. Monitoring results often showed biological colonisation and usage of the sites, but observations were made that the colonisation process was incomplete by the end of the monitoring period, for invertebrates and birds. It is therefore likely that ecological carrying capacity was not achieved during the monitoring period. Nonetheless, results from ecological monitoring were often those which were used to justify the success of each site, despite this being debatable (Mossman et al, 2012; Elliott et al, 2007; Morris, 2013). Bird usage of developing sites mostly met the aims and targets where these had been set, whilst invertebrate aims and targets were mostly not met.

6.2.2. Was the monitoring designed appropriately, or were some changes observed which could have benefitted from being monitored specifically?

Monitoring programmes were generally designed during the environmental impact assessment process and it was noticeable that schemes carried out primarily for sustainable flood defences had fewer monitoring surveys focussed on the biological parameters of site development included.

Length of monitoring programmes did not take into account the timescales of expected continuing change. Continuing monitoring would have provided some evidence of stabilisation of accretion rates, floral assemblages, invertebrate assemblages and bird/fish usage of the sites. These could have provided more understanding of the ecological carrying capacity of the re-created sites. Some monitoring programmes were enhanced by academic studies continuing to be undertaken after the formal monitoring had ceased.

In none of the sites where sustainable long term flood defence was an objective, has any long term engineering monitoring been explicitly put in place to:

- affirm that the coastal defences have remained more effective due to marsh or mudflat fronting them, or
- check that the original problems of erosion of coastal defences has not relocated to adjacent areas.

The Environment Agency does carry out condition assessments of coastal flood defences, but has not published any review of the effect of managed realignment in these terms.

6.2.3. Were unanticipated changes predictable with further knowledge and experience?

None of the sites has achieved a saltmarsh flora community which is regarded as sufficiently similar to the marshes in the vicinity which have been extant for centuries (Wolters et al, 2005, Mossman et al, 2012). This may be due to the timescale of establishment of mature saltmarsh floral communities being much longer than available for monitoring to date and thus could be said to have been predictable.

Changes to sedimentary patterns which weren't predicted could be attributed to the lack of model sophistication and paucity of knowledge to provide robust assumptions on which to base numeric predictions. Further knowledge and experience is beginning to address this and precision tolerances provided. Extensive use of sites by fish for nursery areas was unanticipated, as fish predictions tended towards the usage by adult estuarine species. Consideration of the availability of shelter that such sites could provide may have provided some clue to the possibility.

6.2.4. If changes were unpredictable, has enough knowledge been amassed from investigations into the changes to include them in future predictions, or have hypotheses been developed?

With Tollesbury, the initial timescale and range of monitoring parameters was quickly realised to be insufficient and the resources made available to extend both. The results from this have led to considerable refinement of the assumptions and methods of numerical modelling, using the data from the hydrodynamic and sedimentary regime monitoring (HR Wallingford, 1997; HR Wallingford, 2001; HR Wallingford, 2004; Spearman, 2011). The monitoring result information was invaluable in terms of establishing initial behaviours of a managed realignment site, which can be précised as:

- rapid initial sediment accretion gradually levels off through time;
- creek formation through the newly accreted sediment once that sediment exceeds a critical depth;
- shear strength of the soils were correlated to vegetation colonisation; and
- benthic invertebrates rapidly colonise and patterns can be discerned in the succession of assemblages.

In all cases, more saltmarsh developed than was initially predicted and it is now understood that once sediment accretes to a certain level in the tidal frame within an area suitable for saltmarsh development, pioneer vegetation will quickly colonise it (Mazik et al, 2010). This means that straightforward breach techniques are unsuitable if intertidal mudflat is the long term habitat desired (Morris, 2013). Indeed, the suitability of re-created sites for compensatory habitat is being questioned (Mazik et al, 2010; Mossman et al, 2012; Morris, 2013).

7. Conclusions

None of the monitoring programmes was considered to have been designed to take in the potential timescales of development of the managed realignment sites. Piecemeal studies cannot be relied upon to provide all the answers and a comprehensive assessment of the early experimental sites one decade after breach and after two decades would have provided a considerable benefit in terms of the development of experimental sites in the medium term, given that sustainability was one of the overriding aims. This is particularly true now that further research has indicated that maturity of salt marsh may not be reached for many decades (Wolters et al, 2005). Further academic studies have been undertaken for Tollesbury, with the most recent information being released being that of a study of managed realignment site capacity for carbon sequestration (Burden et al, 2013). Further understanding of ecological services of the re-created habitats could strengthen the case for future re-creations, once more economic and social benefits can be shown to be linked to managed realignment schemes.

Since there were few expectations in the experimental sites, it could be argued that most of the changes were unanticipated, but that the lessons learned from Tollesbury, in particular, were kept in mind when making predictions of change at subsequent managed realignment sites, thus hypotheses of how the sites develop have been developed. Unexpected functionality, such as the usage of the sites by fish fry, can be acknowledged as a further ecological benefit of these created habitats and may have further potential economic benefit in playing a role in ensuring sustainable commercial fish resources.

At more recent sites, the monitoring addressed the predictions initially and were appropriately targetted, but longer term monitoring at Paull Holme Strays would have provided better understanding of the medium term development of the site, particularly since the site did not meet the predictions of the habitat areas (DEFRA, 2002). Changes were predicted over ten years, whilst monitoring did not extend to this timescale. This mismatch between timescale of predictions and monitoring was also observed at the most recent of the sites considered, at Wallasea Island North Shore (Affleet's Marsh), with only five years of monitoring programme planned. There could be considerable improvement in useful data if resource had been allocated such that monitoring was conducted annually for the first three years following breach, a monitoring survey in the fifth year following breach and then a decade after breach to give a better time spread of the monitoring.

Realignment has been judged to be effective in lowering ongoing maintenance costs of coastal defences, but that more expense and complexity of design is required to deliver environmental objectives (Garbutt et al, 2006). However, engineering monitoring information has not been published to give evidence to the assertions of effective coastal defence long-term, nor has any information been published with respect to whether coastal defence problems in adjacent areas have been exacerbated (pers. comm., Alan Brampton). The Environment Agency, who are responsible for most of the English flood defences, concentrate on discussing managed realignment successes in terms of environmental benefit, rather than sustainable coastal defences. Sustainability was not defined nor criteria developed. This aspect should be developed in future, such that evidence of success is directly comparable with the sustainability definition and criteria given.

Providing resource for long-term monitoring is unlikely from the public bodies such as DEFRA and the Environment Agency, however, it could be appropriate to expect monitoring for compensatory habitat re-creation to be funded by developers, who receive benefit from their development and could be perceived to have a duty of care to ensure that the habitat creation is fulfilling the long term aims of the legislatory requirements. Sites that are cared for by charities, as in the case of Abbots Hall and Wallasea Island, may be interested in monitoring them to ensure continued appropriate use of their donators' money.

It was noticeable that predictions became more detailed in the later realignment environmental statements, reflecting that experience had led to a higher understanding and improvements in modelling tools such that there was higher confidence in making the predictions. Monitoring programmes were generally designed during the environmental impact assessment process and it was noticeable that schemes carried out primarily for sustainable flood defences had fewer monitoring surveys focussed on the biological parameters of site development included. Monitoring programmes were passive, focussed on surveillance and information gathering, rather than re-actively developing intervention strategies.

Success was often claimed for individual sites, for example, based on site usage of birds. However, these successes may have been claimed due to political expediency or individual investment and the nature of the success not necessarily linked back to the original requirements and aims of the project. This is a significant weakness which does not provide any recommendation for future managed realignment and could well be used in challenge to developers or regulators wishing to promote these schemes in future.

This study is necessarily limited in its scope, but seems to indicate that monitoring has been of benefit in refining the prediction process and in enhancing understanding of the processes which act on newly tidally inundated areas, particularly with respect to careful design when undertaking compensatory habitat schemes. Monitoring alone has not provided the full understanding, as it has often been followed up by individual academic studies further expounding on monitoring outcomes, often due to monitoring timescales not matching the full timescale of site development. Claims of success for the sites do not always have rigorous evidence, as robust defined success criteria were rarely developed prior to site inundation.

7.1.1. Recommendation 1

The selection of the limited number of sites within this study, constrained by the time available and limited length of the report, may have led to representativeness of the study being limited. However, this could be improved by widening the number of sites studied, as the methods applied could be repeated. Further expansion of the study to consider more sites would be beneficial.

This study would be enhanced if it were further expanded to consider more sites from more geographically diverse areas.

7.1.2. Recommendation 2

The complexity inherent in the ecological systems, with various factors structuring floral and faunal colonisation is recognised. However, insufficient information on the long term development of species assemblages at sites is available, due to monitoring programmes being medium term at best.

Understanding of the ecological functionality of the sites would benefit from longer term monitoring or revisiting to establish the medium and long term behaviour of managed realignment areas.

7.1.3. Recommendation 3

Comparing predictions of sites to the monitoring exposes many of the successes claimed to question, as the outcomes or aims are rarely specific enough prior to sites being approved.

Success criteria should be explicitly defined prior to site development.

7.1.4. Recommendation 4

Sustainability is used regularly as an aim for managed realignment, but rarely seems to be defined in terms of how sustainability is being measured – whether economic, social or environmental.

Key performance indices of sustainability should be developed, included in predictions and thereafter monitored to provide evidence that managed realignment meets economic, social and environmental sustainability.

It is reiterated that this project was undertaken between October 2012 and March 2013 and it is intended that the work is further refined for publication. As such, comments or additional information from the managed realignment community are very much welcomed. Contact details are below.

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