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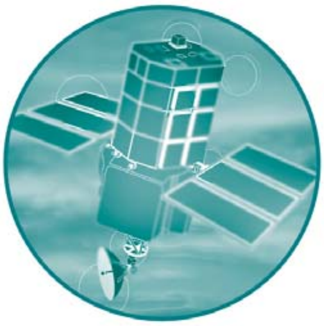  

Habitat quality measures and monitoring protocols

R&D Technical Report FD1918

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Habitat Quality Measures And Monitoring Protocols

R&D Technical Report FD1918

Authors: Natalie Frost, Stephen Hull, Nigel Pontee

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Statement of use
This review and collation of current knowledge, leading to a conceptual model for the specification of habitat monitoring programmes, is for all organisations and individuals involved with the management, conservation and enhancement of estuarine and coastal zones. It provides structured guidance that will aid professionals in Defra, the Environment Agency, Coastal Local Authorities, and all their Consultants in the design of appropriate habitat monitoring strategies that chart the progress of created habitats towards their specified objectives, and allow adaptive management where necessary. It is suitable for use in planning, managing and assessing habitat creation schemes, but is not intended to be used prescriptively.

Keywords
Habitat creation, managed realignment, field measurements, monitoring strategy

Research Contractor
ABP Marine Environmental Research Ltd, Pathfinder House, Maritime Way, Southampton, Hampshire, SO14 3AE, UK, Tel: +44(0)2380 338 100, Fax: +44(0)2380 338 100, E-Mail: enquiries@abpmer.co.uk

Defra / Environment Agency Project Officer
Adrian Dawes, Mouchel Consulting Limited, West Hall, Parvis Road, West Byfleet, Surrey, KT14 6EZ, UK, Tel: +44(0)1932 337427, Fax: +44(0) 1932 350052, E-mail: info@mouchel.com / adrian.dawes@mouchel.com

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EXECUTIVE SUMMARY

The number of managed realignment schemes in the UK being planned and implemented has increased markedly over the last decade. It has therefore become increasingly important that we have a sound understanding of the parameters that influence scheme success. Appropriate monitoring strategies are fundamental in determining whether progress towards scheme objectives is satisfactory, and thus whether or not the scheme has been successful overall.

This project is concerned with providing guidance for the monitoring of managed realignment and habitat creation sites. The project will therefore provide guidance for:

- the collection of better data in terms of relevancy, consistency and statistical validity (including both baseline and ongoing measurements);
- the assessment of the success of habitat creation schemes; and,
- validating the effectiveness of mitigation schemes and assessing the residual impacts.

Additionally, the project will provide guidance to managers to enable corrective action to be undertaken where habitat quality objectives may not be achieved, or to develop alternative quality objectives which better reflect the capacity/ capability of the site.

The report has been produced by ABP Marine Environmental Research Ltd (ABPmer) and has incorporated the comments of the project review panel composed of:

- Mark Rehfisch - British Trust for Ornithology (BTO)
- Sue Brown, Centre for Ecology and Hydrology (CEH)
- Robert Hughes, Queen Mary University of London (QMUL)
- Ruth Parker, Centre for Environment, Fisheries and Aquaculture Science (CEFAS)

The document has also been circulated to a number of other organisations who have a key interest in the project outcome. These include:

- Mouchel (the client representative for the Environment Agency) - Adrian Dawes
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- Department for Environment, Food and Rural Affairs (DEFRA) - Peter-Allen Williams

The outputs of two additional projects, Suitability Criteria for Habitat Creation (CEFAS, 2004) and Design Issues for Managed Realignment (CIRIA, 2004) have also been taken into account.

The task of determining the success of habitat recreation has long been challenging and sometimes contentious because the appraisal of success is dependent on the objectives of the scheme. What may be recognised as a successful scheme by one individual or

organisation might be deemed as failure by another, depending on the criteria used. Each scheme that is undertaken will therefore have different objectives and consequently different measures of success. Thus, because of the range of objectives which habitat creation schemes may be seeking to achieve, different schemes are likely to require different monitoring programmes to chart progress towards these objectives. This highlights the importance of monitoring in the assessment of progress towards objectives and the potential for adaptive management where required. As a consequence practical measures of habitat quality encompass a suite of parameters and statistical measures.

The present review demonstrates that whilst habitat quality may be measured in terms of ecological parameters, the failure to achieve target values for these parameters may be attributed to the creation of inappropriate physical conditions. This emphasises the need, in many cases, to monitor a range of both physical and ecological parameters, to fully understand the development of habitat creation schemes. In terms of physical factors, elevation relative to tidal range is seen to be a prime determinant in the creation of given habitats. Relevant ecological indicators of successful habitat establishment should include vegetation coverage, the status of macrobenthic populations and the bird and fish usage of the site.

This review illustrates that there are a range of techniques available for measuring all of the parameters that have been identified as of interest at habitat creation schemes. The strengths and weaknesses of the various techniques have been evaluated with a trade off usually existing between the speed and simplicity of measurement versus the cost in terms of equipment and time.

Most of the managed realignment schemes that have been implemented to date have incorporated some degree of monitoring. The number of parameters monitored at each scheme is, however, highly variable. The intensity of the monitoring programmes are also quite different depending on the nature of the scheme. A review of several case studies demonstrates that birds, invertebrates and sediments appear to be the most widely monitored aspects. However, the monitoring programmes carried out to date differ from scheme to scheme. This underlines the importance of the current project in providing guidance for the systematic design of monitoring programmes for similar schemes in the future.

A conceptual model has been developed which incorporates the key reasons for monitoring, how this determines what to monitor, what the results are gauged against and the end uses of the monitoring data. The results collected from monitoring of managed realignment schemes can be used in a number of beneficial ways including enhancing the understanding of site design and management.

Following from the identification of a ‘toolbox’ of monitoring techniques it was possible to group the techniques into ‘core tools’, which are relevant for all sites, and ‘optional tools’ whose use is dependent on site specific requirements. Where there is no formal requirement for monitoring it is suggested that core monitoring is still undertaken at as many sites as possible. This would incorporate, as a bare minimum, changes in elevation and habitat boundaries at a site. A large proportion of managed realignment schemes that are undertaken will, however, have statutory requirements for monitoring. Where monitoring forms a requirement for the scheme there may be a shift in emphasis from the quantity to the quality of what develops at a site. The types of parameters that should be monitored include not only the core parameters identified above but also those for which impacts are predicted, those for which compensation objectives have been set and those which have funding conditions attached.

It has been identified that there are no simple rules that can be applied to decide on the parameters that should be monitored at a site. The parameters that require monitoring are largely dependent on a number of factors including the purpose/ objectives of a scheme and a range of site specific issues. To provide guidance on how the selection of monitoring programmes has been undertaken for current schemes two case studies have been presented. The two schemes that have been selected are very different in terms of their overall purpose and as such the process of defining the monitoring protocols also varies.

Once the parameters that require monitoring have been established it is then necessary to select the most appropriate technique. The selection of a technique to use for a specified scheme will be influenced by a number of factors, including the purpose of the scheme, the degree of accuracy required, available budgets and more site specific issues. All the available tools need to be reviewed taking into account the advantages and disadvantages of each and all of these factors.

There are a number of further considerations that need to be taken into account when developing a monitoring programme. These include the duration and timing of the monitoring period, a continual reassessment of monitoring efforts, the expertise of the personnel involved, quality assurance procedures and the appropriate selection of sample size and statistical analysis. All of these factors can contribute to the overall success of the monitoring programme. A decision tree, covering all of these issues, has been designed to guide the user through the types of questions that need to be addressed in designing a successful monitoring programme.

The key aspects required to achieve a successful monitoring programme for a managed realignment site have been addressed throughout this report. The results of such monitoring will not only enable the evaluation of current objectives but will inform the design and management of managed realignment schemes in the future.

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1. INTRODUCTION

Physical pressures such as land claim, shoreline reinforcement and dredging continue to have extensive impacts on the extent of intertidal and other habitats around the UK coastline. Such effects can be exacerbated by relative sea level rise. Habitat creation (the creation of new habitat) or habitat recreation/ restoration (the enhancement or restoration of previous and existing habitats) aims to alleviate some of these losses. The number of habitat creation schemes in the UK being planned and implemented has increased markedly over the last decade. The relative newness of such schemes means that as yet we do not have an adequate understanding of the processes behind the restoration/ creation of saltmarsh and mudflat habitats. It is only through the monitoring of existing schemes that we will be able to enhance our knowledge of the parameters, and their linkages, that are important to successful scheme design.

Appropriate monitoring strategies are fundamental in determining whether progress towards scheme objectives is satisfactory, and thus whether or not the scheme has been successful. To assess the development of the scheme, the results of such monitoring can be compared with baseline conditions at a site, or with local reference sites adjacent to the scheme. This assessment of scheme performance facilitates adaptive management strategies, including remedial action where necessary. Assessing the success of schemes is particularly important for validating the predictions made within any associated Environmental Impact Assessment (EIA). Such assessments may be carried out for schemes which are being implemented for a variety of different purposes including:

- Compensation and mitigation for loss of habitat;
- Beneficial use of dredged material;
- Flood and coastal defence;
- Habitat development for nature conservation;
- Fishery and shell fishery production;
- Water quality improvement;
- Ground water recharge;
- Archaeological conservation;
- Tourism and recreation;
- Provision of educational and research opportunities; and
- Enhancement of urban landscapes.

The purpose of the scheme will influence the objectives of the scheme which will in turn influence the monitoring requirements of a project. There are a number of reasons for monitoring habitat creation schemes including:

- Legal requirement;
- Good practice in EIA;
- Overall evaluation of scheme success and site management;
- Demonstrating the achievement of objectives;
- Allowing site management and remedial action where necessary; and
- Improving understanding (research).

It is therefore important to consider the purpose, objectives and targets of a scheme when the monitoring requirements for a site are being decided. It should be noted that monitoring of a site is not always a requirement for habitat creation schemes. It is however, considered good practice to monitor at least some elements of scheme development at all sites. The requirement, and appropriate level of detail, for monitoring will be considered more thoroughly in Section 8 of this report.

1.1 Aims

This project is concerned with providing guidance for the monitoring of managed realignment and habitat creation sites. Such sites cover the intertidal regions of both estuaries and coastal zones and include saltmarsh and mudflat habitats. This document is aimed at all organisations/ individuals involved with the enhancement, management and conservation of estuarine and coastal zones.

The overall aim of the project is to develop measures of habitat quality and monitoring protocols to implement these. The project will therefore provide guidance for:

- the collection of better data in terms of relevancy, consistency and statistical validity (including both baseline and ongoing measurements);
- the assessment of the success of habitat creation schemes; and,
- providing a basis for consistent monitoring of sites to improve understanding of site development and how this might contribute to the wider functioning of an estuary or coastal system.

Additionally, the project will provide guidance to managers to enable corrective action to be undertaken where habitat quality objectives may not be achieved, or to develop alternative quality objectives which better reflect the capacity/ capability of the site.

1.2 Project Approach and Data Sources

The present report has been produced by ABP Marine Environmental Research Ltd (ABPmer) and has incorporated the comments of the project review panel composed of:

- Mark Rehfisch, British Trust for Ornithology (BTO);
- Sue Brown, Centre for Ecology and Hydrology (CEH);
- Robert Hughes, Queen Mary university of London (QMUL);
- Ruth Parker, Centre for Environment, Fisheries and Aquaculture Science (CEFAS).

The document has also been circulated to a number of other organisations who have a key interest in the project outcome. These include:

- Mouchel (the client representative for the Environment Agency) - Adrian Dawes;
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- English Nature (EN) - Stephen Worrall, Tim Collins and Roger Morris;
- Royal Society for the Protection of Birds (RSPB) - Nicola Melville and Malcolm Ausden; and

- Department for Environment, Food and Rural Affairs (DEFRA) - Peter-Allen Williams.

The project is based on information from a number of sources including existing literature on habitat restoration and intertidal monitoring in general, as well as the design and monitoring reports for managed realignment schemes which have been undertaken to date. To obtain the latter reports, a range of organisations have been contacted including:

- Royal Society for the Protection of Birds (RSPB);
- English Nature (EN);
- Department for Environment Food and Rural Affairs (DEFRA);
- Environment Agency (EA);
- HR Wallingford;
- The Centre for Environment Fisheries and Aquaculture Science (CEFAS); and
- The Centre for Ecology and Hydrology (CEH).

Where information has been forthcoming, it has been incorporated within the present project. The outputs of two additional projects, Suitability Criteria for Habitat Creation (CEFAS, 2004) and Design Issues for Managed Realignment (CIRIA, 2004) have also been taken into account.

1.3 Report Structure

This report represents the key output of project FD1918 and provides:

- Definitions of scheme success;
- A review of the considerations that are relevant to the choice of monitoring parameters for habitat creation schemes;
- An overview of the techniques which are available for monitoring various parameters;
- Statistical Measures;
- Case studies of existing managed realignment sites;
- A Conceptual Model for monitoring;
- Guidance on the parameters to measure at a site;
- Case studies - highlighting the selection of monitoring protocols;
- Selection of appropriate measurement tools;
- General guidance on monitoring; and
- Decision Tree - to summarise all the above information.

The following paragraphs explain the layout of this report.

The success of habitat creation projects can be defined as progress towards the achievement of targets or objectives, which can be defined in absolute terms though comparison to reference sites. The objectives for an individual scheme vary; thus every scheme poses specific information needs, and monitoring efforts need to be tailored to provide this information (this Section). Since most habitat creation schemes will aim to produce ecologically functional habitat, it is appropriate to consider the various ways of defining habitat quality (Section 2).

Section 3 provides an overview of the key factors that need to be considered in the design of successful schemes. This review illustrates that although there is a range of ecological and physical criteria, in many cases it is the physical criteria, in terms of hydrodynamics, sedimentology and morphology, which are key controls on the establishment and development of biological communities.

This report also reviews the techniques which have been used to monitor intertidal areas in general, as well as the monitoring of schemes which have been employed on existing habitat creation schemes (Section 4). Statistical analysis plays a key role in the design of sampling strategies, it therefore requires consideration prior to the start of any monitoring programme (Section 5). The number of parameters monitored for each scheme is shown to be highly variable being governed by the type of scheme, the location in coastal/estuarine areas and the bias towards physical or ecological targets. A number of case studies are also presented in greater detail (Section 6).

A conceptual model has been designed to incorporate all aspects of monitoring including the reasons for monitoring, what and how to monitor and the end uses of the associated data (Section 7). Following from the identification of a 'toolbox' of monitoring techniques it has been necessary to consider the most appropriate parameters to measure at a site. Every scheme poses specific information needs, and monitoring efforts need to designed to provide that information (Section 8). Two case studies are provided as examples of how the associated monitoring programmes were agreed for each scheme (Section 9).

Once the parameters that need to be measured for a particular scheme have been agreed the monitoring technique itself has to be selected. The actual method to use will depend on a number of factors including the purpose of the scheme, the degree of accuracy required, the available budget and site specific variables (Section 10). General guidance on monitoring procedures and additional factors that require consideration are presented in Section 11. A decision tree which covers all of these issues is presented in Section 12. The overall conclusions taken from this report are presented in Section 13.

2. DEFINITIONS OF SCHEME SUCCESS

2.1 Introduction

The task of determining the success of habitat recreation has long been challenging and sometimes contentious because the appraisal of success is dependent on the objectives of the scheme (Kentula, 2000). What may be recognised as a successful scheme by one individual or organisation might be deemed as failure by another, depending on the criteria used.

Lewis (1990) broadly defined success as 'achieving established goals', ideally as specified in quantifiable criteria. Quammen (1986) provided a more detailed definition by distinguishing between compliance and functional success. Compliance success is determined by evaluating whether the project complies with the terms of an agreement whereas functional success is determined by evaluating whether the ecological functions have been restored (Quammen, 1986) and whether the system is biologically viable and sustainable (West *et al,* 2000) and capable of responding to disturbance and human intervention (Mitsch, 1998). Each scheme that is undertaken will therefore have different objectives and consequently different measures of success. Thus, because of the range of objectives which habitat creation schemes can be used to achieve, different schemes are likely to require different monitoring programmes to chart progress towards these objectives.

Success defined by engineers seeking to improve flood defence, or dispose of dredged material, for example, will be determined by how well the scheme serves this purpose. Occasionally such schemes may also include an assessment of some added but often unspecific environmental benefits. More recently within the UK, many intertidal creation schemes aim to compensate or mitigate for damage to existing habitats to meet the requirements of the Conservation (Natural habitats &c.) Regulations 1994, the Wildlife and Countryside Act 1981 or other non-statutory initiatives. The objectives of such schemes need to be agreed by the stakeholders at the outset. In such instances the objective of the scheme could be to provide habitats of comparable type and quality to the habitats damaged or lost. However, in many cases it may be possible to improve on the quality of the habitat which is being damaged. In such cases comparisons may be made with other, more ‘ideal’ reference sites. Ultimately the success or failure of a scheme will be assessed against the targets detailed at the start of a project. It is therefore important that any targets set for a project are realistic and achievable.

The increasing recognition of wider benefits which the environment provides has given rise to a more functional assessment of managed realignment schemes. Functional success is a measure of whether the ecological functions of the system have been restored or created. These functions include, for example, the ability of intertidal habitats to support food chains, to attenuate storm action and to improve water quality. Whilst maintaining ecological functioning is the key to sustaining a healthy environment, a major challenge yet to be overcome is how to determine and quantify, given constraints of time and incomplete knowledge, the functions and values of natural and restored marshes (Atkinson *et al,* 2001). Success criteria need to include physical, spatial and temporal considerations as well as take into account the dynamic nature of coastal and estuarine habitats. It is also important to recognise that we do not currently have a full understanding of all elements of ecosystem functioning.

Ideally a completely successful created habitat would, in time, be indistinguishable in all respects from corresponding natural habitats (Atkinson *et al*, 2001). In other words biological, chemical and physical characteristics would be within the range of those characteristics found at equivalent natural sites. This requires an understanding of the variation which exists in the natural environment in order to determine achievable ecological function. The practical measures of habitat quality therefore encompass a suite of parameters and statistical measures. A number of techniques have been developed to measure habitat quality and these are summarised below.

2.2 Approaches to Assessing Habitat Quality

2.2.1 Reference Conditions

It is possible to assess the performance of a scheme, in absolute terms, by comparing the structure and function of the evolving site with reference conditions which are known to be of a high quality. The development of saltmarsh or the invertebrate composition of a site, for example, can be compared with neighbouring sites. Comparisons between created and reference conditions should ideally be made within the same estuarine or coastal system to reduce the amount of spatial variability added to the analysis. The timescales on which these comparisons are made also requires careful consideration. The establishment and subsequent development of biological communities takes time, and comparisons therefore need to take into account the successional state of each site. Pre-monitoring at a site and the surrounding area also provides information on the degree of natural variability that occurs within the system. This allows the subsequent assessment of scheme success to be placed in the context of natural variation.

One emerging approach to setting success criteria, in the US, is to develop a statistical representation or model of reference sites as the standard for comparison (Brinson *et al*, 1995; Brinson & Rheinhardt, 1996; Brooks *et al*, 1996; Simestad & Thom, 1996; Short *et al*, 2000). These approaches develop a quantitative characterisation of the restoration in the context of the properties and variability of the naturally occurring systems in the area. For example, Short *et al* (2000) calculate a success ratio that compares the value of an indicator against a success criterion established from data from selected reference sites. To meet their definition of success, values of each indicator must fall within the distribution of data from the reference sites for an indicator but be above the lowest 16.7% (i.e. one standard deviation) of this value. Similarly Simenstad and Cordell (2000) propose a hierarchical approach to setting performance standards for habitat restoration that recognises various aspects of the ability to support a target species. Criticisms of such approaches include whether the selected thresholds are appropriate and over what timescales they should be applied. Where naturally occurring systems are either non-existent or in poor condition the goal of restoration should be to improve the current condition, rather than match it.

2.2.2 Quality Indices

A number of techniques have been developed in the US for wetland assessment, each of which varies in its level of complexity; e.g. Wetland Evaluation Technique, Environmental Monitoring Assessment Program and the Hydrogeomorphic Approach (see Appendix A for details). The methods developed typically involve the examination of an array of parameters or variables and incorporate responses from as many ecosystem levels as possible (Adamus, 1988). These methods are often referred to as multi-metric approaches. The quantitative output from each metric is then combined to produce an index. An index is the aggregate of wetland metric scores that serves to summarise the biological, chemical or physical condition. A control data set, or reference condition forms an essential basis for making comparisons and for detecting impairments (Barbour *et al*, 1994). Not all of the assessment methods result in a single index figure, in some instances each attribute is assigned a value and these may be interpreted individually, based on the perceived importance of each indicator.

Most of these methods rely on the available literature, relatively simple observations, calculations and questions to come up with an estimation of wetland functions and values. The accuracy of all the assessment models described will be dependent on a number of factors:

- quality of information used to make an assessment;
- level of knowledge about wetland type;

- skill of individuals; and
- ability of users to acquire the information necessary to use the model.

While these assessment techniques have been developed in the USA, there have been no similar developments in the UK. The approaches that have been adopted in the USA are broadly similar in their design and application. The most applicable type of evaluation method is likely to depend on the nature of the scheme, the objectives of the project and predefined targets for the site. The usefulness of this type of approach also needs to be considered in the context of masking the true environmental picture. The combining of all factors into a single index value does nothing to further the understanding of each of the measured parameters and the linkages that exist between them, although the approach does allow crude comparisons of different sites to be made.

3. FACTORS IMPORTANT TO HABITAT STRUCTURE AND FUNCTION

3.1 Introduction

Coastal and estuarine systems are highly complex due to the feedback which exists between the various physical, chemical and biological processes (Figure 3.1). Previous work has demonstrated that successful habitat creation depends on both physical and ecological criteria. However, physical criteria including hydrodynamics, morphology and sedimentology, are perhaps the most fundamental in determining the overall success of schemes, since these affect the physical and chemical processes occurring within a site. These processes influence ecological structure and function of the created habitat, affecting both the establishment of primary colonisers and, ultimately, the use by higher consumers. The elevation of the substrate for example, can influence the extent and types of saltmarsh that establish, which in turn will affect site usage by invertebrates and ultimately animals such as fish and birds. It is important to note, however, that many plants and invertebrates have wide habitat tolerances and ranges in terms of, for example, salinity, elevation, sediment type, but their distribution and abundance can be determined by biological processes, notably dispersal potential, bioturbation, competition and predation.

Successful habitat creation should embody a holistic rather than atomistic approach. In other words, the whole must be greater than the sum of the parts, in order to create a functional ecological system. In this context it is also important to consider the implications of a scheme on the estuarine system as a whole, not just the proposed site. In addition, the definition of success is very much determined by the objectives of the scheme. Thus, whilst the key parameters in this review have been divided into a number of subcategories, the importance of each parameter will vary between schemes, just as the required values for each parameter will differ depending on the type of habitat to be created. The following sections therefore provide a brief overview of the key parameters including morphological, hydrodynamic, sedimentological, and ecological components required for successful scheme design. A report produced by CEFAS under the DEFRA/ EA flood and coastal defence research theme - Suitability Criteria for Habitat Creation, also provides useful information on this subject (CEFAS, 2004).

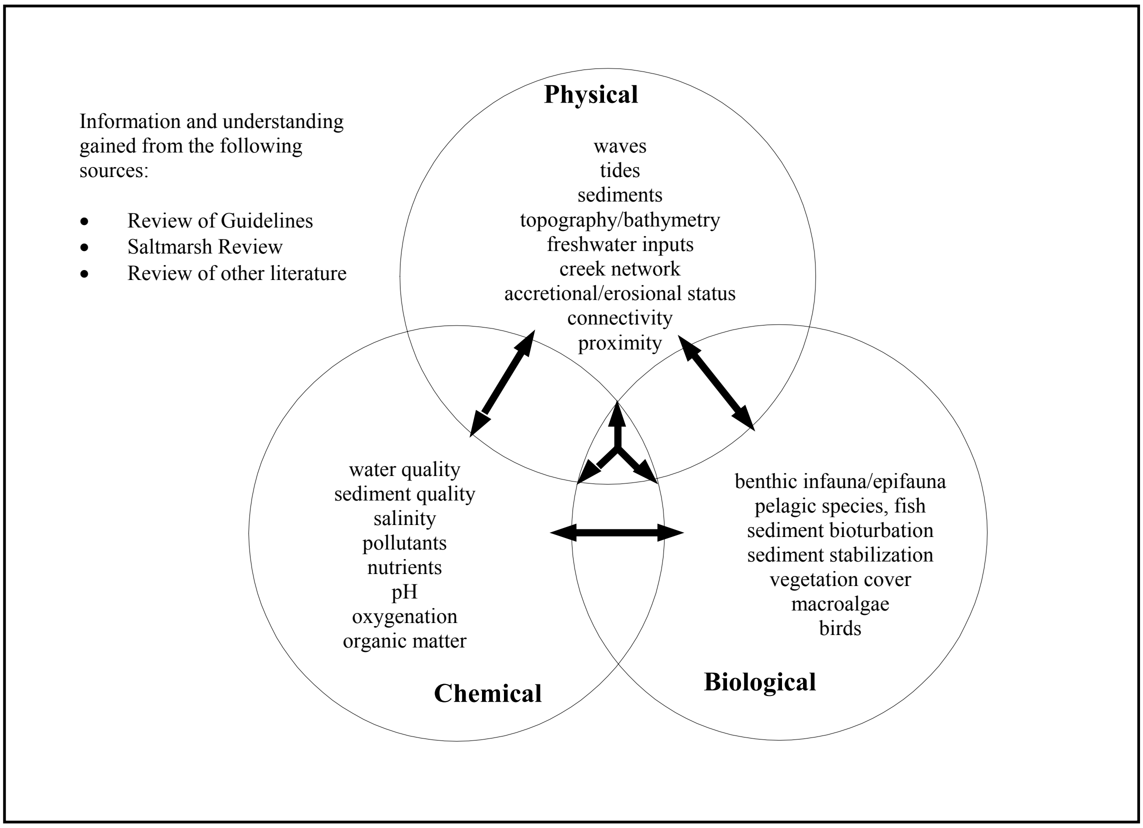


Figure 3.1 The identification of key parameters for successful habitat creation

3.2 Physical Considerations

3.2.1 Morphology

Intertidal morphology includes aspects of elevation, topography, area and the development of creek systems. These parameters affect the hydrological and sedimentological processes occurring within a site which, in turn, influence the ecological structure and function of the created habitat (Zedler, 2000).

Site elevation determines the frequency and duration of the tidal inundation as well as exposure to wave action (French *et al,* 2000), both of which affect primary colonisation. The frequency and duration of tidal inundation (the hydroperiod) plays a major role in the determination of all other estuarine functions, including intertidal morphology and sedimentology (P.E.R.L., 1990; Williams, 1994). In the UK, for example, different elevations are suitable for the development of different saltmarsh species (Section 3.3.1).

In addition to the overall elevation of the site, the range of elevations, or topography, is important in governing the range of hydrodynamic and sedimentological environments for floral and faunal communities. Upper intertidal gradients exert a major control on colonising plant species that help stabilise the slopes and thus control erosion. Furthermore, sites with a gradual, gradient across the marsh surface provide a range of elevations and tidal inundations, which promotes a more diverse saltmarsh (Toft & Maddrell, 1995). A further aspect of topography is the presence of a channel or creek system. In marsh habitats the presence of creek systems has been shown to lead to increased marsh productivity and habitat diversity (US Army Corps of Engineers, 1986). Creek systems affect water movement through a site (Williams *et al,* 2002) as well as supplying sediment and nutrients to the marsh surface. It is therefore important to take account of pre-existing drainage systems, the likelihood of drainage systems developing and the possible effects of engineering these (Hazelden & Boorman, 2001; Crooks *et al*, 2002).

Creeks provide habitat for invertebrates, shelter for birds and conduits for fish and mobile invertebrates foraging within the creeks or on the marsh surface during highest tides (Atkinson *et al*, 2001). In some instances, however, birds may avoid feeding in creeks where their field of view, and hence ability to spot predators, is limited (Cresswell, 1994). Finally, the total area and morphological diversity of a site will influence both the numbers of species and the extent of habitat types that can be supported by a site.

3.2.2 Hydrodynamics and Hydrology

The wave and tidal climate at a site influence physical characteristics, such as the erosion/accretion rates, which in turn influence the establishment of organisms and the overall species abundance and diversity of the communities present (Gray, 1992; Krone, 1993; Austin *et al*, 1996; Zedler, 1996).

The key tidal parameters which are important to habitat recreation schemes are:

- the tidal range and form of the tidal curve which, along with the site elevation, control the inundation period (see Section 3.2.1); and
- the current velocities, which influence the degree of sediment erosion/deposition.

Tidal range and circulation influence the sediment and nutrient fluxes to and from a site; the redox potential of the sediments and, ultimately, the plant growth rates and vegetation diversity (Adam, 1990; Pethick, 1994). Where habitats are created as part of a managed realignment programme, the dimensions of the breach in the former sea defence embankment affects both the circulation and the tidal range within the created habitat (Haltiner & Williams, 1987).

The degree of wave action at a site can have a significant influence on the stability of the sediments as well as the degree of inundation experienced at higher elevations. These factors will in turn influence the types of invertebrates and vegetation that colonise a site and their subsequent development. Wave action can also affect the processes of erosion and deposition at a site.

Hydrological factors such as the degree of tidal mixing and fresh water inputs from precipitation, runoff and ground water can be important factors affecting water quality. Water quality includes variation in salinity, concentrations of dissolved oxygen, water turbidity, organic content and pollutants. All of these elements may exert controls on the species colonising, and the subsequent succession, of newly created habitat.

3.2.3 Sedimentological Considerations

Sediment and soil characteristics affect the substrate stability, nutrient availability and the types of invertebrates that may colonise an area (Knutson *et al*, 1990) and these in turn help determine fish and bird numbers (e.g. Rehfisch, 1994). The most important variables are the soil permeability, penetrability, salinity, the pH, the nitrogen dynamics, the organic matter concentration, the redox potential, particle size, sediment supply, sedimentation rates, consolidation rates, and sediment chemistry. Experiments into the relative importance of these characteristics for subsequent colonisation have been specifically investigated at Tollesbury (Reading *et al*, 2002). Soils of former wetlands will more likely be suitable for native species than soils at newly created sites (Zedler, 2001).

Within a site, sediment deposition rates are related to the suspended sediment concentration, the particle size, the depth of water, the period of slack water and the density of the vegetation through which the flow is occurring. Deposition rates are likely to vary both spatially and temporally in response to changes in tidal range and currents, wave energy, fresh water inputs, suspended sediment concentrations, water temperature, plant morphology and benthic populations. The highest deposition rates often occur near to creeks, where the supply of suspended sediment is greatest.

The high primary productivity in wetlands causes an accumulation of organic matter in the sediments which influences many aspects of saltmarsh ecosystems, including sediment porosity and water holding capacity, nutrient dynamics, plant growth rates, and the abundance, composition and productivity of benthic invertebrates (Zedler, 1996). This is particularly true of US marshes which are more organogenic than UK marshes. Although natural marsh soils are usually highly saline, studies have shown that rates of vegetation establishment are improved in less saline substrates (Knutson *et al*, 1990). Similarly, although the tolerable range of pH is fairly broad for halophytes, with growth being possible from pH 4 to 9, most nutrients are more readily taken up when the pH is between 6 and 8. The redox potential is also important in controlling the cycling and mobility of nitrogen, sulphur, and heavy metals (Pethick, 1994) as well as the distribution of some species of flora and fauna.

3.3 Ecological Considerations

3.3.1 Vegetation

Vegetation density and structure is one of the main factors influencing site use by fauna (Zedler, 1996) and there are also important interactions that occur between the vegetation and fauna at a site (Hughes, 2001). Intertidal and saltmarsh areas also perform significant environmental services in terms of nutrient processing/contaminant storage (Costanza, 2000). The most important parameters for determining vegetation types are elevation, salinity, exposure to wave action, invertebrate herbivory, bioturbation and saturation. The proximity to saltmarsh plants that can act as donors is also important for determining the rates of establishment and subsequent community succession.

Elevation is possibly the single most important factor in determining the saltmarsh assemblage (Krone, 1993; Davy, 2000). Elevation differences of just 10 cm can substantially alter the vegetation composition and diversity (Frenkel & Morlan, 1991; Gray, 1992). Indeed in the UK between 70% and 96% of the total variation in the upper and lower limits of many dominant saltmarsh species can be explained by a simple linear regression equation based upon the mean high water neap tide level (Gray *et al*, 1995 in Toft & Maddrell, 1995).

The length of exposure time to air and the timing of germination are also critical factors in the development of pioneer communities (Pye & French, 1993). In addition communities in wave exposed locations are more likely to suffer setback from storm events. High suspended sediment concentrations are also associated with high wave action which can reduce the ability of newly establishing plants to photosynthesise (Toft & Maddrell, 1995), although this is not thought to be limiting for saltmarsh plants. Similarly particle size, within limits, is not considered important for the development of saltmarsh in the UK; marshes occur naturally on a range of particle sizes from clay to sand, although the grain size can affect the species composition of a community (Sue Brown and Robert Hughes pers. comm. 2003). Particle size does however have implications for the penetrability and permeability of the sediment, which in turn can influence water logging and hence saltmarsh development; saturation often leads to high concentrations of sulphide in the soil, which can be toxic to plants. The organic and nutritional status of the soils can also be important in controlling vegetation type and productivity (Zedler, 1996). The role of herbicides possibly contributing to erosion of saltmarshes is an currently under investigation (Mason *et al*, 2003; Fletcher *et al*, 2004).

3.3.2 Benthic Invertebrates

The benthos plays an essential role in the food webs of estuarine and coastal ecosystems and is especially important in determining bird usage. The importance of benthic communities means that their development is often used to gauge the long-term success of created intertidal habitats (Webb & Newling, 1985; Roberts, 1991). The distribution of invertebrates in the intertidal zone is influenced by a range of both physical and ecological factors.

Most macrobenthic organisms which inhabit intertidal flats are limited by their tolerance to the physiological and biological stresses caused by exposure to air (Peterson, 1991). This is primarily controlled by the hydroperiod, which in turn is a function of elevation relative to tidal frame (Anderson, 1972). Salinity is also important; estuarine invertebrate diversity typically decreases when water salinities drop below approximately 10 psu for extended periods (Zedler, 1996). In addition sediment particle size and sediment stability exerts an important control on benthic species due to their feeding and behavioural requirements. In the context of intertidal habitat creation, the densities and diversity of benthic communities have been reported to be adversely affected by large water level fluctuations (Marble, 1992), high rates of sedimentation (Davison & Evans, 1987; Toft & Maddrell, 1995), compacted sediments (Posford Duvier, 2000) and excessive concentrations of suspended sediment (Marble, 1992).

The distribution and diversity of benthic fauna in intertidal areas is directly related to the habitat types that are present and may also be affected by vegetation type (Jackson, 1985). Saltmarsh plants provide substrate, food, protection from predation and influence the temperature, humidity and light intensity at the sediment surface (Jackson, 1985). Additionally, saltmarsh plants produce changes in the sediment characteristics, including structure and stability, topography, climate, organic content and food availability. In contrast dense algal mats, distributed on the intertidal mudflats, can change the relative species composition and reduce the biomass and diversity of mud-dwelling invertebrates, including *Corophium*, ragworm (*Hediste diversicolor*) and lugworm (*Arenicola marina*), whilst increasing the biomass and number of epibenthic animals and worm species adapted to anaerobic conditions (Tubbs & Tubbs, 1980; Hull, 1987; Raffaelli, 2000). Similarly there is evidence that certain macrobenthic species such as the annelid *Hediste diversicolor* and the gastropod *Hydrobia ulvae* can affect the development and lower limit of saltmarsh vegetation (Hughes and Paramor, 2004a, b).

3.3.3 Fish

Many marine and estuarine fish require the shallow waters provided by estuarine saltmarshes and intertidal flats at some stage in their life cycle (Marble, 1992). In a review of the status of estuarine fish in the UK, Potts and Swaby (1993) identified 41 species that they considered estuarine in nature, being dependent upon estuaries at some time in their lifecycle. Saltmarsh habitat provides nutrients and detritus which, along with the invertebrates of intertidal flats and estuarine phytoplankton and algae, are critical to the fishery food chain. Saltmarshes and eelgrass beds also provide shelter and cover for young fish, such as bass, as well as providing habitats for a number of specialised estuarine species (McIvor & Odum, 1988; Toft & Maddrell, 1995). The number of species found in an estuary depends upon many factors including habitat diversity, estuary size and shape, structural complexity, tidal amplitude and freshwater runoff (Roberts, 1991).

3.3.4 Birds

The habitat preferences of bird species relate primarily to diet and feeding behaviour, although nesting and roosting requirements are also important (Atkinson *et al*, 2001). All bird species have distinctive feeding behaviour and prey types (e.g. Bryant, 1979; Goss Custard *et al*, 1991; Meire 1996). The prey items of bird species (largely invertebrates but also some saltmarsh seeds and plants, algae, eelgrass and diatoms) are also associated with a range of physical conditions which in turn has implications for site design and subsequent bird usage. Studies which characterise the diet of wading birds, and consider aspects of their feeding ecology and behaviour are therefore of great significance to the design and planning of intertidal creation schemes for bird usage. Within the UK, such work has generally concentrated on seven species of wader (redshank, curlew, dunlin, oystercatcher, bar-tailed godwit, turnstone and grey plover) which are typical of intertidal habitats (e.g. Goss-Custard & Durrel, 1990).

Additional factors important in controlling wader utilisation of intertidal habitats include the area of the site, topography, habitat types, disturbance, behavioural patterns and sediment consolidation (Goss Custard *et al*, 1991; Yates *et al*, 1992; Austin *et al*, 1996; Burton *et al*, 2002a, b). The climate (Piersma, 1994; Wiersma & Piersmal, 1994; Rehfisch & Crick, 2003), geographical location and proximity to flyways can also be important factors in locating a suitable site. In terms of topography, the intertidal area at mean low water springs, the ratio of area : length of shore and the coverage sequence, have all been found to affect the feeding distribution of waders (Bryant, 1979; Evans, 1997). Enclosed sites can also give birds the perception of increased risk of predation (Atkinson *et al,* 2001). In terms of disturbance, the close proximity of lights, noise and footpaths may affect wader use of an area. The proximity of disturbance free roost sites and other intertidal areas nearby are also important parameters determining site usage. In addition feeding densities may reflect behavioural mechanisms as well as prey density (Bryant, 1979).

The successful design of intertidal habitats for bird feeding or breeding habitat, will therefore depend indirectly on a number of the physical characteristics of the site since these control both the invertebrates and vegetation upon which the birds depend for food and shelter.

3.4 Linkages

A number of key parameters for the successful development of habitat creation schemes have been identified in Section 3 of this report. It is generally inappropriate to consider any one of these parameters independently due to the strong links that exist between them. Linkages exist between the physical, chemical and biological components of a system and careful consideration therefore needs to be given to the subsequent implications of incorrectly defining a parameter. If, for the example, the elevation of a site is wrongly defined this may have implication for the habitats that develop at a site.

The interaction between physical and ecological processes can be illustrated by considering a hypothetical example of a managed realignment site within an estuary (Figure 3.2). If no earth moving works are undertaken, then the elevation of the site relative to the tidal frame will determine the tidal prism and inundation period of the site. The inundation period is a prime factor in determining the development of marsh habitats. The tidal prism will determine the discharge of water between the site and the estuary and, hence, the scale of impacts on the wider estuary system. The hydrodynamics within the scheme, along with the sediment supply, will play a major role in governing changes in elevation at a site. These elevations, coupled with wave energy, will be the prime factor influencing the establishment and subsequent development of vegetation on the site. An additional level of feedback is then initiated with the vegetation further influencing the degree of wave energy attenuation and sedimentation and thus the bed levels within the scheme.

Similar linkages exist for managed realignment schemes in more coastal settings although, from a physical standpoint, waves and longshore transport assume a greater importance (Figure 3.3).

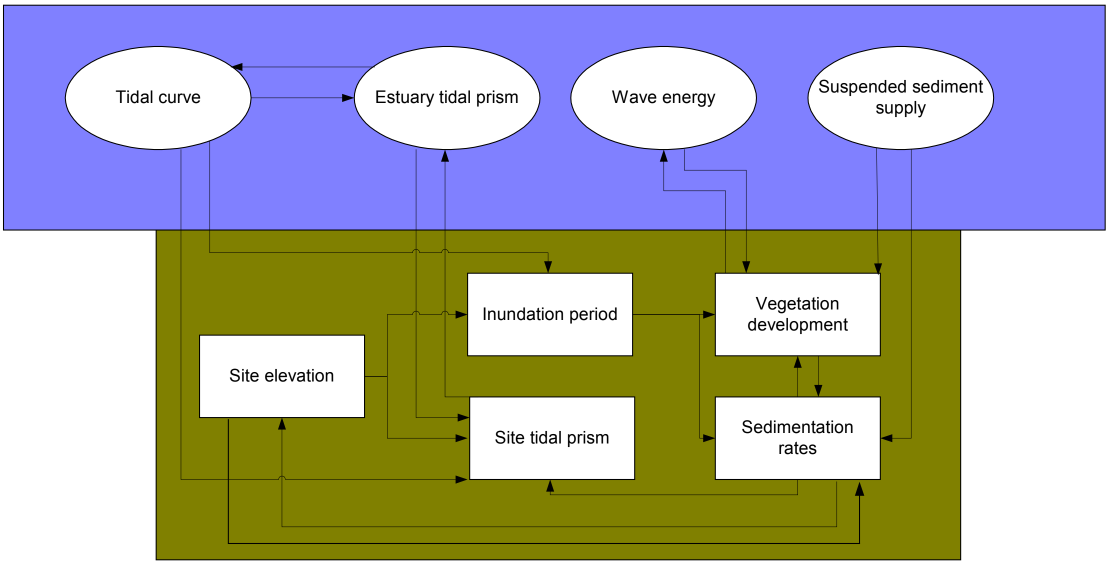


Figure 3.2 Simplified illustration of hydrodynamic and geomorphological linkages between estuary systems (blue) and managed realignment schemes (olive)

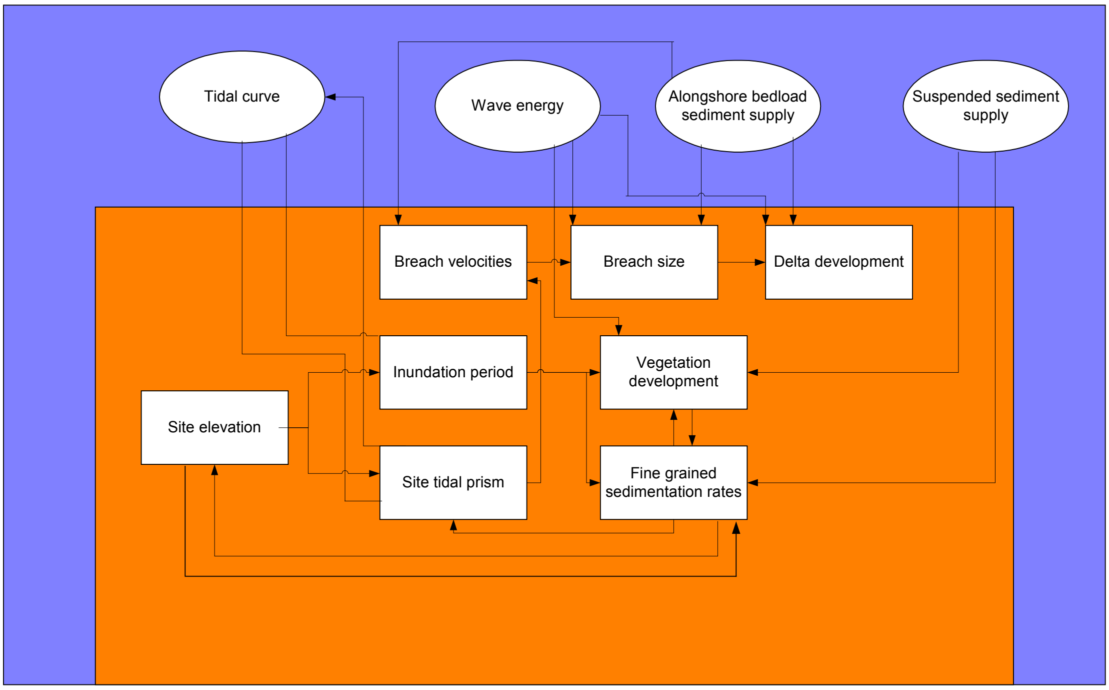


Figure 3.3 Simplified illustration of hydrodynamic and sediment dynamic linkages between coastal systems (blue) and managed realignment schemes (orange)

3.5 Conclusions

Through this review a number of key factors that need to be considered for successful habitat creation have been identified. The main conclusions are as follows:

- Experience has shown that many ecosystem elements rely ultimately on the physical characteristics of the site.
- Elevation and tidal range, which influence the tidal inundation are key factors influencing saltmarsh vegetation, the benthic invertebrate population and, ultimately bird and fish usage of a site.
- Creek systems are important for the successful development of saltmarsh and mudflat habitats and communities.
- Other hydraulic site characteristics, such as the wave climate, also play a major role in the determination of intertidal morphology, sedimentology and ecology.
- Water and sediment quality also exert an important control on habitat type and stability. Water quality factors include the degree of tidal mixing, freshwater inputs, dissolved oxygen, pollutants and turbidity. Important sedimentological considerations include pH, salinity, redox potential, the concentration of pollutants and the relative compaction of the sediment.
- The most important parameters for determining vegetation types are elevation, salinity, exposure to wave action, invertebrate herbivory and bioturbation.
- Most macrobenthic organisms which inhabit intertidal mudflats are limited by their tolerance to the physiological and biological stresses caused by exposure to air.
- The use of an estuary by fish will be affected by many factors including food availability, habitat diversity, estuary size and shape, structural complexity, tidal amplitude and freshwater runoff.
- The habitat preferences of bird species relate primarily to diet and feeding behaviour, although they are also strongly determined by predation risk, climate and unpredictable disturbance.
-

Given the importance of these factors in the creation of successful habitat creation schemes, it is appropriate that suitable monitoring methods are considered for each.

4. AVAILABLE FIELD PROCEDURES

4.1 Introduction

A large number of the attributes identified as important for the development of an ecologically successful managed realignment scheme can be measured and monitored. This section of the report identifies a number of techniques that have been used to measure each of the key parameters (Tables 4.1 and 4.2) based on a review of case studies. This section also considers the existing methods employed by the EA, CEFAS and others such as the Joint Nature Conservation Committee (JNCC) Marine Monitoring Handbook (Davies *et al*, 2001) and CHaMPS (http://www.english-nature.org.uk/livingwiththesea). Table 4.3 identifies the main methods that can be employed for each parameter along with guidance on their usage and the degree of accuracy that can be obtained from each measure. The confidence in each technique is described in terms of accuracy and additional comments that would aid the user is also incorporated into the table. The accuracy of each technique is likely to vary with the exact specification of the equipment used to measure each parameter, the estimates provided in the table therefore provide an indication of the accuracy that can potentially be obtained. Parameters that would benefit from additional methods have also been identified (Section 4.7). The monitoring strategies adopted at Freiston, Paull Holme Strays, Orford Ness, Shotley, Orplands and Tollesbury have also been described in detail to highlight the parameters of interest at these sites (Section 6).

This report details the types of monitoring required once the site has been inundated. It is important to note any post inundation monitoring should be consistent with any baseline monitoring that occurred at a site. The types of techniques that would be used prior to inundation or beyond the boundaries of a scheme would, however, be the same as those used within the scheme itself.

The ability of a monitoring programme to meet its aims successfully hinges on the selection of an appropriate method, together with its deployment strategy, to measure each attribute (Davies *et al*, 2001). It is also important, that where possible comparable methods are used at different sites to ensure that results are directly comparable between projects. Similarly in the selection of an appropriate technique it should be decided whether that same method (and strategy of deployment) should be used for the entire duration of the monitoring programme regardless of technological advancements. The relative importance of these issues will vary for each parameter and guidance on these issues is provided in Davies *et al* (2001).

For the majority of parameters that are monitored representative samples are taken as indicative of the condition of the entire parameter. Sampling stations that are selected for detailed analysis need to be representative of the parameter of interest. The natural variation over different temporal scales, seasonal and annual for example, also has to be taken into account. This combined with the patchy spatial distribution of intertidal habitats and species results in considerable variability which needs to be taken into account when designing a monitoring plan. More than one sampling unit per parameter is required, and replicate recordings at each sampling station are advisable (See Section 5). The use of reference sites (Zedler, 1996) allows comparisons with data in natural neighbouring locations and allows the distinction between natural and created variability to be made.

The actual positioning of sample stations and the number of replicates required for each parameter is beyond the scope of this report, although brief consideration is given to this issue in Section 10. The case studies presented in Section 6 also give some examples of sampling density and frequency. A detailed review of the issues associated with the design and implementation of a sampling strategy can be found in Krebs (1999) and Brown (2000). Similarly issues considered important to create a successful monitoring strategy are presented in Figure 4.1.

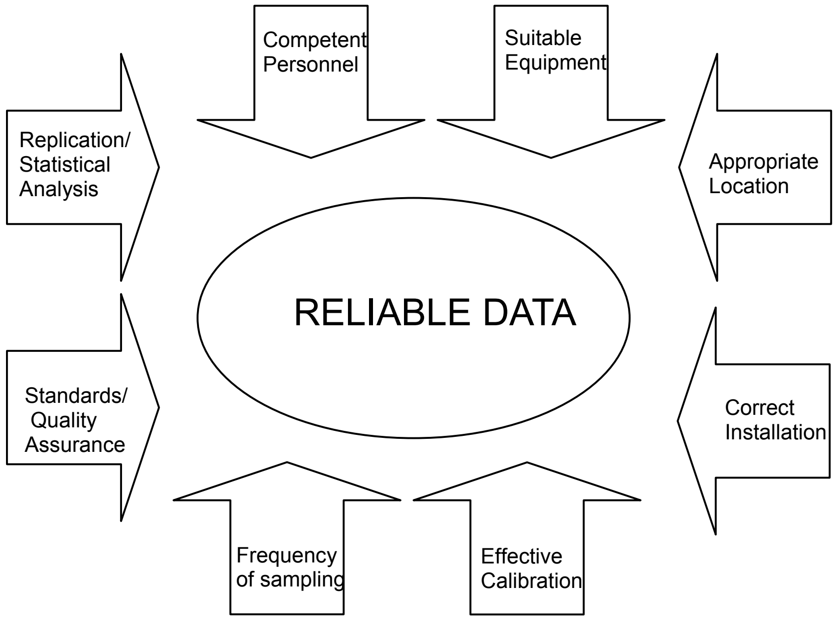


Figure 4.1 Components required for a successful monitoring strategy

4.2 Morphology

4.2.1 Topography and Elevation

The topography and elevation of a site can be measured in a variety of ways, a number of which have been employed at managed realignment sites. The measurement of the topography of a site may incorporate the elevation at a number of points or throughout the entire site. Ground measurements of topography are frequently measured along transects or at set bench mark positions. The elevation of points through time can then be directly compared. At the Orplands site, for example, levels of accretion and erosion were determined by spot height measurements along cross sections of the site (Dixon and Weight, 1995).

Height measurements can be recorded in a number of ways including differential GPS (Ingham & Abbott, 1992) and electronic total stations with critical height control (French & Watson, 1998). On more dangerous and inaccessible mud, at Shotley Point for example, a survey prism mounted on a shallow metal tray was pulled along the site surface to obtain height measurements (French & Watson, 1998). In addition, hovercraft may be used to deploy equipment in areas which are inaccessible on foot. Alternatively bathymetric surveys can be conducted across a site at high water. While this procedure has been used for the sampling of mudflats in general it has not been used at managed realignment sites. Electro magnetic distance measurements (EDM) have been used to determine site elevations at Northey Island (English Nature, 1994). Electronic distance measurement (EDM) uses a laser light source to measure the distance between two locations (Hydrographic Office, 1965). Light Detection and Ranging (LiDAR) data can be used to gain complete elevation coverage for a particular site (www.lidar.com). LiDAR is an airborne mapping technique which uses a laser to measure the distance between the aircraft and the ground. This technique results in the production of a cost-effective terrain map when used over large areas, there are however, limitations associated with this technique including the degree of accuracy obtainable where changes in elevation are small (Table 4.3). In particular the elevation of a site will be distorted by the presence of vegetation and other such structures. These sophisticated techniques require ground truthing and can be supplemented with data collected from walking across a site describing slopes, the geology and habitat types. The relative accuracy of all of these techniques is also highly variable and information is presented on this in Table 4.3.

4.2.2 Area

The area of a site will largely be defined from the start of a project. The extent of different habitat types within a site may, however, vary through time. Aerial photography or remote imagery, combined with conventional methods of site mapping (i.e. descriptive techniques), can be a useful tool for delineating habitat boundaries within a site. The interpretation of these data including the calculation of the total area of each habitat type can be undertaken with GIS software (Wright & Bartlett, 2001). Green & King (2000) and Brown *et al* (2003) provide a comprehensive review on the use of remote sensing for monitoring ecological habitats in the coastal zone.

4.2.3 Creek Systems

Similarly, changes in creek networks may be best identified via aerial photography or derived from LiDAR data. Creek networks can be digitised and their positions and form can be accurately monitored through time. Site mapping and measures of elevation can be used to ground truth these types of analyses, although mapping of entire drainage systems could be a very lengthy exercise. The monitoring of creek systems has only been documented at Freiston, it is probable, however, that this has been considered as part of the general morphological evolution at other managed realignment sites.

4.3 Hydrodynamic Parameters

Parameters such as tidal range, current velocities and wave action have only been measured at a limited number of managed realignment sites (Table 4.1). There are, however, a number of instruments that are designed to measure such parameters, each varying in their degree of sophistication (Palmer, 1989). The types of instrument that have been used at managed realignment sites include:

- Current meters;
- Wave meters; and
- Tide gauges.

For each of these types of instrument there are a number of different devices that can measure the respective parameters. Each instrument has a different specification and use different methods and technologies to collect and process the relevant data. A number of these instruments can, for example, relay data straight to a computerised database; while others retain the information within a data logger, which can later be downloaded. In addition a number of these instruments are capable of measuring a number of hydrodynamic parameters, combined wave and tide gauges, for example.

The specialised equipment used to measure these parameters can often be relatively expensive and time consuming to deploy. Data obtained from such instruments can also be supported with additional less sophisticated measurements. Tide gauge data, for example, can be supplemented with photographs taken at set periods throughout the tide and current velocities can also be measured by the use of surface drogues (Hughes, 2002).

4.4 Water Quality

The parameters considered under the heading of water quality (salinity, dissolved oxygen, turbidity, contaminants and organic content) have rarely been measured in association with managed realignment schemes. The exception to this in the UK was Northey Island where turbidity has been measured. The methods that could be applied at managed realignment sites are described below.

A number of the water quality parameters require the collection of water samples to obtain the relevant data. Organic content and contaminants, for example, requires the further processing of water samples to obtain results. Each contaminant within the water samples is identified through a specific analytical procedure depending on the nature of the contaminant.

Factors such as salinity and dissolved oxygen can be measured *in situ* via a probe deployed from a boat or calculated from collected water samples. Alternatively for longer term continuous measurements an instrument, with an attached data logger, designed to measure such parameters can be deployed. This type of instrument allows measures to be recorded throughout the tidal cycle but only from a single fixed position, whereas water samples can be collected at a range of positions. There is therefore a trade off between these types of techniques and where possible a combination of both provides the most informative results. Similarly, turbidity can be monitored via a turbidity meter in a fixed location with additional water samples collected to gain some indication of spatial variability. A Secchi disk can be used to provide a semi quantitative indication of water clarity (Campbell and Wildberger, 1992).

4.5 Sediments

4.5.1 Sedimentation Rates

An assessment of sediment erosion and deposition at a site is particularly important as this has implications for the elevation of a site, the types of plants and animals that can establish, and where relevant the smothering of benthic species. Sedimentation rates have therefore been monitored at a number of managed realignment schemes (Tables 4.1 and 4.2). The technique used often depends on the relative rates of erosion or deposition at a site and the time period of the study. The most common techniques used to monitor rates of deposition are measurements from the surface to buried accretion plates, or measurements to the surface sediment from a horizontal bar placed between two poles (e.g. Brown *et al*, 1998).

The amount of sediment that accumulates on the plates over a set time period provides an accurate guide to accretion rates at that position. Alternatively pre-weighed filter papers can be placed into the field and an assessment made of the deposition made on these, usually over a single tide. This technique is most suitable for assessing patterns of sedimentation as huge variability can be observed over single tides (Brown, 1998). The use of plates or filter papers to measure sedimentation rates can also have problems, in that their placement can interfere with the biological processes that stabilise or destabilise the surface sediments giving a false impression of sediment processes (Robert Hughes, QMUL. pers. comm. 2003). An additional problem with such techniques is that they are only capable of measuring sedimentation and not erosion. At Shotley Point SETs (Sediment Erosion Tables) were installed to separate the effects of compaction and surface sedimentary processes. The SET (Boumans & Day, 1993) is a temporary levelling device inserted into a permanent aluminium benchmark tube, where a series of pins are pushed through a plate on to the surface. These techniques are most suitable in areas of relatively low deposition.

The location of the plates or filters is always marked in some way so that they can be relocated at set time intervals. A number of replicate plates are required throughout the intertidal zone so that a true representation of the processes occurring across the entire site can be established. Measurements may also be required at a wider spatial scale where predictions for erosion and deposition are beyond the site boundaries of the managed realignment scheme.

Measurements from a parallel bar to the surface have been used at sites such as Tollesbury, and at Frieston in places where the sediment surface is unsuitable for burying plates (Sue Brown, CEH. pers. comm. 2003). The bar is usually placed across vertical poles, anchored in various ways to the sediments. An inexpensive method is to use sturdy bamboo canes, buried deep into the sediments (larger posts can interfere with sedimentation unless they are placed far apart). A builders level, or a specially constructed bar is placed across the posts in the same position each time, and a number of measurements taken.

Where sedimentation rates are higher topographic surveying is often a more applicable technique. This can be done along marked transects or in relation to fixed posts to reduce the error introduced by the offsetting of measurements (Ranwell, 1964). Premarked stakes can also be put into the mudflat to assess changes in elevation of the site.

For longer term measurements of the rates of erosion and accretion at a site artificial marker horizons are commonly used. These are deployed over time scales of between six months to one year. Accretion is usually measured from the depth to which the marker layer is buried after a known time (Ranwell, 1964). Various materials have been used as marker layers for measuring accretion including natural coloured sand (Oliver, 1929; Stoddart *et al*, 1989), dyed sand (Nielsen, 1935), brick dust (Stearns & MacCreary, 1957) iron fillings (Chapman & Ronaldson, 1958), glitter (Harrison & Bloom 1977, Stumpf, 1983), Cs^{137} (Pye, 2000) fiberglass resin and sand (Letzsch & Frey, 1980). To date this technique has not been used at any of the UK managed realignment schemes. Over much longer timescales, decades, sedimentation rates can be obtained by the identification of date specific geochemical horizons within a sediment core (e.g. Stevenson *et al*, 1985).

4.5.2 Sediment Properties

Sediment samples taken throughout the intertidal or subtidal zone can be analysed for a number of parameters (see: Buller & McManus, 1979; Kramer *et al,* 1994). The types of parameters that can be measured include:

- Contaminants;
- Particle size;
- Salinity;
- Water content;
- pH;
- Nitrogen;
- Organic matter;
- Sediment nutrient fluxes;
- Porosity and permeability;
- Redox potential; and
- Surface cohesive strength.

Monitoring for contaminants, in the UK, has most commonly occurred prior to flooding at a managed realignment site. This allows the detection of potentially harmful compounds that may be released into the water column when the site is flooded. Sediment samples are typically collected using cores. Once the sediments have been collected each contaminant of interest has its own analytical procedure to determine the concentration within each sample.

Cores are also used to collect sediments for particle size analysis (PSA), the determination of organic content and the concentration of Nitrogen within the samples. There are three main methods for determining the distribution of particle sizes within the samples which include either sieving the samples through a series of progressively smaller mesh sizes (BS 1377), through a coulter counter or via laser diffraction analysis (BS ISO 13320-1). The organic content of the sediment can be determined through a process known as loss on ignition or through a Carbon, Hydrogen and Nitrogen (CHN) analyser. To determine the specific concentrations of Carbon, Hydrogen and Nitrogen a CHN analyser is also required. Analytical instruments are required to determine specific sediment nutrient fluxes (e.g. www.skalar.com; Kirkwood, 1996). Water content, pH, redox potential and salinity of the sediment can all be measured *in situ* although water content can also be derived from collected sediment samples.

The erodability of sediments has only been monitored at a limited number of managed realignment sites. In these instances erodability has been inferred by measuring the shear strength of the sediment in the field using a hand held shear vane (Serota & Jangle, 1972). More recently technological advances have allowed the development of field deployed cohesive strength meters (Tolhurst *et al*, 1999, 2000). Larger scale field measurements can also be made using frames which hold variety of equipment, including velocity meters and suspended sediment meters such as optical backscatter devices, to record the onset of erosion under flows *in situ*. Such equipment arrays can be deployed from vessels or assembled at low water, although to date, they have not been used at managed realignment sites.

4.6 Ecology

4.6.1 Vegetation

The vegetation at a site can be monitored at a number of spatial scales and taxonomic resolutions. Vegetation colonisation and establishment is important for the successful development of a site and has been monitored at a large number of realignment sites (Tables 4.1 and 4.2). In order to gain a broad scale overview of vegetation types and species within a site mapping techniques can be used. These data can be collected by site based field mapping or through remote sensing. When supported by ground truthing aerial survey techniques can be used to produce detailed vegetation maps which can be classified according to the National Vegetation Classification phase I and II (NVC) system (Rodwell, 2000; described at www.jncc.gov.uk). One such technique for this is the ground truthing of Compact Airborne Spectrographic Imagery (CASI) which has been implemented successfully on Southampton Water (ABP Research, 2001).

To obtain more detailed information on the distribution and abundance of individual species a more intense sampling procedure is required. Measurements have frequently been made within quadrats and sites where this has occurred include Orplands, Abbotts Hall, Tollesbury, Freiston and Blaxton Meadow. The quadrats used have ranged in size, although they have typically been in the region of 1 m^2. Monitored quadrats are usually either randomly distributed across a site, or distributed along transects perpendicular to the coastline, and cover a range of elevations. Features that have been monitored include percentage cover of vegetation, mud and water as well as the species present. Records have also been made of stem density and the heights of each plant species within a quadrat to make assessments of recruitment and subsequent plant development. In order for comparisons to be made through time permanent quadrats have also been established with photographic records taken at each time step (ADAS, 1998).

4.6.2 Benthic Invertebrates

Invertebrate data has been collected from a high proportion of managed realignment sites (Table 4.1). This emphasises the importance of benthic species in terms of their influence on sediments and as prey items. Invertebrate data is also relatively easy to collect, analyse and interpret, although high spatial variation in desnity requires careful consideration of the sampling design. The main expertise and costs of this type of sampling are associated with the identification of taxa found within the samples. Where the site is inaccessible on foot the use of a hovercraft or boat may be required to collect intertidal samples.

There are a number of ways in which invertebrate samples can be collected depending on the tidal elevation and substrate type of the habitat. On intertidal mudflats the most common method used for collecting samples is by using corers, which are typically around 10 cm in diameter to a depth of 30 cm. The sediments from within each core are then sieved at a mesh size of around 0.5 mm, the remaining sieve contents can also be emptied onto a white tray and any invertebrates removed. The invertebrates collected on the sieve are identified and enumerated. Where it is not possible to sieve the samples, due to a high clay content in the sediments, for example, it may be necessary to hand pick the live specimens from the sample. In some instances the biomass and size distribution of the animals within a sample are estimated. This allows the determination of the rates of recruitment of various taxonomic groups. The species richness and diversity of the samples can also be calculated. In addition it is possible to look at the samples in relation to the functional feeding type of each of the taxonomic groups that are collected. The distribution of invertebrates at different depths of sediment can also be examined by splitting the core into measured sections. Surveys of this nature are often repeated on an annual basis for the first five years of a scheme, although this can be extended in some cases at less frequent intervals.

Subtidal samples do not appear to have been collected for UK habitat creation schemes as managed realignment schemes are essentially intertidal. If required, however, samples could be taken using grabs deployed from a boat (Elliot & Drake, 1981). The type and size of grab used would depend on the nature of the substratum. The samples collected would undergo the same processing and analysis procedure as the intertidal cores.

4.6.3 Saltmarsh Invertebrates

Insects have rarely been monitored on managed realignment sites, if at all, but it is planned for the Freiston site because this site is high enough in the tidal frame to be expected to develop into vegetated saltmarsh with no intertidal mudflat (Sue Brown, CEH Dorset, pers. comm. 2003). In this habitat the collection of cores is not an effective sampling technique. A variety of techniques are proposed at the Freiston site as it develops including direct searching, suction sampling and pitfall traps. Additional traps include emergence traps and the collection of invertebrates through the use of sweep nets. A review of techniques available for monitoring terrestrial invertebrates is presented in the reference, Institute of Environmental Assessment 1995. Collected species are then identified, counted and the data is interpreted. An experienced ecologist is needed for identification of the many invertebrates associated with saltmarsh vegetation, and identification is very time consuming. Again the number of traps set will depend on the size of the area and the variability of the habitat types. Comparable reference sites, using nearby saltmarsh, will also aid the interpretation of the results.

4.6.4 Fish

Fish have only been monitored at a limited number of habitat creation sites in the UK. They have, however, been monitored at Freiston (Sue Brown, CEH Dorset, pers. comm. 2003), Abbotts Hall, Orplands site and Paull Holme Strays (Colclough *et al*, 2004). Fish usage has, however, been monitored more frequently in the USA (Zedler, 2001). A number of techniques are available for monitoring fish usage of a site and these largely depend on the types of fish and the accessibility of the site. Netting can be used to examine catches including size distribution and species diversity. Seine nets, for example, can be used to catch fish in shallow waters and the catch is examined for species diversity and size distribution. Static nets, push nets and beam trawls are also used to collect fish when using intertidal sites. In addition one minute kick samples using a standard FBA net with 1 mm mesh can be used in the high intertidal zone around saltmarsh vegetation to catch early fry and post larvae (Colclough *et al,* 2004). The gut contents of the fish can also be analysed to determine the prey items of the species caught. In particular this allows the identification of dietary components which may infer usage of the site. Other types of fishing technique include traps such as pit traps (Able & Ragan, 2000).

A fish survey programme developed in the tidal Thames since 1992 was recognised by the EC Fair programme in June 2000 as European best practice for dynamic, stochastic, estuarine environments. It is now in the process of being developed nationally for all UK transitional waters for compliance with the Water Framework Directive (2000/60/EC). It includes shore and boat seining with different mesh sizes, a 2 m beam trawl, and kick sampling. It comprises a standard semi-quantitative sampling strategy applied twice a year in May/ June and September/ October (Colclough *et al*, 2002). It is therefore a combination of these techniques that would be recommended for use at managed realignment sites.

4.6.5 Birds

Waterbird numbers at a site are typically assessed on a monthly basis, with hourly counts throughout the tidal cycle on each sampling occasion. The data are used to produce distribution maps for individual species and more general site usage. Due to the high natural variability of bird count data it is often best to compare numbers recorded with neighbouring locations or even an estuary system as a whole. Counts are most commonly compared with average and peak records within a site. The average is calculated for a particular species at an individual site by taking an average of the number of birds recorded in each month of the entire survey. The peak mean is calculated by averaging the peak count in each year for a particular species at an individual site, normally using the most recent five years' data. The peak mean over five years is used internationally as a measure of bird usage for comparing the relative usage of different sites.

Great Britain and Northern Ireland hold internationally important numbers of 27 species of wintering waterbirds (Gregory *et al*, 2002; Kershaw & Cranswick 2003; Rehfisch *et al*, 2003). Monitoring is therefore concentrated on the periods September to March, although some programmes continue through the summer months. Counts may be made from a designated view point each month or for larger sites a number of view points may be selected. A review of bird monitoring techniques is presented in Gilbert *et al* (1998).

The Wetland Bird Survey (WeBS) is a joint scheme between the BTO, The Wildfowl and Wetlands Trust, RSPB and the JNCC. Through this forum core counts are made at a number of sites throughout the UK once monthly throughout the winter period. Counts on estuaries are most commonly made at high tide when birds are most easily counted at roosts. Low tide data is also collected at a number of large estuaries in at least one winter every five years. The methods employed for the collection of WeBS data can be used for other purposes such as to determine site usage at managed realignments sites. In the majority of these schemes, however, through the tide counts may be more appropriate than high tide counts. To assess temporal variation in site usage and how this changes as the site develops, monitoring is required across a range of seasons and a number of years. It is also important to determine how birds use the created site. It is therefore advisable to record the behaviour, either feeding, roosting and/ or loafing, displayed by the waterbirds at the site since this can help to inform on the ecological functioning of the scheme. Similarly it is also important to survey breeding birds and wintering passerines using neighbouring and created saltmarsh habitat.

It is also possible to monitor birds using an area of land that is proposed for managed realignment including species of farmland birds and raptors. The techniques available to monitor such species are similar to those used for waterbirds where counts are made across a site at set time intervals. The behaviour of the birds can also be recorded to help inform about site usage.

4.6.6 Freshwater Invertebrates

Freshwater invertebrates and plant species are rarely monitored at managed realignment sites except where freshwater habitat will lost at a site through inundation. The main technique available is pond dipping where water samples are collected and the biological content identified. This allows the identification of any protected species such as great crested newts and a description of the flora and fauna that will be displaced by a scheme. In moving water the use of emergence traps, surber samplers or kick sampling may be more appropriate techniques (Downing & Rigler, 1984).

4.6.7 Mammals and Herptiles

The key mammal that is likely to be of interest at managed realignment sites is water voles, as this is a protected species. Other mammals such as rabbits and deer may, however, be of interest in areas that experience high levels of grazing. There are a number of techniques available for estimating the population size of mammals including the counting of burrows, latrines and droppings. These techniques require no specialised equipment and are relatively simple to employ. In addition mark and recapture methods allow a more accurate representation of a population size but this technique requires repeated sampling (Strachan, 1998). Similarly where lizards and/ or snakes are observed on existing sea walls that are to be breached or removed there may be a requirement for monitoring. The most common method used for monitoring such species is through observation of prime basking areas. Once suitable basking sites are identified, refugia such as sheets of tin, roofing felt etc. should be set down in these areas. Once established, the refugia are left in position for a period of approximately 10 days and then monitoring should commence for a minimum of five days on suitable warm days (www.biota.co.uk/reptiles.php).

4.7 Requirement for New Methods

The majority of parameters that have been identified as important for the successful development of managed realignment schemes have been monitored in at least one scheme around the UK. Exceptions to this include parameters associated with water quality and bio-geochemical cycling. Methods available to measure such parameters have, however, been identified in Section 4.4 and Table 4.3. A number of methods have also been described that have not been applied specifically to managed realignment sites but are relevant to the identified parameters. These include:

- The use of hovercraft to access dangerous areas;
- Water Quality measures; and
- Sediment erodability - Cohesive Strength Meter and larger scale measures.

There are generally a number of techniques available to measure each parameter. The technique selected will depend on a number of factors including the accuracy required, the funding available and the objectives/ targets of the scheme. The selection of the most appropriate techniques for a scheme will be described in Section 10.

4.8 Conclusions

Most of the managed realignment schemes which have been implemented to date have incorporated some degree of monitoring (Table 4.1). The number of parameters monitored at each scheme is, however, highly variable. The intensity of the monitoring programmes are also quite different depending on the nature of the scheme. The most commonly measured parameters for UK based schemes are the distribution and usage of the site by invertebrates and birds. At sites with natural breaches only sediment parameters and vegetation appear to have been monitored, with the exception of Porlock Marsh where topography and birds have also been evaluated. In the USA similar parameters have been measured, although greater emphasis appears to have been placed on the assessment of fish populations (Table 4.2). As a result of this review a 'toolbox' of monitoring techniques that can be used to measure the various parameters at managed realignment sites has been described (Table 4.3). The selection of the appropriate tools for the monitoring at a realignment site will be considered in greater detail in Section 10.

Table 4.1 UK case studies (Source: Adapted from Atkinson *et al,* 2001)

UK Area	Site Type	Topography/ Morphology	Hydrodyna-mics	Water Quality	Sediments	Vegetation	Invertebrates	Birds	Fish	Mammals	References
Devon											
▪ Blaxton Meadow, Saltram - 1995	Recharge	✓				✓					Reading *et al*, 1998, 1999
East Riding of Yorkshire											
▪ Paull Holme Strays	Breach	✓			✓	✓	✓	✓		✓	EA
Essex											
▪ Orplands, 1995	Breach	✓			✓	✓	✓	✓	✓	✓	EA reports
▪ Tollesbury 1995	Breach	✓	✓		✓	✓	✓	✓	✓		Reading *et al*, 1998, 1999
▪ Northey Island 1991	Breach	✓	✓	✓ [1]	✓	✓					EN Reports 103 and 128
▪ Abbotts Hall - 1996	Sluice/ Breach		✓			✓	✓	✓	✓	✓	Colclough *et al*, 1998
▪ Horsey Island - 1998	Recharge						✓	✓			EA Reports (Unpubl.)
▪ Cobmarsh Island - 1998	Recharge						✓	✓			EA Reports (Unpubl.)
▪ Old Hall Point 1998	Recharge						✓	✓			EA Reports (Unpubl.)
▪ Tollesbury Wick 1998	Recharge						✓	✓			EA Reports (Unpubl.)
▪ Wallasea Ness 1998	Recharge						✓	✓			EA Reports (Unpubl.)
▪ Pewet Island 1998	Recharge										
Hampshire											
▪ Thornham Point - 1990-1991	Breach	✓				✓					Chichester Harbour Conservancy
▪ Chaldock Point - 2000	Breach	✓				✓	✓				Chichester Harbour Conservancy
Lincolnshire											
▪ Freiston	Breach	✓	✓		✓	✓	✓	✓	✓		EA
Somerset											
▪ Bleadon Marsh											No details available
▪ Porlock Marsh	Natural breach	✓				✓		✓			
Suffolk											
▪ Shotley Point	Recharge	✓	✓	✓ [2]	✓	✓	✓				
▪ Orford Ness		✓			✓	✓					
▪ Havergate Island - 2000	Breach	✓			✓	✓	✓	✓			EA Reports (Unpubl.)
▪ Trimley - 2001	Recharge - then breached						✓	✓			EA Reports (Unpubl.)
▪ Blythe Estuary	Breach										
Teeside											
▪ Seal Sands - 1993							✓	✓			Evans *et al*, 2001
Scotland											
▪ Nigg Bay	Breach	✓	✓			✓	✓	✓			Chisholm *et al*, 2004
% of times monitored at UK schemes		**54**	**25**	**8**	**33**	**58**	**66**	**66**	**17**	**2**	

[1] Turbidity [2] SSC

Table 4.2 American case studies (Source: Adapted from Atkinson *et al,* 2001)

US Area	References	Size (ha)	Habitat	Tidal Regime	Sedimentary System	Type	Age	Sampling Freq. No	Sampling Freq. Years	Parameters Evaluated: Topography	Seds	Plants	Inverts	Fish	Birds
East Coast															
▪ CT	Sinicrope *et al*, 1990	20	SM	Micro	Muddy	Dike	10	2	2		*	*			
	Fell *et al*, 1991						12	1	1				*		
	Peck *et al*, 1994						13	2	2				*		
▪ VA	Havens *et al*, 1995	2.2	SM	Micro	Muddy	Excavate	5	2-3	1		*	*	*	*	*
▪ NC	Moy & Levin, 1991	0.24	SM	Micro	Muddy	Excavate	3	5	3		*		*	*	
▪ NC	Levin *et al*, 1996	9	SM	Micro	Muddy	Dredge	5	10	5				*		
▪ NC	Rulifson, 1991	2.15	SM	Micro	Muddy	Excavate	3	10	5					*	
	Craft *et al*, 1991								2		*				
Gulf Coast															
▪ TX	Lindau &Hossner, 1981	4.5	SM	Micro	Muddy	Dredge	2	4	3		*				
	Webb & Newlings, 1985						4	3	5			*			
▪ TX	Minello *et al*, 1994	8	SM	Micro	Muddy	Dredge	5	3	2						
Pacific Coast															
▪ WA	Shreffler *et al*, 1990	3.9	SM	Micro	Muddy	Excavate	3		2	*				*	
	Shreffler *et al*, 1992						3		2					*	
	Simenstad &Thom, 1996						8		7		*	*	*	*	*
▪ OR	Frankel & Morlan, 1991	32	SM	Micro	Muddy	Dike	10		11	*	*	*			
▪ CA	Chamberlain & Barnhart	3.5	SM	Micro	Muddy	Dike	2	3-7	1.3					*	
▪ CA	Langis *et al*, 1991	4.9	SM	Micro	Muddy	Excavate	4	2-6	2		*				
	Scatoloni & Zedler, 1996						4	8	1		*		*		
	Zedler, 1996						2	14	6		*	*	*	*	
% Times Monitored at USA schemes										**11**	**53**	**32**	**42**	**42**	

Key: Habitat: SM = Saltmarsh, L = Lagoon, M = Mudflat.
Type: Dike = Breach in sea wall, Excavate = Digging out of site, Dredge = dumping of dredged materials onto site.

Table 4.3 Monitoring tool box

Parameter	Technique	Strengths	Weaknesses	Accuracy	Comments
Morphology					
▪ Elevation and Topography	Differential GPS (Ingham & Abbott, 1992)	Relatively quick to deploy	Requires specialist equipment. Affected by blockage of signal.	±0.03 m (vertical)	Is usually recorded along identified transects and comparisons are made at set time intervals.
	Real Time Kinematic (RTK) GPS http://products.thalesnavigation.com/en/products/aboutgps/rtk.asp	Very accurate	Requires expensive equipment which takes time to set up. Affected by blockage of signal.	±0.01 m (vertical)	Is usually recorded along identified transects and comparisons are made at set time intervals.
	Total station/ theodolite Using Established bench marks to truth levels. (Hydrographic Office, 1965)	Requires relatively unspecialised equipment	Individual spot measurements - poor spatial coverage. Not good in poor visual conditions or in strong winds.	±0.01 m (vertical)	Elevations compared through time against a marked stake. Benchmarks are no longer being maintained. It is recommended that the Ordnance Survey GPS network is used.
	Bathymetric Survey	Deployed at high tide so avoid dangerous areas	Limitations of boat access.	±0.1 m (vertical)	Usually surveyed along line transects.
	LiDAR surveys (www.lidar.com)	Cover extensive areas. Can be used at inaccessible sites such as areas of soft mud.	Expensive to deploy. Less accurate than land based techniques. Not good on wet surfaces or on surfaces covered with dense vegetation of unknown height.	±0.3 m (vertical)	Requires specialist equipment, flown above the site. Data requires further processing. Produces detailed coverage over large scales.
	Electro magnetic distance measurements (EDM) (Hydrographic Office, 1965)	Requires relatively inexpensive kit.	Site has to be accessible. Not good in conditions of poor visibility or rain.	±0.01 m (vertical)	Is usually recorded along identified transects and comparisons are made at set time intervals.
	Use of a survey prism mounted on a shallow metal tray (Adaptation of EDM)	Can be used at inaccessible sites.	Requires relatively flat surface. Limited width.	±0.01 m (vertical)	For use on dangerous inaccessible mud.

Parameter	Technique	Strengths	Weaknesses	Accuracy	Comments
	Site walkover describing slopes, geology and habitat types.	Good descriptive overview.	Poor accuracy	Poor, although can be improved through the use of GPS.	Low tech method; detailed descriptions of site used to describe topography.
▪ Area	Cartographic exercise, supported by aerial coverage data if necessary. (Green & King, 2000)	Overview of entire site. Permanent records of site. Cover large areas.	Images require correction. Costly and timely process.	Scale dependent: 1:100 = ±1 m 1:50000= ±20-50 m	Requires a careful definition of the site boundary.
	GIS (Wright & Bartlett, 2001)	Can compare features and information on land use.	Data compatibility. Digitising features is costly and time consuming. Digitising can lead to inaccuracies.	Scale dependent Can also be issues of overlap and distortion	Can plot and calculate the extent of an entire site and individual habitat types.
▪ Creek systems	Aerial photography (Green & King, 2000)	Gain a broad scale view of the site. Can be compared through time. Can be used at inaccessible sites.	Expensive to get aerial photographs and subsequent analysis is time consuming.	Scale dependent	May be most appropriate technique at large sites with expansive creek networks. Permanent records of site.
	Site mapping via walking and data recording.	Cheap method for obtaining data from small easily accessible sites.	Difficult to compare through time. Relatively poor spatial coverage.	Poor, although improved if combined with GPS.	Recorded on the ground through measurements of topography. Where the site is relatively small and easily accessible.
Hydrodynamic					
▪ Tidal range	Tide gauge	Continuous measures throughout the tide.	Measurements typically from one location. Poor spatial coverage.	±0.01 m	There are a number of different tide gauges available each with their own specifications.
	Photographic records	Cheap equipment	A single snapshot in time.	Dependent on scale	Taken at various states of the tide at known times can give an indication of tidal levels.

Parameter	Technique	Strengths	Weaknesses	Accuracy	Comments
▪ Current velocities	Current meters	Continuous measures throughout the tide.	Measurements typically from one location. Poor spatial coverage.	±0.05 m/s	There are a number of different current meters available each with its own specifications. Resolution is greatly influenced by the number of instruments deployed.
	Surface drogues	Cheap to deploy. Can be used at a number of locations across a site.	Relatively inaccurate technique. Influenced by sea surface wind. Require correction for wind.		Placed onto water surface - can cover a larger area than a current meter. Can be used at various states of the tide.
	Acoustic Doppler Current Profiler (ADCP)	Continuous measures throughout the tide.	Very expensive	± 0.01 m/s	ADCP devices have a number of specifications.
▪ Wave action	Wave recorders	Continuous measures throughout the tide.	Measurements typically from one location. Poor spatial coverage.	±0.05 m	There are a number of different wave meters available each with its own specifications.
Water Quality					
▪ Salinity	Salinity probe	Can be measured *in situ*.	Requires a number of replicates across the site in order to capture spatial variability.	±0.2 %	Deployed from a boat with readings recorded. Can be widely used across a site. Replicate readings are advisable.
	Collection of water samples	More accurate than probe.	Requires subsequent laboratory analysis.		A number of water samples are collected and these require specific analysis under laboratory conditions. Requires careful storage.
▪ Dissolved oxygen	DO probe	Can be measured *in situ*.	Requires a number of replicates across the site in order to capture spatial variability.	0.1 %	Deployed from a boat with readings recorded at high water. Can be widely used across a site. Replicate readings are advisable.

Parameter	Technique	Strengths	Weaknesses	Accuracy	Comments
▪ Turbidity	Turbidity meter	Continuous measures throughout the tide.	Measurements typically from one location. Poor spatial coverage.		There are a number of different turbidity meters available each with its own specifications.
	Water samples collected and analysed.	Spatial data.	Require further processing.		Provides information on spatial variability of turbidity.
	Secchi disk	Easy to deploy. Limited specialist equipment.	Not easy to translate into a suspended sediment concentration.	±0.1 m (approx).	Recorded *in situ*, usually deployed from a boat. A low tech instrument from which it is relatively easy to obtain data.
▪ Contaminants	Collection of water samples and analysed for contaminants of interest.	Easy to collect replicate water samples.	Requires further laboratory analysis.	Varies with contaminants.	A number of water samples are collected and these require specific analysis under laboratory conditions.
Sediments					
▪ Sedimentation rates	Accretion plates (Buried)	Simple to deploy	Can be affected by biological processes.	1 to 2 mm at the point of measurement	Used in areas experiencing relatively low erosion and deposition. Location should be marked.
	Measurement of deposition on pre-weighed filter papers.	Simple to deploy	Not suitable for long term measurements. Only used on a single or few tidal inundations.	±1 mg	Used in areas experiencing relatively low erosion and deposition. Should correct for salt content on filter paper and deposited mud.
	Sediment Erosion Tables (Boumans & Day, 1993)	High precision measurements. Takes account of sediment compaction.	Relatively expensive so limited numbers are set up.	±1-2 mm	Used in areas experiencing relatively low erosion and deposition.

Parameter	Technique	Strengths	Weaknesses	Accuracy	Comments
	Single stakes placed in intertidal	Easy to deploy and relocate stakes.	Least accurate technique. Stakes can cause scouring around them, making true measurements impossible.	±0.5 cm	Used in areas of relatively high erosion and deposition where elevations can be recorded at set time intervals from markers on the stakes.
	Pairs of vertical posts or canes.	Inexpensive and simple to deploy.	Canes can get damaged	±1-2 mm	Canes can be replaced for continued measurements. Can be used at sites unsuitable for placement of plates.
	Bathymetric survey	Covers a large area relatively cheaply. Deployed at high tide to avoid dangerous areas.	Limitations of boat access.	±0.1 m (vertical)	
	Artificial Horizons	Long term measurements	Can be affected by biological processes particularly on mudflats in areas where there is bioturbation		A variety of materials can be used. Not useful in areas of erosion.
▪ Contaminants	Cores collected and analysed for contaminants.	Can be easily collected	Requires further laboratory analysis.	Varies with contaminants.	A number of sediment samples are collected and these require specific analysis under laboratory conditions.
▪ Salinity	Refractometer or conductivity	Data collected in the field. Easy to collect.	Site needs to be easily accessible or may require the use of a hovercraft.	±0.01 psu	Measured *in situ* at a number of stations across a site. Replicate measures are advisable at each location.
▪ Water content	Theta probe - soil moisture sensor method	Data collected in the field. Easy to collect.	Site needs to be easily accessible or may require the use of a hovercraft.	±1 %	Measured *in situ* at a number of stations across a site. Replicate measures are advisable at each location.

Parameter	Technique	Strengths	Weaknesses	Accuracy	Comments
	Suction pressure measurement	Data collected in the field. Easy to collect.	Site needs to be easily accessible or may require the use of a hovercraft.		Measured *in situ* at a number of stations across a site. Replicate measures are advisable at each location.
▪ pH	pH meter	Data collected in the field. Easy to collect.	Site needs to be easily accessible or may require the use of a hovercraft.	±0.02 pH	Measured *in situ* at a number of stations across a site. Replicate measures are advisable at each location.
▪ Nitrogen content	Cores collected and analysed for Nitrogen content.	Easy to collect sediment cores.	Requires further laboratory analysis. Site needs to be easily accessible or may require the use of a hovercraft.		A number of sediment samples are collected and nitrogen content is determined.
▪ Organic Matter	Cores collected and analysed for organic content. (Loss on ignition)	Easy to collect sediment cores.	Requires further laboratory analysis. Site needs to be easily accessible or may require the use of a hovercraft.	±0.1 mg	A number of sediment samples are collected and organic content is determined by loss on ignition.
▪ Redox Potential	Redox potential probe	Data collected in the field. Easy to collect.	Site needs to be easily accessible or may require the use of a hovercraft.	±5 mV	Measured *in situ* at a number of stations across a site. Replicate measures are advisable at each location.
▪ Surface Cohesive Strength	Hand held shear vane (Serota & Jangle, 1972)	No specialist equipment require. Easy to use *in situ*	Not much use on very wet surfaces.	±1 Kpa	Low tech instrument placed on the sediment surface. Quick and simple to use.
	Cone penetrometer	Cost effective real time data.	Site needs to be easily accessible or may require the use of a hovercraft.		Low tech instrument placed on the sediment surface. Quick and simple to use.
	Cohesive Strength Meter (Tolhurst *et al* 1999, 2000)	Gives an indication of potential erosiojn.	Requires specialist equipment and operator. Not much use on very wet surfaces.	±0.1 Nm^{-2}	More sophisticated equipment. Used *in situ*, readings take longer than from shear vane.

Parameter	Technique	Strengths	Weaknesses	Accuracy	Comments
▪ Particle Size	Cores collected and analysed for particle size distribution. (BS 1377 and BS ISO 13320-1).	Data collected in the field. Easy to collect a number of replicates across the site.	Site needs to be easily accessible or may require the use of a hovercraft.	Dependent on analysis technique	Particle size analysis through sieving sediments at a number of mesh sizes, a coulter counter or laser diffraction analysis.
Ecology					
▪ Vegetation Saltmarsh, Transitional Marsh Grassland, Algae	Aerial multispectral remote sensing.	Can be applied to large area.	Resolution can be limited	Dependent on scale	Rapid assessment of biological resources. Requires ground truthing. Can cover areas up to approximately40 km x 40 km.
	Measurements within quadrats on site. Quadrats are typically vertically arranged on transects on slopes.	Quick and easy technique.	Site needs to be easily accessible.	Vary with individual operator experience	Quadrats typically 1 m^2 (minimum) - randomly distributed across a site. Can record species presence, abundance, stem height and stem density per unit area. Best compared with reference sites.
	Photographic records	Permanent record of site. Low cost technique.	Site must be accessible. Images require further interpretation.	Dependent on scale.	Allow comparison through time of fixed positions.
	Production of vegetation maps including National Vegetation Classifications.	Allows generic comparisons between sites.	Possibly subjective and requires an experienced ecologist.	Vary with individual operator experience.	Can be done through aerial photography and detailed site notes.

Parameter	Technique	Strengths	Weaknesses	Accuracy	Comments
▪ Benthic Invertebrates	Coring followed by sieving Core typically 10 cm in diameter, 30 cm deep. Sieve mesh size typically 0.5 mm.	No specialist equipment. Easy to gain a large number of replicates across the site.	Site must be easily accessible or may require the use of a hovercraft.	Accuracy in ID of invertebrates will depend on individual experience.	Usually applied on intertidal mudflats. Invertebrates within a sample are identified and counted. Biomass and size class information can be recorded. Best compared with reference sites.
	Grab samples followed by sieving.	Relatively easy to deploy and collect replicate samples.	Requires a boat for deployment. Ease of sampling varies with the substrate.	Accuracy in ID of invertebrates will depend on individual.	Can be used subtidally or intertidally when the mudflat is covered by the tide.
▪ Invertebrates	Suction sampling, direct searching, emergence traps, sweep nets and pitfall traps during neap tides	No specialist equipment. Easy to gain a large number of replicates.	Can be affected by weather conditions. Quantitative comparisons difficult unless very intensive study.	Accuracy in ID of invertebrates will depend on individual. ID of saltmarsh invertebrates very time consuming	Saltmarsh habitat or amongst vegetation. Often deployed randomly or in a grid system across a site.
▪ Fish	Netting	Easy to gain a large number of replicate samples, although can be hard work.	Mesh size may influence catch. Can be labour intensive. Influenced by seasonal and tidal variability.	Accuracy in ID will depend on individual experience.	Nets such as seine and push nets can be trawled through the water either manually or by boat. The parameters measured can include size distribution, species diversity, and gut content.
	Traps	Can be left in place and surveyed when required. Can be used in creek systems.	Influenced by seasonal and tidal variability.	Accuracy in ID will depend on individual experience.	Traps deployed throughout the intertidal, fish caught are analysed through the same procedures as described above.
	Kick sampling	Can be used for smaller stages of the lifecycle	Influenced by seasonal and tidal variability.	Accuracy in ID will depend on individual experience.	Used high in the intertidal zone around saltmarsh vegetation stands near the breach.

Parameter	Technique	Strengths	Weaknesses	Accuracy	Comments
	Beam trawling	Can cover large areas relatively easily.	Mesh size may influence catch. Can be labour intensive. Influenced by seasonal and tidal variability.	Accuracy in ID will depend on individual experience.	Beam trawl pulled through the water by boat. Requires a firm substrate.
▪ Birds	Bird count data recorded across the site. May record general use of the site, feeding/ roosting behaviour and disturbance. Counts made along transects or at set viewing locations. (Atkinson *et al,* 2001)	No specialist equipment required. Easy to replicate.	Observer requires specialist knowledge. Requires good visibility and site access.	Accuracy in ID will depend on individual experience	Counts are typically made throughout the tidal cycle at monthly intervals. Bird location and behaviour marked on maps. Summer and Winter counts. Best compared with reference sites due to high degree of natural variability.
▪ Fresh Water	Pond dipping, kick sampling, emergence traps, Surber sampler	Easy to collect a large number of replicates samples.	Time consuming to identify species present.	Accuracy in ID will depend on individual experience.	Allows the identification of invertebrates and eggs/ larvae of amphibians.
▪ Mammals	Count burrows	Simple technique to employ. Requires no specialist equipment.	Do not know if burrow is currently in use. Population size is only inferred.	Accuracy in ID will depend on individual experience.	Allows assessment of the use of site by mammals such as water voles, rabbits and deer.
	Latrines/ Droppings	Simple technique to employ. Requires no specialist equipment.	Population size is only inferred.	Accuracy in ID will depend on individual experience.	Allows assessment of the use of site by mammals such as water voles, rabbits and deer.
	Capture/ Recapture	Gain more accurate estimation of population size.	Requires repeated sampling.	Accuracy in ID will depend on individual experience.	Allows assessment of the use of site by mammals such as water voles.
▪ Herptiles	Observation and basking areas	Simple technique to employ.	Population size is only inferred.	Accuracy in ID will depend on individual experience.	Should be conducted on warm sunny days - preferably in April, May and September.

5. STATISTICAL MEASURES

Data sets of natural parameters are often characterised by a high degree of variation which can obscure trends between different parameters. Statistical analysis provides a way of detecting whether trends in data sets are significantly different from random variability and allows confidence to be placed in results. It is therefore important to design a monitoring programme with consideration for the subsequent statistical analysis that will be required to detect a given level of change taking place at a site.

Statistics consists of the principles and methods for:

- Designing studies;
- Collecting data;
- Presenting and analysing data;
- Interpreting the results.

There are a number of statistical techniques that can be applied to analyse data that has been collected. The technique to be applied will depend on the questions being asked, the type of data that has been collected and the number of replicate samples. The techniques range in complexity from describing the distribution of the data with terms such as averages and variance to more complex hypothesis testing. A programme of work should be planned anticipating the statistical methods that are appropriate to the eventual analysis of the data. It is beyond the scope of this report to present a detailed description of the range of statistical tests that are available. A comprehensive text covering statistics and their application is presented in the following texts: Fowler *et al*, 1994; Sokal and Rohlf, 1995 and Greenwood, 1996).

One branch of statistics that is worthy of further note is power analysis which is used to determine the number of samples that should be taken. Statistical power is the probability of getting a statistically significant result given that there is a real effect in the population under investigation. In monitoring terms, careful consideration of the power of a sampling programme can make the difference between insufficient sampling for conclusive decision making and wasting resources by over sampling beyond that necessary to achieve significant results. Ultimately the number of samples taken will be a compromise between cost and accuracy. Sheppard (1999) provides a simple explanation of how power analysis is used to determine sample size in marine environmental science, which includes a quick guide to its use in relation to basic statistical tests.

6. CASE STUDIES OF EXISTING MANAGED REALIGNMENT SITES

This section of the report provides a number of case studies of schemes that have already been undertaken. It provides an indication of the different parameters that have been monitored and the techniques that have been used for a range of different schemes.

6.1 Freiston Case Study

The managed realignment scheme at Freiston was designed to improve the flood defences of this part of the coastline. Three 50 m breaches were cut into the outer sea bank at Freiston shore to the east of Boston, allowing salt water from the Wash to encroach on 78 ha (hectares) of farmland purchased from HMP North Sea Camp by the RSPB. It was breached on the 21 and 22 August 2002. The development of saltmarsh is intended to enhance the degree of protection offered by the newly strengthened embankment. The embankment works began in October 1999 and were completed in September 2000.

The monitoring adopted at Freiston covers a wide range of parameters and incorporates a number of the techniques described in Section 4 (information supplied by the EA and Sue Brown, CEH). The monitoring of the site is partly funded by the Defra/ Ea R& D project FD1911 along with capital scheme funding. The monitoring programme described for the sediment parameters is a particular strength of the scheme and this is supported by a three year PhD research study. Resources were available to undertake a limited fish survey at the site to record fish numbers in catches from the realignment area. This will only provide information on the relative distribution of fish in the site for one sampling period per year and gives no indication of overall site utilisation. If the fish catch data could be more extensive and be supported by stomach content analysis site usage could be inferred.

Table 6.1 Monitoring carried out at Freiston managed realignment scheme

Parameters Measured	Techniques Used	No. of Stations/Replicates	Frequency
Elevation	LiDAR survey (2 m grid resolution) Total station tied into bench marks	One flight per time series	Minimum 6 monthly
Topography	Profiles - Differential GPS	Measured at approx. 100 m intervals along coast. Points surveyed at 20 m intervals along profiles.	Twice a year
Sedimentation rates	Sediment Erosion Tables (SET) Buried plates and levelled canes	6 SETs outside the site 5 SETs inside the site 30 stations inside site and 30 stations outside site	Twice a year
Sediment samples	Collect top 5cm - currently for storage for possible future use	30 stations inside and outside site	Twice a year
Fish	Fyke nets and Beach Seines	Net is 20 m x 1 m	Once a year
Invertebrates	Will vary as vegetate marsh develops, including pitfall traps, direct searching, surface scrapes and suction sampling	30 stations	Once a year
Benthos	Core sampling	Very limited as main focus is saltmarsh not mudflat	Annually
General site mapping	Stereoscopic aerial survey (1:5 000)	One flight per time series	Monthly initially
Vegetation	Quadrats with records of % cover. NVC classification. CASI	30 stations inside and 30 stations outside site 5 replicate quadrats ($1\ m^2$) at each and 30 ($25\ m^2$)quadrats	Annually

Parameters Measured	Techniques Used	No. of Stations/Replicates	Frequency
Waves	Two directional wave recorders	The gauges measure waves at 1 Hz for a 20 minute period every thirty minutes	Continuous for 2 years
Tides	Two directional tide recorders	The gauges measure tidal height at 1 Hz for 1 minute every ten minutes	Continuous for 2-4 years
Birds	Walk over surveys (breeding birds) WeBS methodology (water birds) Transects (winter passerine)	Site is split into 3 sectors. Three transects through each sector.	Breeding birds - at least a month apart Water birds - bimonthly and monthly adjacent to the site. Water passerine - one survey per month (October to March)

Figure 6.1.1 Creek network on mudflat seawards of Freiston managed realignment site

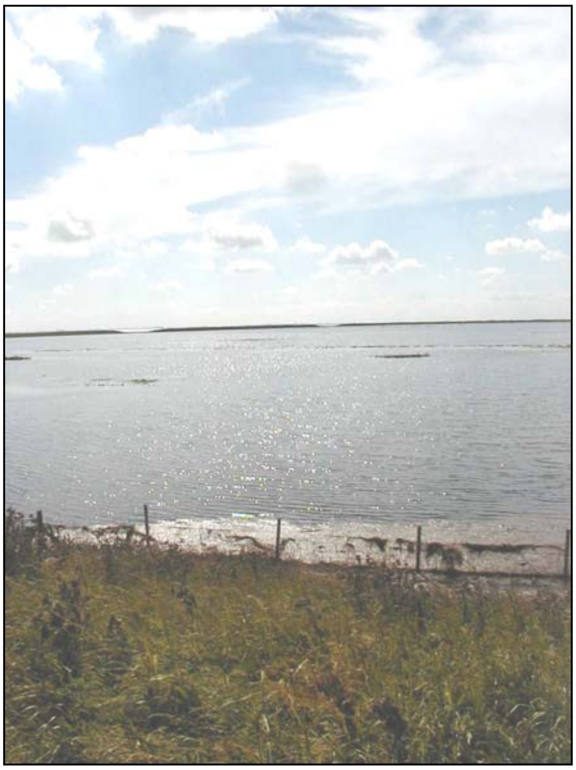


Figure 6.1.2 Freiston managed realignment site at high water

6.2 Paull Holme Strays Case Study

The Paull Holme Strays site is located approximately 10 km to the south east of Hull on the north bank of the Humber Estuary. The length of the current sea defence under consideration is approximately 2.5 km. The scheme is designed in response to the need to implement urgent flood defence works prior to the formulation of a long term flood defence strategy for the entire estuary. The existing defences have been breached in two places in October 2003: a 150 m long breach and a 50 m long breach. Approximately 75 ha of intertidal habitat will be created as a result of the scheme.

The monitoring at Paull Holme Strays is again fairly comprehensive in the types of parameters that are measured (information supplied by the EA). At this particular site there is a requirement for the monitoring of freshwater and terrestrial habitats and species which is not typical at managed realignment sites. In contrast to Freiston there is no monitoring of hydrodynamic parameters at this site. The work is supported by a PhD which is examining breach development.

Table 6.2 Monitoring to be carried out at Paull Holme Strays managed realignment scheme

Parameters Measured	Techniques Used	No. of Stations/Replicates	Frequency
Elevation	LiDAR	One flight per time series	Once a year
Topography and Sedimentation rates	LiDAR Total Station Buried plates and canes	One flight per time series At all sample stations Minimum of 5 stations along 7 transects, plus additional sites in areas of interest. % replicates per station	Twice a year
Invertebrates	Core sampling	1-6 sampling stations on each of 7 transects plus an additional point at the breach. 3 to 5 replicate (0.01 m²) cores	Once a year
Sediment characteristics	Core sampling - Particle Size Analysis and Total Organic Content	1-6 sampling stations on each of 7 transects plus an additional point at the breach. 3 to 5 replicate (0.01 m²) cores	Once a year
General site mapping	Aerial mapping		
Vegetation	Quadrat measures Percentage cover Record of species present. Notes and photo of each quadrat.	5 stations on 5 transects, 5x 1m^2 quadrats and 1 25m^2 quadrat at each station	Once a year
Fish	Small seine and push nets, kick sampling	Across the site	Undertaken prior to breaching
Birds	Hourly counts from a fixed point throughout a half tidal cycle. Monitor disturbance events. Site will also be included within Humber Wader Ringing Group programme.	Counts must cover entire site during the operational phase. Site is divided into a series of sectors. Counts also made of breeding birds.	Monthly during construction and operational phases.
Water voles	Identichip	All captures marked with identichip	One week trapping programme each spring and summer
Freshwater habitat Invertebrates Vegetation	Pond dipping Site survey - NVC	Across the site	Once a year
Terrestrial habitats	Walkover and species identification	Across the site	Twice a year

Figure 6.2 Paull Holme Strays managed realignment site

6.3 Orford Ness Case Study

Lantern Marshes at Orford Ness, Suffolk, is an area of land owned by The National Trust (National Trust, 2000 to 2002). This was previously an enclosed area of land until the sluice gate controlling water movements on the site failed. At this time the marsh area became partially inundated by the tide and saltmarsh vegetation began to cover the mud. After a period of consultation it was decided to deliberately breach the site in 1995.

In contrast to the relatively large schemes described above the monitoring at Orford Ness is much less intensive. This reflects the nature of the scheme which was solely aimed at enhancing the ecological value of the area. Initially there was no structured monitoring programme but in August 2000 a monitoring programme was established. Since this time results have been collected annually and can now be analysed and compared in a meaningful way.

Table 6.3 Monitoring carried out at Orford Ness managed realignment scheme

Parameters Measured	Techniques Used	No. of Stations/Replicates	Frequency
Topography and Sedimentation rates	Measurement of pole heights	100 poles	Once a year
Vegetation	Mapping of site	General map of entire area	Once a year
	Photography of fixed quadrats	100 quadrats	Once a year
	Point transects	11 transects - recordings made every 0.5 m	Once a year

Figure 6.3 Orford Ness managed realignment site

6.4 Shotley Case Study

An experimental cohesive sediment recharge is currently underway on the Shotley foreshore, Orwell Estuary (French and Watson, 1998). The whole foreshore has experienced near complete loss of a narrow saltmarsh fringe over the last century or so. As a consequence the seawall has suffered extensive toe erosion and is now in relatively poor condition. An innovative approach to the immediate problem of estuarine foreshore protection involves the use of dredged sediment to restore eroded intertidal profiles and to thereby enhance both their effectives for flood protection and their ecological conservation.

In order to evaluate the potential for a large-scale recharge involving 200 000 m³ of cohesive sediments and 60 000 m³ of protective gravel bund, a trial placement north of the Shotley marina was undertaken in November 1997 as a joint venture between Harwich Haven Authority and the EA.

The main aim of the monitoring was to determine the post-placement behaviour of fine silts placed within the protective gravel bund, and to evaluate the potential, for flood defence protection and ecological enhancement, of future large scale recharges in the Orwell and elsewhere in the region. There was a pre-placement and placement baseline survey for a number of the parameters measured.

Table 6.4 Monitoring carried out at Shotley intertidal recharge scheme

Parameters Measured	Techniques Used	No. of Stations/Replicates	Frequency
Topography	Topographic surveys Aerial photography	9 Transects Image of entire site	Three monthly
Sedimentation rates	SET	Placed in six locations	Three monthly
Waves	Wave meter	3 wave meters	Three monthly
Vegetation	Quadrats	Unknown	Three monthly
Sediment properties	PSA	18 samples	Three monthly
Suspended sediments	Turbidity sensors	3 turbidity sensors	Three monthly
Invertebrates	Sampled from cores		Three monthly
Vegetation	Observed in quadrats		Three monthly

Figure 6.4 Shotley managed realignment site

6.5 Orplands Case Study

Orplands forms part of the St Lawrence Bay on the south shore of the Blackwater Estuary. The seawall along a 2 km frontage at Orplands had become destabilized as a result of erosion of the saltmarsh. Consequences of this erosion were that the seaward toe of the defences became undermined, with loss of the concrete revetment blocks through the increase in wave energy and overtopping causing scour of the crest and backslope. The objectives of the scheme were to restore saltmarsh yielding a natural defence that will fulfil a number of advantages:

- The creation of a saline flood plain that will reduce the effect of storm tides;
- The creation of a new high level marsh that will be of significant value to both overwintering and summer breeding birds and for immature fish;

- The provision of a public access route for quiet recreation (by footpath diversion);
- The reduction of pollution concentrations (as with all marshes); and
- The reduction of public expenditure by saving £525 000 on conventional flood defence techniques (this habitat cost £60 000 to construct).

A comprehensive monitoring programme has been carried out for the first five years of the site development (information supplied by the EA). This was done to demonstrate the effectiveness of the scheme as a flood control and habitat creation structure and includes monitoring of plants, invertebrates, birds and fish.

Table 6.5 Monitoring carried out at Orplands managed realignment scheme

Parameters Measured	Techniques Used	No. of Stations/Replicates	Frequency
Topography and Sedimentation rates	Marked transects (Feno Marker Pairs)	11 Transects	Annually
Physical and chemical characteristics of the sediment	Redox potential and Particle Size Analysis	14 replicates	Annually
Vegetation	Changes in saltmarsh morphology. Plant vigour and productivity.	48 quadrats across the site	Annually
Benthos	Sediment cores	10 cores for bivalves 14 cores for additional macrofauna	Annually
Birds	Site walked on pre-determined route. Observed breeding territories.	Two areas in summer. Five areas in winter.	Monthly
Fish	Static nets Seine nets Kick samplers Baited minnow traps Push nets	Across the site	Annually

Figure 6.5 Orplands managed realignment site

6.6 Tollesbury Case Study

One key example of managed realignment is at Tollesbury, a tributary of the Blackwater Estuary in Essex (Reading *et al,* 2002; Defra Project CSA 2313). Low embankments were constructed behind the existing sea wall and surrounding approximately 21 ha of low-lying agricultural land adjacent to Tollesbury Creek. Following the completion of the new sea defences, the existing seawall was breached on 4 August 1995 and the enclosed area of agricultural land behind it exposed to tidal inundation for the first time in at least 150 years.

The objectives of the scheme were to:

- To retreat the line of coastal defence;
- To restore saltmarsh habitat for conservation purposed by breaching the existing flood embankment;
- To investigate the re-establishment of natural intertidal processes and habitat.

Intensive monitoring of the site was undertaken for five years post initiation of the scheme.

Table 6.6 Monitoring carried out at Tollesbury managed realignment site

Parameters Measured	Techniques Used	No. of Stations/Replicates	Frequency
Bathymetry	Bathymetric surveys	Line spacing at 100 m intervals	Annually
Physical and chemical characteristics of the sediment Electrical conductivity and pH. Exchangeable sodium percentage Soil bulk density, water content, OC, hydraulic conductivity. Soil stability measurements.	 pH meter Ammonium acetate Extraction Determined from soil cores Quantity of mechanically dispersible clay. Cone penetrometer. Shear stress measurements. Cohesive strength meter.	5 experimental plots	Frequency reduced as date from inundation progressed.
Vegetation and accretion	Changes in surface elevation Bar across posts Aerial photographs CASI image	Network of 2 m sediment transects 20 stations inside and 28 stations outside the site Coverage of entire site	Annually Monthly to Bi-monthly (2000)
Vegetation of surrounding marsh	Permanent quadrats Species present and percentage cover Maps of vegetation type	Forty 25 m^2 quadrats and sixty 1 m^2.	Annually
Enhancement of vegetation establishment	Five experimental treatments	Randomised block design	Annually
Natural colonisation of vegetation	Fixed transects divided into 1 m^2 cells. Record percentage cover.	One transect in each of 3 fields.	Annually
Benthos including size distribution of species	Sediment cores	Nine 10 cm diameter cores in each of 8 sites	Annually
Interaction between invertebrates and saltmarsh establishment	Field and laboratory experiments	Varied for each experiment	Varied for each experiment
Birds	Site walked on pre-determined route. Observed breeding territories.	Two areas in summer. Five areas in winter.	Monthly between 1995 to 1999 at low water, neap high tide and spring high tide.
Fish	Hoop nets placed in creeks	3 Nets	Annually

Figure 6.6 Tollesbury managed realignment site

7. CONCEPTUAL MODEL

A conceptual model has been developed (Figure 7.1) which incorporates:

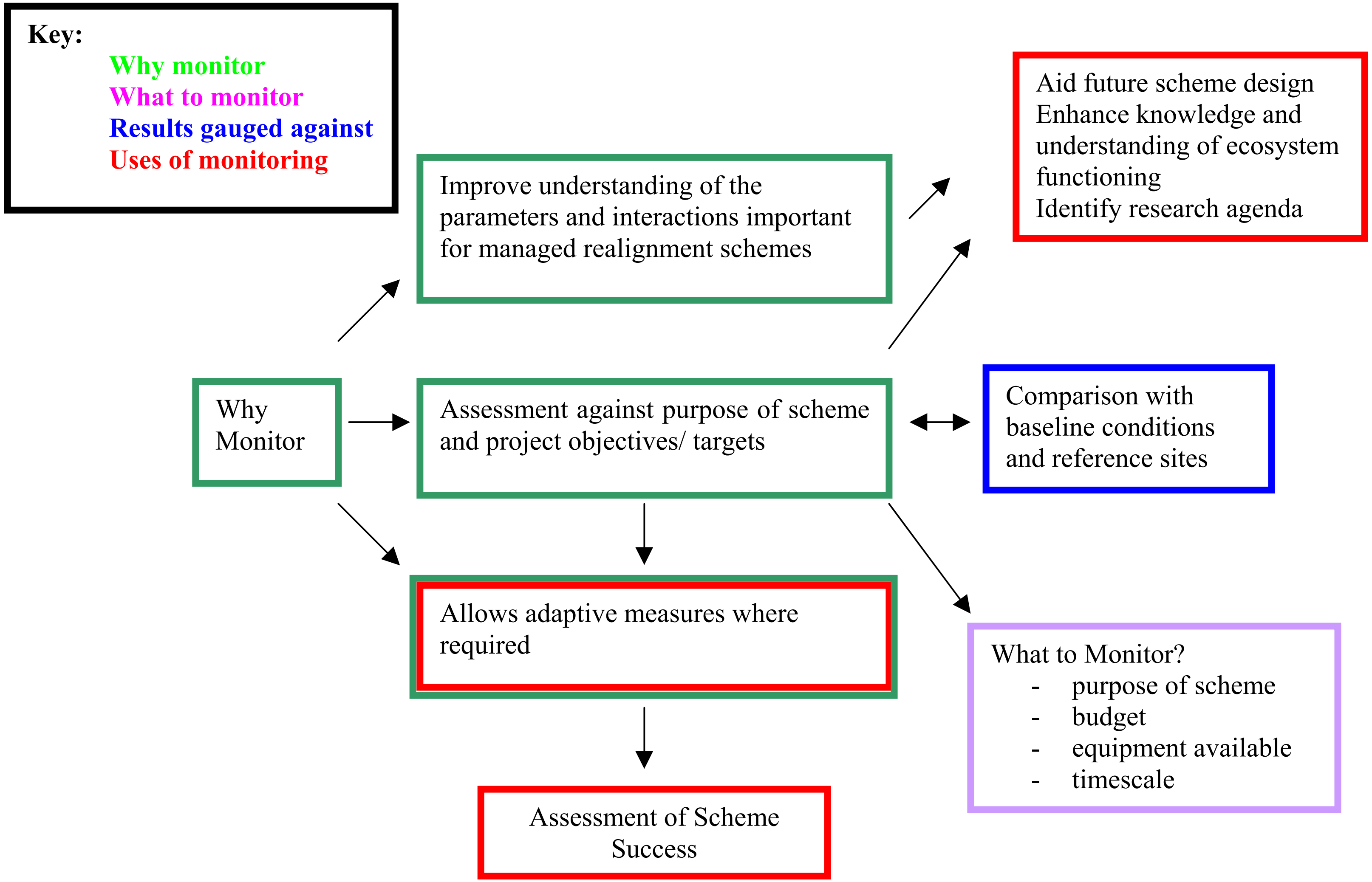
- Key reasons for monitoring;
- How this determines what to monitor;
- What results are gauged against; and
- The end uses of the monitoring data.

The results collected from the monitoring of managed realignment schemes can be used in a number of beneficial ways. Firstly the results obtained can contribute to research regarding the importance of each of the identified parameters and the interactions between them. This research will not only enhance current understanding but can be applied to future scheme designs to increase the likelihood of the success of a scheme. Similarly this greater understanding of site functionality can be applied to the management of this type of environment more generally. This may include the management of designated conservation areas, shoreline management plans, river basin management plans and estuary management plans. It is important to remember that as much can be learnt from the failure of a scheme as the success of a scheme as long as the reasons for the failure are investigated and understood. Lessons learnt from such schemes can then be applied to future scheme designs and management practices.

A continual review of the monitoring results from a site also provides the potential to assess the development of a scheme against the original targets and objectives. The success of the scheme may be assessed in a number of ways, for example, through the comparison with reference sites or baseline conditions or whether aspects of the site perform their intended function. Where the objectives of a scheme are not being met it may be possible to take remedial action in order to get the most out of a scheme. The increased understanding of these systems will also allow the most appropriate remedial action to be undertaken. By promoting a consistent approach to monitoring of habitat creation schemes including a minimum set of monitoring requirements, it will also be possible to compare the performance of individual sites and learn more general lessons about the factors that influence the quality of created habitats.

The selection of what to monitor at a site is dependent on a number of factors. These are primarily related to the overall purpose and objectives of the scheme, statutory requirements for monitoring, the budget and equipment that is available and the timescales over which monitoring is required. The remaining sections of this report are designed to provide guidance on what parameters should be monitored at individual sites.

Figure 7.1 A conceptual model highlighting the importance of monitoring



8. GUIDANCE ON SELECTION OF MONITORING PROTOCOLS

The importance of appropriate monitoring at a site has already been described (Sections 1, 2 and 6). As previously stated managed realignment schemes are undertaken for a number of purposes and as such each scheme has its own unique set of objectives. Every scheme poses specific information needs, and monitoring efforts need to be designed to provide that information. This makes it difficult to provide categoric recommendations of what to monitor at a site. This section provides guidance on the selection of appropriate monitoring tools and establishes a minimum set of core monitoring at all site irrespective of their purpose.

It is important to recognise that not all managed realignment schemes undertaken will have formal requirements for monitoring. In some instances where schemes are undertaken for flood and coastal defence or for the enhancement of existing nature conservation interests, for example, there may be no statutory monitoring requirements associated with the project. However, in the interest of scientific understanding, it is proposed that monitoring should be undertaken at as many schemes as possible following comparable sampling protocols. This would allow maximum experience to be gained relating to the development and subsequent functioning of managed realignment sites. The development of core monitoring protocols would form the basis of a research agenda from which results would require collating and publishing in the public domain in order to gain maximum benefit.

The monitoring of managed realignment sites needs to cover a range of core parameters that describe the key aspects of the site. In addition to these core parameters, individual schemes may opt for, or be required to, perform a more detailed investigation of specific parameters. The choice of these additional measures will depend on the nature of the scheme and its objectives. For example, if the objective of a scheme were to provide habitat for juvenile fish, then the monitoring would need to be tailored to meet this requirement. The following section therefore provides guidance on the parameters that should be monitored at individual sites.

8.1 Core Monitoring

It is recommended that, as a bare minimum, changes in elevation and broad habitat types which establish across a site should be monitored. Elevation is an important parameter as it plays a key role in determining the range of hydrodynamic and sedimentological environments experienced at a site. Such factors ultimately influence the habitat types and species that colonise and use an individual site. Habitats such as saltmarsh also play an important role in flood and coastal defence by reducing wave attenuation across a site. The monitoring of saltmarsh extent therefore helps to estimate the degree of functionality provided by this habitat type. It is unlikely that monitoring outside the boundary of the site would be appropriate at such schemes.

These elements of core monitoring provide very basic information from which it may be possible to infer site usage and functionality. They would also provide useful data for the purposes of inter-site comparisons and support a general research agenda to help enhance and develop our understanding of managed realignment sites. In addition the results from such monitoring would allow an assessment of whether the objectives of a scheme have been met and would indicate whether remedial action needs consideration.

8.2 Statutory Requirement for Monitoring

A large proportion of managed realignment schemes that are undertaken will have statutory requirements for monitoring. Schemes requiring a formal EIA, for example, are likely to have monitoring requirements attached to the planning permission of the scheme. Where monitoring forms a requirement for the scheme there is a shift in emphasis from the quantity to the quality of what develops at a site. For example, it may be appropriate to monitor the species composition of the saltmarsh and the invertebrate assemblages of the mudflat rather than just habitat extents. In this respect more is actually determined and less is inferred about site usage and functioning at higher trophic levels than with the core measurements. The monitoring required will therefore have a greater degree of sophistication and result in more detailed data for the site.

Where an EIA is required the study will examine all aspects of the baseline environment and make predictions on the likely environmental impacts of a scheme. The types of parameters that should be monitored include not only those core ones previously identified above but also those for which impacts are predicted. For example, if the EIA predicted large changes in the patterns of erosion and deposition the associated monitoring would need to focus on this aspect of site development. Where no impacts are predicted there is unlikely to be any requirement for further monitoring of a particular parameter. The parameters monitored would also be a reflection of the overall purpose and objectives of a scheme and would be highly variable between schemes. This again allows an assessment of whether the objectives of a scheme have been met and would indicate whether remedial action needs consideration.

Where the purpose of a scheme forms part of a compensation package for an alternative development detailed monitoring will be required at the site. The parameters and the techniques to be used will require prior agreement with statutory bodies. This is usually agreed prior to the commencement of the scheme and in the early stages of planning. With compensation schemes a higher degree of certainty of what is going to be achieved is required. The monitoring is typically aimed at compliance criteria, that is determining if specific standards are being met. A higher degree of precision will therefore be required from the techniques which are employed for each parameter. The parameters to be measured will reflect what the scheme is designed to compensate for and any impacts that are predicted to arise from the scheme itself. These parameters will be identified from the associated EIAs.

For schemes that are funded, either by a third party or through an associated initiative (e.g. Countryside Stewardship Scheme) there may be requirements to deliver set targets. As with all sites the parameters of interest can be highly variable and the level of accuracy required is also likely to vary depending on the source of funding and the location of the site. Impacts predicted as a result of the scheme will also require some degree of monitoring. This again allows an assessment of whether the objectives of a scheme and the associated funding requirements have been met.

8.3 Relative Importance of Parameters

It has been identified in the previous two sections that there are no simple rules that can be applied to decide on the parameters that should be monitored at a site. The monitoring requirements are dependent on a number of factors including the purpose/ objectives of a scheme and a range of site specific issues. Where agreement with statutory bodies or funding agency is required this may also influence the emphasis of the monitoring schedule for a scheme.

Table 8.1 has been produced in an attempt to rank the relative importance of each of the parameters identified in Section 3 as important for habitat structure and function. The table is meant to serve only as a guideline, as the perceived importance of an individual parameter will be strongly related to site specific issues and the objectives of a scheme.

Table 8.1 Requirement to monitor parameter

	Degree of Importance	Additional Notes
Morphology		
Elevation and Topography	***	Form basis of core monitoring programme
Overall Area	***	Should be determined at the start of the scheme and unlikely to change significantly.
Creek systems	**	Influence site drainage
Hydrodynamic		
Tidal range	**	Linked to colonisation and habitat types at a site.
Current velocities	*	Depend on local hydrodynamic conditions.
Wave action	*	Depend on local hydrodynamic conditions.
Water Quality		
Salinity	*	Not critical to site development
Dissolved oxygen	*	Not critical to site development
Turbidity	**	Can result in smothering
Contaminants	*	Not critical to site development
Sediments		
Sedimentation/Erosion rates	***	Linkages with elevation, site stability
Contaminants	*	Pre-construction
Salinity	*	Not critical to site development
Water Content	*	Not critical to site development
pH	*	Not critical to site development
N content	*	Not critical to site development
Organic matter	**	Not critical to site development
Redox potential	*	Not critical to site development
Surface cohesive strength	**	Indicates the erodability of sediments/stability of scheme
Particle size	*	Not critical to site development
Penetration resistance	**	Can affect colonisation and feeding rates of higher consumers
Ecology		
Vegetation Area and Quality	***	Habitat types affect site usage and may provide role in flood and coastal defence.
Benthic Invertebrates	***	Food resource for higher consumers.
Terrestrial Invertebrates	*	Rarely monitored at managed realignment sites
Fish	**	Can provide important nursery grounds.
Birds	***	Important indicator of site usage, often required at compensation schemes.
Freshwater Invertebrates	*	Rarely monitored at managed realignment sites.
Mammals	*	Rarely monitored at managed realignment sites, unless protected species present.

Key: * = least important, * = most important**

9. CASE STUDIES HIGHLIGHTING THE SELECTION OF MONITORING PROTOCOLS

This section of the report provides two case studies of schemes for which monitoring programmes have already been developed. They provide an indication of how and why each of the parameters to be monitored were selected.

9.1 Welwick Managed Realignment Scheme

Associated British Ports (ABP) is proposing to construct a Roll-on/Roll-off (Ro/Ro) terminal at Immingham and Lift-on/Lift-off (Lo/Lo) berths at Hull, known as "Quay 2005". In consultation with regulatory bodies and local nature conservation interest groups, a potentially acceptable compensation/mitigation package for the two port developments has been identified which includes two managed realignment schemes. This case study provides an example of how the monitoring schedule was designed for one of these schemes, at Oustray Farm, Welwick.

Based on the predicted impacts arising from the port development schemes and, to a lesser extent, from the habitat creation proposals themselves, specific quality objectives for the habitat creation/enhancement measures have been developed. Regular monitoring and review of progress against these objectives is required to assess whether the objectives are being achieved. All monitoring information collected will be available to an Environmental Steering Committee, to enable a review of the environmental information collected during the project to provide advice on and agree any changes in the environmental management of the project.

An extensive programme of environmental monitoring will be carried out, before, during and following completion of the project. A programme of general verification monitoring will be undertaken to seek to assess the longer-term impacts of the realignment scheme on the adjacent intertidal areas, in particular to address the following issues:

- Potential for erosion of the existing intertidal mudflat and saltmarsh;
- Potential changes to the invertebrate assemblage inhabiting the existing mudflat;
- Potential changes to waterfowl usage of the existing intertidal area; and
- Potential changes to waterfowl usage of the local roosting areas

A number of monitoring objectives have also been established for the scheme to seek to achieve the maximum ecological potential for the site. These monitoring objectives have been established as a guide to what the site should be capable of delivering. An initial review is planned after five years to ensure that the habitat creation is on track, followed by a formal review of compliance after ten years. A summary of the monitoring objectives and methods that are proposed for the site are presented in Table 9.1.

Table 9.1 Summary of monitoring requirements and proposed sampling methods at the Welwick managed realignment site

Monitoring Objectives	Parameter	Start Date	Frequency	Duration	No. of Surveys	No. of Sites
Impact Verification Monitoring (existing environment)						
Erosion of existing intertidal - none predicted by numerical modelling but due to importance of site and uncertainty of model results elevation will be monitored.	Visual observation	1 month before inundation	monthly	1 year post inundation	13	
Erosion of existing intertidal - none predicted by numerical modelling but due to importance of site and uncertainty of model results elevation will be monitored.	Bathymetric survey	1 month before inundation	annually	5 years post inundation	6	
There is potential to affect the stability of the saltmarsh fronting the existing sea defences.	Changes in saltmarsh	summer before construction	annually	5 years post inundation	8	
There is potential to affect the stability of the saltmarsh fronting the existing sea defences.	Composition of saltmarsh	summer before construction	annually	5 years post inundation	8	
Changes in the morphological form of the existing intertidal mudflat could alter the invertebrate composition, abundance or biomass.	Changes to intertidal invertebrates	summer before construction	annually	5 years post inundation	8	10 + 5 control
Assess potential changes in waterfowl usage of the existing intertidal area. Waterfowl currently roosting and feeding in the proposed realignment area will be displaced.	Waterfowl on existing intertidal area and adjacent fields. Through the tide counts.	Overwinter season before construction	monthly (Sept to Mar)	5 years post inundation	8 x 7	
Created Habitat Objectives						
Assess changes in elevation of created site.	Visual observation	1 week before inundation	monthly	1 year post inundation	13	
Create between 7 and 37 ha of intertidal mudflat Create between 8 and 32 ha of saltmarsh	Topographic Survey	1 week before inundation	annual in summer thereafter	10 years post inundation	11	
Within ten years of realignment, the saltmarsh created should show a similar zonation and species composition to existing adjacent saltmarsh.	Saltmarsh composition	1st summer following inundation	annually	10 years post inundation	10	
Create between 9 and 15 ha of grassland. At least 50% of the grassland area should support	Monitoring of grassland	1st summer following inundation	annually	5 years post inundation	5	

Monitoring Objectives	Parameter	Start Date	Frequency	Duration	No. of Surveys	No. of Sites
natural plant communities comparable to local reference areas within 5 years of construction						
Within 5 years of creation the pools should support a fauna and flora comparable to local reference pools.	Monitoring of saline pools	1st summer following creation	annually	5 years post inundation	5	
Within 5 years of realignment the mudflat created should support an invertebrate assemblage of similar species, population abundance and biomass to local reference sites.	Changes to intertidal invertebrates	1st summer following inundation	annually	10 years post inundation	10	10
Within ten years of realignment, the mudflat should be regularly be used by 732 overwintering waterfowl (peak) (278 average).	Waterfowl usage of realignment area	overwinter season following inundation	monthly (Sept to Mar)	10 years post inundation	10 x 7	
Grassland habitat to support a range of farmland bird species including reed bunting, skylark and yellow wagtail.	Bird usage on grassland	April/May following inundation	annually	5 years post inundation	5	

9.2 West Chidham

Chichester Harbour Conservancy proposes to carry out a managed realignment scheme along the west shore of the Chidham Peninsula to upgrade the sea defences fronting Chidham Manor Farm. The proposed realignment of the sea defences along this section of shore, is a specific objective of the Chichester Harbour Management Plan (Chichester Harbour Conservancy, 1999) as it has landscape, conservation and long-term flood protection benefits. The application site comprises approximately 24 ha of cultivated agricultural land. The entire shoreline and intertidal area adjacent to the application site within Chichester Harbour is designated a Site of Special Scientific Interest (SSSI), Special Protection Area (SPA), Ramsar Site and candidate Special Area of Conservation (cSAC). An Environmental Statement (ES) for the scheme was submitted in May 2002 (Chichester Harbour Conservancy, 2002). The following information has been extracted from this ES.

The District Planning Authority provided on request a formal opinion on the scope of the ES that was required to accompany an application for the proposed scheme. The Scoping Opinion stated the ES should cover the following issues:

- Why the development is necessary;
- Alternative schemes considered;
- Aspects of the environment that could be significantly affected by the development;
- Whether the impacts will be short or long term;
- Whether the impacts are permanent or temporary, positive or negative;
- Whether the impacts are direct or indirect;
- The proposed lifetime of the bund; and
- Any localised effect due to the altered pattern of water movement.

Of particular concern were the:

- Impacts upon the features of interest of the various designations in Chichester Harbour;
- Impacts to rare and threatened species (especially the intertidal mudflat, saltmarsh habitat and transitional habitats);
- Impacts during construction;
- Impacts on natural estuary processes; and
- The impact of the proposal on the drainage system for the area.

Consultation was undertaken as an integral part of the scheme development and EIA process. This included consultation with Chichester District Council, English Nature, Environment Agency and Chidham Parish Council.

The resulting ES considered each of these issues in turn and determined the likely impacts of the scheme. As a result of discussions with statutory organisations the following monitoring requirements were identified:

- Water quality (suspended solids and nutrient concentrations);
- Sediment profiles;
- Density and distribution of eelgrass beds;

- Benthic macro-invertebrate assemblage within the mudflats;
- Density and distribution of macroalgal mats;
- Distribution pattern of existing saltmarsh; and
- Information on local fish populations as species and age classes.

It was also stated that monitoring should assess colonisation processes within the new intertidal habitat as well as monitoring for potential change within the surrounding intertidal habitat. The baseline surveys should therefore continue but extend into the new intertidal habitat areas.

The actual details of the monitoring programme including the methods to be used and the number of replicates/ sampling stations have not yet been fully defined or agreed. The ES states that the monitoring will be guided by national advice based on experience from other sites (Chichester Harbour Conservancy, 2002). This is in contrast to the monitoring programme for Welwick which is fully defined at a much earlier stage of the planning process. These two case studies, therefore, serve to illustrate the different approaches used to define the monitoring protocols for a site based on the purpose and objectives of a scheme.

10. SELECTION OF APPROPRIATE MONITORING TOOLS

The advantages and disadvantages of each of the techniques capable of measuring relevant parameters at a site have been addressed in Section 4 and Table 4.3. The selection of a technique to use for a specified scheme will be influenced by a number of factors, including:

- The purpose of the scheme;
- Degree of accuracy required;
- Site specific issues;
- Available budget;
- Available equipment; and
- Previous site work.

Where the scheme is undertaken with no formal requirement for monitoring it is probable that the most cost effective, low technology method of data collection would be used. The period and frequency over which the monitoring would be conducted is also likely to be restricted. In contrast, where the monitoring is designed for impact verification, or to assess compliance with an agreement, the techniques used would be required to permit a more detailed assessment of the site. Equipment that can detect the level of change predicted through the impact assessment or to meet an agreed compensation measure would be required. The technique to be used may also require prior agreement with the relevant statutory bodies. Where monitoring is a statutory requirement, the duration and frequency of the monitoring programme is also likely to be predetermined. Typically monitoring periods are set for a period of five years post inundation, with a review of data collected at this time and the requirements for future monitoring assessed. Where ecosystem elements develop over longer timescales, for example, there will be a requirement for monitoring over longer time periods. Similarly where a target condition has been achieved it may be possible to review the monitoring programme at this time.

Each individual site will have a unique suite of physical and ecological characteristics. This will in turn affect the most suitable technique for taking measurements/ samples at a site. Similarly the majority of methods that have been described in Section 4 are best suited to a range of environmental conditions. The relative specificity of the methods will, however, differ between each of the techniques. Other site specific issues include the accessibility of the site in order to take the necessary measurements. Some sites may be inaccessible on foot, for example, and require equipment such as a hovercraft in order to collect the required samples. Access points to a site, and health and safety more generally, also require careful consideration when selecting the parameters to be measured and the associated monitoring tools to be used.

The methods available to measure each of the parameters also differ in their relative costs in both obtaining and deploying the equipment as well as the subsequent analysis and reporting. The actual costs of the different instruments and their deployment is highly variable and as such it is not practical to give an indication of the likely costs associated with a particular monitoring schedule. The costs assigned to the monitoring aspect of the project are again likely to be a function of the purpose of the scheme and the statutory requirements for monitoring. The number of replicate samples taken for each parameter will also be limited by the associated costs. Typically a balance is required between sampling effort and the available funding for monitoring. The equipment that is already available for use is also likely to affect the selection of a sampling method, especially as budgets are generally constrained. In addition the sampling methods used at a site should be consistent with the methods that have already been used to collect the associated baseline information. This ensures that consistency is maintained throughout a dataset and facilitates the further interpretation of the data.

The factors listed above are all important considerations for the selection of a monitoring method for each of the possible parameters. Due to the wide range of reasons for monitoring and the number of methods available it is impossible to make recommendations for which technique would be applicable for individual sites. When selecting a method to use at a site, from the options presented in Table 4.3, each of the factors outlined above needs to be considered in combination with the advice that is presented in Table 10.13. This Table (10.13) presents a summary of the information required to help select the appropriate monitoring tool for each of the parameters of interest. It covers the accuracy, relative costs, associated timings and site specific issues for each of the methods. The following subsections describe the key site specific issues and recommendations that need to be considered when selecting a tool for each of the parameter types.

10.1 Morphology

The factors described above in the introduction to Section 10 all require consideration when selecting a tool for assessing site morphology. Accessibility of the site, both in terms of access and health and safety may also form a large part of the selection process. Where a site is inaccessible on foot, for example, bathymetric surveys may be the only suitable method for assessing bed level changes. Such surveys are typically done along transects, the spacings of which will depend on the level of detail required by the study and the overall size and spatial variability within a site. Similarly surveys carried out on foot are typically undertaken along transects at various line spacings. The overall size of a site will also determine the tool that is selected. At large sites, which require comprehensive coverage, LiDAR may be the most suitable method to use. However, it is important that such data are adequately ground truthed because vegetation can influence the elevations that are recorded. Measurements of site morphological development are typically conducted on an annual basis, although more intensive monitoring may be required in the first few months following habitat creation. On low budget projects simpler techniques such as stakes or pairs of vertical canes may be used. The overall recommendations for monitoring the morphology of a site are presented in Table 10.1.

Table 10.1 Recommendations for monitoring site morphology

Consideration	Recommendation	Reason
Timing	Not critical but should be consistent each year of the survey.	Seasonal variation will occur throughout year
Frequency	At least annually	Incorporate natural variation.
Technique	Site inaccessible on foot - bathymetric survey along transects Site accessible on foot and high degree of accuracy required -Real Time Kinematic GPS, Total Station or EDM. Surveys conducted along transects perpendicular to the shoreline. Large site requiring complete coverage - LiDAR survey.	Boat will provide safe access to site. Accurate techniques for site measurement. LiDAR covers large areas in a cost effective manner.
No. of samples	The number of transects will depend on the overall size of the site and variability.	Required to address issues of natural spatial and temporal variability.
Analysis	Transect data can be used to produce terrain maps. Data compared to baseline conditions and reference sites. Transect data compared through the years.	Used to establish whether objectives of a scheme are being met.
Duration	Typically five years with a review conducted at this time.	Allow time for site development
Additional information	These techniques will also be appropriate for assessing creek systems.	Same methods applicable to assessing overall morphology and individual site features.

10.2 Hydrodynamics

The equipment required to measure hydrodynamic parameters typically requires some form of stable mooring device that will not be interfered with or moved by the currents. This type of equipment can be relatively expensive so it is important that is positioned with care. There is a wide range of equipment with differing specifications that can be used to measure such parameters, the cost of which will also be highly variable. The degree of accuracy required and the level of change that is to be detected will influence the equipment that is selected. Generally measurements of tides and currents are conducted over a spring neap tidal cycle or for the duration of separate spring and neap tides. Measurements of waves need to take account of seasonal variation in the wave climate and would generally be focused on winter measurements covering a period of high wind/ wave conditions The timing of the measurements in relation to breaching will also affect the results that are collected. The placement of the instruments is likely to be dependent on the predicted impacts and/ or areas of interest. They can be placed through the breaches, or both inside and outside of the site boundary. These types of measurement are not typically required at all sites. The overall recommendations for monitoring the hydrodynamic parameters of a site are presented in Table 10.2.

Table 10.2 Recommendations for monitoring site hydrodynamics

Consideration	Recommendation	Reason
Timing	Tides and Currents should be measured over a Spring - Neap cycle. Waves - Ideally measured in winter months to record extremes.	Variation will occur within the tidal cycle. Seasonal variation needs to be taken into account.
Frequency	Post breaching and only after this time if requirement arises.	Most changes in hydrodynamics should be detectable at an early stage of site development.
Technique	There is a wide range of equipment with differing specifications that can be used to measure hydrodynamic parameters.	The costs, degree of accuracy required and the level of change that is to be detected will influence the equipment that is selected.
No. of samples	Number of meters will depend on size of the site and the nature of the breaching. Will be located at the sites of predicted impacts and/ or specific areas of interest.	Allow for spatial variation in areas of predicted impacts.
Analysis	Tide, current and wave data compared to baseline conditions.	Assess changes to hydrodynamic parameters that result from the scheme.
Duration	Post breaching and only after this time if requirement arises.	Most changes in hydrodynamics should be detectable at an early stage of site development.

10.3 Water Quality

Parameters such as salinity, dissolved oxygen, turbidity, contaminants and organic content are rarely monitored at managed realignment schemes. If this type of monitoring were required, however, it would be necessary to consider the natural background variability in each of these parameters. This includes long and short term measurements to cover tidal and seasonal influences as well as variable inputs from neighbouring sources. The number of samples, required both inside and outside of the predicted zone of influence, will largely be dependent on the size of the site and the scale of the issue. Increased turbidity may arise as a result of increased erosion at the time of inundation and through changes in water movements. This has the potential to affect light penetration and cause smothering at sites of deposition and as such is the water quality parameter that is most likely to be monitored. If the baseline survey detects high concentrations of contaminants or other related issues then these would also require careful monitoring. The overall recommendations for monitoring the water quality at a site are presented in Table 10.3.

Table 10.3 Recommendations for monitoring water quality

Consideration	Recommendation	Reason
Timing	Not critical but should be consistent each year of the survey. Need to consider natural background variability.	Seasonal variation will occur throughout year
Frequency	At least annually	Incorporate natural variation.

Consideration	Recommendation	Reason
Technique	Dependent on parameter of interest but rarely monitored at managed realignment sites. See Table 10.13 for suggested methods if required. Turbidity most commonly measured at managed realignment sites - Turbidity meter.	The costs, degree of accuracy required and the level of change that is to be detected will influence the equipment that is selected. Most likely parameter of interest at managed realignment sites.
No. of samples	The number of samples, required both inside and outside of the predicted zone of influence, will be largely be dependent on the size of the site and the scale of the issue.	Required to address issues of natural spatial and temporal variability.
Analysis	Measurements are either collected *in situ* or require subsequent analysis. When data is analysed need to compare to background concentrations.	Used to establish the impacts of a scheme.
Duration	Immediately post breaching and only after this time if requirement arises.	The resuspension of material should be limited to initial period of tidal inundation.

10.4 Sedimentation Rates

Sedimentation rates are likely to be monitored in combination with an overall assessment of the morphology of a site. The techniques used to measure sedimentation rates at a site will largely depend on the relative rates of erosion/ deposition at a site. Where rates are relatively low, for example, it may be appropriate to use accretion plates or SETs. In contrast where rates are relatively high horizontal bars placed across poles or canes or topographic surveys may be the most appropriate technique. Similarly where longer term measurements are required marker horizons or stakes placed in the intertidal may be most suitable. The use of marker stakes or pairs of canes is a cost effective method for assessing sedimentation rates. The timing of the measurements again needs consideration to take into account natural variability within the system. It is necessary to take measurements both within the site boundary and at control sites so that wider estuary trends can be identified. The number of samples required will depend on the overall size and the topographic variability within the site. It may also be necessary to monitor outside the site boundary where impacts are predicted further afield. This may be particularly important if there are features such as shellfish beds or other environmentally sensitive receptors that could be impacted. The overall recommendations for monitoring sedimentation rates at a site are presented in Table 10.4.

Table 10.4 Recommendations for monitoring sedimentation rates

Consideration	Recommendation	Reason
Timing	Not critical but should be consistent each year of the survey.	Seasonal variation will occur throughout year
Frequency	At least annually - although depending on technique can be daily	Incorporate natural variation.

Consideration	Recommendation	Reason
Technique	Dependent on rates of accretion and erosion Low - accretion plates, filter papers or SETs High - topographic surveys or permanent stakes For longer term measurements - marker horizons or permanent stakes	Technique will be highly dependant on site specific factors.
No. of samples	Depend on the overall size of the site and topographic variability within the site.	Required to address natural spatial and temporal variability.
Analysis	Data compared to baseline conditions and reference sites. Changes through time analysed.	Used to establish whether objectives of a scheme are being met. Morphological evolution of site can be assessed.
Duration	Typically five years with a review conducted at this time.	Allow time for site development

10.5 Sediment Properties

There are a number of parameters, related to sediment properties that can be monitored. The concentrations of contaminants in the sediments are usually determined prior to the start of a project to ensure that harmful concentrations are not released into the water column on inundation. There is, however, limited value in measuring contaminants after this time. While salinity, water content, pH, N, and organic content can be important for the development of some plant and animal communities they are not generally considered critical for site development and as such are not commonly measured at realignment sites. Similarly the erodability of sediments, in terms of shear stress or CSM measurements, has only been monitored at a limited number of managed realignment sites. In contrast particle grain size has been monitored at a number of sites. The sediment parameters selected for monitoring are therefore a function of project requirements and available budgets. The overall recommendations for monitoring the sediment properties of a site are presented in Table 10.5.

Table 10.5 Recommendations for monitoring sediment properties

Consideration	Recommendation	Reason
Timing	Not critical but should be consistent each year of the survey. Need to consider natural background variability.	Seasonal variation will occur throughout year
Frequency	At least annually	Incorporate natural variation.
Technique	Dependent on parameter of interest but rarely monitored at managed realignment sites. See Table 10.13 for suggested methods if required.	The costs, degree of accuracy required and the level of change that is to be detected will influence the equipment that is selected.
No. of samples	The number of samples, required will largely be dependent on the size and variability of the site.	Required to address issues of natural spatial and temporal variability.
Analysis	Measurements are either collected *in situ* or require subsequent analysis. When data is analysed need to compare to background conditions.	Used to establish whether objectives of a scheme are being met.
Duration	Dependent on parameter of interest	

10.6 Vegetation

The types of plants that can be identified at a site will be affected by the seasonal variation as saltmarsh plants experience die back during the winter. This will not only affect how identifiable the plant species are but will affect estimates of total coverage and other plant condition indices. The best time to monitor vegetation types is therefore in the summer months. The timing of each annual survey also needs to be consistent to ensure that all results collected are directly comparable. A broad scale overview of vegetation types can be obtained from simple mapping techniques progressing towards more accurate habitat boundaries and species composition with more sophisticated measurements. Vegetation is typically surveyed in quadrats, the number and size of which will depend on the natural variability and overall size of the scheme. To assess elements of functioning such as biomass or stem height/ density far greater survey effort is required. If an objective of the scheme is to achieve a pre-determined species composition it will also be necessary to collect data at local reference sites for comparative purposes. The duration of the monitoring will vary with the purpose of a scheme, but it is typically in the region of five years with a review conducted at this time. The overall recommendations for monitoring the vegetation at a site are presented in Table 10.6.

Table 10.6 Recommendations for monitoring vegetation

Consideration	Recommendation	Reason
Timing	Survey should be conducted in late summer.	Plants easiest to identify at this time
Frequency	At least annually.	Incorporate natural variation
Technique	Surveys should be along vertical transects throughout the site. Quadrat size at least 0.5 m or 1.0 m for larger plants (e.g. *Atriplex*). Percentage cover or specific counts of number of plants.	Most variation is associated with vertical elevation. Appropriate for most plant species. Dependent on species of interest.
No. of samples	Replicate quadrats at as many elevations as possible. Number of replicate quadrats depends on spatial variability (can assess with power statistics) but should be no less than five at each sampling position.	Required to take into account natural degree of variability
Analysis	When the surveys are complete conduct a preliminary statistical analysis. Compare with reference sites and or baseline conditions.	Used to establish whether further samples are required.
Duration	Typically five years with a review conducted at this time.	Allow time for colonisation and subsequent succession.
Additional information	Biomass	May be required in more detailed studies.

10.7 Benthos

Samples for benthic analysis can be collected with either a core or a grab. The method that is used will depend on a number of factors including the sediment type and accessibility of the site. Where a site is difficult to access at low tide, for example, a boat may be used to collect samples at high tide in which case it is likely to be easier to collect grab samples, although long-handled coring devices have been used very successfully. The most common method used at managed realignment sites, however, is a corer. It is typical to collect three replicate samples from each sampling station. This helps to provide an indication of spatial variability which is typically large, although where specific targets have been established for benthic invertebrates, more intensive sampling could be required to demonstrate achievement in a statistically robust way. The number of sample stations required will depend on the size of site and the degree of topographic, substrate or habitat variation. Where there is a requirement for certain assemblages to develop, comparisons will be required between adjacent reference sites. This also serves to place the results in the context of wider influences on an estuary or coastline more generally.

The exact measurements taken from the samples will depend on the requirements of the monitoring. More detailed analysis of colonisation and recruitment patterns requires greater detail in the analysis of samples and more frequent measurements. Samples at managed realignment schemes are typically collected annually. The samples need to be taken at the same time each year to reduce seasonal/ temporal variation. The duration of the monitoring will vary with the purpose of a scheme, but it is typically in the region of five years with a review conducted at this time. The overall recommendations for monitoring benthic invertebrates at a site are presented in Table 10.7.

Table 10.7 Recommendations for monitoring benthic invertebrates

Consideration	Recommendation	Reason
Timing	Not critical but should be consistent each year of the survey. September is recommended as this represents the start of the over-wintering bird season.	Seasonal variation will occur throughout year
Frequency	At least annually.	Incorporate natural variation.
Technique	Site access on foot - cores 10 cm in diameter to a depth of 30 cm. No access on foot - cores/ grabs deployed on boat. Sieve size typically 0.5 mm unless specific requirement for meiofauna.	Standard size in which to collect sediment cores. Used to collect macrofauna within samples.
No. of samples	Number of sampling stations depends on spatial variability (can assess with power statistics) and size of site. At least three replicate cores at each sample station.	Required to address natural spatial and temporal variability.
Analysis	When the surveys are complete preliminary statistical analysis should be undertaken. Compare with reference sites and or baseline conditions.	Used to establish whether further samples are required and whether objectives are being met.
Duration	Typically five years with a review conducted at this time.	Allow time for colonisation and subsequent succession.
Additional information	Biomass, size classes, distribution of invertebrates throughout cores.	May be required in more detailed studies.

10.8 Terrestrial Invertebrates

Where a site is dominated by saltmarsh it may also be appropriate to examine the invertebrate populations present within the vegetation. The timing of the survey would be best suited to the summer months when invertebrates are typically most active. The scale of the monitoring would be dependent on the size of the scheme and any specific objectives relating to this parameter. This is not, however, a typical requirement for managed realignment sites. The overall recommendations for monitoring terrestrial invertebrates at a site are presented in Table 10.8.

Table 10.8 Recommendations for monitoring terrestrial invertebrates

Consideration	Recommendation	Reason
Timing	Summer months (preferably May- June)	Invertebrates are most active
Frequency	At least annually.	Incorporate natural variation
Technique	Various, according to vegetation zone and invertebrate behaviour e.g. Suction sampling, pitfall traps, water traps, direct searching, surface scrapes and sweep netting	Various techniques catch different species
No. of samples	Dependent on size of scheme	Required to address issues of natural spatial and temporal variability.
Analysis	When the surveys are complete a preliminary statistical analysis should be undertaken. Compare with reference sites and or baseline conditions.	Used to establish whether further samples are required and whether objectives are being met.
Duration	Typically five years with a review conducted at this time.	Allow time for site development

10.9 Fish

The technique recommended for monitoring fish usage at a site is that which has been developed on the Tidal Thames since 1992 and adapted for managed realignments (Section 4.6.4; Colclough *et al*, 2004). It is important to remember that fish demonstrate seasonal and localised variability in their usage of estuarine habitats. The timing of fish surveys is therefore very important and needs to remain consistent throughout a study. Analysis of fish gut contents may assist in determining whether particular species are using a site for feeding or as a refuge. The overall recommendations for monitoring fish at a site are presented in Table 10.9.

Table 10.9 Recommendations for monitoring fish

Consideration	Recommendation	Reason
Timing	September/October	Periods of concentrated fish activity and recruitment.
Frequency	Twice a year	Periods of concentrated fish activity and recruitment.
Technique	Multiple Method Fish Population Survey	Covers a range of fish types
No. of samples	Will depend on the size of the site, the variety of habitats and tidal influences	Fish usage of a site can be highly variable.
Analysis	When the surveys are complete a preliminary statistical analysis should be undertaken.	Used to establish whether further samples are required and whether objectives are being met.
Duration	Typically five years with a review conducted at this time.	Allow time for site development
Additional information	Gut content analysis	May be required in more detailed studies.

10.10 Birds

If a scheme is implemented purely to meet flood and coastal defence objectives there may be no statutory requirement for waterbirds to be monitored. In contrast, where a scheme is put in place to compensate for an area of habitat loss an assessment of waterbird usage of the site is typically required. Post inundation counts recorded at the site will need to be put into the context of the estuarine/ coastal system as a whole to reflect any natural or wider scale trends in bird usage. Such comparisons can typically be made using WeBS data as well as counts at neighbouring reference sites. The exact timings and frequencies of counts will need to be agreed with statutory and non-statutory organisations, although typically monthly counts are conducted between September to March to assess overwintering interest. This will, however, be dependent on the species of birds that are being displaced or that have associated specific objectives. For example, where passage species have a functional dependence on a site, sampling may need to be conducted in autumn (July to September) and spring (April to May) passage periods. In summary the following monitoring may be required:

- Usage of the proposed site prior to and post realignment;
- Use of reference sites pre and post realignment and during the construction phase; and
- Monitoring of disturbance, both during and post construction may be required.

A distinction may also be made between waterbirds feeding or roosting at a site. From a research point of view it is beneficial to make counts of all bird species that use the site incorporating seasonal variation and differing usage through the tide. To assess site functioning it is also possible to relate the usage of a site to the food and habitat resource provided by the site. The duration of the monitoring will vary with the purpose of a scheme, but it is typically in the region of five to ten years with a review conducted at this time. In terms of non-waterbirds that may be displaced from the newly inundated land monitoring is typically required for a period of five years. The overall recommendations for monitoring birds at a site are presented in Table 10.10.

Table 10.10 Recommendations for monitoring birds

Consideration	Recommendation	Reason
Timing	Winter birds: October to March inclusive Breeding birds: Dependent on bird species Passage birds: Autumn (July to September) and/ or Spring (April to May)	Will vary depending on species of interest
Frequency	Monthly in the months identified as important for species of interest	Will vary depending on species of interest
Technique	Winter birds - through the tide counts, unless only a specific state of the tide is of interest Breeding birds - counts at high tide in areas of roosting Passage birds - through the tide counts, unless only a specific state of the tide is of interest	Will vary depending on species of interest

Consideration	Recommendation	Reason
No. of samples	The number of locations that counts are required from will be dependent on the size of the site. The access of the site and viewing distances will also affect the number of samples required.	The area that can be covered by a counter will vary between sites
Analysis	Compare numbers with baseline and reference conditions throughout the system	Need to consider natural and spatial temporal variability. Used to assess success against targets.
Duration	Typically five to ten years with a review conducted at this time.	Allow time for site development
Additional information	Record activity of birds - feeding, loafing and breeding Record disturbance events	Useful information

10.11 Freshwater Invertebrates

Freshwater invertebrates will only require monitoring at a scheme if they are being displaced from the site proposed for inundation. In such instances they will be monitored at the site prior to inundation and in any newly created compensatory freshwater habitat once created. Pond dipping is the most common method used to extract water samples from which the biological content can be identified. In moving water, however, the use of emergence traps, surber samplers or kick sampling may be more appropriate techniques (Downing & Rigler, 1984). The timing of such surveys typically occurs on an annual basis, in the spring or summer months when these invertebrates are most active. The overall recommendations for monitoring freshwater invertebrates at a site are presented in Table 10.11.

Table 10.11 Recommendations for monitoring freshwater invertebrates

Consideration	Recommendation	Reason
Timing	Summer months	Invertebrates are most active
Frequency	At least annually	Incorporate natural variation
Technique	Pond dipping in still water Emergence traps, surber samplers and kick sampling in moving water Water beetles and hemiptera can be used as indicators of assemblage type	Most cost effective techniques available
No. of samples	Dependent on size of freshwater habitat At least three replicates required at each sample position	Required to address natural spatial and temporal variability.
Analysis	When the surveys are complete a preliminary statistical analysis should be undertaken. Compare with reference sites and or baseline conditions.	Used to establish whether further samples are required and whether objectives are being met.
Duration	Typically five years with a review conducted at this time.	Allow time for site development

10.12 Mammals and Herptiles

Schemes are generally unlikely to require monitoring for marine or terrestrial mammals or herptiles. An exception might be where water voles or badgers are present on the site prior to realignment. Water voles and badgers are a protected species under the Wildlife & Countryside Act 1981 and as such any impacts on existing populations requires careful consideration. Similarly sea walls can sometimes support lizards and snakes which may have additional monitoring requirements. An assessment of the initial population would generally be required with individuals being translocated where possible. There may also be a requirement to monitor the usage of the relocation site to ensure the population remains stable following translocation. The overall recommendations for monitoring mammals and herptiles at a site are presented in Table 10.12.

Table 10.12 Recommendations for monitoring mammals and herptiles

Consideration	Recommendation	Reason
Timing	Summer months	Animals are most active
Frequency	At least annually	Incorporate natural variation
Technique	Count burrows and/ or latrines Capture/ Recapture Timed Observations and counts under refugia	Most cost effective techniques available
No. of samples	Dependent on species of interest and numbers of animals concerned.	Required to address issues of natural spatial and temporal variability.
Analysis	When the surveys are complete a preliminary statistical analysis. Compare with reference sites and or baseline conditions.	Used to establish whether further samples are required and whether targets are being met.
Duration	Typically five years with a review conducted at this time.	Allow time for site development

10.13 Conclusions

A number of factors require consideration when selecting a measurement tool. The key determinants will be the purpose of the scheme, the degree of accuracy required, the available budget and site specific issues. These factors are summarised for each of the monitoring tools in Table 10.13. This table combined with the issues outlined above should therefore assist in the selection of a suitable monitoring technique.

Table 10.13 The accuracy, costs and time associated with each of the monitoring tools

	Parameter	Monitoring Technique	Relative Accuracy	Relative Costs	Relative Time	Site Specific Issues
Morphology	Elevation	Differential GPS	*	*	*	Require safe access to site on foot.
		RTK GPS	***	**	*	Require safe access to site on foot.
		Total station	***	*	***	Require safe access to site on foot.
		Bathymetric Survey	**	**	*	Conducted at high tide via boat - so no site access required on foot.
		LiDAR	*	*** (cost effective for large areas)	*	Needs to be flown at low tide. Typically done at larger sites.
	Topography	Differential GPS	*	*	*	Require safe access to site on foot.
		EDM	***	*	***	Require safe access to site on foot.
		Descriptive profiling	*	*	*	Require safe access to site on foot.
	Area	Cartographic exercise	**	**	**	Site area should not change significantly.
		GIS	**	*	*	Used to map habitat types - need to be supported by field data. More accurate if supported by GPS.
	Creek systems	Aerial photography	*	***	**	Images need to be taken at low tide.
		Site mapping	**	**	**	Require safe access to site on foot.
Hydrodynamic	Tidal range	Tide gauge	Variable (***)	Highly variable	**	Require secure mooring Need to consider tidal cycle.
		Photographic records	*	*	*	Need consistent viewing location
	Current velocities	Current meters	Variable (***)	Highly variable	**	Require secure mooring Need to consider tidal cycle.
		Surface drogues	*	**	***	Need to consider tidal cycle Seasonal influences of wave and wind.
		ADCP	***	***	**	Require secure mooring Need to consider tidal cycle.
	Wave action	Wave recorders	Variable (**)	Highly variable	**	Require secure mooring Need to consider tidal cycle.
Water Quality	Salinity	Salinity probe	***	*	**	Need to consider natural variability and freshwater input.
		Water samples	***	***	***	Need to consider natural variability and freshwater input.
	Dissolved oxygen	DO probe	***	*	*	Need to consider natural variability.

	Parameter	Monitoring Technique	Relative Accuracy	Relative Costs	Relative Time	Site Specific Issues
	Turbidity	Turbidity meter	**	**	*	Need to consider natural variability.
		Water samples collected and analysed	***	**	***	Need to consider natural variability.
		Secchi disk	*	*	*	Need to consider natural variability.
	Contaminants	Collection of water samples	***	***	***	Need to consider natural variability.
Sediments	Sedimentation/ Erosion rates	Accretion plates	***	**	**	Relatively low deposition.
		Filter papers	*	**	***	Relatively low deposition - over a single tidal cycle.
		Sediment erosion tables	**	*	*	Relatively low deposition.
		Stakes	**	*	*	Can remain in position for long periods.
		Pairs of vertical posts	**	*	*	Can use on sites not suitable for burying plates.
		Artificial horizons	**	***	***	Best used for longer term measurements.
	Contaminants	Sediment cores	***	***	***	Number of samples will depend on size and variability of site.
	Salinity	Refractometer or conductivity	***	**	*	Measured *in situ* - site needs to be accessible.
	Water content	Theta probe	**	**	*	Measured *in situ* - site needs to be accessible.
		Suction pressure measurement	**	**	*	Measured *in situ* - site needs to be accessible.
	pH	pH meter	***	*	*	Measured *in situ* - site needs to be accessible.
	N	Sediment cores	***	**	**	Number of samples will depend on size and variability of site.
	Organic matter	Sediment cores	***	***	***	Number of samples will depend on size and variability of site.
	Redox potential	Redox potential tester	**	*	*	Measured *in situ* - site needs to be accessible.
	Surface Cohesive Strength	Shear vane	**	*	*	Not very good if very wet sediment.
		Cohesive Strength Meter	**	***	**	Requires reasonably dry surface.
		Cone penetrometer	**	**	**	
	Particle size	Particle Size Analysis	***	**	**	Number of cores will depend on size and variability of site.

	Parameter	Monitoring Technique	Relative Accuracy	Relative Costs	Relative Time	Site Specific Issues
Ecology	Vegetation Saltmarsh Transitional marsh Grassland, algae	Aerial multispectral remote sensing	**	**	**	Good coverage for large areas.
		Aerial photographs	**	**	**	Good coverage for large areas.
		Measurements within quadrats	***	*	***	Number of quadrats will depend on size and variability of site. Need to consider seasonality.
		Photographic records	*	**	**	Number of photos will depend on size and variability of site. Need to consider seasonality.
		NVC mapping	**	***	***	Need to consider seasonality.
	Benthic Invertebrates	Sediment cores	***	***	***	Number of cores will depend on size and variability of site. Need to consider seasonality.
		Grab samples	***	***	***	Easier to deploy off a boat, where access to a site is limited. Also more suitable for coarser sediments such as gravel. Need to consider seasonality.
	Terrestrial Invertebrates	Suction sampling, emergence traps, sweep nets and pitfall traps	**	***	***	Traps need to be set above MHWS. Leave out during days of neap tides.
	Fish	Netting	**	**	**	Need to consider seasonal/ localised variability.
		Traps	**	**	**	Need to consider seasonal/ localised variability.
		Beam trawling	***	***	**	Need to consider seasonal/ localised variability. Requires boat access.
	Birds	Visual observation/ recording	***	**	***	Will depend on size of site and layout. Observations will be influenced by seasonal trends in bird usage of a site.
	Freshwater	Pond dipping	**	**	**	Need to consider seasonal variability.
	Mammals	Count burrows	*	*	*	Need to consider seasonal activity of some mammals.
		Count latrines/ droppings	*	*	*	Need to consider seasonal activity of some mammals.
		Capture/ Recapture	**	**	**	Need to consider seasonal activity of some mammals.

Key: * = Least
*** = Most

11. GENERAL GUIDANCE ON MONITORING

There are a number of further considerations that need to be taken into account in developing a monitoring programme and these are discussed in more detail below.

To improve the ability to determine the success of a scheme there is a need for long term data sets before and after the scheme commences and similar data for reference sites for comparative purposes. The more data that are available the better the chance of being able to separate the effects of the scheme from natural background variability operating within the system. Such variation can be particularly high for many aspects of coastal and estuarine environments. Ideally it would be advisable to collect several years pre-realignment data. The collection of data at reference sites also allows the results to be put into context with changes that may be occurring throughout the system. As previously stated the duration of monitoring programmes for managed realignment schemes is typically in the region of five years post construction, although it can be more than this depending on the purpose of the scheme. As with all data the longer the available time series the more useful the information can potentially be.

The number of sampling stations required for each parameter has briefly been described in Section 4.1. In general, the more spatial variability within a site the more sampling stations will be required to adequately describe the area. Similarly the more temporal variation the longer the site will need to be monitored. The statistical validity of the sampling design also requires careful consideration (Section 5).

It is also important to remember that monitoring programs can be expanded or reduced by varying the number of parameters that are measured, the frequency of monitoring, and the number of sampling stations. A monitoring programme may be quite extensive at the start of a project and the results collected may allow the procedures to become more focused, with efforts concentrated on the key parameters at a site in later years. In contrast for some schemes it may be determined that there is the need to consider additional parameters within the monitoring programme as time progresses, for example, where scheme progress against objectives is slower than predicted, or site development does not follow the expected path.

The timing of the monitoring of each of the selected parameters needs to ensure that there will be no conflicting monitoring at a site at any one time. For example, if birds are being counted at a site there should be no additional disturbance caused by the simultaneous measurement of other parameters. The monitoring schedule therefore needs to be designed to eliminate the potential for such conflicts.

The cost, expertise of personnel and background knowledge of how best to sample will all determine the adequacy of the monitoring programme. It is therefore important that the people involved in the development of monitoring programmes are fully aware of the factors that need to be considered. Quality assurance procedures also need to be put in place to ensure that the data collected and subsequent analysis is of a sufficiently high standard. In addition the development of monitoring programmes to meet specified targets should involve consultation with the appropriate statutory organisations to ensure that the work undertaken is appropriate.

12. DECISION TREE FOR MONITORING REQUIREMENTS

To summarise all the information that has been provided throughout this report a decision tree has been developed (Figure 12.1). This tree highlights that one of the first questions that needs to be asked when designing a monitoring programme is whether there is a formal requirement for monitoring. Where there is no formal requirement for monitoring it is suggested that a number of key parameters are investigated. In contrast where there is a formal requirement for monitoring this will largely dictate the parameters that are to be monitored. Once the parameters to be measured have been defined, advice is provided on the selection of an appropriate monitoring tool. Additional factors that require consideration are also highlighted.

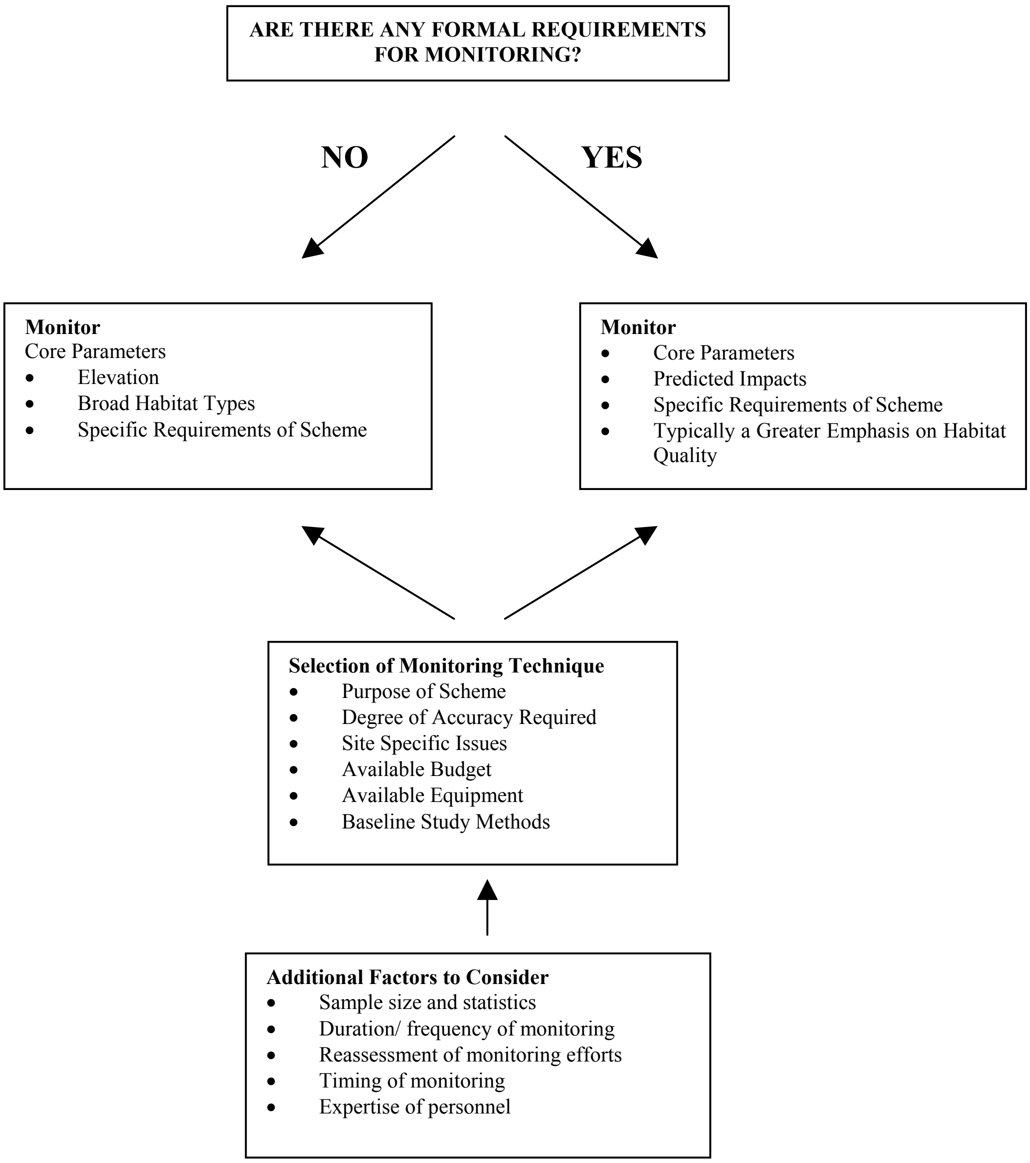


Figure 12.1 A decision tree to aid in the selection of appropriate monitoring protocols

13. CONCLUSIONS

Monitoring strategies are fundamental in charting the progress of managed realignment schemes towards their chosen objectives. These objectives need to be specified using realistic targets and comparison with reference sites or baseline conditions. Habitat creation schemes may have a range of objectives and these influence the choice of parameters to be measured. The results from monitoring may then feed into the overall management of a site and allow adaptive management where required.

The choice of parameters is also influenced by the factors which are known to be crucial to the success of schemes. Monitoring such factors permits an understanding of the performance of the scheme to be developed. For example, whilst habitat quality may be measured in terms of ecological parameters, the failure to achieve target values for these parameters may be attributed to the creation of inappropriate physical conditions. This emphasises the need, in many cases, to monitor a range of both physical and ecological parameters, to fully understand the development of habitat creation schemes. In terms of physical factors, elevation relative to tidal range is seen to be a prime determinant in the creation of given habitats. Relevant ecological indicators of successful habitat establishment, should include vegetation coverage, the status of macrobenthic populations and the bird usage of the site.

The choice of parameters to be measured is also likely to be influenced by the ease with which they can be measured in terms of time and monetary cost. For this reason the report has reviewed the range of techniques which exist for monitoring intertidal sites in general, as well as those habitat creation sites which have been implemented to date. This review illustrates that there is a range of techniques available for measuring a variety of parameters of interest at habitat creation schemes. The strengths and weaknesses of the various techniques have been evaluated. There is usually a trade off between the speed and simplicity of measurement versus the cost in terms of equipment and time.

The present report has also reviewed a number of implemented habitat creation schemes and the findings have been presented as case studies. These case studies demonstrate a range of scheme designs and objectives and illustrate that in the UK to date, the monitoring programmes which have been carried out differ from scheme to scheme. This underlines the importance of the current project in providing guidance for the systematic design of monitoring programmes for similar schemes in the future. In the long term this will improve understanding of the reasons for success or failure of a scheme and assist in improving future scheme design.

The importance of monitoring managed realignment sites has been highlighted throughout this report. A conceptual model has been developed which incorporates the key reasons for monitoring, how this determines what to monitor, what the results are gauged against and the end uses of the monitoring data. The results collected from monitoring of managed realignment schemes can be used in a number of beneficial ways including enhancing the understanding of site design and management.

Following from the identification of a ‘toolbox’ of monitoring techniques it was possible to group the techniques into ‘core tools’, which are relevant for all sites, and ‘optional tools’ whose use is dependent on site specific requirements. Where there is no formal requirement for monitoring it is suggested that core monitoring is still undertaken at as many sites as possible. This would incorporate, as a bare minimum, changes in elevation and habitat boundaries at a site. A large proportion of managed realignment schemes that are undertaken will, however, have statutory requirements for monitoring. Where monitoring forms a requirement for the scheme there is a shift in emphasis from the quantity to the quality of what develops at a site. The types of parameters that should be monitored include not only the core parameters identified above but also those for which impacts are predicted, those for which compensation objectives have been set and those which have funding conditions attached.

It has been identified that there are no simple rules that can be applied to decide on the parameters that should be monitored at a site. The parameters that require monitoring are dependent on a number of factors including the purpose/ objectives of a scheme and a range of site specific issues. A summary table (Table 8.1) has been produced to serve as a guideline as to the perceived relative importance of each of the parameters. To provide guidance on how the selection of monitoring programmes has been undertaken for current schemes, two case studies have been provided. The two schemes that have been selected are very different in terms of their overall purpose and as such the process of defining the monitoring protocols is very different. This section therefore provides an indication of what may be required to define the appropriate measures.

Once the parameters that require monitoring have been established, it is then necessary to select the most appropriate technique. The advantages and disadvantages of each of the techniques capable of measuring each of the relevant parameters therefore needs to be considered. The selection of a technique to use for a specified scheme will also be influenced by a number of factors, including the purpose of the scheme, the degree of accuracy required, available budgets and more site specific issues.

There are a number of further considerations that need to be taken into account when developing a monitoring programme. These include the duration and timing of the monitoring period, a continual reassessment of monitoring efforts, the expertise of the personnel involved, quality assurance procedures and the appropriate selection of sample size and statistical analysis. All of these factors contribute to the overall success of the monitoring programme. A decision tree, covering all of these issues, has been designed to guide the user through the types of questions that need to be addressed in designing a successful monitoring programme. As an additional project it would be possible to increase the sophistication of this decision tree, in an electronic format, which guides the user through the selection of parameters and techniques required to monitor a particular scheme. It is also important to remember that in the light of new technologies and advancements the recommendations made throughout this report may require updating.

The key aspects required to achieve a successful monitoring programme for a managed realignment site have been addressed throughout this report. The results of such monitoring will not only enable the evaluation of current objectives but will inform the design and management of managed realignment schemes in the future.

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APPENDIX A

Wetland Function

An ecosystem is a geographic area including all the living organisms, their physical surroundings and the natural cycles that sustain them. The measuring of ecosystem attributes, such as the number of species or the size of an area is a reductionist approach to assessing habitat quality. The key interest is function, but it is difficult to derive attributes which are indicative of functionality. Using this type of approach the functionality and linkages within a system have to be inferred from the individual components of a system.

In the US functions are defined for physical, chemical and biological characteristics of a wetland. The value of a wetland lies in the benefits that it provides to the environment or to people. It is important to remember that not all wetlands perform the same function nor do they perform all functions equally well. Each site that is likely to be impacted by a proposed scheme therefore needs to be evaluated for functionality and compared to natural wetlands (or more specifically those that are designed to be replaced). The use of function versus form in the assessment of wetlands may also demonstrate that more area is not necessarily better, and that ecosystem functioning is of greater importance.

The development of a single method which covers all areas and options is not a simple procedure. However, assessing each function of a wetland and then assigning a value to each function is a step towards the protection of sensitive wetlands. It is important to note that wetland values are not absolute, nor do they assign a monetary value to a wetland. In many instances it is the perceived value of each function that will be important and priorities may change.

The following examples represent a range of the types of indices that have been developed. In some instances these indices result in a single figure whilst in other a value exists for a range of functions. The list is not exhaustive and many other similar approaches exist. The exact nature of the assessment technique will depend on its intended purpose.

WET - Wetland Evaluation Technique

The Wetland Evaluation Technique (WET) is a balance between costly site specific studies and the best professional judgement approach (Adamus, 1988). This scheme evaluates functions and values in terms of effectiveness, opportunity, social significance (special designations, potential economic value and strategic location) and habitat suitability. It is intended for use by any environmental professional.

Environmental Monitoring Assessment Program (EMAP)

The Environmental Monitoring Assessment Program (EMAP) was developed in the US by the Environmental Protection Agency (EPA) in 1988. It was intended to develop an approach for assessing the condition of different types of wetlands in a region and in the nation as a whole (Novitzki *et al*, 1994). It is again based on indicators of wetland condition in terms of biological integrity, habitat quality, hydrolic integrity and water quality. Wetland health may be evaluated either by similarity (how similar sampled wetlands are to reference wetlands) or by biological criteria (are the sampled wetlands above or below a level determined from measurements obtained in the reference wetlands).

Hydrogeomorphic Approach

The Hydrogeomorphic (HGM) approach was developed in 1990 by the US Army Corps of Engineers in an attempt to simplify the WET approach. The method compares the characteristics of a specific wetland with the characteristics of a group of wetlands (reference wetlands) in the region, and this information is used to assess the degree to which the individual wetland is performing selected functions. The characteristics to be evaluated by HGM are limited to those that are important in the specific region and hydrogeomorphic setting (http://www.wes.army.mil/el/wetlands/hgmhp.html).

Functional Capacity Assessment

The change in ability of a wetland to perform a function can also be measured in terms of functional capacity. Functional capacity is defined as the degree to which an area of wetland performs a specific function (single functions). The approach assumes sustainable functional capacity is achieved in wetland ecosystems and landscapes that have not been subject to long-term anthropogenic disturbance. Variables in the assessment model are assigned a subindex ranging from 0 to 1, based on the relationship between the variable and functional capacity. Variables are assigned a subindex based on either a quantitative or qualitative scale, or if these options are not available then an indicator will be used. In addition to defining the relationship between variables and functional capacity the assessment model defines how variables interact to influence functional capacity. Interaction between variables is defined using an aggregation function or logical rules. The result is a functional capacity index (FCI) which is the ratio of the functional capacity of a wetland under existing conditions, and the functional capacity of a wetland exhibiting reference standards for the regional subclass in the reference domain (http://www.wes.army.mil/el/emrrp/emris/emrishelp6/method_for_the_assessment_of_wetland_function.htm). The size of the wetland is also taken into account: the functional capacity index of the wetland is multiplied by the size of the wetland area.

Wetland ecosystems are, however, dynamic and constantly changing so natural variability must be taken into account. It is also difficult to establish truly natural reference sites since anthropogenic disturbance occurs in most areas and has done for centuries in many cases. Therefore reference wetlands are actual wetland sites that represent the range of variability exhibited by a regional wetland subclass in response to natural processes and anthropogenic disturbance.

Specialised Indices

A number of additional indices have also been considered which use a single parameter as an indicator of the health of a wetland system. Garon *et al,* 1994 (http://twri.tamu.edu/research/tnrcc/1.html) for example, have used wetland insect populations as a biological indicator in the wetlands in six biological provinces in Texas. An index of Vegetative integrity has also been used as an assessment methodology (www.state.ma.us/czm/waVEG.HTM).