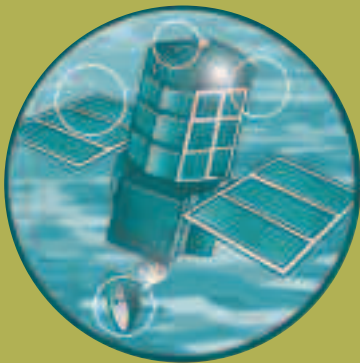


Suitability Criteria for Habitat Creation – Report I:

Reviews of present practices and scientific
literature relevant to site selection criteria.

R&D Technical Report FD1917TR1



**Defra/Environment Agency
Flood and Coastal Defence R&D Programme**

**Suitability Criteria for Habitat Creation – Report I:
Reviews of present practices and scientific literature relevant to site
selection criteria.**

R&D Technical Report FD1917TR1

Authors:

Ruth Parker, Stefan Bolam, Jo Foden, David Morris (Centre for
Environment Fisheries and Aquaculture Science),
Sue Brown (Centre for Ecology and Hydrology),
Tim Chesher, Caroline Fletcher (HRWallingford),
Iris Möller (Cambridge Coastal Research Unit).

Produced April 2004

Statement of use

This research project brings together the present scientific understanding of the physical, chemical and ecological factors controlling habitat (saltmarsh, intertidal mudflat and eelgrass beds - *Zostera Marina*) creation at coastal and estuarine realignment sites. It also provides tools for engineers and managers to facilitate the selection of suitable sites within a given estuary or coastal location.

Dissemination Status

Internal: Released internally

External: Released to public domain

Keywords: Habitat creation, managed realignment, suitability criteria

Research contractor: Centre for Environment Fisheries and Aquaculture Science (CEFAS) Lowestoft Laboratory, Pakefield Road, Lowestoft, Suffolk, NR33 0HT, UKTel: +44(0) 1502 562244, Fax: +44(0) 1502 513865, <http://intranet/cefaswww/homepage.htm>

Defra project officer: James Twohig/Adrian Dawes Mouchel Consultant Ltd
West Hall, Parvis Road, West Byfleet, Surrey, KT14 6EZ, UK
Tel: +44(0)1932 337262, Fax: +44(0) 1932 340673, E-mail: info@mouchel.com
Adrian.Dawes@mouchel.com

This document is also available on the Defra website
www.defra.gov.uk/environ/fcd/research

Department for Environment, Food and Rural affairs
Flood Management Division
Ergon House
Horseferry Road
London SW1P 2AL
Tel: 020 7238 3000 Fax: 020 7238 6187
www.defra.gov.uk/environ/fcd

© Crown copyright (Defra); March 2006

Copyright in the typographical arrangement and design rests with the Crown. This publication (excluding the logo) may be reproduced free of charge in any format or medium provided that it is reproduced accurately and not used in a misleading context. The material must be acknowledged as Crown copyright with the title and source of the publication specified. The views expressed in this document are not necessarily those of Defra or the Environment Agency. Its officers, servants or agents accept no liability whatsoever for any loss or damage arising from the interpretation or use of the information, or reliance on views contained herein.

Published by the Department for Environment, Food and Rural Affairs. Printed in the UK, (March 2006) on recycled material containing 80% post-consumer waste and 20% chlorine-free virgin pulp.

PB No. 11547

EXECUTIVE SUMMARY

This research project brings together the present scientific understanding of the physical, chemical and ecological factors controlling habitat creation (saltmarsh, intertidal mudflat and eelgrass (*Zostera Marina*) beds) at coastal realignment sites. It also provides tools for engineers and managers to facilitate the selection of suitable sites within a given estuary or coastal location.

The specific purpose of this project is to produce electronic decision tools for users to assess the potential of specific sites for habitat creation schemes. These will be:

- at an estuary scale (screening tool) using a Geographical Information System (GIS);
- at a local scale using an influence diagram tool¹.

The necessary site selection criteria and associated thresholds for different habitats were determined by:

- A review of the existing selection procedure and criteria for sites appropriate for habitat creation.
- A review of existing knowledge and understanding of the processes and parameters that influence the growth and functioning of natural saltmarsh and intertidal habitats.

Both of the reviews facilitated the identification of parameters and relevant limits (criteria) which can describe potential realignment sites with regard to habitat creation. This information provides a clear audit trail for incorporation into decision tools for policy makers and managers concerned with managed realignment and habitat creation or restoration.

The project outputs comprise two reports and the associated tools:

1) Report I (this report): Suitability Criteria for Habitat Creation: Reviews of present practises and scientific literature relevant to site selection criteria.

This review brings together the present scientific knowledge and associated criteria relating to the control of habitat creation at a given location. Not all the parameters reviewed were selected as suitable criteria for the decision tools.

2) Report II: Tools for Site Selection for Habitat Creation

This report integrates the main controlling criteria for habitat creation identified by the reviews into tools that will aid site selection in a screening mode (GIS) and on a site-by-site basis (influence diagram tool and software).

This project is complementary to FD1918: Habitat Quality Measure and Monitoring Protocols and also with FD2413: Guidance On Design and Implementation of Managed Realignment (CIRIA, 2004: Design Issues for Managed Realignment) and the recent English Nature/Living with the Sea project: Coastal Habitat Restoration Guide

¹ An influence diagram is a simple visual representation of a decision problem. It provides a way of carrying out calculations on screen and can identify and display the way essential elements in a decision process influence each other.

**([http://www.english-nature.org.uk/livingwiththesea
/project_details/good_practice_guide/habitatcrr/ENRestore/Habitats/Index.htm](http://www.english-nature.org.uk/livingwiththesea/project_details/good_practice_guide/habitatcrr/ENRestore/Habitats/Index.htm))**

EXECUTIVE SUMMARY: REPORT I

REVIEWS OF PRESENT PRACTISES AND SCIENTIFIC LITERATURE RELEVANT TO SITE SELECTION CRITERIA.

This report provides detailed reviews of:

- The present approach to, and criteria used for, site selection for habitat creation.
- The physical, chemical and ecological criteria relevant to habitat creation.

Both detailed reviews appear in full in Appendices (I and II) and are summarised in the main body of this report.

The main findings of this report are:

- The relationship between the success of created habitat (in terms of establishment and continuing health of the created/restored ecosystems) and the physical, chemical and ecological conditions at the site before the habitat creation commenced is a key concern of estuary and coastal managers.
- The creation of managed realignment areas is considered a viable and cost-effective alternative, from flood and coastal defence and habitat creation points of view. However, outcomes of such schemes are not always predictable and there is a clear need for a framework to make the site selection and decision process more transparent and with better prediction capabilities of the type of habitat which will emerge.
- The success of many schemes is well publicised but the failure of others highlights the need for the development of a more structured approach to site selection and assessment of interaction of the schemes with local and regional issues.
- Central to the suitability criteria in place at present are the differences in the need to create a habitat.
- Four main drivers have been identified, which, importantly, are not always mutually exclusive;
 - Mitigation sites for a development where habitat will be lost.
 - Compensation for natural habitat loss (potentially due to coastal squeeze/sea level rise)
 - Compliance with EU Habitats or other directives for creation of habitat.
 - Cost-effective flood defence strategy for a particular area.

Habitat creation as an objective may be particularly important for the first three and less relevant for the fourth, even though habitat creation is potentially an indirect benefit and aim. The relative importance of criteria (ecological, social, economic) in site selection will alter depending on the main drivers and stakeholders involved.

- Strategic plans give a large-scale approach, and sites may be selected according to a combination of criteria, of which habitat creation may only be one. The decision tools developed as part of this project need to sit within this strategic framework. However, approaches taken within and between agencies and end-users can vary and, therefore, an overview of the range of approaches taken at present is essential.
- Key factors affecting site selection for salt marsh or mudflat habitats are similar, and include the following:
 - Proximity to similar habitats (indicating potential for successful creation);
 - History of previous habitat at the site;
 - Site elevation and tidal inundation;
 - Site gradient;
 - Drainage;
 - Sediment supply and the ability to adjust to sea level rise;
 - Salinity;
 - Water quality.
- Key factors affecting site selection for eelgrass habitats include the following:
 - Proximity to similar habitats (indicating potential for successful creation);
 - Turbidity;
 - Degree of exposure to waves and currents;
 - Composition of the substrate;
 - Site elevation and tidal inundation;
 - Water quality;
 - Competition from invasive species.

A summary of the criteria and thresholds relevant to habitat creation as derived from the scientific reviews is given in Table A.

Review of the Present Approach and Criteria used relevant to Site Selection for Habitat Creation.

- This review assesses the current guidelines and procedures for site selection, the criteria used and how habitat creation features within this framework. The full review is given in Appendix 1.
- The protocols implemented by main stakeholders in site selection and the criteria used were reviewed by examination of relevant literature (site reports, monitoring reports, engineering reports, strategy documents, SMPs, CHaMPs² etc) and also meetings with representatives from stakeholder organisations.
- Between and within various agencies there are many initiatives concerned with identifying and selecting sites for potential managed realignment. These may be driven by different policies or strategies but generally the approaches and criteria employed have much in common.

² SMPs (Shoreline Management Plans), CHaMPs (Coastal Habitat Management Plans)

- Many site selection processes involve a generic screening/coarse filtering/primary matrix stage to create a short list of sites that are then examined with a more detailed approach (for example: Atkins, 2002; Binnie Black and Veatch, 2000; HESMP, 2000).
- The site selection approaches implemented have many criteria in common and are generic in nature covering all potential aspects of site selection, not only the environmental but also economic, social and political (HESMP, 2000). The criteria relevant to habitat creation identified from the present site selection overview are presented in Table B.
- A number of the approaches involve the use of matrices or multi-criteria analysis to rank sites against the generic criteria (Halcrow/EA, 2003; ABPmer, 2002; Coutts and Roberts, 2003).
- In each case, although the criteria may be similar, the exact approach taken to give an overall ranking is different not only in the combination of scores but also in the methodology to derive those scores/thresholds. In many cases apart from elevation/tidal inundation the scores and thresholds are qualitative rather than quantitative (For example: Binnie Black and Veatch, 2000).
- The weighting/scoring of various criteria can vary depending on the main driver for site selection (mitigation/compensation, flood and coastal defence etc). For example, conservation agencies may weight the environmental criteria for habitat creation or bird usage more highly than stakeholders who are looking for sites for flood and coastal defence. In this way sites can be ranked differently depending on FCD/habitat creation priorities and also for their purpose.
- There is a benefit in bringing all these various approaches and ranking systems together in terms of common criteria, methodology and scoring so that for those schemes where habitat creation is a key consideration, the potential can be assessed in the light of all available knowledge and experience.
- However, at present the main controls on site selection are not only the type of habitat to be created, the emphasis of this project. Often, flood and coastal defence as well as habitat creation is the objective of many schemes. Site selection is, therefore a pragmatic process and other over-riding factors, such as land purchase or other socio-economic issues, may have higher priority than purely environmental or habitat creation concerns in the assessment of a sites viability.
- The GIS approach and Decision Tools (Report II) can be adapted to give a more generic screening tool in terms of other socio-economic factors as determined by the various matrix approaches implemented by different agencies and lead to standardisation of site selection. The approach adopted in this project, and the overview provided from the review of present site selection processes, gives a good starting point for a more generic selection tool, which could be applied by any end-user.

These reviews have provided an up to date assessment of scientific understanding of how habitat creation is related to site criteria. However, despite this information there are limits of the present understanding of the complex processes that interact to produce a given habitat. The outputs of this project will not necessarily provide predictions of habitat created in terms of quality, or help determine success or failure of a scheme, as this will vary depending on the site purpose and stakeholder priorities. However, the reviews and decision tools provide a procedure and auditable pathway to site selection and the decisions made.

The table below summarises the criteria and thresholds that are relevant to habitat creation, identified from this review, and this information was used in the decision tools as described in Report II.

Table A: A summary of the criteria and thresholds relevant to habitat creation as derived from scientific reviews.

Criteria	Threshold	Habitat	Comments and References
Mean High Water Springs	MHWS – MHWN	Saltmarsh	Delineation by tidal level should be considered as a first approximation, and if possible, use site-specific information to give more accurate criteria.
Mean Low Water Springs			
Mean High Water Neaps	MHWN - MLWS	Intertidal flats	Thresholds for saltmarsh, e.g. Burd, 1989; S. Brown (pers. Measurements); Zedler, 1984; Webb and Newling, 1985; Woodhouse, 1979
Mean Low Water Neaps	Below MLWS	Eelgrass*	Thresholds for intertidal flats, e.g. Little, 2000; McLusky, 1989; Gray, 1981. Slope gradient thresholds from selected Environment Agency profiles of East Anglian intertidal flats (0.17 – 0.27%).
Elevation	Minimum at ~MHWN (450-500 inundations p.a.)	Saltmarsh	General saltmarsh and intertidal flats texts, e.g. Adam, 1990; Packham and Willis, 1997; Long and Mason, 1983; Gray, 1992; Gray <i>et al</i> , 1995;
	Lower than MHWN	Intertidal flats	
	Subtidal; MLWS to 4m	Eelgrass*	
Mean slope	1-2% (1:0-1:64) ideal. >0-7% (1:0-1:18) possible for saltmarsh	Saltmarsh Intertidal flats Eelgrass*	NB: Eelgrass is used to refer to subtidal <i>Zostera marina</i> only. Thresholds for eelgrass (<i>Z. marina</i>), e.g. Rodwell, 2000; Davison and Hughes, 1998
Length of site	Length of site along shore, parallel with waterline.	Saltmarsh Intertidal flats Eelgrass*	Parameters used to calculate overall area, from which habitat areas can be calculated based on inundation (see above for threshold information and references).
Width of site	Width of site across shore, perpendicular to waterline.	Saltmarsh Intertidal flats Eelgrass*	
Is the land polluted?	Absence of contaminants or presence below pollutant level	Saltmarsh Intertidal flats Eelgrass*	Assessment may be made using the EA's guidance: Contaminated Land Exposure Assessment (CLEA). Compare contaminant level measured at site with EA Soil Guideline Values and Groundwater and Contaminated Land publications: www.environment-agency.gov.uk/subjects/landquality/ . Also public authorities hold Contaminated Land Registers and these should be consulted. Also for eelgrass see Davison and Hughes, 1998.
Water salinity	>10 – full salinity: optimum 22	Saltmarsh Intertidal flats	References, e.g.; Zedler, 1996.
	Saline	Eelgrass*	Almost exclusively in fully saline conditions in UK; e.g., Tutin, 1942; Stewart <i>et al.</i> , 1994; Davison and Hughes, 1998

Water Quality	Absence of water-borne contaminants or presence below pollution levels e.g. EA Action Levels. Minor or no eutrophication/ nor elevated nutrients.	Saltmarsh Intertidal flats Eelgrass*	High levels of nutrients can produce algal blooms and mats, smothering invertebrate intertidal flats; e.g. Nicholls <i>et al.</i> , 1981. Algae may also smother and kill saltmarsh vegetation; e.g. Adam, 1990; or eelgrass; e.g., Davison and Hughes, 1998; van Katwijk <i>et al.</i> , 1997, 1999.
Light Climate	Tolerant of wide turbidity range.	Saltmarsh Intertidal flats	Turbidity levels affect composition of intertidal flats; e.g., Little, 2000.
	Intolerant of high turbidity, low light climate. Sensitive to physical disturbance.	Eelgrass*	Sensitive to turbidity and reduced light penetration; e.g., Giesen <i>et al.</i> , 1990a & b; Duarte, 1991; Davison and Hughes, 1998.
Soil type	Various grain sizes from heavy clays to sands	Saltmarsh Intertidal flats	Grain size influences organic content and porosity affecting the competitive outcome of saltmarsh halophytes; e.g. Pye and French
	Sand – sandy/mud, sand/fine gravel	Eelgrass*	Reference; e.g., Davison and Hughes, 1998; de Jong <i>et al.</i> , 2000)
Site Location	Muddy estuary with high accretion rates - resulting in potentially high rates of sedimentation. Open coastline with lower levels of suspended sediment is likely to accrete at a lower rate	Saltmarsh Intertidal flats	This parameter included to provide an indication of how likely it will be that the site evolves quickly due to settling of fine sediment. On the basis that it is unlikely that suspended sediment concentration levels will be known the options range from a muddy estuary (high suspended sediment concentrations) to an open coast (with lower SSCs)
Exposure	Sheltered, low energy environments protected from wave action	Saltmarsh Intertidal flats Eelgrass*	Penetration of high wave energy into the site will tend to inhibit settling of suspended sediment. Low currents and flows needed for eelgrass; Fonseca and Kenworthy, 1987; Fonseca <i>et al.</i> , 1983; de Jonge <i>et al.</i> , 2000
Freshwater flows	Freshwater can be a pollutant to habitats by reducing salinity	Saltmarsh Intertidal flats Eelgrass*	Saltmarsh/halophytic plants and eelgrass habitats polluted by reducing salinity. Diversity of marine organisms reduced in intertidal flats by freshwater. See 'salinity' references
Bed stability	Compressed soil is erosion-resistant. Weak, friable soil will erode more easily. Bed stability likely to increase with accretion, post breach	Saltmarsh Intertidal flats Eelgrass*	e.g. Whitehouse, Soulsby, Roberts and Mitchener (2000). Dynamics of Estuarine Muds. Thomas Telford Publishing.
Connectivity inside site	The degree to which a site drains will affect the proportion of intertidal flats to saltmarsh. Natural creek development in newly accreted material is slow - consider excavating channels pre-breach	Saltmarsh Intertidal flats Eelgrass	No references (T. Chesher, personal experience)

Propagule/ biological supply to site	Supply of seeds, rhizomes and tiller fragments needed to generate saltmarsh and eelgrass habitat, and supply of organisms for intertidal flats.	Saltmarsh Intertidal flats	Dependent on proximity of nearest established habitat and natural direction of transport; e.g., Koutsall <i>et al.</i> , 1987; Rand, 2000; Huiskes <i>et al.</i> , 1995; Garbutt <i>et al.</i> , in Reading <i>et al.</i> , 2002. Supply of larval or mobile adult invertebrates needed to generate intertidal flats communities; e.g. Little, 2000.
	Site needs to be directly adjacent to established eelgrass bed with identical environment.	Eelgrass*	Eelgrass growth in northern latitudes is thought to persist by vegetative means rather than seed production; e.g., Davison and Hughes, 1998; Fonseca <i>et al.</i> , 2000, 2002; Calumpong and Fonseca, 2001

*Eelgrass refers to subtidal *Zostera marina* only.

Table B: Summary table of presently used criteria and thresholds relevant to habitat creation.

Criteria	Threshold	Habitat	Reference
Contaminated land	Presence/absence	Saltmarsh	Halcrow/EA, 2003
Site elevation	2-3 m OD	Saltmarsh	Halcrow/EA, 2003
Site elevation	<1 m OD	Mudflat	Halcrow/EA, 2003
Site elevation	1-2m OD	Transitional	Halcrow/EA, 2003
Surface soils	Clay/Clay loam	Saltmarsh	Halcrow/EA, 2003
Site gradient	1-2% (< 1 :50)	Saltmarsh	Halcrow/EA, 2003
Wave-exposure	% of estuarine length	Saltmarsh/ mudflat	Halcrow/EA, 2003
Height boundaries	-0.49 (m MHWS OD)	Mudflat – saltmarsh	Humber observations; EA, 1998.
Height boundaries	-0.1 (m MHWS OD)	Pioneer marsh – Mid marsh	Humber observations; EA, 1998.
Height boundaries	-0.06 (m MHWS OD)	Mid marsh – Upper marsh	Humber observations; EA, 1998.
Height boundaries	0.03 (m MHWS OD)	Upper marsh – Brackish marsh	Humber observations; EA, 1998.
Height boundaries	0.31 (m MHWS OD)	Brackish marsh – Grassland	Humber observations; EA, 1998.
Salinity, water velocity, sedimentation/ erosion patterns, physico-chemico soil characteristics, wave exposure, coloniser availability	Qualitative	All	Binnie Black and Veatch, 2000; Burd, 1995; Burd et al., 1994.
Potential to improve environment – topography	Scoring 0 – 5	Saltmarsh, intertidal mudflat	Halcrow/EA, 2002
Topography/elevation (OS heights OD)	MLW: 0m OD	> intertidal mudflat	Atkins, 2002; Coutts and Roberts, 2003.
Topography/elevation (OS heights OD)	MHWN: 1.5m OD	< intertidal mudflat, > saltmarsh.	Atkins, 2002; Coutts and Roberts, 2003.
Topography/elevation (OS heights OD)	MHWS: 2.0m OD	< saltmarsh	Atkins, 2002; Coutts and Roberts, 2003.
Topography/elevation (OS heights OD)	HAT: 2.5m OD	> upper level of saltmarsh in 80yrs	Atkins, 2002; Coutts and Roberts, 2003.
Is there a history of pollution or contamination on the site?	History to no history Score –2 to +2.	All	Atkins, 2002; Coutts and Roberts, 2003.
Inundation	400-500 times per yr	Saltmarsh	Burd, 1995
Inundation	>500 times per yr	Mudflat	Burd, 1995
Slope	1-2%	Greatest diversity	Burd, 1995
Fetch	<1000ft	Affects accretion	Burd, 1995
Elevation	<MLWN	Mud/sand flats – Eel grass	ABPmer, 2002
Elevation	MLWN - MHW	Pioneer/low-mid Marsh	ABPmer, 2002
Elevation	MHW - MHWS	Mid-upper marsh	ABPmer, 2002
Elevation	MHWS - HAT	Strand line/upper saltmarsh transitions	ABPmer, 2002
Exposure	fetch	All	ABPmer, 2002
Proximity (not a major factor)	Similar habitat next door to site / Max distance 88Km	Invertebrate migration / bird population transfer	ABPmer, 2002

CONTENTS

EXECUTIVE SUMMARY: REPORT I	v
CONTENTS	viii
1.0 Introduction	1
1.1 Context.....	1
1.2 Drivers for managed realignment and hence site selection	1
1.3 Project purpose	2
2.0 Methods	3
2.1 Collation of present site-selection criteria and procedures	3
2.2. Review of criteria relevant to growth and establishment of natural saltmarsh and intertidal habitats.....	4
2.3. Synthesis – the logic and tool design process.....	4
3.0 Summary of overview of present site selection criteria and procedures	6
4.0 Introduction to the habitat types that are highlighted for creation (Saltmarsh, Mudflat, Zostera)	10
4.1 Introduction.....	10
4.2 General description and importance of salt marshes	10
4.3 General description and importance of sand and mud flats.....	12
4.4 General description and importance of eelgrass beds.....	13
5.0 A summary of the criteria for growth of natural saltmarsh and intertidal habitats	15
5.1 Review of Physical Processes.....	16
5.1.1 Hydrodynamics	16
5.1.1.1 Tidal levels and inundation.....	16
5.1.1.3 Tidal currents	18
5.1.1.4 Wave climate	18
5.1.1.5 Freshwater and drainage flows	19
5.1.2 Sediment	19
5.1.2.1 Erosional characteristics	19
5.1.2.2 Depositional characteristics	19
5.1.2.3 Other factors	20
5.2 Review of Chemical Processes	20
5.2.1 Biogeochemistry	21
5.2.1.1 Nutrients.....	21
5.2.1.2 Physico-chemical parameters	21
5.3 Review of Ecological Processes	25
5.3.1 Salt marsh	25
5.3.2 Mudflat and sand flats.....	26
5.3.3 Eelgrass beds.....	28
6.0 Conclusions	30
7.0 Bibliography	34
APPENDIX 1: Review of present site selection procedures and criteria	47
4.0: Synthesis	86
APPENDIX 2: Review of biological, physical and chemical processes affecting habitat creation of saltmarshes, mudflats and Zostera beds	90

List of Figures:

Figure A1: Elevation map of Orplands managed realignment site, Blackwater...	55
Figure A2: Decision tree for scheme selection (Halcrow, 2002)	57
Figure A3: Process for selecting a suitable site for breach retreat (Burd, 1995)...	68
Figure A4: Elevations, slopes and habitat types predicted to occur on managed retreat saltings (Burd, 1995)	70
Figure A5: The CHaMP planning cycle (from Solent CHaMP, 2003).	71
Figure A6: Potential habitat creation areas (Solent CHaMP, 2003).....	74
Figure A7: Intertidal habitat creation potential and estimated loss by 2100 (Solent CHaMP, 2003).....	75
Figure A8: The relationship between the flood and coastal defence process and archaeological evaluation and mitigation procedures (English Heritage, 2003).	82
Figure A9. Distribution map of <i>Zostera marina</i> from Preston <i>et al</i> (2002).....	148
Figure A10. Distribution map of <i>Zostera angustifolia</i> from Preston <i>et al</i> (2002)..	149
Figure A11. Distribution map of <i>Zostera noltii</i> from Preston <i>et al</i> (2002)	150
Fig. A12 Decision flow diagram for site selection for seagrass restoration (Campbell <i>et al.</i> (2000).....	157

List of Tables:

Executive summary

Table A: A summary of the criteria and thresholds relevant to habitat creation as derived from scientific reviews.	iv
Comments and References.....	iv
Table B: Summary table of presently used criteria and thresholds relevant to habitat creation.	vii
Executive summary.....	ix
Table 1: Summary table of presently used criteria and thresholds relevant to habitat creation.	9
Table 2: Example UK managed realignment and habitat creation site information.	17
Table 3: Summary of criteria and threshold relevant to habitat creation as derived from the reviews.....	31
Comments and References.....	31
Table A1: Mean height (mMHWS) of occurrence of each habitat type in the Humber estuary (EA, 2000)	52
Table A2: Derived heights (mMHWS) of the boundaries between adjacent vegetation zones in the Humber Estuary (EA 2000).....	52
Table A3: Sample score sheet for site assessment criteria (Halcrow, 2002).....	58
Table A4: Assessment criteria – additional information (Halcrow, 2002).	59
Table A5: Salt marsh regeneration and managed realignment site selection criteria (Halcrow/EA, 2003).	60
Stage 1: Geographical Site identification (land elevation mapping).....	61

Table A6: Tidal levels used to discriminate habitat boundaries (from Coutts and Roberts, 2003).....	62
Table A7: Environment Agency’s Criteria for Identifying and Evaluating potential sites for managed realignment.....	64
Table A8: Secondary Assessment Matrix (Roberts and Coutts, 2003).....	66
3.2 English Nature.....	68
Criteria.....	82
Table A9: Summary table of presently used criteria and thresholds relevant to habitat creation.	89
Table A10: Notes on colonisation by salt marsh biota at some managed realignment sites	107
Table A11. Average Percentage Slope on the East Anglian Coast (EA data)	133
Table A12 Summary of some UK Sites containing areas for mudflat creation or recharge schemes which were monitored to some degree for invertebrates.....	136
Table A13. Biotopes typical of intertidal mud and sandflats.....	140
Table A14. Typical infauna found in intertidal sandflats according to their exposure, and in intertidal mudflats (sheltered areas).....	143
Table A15. Habitat requirements for the 3 species of <i>Zostera</i>.....	151
Table. A16 Class ranges of several factors used to make GIS maps for site selection for suitable transplantation sites for <i>Zostera marina</i> in the Netherlands.	158
Table A17. Factors that may affect <i>Zostera</i> bed recovery.....	159

1.0 INTRODUCTION

1.1 Context

The value of saltmarsh, seagrass beds and intertidal mudflat habitats is well recognised. Saltmarsh and intertidal mudflats provide essential habitat for fish, birds and infauna, food for birds and fish, have a significant function biogeochemically in the context of nutrient attenuation and storage (Jickells et al., 2001) and are important ecological systems within an estuary supporting wider fisheries interests (Colclough et al., 2004). Costanza et al., (1997) have argued that nutrient cycling, especially from intertidal and saltmarsh areas, represents the major environmental service from coastal areas. However, most importantly with respect to flood and coastal defence, saltmarshes buffer significantly wave energy, affording valuable coastal defence (Möller et al., 1996; 1999; 2003).

Creation of managed realignment areas is recognised to be a viable and cost-effective solution to habitat loss from a flood and coastal defence and habitat creation point of view. The success of many schemes is well publicised but the perceived failure of others requires improved understanding of the complex processes involved in habitat creation and of the interaction of the schemes with local and regional issues. Key concerns of estuary and coastal managers include the pre-existing physical, chemical and biological characteristics of a site and interactions between them, and the success of created habitat, assessed in terms of the establishment and continuing health of the restored ecosystems.

Areas of reclaimed land have significant economic value as part of a flood defence scheme, as well as considerable importance as habitats. The site objectives, selection process and drivers that managers need to consider in selecting a site, are complex and will influence the habitat type and quality created³.

1.2 Drivers for managed realignment and hence site selection

The drivers for managed realignment have been identified and discussed at length in many previous and present project reports (ABP, 1998; DEFRA/EA, 2002; CIRIA; 2003) and are not repeated here. However, it is worth summarising the main reasons behind the search for a prospective site, because this will often form a basis for site-selection procedure and affect the priority given to various criteria used.

Regarding the need to create a habitat, four main drivers have been identified, more than one of which may occur at the same time ;

1. Mitigation for a development where habitat will be lost;
2. Compensation for natural habitat loss (perhaps related to coastal squeeze and sea-level rise);
3. Compliance with the EU Habitats Directive (or other directives);

³ The prediction of habitat quality is of clear relevance when looking at habitat creation. However, estimation of habitat quality is complex and can alter depending on the main drivers behind habitat creation. The issue of quality is not dealt with in this project but discussed in full in the complementary project FD1918: Habitat quality measures and monitoring protocols.

4. Cost-effective flood defence strategy for a particular area.

These distinctions are important, as habitat creation is the specified aim of the first three drivers, but it is often of lower priority for the fourth even though habitat creation will potentially be an indirect benefit and possible future aim.

The overview of how sites are identified within an estuary by any of the main management organisations is generally co-incident with a strategic perspective of the four main issues listed above. Hence, identification of sites may be in line with all or some of the main plans and policies managers may be following. Managed realignment is mainly addressed today on an individual site basis but usually within a wider framework of strategic plans (Shoreline Management Plans (SMPs), Coastal Defence/Flood management Strategies (FMS), Estuary Management Plans, Coastal Habitat Management Plans (CHaMPs) and Biodiversity Action Plans (BAPs)). A full review of each of these types of plan and policies and their recommendations in terms of site selection for managed realignment is given in a CIRIA report (CIRIA; 2004).

In combination, these strategic plans give a large-scale approach, and sites may be selected according to a combination of criteria of which habitat creation may only be one. Each of these plans is drafted regionally and the approaches taken within and between agencies and end-users can vary. However, there is a clear need for suitable decision making tools that can be used to take a more strategic overview nationally and regionally, on an estuary wide scale. Alongside assessment of potential site suitability there needs to be an estuary wide assessment of the impacts of managed realignment.

However, outcomes of such habitat creation schemes are not always predictable and there is a clear need for a framework to make the site selection and decision process more transparent and with better prediction capabilities in terms of type of habitat created. Clearly, to identify and select the key driving forces and criteria that dictate habitat creation is a complex task especially as the development of ecological communities in managed realignment is not a simple or linear process (Atkinson et al., 2001).

1.3 Project purpose

The overarching purpose of the work of this project is to improve considerations in the project planning process of the suitability of potential managed realignment sites for the creation of preferred habitat types e.g. mudflat, saltmarsh, or eelgrass beds.

Specifically, this research project is intended to bring together the present scientific understanding of physical, chemical and ecological criteria controlling habitat creation (namely saltmarsh, intertidal mudflat and *Zostera* beds) at coastal realignment sites and provide tools and guidance to engineers and managers to facilitate the selection of suitable sites within a given estuary or coastal location. Part of this is to provide a clear framework and auditable process to help guide decision making with respect to site selection.

To achieve this the main deliverables from the project are in the form of two reports, an influence diagram⁴ model and GIS demonstration:

- **Report I** (this report) includes reviews of present site selection procedures and scientific understanding of the criteria influencing the growth of natural saltmarsh and intertidal habitats.
- **Report II** covers the design and testing of two decision tools (a whole estuary GIS screening demonstration and site specific influence diagram model), which utilise the criteria and thresholds relevant to site selection, derived from the reviews.

2.0 METHODS

The overarching purpose of this project is to improve considerations in the project-planning process of the suitability of potential managed realignment sites for the creation of preferred habitat types e.g. mudflat, saltmarsh, or eelgrass beds.

This involved bring together the present scientific understanding of physical, chemical and ecological criteria controlling habitat creation (namely saltmarsh, intertidal mudflat and *Zostera* beds) at coastal realignment sites and provide tools and guidance to engineers and managers to facilitate the selection of suitable sites within a given estuary or coastal location. In doing so, this provides a clear framework and auditable process to help guide decision-making with respect to site selection.

To this end, activities were divided into review and tool-development components (Report I & II). The review process comprised 3 stages;

- collation of information on present site-selection criteria and procedures
- review of criteria relevant to growth and establishment of natural saltmarsh and intertidal habitats
- synthesis of this information to inform the requirements and design of the site-selection tools

In combination, these stages facilitated development of the decision tools to aid site selection and the criteria to be used with associated thresholds. Each stage is described below.

2.1 Collation of present site-selection criteria and procedures

Various site-selection procedures and criteria are presently used by estuary managers and prospective end-users of the decision tools. A collation was undertaken of existing procedures and criteria in order to assess the current guidelines and procedures used in site selection, the criteria used and how ecological factors related to habitat creation featured within these frameworks. In addition, there was an aim to determine those

⁴ An influence diagram is a simple visual representation of a decision problem. They provide a way of carrying out calculations on screen and identify and display the way essential elements in a decision process influence each other. This is more powerful than a decision tree, which requires a more linear process to decision making.

aspects of site selection and success description which were well accounted for and understood and where improvements could be made.

A review was conducted of case studies of sites selected for habitat creation, to collate the associated methodologies and criteria implemented by the main stakeholders. Relevant case-study literature was examined (e.g. site reports, monitoring reports, engineering reports, strategy documents, SMPs, CHaMPs etc) and meetings were held with representatives of stakeholder organisations, to provide an overview of present site-selection protocols and associated criteria. The review of documentation and site selection included sites that proceeded and those that didn't. Other interest groups were consulted or were otherwise engaged in the process, including: wildlife trusts, local and county councils and consultants, all of whom may carry out work on behalf of the main agencies or be involved in the consultation process.

The collated criteria and threshold information was summarised into a table (Table 1) to provide an overview of the ecological criteria and the study in which they had been applied. The data highlight the facts that some criteria are used on an estuary-specific basis, whilst others are of a geographically generic nature. The table also shows how extensive or restricted the ecological criteria used were, in terms of the type of parameters assessed. The various site-selection methodologies were compared for their approach, the nature of screening methods and the weighting process, to help inform requirements for the decision tools in terms of habitat-creation procedure and application (Sections 2.0 and Appendix I 4.0).

2.2. Review of criteria relevant to growth and establishment of natural saltmarsh and intertidal habitats

Reviews were conducted of the major physical, chemical and ecological processes and parameters relevant to intertidal habitat establishment and growth, with the overall purpose of identifying the important scientific processes and outlining those parameters that warrant consideration when planning habitat creation from a managed realignment scheme.

The reviews focussed on observations and knowledge gained from managed realignment trials performed in the UK, because they gave the best site descriptions in relation to the resulting habitat created. Reports of such trials also identify issues related to habitat quality, type and timescale of creation which need to be considered. This information was augmented with information from research on natural coastal and marsh systems, including relevant overseas examples. Section 4 and Appendix 2 presents the knowledge thus gained for the individual habitats: saltmarshes, mudflats and eelgrass beds. The influence of each parameter on saltmarsh, mudflat and eelgrass habitats was considered so that a list of suitable parameters could be selected for use in the decision tools as site-selection criteria (See Report II). Not all parameters reviewed and outlined in this report became suitable as criteria for the decision tools.

2.3. Synthesis – the logic and tool design process

Information gained from the above two activities was then synthesised to inform the development of the GIS and influence diagram site-selection tools. The full draft list of criteria was screened and prioritised using expert judgement, which included consideration of the availability of quantitative evidence of their relative importance in

control of habitat creation. A final list of criteria was defined with, where possible, supporting references for the quantitative thresholds, as evidence for the thresholds and their specificity (Table 3, section 5.0).

The result of the review of methodology was used, together with stakeholder feedback, to develop the structure of the influence diagram and associated GIS screening site-selection tools. Issues included the consideration of, for example, how end-users approached site selection and what their priorities were for overall site requirements and transparency of the process. From this were determined the flexibility required in the definition of each criterion threshold (e.g. thresholds of elevation are different for different estuaries) and the relative weighting applied to each criterion. This process identified the need to predict the potential area of habitat area and also to incorporate options which allowed different weighting of parameters and criteria in relation to changing site requirements, as well as taking into account the confidence in the prediction, related generally to data quality, associated with each site. This process and the resulting structure and features of the Influence Diagram tool are described more fully in section 3.0 of report II.

3.0 SUMMARY OF OVERVIEW OF PRESENT SITE SELECTION CRITERIA AND PROCEDURES

This review (in full in Appendix 1) is designed to assess the current guidelines and procedures for site selection, the criteria used and how habitat creation features within this framework. In addition there is an aim to determine those aspects of site selection which are well accounted for and understood and where improvements could be made. The decision tools developed as part of this project need to sit within the coastal strategies in place at present and therefore an overview of the range of approaches to site selection taken at present is essential.

The overall aim is to try and bring knowledge and understanding ('best practise') on site selection together and through this entire project help deliver an approach which could be implemented by many end-users and provides a clear and transparent audit trail towards a decision and site selection.

The approach taken was to review the protocols implemented by main stakeholders in site selection and the criteria used. This was undertaken by examination of relevant literature (site reports, monitoring reports, engineering reports, strategy documents, SMPs, CHaMPs etc) and also meetings with representatives from stakeholder organisations. This was designed to provide an overview of present protocols and criteria used in site selection.

The criteria used at present by 3 main organisations (the EA, EN, and the RSPB) involved in implementing schemes are outlined in the full review in Appendix 1. Other interest groups which were consulted or involved were: wildlife trusts, local and county councils, consultants all of whom may carry out work on behalf of the main agencies or be involved in the consultation process. The information has been compiled using reports / publications and following discussions with relevant personnel within each organisation. An overview of the present procedures and strategy involved with site selection by these organisations and overall conclusions are summarised here.

This consultation process has also informed requirements for the decision tools in terms of habitat creation procedure and application.

The overview of present site selection criteria across various agencies and potential end-users of the decision tools (Appendix 1) has given some examples of the approaches being implemented and the emphasis and priorities when selecting sites. It also helps to set this project (FD1917), which is focused clearly on the creation of various intertidal habitats in context of procedures that are ongoing. Several observations can be made given this overview:

Between and within various agencies there are many initiatives concerned with identifying and selecting sites for potential managed realignment. These may be driven by different policies or strategies but generally the approaches and criteria employed have much commonality. For example:

- They generally involve a more generic screening/coarse filtering/primary matrix stage to create a short list of sites which are then examined more closely with a

more detailed approach (for example: Atkins, 2002; Binnie Black and Veatch, 2000; HESMP, 2000)

- The site selection approaches implemented have many criteria in common and are generic in nature covering all potential aspects of site selection, not only the environmental but also economic, social and political (HESMP, 2000). The environmental criteria relevant to habitat creation identified from the present site selection overview are presented in Table 1.

A number of the approaches involve the use of matrices or multi-criteria analysis to rank sites against the generic criteria (Halcrow/EA, 2003; ABPmer, 2002; Coutts and Roberts, 2003). In each case, although the criteria may be similar the exact approach taken to give an overall ranking is different not only in the combination of scores but also in the methodology to derive those scores/thresholds. In many cases apart from elevation/tidal inundation the scores and thresholds are qualitative rather than quantitative (For example: Binnie Black and Veatch, 2000).

The weighting/scoring of various criteria can vary depending on the main driver for site selection (mitigation/compensation, flood and coastal defence etc). For example, conservation agencies may weight the environmental criteria for habitat creation or bird usage more highly than stakeholders who are looking for sites for flood and coastal defence. In this way sites can be ranked differently depending on FCD/habitat creation priorities and also for their purpose.

However, at present the main controls on site selection are not always the type of habitat to be created, as is the purpose of this project. Site selection is far more pragmatic and other overriding factors such as land purchase or other socio-economic factors may have higher priority in the viability of a site than environmental concerns. It is clear that priorities in terms of site selection and habitat creation for different stakeholders and locations can vary (flood and coastal defence, mitigation, compensation etc.). Although to some extent, scheme design may be able to create site conditions suitable for habitat creation, if in future the habitat type and quality created at a site becomes paramount in terms of the selection of compensation or mitigation schemes the ecological understanding of site controls on habitat creation will need further development.

It was clear that some of the issues addressed by various initiatives on site selection are relevant to the decision outputs of this project such as; weighting of criteria, assessment of criteria over a large area i.e. description of slope/topography, elevation (from LiDAR data but screened to remove upper and lower 95%ile), issues of uncertainties of a criteria, data availability, timescale of recovery etc. are all relevant to consistency in site selection within any decision tool and have been carried forward within this project in drafting of the GIS and influence diagram decision tools (Report II).

There is a benefit in bringing all these various approaches and ranking systems together in terms of common criteria, methodology and scoring so that for those schemes where habitat creation is a key consideration, the potential can be assessed in the light of all available knowledge and experience. It should be possible to produce a single set of parameters (appropriately weighted) from analysis and discussion of the various initiatives that are being implemented at present by various agencies or groups. Given a

common approach then site selection with different priorities can be compared. Within the Environment Agency in particular there is apparently no overarching national strategy for site selection within the context of SMPs or common protocols for site selection and this would be worthwhile. Standardisation of site selection processes will also aid site prioritisation regionally or nationally in terms of funding needs.

It is clear that the focus of this project on site suitability purely for habitat creation type will fit well into the wider strategic framework of coastal and shoreline management and also in the context of other projects such as;

- FD1918: Habitat quality measure and monitoring protocols
- FD2413: Guidance on design and implementation of managed realignment (CIRIA, 2004: Design issues for managed realignment)
- English Nature/Living with the Sea project: coastal habitat restoration guide
[http://www.english-nature.org.uk/livingwiththesea/project details/good practice guide/habitatcrr/ENRestore/Habitats/Index.htm](http://www.english-nature.org.uk/livingwiththesea/project%20details/good%20practice%20guide/habitatcrr/ENRestore/Habitats/Index.htm)

The GIS approach and decision tool (Report II) could easily be expanded to give a more generic screening tool in terms of other socio-economic factors as determined by the various matrix approaches implemented by different agencies and which could lead to standardisation of site selection across the board. The approach adopted in this project and the overview provided from present site selection review provide the basis for a more generic selection tool which could be applied by any end-user and could deal with changing priorities in site selection.

Table 1: Summary table of presently used criteria and thresholds relevant to habitat creation.

Criteria	Threshold	Habitat	Reference
Contaminated land	Presence/absence	Saltmarsh	Halcrow/EA, 2003
Site elevation	2-3 m OD	Saltmarsh	Halcrow/EA, 2003
Site elevation	<1 m OD	Mudflat	Halcrow/EA, 2003
Site elevation	1-2m OD	Transitional	Halcrow/EA, 2003
Surface soils	Clay/Clay loam	Saltmarsh	Halcrow/EA, 2003
Site gradient	1-2% (< 1 :50)	Saltmarsh	Halcrow/EA, 2003
Wave-exposure	% of estuarine length	Saltmarsh/ mudflat	Halcrow/EA, 2003
Height boundaries	-0.49 (m MHWS OD)	Mudflat – saltmarsh	Humber observations; EA, 1998.
Height boundaries	-0.1 (m MHWS OD)	Pioneer marsh – Mid marsh	Humber observations; EA, 1998.
Height boundaries	-0.06 (m MHWS OD)	Mid marsh – Upper marsh	Humber observations; EA, 1998.
Height boundaries	0.03 (m MHWS OD)	Upper marsh – Brackish marsh	Humber observations; EA, 1998.
Height boundaries	0.31 (m MHWS OD)	Brackish marsh – Grassland	Humber observations; EA, 1998.
Salinity, water velocity, sedimentation/ erosion patterns, physico-chemico soil characteristics, wave exposure, coloniser availability	Qualitative	All	Binnie Black and Veatch, 2000; Burd, 1995; Burd et al., 1994.
Potential to improve environment – topography	Scoring 0 – 5	Saltmarsh, intertidal mudflat	Halcrow/EA, 2002
Topography/elevation (OS heights OD)	MLW: 0m OD	> intertidal mudflat	Atkins, 2002; Coutts and Roberts, 2003.
Topography/elevation (OS heights OD)	MHWN: 1.5m OD	< intertidal mudflat, > saltmarsh.	Atkins, 2002; Coutts and Roberts, 2003.
Topography/elevation (OS heights OD)	MHWS: 2.0m OD	< saltmarsh	Atkins, 2002; Coutts and Roberts, 2003.
Topography/elevation (OS heights OD)	HAT: 2.5m OD	> upper level of saltmarsh in 80yrs	Atkins, 2002; Coutts and Roberts, 2003.
Is there a history of pollution or contamination on the site?	History to no history Score –2 to +2.	All	Atkins, 2002; Coutts and Roberts, 2003.
Inundation	400-500 times per yr	Saltmarsh	Burd, 1995
Inundation	>500 times per yr	Mudflat	Burd, 1995
Slope	1-2%	Greatest diversity	Burd, 1995
Fetch	<1000ft	Affects accretion	Burd, 1995
Elevation	<MLWN	Mud/sand flats – Eelgrass	ABPmer, 2002
Elevation	MLWN - MHW	Pioneer/low-mid Marsh	ABPmer, 2002
Elevation	MHW - MHWS	Mid-upper marsh	ABPmer, 2002
Elevation	MHWS - HAT	Strand line/upper saltmarsh transitions	ABPmer, 2002
Exposure	fetch	All	ABPmer, 2002
Proximity (not a major factor)	Similar habitat next door to site / Max distance 88Km	Invertebrate migration / bird population transfer	ABPmer, 2002

4.0 INTRODUCTION TO THE HABITAT TYPES THAT ARE HIGHLIGHTED FOR CREATION (SALTMARSH, MUDFLAT, ZOSTERA)

4.1 Introduction

The reviews of salt marshes, sand and mud flats, and eelgrass beds describe important factors known to be necessary for the growth and survival of salt marsh plants, mudflat organisms and eelgrass beds, some of which are key parameters that need to be considered in selecting a site for creation of these habitats. The full text of these reviews is in Appendix 2 for completeness, but some general background information on salt marshes and mudflats (taken from Brown and Cox, 2001), and eelgrass beds is given in the following sections.

4.2 General description and importance of salt marshes

Coastal salt marshes are vegetated areas bordering saline water, subjected to periodic flooding by the tides. Salt marshes develop on sheltered, low energy coasts where fine sediment accumulates. The vegetation of salt marshes develops between approximately MHWN tides (Mean High Water Neap) and high spring-tide levels, and is usually fronted by mudflats. Salt marshes are now recognised as a key natural resource playing a vital role in coastal defence and in wildlife conservation, and they provide an important source of organic material and nutrients that support adjacent marine communities. They can also function as a sink for various environmental pollutants, many of which may accumulate in the sediments and be taken up by salt marsh plants. If the sediments are reworked some pollutants can be re-mobilised and re-enter the environment.

Coastal salt marshes have been classified into 5 different types according to their physical setting (Allen and Pye1992): embayment marshes; open coast marshes; estuarine fringing marshes; back-barrier marshes and; loch or fjord-head marshes. In the UK, for example, all these types can be found. Estuarine marshes: almost all UK estuaries have salt marshes, e.g. Humber, Thames, Severn; Embayment marshes: many harbours on the south coast such as Poole Harbour, also The Wash and Morecambe Bay; Open coast (less common in the UK): Dengie Peninsula, Essex; back-barrier marshes: north Norfolk; Loch/ fjord-head marshes: northwest Scotland.

Emergent plants on salt marshes are tolerant to salt (halophytes). Differences in tolerance to tidal inundation (submergence) and associated factors by salt marsh plant species results in bands of vegetation at different levels on the marsh (zonation). The vegetation of the salt marsh traps and stabilises sediment, protecting against erosion by storms.

The vegetated salt marsh is fronted by mudflat, on which the main plants are microscopic algae such as diatoms, although in some areas eelgrass (*Zostera* spp.) is found. Salt marshes and associated mudflats are highly productive ecosystems, important as habitats and source of food for a variety of marine and terrestrial animals. Primary production comprises the vascular saltmarsh plants, macroalgae,

phytoplankton and benthic microalgae. The contribution of algae and vascular plants to primary production varies seasonally in temperate regions, but the contribution by the microphytobenthos (benthic microalgae such as diatoms) that cover the surface of the intertidal flats for much of the year can be much higher than that of the halophytic salt marsh vegetation (e.g. work by Sagan in Mont Saint Michel Bay, in Brown *et al.* (in press)). Numerous invertebrates and birds graze diatoms that live on the mud surface. Most of the vascular plant material is converted to detritus, which forms the basis of a detrital saltmarsh food web, in which the decomposer microorganisms convert the detritus into a suitable food source for detritus consumers.

Salt marshes provide a nursery area for juvenile fish, nesting sites for breeding birds, and are used by a variety of small mammals such as rabbits, hares, and rodents. Terrestrial insects and spiders are abundant on salt marsh vegetation. The salt marsh is used as a source of food by wildfowl, and the mudflats harbour many invertebrates and are important feeding grounds for waders. Many estuaries and salt marshes support nationally and internationally important numbers of shorebirds. Substantial loss of salt marsh and associated mudflats on bird migration routes is likely to have a major impact on bird populations.

Seals use salt marsh creeks and marsh edges; for example, common seals are regularly seen in the Wash and on the Lincolnshire coast in the UK.

A variety of economic activities occur on salt marshes, although many of the traditional uses are now declining. The most common use is livestock grazing, which has been important historically in shaping the composition of the flora. Shellfish culture (mussel beds and oyster farms) is another activity that is important in many UK and other European sites.

Salt marshes can be lost through reclamation for agricultural land or for industrial and leisure developments, and they are increasingly being affected by rising sea levels.

Salt marshes are either of natural origin, or have been created by man as a result of sedimentation works, such as polders in the Netherlands. Both natural and man-made salt marshes have often been embanked, so that they cannot move inland in response to sea level rise (coastal squeeze). In Great Britain, the total area of salt marsh is approximately 44,370 ha (Burd, 1989), but an estimated 100ha of salt marsh is being lost every year.

4.3 General description and importance of sand and mud flats

Where sites are too low in the tidal frame for salt marsh vegetation to grow (generally >500-600 tidal inundations per year), but where there is sufficient width of intertidal sediments, intertidal sandflats or mudflats can be created. The structure of the benthic community that develops (epifauna and burrowing infauna, both macrofauna and meiofauna, with various feeding strategies e.g. deposit feeding, suspension or filter feeding, carnivores) is influenced by various interrelated factors including the hydrodynamic conditions (tidal currents and wave action) and resulting substrate type, which in turn will determine factors such as substrate mobility, suspended sediment load, sediment organic content and redox potential, and so on. Where there are suitable surfaces for attachment, mussel beds may develop. Shore level (elevation), fresh water inputs and salinity also affect community type and distribution. These physical and chemical factors combined with biotic factors such as competition, predation, larval settlement, mobility and mortality of juveniles, act together to produce a complex picture (Little 2000).

The fauna must withstand changes in salinity and problems of desiccation; there are many burrowing forms of invertebrates that can escape desiccation at low tide. The sediments are inhabited by meiofauna (e.g. nematodes, ostracods, copepods) and larger macrofauna (including molluscs, various small crustaceans, polychaetes and oligochaetes). The microphytobenthos and mudflat fauna make these environments extremely important feeding grounds for both resident and migrant birds.

Sandflats are characteristic of more wave-dominated environments than mudflats, which occur on coasts sheltered from wave action where fine particles can settle. Clay particles in seawater form flocs, increasing the settling rate compared with that of individual particles, and extracellular mucoid substances produced by diatoms, worms and molluscs also help to bind the sediment once it is deposited. Cohesive sediments on mudflats are therefore relatively stable, requiring greater tidal velocities to erode them than is needed to shift unconsolidated sand (Little 2000).

In general, intertidal mudflats and sheltered sandflats with shallow gradients reflect low energy conditions which are characterised by particles of small to medium diameter, shallow slope, high water content, high sorting coefficient, low permeability and generally low porosity, high organic content and therefore high reducing conditions, high carbon to nitrogen ratio, high microbial population and high sediment stability (Elliott *et al.* 1998).

Land-claim for agriculture and industry in Britain has removed considerable areas of mudflat (and salt marsh) and losses of coastal and estuarine wetlands to land-claim have been estimated as between 25 and 50% (Davidson *et al.* in Jones 1995). In the Tees estuary, developed for industry and port facilities, the 2740ha of mudflats and salt marsh existing in the 1850s was reduced to 470 ha by the 1970s (Davidson *et al.* 1991). Reductions in intertidal area alter the tidal regime and reduce productivity and bird feeding areas, with possible consequences to fish and bird populations (Little 2000). Sea level rise will add to the losses of intertidal areas and it is likely that creation of mudflats as well as salt marshes will become increasingly necessary to conserve these important productive ecosystems.

Whereas some site features can be improved to encourage salt marsh development, including the possibility of contouring a site to encourage establishment of particular vegetation communities within the salt marsh zonation, there seems to be less scope to engineer sites selected for intertidal flat creation, except to ensure that the elevation and site profile is suitable. Areas selected for intertidal flat creation will develop according to local conditions and the type and amount of sediment that will accumulate on the site. The benthic community types that will establish will depend upon prevailing conditions such as exposure, position on shore, substrate type and salinity.

4.4 General description and importance of eelgrass beds

The UK Biodiversity Action Plan for seagrasses recognises the need to restore areas of *Zostera* beds, many of which have not recovered well from wasting disease several decades ago. Large-scale transplantation trials have been carried out around the south coast of England, but with little success in the long-term. As yet there appear to be no examples of managed realignment sites that have included creation of habitat suitable for eelgrass in their objectives, but this may be considered in the future.

Eelgrasses are marine flowering plants of sheltered environments anchored to shallow subtidal and intertidal sands and muds by a rhizome and root system, often growing in extensive beds and providing shelter, nursery areas, and food web support for a numerous organisms, including crustaceans and juvenile commercial fish species. They also provide and feeding grounds for over-wintering wildfowl, particularly Brent geese and wigeon, and food web support for waders. In higher energy environments the beds tend to be smaller and patchier. Eelgrass beds are productive and an important source of organic matter to the detrital food web. The root networks increase sediment stability, reducing erosion (Fonseca and Fisher 1986, Gambi *et al.* 1990), while the canopy buffers water movement, reducing current flow and trapping suspended sediment and organic particulates. Seagrasses also help to maintain water quality as the canopy and epiphytic algae scrub nutrients and toxins from land run-off (Lee Long and Thom, 2001). The ecological value of eelgrass beds results in economic benefits: stabilization of foreshore topography lowers costs of foreshore protection; water quality maintenance and support of recreational fisheries helps to maintain tourism economies; and nursery habitat for commercial fish populations helps to support fisheries economies (Lee Long and Thom, 2001). Eelgrass beds are therefore of considerable economic and conservation importance (Davison and Hughes 1998), but have unfortunately undergone significant declines due to human pressures and a severe outbreak of wasting disease in the 1930s, and to a lesser extent in the 1980s, affecting particularly the common eelgrass, *Z. marina*. Substantial declines were recorded on the East Anglian and north Kent coasts and around the Solent (Butcher 1934, 1941). It has recovered quite well in the Solent, but seems to have remained rare elsewhere in the southeast. The fungal pathogen (*Labyrinthula macrocystis*), responsible for causing the loss of over 90% of *Zostera marina* beds in the 1920s and 1930s (according to the UK Marine SACs project website: www.ukmarinesac.org.uk) and may persist as a low-level parasite subject to periodic population explosions, which was particularly large in the 1930s (Tubbs 1995). The factors triggering the disease epidemics are not fully understood, but plants may be more susceptible when stressed by some environmental factor such as increased water temperatures, low light levels, or pollution (Short *et al.* 1988).

There are three species of *Zostera* in the UK, common eelgrass *Z. marina*, narrow-leaved eelgrass, *Z. angustifolia*, and dwarf eelgrass, *Z. noltii*. *Z. marina* shows morphological variation with a decrease in leaf size and density upshore (Rodwell 2000) and may be confused with *Z. angustifolia*. Because *Z. angustifolia* is not consistently distinguished from narrow-leaved forms of *Z. marina*, it is often regarded as a variant of *Z. marina* outside the UK, but here they are treated as distinct species, first described as *Z. hornemanniana* by Tutin in 1936 (Tutin 1942). On the shore, *Zostera angustifolia* and *Z. noltii* often occur in the same zone, but according to the sediment drainage characteristics, with *Z. noltii* on the hummocks or ridges and *Z. angustifolia* in hollows that retain standing water at low tide. *Z. marina* inhabits the lower zone of the three species. Although once abundant and widespread around the coast, all three UK species are now classed as nationally scarce (Stewart *et al.* 1994). Seagrass beds are a high priority for conservation measures in the UK (Davison and Hughes 1998). In the NVC classification (Rodwell 2000) *Zostera* communities are designated as NVC Salt Marsh Community SM1: *Zostera* communities. Notes on NVC classification for *Zostera* and salt marshes are given in Appendix 2.

Short *et al.* (2001) provide a useful overview of the many parameters critical for the occurrence of seagrasses in general (including *Zostera* spp.). These comprise physical parameters that affect physiological activity (temperature, salinity, waves, currents, depth, substrate, day length), natural factors that limit photosynthetic activity (light, nutrients, epiphytes, diseases), and anthropogenic inputs such as nutrient and sediment loading. More detail on these is given in the Appendix, but the critical factors for site selection are summarised below. Methods for the measurement of physical parameters, sediment characteristics, and light and water quality, which may be necessary for site selection, sampling and monitoring techniques, and management measures to improve habitat quality, can be found in various chapters in Short and Coles (2001). However, once the appropriate basic conditions of water depth/surface elevation and substrate type of a potential site are known, the best guide to whether there is a good chance for successful establishment of *Zostera* is the presence of existing beds in the region of the proposed site (see section on site selection).

5.0 A SUMMARY OF THE CRITERIA FOR GROWTH OF NATURAL SALTMARSH AND INTERTIDAL HABITATS

The following three sections outline separately, summary reviews for physical, chemical and ecological processes. They aim to summarise the scientific processes of importance and outline the parameters that warrant consideration when planning habitat creation from a managed realignment. Clearly the physical, chemical and ecological processes are inter linked and consequently some parameters appear in more than one section below, but have been left as such to demonstrate this linkage.

The reviews focus on observations and knowledge gained from UK managed realignment trials with information from natural marsh research only being used for some parameters. Appendix 2 presents the integrated knowledge for the individual habitats: saltmarshes, mudflats and eelgrass beds.

The influence of each parameter on saltmarsh, mudflat and eelgrass habitats was then considered so that a list of suitable parameters could be selected for use in the decision tools (See Report II). Not all parameters reviewed and outlined in this report became suitable as criteria for the decision tools.

When considering the parameters of importance the following points are worth noting:

- The scientific knowledge of these complex habitats involves some uncertainty;
- Dynamic nature of the habitats: the inter-tidal habitat systems created from managed realignment are dynamic in nature with complex feed back mechanisms. For example, knowledge of the effect of temporal changes in individual parameters (i.e. incident wave conditions, water depths / tidal elevations, pollution, vegetation cover) is unknown. In particular the possible effects of very high values of individual parameters at low frequency of occurrences (i.e. storm surges) on the sustainability of inter-tidal habitats is presently, to a large extent, not available. Likewise the effects of very low values of a number of contaminants over a long time are not known;
- Timescales: different parameters will influence the systems over different timescales. There are clearly annual variations related to the seasonal vegetation/sedimentation cycle, but there are also longer term changes in the relative importance of individual parameters brought about by changes in the physical, biological and chemical characteristics of the habitat over several years / decades;
- Access to potential sites or to appropriate data sets may always be possible for a variety of reasons including consent and cost.

5.1 Review of Physical Processes

In respect of Managed Realignment, issues associated with physical processes fall into two broad categories: hydrodynamics and sediment. Each of these categories is discussed in turn in the following section.

5.1.1 Hydrodynamics

Hydrodynamic processes can be categorised into the following sub-areas:

- Tidal levels and inundation;
- Tidal currents;
- Wave climate;
- Freshwater and drainage flows;

Salinity, as well as influencing the hydrodynamics, also plays a significant role in determining the creation of habitat, and is covered in the sections reviewing chemical and ecological processes.

5.1.1.1 Tidal levels and inundation

The topography of the realignment site, and the tidal levels adjacent to it are a key factor in the determination of the habitat to be created, and one of the principal issues to be considered at the planning stage of a habitat creation scheme. The degree of inundation of the site by the tidal waters (together with other factors) will determine the habitat that will be created and evolve, both in the short and long term.

In simple terms, the height of the realignment site relative to (varying) tidal range is used as a measure for first approximation of the areas of the site that will turn into mudflat and saltmarsh. Simplistically, saltmarsh colonises those areas that are between the mean high water neap tide mark and the mean high water spring tide mark, with areas lower than this (that drain) turning into mudflat.

The actual processes of inundation, however, are complicated by factors such as the slope of the site, the complexity of the topography (e.g. the degree of creek formation, and stability of the ground to form creeks), and the way in which the site is allowed to inundate. Inundation is typically carried out by simply breaching the seawall although more elaborate schemes may be considered including regulated tidal exchange (e.g. the alternative feeding grounds for birds developed in association with the Cardiff Barrage Scheme), or even complete removal of the seawall. The position, width and sill height of the breach will determine the degree of exchange of tidal water, and thereby potentially affect the habitat that is created.

In some instances, the site is well suited for other reasons (e.g. in the case of a compensation scheme for impact due to a development, proximity to the development is often a significant factor) although the topography of the realignment site may not be appropriate for the type of habitat that is required to be created for compensation. In this case action may be taken to raise (or lower) the site in order to achieve the required degree of inundation. Similarly, creeks may be constructed to improve drainage. In the case of mudflat creation, the topsoil of the site may also be removed (or soil added) as a means of speeding up the creation process.

In the case where suspended sediment concentrations are high, following breaching the site may *warp up* quite rapidly, thereby changing the degree of inundation.

Table 2 below summarises information on the inundation of various managed realignment and habitat creation sites in the UK. The degree of inundation has been calculated using a simple model which considers the basic information that may be readily to hand (mean level, slope of land, and tidal information). Clearly, the actual degree of inundation will depend on the complexity of the various processes, for which it may be necessary to undertake comprehensive modelling studies.

Table 2: Example UK managed realignment and habitat creation site information.

Place	Mean height of field/site (mCD)	Range in height of field/site (mCD)	Mean water level (mCD)	Number of wet tides per year ⁺	% of time wet ⁺	Datum	Size of field/site (ha)
Orplands	4.7	3.4 - 5.9	2.72	234	5	Bradwell	40
Tollesbury	3.7	3.2 - 4.2	2.72	730	31	Bradwell	21
Abbot's Hall*	4.2	2.2 - 6.2	2.72	580	17	Bradwell	40
Northey Island	5.2	4.5 - 5.0	2.68	0	0	Osea Island	2.7
Shellhaven - Site X	4.5	3.5 - 5.5	3.19	730	29	Coryton	78
Shellhaven - Site A	4.6	3.3 - 5.8	3.19	730	28	Coryton	33
Parkstone	2.1	1.2 – 3.0	1.58	190	5	Poole Harbour	0.65
Shotley (pre-placement)	1.3	0.7 - 1.9	2.09	730	73	Harwich	3.01
Shotley (post-placement)	3.0	Relatively flat	2.09	660	23	Harwich	3.01
Paul Holme Strays (Humber)	5.9	5.1 - 6.7	4.23	564	19	Hull (King George Dock)	83
Saltram	4.7	4.2 - 5.2	3.32	494	15	Turnchapel	5

* Abbot's Hall comprises four sites – information shown is for the largest site

⁺ estimated by consideration of the four main tidal constituents, and refers to the mean height of the site

5.1.1.2 Gradient

In order to encourage adequate drainage, and provide conditions for the development of the range of salt marsh communities from pioneer to upper marsh (eventually) and driftline, a gently sloping site is recommended. A gradient between 1% and 3%, as suggested from US experience would seem to be optimum. Less than 1%, say 0.5% may be sufficient for wide (landward to seaward sites), as found on some of the large

marshes of the east coast, provided some drainage system is in place. Sites backed by naturally sloping land behind are ideal for creation of rare upper transitional habitats.

5.1.1.3 Tidal currents

The strength of the tidal currents may be a governing factor in the habitat creation process in terms of the high energy areas and the low energy areas. In the high energy areas, typically close to the breach in the seawall but also in creeks of significant size, disturbance of the seabed surface may prevent colonisation of vegetation. Conversely, deposition of fine sediment and flora seeds in the more quiescent areas of the realignment site would promote vegetation growth provided other factors including the degree of inundation are suitable.

In the case where there is more than one breach in the seawall for inundation of a site the distribution of the tidal currents may be complex and vary throughout the spring-neap cycle.

The tidal currents are clearly related to the degree of exchange of tidal water between the realignment site and the sea outside, and will therefore vary throughout the spring-neap cycle and also be affected by other factors such as storm surge and local wind-induced changes in the tidal levels.

Currents outside the site in the vicinity of the breach are also likely to be affected as a result of the tidal filling and emptying of the site.

5.1.1.4 Wave climate

Waves inside the realignment site may be as a result of local generation by the wind blowing over the water (especially in the case of larger realignment sites) and also by the propagation of waves from outside into the site through the breach. As they propagate across the site, the waves will deform as a result of refraction, diffraction, shoaling, reflections and breaking and will also lose energy through friction with the seabed.

Theoretical knowledge and preliminary model applications at two natural marsh sites, Stiffkey and Dengie, suggest that, where surface slopes are generally small, it is the effect of bottom friction that dominates the wave attenuation process. Surface slope thus has a low priority in this context – but should have a higher priority when the link to existing surface drainage patterns (e.g. orientation of channels) is considered.

The principal effect of the waves in a created site is to agitate the seabed and thereby induce a stress on it. This can lead to erosion and scour (around hard structures) and corresponding deposition of the material elsewhere, and can also modify the distribution of vegetation seeds and the ability of the vegetation to grow. Incident wave energy is linked to the morphology of intertidal habitats and in particular the configuration of the mudflat-to-saltmarsh transition zone. Similarly, the transition zone morphology will affect the degree of wave energy dissipation and/or reflection and thus sediment erosion/accretion patterns and the future existence of the habitat. Observations at the natural marsh sites of Stiffkey and Dengie support the suggestion of a relationship between incident wave energy and the transition zone morphology that develops in response. It is suggested here that incident wave energy in excess of

that observed at existing sites with cliffed margins is not suitable for the creation of sustainable marsh habitats.

Wave action can also have a significant effect on the periphery of the site, often requiring remedial action to be taken where erosion occurs at the new water edge. Taking Tollesbury as an example, the propagation of waves into the site through the breach and across to the new embankment required the placement of revetment to prevent erosion, whereas local wave action has eroded the landward-facing side of the old seawall compounded by a degree by slumping of the embankment under the new hydraulic conditions. Outside the site the changes to the wave climate (for example a reduction in wave energy as a result of removal of the seawall) may have an effect on habitats.

5.1.1.5 Freshwater and drainage flows

Inundation of the site will also be affected by the degree of freshwater, and this may be a controlling factor especially in areas of high rainfall. It is not uncommon for realignment sites to have drainage networks running through them (e.g. Tollesbury) and prior to breaching such sites may have flooded under high freshwater events. Following breaching the combination of tidal and freshwater levels may have an effect on the habitat. Similarly, the persistence of freshwater flows in creeks may control the type of habitat that is created.

5.1.2 Sediment

Sedimentary processes can be categorised into the following sub-areas:

- Erosional characteristics;
- Depositional characteristics.

5.1.2.1 Erosional characteristics

Erosion within the realignment site will be determined by a combination of the strength of the bed and the hydrodynamic conditions. Many of the sites that have been set back (e.g. Orplands, Tollesbury, Abbott's Hall) were farmed and the ground was relatively strong at the time of first inundation. In the case of Tollesbury, after a period of five years since breaching, the area in the vicinity of the breach (both inside and outside the site) has had the weaker parts of the topsoil removed, leaving a hard compacted subsoil. At the breach location itself, the strongly compressed foundations of the former seawall formed a hard point that was more resistant to erosion than the area outside the breach.

The increase in tidal currents can often lead to erosion of the foreshore outside the managed realignment site, if the strength of the bed outside is unable to withstand the shear induced by the current.

In the case where the topsoil is prepared prior to breaching, or if material is pumped in to raise the level of the field, erosion can occur following inundation leading to dispersion of the material both within and without the site.

5.1.2.2 Depositional characteristics

Deposition will occur within the realignment site if there is material in suspension to be deposited (and this may arise from erosion of material at the breach or outside the site completely), and the hydrodynamic conditions allow the material to settle onto the

bed. Deposition may occur under some tidal states (e.g. neaps) only to be re-eroded on the following stronger spring tides. The ultimate configuration of the deposition will evolve over the long term following inundation.

Deposition tends to occur in the calmer areas of the site, and this can also often lead to colonisation by vegetation. Under these conditions the vegetation can have a positive feedback effect, reducing the strength of the current on the bed and promoting further deposition and thereby promoting further growth. By this mechanism salt marsh areas can grow in the vertical and also expand in the horizontal dimensions.

Clearly, the combination of the hydrodynamic and sedimentological processes has a significant effect on the determination of the habitat creation, both in the short and longer term, and this process is dynamic.

5.1.2.3 Other factors

It is worth also mentioning here other physical factors that are of interest but are not part of this review, which focuses on science. They include: pathways/public rights of way; pipelines and cables; pylons; third party interests close by/outside the site; water quality issues (e.g. at Tollesbury the proximity of the realignment site breach to the sewage outfall was an issue for the selection of the breach location); and, external issues such as the proximity of adjacent SSSIs.

5.2 Review of Chemical Processes

An important factor when considering chemical processes and habitats is to separate the growth and functioning processes (biogeochemistry) from detrimental (or even toxic) processes that affect the species and system (pollution). Some chemical parameters of the system must be present at a given level in order to sustain biological productivity, but may become detrimental (even toxic) to key species at different levels. Needless to say, other chemical parameters are inherently detrimental, at any level. It follows that both the identity of various chemical parameters, and the level (in terms of exposure, concentration, and uptake) of these, play an important role in the processes or potential toxicity.

A general guide as to whether a site is suitable for habitat creation is the presence of desired species/habitats in adjacent existing inter-tidal areas (English Nature, 1995). The water quality of the flooding tidal waters may be considered to be adequate if the desired habits exist adjacently and are exposed to the same flooding waters. That said, the suitability of the any site needs to be assessed in terms of local pollutants specific to that site (e.g. land contamination, sewage, industrial discharges, or agricultural run-off).

The issues associated with chemical processes are divided below into two broad categories: biogeochemistry and pollution. Chemical parameters and relevant processes, involved in the different matrices (air, water and sediment/soil) relevant to each of these categories are then discussed in turn.

5.2.1 Biogeochemistry

Biogeochemical processes can be categorised into the following sub-areas:

- Nutrients and essential trace elements
- Physico-chemical parameters

5.2.1.1 Nutrients

Nutrients and essential trace elements must be available for uptake for biological productivity and growth. Nutrients (Nitrogen, Phosphorus, Silicon etc) occur in various chemical forms and are key elements. Other elements of importance include Potassium, Sodium, Calcium, Magnesium, Copper, Zinc, and Iron. It is important to note that there is a threshold concentration for these parameters above which they may become detrimental (e.g. by encouraging algal growth problems/eutrophication) or toxic (e.g. Copper) to the very species that require them for growth and functioning.

5.2.1.2 Physico-chemical parameters

Salinity (High Priority)

Salt marsh plants can tolerate high salinities (at least up to 35psu) but growth and establishment of halophytes is easier in lower salinities. Salinity at a site will be influenced by flood water salinity, adjacent freshwater inputs (local discharges and groundwater flow) and tidal inundation patterns. Freshwater inputs can lead to changes in saltmarsh extent (establishment or loss), as the conditions created will favour different plants (e.g. reeds will out compete salt marsh plants at low salinities).

The sediment salinity vertical gradient will be related to a number of processes, including groundwater and surface water interaction. In addition, the salinity will influence the hydraulic conductivity, and this may affect flow rates within the sediment and impact drainage.

Suspended Solids

Suspended solids concentrations are important because of their impact on sensitive species (e.g. *Zostera* beds). Suspended solids in the water column will influence the amount of incident light, thereby affecting photosynthetic and microbial activity, and ecological growth etc).

Temperature

Saltmarsh plants are encountered in temperate systems, although they are capable of withstanding temperature fluctuations and shock. The surrounding water temperature, tidal inundation and ambient air temperature affect temperatures experienced.

In addition, the temperature of the air can affect the consolidation process of the incoming sediments following settlement. Consolidation is an important process for sites considering dredged material to "ramp-up" the level of the area to be inundated.

pH

The tolerance range of pH for salt marsh species is fairly broad, with growth being possible from pH 4 to pH 9. The pH level will affect nutrient uptake. The optimal range is pH 6 to 8. The pH level will also influence the chemical form and subsequent uptake of contaminants. Sediments do, however, have buffering capacity to resist changes in pH.

Grain size distribution (sediment type)

The grain size of the sediments is important. For instance, sand and soft mud will support quite different species. In addition, a root depth of appropriate sediment is needed for saltmarsh plants to grow. For example, different species of *Salicornia* occupy different habitats within the marsh that can vary according to sand content. The grain size will also influence the drainage of the sediment.

Sediment Moisture Content

The Sediment moisture content is not a major factor but links to sediment erodibility. The moisture content of clays is largely governed by the ratio of calcium and sodium ions. Moisture content also has implications for the sediment consolidation for both the site soil and the sediment being deposited.

Organic Carbon

Organic matter content is important for a number of reasons, including: altering sediment porosity and water holding capacity; influencing nutrient dynamics; controlling the growth rates of plants and algae; and, influencing the abundance composition and productivity of benthic invertebrates. It also influences biological processes. A wide variance in organic content can occur. For example, average organic content in thirty-eight created marshes studied in Florida ranged from 0.2 to 14.4 per cent.

The organic content of sediments may also influence the degree of shallow subsidence (compaction) experienced over greater than annual time scales, thus leading to changes in surface elevation.

Dissolved oxygen and oxic/anoxic sediment conditions (Redox)

Oxygen levels of flooding waters need to be sufficiently high for biological growth and for maintaining sufficient flushing so that stagnant areas and ponds do not develop.

Data from a saltmarsh site in the Humber estuary demonstrates the rapidity and magnitude of fluctuations in the redox potential of saltmarsh sediments. There are temporal variations on a daily and seasonal basis, and different zones in the marsh (i.e. different species distributions) display different patterns. The variations will be influenced by tidal flooding and sediment/soil drainage (hydraulic conductivity).

Mudflat sediments generally demonstrate negative redox potentials below a few millimeters of sediment due to regular tidal inundation. The redox will dictate the aerobic/anaerobic processes occurring in the sediment. This is important as negative redox processes can restrict the growth of plants such as *Salicornia*.

5.2.2 Pollution

5.2.2.1 General

This section considers chemical parameters that can have a negative impact on the habitats being created. It is important to understand the difference between a contaminant and a pollutant (a pollutant is a contaminant that induces undesirable

toxic effects). This review focuses on contaminant concentrations, which lead to biological effects i.e. pollutants.

The effect of a pollutant depends on its uptake (exposure) and toxicity. This includes the concentration of active ingredient present and bioavailability. The literature contains contradictory information on toxic effects, particularly in the context of field evaluations where other processes which effect the toxicity, but which have not been measured or are not fully understood, may not be taken into account fully. In addition, laboratory experiments and data (LC50s etc) are difficult to extrapolate to the field.

An assessment of the site for potential pollutant inputs will need to be undertaken. Generally if habitats exist adjacent to the managed realignment site and there are no obvious local sources (e.g. direct discharges or the land to be inundated is contaminated from historical inputs) then pollution should not be an issue.

The impact of low levels of pollutants over the long term and the synergistic and additive effect of mixtures of pollutants are not certain. The effects of some contaminants or mixtures of contaminants could occur at levels, which are not easily detectable (e.g. Tributyltin).

Directly relevant information on the effect of potential pollutants present at environmental concentrations in river and estuary systems, on mud flat, and salt marsh communities, is limited and generally only becomes important or noticed if acute pollution occurs. The toxic impact of a pollutant on a single species may be known and it will be important to identify and avoid the presence of such pollutants. However, identifying the significance of an impact at a species level to the population, community and ecosystem/habitat is not always possible.

A further difficulty in undertaking the assessment is that some pollutant events are transient e.g. herbicide spring flushes, and effects will vary from species to species and at different times in their life cycle (for example, during the flowering season or when seedlings are germinating).

The text below outlines some examples of potential pollutants that are known to be of concern in the marine environment. Some of these have been observed to have a toxic effect on key mud flat, saltmarsh or eelgrass species. The main types of pollutants include:

- Physico-chemical parameters;
- Metals;
- Organo-metallics; and,
- Synthetic organic micropollutants.

4.2.2.2 Freshwater

Freshwater can be a pollutant to saltmarsh/halophytic plants and eelgrass habitats by influencing salinity as discussed previously.

5.2.2.3 Suspended solids

Eelgrass habitats are very sensitive to suspended solids whereas saltmarsh plants are less sensitive due to lower inundation levels.

5.2.2.4 Metals

Metals (e.g. Copper, Zinc) exist naturally (i.e. background concentrations) in the marine environment. Trace metals are sometimes essential at low concentrations as mentioned earlier, but can be toxic above a certain threshold. Metal concentrations in mudflat, saltmarsh sediments and vegetation are reported, however, their toxic significance is rarely given and field observations of toxic impacts of metals on mudflats and saltmarsh systems at environmental concentrations are not reported for UK systems.

Copper (Cu) is known to be toxic in the aquatic environment, even at levels just above background, if it is in a highly bioavailable form. Mercury (Hg) and methylmercury (an organometallic) have in localised examples been shown to be of concern. Inorganic mercury can be methylated to organic mercury compounds in aquatic sediments, which can bioaccumulate.

5.2.2.5 Organometallics

Methylmercury is of most concern if present at high concentrations in areas where it may enter the human food chain (e.g. fisheries).

Another organometallic that is a synthetic (man-made) compound recognised to be highly toxic in the marine environment is tributyltin - actively used as a biocide anti-foulant.

5.2.2.6 Synthetic organic micropollutants

Polychlorinated Biphenyls (PCBs), insecticides (e.g. Lindane) and herbicides are examples of synthetic organic micropollutants.

Some studies have shown the direct toxic impact of a chlorophenoxyacid herbicide, where it was used to kill eelgrass (*Zostera marina*) in oyster growing areas in the USA. It was also shown to have an effect on the epiphytic (plant that derives water and nutrients from the rain and air) microalgae community. In addition, chlorophenoxy acid herbicides and triazine herbicides have been shown to be present in salt marsh systems along the Essex coast, possibly resulting from agricultural runoff into the estuary. The in field toxicological significance is, however, not known. Laboratory studies and field trials have been undertaken which show that sub-lethal concentrations of a triazine herbicide can result in decreased growth rates and photosynthetic activity of diatoms and photosynthetic efficiency of higher plants.

5.3 Review of Ecological Processes

5.3.1 Salt marsh

There are many environmental factors, several of them interacting, which influence the colonisation and distribution of salt marsh flora. These include elevation (and consequently tidal submergence), sediment supply, estuary size, exposure or fetch, tidal range, currents and wave action, latitude, gradient, drainage characteristics, sediment stability and water content, salinity, aeration and redox potential, pH, organic content and mineral nutrients, propagule supply, freshwater inputs, and some environmental levels of pollutants of which herbicide run-off may prove to be important.

As far as existing knowledge and current UK experience shows, the following is a summary of the key factors affecting the success of salt marsh creation, which should be considered in selecting sites. The process of site selection should also aim to ensure that there would be no adverse impacts on the environment or activities in the surrounding estuary or other areas.

- As a general guide, the **presence of natural salt marshes in the proposed area** would indicate that overall conditions are suitable for salt marsh creation, providing the following important parameters are met.
- **Elevation** must be suitable for salt marsh vegetation colonisation. The minimum elevation should be around the level of MHWN *in the location of the proposed site*, or at a level that would experience 450-500 tidal inundations per year. Levels lower than this would be likely to develop mudflat, which may be required as part of the scheme.
- **Drainage:** creeks supply the marsh surface with sediment and nutrients, and drain the marsh, increasing sediment stability. As natural development of a creek system is slow, and appears to only develop in newly accreted sediment, excavation of a drainage system should be considered, particularly for large sites. In site selection, therefore, accessibility for earthmoving vehicles needs to be considered.
- **Sediment supply** needs to be sufficient to maintain an accretion rate sufficient to offset predicted sea level rise.
- **Soil grain size** is not an important factor for site selection, but if the proposed site needs the artificial addition of sediment to produce the right configuration, the use of sediment finer than sand is preferable.
- **Propagule supply:** the presence of a natural salt marsh in the vicinity will provide a source of propagules to the new site, although colonisation at Saltram has shown that salt marsh can develop at some distance from the nearest salt marsh. If natural colonisation is slow, some assisted seeding of the site can be considered.

- **Contamination:** areas away from major pollutant sources are preferable, and it may be necessary to provide ways of diverting any excessive herbicide input if used on adjacent agricultural land.
- **Site history:** sites reclaimed from salt marsh are likely to be the most suitable, particularly if reclamation was relatively recent (in terms of elevation differences).
- **Tidal prism:** the effect of increasing tidal prism (particularly for large sites in high tidal ranges) needs careful prediction to ensure no detrimental effects on adjacent areas of coast.
- **Conservation status of proposed site:** sites selected for salt marsh creation should not involve damage to existing sites of high conservation value.
- **Local economic activities -shellfisheries:** any activities in the area, such as shellfisheries, should be determined and efforts made to ensure that there will be no detrimental impacts from a realignment scheme.

5.3.2 Mudflat and sand flats

The distribution and zonation of communities that will naturally colonise intertidal flats vary according to the particular site conditions of water depth and exposure during the tidal cycle, tidal currents, salinity, and pollutants, as well as the important substrate-related parameters such as particle size and cohesiveness, but the precise determinants are still far from clear (Little 2000).

Shore level (elevation) and sediment particle size

Shore level and sediment grain size are two key environmental factors (Anderson 1990; Goss-Custard and Yates 1992) determining species distributions.

Different organisms inhabit different levels on the shore according to their tolerance to the physiological stresses imposed by exposure to air, or their abilities to avoid them by burrowing into the sediment. Exposure at low tide exposes the benthos to various stresses including temperature and salinity fluctuations, UV radiation and desiccation.

Sediment grain size and composition varies according to hydrodynamic conditions and along the shore profile. On mudflats sediment tend to be coarsest at mean tide levels (MTL) because tidal velocities are highest at mid tide.

Sediment grain size preferences relate to behavioural and feeding methods of the invertebrates. Particle size composition affects the characteristics of the sediment substrate in several ways. For example, affecting drainage through its porosity and permeability (hence extent of drying out at low tide), sediment behaviour under disturbance (thixotropic sediments are easy to burrow in; dilatant sediments are not), organic content and microbial biomass (inversely related to particle size) and oxygen content, redox potential and depth of reduced sediments (Little 2000).

Coarse, mobile sand is unsuitable for permanent macrofaunal burrows, and contains little associated organic matter needed by deposit feeders. In contrast, very fine soft muds that are easily resuspended and create turbid conditions can be unsuitable for filter feeders where suspended particles clog their gills.

Current Speeds and Bed Stress

Current speeds and bed stress determine the character of the substrate and affect benthic community type. Current speeds change within an estuary as well as changing along an intertidal flat profile. For example, maximum current speed and bed stress increase towards the head of a funnel-shaped estuary such as the Severn and species communities change with increasing bed stress (Warwick and Uncles 1980).

Turbidity

Turbidity levels influence the distribution of species. As noted previously, high turbidity may interfere with feeding and respiratory apparatus of many suspension feeding species, and it also reduces light penetration and therefore primary production. Highly turbid estuaries may therefore tend to be dominated by deposit feeding infauna, with few suspension feeders except for those which have mechanisms to deal with unwanted particles, such as binding them with mucus.

Salinity

Estuarine/marine invertebrate diversity declines with decreasing salinity within an estuarine gradient, and are gradually replaced by freshwater species. For example, in the Tay Estuary, McLusky (1989) reported that marine species die out over a 30 km distance from the sea and a minimum number of species occurs at about 25 km from the sea.

Gradient

Mudflats can be very flat, with slopes of 1 in 1000, although their cohesive nature allows steep banks to form, such as on the side of creeks (Little 2002).

Sediment accretion

In selecting sites suitable for intertidal flat creation, sediment accretion in the area should be sufficient to keep up with sea level rise, otherwise it will not be sustainable, but a higher accretion rate would be preferable for early colonisation by a variety of benthic infauna, as those inhabiting permanent burrows are unlikely to burrow into the terrestrial soils of the flooded area.

Water quality- nutrient levels

Excessive nutrient levels can result in dense algal mats on the surface of the sediment which can reduce the diversity and biomass of some mud-dwelling invertebrates such as ragworm, *Hediste diversicolor*, and lugworm, *Arenicola marina*. In Langstone Harbour, Hampshire, the spread of algal mats reduced the area available to feed for some estuarine waders (Tubbs and Tubbs 1980, Nicholls *et al.* 1981). Furthermore, where mudflats are bordered by salt marshes, the algal mats can be washed up onto the marsh surface, smothering and killing the vegetation.

Pollutants

A few infaunal species are tolerant to relatively high levels of heavy metals and other chemical pollutants, so that the biomass may remain high, but the diversity of fauna is

drastically reduced. There is little information on the effects of low concentrations of toxic elements on salt marsh and mudflat fauna or on food chain transfer.

Quality of land: Contaminated soils would not be recommended as inundation by seawater can result in mobilisation of toxic elements. A few infaunal species are tolerant to relatively high levels of heavy metals and other chemical pollutants, so that the biomass may remain high, but the diversity of fauna is drastically reduced. There is little information on the effects of low concentrations of heavy metals on salt marsh and mudflat fauna.

Biotic factors

Biotic factors are also important influences on the distribution and abundance of intertidal benthos. These include interspecific competition, predation and mortality from other causes, mobility of adults and distribution of larval forms by currents. Food supply may also be important, particularly in coarse sediments, although in mudflats the supply of the microphytobenthos such as benthic diatoms, microbial populations, and detritus is generally thought not to be limiting, but may be more variable than is currently assumed (Little 2000).

Timing of intertidal flat creation

In view of many of the factors outlined above, such as the time needed for accumulation of suitable depths of sediment for different species of burrowing invertebrates, and the time for growth from larval to adult forms of many invertebrates, it would be prudent to plan and select sites for intertidal flat creation early if they are to provide compensation for current losses of important intertidal flat habitats as feeding areas for birds.

5.3.3 Eelgrass beds

Ecological factors affecting the site selection for eelgrass beds depend on the species of eelgrass under consideration. Some of the factors listed below are physical but are included for completeness because they influence the ecology. Full details are presented in Appendix 2. However, in general areas close to existing beds would be the best indication that requirements for the species are met in the area.

- **Substrate:** All three species require sandy to muddy substrates and shelter from strong tides, currents and wave exposure. Dense swards can develop in sheltered inlets, bays, estuaries and saline lagoons, but in more exposed sites the beds are usually smaller and patchier and vulnerable to storm damage.
- **Water clarity:** Different species of seagrasses have varying light requirements, but in general, the minimum requirement is around 10-20% of surface light (Duarte 1991). In the intertidal, photosynthesis and production are inhibited by high light intensity (see references in Short *et.al* (2001), but this may not be an important consideration in the UK.
- **Water quality / contamination:** although there is little evidence of significant damage by environmental levels of pollutants, avoid contaminated areas

(sediments and water) including areas with excessive nutrient inputs (particularly nitrogen load).

- **Alien /invasive species:** avoid areas with *Spartina anglica* or *Sargassum muticum* growing at similar elevations as eelgrass requirements as these may compete with *Zostera* and prevent good colonisation
- **Current velocities and wave action:** some protection may be required to promote colonisation. However, water movement affects seagrass biomass and habitat structure (see references in Short *et al.* 2001), for example, biomass and height may increase with increasing velocity (but within limits). Water movement is also important for pollination.
- Information on **transplanting** is beyond the scope of this report. However, it is quite likely that some transplanting may need to be done on any site selected for creation of *Zostera* beds. If transplanting is to be carried out in a newly flooded area, it may be necessary to wait until the site has ‘settled down’ for a while and appropriate conditions are met. Information on accretion or erosion rates of the new site, and resuspension of the newly accreting surface, should be gathered first, and checked with the literature on *Zostera* transplantation to ensure that conditions will be suitable for transplant survival.

6.0 CONCLUSIONS

In response to the need to bring together the various approaches and ranking systems regarding site rankings and criteria, and assess the common criteria, methodology and scoring to allow comparison of site assessments within and between areas and agencies, a single set of criteria has been developed. This set of criteria has resulted from an analysis of the various initiatives that are being implemented at present by various agencies/groups etc., and by a critical review of the relevant science and case studies.

The criteria identified from the reviews have been implemented into the Influence Diagram and GIS tools. Table 3 shows the overall summary of parameters identified by the reviews that will be implemented into the decision tools. The development of both decision tools is covered in a separate report (Report II).

Various physical, chemical and biological factors play a small (but significant) part in the site selection process for habitat creation schemes, and that many of these parameters are difficult to quantify (for various reasons). The first reason is that the scientific understanding of the underlying processes is not fully understood. Secondly, in many instances it would not be possible for an interested party to define some of the parameters without expending a degree of effort and perhaps cost. Accordingly, the Influence Diagram aims to represent the various parameters and linkages between them, to help inform the user of the various processes that affect habitat creation.

The Influence Diagram is based on *readily available data*. As an example, the simple predictive model of the areas of salt marsh and mudflat is based upon a representation of the inundation calculated from the topography of the realignment site and tidal conditions. In reality, the actual distribution of salt marsh and mud flat will evolve due to many more complex processes.

The reviews contained within this report provide a good starting point for a more generic site-selection tool which could be applied by any end-user. The focus of FD1917 is that of site suitability for habitat creation, type and quality, which fits well into the wider framework, including projects such as FD2413 “Guidance on design and implementation of managed realignment” (CIRIA, 2004: Design issues for managed realignment).

Table 3: Summary of criteria and threshold relevant to habitat creation as derived from the reviews.

Criteria	Threshold	Habitat	Comments and References
Mean High Water Springs	MHWS – MHWN	Saltmarsh	Delineation by tidal level should be considered as a first approximation, and if possible, use site-specific information to give more accurate criteria.
Mean Low Water Springs			
Mean High Water Neaps	MHWN - MLWS	Intertidal flats	Thresholds for saltmarsh, e.g. Burd, 1989; S. Brown (pers. Measurements); Zedler, 1984; Webb and Newling, 1985; Woodhouse, 1979
Mean Low Water Neaps	Below MLWS	Eelgrass*	
Elevation	Minimum at ~MHWN (450-500 inundations p.a.)	Saltmarsh	Thresholds for intertidal flats, e.g. Little, 2000; McLusky, 1989; Gray, 1981. Slope gradient thresholds from selected Environment Agency profiles of East Anglian intertidal flats (0.17 – 0.27%).
	Lower than MHWN	Intertidal flats	
	Subtidal; MLWS to 4m	Eelgrass*	
Mean slope	1-2% (1:0-1:64) ideal. >0-7% (1:0-1:18) possible for saltmarsh	Saltmarsh Intertidal flats Eelgrass*	General saltmarsh and intertidal flats texts, e.g. Adam, 1990; Packham and Willis, 1997; Long and Mason, 1983; Gray, 1992; Gray <i>et al</i> , 1995; NB: Eelgrass is used to refer to subtidal <i>Zostera marina</i> only. Thresholds for eelgrass (<i>Z. marina</i>), e.g. Rodwell, 2000; Davison and Hughes, 1998
Length of site	Length of site along shore, parallel with waterline.	Saltmarsh Intertidal flats Eelgrass*	Parameters used to calculate overall area, from which habitat areas can be calculated based on inundation (see above for threshold information and references).
Width of site	Width of site across shore, perpendicular to waterline.	Saltmarsh Intertidal flats Eelgrass*	
Is the land polluted?	Absence of contaminants or presence below pollutant level	Saltmarsh Intertidal flats Eelgrass*	Assessment may be made using the EA's guidance: Contaminated Land Exposure Assessment (CLEA). Compare contaminant level measured at site with EA Soil Guideline Values and Groundwater and Contaminated Land publications: www.environment-agency.gov.uk/subjects/landquality/ . Also public authorities hold Contaminated Land Registers and these should be consulted. Also for eelgrass see Davison and Hughes, 1998.
Water salinity	>10 – full salinity: optimum 22	Saltmarsh Intertidal flats	References, e.g.; Zedler, 1996.
	Saline	Eelgrass*	Almost exclusively in fully saline conditions in UK; e.g., Tutin, 1942; Stewart <i>et al.</i> , 1994; Davison and Hughes, 1998

Water Quality	Absence of water-borne contaminants or presence below pollution levels e.g. EA Action Levels. Minor or no eutrophication/ nor elevated nutrients.	Saltmarsh Intertidal flats Eelgrass*	High levels of nutrients can produce algal blooms and mats, smothering invertebrate intertidal flats; e.g. Nicholls <i>et al.</i> , 1981. Algae may also smother and kill saltmarsh vegetation; e.g. Adam, 1990; or eelgrass; e.g., Davison and Hughes, 1998; van Katwijk <i>et al.</i> , 1997, 1999.
Light Climate	Tolerant of wide turbidity range.	Saltmarsh Intertidal flats	Turbidity levels affect composition of intertidal flats; e.g., Little, 2000.
	Intolerant of high turbidity, low light climate. Sensitive to physical disturbance.	Eelgrass*	Sensitive to turbidity and reduced light penetration; e.g., Giesen <i>et al.</i> , 1990a & b; Duarte, 1991; Davison and Hughes, 1998.
Soil type	Various grain sizes from heavy clays to sands	Saltmarsh Intertidal flats	Grain size influences organic content and porosity affecting the competitive outcome of saltmarsh halophytes; e.g. Pye and French
	Sand – sandy/mud, sand/fine gravel	Eelgrass*	Reference; e.g., Davison and Hughes, 1998; de Jong <i>et al.</i> , 2000)
Site Location	Muddy estuary with high accretion rates - resulting in potentially high rates of sedimentation. Open coastline with lower levels of suspended sediment is likely to accrete at a lower rate	Saltmarsh Intertidal flats	This parameter included to provide an indication of how likely it will be that the site evolves quickly due to settling of fine sediment. On the basis that it is unlikely that suspended sediment concentration levels will be known the options range from a muddy estuary (high suspended sediment concentrations) to an open coast (with lower SSCs)
Exposure	Sheltered, low energy environments protected from wave action	Saltmarsh Intertidal flats Eelgrass*	Penetration of high wave energy into the site will tend to inhibit settling of suspended sediment. Low currents and flows needed for eelgrass; Fonseca and Kenworthy, 1987; Fonseca <i>et al.</i> , 1983; de Jonge <i>et al.</i> , 2000
Freshwater flows	Freshwater can be a pollutant to habitats by reducing salinity	Saltmarsh Intertidal flats Eelgrass*	Saltmarsh/halophytic plants and eelgrass habitats polluted by reducing salinity. Diversity of marine organisms reduced in intertidal flats by freshwater. See 'salinity' references
Bed stability	Compressed soil is erosion-resistant. Weak, friable soil will erode more easily. Bed stability likely to increase with accretion, post breach	Saltmarsh Intertidal flats Eelgrass*	e.g. Whitehouse, Soulsby, Roberts and Mitchener (2000). Dynamics of Estuarine Muds. Thomas Telford Publishing.
Connectivity inside site	The degree to which a site drains will affect the proportion of intertidal flats to saltmarsh. Natural creek development in newly accreted material is slow - consider excavating channels pre-breach	Saltmarsh Intertidal flats Eelgrass	No references (T. Chesher, personal experience)

Propagule/ biological supply to site	Supply of seeds, rhizomes and tiller fragments needed to generate saltmarsh and eelgrass habitat, and supply of organisms for intertidal flats.	Saltmarsh Intertidal flats	Dependent on proximity of nearest established habitat and natural direction of transport; e.g., Koutsall <i>et al.</i> , 1987; Rand, 2000; Huiskes <i>et al.</i> , 1995; Garbutt <i>et al.</i> , in Reading <i>et al.</i> , 2002. Supply of larval or mobile adult invertebrates needed to generate intertidal flats communities; e.g. Little, 2000.
	Site needs to be directly adjacent to established eelgrass bed with identical environment.	Eelgrass*	Eelgrass growth in northern latitudes is thought to persist by vegetative means rather than seed production; e.g., Davison and Hughes, 1998; Fonseca <i>et al.</i> , 2000, 2002; Calumpong and Fonseca, 2001

*Eelgrass refers to subtidal *Zostera marina* only.

7.0 BIBLIOGRAPHY

ABP Research & Consultancy, 1998. *Review of coastal habitat creation, restoration and recharge schemes*. Report No. R.909

ABPmer and BTO (2002) Lappel Bank and Fagbury flats compensatory measures: Phase 1. English Nature.

Adam, P. 1978. Geographical variation in British saltmarsh vegetation. *Journal of Ecology*, **66**, 339-366.

Adam, P. 1981. The vegetation of British saltmarshes. *New Phytologist*, **88**, 143-196.

Adam, P. 1990. *Saltmarsh Ecology*. Cambridge University Press, Cambridge.

Addy, C.E. 1947. Eelgrass planting guide. *Maryland Conservationist*, **24**, 16-17.

Allen, J.R.L. and Pye, K. 1992 (eds). *Saltmarshes: Morphodynamics, Conservation and Engineering Significance*. Cambridge University Press, Cambridge.

Anderson, S. 1990. The Ecology of Morecambe Bay II. Intertidal invertebrates and factors affecting their distribution. Cited in ABP (1998)

Armstrong, W., Wright, E.J., Lythe, S. and Gaynard, T.J. 1985. Plant zonation and the effects of the spring-neap tidal cycle on soil aeration in a Humber salt marsh. *Journal of Ecology*, **73**, 323-339.

Atkins (2002) Selsmore to Mengham Coastal Defence Scheme; Managed realignment Opportunities in Portsmouth, Langstone Chichester and Pagham Harbours. Environment Agency.

Atkinson, P.W., Crooks, S., Grant, A. and Rehfisch, M.M. 2001. *The Success of Creation and Restoration Schemes in Producing Intertidal habitat Suitable for Waterbirds*. English Nature Research report 425.

Baker, J.M., Oldham, J.H., Wilson, C.M., Dicks, B., Little, D.I. and Levell, D. 1990. *Spartina anglica* and oil: spill and effluent effects, clean-up and rehabilitation. In: *Spartina anglica – a research review*. A.J.Gray and P.E.M.Benham (eds). Institute of Terrestrial Ecology research publication no. 2. Natural Environment Research Council, HMSO, London, pp.52-62.

Beefink, W.G. 1977. The coastal salt marshes of western and northern Europe: an ecological and phytosociological approach. In: V.J.Chapman (ed.), *Wet Coastal Ecosystems*, Elsevier, Amsterdam, pp. 109-155.

Bertness, M.D. 1991a. Interspecific interactions among high marsh perennials in a New England salt marsh. *Ecology* **72**, 125-137.

Bertness, M.D. 1991b. Zonation of *Spartina patens* and *Spartina alterniflora* in a New England salt marsh. *Ecology* **72**, 138-148.

- Binnie Black and Veatch (2000) *Potential for sustainable habitat creation in the Humber Estuary*. Environment Agency Humber estuary shoreline management plan habitat migration study. Pp43 and appendices.
- Brereton, A.J. 1971. The structure of the species populations in the initial stages of salt-marsh succession. *Journal of Ecology*, **59**, 321-338.
- Broome, S.W. 1990. Creation and restoration of tidal wetlands of the southeastern United States. In: J.Kusler and M.E.Kentula (eds), *Wetland Creation and Restoration: the status of the Science*. Island Press, Washington D.C., pp.37-72.
- Broome, S.W., Seneca, E.D. and Woodhouse, W.W.Jr. 1988. Tidal salt marsh restoration. *Aquatic Botany*, **32**, 1-22.
- Brown, S.L 1998. Sedimentation on a Humber saltmarsh. In: Black, K.S., Paterson, D.M. & Cramp, A. (eds) *Sedimentary Processes in the Intertidal Zone*. Geological Society, London, Special Publications, **139**, 69-83.
- Brown, S.L., Warman, E.A., McGroarty, S., Yates, M., Pakeman, R.J., Boorman, L.A., Goss-Custard, J.D. & Gray, A.J. 1998. Sediment fluxes in intertidal biotopes: BIOTA II. *Marine Pollution Bulletin*, **37**, 173-181.
- Brown, S.L. and Cox, R. 2001. EUROSAM Decision Support System. A CD-rom produced for the EUROpean SAlT marshes Modelling programme, EU Environment and Climate RTD Programme, Contract number ENV4-CT97-0436.
- Brown, S.L. Cox, R., Feunteun, E., Thorin, S. and Lefeuvre, J-C. 2003. Overview of the EUROSAM project and a Decision Support System. *Continental Shelf Research*, **23**, 1617-1634.
- Burd, F. 1989. The Saltmarsh Survey of Great Britain. An inventory of British Saltmarshes. Nature Conservancy Council, Peterborough.
- Burd, F.H., J. Clifton and B.J. Murphy (1994) *Sites of historical sea defence failure. Phase II study*. Report to English Nature
- Burd, F.H., 1995. *Managed retreat: a practical guide*. English Nature, Campaign for a living coast series.
- Butcher, R.W. 1934. *Zostera*. Report on the present condition of eelgrass on the coasts of England, based on a survey during August to October, 1933. *Journal du Conseil*, **9**, 49-65.
- Butcher, R.W. 1941. The distribution of *Zostera* (eelgrass, wigeon grass) and other seashore plants in relation to the migrations of wildfowl. In *International Wildfowl Inquiry*, Volume I, pp.29-49. Cambridge University Press, Cambridge.

- Callaway, J.C., Sullivan, G., Desmond, J.S., Williams, G.D. and Zedler, J.B. 2001. Assessment and monitoring. In: J.B.Zedler (ed.) Handbook for Restoring Tidal Wetlands. CRC Press, Boca Raton, Florida, USA, pp.271-335.
- Calumpang, H.P. and Fonseca, M.S. 2001. Seagrass transplantation and other seagrass restoration methods. In *Global Seagrass Research Methods*, eds F.T.Short and R.G.Coles, Elsevier, Amsterdam, The Netherlands, pp. 425-443.
- Campbell, M.L., Bastyan, G.R. and Walker, D.I. 2000. A decision-based framework to increase seagrass transplantation success. In: Proceedings of the 4th International Seagrass Biology Workshop, eds G.C. Pergent-Martini, M.C. Buia and M.C.Gambi, pp. 332-335. Società Italiana di Biologia Marina, Biologia Marina Mediterranea, Corsica, France.
- Chapman, V.J. 1947a. *Suaeda maritima* (L.) Dum.: Biological Flora of the British Isles, *Journal of Ecology*, 35, 293-302.
- Chapman, V.J. 1947a. *Suaeda fruticosa* (L.) Forsk.: Biological Flora of the British Isles, *Journal of Ecology*, 35, 303-310.
- Chapman, V.J. 1950. *Halimione portulacoides* (L.) Aell.: Biological Flora of the British Isles, *Journal of Ecology*, 38, 214-222.
- Chapman, V.J. 1976. Coastal Vegetation. 2nd Edition, Pergamon Press, Oxford.
- CIRIA (2003) Design issues for managed realignment (draft)
- Clapham, A.R., Pearsall, W.H. and Richards, P.W. 1942. *Aster tripolium* L. Biological Flora of the British Isles. *Journal of Ecology*, 30, 385-395.
- Colclough, S., Fonseca, L and Astley, T. 2004 Fish utilisation of managed realignments. Report. Environment Agency.
- Connor, D.W., Brazier, D.P., Hill, T.O., Holt, R.H.F., Northen, K.O., and Anderson, W.G. 1997. Marine Nature Conservation Review: Marine biotopes. A working classification for the British Isles. Version 97.06. Peterborough, JNCC. 340pp.
- Costanza, R. et al., 1997. *The value of the world's ecosystem services and natural capital*. Nature 387, 253-260.
- Coutts, H. and H. Roberts 2003 *Streamlining Site Selection For Managed Realignment*. Conference Report - ICE Coastal Management, Brighton October 2003
- Crooks, S., Schutten, J., Sheern, G.D., Pye, K. and Davy, A.J. 2002. Drainage and elevation as factors in the restoration of salt marsh in Britain. *Restoration Ecology*, **10(3)**, 591-602.
- Davidson, N.C., Laffoley, D.d'A., Doody, J.P., Way, L., Gordon, J., Key, R., Drake, C.M., Pienkowski, M.W., Mitchell, R. and Duff, K.L. 1991. *Nature Conservation and Estuaries in Great Britain*. Nature Conservancy Council, Peterborough.

Davison, D.M. 1997. The genus *Zostera* in the UK: a literature review identifying key conservation, management and monitoring requirements. Report to the Environment and Heritage Service, D.o.E. (N.I.), Belfast.

Davison, D.M and Hughes, D.J. 1998. *Zostera* Biotopes (volume I). An overview of dynamics and sensitivity characteristics for conservation management of marine SACs. Scottish Association for Marine Science (UK Marine SACs Project). 95 pages.

Defra/Environment Agency, 2002: *Managed Realignment Review*, Project Report. Flood and Coastal Defence R&D Programme, Policy Research Project FD 2008 Halcrow, 2002.

De Jonge, V.N., and de Jong, D.J. 1992. Role of tide, light and fisheries in the decline of *Zostera marina* L. in the Dutch Wadden Sea. In: Proceedings of the 7th International Wadden Sea Symposium, Ameland, The Netherlands. Publication series no. 20, Netherlands Institute of Sea Research, Casparie, Heerhugowaard, The Netherlands, pp. 161-176.

De Jonge, V.N., de Jong, D.J. and van den Bergs, J. 1996. Reintroduction of eelgrass (*Zostera marina*) in the Dutch Wadden Sea; review of research and suggestions of management measures. *Journal of Coastal Conservation* **2**, 149-158.

De Jonge, V.N., de Jong, D.J. and van Katwijk, M.M. 2000. Policy plans and management measures to restore eelgrass (*Zostera marina* L.) in the Dutch Wadden Sea. *Helgoland Marine Research* **54**, 151-158.

Den Hartog, C. 1994. Suffocation of a littoral *Zostera* bed by *Enteromorpha radiata*. *Aquatic Botany*, **47**, 21-28.

Dennison, W.C. and Kirkman, H. 1996. Seagrass survival model. In: J.Kuo, R.C.Phillips, D.I.Walker, H.Kirkman (eds), *Seagrass Biology: Proceedings of an international workshop*, Rottneest Island, Western Australia, 25-29 January 1996, pp.341-344.

Dent, D., Downing, E.J.B. and Rogaar, I.I. 1976. The changes in structure of marsh soils following drainage and arable cultivation. *Journal of Soil Science*, **27**, 250-265.

Elliott, M., Nedwell, S., Jones, N.V., Read, S.J., Cutts, N.D. and Hemingway, K.L. 1998. Intertidal Sand and Mudflats and Subtidal Mobile Sandbanks (Volume II). An overview of dynamic and sensitivity characteristics for conservation management of marine SACs. Scottish Association for Marine Science (UK Marine SACs Project). 151 pages.

English Heritage, 2003. *Coastal defence and the historic environment*. English Heritage guidance. 15pp.

English Nature (2002) *Essex Estuaries Coastal Habitat Management Plan*

English Nature (2003) *Solent Coastal Habitat Management Plan*

English Nature, Environment Agency, DEFRA, LIFE and NERC, (2003) *'Living with the Sea': Coastal Habitat Creation: towards Good Practice*

Environment Agency (1998) *HEEBS, Humber Estuary Environmental Baseline Study*.

Environment Agency, Humber Estuary Shoreline Management Plan. Environment Agency Report, 2000.

Environment Agency (2002). The Humber Estuary: Consultation on Managed Realignment: Information for Landowners and Tenants. Planning for the Rising Tides.

Environment Agency (2003) *The Humber Estuary, Update on managed realignment*. pp. 9.

Environment Agency 2003. *Regulated Tidal Exchange: An Inter-tidal Habitat Creation Technique*.

Feekes, W. 1936. The development of the natural vegetation in the Wieringermeerpolder, the first significant reclamation of the Zuiderzee (in Dutch). *Ned Kruidk Arch* **46**, 1-295.

Fonseca, M.S. and Fisher, J.S. 1986. A comparison of canopy friction and sediment movement between four species of seagrass with reference to their ecology and restoration. *Marine Ecology Progress Series*, **29**, 15-22.

Fonseca, M.S. and Kenworthy, W.J. 1987. Effects of current on photosynthesis and distribution of seagrasses. *Aquatic Botany*, **27**, 59-78.

Fonseca, M.S., Kenworthy, W.J., Courtney, F.X., Hall, M.O. 1994. Eelgrass planting in the south-eastern United States: methods for accelerating habitat development. *Restoration Ecology*, **2**, 198-212.

Fonseca, M.S., Kenworthy, W.J., Julius, B.E., Shutler, S. and Fluke, S. 2002. Seagrasses. Chapter 7, In: M.R.Perrow and A.J.Davy (eds), *Handbook of Ecological Restoration, Volume 2, Restoration in Practice*, Cambridge University Press, pp.149-170.

Fonseca, M.S., Julius, B.E. and Kenworthy, W.J. 2000a. Integrating biology and economics in seagrass restoration: how much is enough and why? *Ecological Engineer*, **15**, 227-237.

Fonseca, M.S., Zieman, J.C., Thayer, G.W. and Fisher, J.S. 1983. The role of current velocities in structuring eelgrass (*Zostera marina* L.) meadows. *Estuarine and Coastal Shelf Science* **17**, 367-380.

Fredette, T.J., Fonseca, M.S., Kenworthy, J.W. and Thayer, G.W. 1985. Seagrass transplanting: 10 years of U.S. Army Corps of Engineers research. In *Proceedings of the 12th Annual conference on Wetland Restoration and Creation*, ed. F.J.Webb, pp. 121-134. Hillsborough Community College, Tampa, FL.

- Frid, C.L.J., Chandrasekara, W.U. and Davey, P. 1999. The restoration of mud flats invaded by common cord-grass (*Spartina anglica*, CE Hubbard) using mechanical disturbance and its effects on the macrobenthic fauna. *Aquatic Conservation: Marine and Freshwater Ecosystems*, **9**, 47-61.
- Gambi, M.C., Nowell, A.R.M. and Jumars, P.A. 1990. Flume observations on flow dynamics in *Zostera marina* (eelgrass) beds. *Marine Ecology Progress Series*, **61**, 159-169.
- Gerdol, V. and Hughes, R.G. 1993. Effect of the amphipod *Corophium volutator* on the colonisation of mud by the halophyte *Salicornia europaea*. *Marine Ecology Progress Series*, **97**, 61-69.
- Giesen, W.B.J.T., van Katwijk, M.M., and den Hartog, C. 1990a. Eelgrass condition and turbidity in the Dutch Wadden Sea. *Aquatic Botany*, **37**, 71-85.
- Giesen, W.B.J.T., van Katwijk, M.M., and den Hartog, C. 1990b. Temperature, salinity, insolation and wasting disease of eelgrass (*Zostera marina*) in the Dutch Wadden Sea in the 1930s. *Netherlands Journal of Sea Research*, **25**, 395-404.
- Goss-Custard, J.D. and Yates, M.G. 1992. Towards predicting the effects of salt marsh reclamation on feeding birds in the Wash. *Journal of Applied Ecology*, **29**, 330-340.
- Gray, A.J. 1992. Saltmarsh plant ecology: zonation and succession revisited. In: *Saltmarshes: morphodynamics, conservation and engineering significance*, J.R.L.Allen and K.Pye (eds), pp.63-79, Cambridge University Press, Cambridge, England.
- Gray, A.J. and Scott, R. 1977. *Puccinellia maritima* (Hud.) Parl.: Biological Flora of the British Isles, *Journal of Ecology*, **65**, 699-716.
- Gray, A.J., Warman, E.A., Clarke, R.T. and Johnson, P.J. 1995. The niche of *Spartina anglica* on a changing coastline. In: *Coastal Zone Topics: Process, Ecology and Management* **1**, 29-34.
- Gray, J.S. 1981. *The ecology of marine sediments*. Cambridge University Press, Cambridge
- Groenendijk, A.M., Spieksma, J.G.J. and Vink-Lievaart, M.A. 1987. Growth and interactions of salt-marsh species under different flooding regimes. In: A.H.L. Huiskes, C.W.P.Blom and J.Rozema (eds), *Vegetation Between Land and Sea*. Dr. W.Junk, Dordrecht, Netherlands, pp.236-259.
- Halcrow/EA 2003; *Roach and Crouch flood management strategy study; Evaluation of potential realignment sites*.

Haltiner, J. and Williams, P. 1987. Hydraulic Design in Saltmarsh Restoration. Proceedings of the National Symposium on Wetland Hydrology. Association of State Wetland Managers, pp.293-299.

Harmsen, G.W. 1936. Systematische Beobachtungen der Nord-west-Europaeischen Seegrasformen. *Ned Kruidk Arch* **46**, 852-877.

Harvey, H.T., Williams, P. and Haltiner, P.E. 1983. Guidelines for Enhancement and Restoration of Diked Historic Baylands. San Francisco Bay Conservation and Development Commission.

Harwood, T.R. and Scott, R. 1999. *Spartina anglica* control, Grange-over-Sands 1998-1999. Report to South Lakeland District Council.

Havill, D.C., Ingold, A. and Pearson, J. 1985. Sulphide tolerance in coastal halophytes. *Vegetatio*, **62**, 279-285.

Haycock Associates 2001. Regulated Tidal Exchange: Phase II Report to The Royal Society for the Protection of Birds and The Environment Agency.

Hazelden, J. and Boorman, L.A. 2001. Soils and 'managed retreat' in south east England. *Soil Use and Management*, **17**, 150-154.

Hermus, D.C.R. 1995. Reintroduction of seagrass in the Wadden Sea (in Dutch). Rapport Laboratorium voor Aquatische Oecologie, Katholieke Universiteit, Nijmegen, The Netherlands.

HR Wallingford (1994). Orplands Seawall, River Blackwater, Essex Hydrodynamic assessment of proposed managed retreat. HR Wallingford Report EX 3019.

HR Wallingford (1994). Tollesbury Creek Essex, MAFF – Set Back Trial Field Data Collection, HR Wallingford Report SR399.

HR Wallingford (1997). Tollesbury Creek Managed Set Back Experiment. Comparison of Model Results with Field Observations, HR Wallingford Report TR 35.

HR Wallingford (1998). Tollesbury Creek Managed Set Back Experiment. Analysis of bathymetric changes between 1996 and 1997, HR Wallingford Report TR 58.

HR Wallingford (1999). Tollesbury Creek Managed Set Back Experiment. Analysis of bathymetric changes between 1997 and 1998, HR Wallingford Report TR 76.

HR Wallingford (2000). Tollesbury Creek Managed Set Back Experiment. Analysis of bathymetric changes between 1998 and 1999, HR Wallingford Report TR 101.

HR Wallingford (2001). Tollesbury Creek Managed Set Back Experiment. Analysis of bathymetric changes between 1999 and 2000, HR Wallingford Report TR 120.

- HR Wallingford (2002) Tollesbury Creek Managed Set Back Experiment. Analysis of bathymetric changes between 2000 and 2001, HR Wallingford Report TR 126.
- HR Wallingford (1995). MAFF Set Back Experiment, Tollesbury Creek, Report on model investigation of breaching scenarios, HR Wallingford Report SR 413.
- HR Wallingford (2001). Sustainable Flood Defences. Monitoring of Retreat and Recharge Sites. Project Number MRD 21110 Abbotts's Hall, Numerical Modelling. HR Wallingford Report EX 4367.
- HR Wallingford (2001). Beneficial Use of Dredged Material: North Shotley. HR Wallingford Report TR 72.
- HR Wallingford (2001). Beneficial Use of Dredged Material: Horsey Island. HR Wallingford Report TR 74.
- HR Wallingford (1997). Harwich Harbour Strategic Studies Potential breaching of Trimley and Shotley flood defences. HR Wallingford Report EX 3732.
- HR Wallingford (2002). London Gateway Development Studies. Hydraulic study of amelioration Sites A and X. HR Wallingford Report EX 4634.
- Huckle, J.M., Potter, J.A. and Marrs, R.H. 2000. Influence of environmental factors on the growth and interactions between salt marsh plants: effects of salinity, sediment and waterlogging. *Journal of Ecology* **88**, 492-505.
- Hughes, R.G. and Gerdol, V. 1997. Factors affecting the distribution of the amphipod *Corophium volutator* in two estuaries in south-east England. *Estuarine and Coastal Shelf Science*, 44, 621-627.
- Hughes, R.G., Lloyd, D., Ball, L. and Emson, D. The effects of the polychaete *Nereis diversicolor* on the distribution and transplanting success of *Zostera noltii*. *Helgoland Marine Research*, **54**, 129-136.
- Hughes, R.G (2001).
- Huiskes, A.H.L., Koutstaal, B.P., Herman, P.M.J., Beeftink, W.G., Markusse, M.M. and de Munck, W. 1995. Seed dispersal of halophytes in tidal salt marshes. *Journal of Ecology*, **83**, 559-567.
- Ingold, A. and Havill, D.C. 1984. The influence of sulphide on the distribution of higher plants in salt marshes. *Journal of Ecology*, **72**, 1043-1054.
- Jacobs, R.P.W.M., den Hartog, C., Braster, B.F. and Carriere, F.C. 1981. Grazing of the sea grass *Zostera noltii* by birds at Terschelling (Dutch Wadden Sea). *Aquatic Botany*, **10**, 241-259.
- Jickells, T., Andrews, J., Samways, G., Sanders, R., Malcolm, S., Sivyer, D., Parker, R., Nedwell, D., Trimmer, M. and J. Ridgeway (2000) *Nutrient fluxes through the Humber estuary: Past, present and future*. *Ambio* **29**, 130-135.

JNCC. 1993,1996,1997. An Inventory of UK Estuaries. Volumes 1-7. Peterborough, Joint Nature Conservation Committee.

Jones, N.V. (ed.) 1995. *The Changing Coastline*. Coastal Zone Topics: Process, Ecology and Management 1. Joint Nature Conservation Committee and Estuarine and Coastal Sciences Association, Peterborough.

Koutstaal, B.P., Markusse, M.M. and De Munck, W. 1987. Aspects of seed dispersal by tidal movements. In: A.H.L.Huiskes, C.W.P.Blom and J.Rozema (eds), *Vegetation Between Land and Sea*, pp.226-233. Junk, Dordrecht, Netherlands.

Knutson, P.L., Allen, H.H., and Webb, J.W. 1990. *Guidelines for vegetative erosion control on wave-impacted coastal dredged material sites*. US Army Corps of Engineers.

Krone, R.B. 1993. Fundamental principles of tidal wetland restoration. In : H.W.Shen, S.T.Su, and F.Wen (eds), *Hydraulic Engineering '93*. American Society of Civil Engineers, New York, pp.137-142.

Langlois, E., Bonis, A. and Bouzille, J.B. 2001. The response of *Puccinellia maritima* to burial: a key to understanding its role in salt marsh dynamics? *Journal of Vegetation Science*, **12**(2), 289-297.

Lee Long, W. and Thom, R.M. 2001. Improving seagrass habitat quality. In: F.T.Short and R.G.Coles (eds), *Global Seagrass Research Methods*. Elsevier Science B.V., Amsterdam, The Netherlands, pp.407-423.

Little, C. 2000. *The Biology of Soft Shores and Estuaries*. Oxford University Press, Oxford, England.

Long, S.P. and Mason, C.F. 1983. *Saltmarsh Ecology*. Blackie, Glasgow.

MAFF 1996. *The Habitat Scheme, Saltmarsh Information Pack*.

McLusky, D.S. 1989. *The Estuarine Ecosystem* (2nd edition). Blackie, Glasgow.

Mettam, C. 1980. The intertidal ecosystem. In: T.L.Shaw (ed.), *An Environmental Appraisal of Tidal Power Stations*, pp.87-108. Pitman, London.

Mitch, W.J. and Gosselink, J.G. 1993. *Wetlands*. 2nd edition. Van Nostrand Reinhold, New York, USA.

Möller I, Spencer T & French JR, 1996. *Wind wave dissipation over saltmarshes surfaces: preliminary results from Norfolk, England*. *Journal of Coastal Research*, **12** (4), 1009-1016.

Möller I, Spencer T, French JR, Leggett DJ and Dixon M, 1999. *Wave transformation over salt marshes: a field and numerical modelling study from North Norfolk, England*. *Estuarine, Coastal and Shelf Science*, **49**, 411-426

Mucmullon and Collins, draft (2003) *Compensation for F & CD operations. East Solent Coastal Group; Environmental issues – compensatory habitat.*

Muehlstein, L.K., Porter, D. and Short, F.T. 1988. *Labyrinthula sp.* A marine slime mould producing the symptoms of wasting disease in eelgrass, *Zostera marina*. *Marine Biology*, **99**, 465-472.

Muehlstein, L.K., Porter, D. and Short, F.T. 1991. *Labyrinthula zosterae*, the causative agent of wasting disease of eelgrass, *Zostera marina*. *Mycologia*, **83**, 180-191.

Nelson, T.A. 1997. Epiphyte-grazer interactions on *Zostera marina* (Anthopyta monocotyledons): effects of density on community structure. *Journal of Phycology*, **33**, 740-752.

Nicholls, D.J., Tubbs, C.R. and Haynes, F.N. 1981. The effect of green algal mats on intertidal macrobenthic communities and their predators. *Kieler Meerestorsch*, **5**, 511-520.

Ogilvie, M.A. and Matthews, G.V.T, 1969. Brent geese, mudflats and man. *Wildfowl*, **20**, 110-125.

Olney, P.J.S. 1963. The food and feeding habits of teal *Anas crecca crecca* L. *Proceedings of the Zoological Society of London*, **140**, 169-210.

Packham, J.R. and Willis, A.J. 1997. *Ecology of Dunes, Salt Marsh and Shingle*. Chapman and Hall, London

Paterson, D.M. 1994. Microbiological mediation of sediment structure and behaviour. In: P.Caumette and L.J.stal (eds), *Microbial Mats*. NATO ASI series 35, 97-109. Springer, Berlin.

Percival, S.M., Sutherland, W.J. and Evans, P.R.1998. Intertidal habitat loss and wildfowl numbers: applications of a spatial depletion model. *Journal of Applied Ecology*, **35**, 57-63.

Pethick, J.S. 1984. *An Introduction to Coastal Geomorphology*. Edward Arnold, London.

Pethick, J. 2003 *Option Assessment: Rewalls, East Mersea*. University of Newcastle. Pp 46.

Phillipart, C.J.M. 1995. Effect of periphyton grazing by *Hydrobia ulvae* on the growth of *Zostera noltii* on a tidal flat in the Dutch Wadden Sea. *Marine Biology*, **122**, 431-437.

Pielou, E.C. and Routledge, R.D. 1976. Salt marsh vegetation: latitudinal variation in the zonation patterns. *Oecologia* **24**, 311-321.

Preston, C.D., Pearman, D.A. and Dines, T.D. 2002. The New Atlas of the British and Irish Flora, Oxford University Press, Oxford, England.

Pritchard and Kirby (2002) *Areas of Potential Intertidal Habitat Creation in Hampshire*. Hampshire County Council report.

Proctor, M.C.F. 1980. Vegetation and environment in the Exe Estuary. In *Essays on the Exe Estuary*, pp.117-34. Devonshire Association, Exeter.

Rand, T.A. 2000. Seed dispersal, habitat suitability and the distribution of halophytes across a salt marsh tidal gradient. *Journal of Ecology* **88**, 608-621.

Randerson, P.F. 1979. A simulation model of saltmarsh development and plant ecology. In: B.Knights and A.J. Phillips (eds) *Estuarine and Coastal Land Reclamation and Water Storage*. Saxon House, Farnborough, pp. 48-67.

Ranwell, D.S. 1972. *Ecology of Salt Marshes and Sand Dunes*. Chapman and Hall, London.

Ranwell, D.S., Wyer, D.W., Boorman, L.A., Pizzey, J.M. and Waters, R.J. 1974. *Zostera* transplants in Norfolk and Suffolk, Great Britain. *Aquaculture*, **4**, 185-198.

Rasmussen, E. 1977. The wasting disease of eelgrass (*Zostera marina*) and its effects on environmental factors and fauna. In: C.P. McRoy and C. Helfferich (eds), *Seagrass Ecosystems – a Scientific Perspective*. Marcel Dekker Inc., p.1-51.

Reading, C.R., Gray, A.J., Paramor, O.A.L., Garbutt, R.A., Watts, C.W., Spearman, J.R., Barratt, D.R., Chesher, T., Cox, R., Hughes, R.G., Mann, J.L., Myhill, D.G., Rothery, P., Semmence, J., Wolters, M. 2002. Managed Realignment at Tollesbury and Saltram. Final Report to DEFRA and NERC (DEFRA project CA 2313), Centre for Ecology and Hydrology, Natural Environment Research Council.

Rodwell, J.S. (ed.) 2000. *British Plant Communities, Volume 5, Maritime Communities and Vegetation of Open Habitats*. Cambridge University Press, Cambridge.

RSPB, June 2000, 'Seas of Change: An evaluation of potential sites for intertidal habitat creation'

Scholten, M. and Rozema, J. 1990. The competitive ability of *Spartina anglica* on Dutch salt marshes. In: *Spartina anglica – a research review*. A.J.Gray and P.E.M.Benham (eds). Institute of Terrestrial Ecology research publication no. 2. Natural Environment Research Council, HMSO, London, pp.39-47.

Scholten, M., Blaauw, P.A., Stroetenga, M. and Rozema, J. 1987. The impact of competitive interactions on the growth and distribution of plant species in salt marshes. In: A.H.L. Huiskes, C.W.P.Blom and J.Rozema (eds), *Vegetation Between Land and Sea*. Dr. W.Junk, Dordrecht, Netherlands, pp. 270-281.

Sharpe, J. .1999, *An evaluation of potential sites for intertidal habitat creation in East Anglia*. Proceedings of the 34th MAFF Conference.

Short, F.T., Ibelings, B.W. and den Hartog, C. 1988. Comparison of a current eelgrass disease to the wasting disease of the 1930s. *Aquatic Botany*, **30**, 295-304.

Short, F.T. and Coles, R.G. (eds), 2001. *Global Seagrass Research Methods*. Elsevier Science B.V., Amsterdam, The Netherlands.

Short, F.T., Coles, R.G. and Pergent-Martini, C. 2001. Global seagrass distribution. In: F.T.Short and R.G.Coles (eds), *Global Seagrass Research Methods*. Elsevier Science B.V., Amsterdam, The Netherlands, pp.5-30.

Short, F.T., Ibelings, B.W. and den Hartog, C. 1988. Comparison of a current eelgrass disease to the wasting disease of the 1930s. *Aquatic Botany*, **30**, 295-304.

Stewart, A., Pearman, D.A. and Preston, C.D. 1994. *Scarce plants in Britain*, JNCC, Peterborough.

Toft, A.R. and Maddrell, R.J. (eds) 1995. A Guide to the Understanding and Management of Saltmarshes. NRA, R&D Note 324

Tubbs, C.R. 1995. The Meadows in the sea. *British Wildlife*, **6**, 351-5.

Tubbs, C.R. and Tubbs, J.M. 1980. Wader and Shelduck feeding distribution in Langstone Harbour, Hampshire. *Bird Study*, **27**, 239-248.

Tutin, T.G. 1942. *Zostera marina* L.: Biological Flora of the British Isles. *Journal of Ecology*, **30**, 217-24.

Underwood, G.J.C 2000. Changes in microalgal species composition, biostabilisation potential and succession during saltmarsh restoration. In: B.R.Sherwood, B.G.Gardiner and T.Harris (eds), *British Saltmarshes*. Linnean Society of London, Forrest Text, Cardigan, pp.143-154.

Van Diggelen, J., Rozema, J. and Broekman, R. 1987. Growth and mineral relations of salt-marsh species on nutrient solutions containing various sodium sulphide concentrations. In: A.H.L. Huiskes, C.W.P.Blom and J.Rozema (eds), *Vegetation Between Land and Sea*. Dr. W.Junk, Dordrecht, Netherlands, pp. 260-268.

van Katwijk, M.M., Hermus, D.C.R., de Jong, D.J. and de Jonge, V.N. 2000. Habitat suitability of the Wadden Sea for *Zostera marina* restoration. *Helgoland Marine Research*, **54**, 117-128.

van Katwijk, M.M., Schmitz, G.H.W., Gasseling, A.P. and van Avesaath, P.H. 1999. Effects of salinity and nutrient load and their interaction on *Zostera marina*. *Marine Ecology Progress Series*, **190**, 155-165.

van Katwijk, M.M., Vergeer, L.H.T., Schmitz, G.H.W. and Roelofs, J.G.M. 1997. Ammonium toxicity in eelgrass *Zostera marina*. *Marine Ecology Progress Series*, **157**, 159-173.

- Vivian-Smith, G. and Stiles, E.W. 1994. Dispersal of saltmarsh seeds on the feet and feathers of waterfowl. *Wetlands* **14**(4), 316-319.
- Warwick, R.M. and Uncles, R.J. 1980. Distribution of benthic macrofaunal association in the Bristol Channel in relation to tidal stress. *Marine Ecology Progress Series*, **3**, 97-103.
- Webb, J.W and Newling, C.J. 1985. Comparison of natural and man-made salt marshes in Galveston Bay complex, Texas. *Wetlands*, **4**, 75-86
- Weckman, J. and Sales, L.W. 1993. Data collection preogram for the design of a wetlands restoration project. *Coastal Engineering Considerations in Coastal Zone Management*. S.A.Hughes.
- Weihe, P.O. 1935. A quantitative study of the influence of tide upon populations of *Salicornia europaea*. *Journal of Ecology*, **23**, 323-33.
- West, P.G. 2001. The conditions required for *Salicornia europaea* to grow and establish pioneer saltmarsh. A review of experimental work for the Environment Agency, January 2001.
- Whelan, P.M. and Cullinane, J.P. 1985. The algal flora of a subtidal *Zostera* bed in Ventry Bay, south-west Ireland. *Aquatic Botany*, **23**, 41-51.
- Wolaver, T.G., Zieman, J. and Kjerfve, B. 1986. Factors affecting short-term variability in sediment pH as a function of marsh elevation in a Virginia mesohaline marsh. *Journal of Experimental Marine Biology and Ecology*, **101**, 227-237.
- Woodhouse, W.W. 1979. Building salt marshes along the coasts of the continental United States. US Army Corps of Engineers, Coastal Engineering Research Center, Special report 4.
- Zedler, J.B. 1984. *Saltmarsh restoration: a guidebook for Southern California*. No 7-CSGCP-009). California Sea Grant College.
- Zedler, J.B. 1996. Tidal Wetland Restoration: A Scientific Perspective and Southern Californian Focus. California Sea Grant College System, University of California, La Jolla, California.
- Zedler, J.B. and Adam, P. 2002. Saltmarshes. In: M.R.Perrow and A.J.Davy (eds), *Handbook of Ecological Restoration, Volume 2 Restoration in Practice*. Cambridge University Press, Cambridge, England.

APPENDIX 1: REVIEW OF PRESENT SITE SELECTION PROCEDURES AND CRITERIA

1.0 Aims and approach:

The aim of this chapter is to review the present site selection procedures and criteria that are implemented by managers and prospective end-users of the decision tools. This review is designed to assess the current guidelines and procedures for site selection, the criteria used and how habitat creation features within this framework. In addition there was an aim to determine those aspects of site selection and success which are well accounted for and understood and where improvements could be made.

The overall aim is to try and bring knowledge and understanding ('best practise') on site selection together and through this entire project help deliver an approach which could be implemented by many end-users and provides a clear and transparent audit trail towards a decision and site selection.

The approach taken was to review the protocols implemented by main stakeholders in site selection and the criteria used. This was undertaken by examination of relevant literature (site reports, monitoring reports, engineering reports, strategy documents, SMPs, CHaMPs etc) and also meetings with representatives from stakeholder organisations. This was designed to provide an overview of present protocols and criteria used. The review of documentation and site selection of sites included those that proceeded but also those that didn't.

The criteria used at present by the three main organisations (the EA, EN, and the RSPB) involved in implementing schemes are outlined below. The information has been compiled using reports / publications and following discussions with relevant personnel within each organisation. An overview of the present procedures and strategy involved with site selection by these organisations is reviewed here.

Other interest groups which were consulted or involved were: wildlife trusts, local and county councils, consultants all of whom may carry out work on behalf of the main agencies or be involved in the consultation process.

This consultation process will also inform requirements for the decision tools in terms of habitat creation procedure and application.

2.0 Drivers for managed realignment and hence site selection

The drivers for managed realignment have been identified and discussed at length in many previous project reports (ABP, 1998; DEFRA/EA, 2002; CIRIA, 2003) and so will not appear here. However, it is worth here presenting briefly the main reasons behind why a prospective site is identified as this will often form a basis for site selection procedure and criteria used.

Central to the suitability criteria in place at present are the differences in the need to create a habitat. Four main drivers have been identified, which, importantly, are not always mutually exclusive;

- 1 – Mitigation sites for a development where habitat will be lost.
- 2 – Compensation for natural habitat loss (potentially due to coastal squeeze/sea level rise)
- 3 – Compliance with EU Habitats or other directives for creation of habitat.
- 4 – Cost-effective flood defence strategy for a particular area.

These distinctions are important, as while habitat creation are particularly important for the first three, it is less relevant for the fourth. Consequently, the importance of scientific understanding of the factors which contribute to the type of habitat as compared to logistical constraints vary. This will ultimately have implications for the relevance of a decision-making tool based on the scientific understanding within the site selection criteria of an end-user.

3.0 Reviews of present site selection procedures and suitability criteria:

How sites are identified by any of the main coastal management organisation is generally co-incident with a strategic perspective of the four main drivers listed above and hence identification of sites may be in line with all or some of the main plans and policies which managers may be following. The main estuarine and coastal plans, which will incorporate managed realignment in decision-making, are:

Shoreline Management Plans (SMPs), Coastal Defence/Flood management Strategies (FMS), Estuary Management Plans, Coastal Habitat Management Plans (CHaMPs) and Biodiversity Action Plans (BAPs). A full review of each of these types of plan and policies and their recommendations in terms of site selection for managed realignment is given in the CIRIA document (CIRIA, 2003) and so will not be expanded here.

In combination, these strategic plans give a large-scale approach, and sites may be selected according to a combination of criteria of which habitat creation may only be one. However, each of these plans are drafted regionally and the approaches taken within and between agencies and end-users can vary. The decision tools developed as part of this project need to sit within this strategic framework and therefore an overview of the range of approaches taken at present is essential and is discussed here using case studies as examples.

3.1 The Environment Agency:

Site selection by the EA is linked closely in terms of all four drivers listed above. Various plans (such as the SMPs) can give policy options for the coastline, within which managed realignment may be considered and site selection is taken forward. In most cases site selection is directed under the SMPs which co-ordinate flood and coastal defence issues, however, sites primarily for mitigation and compensation are usually covered at the scheme or strategy level and may be outside the SMP. Of high priority to the EA is a balance to set any site selection in context of all the other management issues within the estuary. The balance can shift depending on the issues in any particular estuary or area.

From various contacts in the EA a survey was conducted to try and ascertain if there was a strategic protocol for site selection that was being followed either at a local,

regional or national level. It was found that there was no overarching strategy or document/guidance for this but that there had been some good examples of protocol for site selection and these were actively disseminated across regions where possible. A few examples are given here of various approaches taken and the criteria used in different regions. This is not exhaustive but covers a good scope of approaches being taken. Several contacts within different regions were approached whom had experience of managed realignment site selection and implementation and along with documentation on sites these form the basis of the text here:

3.1.1: The Humber

The Humber Estuary Shoreline Management Plan (Planning for the rising tides, 2000) sets out the EAs strategy for managing the flood defences of the Humber estuary over the next 50 years and the key issues.

The overall flood defence strategy has three elements;

- 1) Protect people and property by maintaining a line of defences around the estuary
- 2) Review the existing line to determine whether moving it locally will;
 - a. Reduce flood defence costs
 - b. Provide benefits by affecting estuary behaviour (water levels)
- 3) Support the creation of new intertidal habitat to maintain the estuary's conservation status.

This document takes a whole estuary approach in looking at how the estuary is likely to change in the future, a review of the defences and implicit within aims 2 and 3 is the need to identify areas that would be appropriate for managed realignment. In this way the main aims for managed realignment is to lower peak water levels (by storing floodwater) or to provide replacement habitat or both.

Site selection process:

The selection of sites suitable for managed realignment within the Humber has been a long term process starting in 1998. There are 3 main steps to identifying sites:

- Improving the understanding of how the estuary is likely to develop in the long term (to confirm that setting back of defences in some places will provide the expected benefits).
- Preliminary identification of potentially suitable sites
- Detailed appraisal of these sites (including modelling to look in more detail at the effects on the estuary).

Detailed management realignment studies were carried out to give insight into the preliminary identification of potential setback sites. These estuary development studies examined how the estuary is likely to develop over the next 50 years and how this development will be affected by variations in river flow, frequency of storms and surges, sea level changes and sediment supply, i.e. to give insight into long-term estuary and coastal development. Some example studies are listed below;

- Analysis of historic changes in bed and water levels;

- Patterns of sediment movement near estuary mouth;
- Long-term development of Spurn Head;
- Long term morphological modelling of the estuary;
- Long-term development of the coast;
- Inter-action between coastal and estuary processes;
- ‘Top-down’ studies deducing long-term developments in the Humber by comparison with developments in other estuaries.

These studies also estimated how much of the intertidal foreshore is likely to be lost in different parts of the estuary for a range of possible conditions and therefore how much needs to be replaced by managed realignment. This feeds directly into the CHaMP to maintain the estuary’s conservation value and meet obligations under EU legislation. For example: modelling has identified an estimated loss of 460ha of intertidal area, mostly in the middle estuary with a small gain further upstream. Overall, within the CHaMP a total of between 650 and 850 hectares of replacement habitat needs to be provided. The new habitat should be distributed to maintain and enhance the estuary’s environmental quality which means that a good proportion will be in the middle and outer estuary. (Update, 2003).

At this point, potentially suitable sites were identified.

The original shortlist of generic site selection criteria were:

- Site size and estuary position;
- Potential improvement to the estuary’s defence system;
- Impacts on owners, occupiers and local community;
- Presence of homes, properties and industrial sites;
- Important roads, railway lines and other facilities;
- Features of historic or wildlife value;
- Effects of estuary processes;
- Area and quality of new habitat created;
- Engineering feasibility;
- Likely costs.

Within these criteria the area and quality of new habitat created is only one aspect. To aid in the selection of sites that had high potential for sustainable habitat creation a habitat migration study (EA, 2000) was completed as part of the further development of the SMP. The approach and parameters used in this study for site selection are summarised here.

Habitat Migration study:

The main objectives for the habitat migration study were:

- To identify existing areas of habitat in and around the Humber estuary using the HEEBS (Humber Estuary Environmental Baseline Study) database.
- To identify the potential for sustainable habitat creation in the immediate vicinity of the estuary

- To identify broad requirements for habitat creation and locate where these conditions can potentially be met within the existing environment.

The last two aims and overall approach in particular are relevant to this project (FD1917). The process and criteria used and developed in this process are summarised here.

The main source of data was the HEEBS which provided baseline data for the estuary and a GIS-based data management system for the SMP.

The identification of the broad requirements for habitat creation and where these conditions could be met spatially was achieved by a three stage screening process which progressively removed areas of land from a study area due to physical and environmental constraints which would restrict opportunities for habitat creation. This approach therefore highlights the areas with most constraints upon habitat creation rather than targeting suitable sites.

For example: A landward limit of 1Km was used behind any particular section of sea wall for the purpose of screening out areas unsuitable for habitat creation.

The **first stage** involved the description (extent and distribution) and evaluation of existing areas of habitat and their location. Main descriptions were: wetland/freshwater communities, sand dunes, saltmarsh, waste ground, reedbeds, Grassland, non-natural. Evaluation was completed in the context of national and international designations for nature conservation. Habitat mosaics (shape and proximity to other habitats) were also documented.

The second stage involved is the prediction of the vegetation zonation in the absence of sea defences. A relationship was determined between the existing distribution of vegetation types and the tidal frame using an empirical model. This model was then applied to an elevation (LIDAR) map of the estuary in order to predict the habitats that could potentially be created if the sea defences were removed.

The main factors controlling vegetation zonation were identified as:

- Elevation of the land with respect to tide (periodicity and duration of inundation)
- Salinity (type of vegetation, varies with ratio of fresh to seawater)
- Sediment supply (rate of deposition/surface elevation change)

The assumptions that were made were:

- Zonation is predominantly controlled by elevation
- Elevation of the land remains constant during vegetation development (in reality this will alter and zonation will develop/change with sediment accretion which is a function of vegetation, elevation and sediment supply)

The effects of salinity were not examined

Vegetation prediction is assumed to be mainly a product of:

- Elevation of the land
- Tidal frame
- Salinity characteristics
- Relationship between vegetation type and position in the tidal frame.

Flood plain elevations (between present defences and 5m (OD) contour) were determined using a BGS terrain model.

Tidal inundation was assessed from Admiralty charts and trend lines fitted to mean high and low water springs to give a tidal frame envelope for the whole estuary.

The relation of vegetation type to position in the tidal frame was determined by derivation of an empirical model which compared observed zonation and corresponding tidal topography of the estuary. The detailed procedure can be found in the habitat migration study report (EA, 2000)

The mapping of habitat types and application of the tidal elevation allowed derivation of mean and derived heights (mMHWS) for the occurrence of each habitat type and boundaries between adjacent vegetation zones (see Tables A1 and A2).

Table A1: Mean height (mMHWS) of occurrence of each habitat type in the Humber estuary (EA, 2000)

	Grassland	Reedbed	Upper Marsh	Brackish Saltmarsh	Mid Marsh	Pioneer Marsh	Mud/saltmarsh boundary
Mean height	0.8	-0.1	0.3	0.0	-0.1	-0.6	-0.5
St. dev.	0.6	0.5	0.7	0.4	0.2	0.7	0.6

Table A2: Derived heights (mMHWS) of the boundaries between adjacent vegetation zones in the Humber Estuary (EA 2000)

Habitat Boundary	Height (MHWS)
Mudflat – saltmarsh	-0.49
Pioneer marsh – Mid marsh	-0.1
Mid marsh – Upper marsh	-0.06
Upper marsh – Brackish marsh	0.03
Brackish marsh - Grassland	0.31

Appendix J in the habitat migration report (EA, 2000) also documents the estimated average height of occurrence for each vegetation type on the North and South Bank relative to mOD.

Appendix C in this report is a generic review of requirements for estuarine habitat creation for various habitats (including saltmarshes) from the US and European literature and also from various schemes in the UK (Blackwater) and historical setback studies (Burd, Clifton and Murphy, 1994; Burd, 1995).

The main criteria used in this study for predicting the suitability for habitat creation has been largely based on the influence of elevation on plant colonisation. In practise it is acknowledged that habitat types can be controlled by a number of factors such as salinity, water velocity, sedimentation/erosion patterns, physical and chemical characteristics of the soils, exposure to wave action, availability of colonisers. All these factors would need to be examined on a site-by-site basis. The study recommends investigation of the relationship between salinity, tidal velocity, rates of sedimentation/erosion and plant colonisation could be usefully investigated at an estuary wide scale and incorporated into the model used for vegetation prediction. Improvements of this type are the aim of this project in refining habitat creation requirements and prediction.

This analysis in the Humber indicated that due to low elevation of the land that large areas of mudflat would develop with relatively restricted creation of saltmarsh in areas flooded without any mitigation.

The **third stage** constitutes removal of areas which are considered unsuitable for habitat creation. These are implemented in three stages of screening which involves removal of areas which incorporate:

- 1)
 - built-up areas
 - industry
 - A-roads and railway lines
- 2)
 - Land over 5m contour
 - Roads leading to built up areas
 - Known areas of contaminated land
 - 'fixed' waste management sites
 - source protection zones
- 3)
 - High voltage power lines
 - 'moveable' waste management sites
 - areas to landward of A-roads and railway lines in use
 - nationally and internationally designated conservation sites (SPA/SAC/SSSI)
 - Grade 1 agricultural land
 - Golf courses and other forms of recreational areas
 - Surface and groundwater abstraction points
 - Consented discharges
 - Archaeological sites
 - Oil and gas pipelines

The remaining areas after this three stage process are those identified as being suitable for habitat creation.

Further screening may then be applied with respect to the quality of the existing defences throughout the whole estuary to give a first cut at prospective set-back sites. (~35 sites)

Once sites have been identified a detailed appraisal of the sites will take place which examines the effect of setting back the defences at the site on aspects of the estuary's behaviour, navigation and estuary users. Other considerations are the condition of the existing defences and new defences that may be needed, existing habitats in the area and new habitats that are likely to develop.

Site specific studies that have been undertaken are:

- Impact on water levels and estuary development;
- Habitat survey and site inspection;
- Strategic environmental assessment;
- Outline design and cost estimates;
- Cost and benefit assessment.;
- Detailed modelling of setback sites;
- Detailed morphological modelling of setback sites.

For each of the sites a multi-criteria analysis is performed (seven groups of variables of which one was environmental) to assess the assets gained or lost. Environmental assets were only 1-2 issues in the whole list. The main drivers are compensation and setback issues.

Overall this process has worked very well and several sites have now been identified and taken forward. However, this approach also requires a lot of resource and time consuming in terms of the modelling approaches. The approaches used for identifying possible baselines for habitat creation is very applicable to other estuaries i.e. stage 2. This approach should be applicable to other estuaries either by survey or by providing generic habitat and vegetation prediction information.

3.1.2: Essex estuaries

Issues of managed realignment are at the forefront in the Essex estuaries due to issues of sea level rise and low lying land. There has been a significant loss of saltmarsh due to coastal squeeze (For example, ~140ha in the Blackwater estuary between 1973 and 1998). This area therefore has a relatively high number of habitat restoration sites.

Examples of habitat restoration in the Essex estuaries are:

- Hamford Water- beach nourishment using harbour dredgings;
- Cudmore Grove - historical saltmarsh restoration site (1988/89);
- Abbots Hall - recent (November 2002) realignment site;
- Tollesbury - realignment site (1995);
- Northey Island - realignment site (1991);
- Orplands - realignment site (1995);
- Dengie - historical saltmarsh restoration sites (1980-1989);
- Blue House Farm - coastal grazing marsh management.

Each of these sites has gone through some assessment en route to creation but these may vary depending on various issues: The main focus is provided by the SMPs (created in 1996/7) which identify options for the coastline, mainly in terms of socio-economics, infrastructure, land-use and coastal processes where information was available.

An example of the protocol followed for a given site is as an option assessment for a given area of land (Pethick, 2003, Rewalls). This involves appraisal of the various options on a site-by-site basis. This may involve looking at the history, geology and geomorphology of a site and using numerical modelling to assess/predict sediment budgets and morphological/profile change which would occur if the site was realigned. The option of managed realignment is then set in context of other options such as 'do nothing', 'hold the line' or other options and hence a suitable option is recommended. This approach relies heavily on expert judgement and is focussed on identifying the sustainable option in terms of hydrodynamics and coastal processes however, other considerations such as practical removal of the flood embankments and economic considerations have also to be added in due course. In this case habitat creation assessment is undertaken separately. The exact approach may differ between sites but the overall criteria examined are common to most sites.

For example (Karen Thomas (EA) pers comm): The site at Orplands was preliminarily decided upon due to 3-4 pinch points identified on the Blackwater estuary where saltmarsh had been eroded back to the walls (in many areas this is the case in the Blackwater). The site was in a long strip with naturally rising ground behind and appropriate elevations which would give some indication of resulting habitats (See Figure A1). Purchase of the land was possible via a wildfowling association and could be offset for saltmarsh creation (EU funded) under the Habitats directive (50ha/yr) plus the additional flood and coastal benefits.

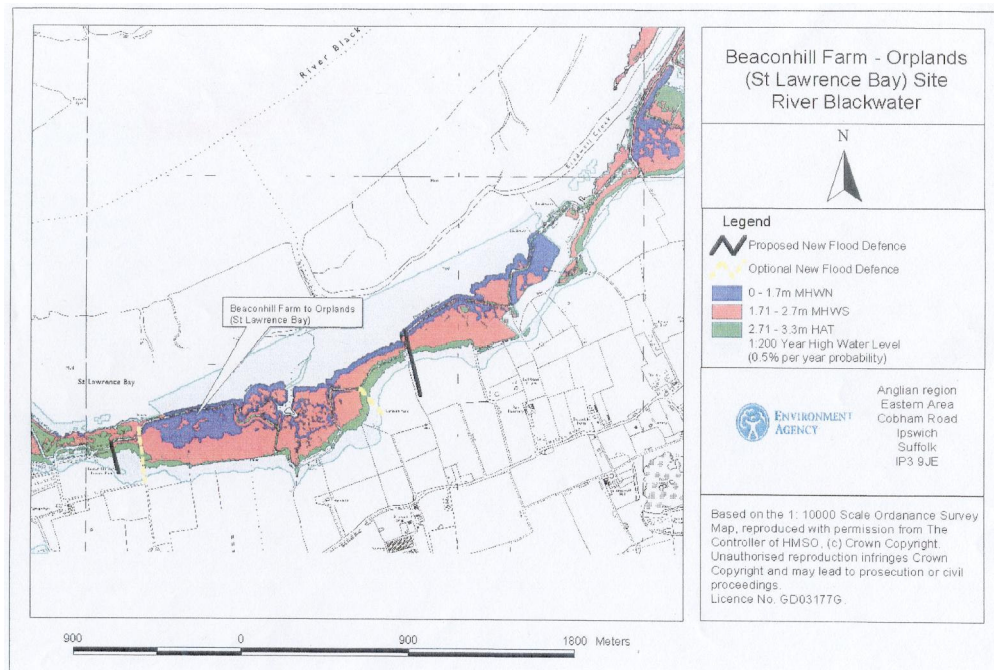


Figure A1: Elevation map of Orplands managed realignment site, Blackwater.

For other sites (Abbotts Hall and Tollesbury) in the Blackwater hydrodynamic modelling was carried out to look at creek development, wider impact of the site on the surrounding area and optimum breach locations. However, this usually happens when sites have already been selected and is therefore not part of the site selection process.

The site selection approach and expertise gained from various Essex sites has been formalised into assessment criteria and decision tree under the Essex Estuaries Strategy. It should be noted that the main categories for site assessment are cost, hydrodynamics, environment, owner interest and defence condition and hence habitat creation potential is only one factor in five. Each site is given a non-weighted score according to the assessment against these criteria which will rank potential sites against each other. The decision tree, example score sheets and additional information to the assessment criteria are given in Figure A2 and Tables A3 and A4.

This approach has been further refined under the Essex Flood management strategy. The matrix has been tested in the Crouch and Roach (and will be applied to Blackwater eventually):

Under the flood management strategy possible set-back sites (at the Flood management unit scale) are being identified and ranked using various criteria. The criteria are:

- Site size and position in the estuary;
- Potential harmony with the estuary's predicted natural response to water movements;
- Impacts on owners, occupiers and the local community;
- The presence of properties, industrial sites and transport infrastructure;
- Features of historic or wildlife value;
- Area and quality of new habitat created ;
- Engineering feasibility and likely costs.

Within this framework a more detailed assessment of flood management units has been carried out using a matrix of site selection criteria for salt marsh generation and managed realignment for the Roach and Crouch Estuaries (Halcrow, 2003). The criteria are grouped into 3 categories according to level of importance for salt marsh regeneration (see Table A5). Sites are then scored against each criterion and the preferred sites are those that meet most (or all) category A criteria, then within those the sites that meet most category B criteria and amongst those sites meeting most category C criteria. The output is an overall score in which to rank the Flood management units with a higher score giving a greater feasibility of saltmarsh/mudflat regeneration.

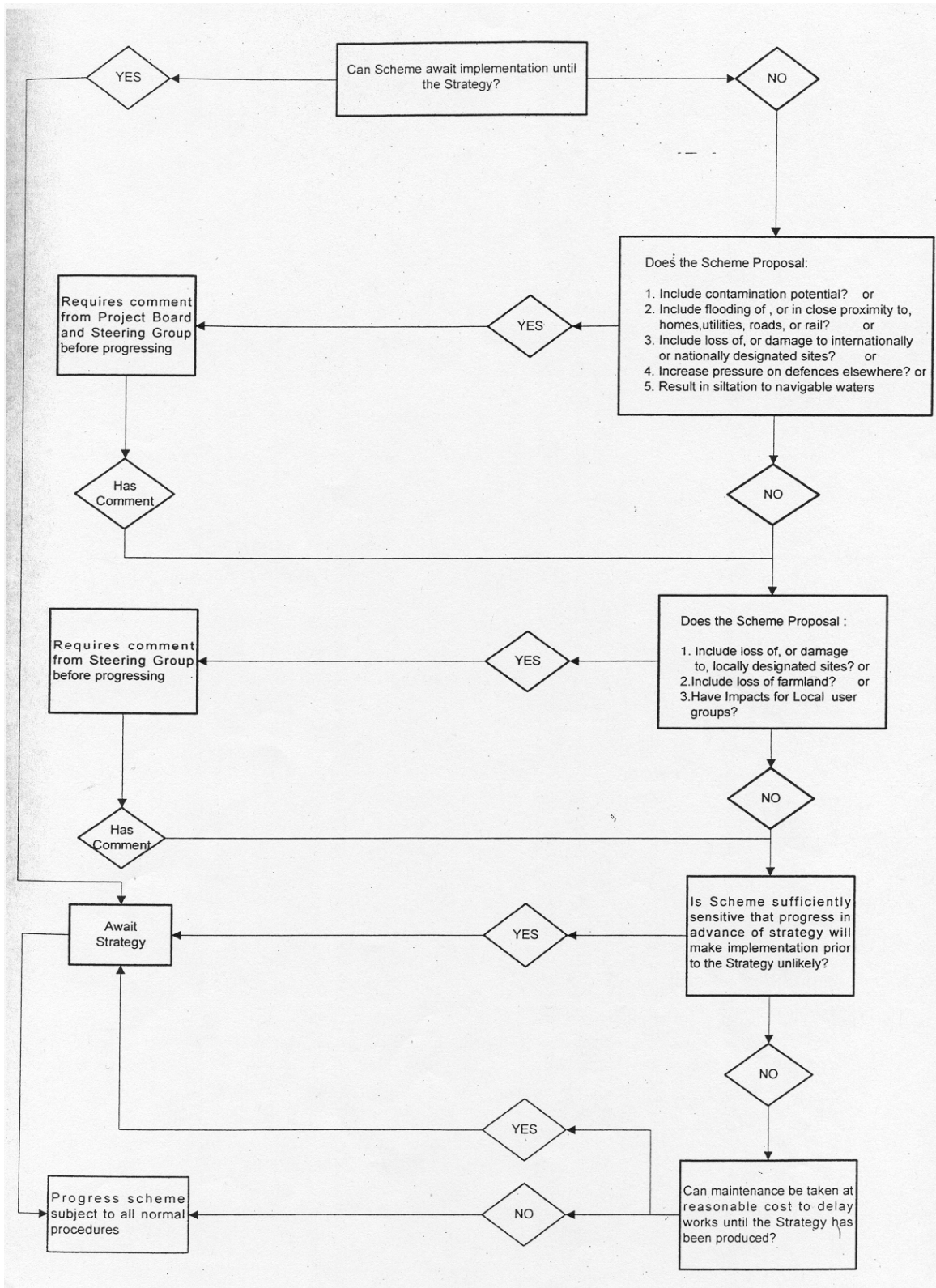


Figure A2: Decision tree for scheme selection (Halcrow, 2002)

Table A3: Sample score sheet for site assessment criteria (Halcrow, 2002)

<u>CATEGORY</u>	<u>ASSESSMENT CRITERIA</u>	<u>POSSIBLE POINTS</u> (*min threshold level)	<u>NON-WEIGHTED SCORE</u>
<u>Costs</u>	<p><u>Cost per hectare of habitat created</u></p> <p>a) Minimal work required: Breach only. b) Breach and creek design. c) Breach, creek design and small counterwalls. d) Breach, creek design and large counterwalls. e) Maximum work required: Breach, creek design, counterwalls and back wall.</p>	<p>5 4 3 2 1</p>	
<u>Hydro-dynamics</u>	<p><u>Potential for impact on coastal/estuarine processes.</u></p> <p>a) Minimum impact: Some direct losses of intertidal habitat anticipated as a result of breaches. Size. b) Some direct losses of intertidal habitat anticipated as a result of breaches, coupled with some increase in tidal volume and velocity. Increases in erosion or accretion adjacent to site <i>not</i> anticipated. c) Some direct losses of intertidal habitat anticipated as a result of breaches, coupled with some increase in tidal volume and velocity. Increases in erosion or accretion adjacent to site <i>are</i> anticipated. Habitat gain significantly outweighs loss. d) Considerable loss of intertidal habitat anticipated as a result of breaches. Significant increases in tidal volume and tidal velocities. Significant risk of increased erosion both directly and indirectly of adjacent intertidal sites. e) Maximum impact likely: Significant increases in tidal volume and tidal velocities. Significant risk of increased erosion both directly and indirectly of adjacent intertidal sites. Potential for damage to strategic coastal features e.g. relict ebb tide delta's, islands. Potential for damage to adjacent flood defences.</p>	<p>5 4 3* 1 0</p>	
<u>Environment</u>	<p><u>Potential to improve the local environment</u></p> <p>a) Positive improvement: Good topographic levels throughout site. Freshwater inputs present. Other impacts can be addressed. b) Positive improvement: Good topographic levels throughout site. 3 or less significant impacts present/likely. c) Some improvement: Good topographic levels throughout <i>most</i> of site. 3 or less significant impacts likely. d) Little or no improvement: Poor topographic levels throughout site. Most impacts considered to be present/likely. e) Negligible Improvement: Poor topographic levels and/or presence of Ancient Scheduled Monument (SAM) on site.</p>	<p>5 4 3* 1 0</p>	
<u>Owner Interest</u>	<p><u>Is the landowner(s) interested in managed re-alignment on his/her land?</u></p> <p>a) All landowners interested. b) Landowner may be interested/Good possibility. c) No landowners agree/Landowner view not known.</p>	<p>5 3 0</p>	
<u>Defence Condition</u>	<p><u>What is the standard of the current flood defence at this location? (Using asset survey data).</u></p> <p>a) Excellent condition b) Good condition c) Average condition d) Poor condition e) Very poor condition</p>	<p>1 2 3 4 5</p>	

Table A4: Assessment criteria – additional information (Halcrow, 2002).

CATEGORY	ASSESSMENT CRITERIA
Costs	<p>Cost per hectare of habitat created</p> <p>Included to give an idea of how much construction work would be involved and therefore give a 'scale' of costs rather than actual financial figures. Actual costs will be calculated on a scheme by scheme basis once favourable sites have been identified.</p>
Hydro-dynamics	<p>Potential for impact on coastal/estuarine processes.</p> <p>Designed to eliminate sites which, if taken forward, could have significant impacts on local coastal processes. These scores will have to be based on current scientific principles for most sites and may require some discussion. These scores are likely to be modified in future once estuarine modelling studies have been completed for the Essex Estuaries. Some sites already have hydrodynamic surveys/studies and/or models in place which should make the scoring process easier. This category carries a threshold score. Any site not meeting this score should be eliminated on the grounds that it would be damaging to the local coastal/estuarine environment and processes. In the absence of hydrodynamic modelling reports, at present large sites are considered to be potential damaging to the adjacent environment due to the large increases in tidal volume that will occur. Sites in the order of 35-40 ha or less should be favoured when scoring in this section as this process is just an interim measure until further studies are completed.</p>
Environment	<p>Potential to improve the local environment</p> <p>As the main requirement of this work is to identify sites that would create saltmarsh, topographic level is considered the most significant environmental factor. After this a variety of other potential impacts come into play which may be of some significance but can be overcome. Alternatively, some impacts may be of much greater significance, causing delays to the scheme, requiring more extensive surveys or completely halting a scheme altogether. This category carries a threshold score. Any site not meeting this score should be eliminated for the following reasons. Either the topography is not suitable to create saltmarsh* and/or the potential impacts on the environmental aspects of the site are considered to be too great thus reducing the likelihood of completing a scheme successfully is unlikely. *It is accepted that other intertidal habitat is of importance e.g. mud flat, however the EA requirement in the interim guidance is to create saltmarsh as a priority.</p> <p>Environmental criteria/impacts include:</p> <p>Current designation (other than SPA) on the site. Presence of BAP and protected terrestrial species on the site. Loss of access/recreational area/amenity value to the public. Lack of adjacent saltmarsh habitat. Site is deemed important for archaeological reasons. Presence of a Scheduled Ancient Monument (SAM). Landscape issues (eg. Loss of trees)</p> <p>It should be noted that all sites have already been screened for people, property, infrastructure, and landfill issues as well as SPA designations. Sites where any of these issues are present are not included in this scoring process.</p>
Owner Interest	<p>Is the landowner(s) interested in managed re-alignment on his/her land?</p> <p>If the land-owner(s) shows no interest then obviously schemes will be very difficult to progress, if at all. Hopefully, this one is relatively self-explanatory.</p>
Defence Condition	<p>What is the current condition of the defence?</p> <p>Designed to give priority to walls in a poor state to minimise maintenance costs and avoid the breaching of potentially good seawalls</p>

Table A5: Salt marsh regeneration and managed realignment site selection criteria (Halcrow/EA, 2003).

<p>Category A Considered to be essential to feasibility, as the cost of overcoming them would be likely to be prohibitive</p>	<p>Economic viability of existing defence: The cost-benefit ratio for maintaining existing flood defences (a ratio of less than 1 will favour realignment).</p>
	<p>Contaminated land: the presence of landfill sites, refuse filled sea-walls and potentially contaminated land.</p>
	<p>Site elevation: ***</p>
<p>Category B Highly desirable, as the absence of these factors would give rise to significant policy issues, make it hard to comply with legislation or create practical difficulties</p>	<p>Level of confidence that existing estuary is unsustainable at that location: The level of confidence is extracted from the Sustainable Estuary Morphology report prepared for this FMS. The level of confidence is derived from estuary modelling, desktop studies and anecdotal evidence.</p>
	<p>Potential impact on local environment: absence of freshwater or terrestrial habitat within European/Ramsar site, SAC, SPA, LNR, SINC or SSSI; Scheduled Monument; freshwater abstraction etc</p>
	<p>Impact of managed realignment on existing salt marsh: no accelerated potential for erosion</p>
	<p>Surface soils: Clay or clayey loam soils are considered to adopt saltmarsh habitat more rapidly than gravel, sandy or alluvium soils (although both are acceptable).</p>
	<p>Landowners' willingness to sell: interested or some landowners if shared land</p>
	<p>Landowners' willingness to sell: interested or some landowners if shared land</p>
<p>Category C Preferred factors</p>	<p>Flood risk: sites breached to higher ground preferred as flood risk to neighbouring land would be low.</p>
	<p>Site gradient: 1% to 2% slope preferred (from LIDAR data and OS maps)</p>
	<p>Wave exposure: sheltered sites preferred (proportional to proximity to estuary mouth)</p>
	<p>Residual life of existing flood defences: Graded by proportion of defences in poor to excellent condition (residual life of 1-6yrs to >20yrs respectively) poor condition preferred.</p>
	<p>Ease of implementation: ranges from breach alone required to breach, creek design and secondary defence.</p>
	<p>Agricultural land classification: Grades 3a or above</p>
	<p>Potential source of funding and/or financial support e.g. DEFRA, countryside stewardship, others.</p>
	<p>Ease of site access: road, track, and/or foot.</p>

*** Topographical elevation maps can be developed from LIDAR data. The potential saltmarsh site are defined as those comprising more than 50% of the plan area at an elevation of + 2 to 3 mOD and the remainder below the 2mOD contour. The area below the 1 mOD contour is identified as potential mudflat.

More recently site selection has been implicitly linked to the Essex Estuaries Coastal Habitat Management Plan (CHaMP). A clear part of the Essex Estuaries CHaMP is to identify suitable areas for new habitats to be created and in conjunction with this documents the historic loss and gains of habitats in many estuaries. The Essex estuary system as a whole is losing 50ha per year of valuable saltmarsh environment which is there a legal duty on the UK government to protect or replace (FMS, 2003). As such it provides the context for site selection but is generic and for many estuaries does not include specific sites or approaches to selection.

3.1.3 : Hampshire/Solent (compensatory habitat)

The Environment Agency, Southern Region is looking to upgrade existing coastal defences along the Selsmore/Eastoke frontage (but also more widely) on Hayling Island, Hampshire. The scheme's accompanying Environmental Impact Assessment has shown that upgrading the defences on these two frontages will result in a total loss of 2.52 ha of intertidal habitat. The Agency is therefore looking to identify potential realignment sites in the region to compensate for habitat loss at the Selsmore/Mengham frontage over the next 50 years. To 'compensate' for the loss of intertidal habitat over the next 50 years the Agency must acquire and realign a suitable site in the surrounding area to offset this predicted loss.

To do this a study of managed realignment opportunities was carried out in Portsmouth, Langstone, Chichester and Pagham Harbours by the EA/ Atkins and in consultation with other authorities and agencies. The approach taken and site selection criteria used are described below (from Coutts and Roberts, 2003);

The development of the matrix and site selection was undertaken in a two-stage process. The first stage was a broad site identification exercise, which used a Geographical Information System (GIS) to identify areas of low-lying coastal land. The second stage was a refinement process in site selection using the matrices to evaluate the suitability of each site to realignment and reject those that were unsuitable for habitat creation.

Site identification was based originally on a two step process:

- **Stage 1:** Geographical site identification by topographical mapping;
- **Stage 2:** Two part site evaluation comprising:
 - Workshop discussions and scoring of sites by a primary site assessment matrix.
 - Application of a secondary site assessment matrix

Stage 1: Geographical Site identification (land elevation mapping)

This stage of site selection used a GIS program to identify broad potential sites. Electronic Ordnance Survey map tiles (Scale 1:10000) were obtained and the tidal levels shown in Table A6 were digitised onto the maps.

Table A6: Tidal levels used to discriminate habitat boundaries (from Coutts and Roberts, 2003)

Elevation	Habitat
Mean Low Water: 0m OD	> intertidal
Mean High Water Neaps: 1.5m OD	< intertidal, > saltmarsh.
Mean High Water Springs: 2.0m OD	< saltmarsh
Highest Astronomical Tide: 2.5m OD	> upper level of SM in 80yrs
Predicted 1:200 year flood level: 3.5m OD	

Although published literature on salt marsh development indicates that there are numerous factors to consider aside from simple site elevation, as a general rule, salt marsh vegetation begins to develop at approximately MHWN, and is found up to about the level of MHWS. Below MHWN mud flats are formed. On this basis, all areas between MLW and MHWN are digitised on the maps, indicating potential formation of mud flat, and areas between MHWN and MHWS are digitised separately to indicate potential formation of salt marsh. By digitising the sites in this way, the amount of potential habitat can be easily and accurately calculated.

At this stage, sites are identified solely on the basis of land elevation and tidal height data. The purpose of the mapping is to identify all areas that were potentially suitable for retreat/habitat creation, regardless of the issues of land ownership, existing land use or economic assets (e.g. houses or other buildings).

The mapping provides an initial estimate of mudflat and saltmarsh that may be created through realignment. However, this is an initial screening process and further investigation is required using more accurate data sources before a more precise assessment of habitat creation can be made. The HAT contour provides an indication of the upper level of intertidal saltmarsh in approximately 80 years (based on current estimates) and indicates the sites' sustainability in light of climate change.

The mapping exercise also collates data on existing conservation designations in the vicinity of each of the harbours. GIS data from English Nature's website are used in conjunction with the potential sites identified from the elevation mapping to produce electronic maps showing the location of both national (Sites of Special Scientific Interest) and European (SPA and cSAC) sites within the study area. These maps are used to show which sites are already subject to designations. All the sites are then ranked in two phases using the criteria identified for the matrices.

Stage 2: Site Evaluation Using Matrices

Primary site assessment matrix and stakeholder workshop

The primary site assessment matrix is a 'scoping exercise' and is designed to deal principally with non-technical information about each potential site with the scope of the matrix intended to be as broad as possible in order to cover as many potential issues as possible. The aim of this stage of the matrix is to eliminate those sites that are wholly unsuitable for realignment, to determine which sites are most suitable for further investigation and the identification of any site specific factors (both positive and negative) that could affect the potential of the site for realignment. To this end,

the topics included in the primary assessment matrix were based around very general concepts, such as whether the site had an intrinsic nature conservation value or whether there were any assets adjacent to the site that would be at risk from flooding if it were realigned. The matrix is designed to allow the assessment of multiple sites in a single table, and therefore facilitate a rapid assessment of site suitability.

The main factors considered in scoring the sites in addition to technical, coastal process and environmental constraints are:

- ◆ Existing nature conservation interest;
- ◆ The long term sustainability of the site (i.e. can the habitat retreat with predicted sea level rise?);
- ◆ The potential increased flood risk to adjacent properties/assets and the additional sea defence requirement to protect those assets;
- ◆ Potential conflicts with local planning and other policies;
- ◆ Potential impact on public access, recreation and landscape;
- ◆ Existing ownership and political acceptability of realignment.

As the scope of the matrix is very broad and the scoring system is limited to giving each site a positive, negative or neutral score for each item, with further space to record additional comments where necessary. The rationale behind each score was whether or not the item would contribute to the success of the scheme or made the site more suitable for realignment (+), prove to be a barrier to realignment or make it less feasible (–) or finally, have no discernible effect on the suitability or success of the site in realignment (0). At the end of the exercise, the total number of each type of score are added together to give an overall score for each site, with negative scores being subtracted from positives or vice versa. As there are a total of 13 categories upon which each site is scored, the highest possible score for each site is +13, and the lowest possible score –13. Once the sites are ranked, the highest scoring areas can be taken forward for more detailed investigation using the secondary matrix. The primary assessment matrix is shown in Table A7.

Secondary site assessment matrix

The rationale behind the structure of the secondary site assessment is to take forward a selection of potential sites for more detailed investigation. At this stage there are still too many sites and too many unknown factors to make it logistically justifiable to carry out a complete site investigation on each site (for example, using hydraulic modelling or trying to determine local accretion rates), and so the focus of the secondary site investigation is primarily to collect baseline (existing) data and use it in conjunction with the known technical requirements for salt marsh creation in order to make a direct comparison of suitability between each site.

The information to be included in the secondary site assessment matrix is based around a literature review. At this point, further investigation of the environmental and policy issues that would make each site either environmentally or politically

unacceptable is necessary, and also an initial investigation of land ownership issues. Technical issues that could be assessed without extensive detailed investigation are also included. The desired end result of this exercise is to identify two or three of the most appropriate sites that were worthy of a final detailed technical investigation and potentially, eventual realignment.

Table A7: Environment Agency’s Criteria for Identifying and Evaluating potential sites for managed realignment.

(from ‘Managed Realignment Opportunities in Portsmouth, Langstone, Chichester and Pagham Harbours, Atkins, 2002)

CRITERIA	SCORE (✓)		
	-	0	+
Environment	-	0	+
What is the intrinsic nature conservation value of the site (- internationally designated, 0 local/national designations, + no designations)			
Are there any habitats/species of interest? (even if not designated) (- numerous protected species/habitats, 0 a few protected species/habitats, + no protected species/habitats)			
Would the site be able to evolve with climate change (i.e. does it slope to the rear?), will it be sustainable? (-only mudflat created, 0 saltmarsh & some room for transition, + site elevated to rear)			
Will the current use of the site pose problems for any potential retreat scheme? (- existing public amenity, 0 agriculture, + no specific use)			
Flood Defence/Economics	-	0	+
Would realigning the site increase flood risk to neighbouring properties/services? (- numerous properties/services could be at risk, 0 a few properties/services could be at risk, + no properties/services at risk)			
Would rear defences be needed? (- extensive defences probably needed, 0 moderate/small scale defences may be required, + no defences thought to be required)			
Planning	-	0	+
Would realignment meet/conflict with the shoreline management policy? (- improve existing defences, 0 maintain the line, + do nothing/retreat)			
Would realignment conflict with local planning policy? (- site designated for development, 0 agricultural/amenity use, + no specific planning policies)			
Are there any services running through the site which could be affected by realignment? (- numerous services would need re-routing, 0 minimal impact, + no services at site)			
Would there be any loss of amenity value to the site? (- significant loss, 0 little impact on amenity value, + positive amenity benefit)			
Other	-	0	+

Who owns the land? (- unknown, 0 private landowner, + statutory authority or Wildlife Trust)			
Would they be interested in working with the Environment Agency to realign the site? (- known hostility, 0 unknown, + could be persuaded)			
What is the local feeling about realignment in this area? (- hostile, 0 unknown/unconcerned, + welcome)			
Additional issues			
What is the history of the site (reclaim, old saltmarsh etc)?			
Are there any footpaths or other access routes (e.g. slipways) through/on the perimeter of the site?			
Would the site be improved through realignment?			

The scope of the secondary matrix covers several sections;

- Statutory and legal issues,
- Environmental issues (including landscape),
- Technical issues,
- The potential sustainability of the site,
- Flood defence and economic issues, and;
- Social and recreational issues.

A wider ranging scoring system is employed in order to ensure issues that could have a major impact on the viability of a site were given greater weight, for example, if the site is already subject to an international designation and the statutory nature conservation authority were unlikely to grant permission for its use. For this phase, five possible scores are assigned to each of the 28 categories from -2 to +2, giving a maximum/minimum possible score of +/- 54 respectively. One matrix is completed for each site investigated. The secondary matrix is shown as Table A8.

Application of this full procedure allowed identification of an original 40 sites of which at the end of the secondary assessment exercise, three clearly emerged as being the most suitable for realignment. The scores for the top three sites were +15, +12 and +3 (with a possible maximum score of +54). These three sites have formed a starting point from which the Environment Agency can open up discussions with landowners in relation to land purchase.

This process also highlighted other generic issues that need to be considered in site selection such as;

- A higher number of smaller sites versus fewer larger sites
- Suitability of sites in the medium/long-term
- Changes in land valuation
- Restrictions due to conservations areas (SSSI, SPA/Ramsar)
- Clarity between sites that are identified to provide compensatory habitat and those that are to meet BAP targets.

Table A8: Secondary Assessment Matrix (Roberts and Coutts, 2003)

CRITERIA	SCORE
Statutory and Legal Issues	
Level of environmental protection (-2 international SPA/SAC/Ramsar, -1 SSSI other national, 0 local, +1 partial designation, +2 no designations)	
What will be the impact on the current site designation? (-2 major adverse impact, -1 minor adverse impact, 0 no effect, +1 minor beneficial impact, +2 major beneficial impact)	
What is English Nature's view of the project likely to be? (-2 likely to oppose without negotiation, -1 opposition negotiable with mitigation/compensation, 0 unknown, +1 agreement with minor conditions such as working methods, +2 no objections)	
Will appropriate assessment be required under the Conservation (Natural Habitats &c) Regulations 1994? (-2 yes: for majority or whole site area, -1 yes: for less than half site area, 0 not determined, +1 negotiation possible due to low conservation value, +2 highly unlikely)	
Will compensation be required under the Conservation (Natural Habitats &c) Regulations 1994? (-2 yes: for majority or whole site area, -1 yes: for less than half site area, 0 not determined, +1 negotiation possible due to low conservation value, +2 highly unlikely)	
Will the site create suitable compensation habitat? (related to site elevation) (-2 significant engineering works required to create habitat, -1 mudflat only without engineering, 0 majority mudflat with some saltmarsh, +1 the required combination of mudflat/salt marsh habitat, +2 required habitat plus transition to upper salt marsh habitats)	
Land ownership - is the landowner amenable to sale? (-2 no, -1 with conditions resulting in extra costs, 0 not approached, +1 will sell exact amount required only, +2 is prepared to sell more than required for this scheme)	
Could the site be 'landbanked' for other schemes? (-2 site too small to provide initial compensation for current scheme and has to be considered in combination with another site, -1 no, site too small to bank, 0 under discussion, +1 small additional area available, +2 large area can be banked as part of a regional strategy)	
Environmental Issues	
Existing conservation value (-2 Annex I listed European species, -1 BAP/species protected under the CRoW Act 2000, 0 unrecorded, +1 locally rare or low conservation species only, +2 no species of interest)	
Potential impact on features of interest/protected species (-2 loss of numerous species with high costs for alternative habitats or translocation, -1 some expenditure for on-site mitigation required, 0 not determined due to gaps in data, +1 some impact but mitigation not required, +2 no impacts predicted)	
Will the site improve the conservation value of the area? (-2 will result in a loss/change of more than one existing good quality habitats/species, -1 will result in loss of one desirable habitat/species without much biodiversity gain, 0 scheme not likely to have an effect, +1 biodiversity or habitat quality could be slightly improved, +2 biodiversity/habitat quality could be significantly improved)	
Is there a history of pollution or contamination on the site? (-2 known history and high remediation costs, -1 possibility of minor contamination but not a barrier to retreat, 0 site investigation required, +1 some agricultural chemicals in use, can be reduced prior to breaching, +2 no history of contamination)	
Potential landscape impact/impact on visual amenity (-2 permanent major detrimental impact (e.g. from extensive new flood defences), -1 permanent minor adverse effect with mitigation available, 0 temporary detrimental impacts during transition of habitat, +1 minor improvement on existing situation, +2 major improvement on existing situation (e.g. removal of unsightly structures prior to breaching))	
Potential impact on archaeology/cultural heritage (-2 high designation (e.g. SAM) will have to be defended from flooding, -1 archaeological sites of lesser importance at risk, with associated mitigation costs, 0 unknown archaeological interest, +1 minor archaeological sites at risk or low risk with minor mitigation costs, +2 no archaeological interests at risk)	
Technical	
Proximity of extant salt marshes as a seed supply for new site (-2 no extant salt marshes, -1 salt marshes removed from site locality, 0 not assessed, +1 limited salt marshes nearby, +2 extensive salt marshes immediately adjacent to site)	
Site history (-2 always terrestrial and evidence of former development, -1 always terrestrial and used for agriculture, 0 possibly former wetland, +1 former salt marsh reclaimed >100 yrs ago, +2 recent land reclaim)	
Evidence of relict creeks (-2 no patterns visible, -1 fluvial/agricultural drainage channel(s) present, 0 information not available, +1 limited creek network visible, +2 extensive former creek network visible)	
Sustainability	
Will the site/scheme help to return the coast/estuary to a more 'natural' profile? (-2 site was never part of intertidal, -1 negligible effect because scheme is isolated, 0 information incomplete, +1 a few other realignments planned in combination, +2 scheme is part of a strategic plan for the estuary)	
Can the site be maintained (will it roll-back) with increased sea levels? (-2 site will be completely constrained by existing topography, -1 over half of site will be constrained, 0 still under discussion, +1 site partially constrained, +2 site rises naturally to the rear, will evolve with sea level rise)	
Flood Defence Issues and Economics	
Would this increase flood risk to economic assets? (-2 extensive development at risk, -1 few properties and high grade agricultural land at risk, 0 very few assets at risk, +1 low grade agricultural land/public amenity areas only, +2 standard of flood defence improved)	
Will there be a requirement for new defences? (-2 high cost defences required to 1:200yr standard, -1 lower cost defences required to 1:100yr standard for more than half of site, 0 low cost defences required to 1:50yr standard for more than half of site, +1 1:100/1:50yr defences required for less than half of site, +2 no new defences required)	
Will these new defences constrain the realigned site? (-2 whole site will be enclosed, -1 over half of site constrained, 0 not determined, +1 less than half of site will need defences, +2 no defences required)	

Will there be an impact on flood storage capacity? (-2 reduced flood storage will entail extensive mitigation such as pumping, -1 reduced flood storage but no/few properties at risk and little mitigation required, 0 modelling required but no adverse impact envisaged, +1 no change, +2 increase in flood storage volume)	
What will be the cost of land purchase? (-2 direct competition from other sources and likely to be outpriced by competitors, -1 land owner prepared to sell for well above market value, 0 under discussion, +1 may sell for slightly above agricultural market value, +2 in line with agricultural market prices)	
Would the site be eligible for payments through agri-environment schemes? (-2 no possibility of funding resulting in loss of income, -1 further investigation, no obvious schemes available, 0 no funding required, +1 eligible for a limited amount of funding, +2 funding available from a number of schemes)	
Social/Recreational	
would there be political acceptance of the option? (-2 against local policy, -1 local political opposition, 0 no view, +1 local support, +2 in line with local policy and has local support)	
Potential impact on public access (-2 extensive permanent reduction in access, -1 minor permanent restrictions, 0 temporary restrictions during implementation only with no net improvement, +1 no change at any time, +2 access improved when fully implemented)	
Impacts on rights of way (-2 permanent closures required, -1 permanent re-routing of Right of Way necessary, 0 temporary closure/diversions only, +1 no impact on rights of way, +2 Rights of Way improved through scheme)	
Will there be an impact on health and safety? (-2 permanent detrimental impact with high expenditure for mitigation required, -1 minor permanent adverse impact with some mitigation, 0 temporary impact associated with construction, +1 no impacts envisaged, +2 improvement in health and safety)	
FINAL SCORE	
FINAL RANK	

3.1.4: EA summary

This review has not provided a comprehensive overview of all site selection processes that are being implemented by the Environment Agency. However there are several themes that emerge. These are:

There is no overall UK strategy or protocol for site selection or criteria to be used, however the various procedures and approaches taken have some overall consistencies in terms of the criteria used and their scoring approaches (i.e. matrices to score/rank sites). It would be possible to bring these approaches and criteria in line.

In the criteria used there are many issues being addressed in selection of sites and generally habitat creation (type of habitat, area) is a feature included but is not a top priority in terms of site selection. The main criteria employed to predict habitat created is elevation/inundation and it is perceived that site design can give what is needed. In real terms site selection often comes down to more practical constraints such as socio-economic/land purchase decisions etc. Overall from the EA point of view initiatives for site selection have been developed but not focussed on habitat creation *per se*.

The various matrix protocols from the EA provide good context for this study which is targeted specifically towards habitat quality and creation. These approaches provide a focus on the wider issues of site selection within which this project outputs will sit.

3.2 English Nature

3.2.1: Strategic site selection guidance

English Nature do not implement habitat creation schemes directly, their involvement comes from their duty to guide operating authorities on the most appropriate site for compensatory packages. Their duties also involve assessing the deleterious impacts of a proposal and advise DEFRA what the scheme would need to achieve in term of habitat quality. Because the compensation packages have to meet specific habitat quality objectives, tight strategic guidelines are set in place. English Nature's understanding of the scientific factors relevant to the establishment of a created habitat following a sea wall breach was laid down in the report by Burd (1995). This report was compiled following a review of past schemes in the UK and the USA. The following factors were recognised as primarily important and a schematic of the process of site selection for breach retreats is shown in Figure A3.

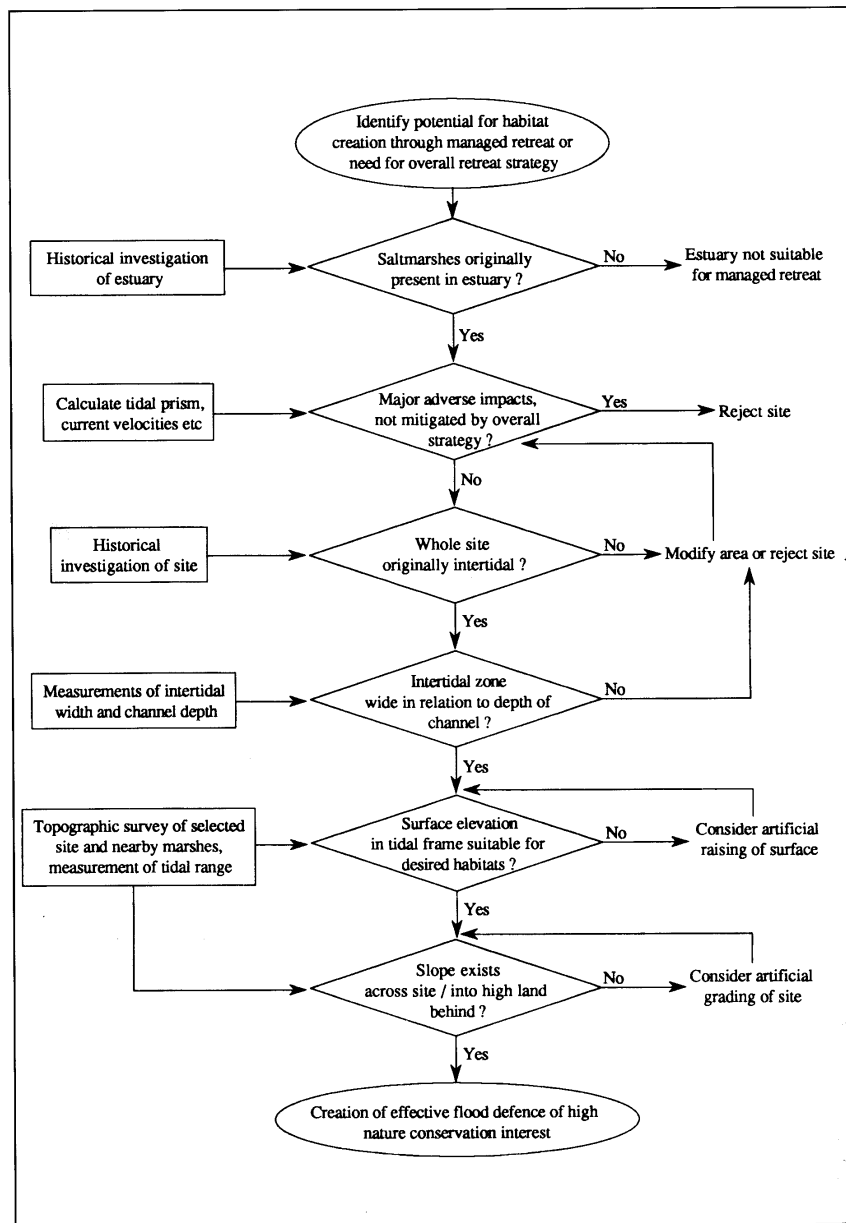


Figure A3: Process for selecting a suitable site for breach retreat (Burd, 1995).

1 - Tidal prism. The primary consideration in selecting a site is the impact that the retreat may have on estuary processes. The impact of a scheme on the erosional / depositional processes within an estuary should be considered. This estuary-wide strategic approach should always be adopted to ensure that the long term development of the estuary will result in a more balanced and responsive system.

2 - Estuary morphology. Identification of retreat areas should form part of a whole-estuary approach aimed at returning the estuary to a more natural shape which is more appropriate to large-scale coastal processes.

3 - Site history. The most suitable areas for managed retreat are those which were originally that habitat type (e.g., saltmarsh) before being enclosed by the sea walls.

4 - Surface elevation. If saltmarsh habitat is required the surface elevation of the proposed site should be relatively high in relation to the local tidal range in the estuary. This can be done by relating the area to the range of elevations of the surrounding saltmarshes, if any. The report found that the original average elevation of the most successful sites in the past have been approximately 2.1mOD when breached, or 400 – 500 (450) tidal inundations per year (2.34 O.D/ <300inundations when established). Since conditions in each individual estuary determine the actual number of inundations per year, this factor rather than height above ordnance datum is advocated. For mudflat sites with >500 tides per year are particularly suitable.

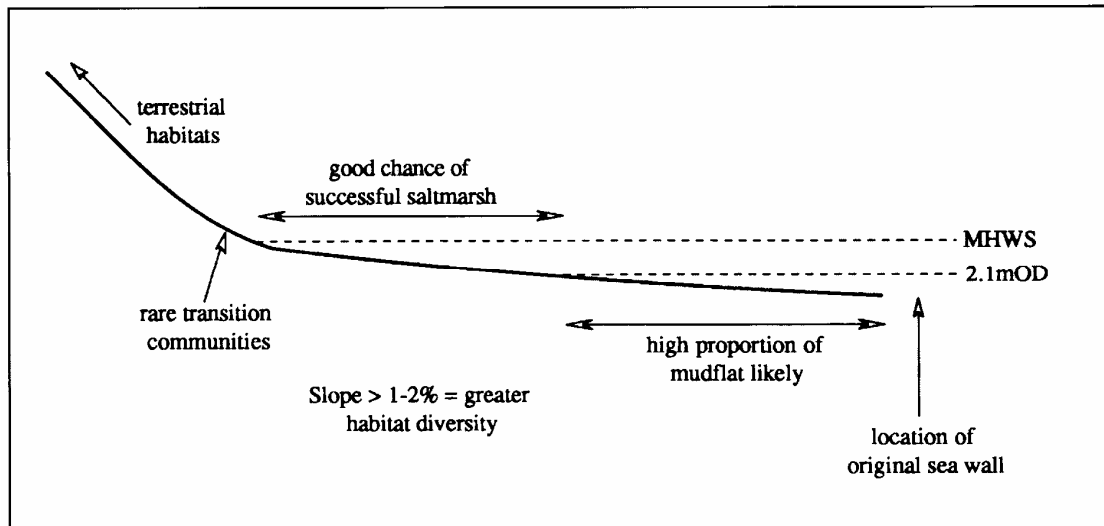
5 - Surface gradient. A site with a more natural gradient from land to sea allows a more diverse habitat type to be created, a positive feature for any potential site. A site where the land is flat is likely to result in a marsh of poor diversity with vegetation types consisting of largely pioneer and low marsh plant species. A natural, gradual slope is likely to result in low management. In the United States slopes between 0 and 2% have been recommended (Zedler, 1984) up to 6-7% (Knutson, et al., 1990) with uniform vegetation resulting from historical sites of <0.1%. An optimum of 1-2% is recommended overall.

Figure A4 illustrates the predicted habitat types to occur on managed realignment areas in relation to elevation and slope (Burd, 1995)

6 - Sediment characteristics and accretion processes. The substrate of the new marsh can affect the degree of success with which plants colonise the site. However, this is potentially only a problem if accretion rates are low.

7 - Creek network. In the natural saltmarsh habitat a system of creeks is fundamental to the inundation and drainage of the marsh in order to give the required hydraulic, sediment and water quality regime. If the proposed site is enclosed saltmarsh then the relic of a creek network should be present, this should be enhanced. Where no historic creeks exist, two considerations are available, either allowing a natural creek network to establish (a long term process) or excavating an artificial network.

8 - Tidal hydraulics. Tidal hydraulics results in careful consideration over the breach width and location.



Source: Institute of Estuarine and Coastal Studies, University of Hull

Figure A4: Elevations, slopes and habitat types predicted to occur on managed retreat saltings (Burd, 1995)

9 - Wave climate. Wave action can limit the success of saltmarsh development following managed realignment, indicating that a portion of the sea wall must be kept at least in the early stages. Work in the US has suggested that fetch distances of more than 1000ft can adversely affect accretion rates.

3.2.2: Living With the Sea (CHaMPs)

Integral to site selection is the Living with the Sea project (funded by EC LIFE) which aims to tackle the impact of sea level rise and flood and coastal defence on areas protected by the EC Habitats and Birds Directives (Natura 2000). The project has focused on developing sustainable flood and coastal management approaches based on better knowledge and understanding of likely future changes and identifying the requirements for habitat creation to offset any losses. Within this are elements of the project that are especially relevant to site selection criteria for habitat creation, both on a strategic and site level. They are:

- **Development of Coastal Habitat Management Plans (CHaMPs) for seven pilot areas where research has indicated significant habitat change over the next 50 years.** The main aims of the CHaMPs are to develop mechanisms for delivering Habitats Directive compliant flood and coastal defence schemes. These will be designed to quantify habitat change, (loss and gain), and recommend measures to prevent future losses. These will include modifying flood and coastal defence options to avoid damage, or identifying the necessary habitat creation works to compensate for unavoidable losses. They will look at the cumulative impact on these features over a 30-100 year timescale. CHaMPs will also include strategic habitat monitoring programmes to map future changes. The actions will be delivered through Shoreline Management Plans (SMP's) and flood and coastal defence strategies and schemes (see Figure A5)

- **Development of best practice guidance on the re-creation and/or restoration of coastal habitats** (including a guide to provide advice on habitat restoration/re-creation).
- **Implementation of North Norfolk Coastal Management Plan overview** to examine actual, on the ground coastal habitat re-creation and restoration, and understanding the role of this work in maintaining the ecological integrity of features of European importance.

All these initiatives are complimentary to this project in providing a framework for describing intertidal habitats of importance and factors that are relevant to their habitat restoration/sustainability and in particular in making information accessible to end-users within the guide. Further information is available at <http://www.english-nature.org.uk/livingwiththesea/>

Figure 1.1 The CHaMP planning cycle

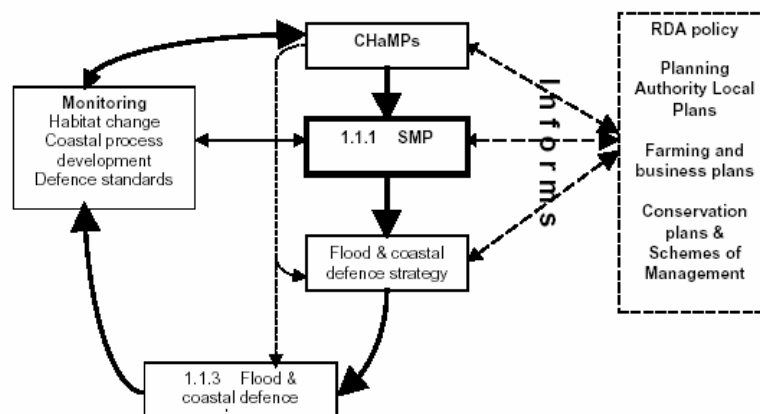


Figure A5: The CHaMP planning cycle (from Solent CHaMP, 2003).

Within the development of CHaMPs, in particular, have been several initiatives aimed at identifying site selection criteria for habitat creation.

For example: within the Solent Coast and Estuaries CHaMP various site selection criteria have been used to identify potential sites for intertidal habitat creation (Solent CHaMP, 2003).

On the basis of the analysis undertaken for the CHaMP it is apparent that predicted geomorphological change over the next 30-100 years would lead to significant change to designated habitats and features within the Solent CHaMP area. One of the aims of the CHaMP is to assess the likely scale of change and inform the strategic direction for the conservation measures that may be necessary to offset predicted loss to designated features. As part of this process, suitable locations for new habitats that may need to be created and the flood and coastal defence policy required to maintain protected habitats have been identified.

The key local factors that would need to be considered from the perspective of creating viable replacement habitats and the practical issues and operations likely to be involved.

The aim was not to identify definitive mitigation areas, but instead to identify possible sites where physical and biological conditions could be favourable for the creation of new intertidal habitat. Built-up areas are unlikely to be feasible for habitat creation and all such areas have been eliminated from this appraisal. Potentially complex issues associated with land uses, property rights, local politics and economics of predominantly undeveloped lands have not been considered at this stage. It is recommended that the sites here represent a broad initial inventory that would then require subsequent detailed appraisals to filter and to test actual feasibility and define optimum boundaries for selected sites.

Information on the strategic coastal defence options (SCDO) for the relevant frontages has been collected from SMPs and Coastal Defence Strategy Plans. In the majority of cases the present SCDO would not accommodate habitat creation. Such sites nevertheless are listed here for it must be acknowledged that over time some SCDOs may need to alter in order to provide for sustainable management in the future. Indeed the concept of time dependent SCDOs and of the need for preparatory actions at some locations are key elements of the new guidance issued for the preparation of second generation SMPs (DEFRA, 2001). Potential sites for habitat creation were identified according to the following **criteria**:

CRITERIA:

- 1) Habitat losses within the Solent overwhelmingly involve intertidal foreshore especially saltmarsh so that these are the main types for which creation is required;
- 2) The areas likely to be subject to inundation following breaching or removal of defences were identified from Environment Agency tidal flood risk mapping and from inspection of the 5m contour on Ordnance Survey Plans. The boundaries marked are approximate and further, more detailed studies of land surface levels are recommended wherever there is a need to more precisely define likely boundaries;
- 3) All significant existing built up areas were excluded from consideration;
- 4) Existing roads would not necessarily constrain the extents of habitat creation sites due to the possibilities of realignment, raising their levels, or directing tidal flows beneath them by means of bridges and/or culverts. Such instances require further evaluation to test for feasibility;
- 5) Sites are identified even where the present SCDO does not allow for tidal inundation. This is because SCDOs may alter and an inventory of potential sites could inform such decisions when SMPs and coastal defence strategy plans are revised in future. A number of SMPs and Strategy Plans identify several frontages where the existing hold the line policies may in future need to alter to satisfy sustainability criteria; and
- 6) The erosion of some shorelines provides sediments that sustain local habitats.

Where such links operate, those “donor” shorelines have been identified as “sacrificial shorelines” where maintaining the freedom to erode constitutes an important part of maintaining local habitats and in providing conditions for successful habitat creation.

Furthermore, the areas identified are subject to a general series of **constraints** that could apply differently according to site. It is recommended that sites should be evaluated specifically to identify the precise nature of such constraints as part of any further appraisals to select habitat creation sites. The key constraints are as follows:

CONSTRAINTS:

- 1) Sites need to contain a good proportion of ground levels within $\pm 1\text{m}$ of Mean High Water is the aim is to create saltmarsh habitat. Elevations below this would typically convert to mudflats following inundation;
- 2) In proximity to built-up areas inundation would need to be controlled by the contours of the land, or by building of secondary defences;
- 3) Inundation could adversely affect the drainage of adjoining lands;
- 4) Checks are needed to ensure that contaminated lands are not inundated. Contaminants could otherwise leach or be eroded out and affect the ecology of the inundated land. They could also potentially disperse into the wider estuary to pose risks for its ecology and for public health.
- 5) Inundation of large inner estuary sites could increase estuary tidal prisms such that currents increased and mudflats flanking the mid and outer estuary could be eroded. The potential severity of such problems can be assessed by analysis of estuary regime. Estuaries that have achieved equilibrium between their inlet or channel geometry and their tidal prism are typically the most sensitive. Many Solent estuaries are out of hydraulic equilibrium, having inlet sections that are significantly wider than might be anticipated. As such they may be relatively insensitive to increases in their tidal prisms.
- 6) Inundation has the potential to lead to the permanent loss of designated terrestrial habitats located behind existing defences. Where such habitats are designated, new terrestrial habitats would need to be created to compensate for those lost.

An overview of intertidal habitat creation potential, corresponding areas and predicted losses and areas are identified within Figures A6 and A7.

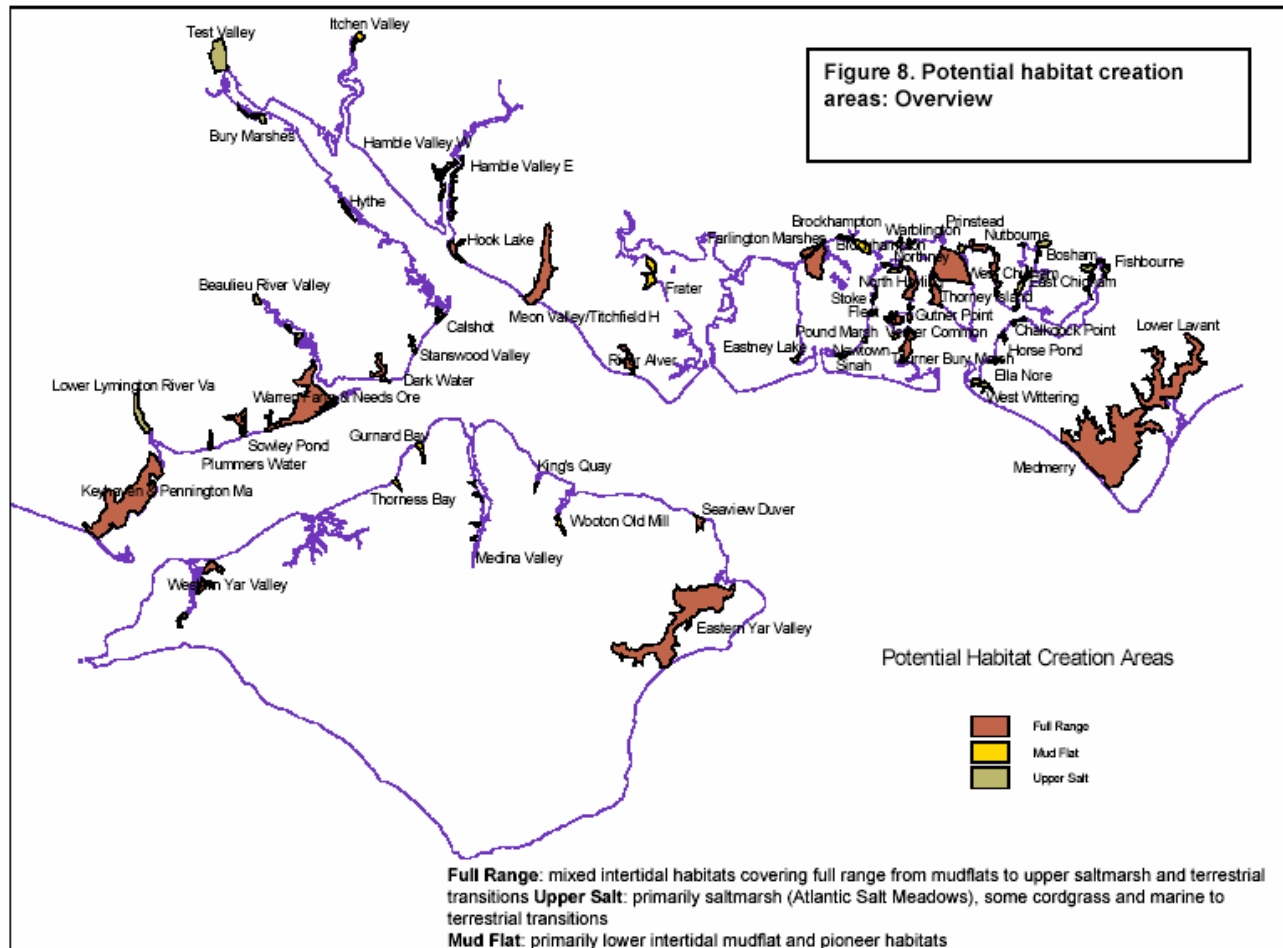


Figure A6: Potential habitat creation areas (Solent CHaMP, 2003)

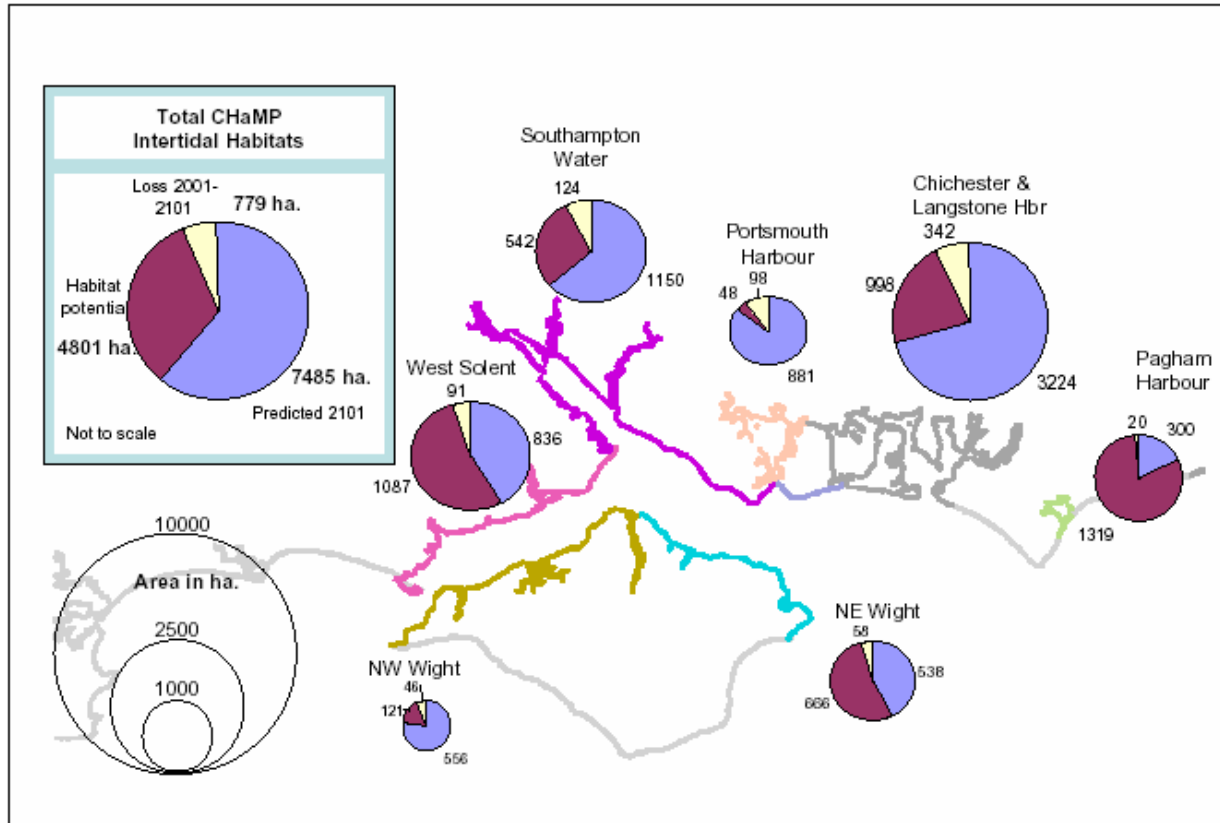


Figure 4. Intertidal habitat creation potential and estimated loss by 2100.

Figure A7: Intertidal habitat creation potential and estimated loss by 2100 (Solent CHaMP, 2003)

The following **main points** emerge from this analysis (Solent CHaMP, 2003):

- 1) Large areas of around 4,800 ha. in total exist within which intertidal habitats could potentially be created. Further assessment and refinement of boundaries will be needed according to economic, social, political and coastal defence considerations. These will tend to reduce the sizes of the areas within which habitat creation is likely to be feasible;
- 2) Many of the areas identified are reclaimed saltmarshes and estuarine margins that contain suitable ranges of surface elevations and potentially relic seed banks that could result in effective regeneration of saltmarshes if they were in future subject to regular tidal inundation;
- 3) Larger sites are preferred for habitat creation as they afford opportunity for creation of full ranges of intertidal habitats from mudflats up to saltmarshes and transitions to terrestrial habitats.
- 4) Smaller sites could be valuable for creation of upper saltmarsh, especially where they adjoin existing areas of quality saltmarsh
- 5) Significant coastal protection issues are apparent, not least of which the fact that the existing SCDOs at the majority of sites would not allow for the inundation necessary for intertidal habitat creation. Where realignment is possible there are likely to be a requirement to breach or remove existing defences and to provide secondary defences to control inundation and protect assets *e.g.* residential properties, roads and possibly some key designated habitats *e.g.* saline lagoons and freshwater habitats;
- 6) Considerable overlap is identified between the potential intertidal creation areas and existing designated terrestrial habitats located behind existing defences. New terrestrial habitats would need to be created to compensate for those lost if intertidal habitat were to be created in these areas.
- 7) The majority of sacrificial coastlines identified are valuable for the supply of coarser sediments that contribute to local shingle beaches and spits. They maintain shingle habitats and in some instances upper saltmarsh habitats that are protected by spits.
- 8) A novel opportunity for intertidal habitat creation could potentially be developed in association with coastal minerals working. It is proposed that working of terrestrial plateau or valley gravels adjacent to the coast could lower ground levels sufficiently to permit tidal inundation of the abandoned workings to create a small new estuary. A major benefit is that channels and ground levels could be designed to produce an optimum estuary configuration conducive to formation of mudflats and saltmarsh. Furthermore, it would not overlap with any existing designated habitats so there would be no requirement for creation of terrestrial habitats.

3.2.3: Site selection criteria primarily for compensation schemes

Within the framework provided under CHaMPs English Nature are currently in the process of formulating a more strategic approach to managed realignment for compensation schemes in particular. This follows concerns of operating authorities with respect to the available guidance on compensation for those involved in the design, delivery and approval of compensation packages resulting from flood management options.

It is intended that the criteria below could provide general guidance to Operating Authorities required to provide compensation as a result of flood management operations (Mucmullon and Collins, draft (not EN policy at present);.

1. **The compensation should have no adverse effect on a habitat of European or Ramsar interest** - any habitat created as compensation should not directly or indirectly, immediately or eventually lead to an adverse effect on any habitat of European or Ramsar interest, whether within a designated site or habitat on which mobile fauna in a designated site rely. Any consequent adverse effects on the integrity of European sites or their features would need to be compensated.
2. **The compensation should create habitat that is fit for the purpose it has to fulfil** - this has been expressed in European policy (at para 5.4.2 of Managing Natura 2000 Sites [EC 2000] as “*equivalent biological characteristics*”. It is considered reasonable that the compensatory measures (for example in respect of the SPA / Ramsar bird interests) should fulfil the same special contribution and particular function of the areas lost or damaged for the same species of birds, at the same time, for the same purpose and in all the same relevant circumstances. In choosing between options, the habitats selected in any particular scheme should be those that, in the judgement of English Nature, provide the most appropriate solution in respect of the following criteria ranked in order of importance in respect of fulfilling the required ecological function (equivalent biological characteristics):
 - A] **Habitat type** - normally “like for like” but “like for like” habitat need not always be selected so long as what is created or improved performs the same range of ecological functions as the lost or damaged habitat; and
 - B] **Timing of availability of adequately functioning habitat** - operational at the time it is required. Essentially, “in time” to offset the adverse effects which are being compensated, but not necessarily simultaneously with the action that will cause the harm if there is a time lag between the action and the potential effects on the European or Ramsar site interests; and
 - C] **Quality of habitat** - normally the objective would be to achieve the best quality habitat that can be achieved; and
 - D] **Area of habitat** – where the replacement habitat would be of equal ecological quality, at least a parity of area with that lost or damaged would be required. More often however, a greater area

is required to reflect the likelihood that the habitat created will be of poorer quality, at least in the short term, to that lost or damaged; and

- E] **Geographic location** – as close to the area to be compensated for as possible, taking into account any likely impacts on the replacement habitat or species likely to use it; (see additional note at end in relation to this point)

Any solution selected should also be most capable of being:

- F] **Validated** in respect of achieving its ecological function / purpose; and
- G] **Monitored** for effectiveness; and
- H] **Adapted** to adjust to unfolding circumstances in future management.

3. **Feasibility** - The measures must be technically feasible and have a good prospect of success. That is to say, given the present understanding of science, engineering and technology, and accepting that nothing can be certain in this field of work, they are expected to be achieved and successful in their purpose and failure is unlikely.

4. **Capable of Being Consented** - The measures must be capable of achieving all necessary consents from all competent authorities, within the relevant and reasonable timescales.

5. **Reliance on the Project** – “Managing Natura 2000” at paras 5.4.1 and 5.4.2 make it clear that compensatory measures must be additional to measures which a Member State would secure in any event. They must be measures that would not be done if it were not for the project requiring them as compensatory measures. To this extent, therefore, they must be reliant on the project and it follows that the test is - if the project does not go ahead would the measures be carried out? If the answer is “yes” or “probably”, at least in the short term, it is likely that the measures could not be regarded as compensatory measures under Reg 53.

6. **Sustainability** - the habitat created must be sustainable over a very long period of time (50 years at least). Accepting that it will probably mature and evolve, like any habitat, it should not need regular major works to prevent its loss or deterioration or to keep reconstructing it. It should not require ongoing works, such as pumping of water to maintain water levels on a site, to sustain the conservation interest.

7. **Benefits to other nature conservation interests** - where the necessary requirements to secure the coherence of Natura 2000 could be met in more than one way, or on more than one site, it would seem to be in the spirit of the Habitats

Directive to select the package or permutation with the best overall benefit for biodiversity conservation, in its wider sense.

8. Meeting Good Practice Guidelines - the measures should be capable normally of meeting all relevant good practice guidelines that may be operated by other competent authorities. Whilst this cannot be an absolute requirement, because the need to maintain the coherence of Natura 2000 will need to prevail, it should only be in exceptional circumstances that agreed compensatory measures would not meet good practice guidelines and therefore, even in these cases, the measures would not create a precedent for non-compliance that may have other adverse environmental effects if repeated.

9. Potential for Designation – it can reasonably be anticipated that the habitat can, having achieved the relevant ecological criteria, be designated as a cSAC, SPA or Ramsar site as appropriate. It follows that compensatory sites are likely to be close to an existing SAC, SPA or Ramsar site (and could be designated as an extension to that site) or have the potential for designation in their own right.

3.2.4: Geographic Location: Area of Search for Compensatory Measures

The following list is intended to identify, in order of preference, the area of search for the required compensatory measures. It will be necessary for the operating authority to show that they have taken reasonable steps to identify and secure a suitable site at each level before expanding the area of search to the next level;

- Adjacent or in close proximity to the European or Ramsar site where the damage occurs
- For areas that are covered by a CHaMP, within the same site complex (the Suffolk Coast and Estuaries or The Solent are 2 examples of site complexes)
- Adjacent or in close proximity to a neighbouring European or Ramsar site, with similar ecological characteristics, close to where the damage occurs
- Within the same Natural Area (see http://www.english-nature.org.uk/science/natural/na_search.asp for an explanation of Natural Areas)
- Within an adjacent Natural Area with similar ecological characteristics
- Within the same geographical region

3.3: RSPB

The suitability criteria which the RSPB have adopted were laid down in a paper given in the 34th MAFF conference (Sharpe, 1999). Although these were for the Lincolnshire, Norfolk, Suffolk and Essex estuaries, the same criteria were used throughout the UK (J. Sharpe, pers.comm.). A study was conducted to identify potential sites for intertidal habitat creation within this region involving a reconnaissance method, i.e., potential sites were identified for more detailed, site-specific investigation. This involved analysing maps and other published information, supplemented through discussion with officers of statutory agencies. Sites were then evaluated against a list of factors likely to influence the implementation of any habitat creation. The approach can therefore be separated into 3 main components;

1 – Site identification

This is primarily a map-based approach. The sites chosen are those where managed realignment of man-made sea defences is thought likely to be practical and not entail excessive costs. Sites fall mainly into 2 main types;

- (i) peninsulas: where construction of a relatively short counterwall would remove the need to maintain a much greater length of existing sea wall;
- (ii) longer stretches of coast where realignment would be possible to rising ground (using 5 m contour) or previous sea defences, with short counterwalls at each end of the site. This would again remove the need to maintain a much greater length of current sea wall.

2 – Evaluation of potential sites against criteria

12 criteria have been used for evaluation and each site is scored against each criterion;

- existing wildlife interest of site
- date of land claim (and, therefore, tidal elevation of site)
- presence of privately maintained banks
- property and roads affected
- amount of new sea wall required
- condition of existing sea defences
- cost benefit ratio for maintaining existing defences
- condition of intertidal habitats
- area of scheme
- type of land ownership
- number of owners
- shoreline management strategy

3 – Other significant factors

These are more difficult to evaluate, but are only addressed for the most likely schemes to go ahead based on the above selection criteria. For example,

- effect on surrounding intertidal areas and other geomorphological factors
- site topography
- current policy framework

This suitability criteria established for the RSPB in the mid-90s has been well received and well used since its development (J. Sharpe, pers. comm.). Since then another document 'Seas of Change' (RSPB, 2000) has outlined the potential for intertidal habitat creation at a regional level.

3.4: Other potential end-users and site selection criteria

There are many other potential end-users and stakeholders involved in site selection. For example priority managers and selectors of sites may also be local authorities, ports who design, approve, implement monitor or evaluate flood and coastal defence schemes. Other conservancy organisations such as JNCC, CCW and wildlife trusts are also affected by flood and coastal defence issues and would be interested in site selection from the point of view of concern in the sustainable ecological functioning of an estuary system. Although most groups don't have a statutory role they have guidance towards giving their advice and opinion on various schemes.

3.4.1: English Heritage

English heritage are consultees on proposed sites but are not interested in habitat creation but not loss of sites where significant archaeological artefacts are present is of high consideration in site selection. The key to ensuring proper consideration of the historic environment within shoreline management planning process is to ensure that adequate information is integrated into all stages of site identification and planning as well as operational procedures (English Heritage, 2003). An example of this is shown in Figure A8. In most of the site selection matrices reviewed here presence of archeological features is included at some point in generic screening level.

3.4.2: County Councils

Hampshire County Council employed a student on placement to carry out a study of Areas for Potential Intertidal Habitat Creation in Hampshire. This study was based on the RSPB's 'Seas of Change' study which had looked at the potential at regional level. The Hampshire study (Pritchard and Kirby, 2002) applied the RSPB's criteria (reproduced verbatim below) to the county's coastline. It resulted in 18 sites being evaluated. The findings of the study need to be treated with caution, not least because some of the various RSPB's criteria, and all the criteria are given equal weight even though some might be overriding and others of little significance. Nevertheless it was a useful exercise as a first attempt to look at the whole of the county's coastline for potential habitat creation sites. The criteria used and the scoring adopted is listed below.

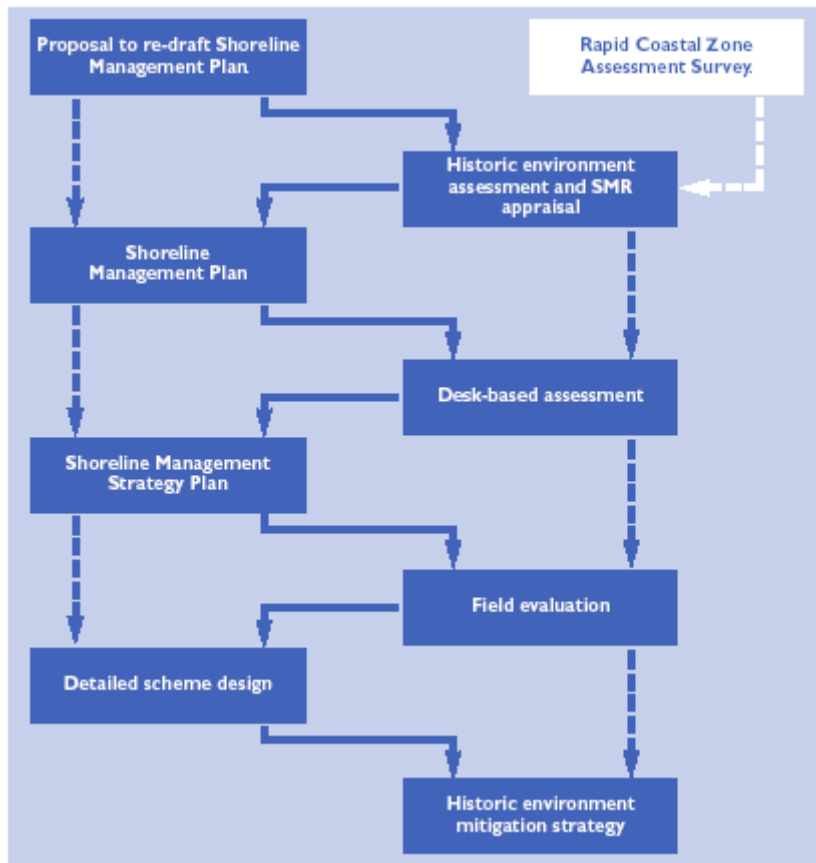


Figure A8: The relationship between the flood and coastal defence process and archaeological evaluation and mitigation procedures (English Heritage, 2003).

Extract from 'Areas of Potential Intertidal Habitat Creation in Hampshire' (informal report written for Hampshire County Council by Helen Pritchard and Lisa Kirby, July 2002).

Criteria

The criteria used within this report were taken from the RSPB 'Seas of Change' study (2000). The sites that were identified as possibilities for inundation or realignment were evaluated against 11 criteria, and the information gained from this assessment indicated the practicality of each site. The criteria and scoring are outlined in subsections below;

Wildlife interest

Sites that are classed as arable are preferable although sites that contain pasture areas can be considered. Sites that have existing wildlife designations such as SSSI, SPA or cSAC are not as desirable due to the inundation possibly disrupting the existing habitats. However in some cases inundation may improve the conservation of the area and could possibly create new areas for wildlife.

Scoring:	
Pasture	3
Country wildlife Site / Local Nature Reserve	2
SSSI /SPA /cSAC	1

Date of Land claim

The more recent the land claim the less likely that there will be substantial differences in the height of the marshes on either side of the wall; this will allow intertidal habitats to colonise the area in a shorter amount of time.

Scoring:	
Land claim <20 years ago	3
Land claim 20 – 50 years ago	2
Land claim >50 years ago	1

Presence of privately maintained banks

Privately maintained banks may be expensive to maintain, and there is a possibility that this could lead to standards decreasing, which would increase the potential for realignment.

Scoring:	
Banks maintained by private landowner	3
Banks maintained by statutory body (not EA)	2
Banks maintained by EA	1

Property in retreat area

Minimal property in the retreat area is preferable both from a cost-benefit view, as this will support a ‘retreat the line’ option and from a public viewpoint, as this will reduce the potential conflicts.

Scoring:	
No property	3
Defendable property (i.e. minimal earthworks)	2
Minimal property (no more than two residential properties)	1

Infrastructure required

There should be minimal infrastructure required for the realignment of any given site in order to cut the costs involved. This could be achieved by retreating to higher ground or previous defences.

Scoring:	
Retreat to old sea defences or higher ground	3
Less new wall needed for realignment than existing defences	2
Equal new wall needed for realignment as existing wall	1

Sea defence condition

The condition of the existing sea defences gives good indication of the pressures acting on the stretch of coastline. The higher the cost of maintaining the defences the stronger the argument for managed realignment.

Scoring:	
Current defence in poor condition	3
Current defence in reasonable condition but needing improvement	2
Current defence in good condition	1

Condition of intertidal habitat

The condition of the intertidal fronting habitat gives an indication of the need for realignment. Eroding saltmarsh will eventually lead to greater wave action upon the defence and an absence of any fronting saltmarsh could indicate that the sea wall has been extended too far out. The most suitable long-term defence option would be to retreat the defences.

Scoring:	
No saltmarsh fronting site	3
Eroding saltmarsh fronting site	2
Mature saltmarsh fronting site	1

Area of potential size

There has been no minimum size set for sites, however the larger the site the more preferable for managed retreat as there will be less knock on effects for adjacent coastlines/areas. The potential for habitat recreation is greater where larger sites are considered.

Scoring:	
Site greater than 50ha	3
Site between 20ha – 50ha	2
Site less than 20ha	1

Number of owners

Sites with only one owner will be preferable as the number of owners is likely to affect the ease of the realignment.

Scoring:	
One owner	3
Two owners / Leaseholders	2
More than two owners / Leaseholders	1

Shoreline Management plan policy

The existing shoreline management policy for the sites will influence the acceptability of realignment. If the policy is hold the line and it can be demonstrated that retreating the line will not have any adverse effects on the other defences within the management unit, realignment may be considered.

Scoring:	
Preferred policy is to retreat the line	3
Preferred policy is to do nothing	2
Preferred policy is to hold the line, but in isolated instances to observe and monitor	1
Preferred policy is to hold the line	0

Other significant factors

This refers to the other factors that would affect the case for realignment at a given site. These factors are more difficult to evaluate and should be looked at in more detail through further investigation.

3.4.3: Contractors/consultants: Lappel Bank and Fagbury Flats compensatory measures and multi-criteria analysis

There are many reports on individual schemes carried out by various consultancies on behalf of regulatory agencies (EA/EN/RSPB) in respect of site identification. These reports employ various criteria for appraisal of sites and these may vary depending on the agency that is funding the work and area of interest. However, many of the criteria are common (see below) although the method of assessment for sites and weighting of any criteria may vary.

- Current standard of flood defence
- Elevation of site
- Location in the estuary/whole estuary morphology
- Impacts on adjacent land, wildlife habitats, flood defences, navigation etc
- Sediment availability and suitability
- Wave climate and tidal characteristics
- Engineering requirements
- Cost implications
- Habitat requirements of bird species displaced
- Preferred flood defence option
- Long-term sustainability
- Proximity to areas lost

An example of this is the Lappel Bank and Fagbury Flats compensatory measures study undertaken by ABPmer and BTO (ABPmer, 2002) on behalf of English Nature and the Department of the Environment (DOE) to identify suitable large sites at which realignment could be undertaken to provide mudflat and saltmarsh in compensation for losses of these habitats at Lappel Bank (Medway) and Fagbury Flats (Orwell). The site selection was pursued at four different stages of detail which is common to many approaches. Subsequent to the above coarse filter of criteria (initial site selection), a more detailed consideration of a short-list of sites was undertaken in respect of effects on landowners, leaseholders and other interested parties which was incorporated into a multi-criteria analysis (MCA) approach. This involved taking a range of objectively derived design parameters and comparing and ranking them for each site to give an overall rank. In this way this approach is comparable to and is highly complementary to

the site selection (influence diagram) model being used in this study (FD1917). Overall the criteria used in this ranking procedure and scored for each site were:

- Habitat, bird numbers and species
- No adverse impact on geomorphology (% change in high water area)
- No adverse impact on ecological function in long term
- Self-sustaining system (or systems)
- Engineering feasibility and costs
- Current standard of flood defence
- Preferred flood defence option
- Number of owners and leasees
- Proximity to areas lost from Medway, Stour and Orwell SPAs

The ecological assessment side of the criteria in terms of habitat creation was limited to saltmarsh colonisation, tidal range, effective fetch, sediment type and development of intertidal macrobenthic assemblages with particular focus on an estimate of the numbers and range of birds that each site has the potential to support. An estimate of the total area of mudflat and saltmarsh that would develop was derived using transition information of saltmarsh vegetation in relation to tidal height and morphological constraints (in particular exposure). In this way this study and others are complimentary to outputs from this project in terms of their broader approach and criteria.

The stage 1 reports are referenced here (ABPmer, 2002) and for further information a copy of the Stage 2 report (ABPmer,2002) is available on the DEFRA web-site (<http://www.defra.gov.uk/wildlife-countryside/ewd/weymarks/index.htm>).

4.0: SYNTHESIS

This overview of present site-selection criteria and procedures across various agencies and potential end-users of the decision tools has presented examples of the approaches being implemented and the emphasis and priorities used when selecting intertidal habitats.

4.1: Analysis and synthesis:

Between and within various agencies there are many initiatives concerned with identifying and selecting sites for potential managed realignment. These may be driven by different policies or strategies but generally the approaches and criteria employed have much in common, for example:

- They generally involve a more generic stage of screening, coarse filtering or forming a primary matrix to create a short list of sites which are then examined more closely using a more detailed approach (for example: Atkins, 2002; Binnie Black and Veatch, 2000; HESMP, 2000).
- The criteria implemented have many common aspects and are generic in nature, covering all potential aspects of site selection, i.e. not only environmental aspects, but also economic, social and political issues (HESMP, 2000).

Within the Environment Agency, in particular, there seems to be no overarching national strategy on these issues, so that common protocols for site selection would be particularly worthwhile and would aid site prioritisation in terms of funding.

A number of approaches involve the use of matrices to rank sites against the generic criteria (Halcrow/EA, 2003; ABPmer, 2002; Coutts and Roberts, 2003). In each case, although the criteria may be similar, the approach taken to give an overall ranking is different, not only in the combination of scores but also in the methodology to derive the scores or any associated thresholds. In many cases, apart from elevation and tidal inundation, the scores and thresholds are qualitative rather than quantitative (Binnie Black and Veatch, 2000).

Clearly also the weighting and scoring of various criteria can depend upon the main driver for site selection, whether it is mitigation, compensation, flood and coastal defence or other reasons. For example, conservation agencies may weight the environmental criteria for habitat quality or bird usage more highly than the Environmental Agency, who might be focussed upon sites for purposes of flood and coastal defence. In this way, sites are ranked differently, depending on FCD/habitat creation priorities and their intended purpose.

The present main controls on site selection are not necessarily focussed upon the quality of any created habitat. Other overriding factors, such as land purchase or other socio-economic factors often have higher priority in determining the viability of a site than environmental issues. However, it is clear that in future, the criteria of English Nature (the conservation agency applying the Habitat regulations) and those of other conservation agencies may carry greater weight if habitat type and quality become paramount, together with maintenance of any presently protected areas, in terms of the selection of compensation or mitigation schemes. The role of projects such as FD1917 would thus assume greater importance.

Some of the lessons being learnt by various initiatives on site selection are relevant to this project. Issues such as weighting of criteria, assessment of criteria over a large area (i.e. description of slope/topography), elevation (from LIDAR data but screened to remove upper and lower 95%ile), uncertainties of each criterion, data availability, and timescale of recovery are all relevant to producing consistency in site selection within any decision tool.

The parameters relevant to habitat creation identified from the present site selection review are presented in Table A9.

4.2: Conclusions: are these project specific rather than to this section...i.e. this text to conclusions for the project?

In response to the need to bring together the various approaches and ranking systems regarding site rankings and criteria, and assess the common criteria, methodology and scoring to allow comparison of site assessments within and between areas and agencies, a single set of criteria (appropriately weighted) has been developed.

This set of criteria has resulted from an analysis of the various initiatives that are being implemented at present by various agencies/groups etc., and by a critical review of the relevant science and case studies.

The GIS approach and decision tool developed here could easily be adapted to give a more generic screening tool (as determined by the various matrix approaches implemented by different agencies) and thus promote standardisation of site selection.

The focus of FD1917 is of site suitability for habitat creation, type and quality, which fits well into the wider framework, including projects such as FD2413 “Guidance on design and implementation of managed realignment” (CIRIA, 2004: Design issues for managed realignment).

This review provides a good starting point for a more generic selection tool which could be applied by any end-user.

Table A9: Summary table of presently used criteria and thresholds relevant to habitat creation.

Criteria	Threshold	Habitat	Reference
Contaminated land	Presence/absence	Saltmarsh	Halcrow/EA, 2003
Site elevation	2-3 m OD	Saltmarsh	Halcrow/EA, 2003
Site elevation	<1 m OD	Mudflat	Halcrow/EA, 2003
Site elevation	1-2m OD	Transitional	Halcrow/EA, 2003
Surface soils	Clay/Clay loam	Saltmarsh	Halcrow/EA, 2003
Site gradient	1-2% (< 1 :50)	Saltmarsh	Halcrow/EA, 2003
Wave-exposure	% of estuarine length	Saltmarsh/ mudflat	Halcrow/EA, 2003
Height boundaries	-0.49 (m MHWS OD)	Mudflat – saltmarsh	Humber observations; EA, 1998.
Height boundaries	-0.1 (m MHWS OD)	Pioneer marsh – Mid marsh	Humber observations; EA, 1998.
Height boundaries	-0.06 (m MHWS OD)	Mid marsh – Upper marsh	Humber observations; EA, 1998.
Height boundaries	0.03 (m MHWS OD)	Upper marsh – Brackish marsh	Humber observations; EA, 1998.
Height boundaries	0.31 (m MHWS OD)	Brackish marsh – Grassland	Humber observations; EA, 1998.
Salinity, water velocity, sedimentation/ erosion patterns, physico-chemico soil characteristics, wave exposure, coloniser availability	Qualitative	All	Binnie Black and Veatch, 2000; Burd, 1995; Burd et al., 1994.
Potential to improve environment – topography	Scoring 0 – 5	Saltmarsh, intertidal mudflat	Halcrow/EA, 2002
Topography/elevation (OS heights OD)	MLW: 0m OD	> intertidal mudflat	Atkins, 2002; Coutts and Roberts, 2003.
Topography/elevation (OS heights OD)	MHWN: 1.5m OD	< intertidal mudflat, > saltmarsh.	Atkins, 2002; Coutts and Roberts, 2003.
Topography/elevation (OS heights OD)	MHWS: 2.0m OD	< saltmarsh	Atkins, 2002; Coutts and Roberts, 2003.
Topography/elevation (OS heights OD)	HAT: 2.5m OD	> upper level of saltmarsh in 80yrs	Atkins, 2002; Coutts and Roberts, 2003.
Is there a history of pollution or contamination on the site?	History to no history Score –2 to +2.	All	Atkins, 2002; Coutts and Roberts, 2003.
Inundation	400-500 times per yr	Saltmarsh	Burd, 1995
Inundation	>500 times per yr	Mudflat	Burd, 1995
Slope	1-2%	Greatest diversity	Burd, 1995
Fetch	<1000ft	Affects accretion	Burd, 1995
Elevation	<MLWN	Mud/sand flats – Eelgrass	ABPmer, 2002
Elevation	MLWN - MHW	Pioneer/low-mid Marsh	ABPmer, 2002
Elevation	MHW - MHWS	Mid-upper marsh	ABPmer, 2002
Elevation	MHWS - HAT	Strand line/upper saltmarsh transitions	ABPmer, 2002
Exposure	fetch	All	ABPmer, 2002
Proximity (not a major factor)	Similar habitat next door to site / Max distance 88Km	Invertebrate migration / bird population transfer	ABPmer, 2002

APPENDIX 2: REVIEW OF BIOLOGICAL, PHYSICAL AND CHEMICAL PROCESSES AFFECTING HABITAT CREATION OF SALTMARSHES, MUDFLATS AND *ZOSTERA* BEDS

1.0 SALTMARSHES

Introduction

This review on salt marshes describes important factors known to be necessary for the growth and survival of salt marsh plants, some of which need to be considered in selecting a site for creation of vegetated salt marsh. Before discussing these parameters, some general background information on salt marshes is given below, taken from Brown and Cox (2001).

General description and importance of salt marshes

Coastal salt marshes are vegetated areas bordering saline water, subjected to periodic flooding by the tides. Salt marshes develop on sheltered, low energy coasts where fine sediment accumulates. The vegetation of salt marshes develops between approximately MHWN tides (Mean High Water Neap) and high spring-tide levels, and is usually fronted by mudflats. Salt marshes are now recognised as a key natural resource playing a vital role in coastal defence and in wildlife conservation, and they provide an important source of organic material and nutrients that support adjacent marine communities. They can also function as a sink for various environmental pollutants, many of which may accumulate in the sediments and be taken up by salt marsh plants. If the sediments are reworked some pollutants can be re-mobilised and re-enter the environment.

Coastal salt marshes have been classified into different 5 types according to their physical setting (Allen and Pye 1992): embayment marshes; open coast marshes; estuarine fringing marshes; back-barrier marshes; and loch or fjord-head marshes. In the UK, for example, all these types can be found. Estuarine marshes: almost all UK estuaries have salt marshes, e.g. Humber, Thames, Severn; Embayment marshes: many harbours on the south coast such as Poole Harbour, also The Wash and Morecambe Bay; Open coast (less common in the UK): Dengie Peninsula, Essex; back-barrier marshes: north Norfolk; Loch/ fjord-head marshes: northwest Scotland.

Emergent plants on salt marshes are tolerant to salt (halophytes). Differences in tolerance to tidal inundation (submergence) and associated factors by salt marsh plant species results in bands of vegetation at different levels on the marsh (zonation). The vegetation of the salt marsh traps and stabilises sediment, protecting against erosion by storms.

The vegetated salt marsh is fronted by mudflat, on which the main plants are microscopic algae such as diatoms, although in some areas eelgrass (*Zostera* spp.) is found. Salt marshes and associated mudflats are highly productive ecosystems, important as habitats and source of food for a variety of marine and terrestrial animals. Primary production comprises the vascular salt marsh plants, macroalgae, phytoplankton and benthic microalgae. The contribution of algae and vascular plants to

primary production varies seasonally in temperate regions, but the contribution by the microphytobenthos (benthic microalgae such as diatoms) that cover the surface of the intertidal flats for much of the year can be much higher than that of the halophytic salt marsh vegetation (e.g. work by Sagan in Mont Saint Michel Bay, in Brown *et al.* 2003). Diatoms that live on the mud surface are grazed by numerous invertebrates and birds. Most of the vascular plant material is converted to detritus, which forms the basis of a detrital salt marsh food web, in which the decomposer microorganisms convert the detritus into a suitable food source for detritus consumers.

Salt marshes provide a nursery area for juvenile fish, nesting sites for breeding birds, and are used by a variety of small mammals such as rabbits, hares, and rodents. Terrestrial insects and spiders are abundant on salt marsh vegetation. The salt marsh is used as a source of food by wildfowl, and the mudflats harbour many invertebrates and are important feeding grounds for waders. Many estuaries and salt marshes support nationally and internationally important numbers of shorebirds. Substantial loss of salt marsh and associated mudflats on bird migration routes is likely to have a major impact on bird populations.

Seals use salt marsh creeks and marsh edges, for example, common seals are regularly seen in the Wash and on the Lincolnshire coast in the UK.

A variety of economic activities occur on salt marshes, although many of the traditional uses are now declining. The most common use is livestock grazing, which has been important historically in shaping the composition of the flora. Shellfish culture (mussel beds and oyster farms) is another activity that is important in many UK and other European sites.

Salt marshes can be lost through reclamation for agricultural land or for industrial and leisure developments, and they are increasingly being affected by rising sea levels.

Salt marshes are either of natural origin, or have been created by man as a result of sedimentation works, such as polders in the Netherlands. Both natural and man-made salt marshes have often been embanked, so that they cannot move inland in response to sea level rise (coastal squeeze). In Great Britain, the total area of salt marsh is approximately 44,370 ha (Burd, 1989), but an estimated 100ha of salt marsh is being lost every year.

Salt Marsh Formation

Four physical processes govern the location and dynamic behaviour of salt marshes and mud flats: sediment supply, tidal regime, wind wave climate and relative sea level (Allen and Pye 1992). Salt marshes form in low energy or sheltered areas with shallow water, such as in estuaries, behind spits and barrier islands, and in protected bays, where there is a supply of suspended sediment that can settle out and build up the level of the sediment (accretion). When tidal current velocities slow near slack water, fine suspended particles can settle. Sources of sediment are: marine (from the sea bed), fluvial (from river erosion), coastal cliff erosion, and *in situ* reworking of sediments.

The semi-diurnal tides experienced the Atlantic and North Sea coasts of Europe, vary in range between springs and neaps, with distance from their amphidromic points about

which they rotate in an anti-clockwise direction in the northern hemisphere, and with geomorphology, e.g. as they enter funnel-shaped estuaries. Tidal range can be classified into three types: micro (0-2m), meso (2-4m), and macro (>4m). In the UK, macrotidal estuaries are the most common (e.g. the Severn, Thames and Humber), and are also found in other parts of Europe (e.g. Gironde estuary, Schelde estuary). Most of the European Atlantic and North Sea coasts experience macro- or mesotidal regimes, although the extent of tidal range can vary considerably along the North Sea coast due to the occurrence of three amphidromic systems (see Pethick 1984).

As tidal range increases, tidal current velocity and suspended sediment transport increases. As the tidal wave moves up an estuary, it is affected by frictional drag on the bed and it may become increasingly asymmetrical in terms of duration and therefore velocity. In general, in long narrow macrotidal estuaries with a landward decrease in width and depth, the flood tide period is shortened with correspondingly higher velocities. In terms of sediment transport, the upper parts of such estuaries become net sediment traps, so estuaries are predominantly depositional environments.

Tidal currents are of major importance in shaping coastal morphology; but wave energy becomes increasingly influential as tidal range decreases. The effect of waves depends on wind strength and duration, fetch (uninterrupted distance of open water for wave generation), and water depth. Waves and wave induced currents can resuspend material deposited by previous tides, and the tidal currents transport the material away, or redistribute it elsewhere within the system, often interchanged between the two zones of the intertidal (salt marsh and mudflat). The erosion threshold of the mudflat or salt marsh surface is a balance between wave shear stress and sediment shear strength. Erosion of the surface under vegetation is less easily achieved than on mudflats, which display larger oscillations in sediment bed level. However, wave action is an important factor causing erosion of the marsh edge or creek sides by undercutting them so that they subsequently collapse.

The rate of formation of salt marshes depends upon the degree of protection, the topography of the near shore sea-bed, and the supply of suspended sediment (Long and Mason, 1983). Where the slope is very gradual the marshes can become very wide, such as those in the Wash, on the east coast of England. On steeper slopes, e.g. the sea lochs of W. Scotland, they may be just a few metres wide. They may develop on rising, stable, or submerging coasts (Chapman 1976). In the UK, areas in the north have been rising since the last ice age (isostasy). On such coasts, e.g. in Scotland, there is usually only a narrow strip of marsh as the upper zones of a marsh on a rising coastline cease to be influenced by tidal cover. The North Sea coasts of south east England and the Netherlands are sinking relative to sea level, and hence further increasing the effects of rising sea levels due to global warming. Here salt marshes can only continue to develop and survive as long as the rate of sedimentation exceeds the combined rates of sinking and sea level rise.

Vegetation on salt marshes can establish between mid neap tides and high water spring tides. The higher the tidal range, the higher the vertical range of salt marshes, typically 1-4m in a mesotidal or macrotidal regime (Allen and Pye 1992). Below the level of MHWN (Mean High Water Neaps), microalgae such as diatoms, and filamentous algae, colonise the mud surface and bind it with mucopolysaccharide secretions, helping to stabilise it. Above this level, rooted vascular plants can colonise the mud surface. These

'pioneer' species (e.g. the cord-grass, *Spartina*; and to some extent, the glassworts, *Salicornia* spp.) bind the sediment particles with their roots. At first, the vegetation is patchy, forming mounds and ridges, with hollows and runnels (drainage channels) between them. Once the above ground vegetation has developed sufficient continuous cover, the shoots help to slow the water velocity and aid further sedimentation. Mud deposited on the vegetation dries and falls to the sediment surface. The plants also add organic matter to the sediments. As accretion continues, the marsh grows vertically and the number of tidal inundations decreases, until the surface is raised to that only reached by the highest tides. Different vegetation species find conditions suitable for establishment in a process called succession. In this way, low marsh is eventually transformed into high marsh.

Drainage channels deepen into creeks as the marsh surface increases in height. Well developed, mature marshes, are dissected by numerous tidal creeks that channel the flood tides into the marsh and drain the marsh on the ebb. Where hollows and small creeks become cut off or blocked, bare areas called pans, or channel pans, respectively, form that may be alternately waterlogged, then dry and hypersaline in the summer, hence unsuitable for plant colonisation. Pans formed during salt marsh formation are called primary pans. Other pans may develop subsequently, for example, after litter smothers and kills off vegetation producing 'rotten spots'.

Over a long period of time, an area of salt marsh may be subjected to periods of accretion and erosion. This can result in a series of small erosion cliffs on the marsh surface. Where the salt marsh surface is lowered, there is a reversal of the process of plant succession. Salt marshes can recover from storm events, provided there are sufficient return times between events. In future, storms are likely to become more frequent and intense with global warming, which will threaten the stability of salt marshes. A wide, mature, well-developed salt marsh takes tens to hundreds of years for formation. Currently, many European salt marshes appear to be accreting at a rate to keep up with sea level, although there are areas, notably SE England, where there is considerable evidence of erosion and decline. The natural response for a salt marsh under rising sea levels is to move landward, but because of extensive reclamation and construction of protective embankments for coastal defence, the salt marsh has nowhere to go and is being subjected to 'coastal squeeze'.

Salt marsh vegetation

Salt marsh plants are fundamentally terrestrial, but tolerant of salt (halophytes). As well as coping with large fluctuations in salinity from seawater influx, rainfall, and drying out, salt marsh vegetation has to withstand periods of tidal inundation, waterlogging and changing oxygen levels, and mechanical forces of moving water.

The major limit to the seaward extension of salt marsh vegetation is tidal inundation and the physical forces of moving water that can prevent seedling establishment.

Tidal submergence cuts down time available for photosynthesis, particularly in water with high levels of suspended sediment, and associated with flooding and waterlogging is lack of oxygen in the substrate (anoxic conditions).

Most species belong to a few genera: the glassworts (*Salicornia*), seablites (*Suaeda*), cord-grasses (*Spartina*), and other grasses (*Puccinellia*, *Elytrigia*/*Agropyron*, *Festuca*), sea aster (*Aster*), plantains (*Plantago*), sea lavenders (*Limonium*), sea purslane and oraches (*Atriplex*), rushes (*Juncus*) and sedges (*Scirpus*), scurvy-grass (*Cochleria*), sand-spurreys (*Spergularia*), arrow-grass (*Triglochin*). Different species have adapted different ways to cope with salinity, and waterlogging. For example, *Spartina* has glands in the leaves, which excrete salt, and sheds salt in old tissues (also *Suaeda maritima*). *Spartina* has large air spaces in the root cells, which diffuses out to aerate the soil around the root. *Salicornia* is succulent, reducing the concentration of salt in the tissues. Salt marsh plants also have mechanisms to reduce water loss through transpiration.

Tidal submergence and related abiotic factors have a major influence on plant species distribution, particularly for the lower limits of species on the lower part of the marsh. Each species has a different tolerance to tidal flooding, and therefore a different, although often overlapping, vertical range (e.g. see Gray's chapter on Saltmarsh ecology in Toft and Madrell 1995). The vegetation communities occur in bands associated with the environmental gradient of changing conditions, i.e. salt marsh vegetation exhibits zonation, changing with increasing elevation. Zonation tends to be better developed in areas with a large tidal range, and the sharpness of the boundaries depends upon the gradient of the marsh surface, thus boundaries can be sharp on a steeply sloping marsh, but on large very flat marshes there may be extensive transitions between zones (Adam 1981). As the marsh surface level rises by sediment accretion different species are able to establish in a process termed succession. Biotic interactions between plants, particularly interspecific competition, also determine species distribution; but the outcome of plant competition between species also changes with environmental conditions, particularly those relating to submergence, including small-scale differences in elevation (microtopographic variation, affecting drainage) in the marsh surface, and also salinity, oxygenation, and substrate type. The general, although simplified, view is that the lower vertical limit is controlled mainly by tolerance of tide related factors, and the upper limit is determined by interspecific plant competition.

Three distinctive marsh types (A,B and C) are recognised, one mainly southeastern in distribution, one mainly on the west coast of England and Wales, and one characteristic of western Scotland. Substrate, climate and land use history appear to be important determinants of the vegetation characteristics of these marsh types (see Adam 1978, 1990 for more details).

As noted above, different salt marsh plant communities are found at different elevations on the marsh. Details of the dominant species that determines each community as designated by the NVC classification (Rodwell 2000) are given below. The following simplified table shows the typical key species of the major plant communities in UK salt marshes:

[MHWN=Mean High Water Neaps; MHW=Mean High Water; EHWS=Extreme High Water Springs]

Zone	Dominant species in community
Pioneer marsh: Most seaward zone, down to approx. MHWN	<i>Spartina anglica</i> (cord grass) <i>Salicornia</i> (annual glasswort), <i>Suaeda maritima</i> (seablite) <i>Aster tripolium</i> (sea aster)
Low-mid marsh: Up to MHW	<i>Puccinellia maritima</i> (common salt marsh grass) <i>Atriplex</i> (formerly <i>Halimione</i>) <i>portulacoides</i> (sea purslane)
Mid-upper marsh: Approx. from MHW to EHWS	<i>Puccinellia maritima</i> (salt marsh grass), <i>Limonium vulgare</i> (sea lavender), <i>Armeria maritima</i> (sea thrift), <i>Festuca rubra</i> (red fescue) <i>Juncus gerardii</i> (saltmarsh rush) <i>Juncus maritimus</i> (sea rush)
Driftline: Around EHWS	<i>Elymus pycnanthus</i> (= <i>Elytrigia atherica</i> (sea couch)) <i>Suaeda vera</i> (Shrubby seablite)
Transitional: Around & above Highest Astronomical Tides	Transitions, e.g. to reed swamp, freshwater marsh, grazing marsh, sand dunes or shingle.

HABITAT REQUIREMENTS FOR SALT MARSH DEVELOPMENT

The following section describes the factors affecting the distribution of salt marsh plants. Not all of these are key criteria for selecting a site for salt marsh creation, but they may affect the species that may be expected to colonise, and their vertical distributions in the salt marsh. The main factors to be considered in site selection are summarised at the end of this report on salt marshes.

Elevation / tidal submergence

The most important factor determining whether salt marsh plants will colonise a managed realignment site is the elevation of the site in relation to the tidal frame. Although other factors are important, salt marsh plants will not establish and survive until the elevation is suitable. Elevation also determines which species will be present at each level. Salt marsh plant species occur in overlapping zones and the generally accepted, although simplistic view is that the lower vertical limit is set by tolerance to tide related factors, while biotic factors such as interspecific competition are important at the upper limits (Pielou and Routledge 1976, Bertness 1991a&b, Gray 1992).

In general, the lower limit of salt marsh is approximately at the level of Mean High Water Neap tides (MHWN), although it may be lower downshore in areas of small tidal range and in areas with a shorter fetch, presumably because of less exposure and wave action (Gray 1992).

MHWN is tabulated for all primary and secondary ports, in relation to Chart Datum, in Part II of the Admiralty Tide Tables, Volume 1 (European Waters), published annually by the Hydrographer of the Navy. These values can be converted to heights in relation to land survey datum - Ordnance Datum, Newlyn (ODN), using Table III of the Admiralty Tide Tables. MHWN varies around the coast, for example, in mODN: Holy Island, Northumberland: 1.3; Spurn Head, Humber Estuary: 1.6; Boston, Lincolnshire: 1.93; Kings Lynn, Norfolk: 1.97; Blakeney, Norfolk: 1.2; Hamford Water, Essex: 1.24; Bradwell, Essex: 1.52; Cleavel Point, Poole Harbour, Dorset: 0.1; Burnham, Somerset: 2.77; Burry Port: 1.9; Milford Haven: 1.49; Porthmadog: 0.96; Morecambe: 2.5. Once specific sites have been narrowed down as likely to be suitable for salt marsh creation, measurements of elevations on adjacent marshes at the marsh front and in different communities, will provide a more reliable guide to the extent and type of vegetation communities that are likely to develop on a chosen site.

A study of sites of historic sea defence failures in Essex, by Burd (1994) found that the original elevations would have been equivalent to a present day level of about 2.1mOD (which would be covered by between 400-500 tides per year, depending on the estuary), and that the most successful of these sites to develop and retain salt marsh (defined as vegetation surface exceeding 60% of the total area) subsequently had elevations now generally greater than 2.34m OD, which would be equivalent to fewer than 300 tidal inundations per year (and see Huggett, 2003, report to RSPB). As Burd (1994) acknowledges, this may be a suitable guideline for elevation around the historic Essex sites. However, it will not be appropriate for all areas of the coast, such as Burnham, Somerset, or Poole Harbour, as can be seen from the examples of elevations at MHWN around Britain, above. If the level of MHWN is used as a general guideline, its height in the area under consideration for salt marsh creation should be determined and then it can be used as a good approximation. For example, around Poole Harbour, where MHWN is 0.1mODN (Cleavel point), the pioneer species *Spartina anglica*, extends down shore to this approximate elevation. At various points around the Harbour, the lower limit of *Spartina* lies between -0.2 and +0.2m ODN.

Most of the area within the Tollesbury realignment site is too low at present for salt marsh to develop, except for the highest zones. Here, by 2001, the lower limit of the fringing salt marsh was at the 1.5mODN contour (Garbutt *et al.*, in Reading *et al.* 2002), which is equivalent to the MHWN level in this area, at Bradwell.

In terms of tidal inundations, sites with elevations that will experience less than about 450 tidal inundations would be expected to develop salt marsh, whereas mudflat will develop at levels that experience greater than 500 inundations per year (Burd 1995).

This is a useful general guideline. Some pioneer species such as *Spartina anglica* and annual *Salicornia*, which are tolerant to frequent submersion, can tolerate up to 600 tides a year. The section on salt marsh NVC communities in this report gives some examples of the number of tidal submergences that are experienced by different plant communities on marshes where they have been studied.

The elevations at the lower limits for colonisation by salt marsh flora are therefore of great importance in selecting a site for salt marsh creation by managed realignment. Studies on the niche of *Spartina anglica* and other salt marsh species on south and west

coasts of Britain, from Poole Harbour to Morecambe Bay, by Gray (1992, Gray *et al.* 1995) demonstrated that much of the variation in upper and lower limits, could be accounted for by a multiple regression model using a set of physical (mainly tide-related) variables, including tidal range, submergence times, submergence during daylight hours, fetch, estuary area and latitude. Over 90% of the variation in the lower limits of *Spartina* could be attributed to physical variables.

The lower limit of *Spartina* was described by:

$$LL = -0.805 + 0.366SR + 0.053F + 0.135 \text{ Log}_e A$$

where, *LL* = lower limit of *Spartina* (mODN), *SR* = spring tidal range (m), *F* = fetch in the direction of the transect (km) and $\text{Log}_e A$ = Log_e estuary area (km²)

The lower limit of *Puccinellia maritima* (Gray, in Toft and Madrell, NRA 1995) was best described by:

$$LL = 0.23 + 1.39\text{MHWN}$$

These general equations may not be directly applicable to the east coast however, due to differences in climate (temperature variation and rainfall) and exposure, substrate (west coast marshes are predominantly sandy), grazing history, or some other 'east coast' factors. Work on models for the east coast is being carried out at CEH Dorset (S.Brown).

There may be a trade-off in choice of elevation for creation of salt marsh habitat, between time for salt marsh colonisation and development of necessary creek drainage systems. Drainage is discussed further below, but from US experience (ABP, 1998), generally sites that are too high (usually filled with dredged material) are found not to develop adequate drainage systems and lacked habitat diversity. Conversely, those sites that were lower than the recommended level (and therefore taking longer for accretion to attain suitable elevations), developed numerous branching channels and a variety of marsh habitats and a variety of marsh habitats consistent with a natural system (Weckman and Sales 1993, cited in ABP, 1998). Observations from the Tollesbury managed realignment site found that creeks did not begin to develop until about 20-30cm of sediment had accreted on top of the agricultural site surface. This suggests that it might be important to excavate drainage channels in some or all sites that are initially suitable for salt marsh development in terms of their elevation. Alternatively, if there is to be no intervention, sites that slope gently to levels slightly lower than those needed for salt marsh establishment might, in the long term, produce marshes of better quality and diversity as natural drainage systems develop in the accreting sediment. The UK experience is currently too short to be able to predict the best way to achieve optimum ecological function in created salt marshes.

Ideally a proposed site should slope gently upwards from the minimum level needed for plant establishment, to encourage the development of a range of salt marsh community types from low to upper marsh, and where possible, continuing into salt marsh-terrestrial transitions (see slope below).

Also related to elevation and frequency of tidal submergence are many other factors affecting growth and distribution of salt marsh plants, including soil salinity, aeration

and redox potential, drainage characteristics, and soil 'maturity' (organic content, calcium content, nutrient status (particularly N&P)).

Estuary size, exposure and fetch

Estuary size has a significant influence of elevational limits of salt marsh species. The lower limits of several species are further upshore on large estuaries than smaller ones (Gray 1992), probably because of a greater degree of exposure (in terms of fetch) to wind and wave action.

Tidal range

Tidal range also affects the distributional limits of salt marsh plants, for example, the lower limit of the pioneer species *Spartina anglica* rarely extends below MHWN in estuaries with a spring tidal range of 7m or more, but it may occur up to a metre below MHWN in estuaries with smaller tidal ranges (Gray *et al.* 1995).

In the UK, most marshes are macrotidal (>4m tidal range) or mesotidal (2-4m), but there are areas of important salt marshes that experience smaller tidal ranges, as low as 1.2m and 1.4m (Christchurch Harbour and Poole Harbour, Dorset). The highest tidal range of 12.3m is found in the Bristol Channel/Severn Estuary. The vertical range in level of a salt marsh is primarily related to tidal range (and secondarily to turbidity – high turbidity reduces the potential vertical range). In the maximum tide range in the Bristol Channel, salt marsh growth covers a vertical range over 4m, in contrast to the small tidal range in Poole Harbour, where salt marsh covers a vertical range of only about 1m (Ranwell 1972).

Out of 155 estuaries with salt marsh, and/or mudflats or sandflats, 16 experience tidal ranges less than 3m (JNCC 1993,1996,1997). There are no indications why any tidal range that occurs in areas of natural salt marsh development should not be suitable for the selection of sites for managed realignment, however a tidal range minimum of 3m is appearing in some reports on site suitability. For example, the report by Haycock Associates (2001) for the RSPB and the Environment Agency contains a dichotomous key for the identification of habitats for regulated tidal exchange, in which intertidal sites suitable for salt marsh or mudflat habitats are defined as having a tidal range greater than 3m. In the accompanying text it states 'The most ideal sites for mudflat and saltmarsh restoration or creation are in coastal regions with greater than a 3m tidal range (Gray 1988)'. This is a myth. The reference is purportedly an annual report about Tollesbury, but this site was not initiated until 1994. Gray (*pers. comm.*) thinks that this may be a misquotation from work in which he noted that the main targets for *tidal barrage construction* are in areas with tidal ranges greater than 3m. Thus there appears to be no foundation for this cut-off point for intertidal habitat creation. In fact, in areas with very high tidal range it might be expected that a realignment site may require additional protection for the establishment of salt marsh plant seedlings and will need considerable care in design of the site in view of the higher energies and bigger forces involved, particularly if the site is large and emptying large volumes of water through breaches. At the Frieston realignment site (tidal range in The Wash approximately 6.5m), there has been a rapid, and extensive cutting back of creeks out on the mudflat

after the site was breached (S. Brown, personal observation). Providing care is taken to ensure no adverse impacts from increase in tidal prism to the surrounding coast, there appears to be no contra-indications to suggest that any tidal range would be unsuitable for salt marsh creation.

As a general comment on the design of practical guidelines for intertidal habitat selection and creation, which involves an understanding of many disciplines, including hydrodynamics, geomorphology, biogeochemistry, engineering, economics and ecology, it is important that contributors from all disciplines are involved in some way, directly or as peer review groups. Also, as far as possible, the sources of information on parameters on which decisions are based should be supplied, perhaps in an accompanying text. The Haycock report draws on reports from the United States, where there is far greater experience of intertidal habitat creation and restoration, but there are differences between the US and the UK that need to be realised, for example in some aspects of salt marsh ecology. Haycocks' descriptions of plant colonisation on developing salt marsh, are about North American species, which do not occur naturally in Britain. Furthermore, the American *Spartina alterniflora* grows lower in the tidal frame than the British *Spartina anglica*.

Latitude

Latitude also modifies the effects of tidal range and submergence on salt marsh plants. The upper limit of *Spartina* is lower down the shore in northern England than it is in the south, possibly because its growth and competitive ability with other species such as *Puccinellia* is reduced under colder conditions (Gray 1992). *Spartina* has a C₄ photosynthetic pathway, and active leaf growth requires higher temperatures than C₃ plants, so at higher latitudes canopy development of C₄ species is delayed compared with that of C₃ species. A number of salt marsh plant species reach their northern limits of distribution in the UK, and for many the limit runs from just north of the Solway Firth in the west, to between the Firth of Forth and Scottish border in the east (Adam 1990 and references cited in this publication). These species include *Atriplex portulacoides*, *Artemisia maritima*, *Limonium vulgare*, *Limonium humile*, *Elymus pycnanthus*, *Parapholis strigosa*, *Spartina anglica*, *Centaurium pulchellum*, *Apium graveolens*, *Trifolium fragiferum*. Species with a southern distribution (south of the latitude of the Humber Estuary) include *Suaeda vera*, *Alopecurus bulbosus*, *Althaea officinalis*, *Sarcocornia perennis*, *Spartina maritima*, *Aster tripolium* var. *discoideus*, *Inula crithmoides*, among others (see Adam 1990 for more detail), some of which have a more local distribution within the southern half of Britain.

Gradient / slope

The gradient of land selected for salt marsh creation will affect the survival and diversity of vegetation that will establish, through its affect on drainage and zonation of plant species, which tolerate different amounts of tidal inundation. In general the more gentle the slope, the wider the area of marsh that can develop within the appropriate tidal frame for vegetation establishment. However, the surface gradient must be sufficient to allow drainage to prevent ponding, as prolonged waterlogging will result in the death of vegetation, and also to prevent high salinities resulting from evaporation of waterlogged areas, as many salt marsh plants are sensitive to excessive salinities (Brereton 1971). Areas of standing water have been a major factor in vegetation

mortality at some UK managed realignment sites, including Northey Island (IECS 1992-1995), Saltram and Tollesbury (Reading *et al.* 2002).

Studies on historical sites of accidental sea defence failure in Essex by Burd (1994), found that the sites were very flat with slopes mostly of 0.1% or less, and at the time of the accidental breaches they would have been very low in the tidal frame due to lack of accretion and to compaction of the sediment. As most of these sites would have been flooded on most tides, a similar accretion rate would have occurred over the flooded area. This effectively produces a marsh of uniform age and uniform vegetation composition. Where there was some variety in the vertical range, more varied vegetation community types were observed.

Steeper slopes aid drainage and aeration, but increasing gradients offer narrower zones for the different plant species to establish. Furthermore, wave energy is dissipated over a narrower area, which may cause increased tidal scour compared with that on a gently sloping pioneer zone. Studies on marsh restoration in the United States have recommended various gradients, for example, slopes between 0-2%, probably 1-2% preferable (Zedler 1984), up to a maximum of 6-7% or more gradual (Knutson *et al.*, 1990). Webb and Newling (1985) report that a slope of 0.7% was considered suitable for salt marsh creation with dredged material in Texas, and Woodhouse (1979) recommended a slope between 1-3%. Broome *et al.* (1988) state that slopes of 1-3% are considered optimum, although marshes have been established on slopes between 10% to <1%. Toft and Madrell (NRA 1995) recommend that to allow adequate drainage the marsh surface should slope from land to sea with a gradient between 1-10%, although between 1-3% is preferable. This recommendation is presumably taken from the above reference sources.

Zedler (1984) states that the best advice for salt marsh creation is to create relatively flat intertidal topography that slopes very gradually toward the intertidal channels, to make large areas available for salt marsh. Small intertidal pools that may form with the shrinking of sediments may be an asset to the marsh ecosystem, supporting algae and invertebrates.

Salt marsh surface slopes are not constant, particularly where they grade upward through transitional habitats at the landward side, and it is not clear exactly where the gradients are calculated from. Most of the salt marshes on the east coast of Britain are backed by high flood defence embankments, constructed after successive reclamations to protect the lower lying agricultural land behind. Approximate overall gradients of some natural marshes on the east coast of Britain, around Lindisfarne, the Humber, Wash, and north Norfolk, calculated from the difference in elevation between a sampling site nearest to the base of the defence embankments and the seaward marsh edge, vary between approximately 0.1% and 2.5%, as follows:

Location	Approximate Gradients (%)	Source of information
Mainland across from Lindisfarne	0.23-0.66 (4 transects)	S.Brown, CEH Dorset, unpublished data
North Humber Estuary	0.50-2.46 (6 transects)	
North Lincolnshire coast	0.13-0.17 (4 transects)	
Wash embayment	0.10-0.25 (10 transects)	
North Norfolk coast	0.16-0.75 (8 transects)	

A gradual transition of a site to land beyond tidal reach would make an ideal site for salt marsh creation by allowing the possibility for the development of upper transitional habitats, which are rare on the embankment backed marshes of the east coast and other parts of the coastline. Sites with naturally sloping land behind will also be cheaper to create as there will be no need to construct flood defence embankments.

The recently breached site at Paull Holmes Strays (Thorngumbold, Humber Estuary) contains areas in which the gradient falls landwards from behind the breached embankment. Providing that there is sufficient connectivity for incoming water to reach all parts of the site, salt marsh should develop and undergo successional change at the appropriate elevations, although the traditional pattern of zonation (higher zones landward, pioneer zones seaward) is expected to be reversed in parts of the Paull Holmes site.

Drainage and creeks

Site drainage characteristics govern the time that tidal water remains standing on the marsh surface, sediment stability, and the velocities of currents across the marsh and through the breach(es), and are determined by sediment grain size, slope and creek systems. Early development of an efficient drainage system seems to be critical for the success of salt marsh creation. Creeks are important for supplying the marsh surface with sediment and nutrients and dissipating tidal energy, and for draining the marsh during the ebb tide, which will increase sediment stability and reduce waterlogging, which is detrimental to plant colonisation and survival.

At Tollesbury, Watts (2002, in Reading *et al.* 2002) found that embryo creeks only formed in the newly accreted sediments once a critical depth (20-30cm) was reached, and subsequently the banks drained faster than the surrounding sediments and showed an increase in sediment stability and shear strength. *Salicornia* has colonised the edges of the embryo creeks, but not on the adjacent sediments. In general the accreting sediments at Tollesbury have poor drainage, low bulk density and low resistance to resuspension and erosion, which are only just beginning to develop a system of drainage creeks. This may be due in part to the formation of an unconsolidated horizon with low hydraulic conductivity on the reclaimed agricultural soil, forming an aquaclude or barrier to water (Crooks *et al.* 2002). The extent to which creek development is limited to newly accreted marine sediments probably depends on several factors including soil type and consolidation, and elevation of a proposed realignment site. Some new drainage creeks are starting to develop at Frieston, but they also appear to be in areas where there has been deposition of new sediment (much of which may be reworked

material washed out from the breaches), or where there is a rapid fall off into previously excavated dykes. It is too soon to tell at this site whether creeks will develop more readily through the agricultural soil than at Tollesbury.

Drainage design

Relying on natural processes to establish adequate drainage patterns takes a long time, particularly where sediment is consolidated (Haltiner and Williams 1987). If a site to be selected is large, or with a very shallow gradient, it will probably be necessary to construct drainage creeks to ensure connectivity to the breach areas and adequate drainage for healthy vegetation establishment. Vehicular access to the site will be necessary, and if not in place, will therefore need to be taken into account when considering costs for a realignment scheme. Often old creek networks can be seen in aerial photographs of reclaimed areas, which may help to determine the best positions for creek excavation.

According to Harvey *et al.* (1983) and Haltiner and Williams (1987) drainage networks should be designed so that no point on the marsh surface is farther than about 100feet or 30m from a channel (30m in Toft and Maddrell/NRA, 1995, presumably from these reference sources), and should meander in a similar pattern to local natural systems to cover the largest drainage area.

Sediment supply and accretion rate

Experience of wetland creation in the United States has found that a surface layer of freshly deposited sediment is the most ideal substrate for vegetation establishment (Krone 1993). A sufficient sediment supply to maintain steady rate of accretion will sustain the surface at a suitable level for continued vegetation survival, providing it is sufficient to offset the predicted sea level rise in the area of coastline where salt marsh creation is desired. The low-lying managed realignment site at Tollesbury has been accreting (on average) at about 23mm year (Garbutt *et al.*, in Reading *et al.* 2002). Excessive accretion at levels suitable for marsh colonisation may result in burial of seedlings and vegetation, although salt marsh plants are tolerant to quite high levels of accretion. For example, salt marsh vegetation in Mont Saint Michel Bay in France experiences one of the highest accretion rates in the world, on average 35mm per year close to the Mont, and the growth of common salt marsh grass, *Puccinellia maritima* appears to be stimulated by sediment burial rates of about 4mm per month (Langlois *et al.* 2001).

Sediment characteristics: grain size, salinity, waterlogging, aeration and redox potential, pH

In addition to the key controls of elevation and tidal submergence on plant zonation, salinity and waterlogging are considered to be major factors controlling species distributions on salt marshes. These and other various inter-related abiotic factors affect the growth and distribution of salt marsh flora in complex ways, often exhibited as different outcomes of competitive (biotic) interactions between species.

Grain size

Most salt marsh plants are not limited by sediment types and textures that occur on natural salt marshes, and are found on various marine sediments from coarse sands to heavy clays. The types of sediments that will accumulate naturally in areas sheltered enough to sustain salt marshes are not likely to create problems for plant colonisation on the basis of their particle size. However, sediment grain size composition and porosity affect drainage characteristics and organic content, and can influence the elevation of species colonisation and the outcome of plant competition. For example, around the Wash, the elevation of the pioneer zone was found to be correlated with the sand content of the sediment. On the sandiest areas, the lowest marsh zones were at a higher elevation than on silt (Randerson 1979). He suggested that this might be due to lower nutrient content of the sandier sediments reducing colonisation potential. Another possibility is that there is greater seedling wash-out in the pioneer zone in higher energy areas. Sediment stability is important for seedling establishment as wave action on loosely consolidated sands can dislodge seedlings before they become adequately rooted. Another example of possible substrate effects on plant distribution is that sea purslane, *Atriplex portulacoides*, which favours well-drained areas, is found in the low marsh in southeast England on coarse shell-rich sediment (Adam 1990), compared with its more usual occurrence in the mid-marsh on silt.

Grain size affects the outcome of competition. For example, *Puccinellia maritima*, which begins seasonal growth earlier than *Spartina maritima*, reduces the competitive ability of *Spartina* and replaces it on the silty sand marshes in the northern marshes of the Netherlands, but it cannot outcompete *Spartina* on the clay rich salt marshes in southwest Netherlands (Scholten and Rozema 1990).

Use of sandy dredge spoils or other materials to build up areas before tidal inundation may affect plant growth. Zedler and Adam (2002) note that although plants re-established on sandy dredge spoils in San Diego Bay, low nitrogen levels limited optimum growth such that the site would not achieve the desired outcome. Finer sediments would be best to use in marsh restoration.

Substrate salinity

Salinity, in terms of the position of a site on an estuarine gradient influences the species found, for example, in upper estuaries low marsh zones may have low soil salinities and brackish water species such as the common reed, *Phragmites australis*, can be abundant.

The salinity of the site in general will be determined by the waters (sea and freshwater inputs) that flow into the site. In the lower sections of estuaries and around the coast, soil salinities in the lower salt marsh, which receives frequent tidal inundation, are relatively constant and rarely exceed that of seawater. Soil salinities are much more variable at higher elevations, being reduced by rainfall or freshwater inputs, and increased by evaporation to levels higher than seawater (Beeftink 1977, Adam 1990). Species patterns reflect their tolerance to these conditions.

Most salt marsh plants can grow well in non-saline soils (i.e. they are not obligate halophytes), but show poor competitive ability with terrestrial species (glycophytes) and

brackish marsh plants. Freshwater flows into the site can introduce greater diversity of species, but if excessive may have an adverse impact on salt tolerant plants as they may be unable to compete with terrestrial and brackish water species.

Major freshwater inputs to salt marshes will therefore change the species composition and is a factor to be considered in site selection if salt marsh communities are the desired outcome.

Waterlogging, aeration and redox potential

Where drainage is poor, waterlogging affects soil aeration and redox potential, which in turn influences soil chemistry, including the amount of toxic substances, particularly sulphide and reduced form of metal ions. These may be directly toxic to plants, or may act indirectly, for example, by reducing the availability of essential micronutrients. Redox potential can change rapidly during tidal flooding (Armstrong *et al.* 1985), but in highly reducing conditions the substrate becomes black and anaerobic with high concentrations of sulphide. Tolerance to these conditions requires mechanisms to maintain oxygenation of root systems or adaptation to anaerobic respiration.

Areas of waterlogging have been a major factor in vegetation mortality at some managed realignment sites, including Tollesbury, Saltram and Northey Island (see Table A10)

Different species have different tolerances to the effects of waterlogging and/or to sulphide levels. Seedlings and young plants of purslane, *Atriplex portulacoides*, cannot tolerate waterlogging and standing water can kill mature plants (Chapman 1950). This plant is well known to be intolerant of waterlogged substrates, and is found most frequently on well-drained sites, particularly along creek levees. Glasswort, *Salicornia europaea*, distribution is controlled by variations in salinity and waterlogging, and generally occurs in well-drained saline conditions, whereas saltmarsh grass, *Puccinellia maritima* appears to be relatively tolerant of waterlogged soils (Brereton 1971), although possibly not combined with high sulphide levels, as Ingold and Havill (1984) and Havill *et al.* (1985) found *Puccinellia* to be only moderately tolerant to high sulphide levels. *Salicornia* (in spite of its apparent preference for well drained sites), and *Aster tripolium* were found to be tolerant of high sulphide levels, in contrast to the grasses *Festuca rubra* and *Agrostis stolonifera* (characteristic of upper salt marsh with occasional flooding), which were intolerant to sulphide. *Atriplex portulacoides* and *Agrostis stolonifera* were also found to be sulphide sensitive species by van Diggelen *et al.* (1987), compared with *Salicornia* spp. and *Spartina anglica*, which were not inhibited at the experimental concentrations of sodium sulphide used.

Interactions of environmental factors and stresses

Experimental work on physiological tolerances often appears to be equivocal. Complex processes and abiotic and biotic interactions are involved, and there may be different genotypes or ecotypes with different tolerances. Environmental factors affect growth of salt marsh species at both intraspecific and interspecific levels. Interactions between environmental factors, including substrate, salinity, waterlogging and nutrients, affect the intensity and outcome of interspecific competition (see, for example, Groenendijk *et al.* 1987, Scholten *et al.* 1987, Huckle *et al.* 2000).

pH

Soil pH affects nutrient availability and concentrations of soluble ions which may have toxic effects, for example at low pH values around 4, aluminium may be released in toxic concentrations in soluble form (Ranwell 1972). According to Wolaver *et al.* (1986), soil pH can vary by as much as 2 units within a tidal cycle because of water infiltration or benthic biological activity. The range of pH suitable for halophyte growth is fairly broad (pH4-9), but most nutrients are readily taken up at pH between 6 and 8 (Harvey *et al.* 1983). Values below pH 4 are detrimental to salt marsh plant establishment, and Broome (1990) noted no survival of vegetation planted in soils of pH<3.

The soil pH in a proposed realignment site is unlikely to be an important selection criterion, unless it has a very low pH detrimental to plant growth. Tidal inundation of a managed realignment site and deposition of suspended sediments is likely to alter the pH to close to that typical of seawater (7.8-8.2) relatively quickly. After tidal inundation, pH of one of the plots at Tollesbury, with an initial pre-breach pH of 4-5, increased to pH 7.9 after at the surface and 7.3-7.4 down to 35cm (measured in 1997; Watts, in Reading *et al.* 2002). How quickly the pH changed post-breach is not known, although the report notes a sharp initial increase in soil water content, exchangeable sodium, pH and soluble salts.

One word of caution, described by Callaway *et al.* (2001), is that low soil pH could be a major concern at restoration sites where soils are drained and exposed to air. When tidal inundation is stopped, salt marsh soils can become extremely acidic following the oxidation of sulphides to sulphuric acid and when leaching of sulphuric acid is impeded by a high clay content (see Mitsch and Gosselink 1993).

Table A10: Notes on colonisation by salt marsh biota at some managed realignment sites

Site information (and reference sources)	Date	Size (ha)	Elevations (mODN) & gradient	Notes and Colonisation (biota)	Comments
Northey Island Highest areas: 10-18 tides per year. Most of site: 100 tides per year. (IECS1992-1995, Research Reports to English Nature)	Aug 1991	0.8	Highest area 3.2m-3.3mODN in W corner, down to 2.6mODN. No information on average gradient	Relic creek through centre of the marsh (20cm depth, deepened to 30cm by July 1992). Over first 2.5 years, 8.6cm on the 'mudflat', 1.8cm on 'marsh surface'. Rapid colonisation by halophytes. By 1993 a pioneer community had established across whole area of survey. Most common: <i>Salicornia</i> spp. and <i>Suaeda maritima</i> . By 1994, 23 vascular plant species had colonised. Other communities developing. Greatest diversity and density of plants near new sea wall on highest areas of ground, at approx 3.1mODN, increasing with time.	Rapid colonisation may be due to relatively high surface elevations, but dominated by <i>Salicornia</i> after 3 ½ years despite relative elevation of site. Colonisation of bare ground (clay infill) around edges of site poorer, possibly because of compaction during remedial works. Areas of shallow standing water were not colonised by higher plants. Drainage system of the site less satisfactory – channel had deepened after 3 ½ years but not connected to standing water. Large areas of standing water remained along predicted line of creek after 3 ½ years.
Blaxton Meadow, Saltram, Devon. Spillway in sea wall (Reading <i>et al.</i> 2002; ADAS 1998)	Mar 1995	5	No information found	1 st year –prolonged flooding for 3 months (vandalism to sluices) restricted plant establishment. Frequently flooded areas covered by mats of algae. 2 sps halophytes in flooded area. In 1997, 11 sps. halophytes (most common: lesser sea spurrey and spear-leaved orache) covered just under ½ the site. Lowest part of site almost permanently flooded (approx. 1/5 of site), preventing plant colonisation. Higher land at back had recognisable transitional salt marsh-grassland community. In early 2000 flap valves removed by vandals so now the site is inundated at high tide every day and most of the vegetation covering the site where there is such frequent inundation has died. Common glasswort recorded for first time in 2000.	Flooding and standing water in first year killed off terrestrial vegetation, but retarded halophyte growth also. Site subject to irregular uncontrolled flooding due to vandalism. A range of halophytes were found within the site even though the nearest extensive salt marshes (just a fragment of sea aster occurs opposite), is approx. 10 miles away.

Site information (and reference sources)	Date	Size (ha)	Elevations (mODN) & gradient	Notes and Colonisation (biota)	Comments
Abbot' Hall, Essex. Pipes in sea wall – controlled inundation (ADAS 1998, ABP 1998)	Apr 1996	20	1.0m to 2.5mODN No information on average gradient	Network (2.2km) of meandering creeks (1-3m wide and deep) dug to distribute and drain water over site. Sluices low down in tidal frame and thought floating propagules may not enter naturally, so seeded site with strandline material from adjacent salt marshes. In 1996 colonisation v.sparse (3 sps), restricted to margins of creeks. 1997, one year after inundation – 10 species of salt marsh plants established, colonising approx. 1/3 of site. Early marine invertebrate colonisation.	Most of area lower than elevation at which salt marsh is likely to develop under normal tidal elevation, therefore set up with controlled inundation through pipes. Although sparse cover of plants, their presence at an early stage suggests conditions on site suitable for salt marsh vegetation.
Orplands, Essex. Breached (2) embankment (ADAS 1998; HR Wallingford 1996, 1997, 1999) MHWS 2.6mODN MHWN 1.5mODN (at Bradwell)	Apr 1995	30	1.5m to 3.5m (NE end); to 2.0m (SW end). Higher area 2.0 to 3.0-4.0 (ex set aside field) No information on average gradient	Seawater killed 90% of terrestrial vegetation. Original vegetation survived above 3.0m. Creeks excavated at site, where possible following relic creeks. Accretion over most of site, annual rates not given, but from table, amount per year varied, often less than 1cm, to max 2.7cm at one station. In 1996, one year after inundation, salt marsh plants (8 sps, pioneer annual <i>Salicornia</i> spp.and <i>Suaeda maritima</i> most common) on parts of site, most cover was mud and algal mats. 1997, almost half of site colonised by halophytes (12sps), pioneer community over 1/3 of the site. Distinct vegetation zones. On higher ground at back, rare transitional communities developing. Creeks used by invertebrates and fish, in greater numbers than control salt marsh. Birds soon made use of area as feeding, roosting and nesting grounds.	Poor establishment at low elevation. Lower limits of halophyte growth on ex set-aside site (Site B) was approx.2.0m, but higher at 2.5m on ex-grassland field (Site A) by 1997. Thought to be due to sediment chemistry –redox potential in Site A much more reducing; Site B not too different from adjacent marsh. Site A had higher groundwater table, more organic matter (dead grass), and poorer drainage, producing anaerobic highly reducing sediments. Sediment in Site B comparatively rich in invertebrates by 1997, but no infauna were recorded from intensely reducing Site A. Both Sites A & B similar in reducing conditions to control salt marsh by 1999. Limits of distribution and density increased in both areas by 1999.

Site information (and reference sources)	Date	Size (ha)	Elevations (mODN) & gradient	Notes and Colonisation (biota)	Other features and Comments
Tollesbury, Essex (Reading <i>et al.</i> 2002)	Aug 1995	21	<p>0.90m to 3.0m ODN, most <2.0mODN, most sampling sites below 1.4m</p> <p>No information on average gradient. Gradient along vegetation transects in higher area at back of site calculated as approx 1.0-1.6% (from transect profiles)</p>	<p>Mean annual rate of accretion in site: 23mm per year (30mm 1996, 15.1mm 2001). Highest rates between 1.2m-1.3mODN (approx. half the area of the site), little or no accretion on highest parts of site. Change in surface level at individual monitoring sites to Sept 2001 ranged from 8mm-258mm. On 2 adjacent marshes mean annual rates of accretion: 3.7-4.7mm per year (range 1.6-7.4mm).</p> <p>Initial colonisation was limited to pioneer species. In 1996, <i>Salicornia</i> was the only species (few scattered individuals). 1997: + annual seablite, perennial glasswort and common cord grass; 1998: + Aster, sea purslane, common salt marsh grass and lesser sea spurrey, grass-leaved orache. 17 species by 2001. Most species reached maximum seaward extent in the 1st or 2nd year after establishment, and little change in distribution of vegetation between 2000-01. Glasswort occurred down to 1.5mODN, roughly the level of MHWN, but mostly between 1.8m-2.7mODN; perennial glasswort and cord grass to just below 2.0mODN, all other species between 2.0-2.9mODN, most above 2.4mODN.</p> <p>By 2001, 6ha of site vegetated, 15ha intertidal mudflat. The lower limit corresponded with the 1.5m contour. Dominant vegetation community annual <i>Salicornia</i> salt marsh (NVC: SM8) Still new plant species arriving each year. Only very small area of site high enough to develop mid to upper marsh species.</p> <p>Invertebrates: the mudflats were rapidly colonised by benthic invertebrates, with 16 of the 20 species found after 6 years being present in the year following the breach. Numbers and distribution of most species continue to expand.</p>	<p>Gullies only formed in soft sediment once a critical depth of 20-30cm had been exceeded, improving drainage, stability and shear strength.</p> <p>Waterlogging thought to be major factor in mortality of introduced plants.</p> <p>Leaving ryegrass on the site, and to a lesser extent stubble, appeared to increase colonisation rates of <i>Salicornia</i>, compared with bare and ploughed areas, presumably because the dead vegetation affords protection to seeds and seedlings from being washed out by wave action or removed by invertebrates. Effect of land treatment diminished after 2 years, once the site was covered by marine sediments.</p>

Nutrients

Nitrogen (particularly) and phosphate can be limiting to some salt marsh plant growth, and improved growth has sometimes been observed following the addition of fertilisers (Adam 1990), mainly nitrogen, or nitrogen and phosphate together, which may interact with salinity and other factors. Nutrient addition can cause shifts in plant zonation and the outcome of plant competition. High levels of nutrients can cause greater problems by encouraging excessive algal growth and large algal mats washed up and deposited on marsh vegetation smother and kill off the halophytes. Algae present for much of the summer of 2001 at Tollesbury overlaid the *Salicornia* and killed it. Sites chosen for salt marsh creation from agricultural land are unlikely to be too deficient in nutrients for halophytes to grow, and where they are low enough in the tidal frame, a build up of sediment from tidal inundation will soon cover the soil with naturally derived marine sediments, which will contain clay particles and adsorbed nutrients suitable for salt marsh vegetation growth.

Proximity to source of seed and propagules.

The presence of a natural salt marsh in the vicinity of sites selected for salt marsh creation will provide a natural source of propagules to the new site. This may be in the form of tiller fragments, for example, *Puccinellia maritima* readily develops from rooted fragments, and has been found in the first spring season after the breach at Freiston (S.Brown, personal observation); or as seed dispersed by tidal currents or by shorebirds (Olney 1963, Vivian-Smith and Stiles 1994). The longevity of seeds in salt marsh soils is largely unknown. It may be theoretically possible that some seeds of salt marsh species may remain in soils that have been reclaimed for agriculture, and which are subsequently returned to the sea, but for how long they remain viable, uneaten, or whether any remain near the surface after agricultural and earthworm activities is not clear.

It seems most likely that seeds and propagules will have to reach a new site from adjacent marshes, via dispersal by water and birds. Little is known about seed and propagule dispersal between marsh sites. Seeds or plant fragments have to reach the site, and be deposited in the right environment for germination and establishment. Not all salt marsh plant species produce viable seeds each year (particularly *Spartina*).

Germination requirements vary in terms of temperature, salinity, light *etc.* Some species e.g. *Salicornia* can germinate in full saline conditions, a useful attribute for plants occupying the low marsh with more frequent flooding, but most species show maximum germination in fresh water conditions or low salinities, following rainfall. *Spartina anglica* may require a low temperature before germination (Hubbard 1970, Marks and Truscott 1985). Different salt marsh species have different requirements of temperature and light, and there may be interactions with salinity and temperature (Adam 1990). Some species produce dimorphic seeds, which have different germination requirements, helping to extend the germination period.

Studies on salt marsh seed banks have found that seed distributions strongly paralleled adult plant abundance patterns across the marsh, suggesting localised dispersal with limited movement out of parental environments (Bakker 1985, Rand 2000). Rand (2000) also found that adding seeds to an existing New England salt marsh typically

increased seedling densities by at least an order of magnitude, indicating that lack of seed availability may be an important factor limiting plant abundance within marsh zones.

Propagules may be transported either floating in the water column or along the sediment surface. Many floating propagules have long buoyancy periods and retain their viability (Koutsaal *et al.* 1987), and so they have potential to travel considerable distances: *Spartina anglica* 4->60days, *Triglochin maritima*: > 6 months, *Limonium vulgare*: 18-60 days, although *Elymus (Agropyron) pungens* has a shorter buoyancy period of 5-12 days. Some propagules transported along the bottom generally have shorter buoyancy periods: *Salicornia* spp: <1day, *Spergularia* spp.: 5-7h, although *Aster tripolium*: 7-15days and *Atriplex portulacoides*: over a month, are exceptions (Huiskes *et al.* 1995). Floating net and surface net traps on a Dutch mudflat found that few propagules were imported into the marsh from elsewhere (Huiskes *et al.* 1995), and traps over the vegetated marsh found the net transport of floating and surface moving propagules to be mainly landward (i.e. to higher zones) with the flood tide. Fewer propagules were transported back from higher marsh zones into lower areas on the ebb. However, on the mudflat, the net transport of propagules was seaward with the outgoing tide, mainly from plants growing in lower parts of the marsh, although small numbers of propagules of most main salt marsh species were found in these catches, indicating potential exchange (although low) between different salt marshes.

These observations (limited dispersal and low seed availability on natural marshes) suggest that it is likely that the rate of colonisation of newly created sites could be limited by seed availability even when elevations are suitable for salt marsh establishment, and initial colonisation may be a reflection of seed abundance.

Nevertheless, the establishment of a range of halophytes at Blaxton Meadow, Saltram, Devon (Appendix Table A10), demonstrates that natural colonisation of new sites is possible, even where there is no nearby adjacent salt marsh. The nearest salt marsh (except for some fragments of *Aster* marsh) is 10 miles away. Unfortunately, persistent vandalism to the flap valves draining the site resulted in long flooding events and death of the vegetation. It was therefore not possible to follow successional changes in the vegetation community at this site (Garbutt *et al.*, in Reading *et al.* 2002).

Initial colonisation of managed realignment sites is predominately by pioneer species, particularly the annuals, *Salicornia* and *Suaeda maritima*. In the first year after the breach at Frieston, the site is colonised by these species in particular, although other mid-marsh species, and higher marsh species are already present in higher areas of the site. Sites suitable for colonisation by upper transitional communities are only covered occasionally by tides and are rare on the embanked marshes of the east coast. Whether these will be slow to develop due to seed limitation is not known. However, it is encouraging to see that such communities occur at the Orplands managed realignment site.

Conditions for establishment of seedlings of pioneer plants

As well as tolerance to tidal submergence by adult pioneer species, the seaward extension of pioneer plants is limited by the mechanical effects of tidal currents and

wave action, washing out young seedlings. The lower limits of salt marsh plants are at higher elevations in estuaries with larger tidal ranges and stronger tidal currents, and it is likely that the physical forces on seedlings are a major reason for this. In the Dovey estuary, Weihe (1935) showed that seedling establishment of *Salicornia* was influenced by current strength and frequency of tidal cover. He found a high correlation between the density of *Salicornia* and the number of days free from tidal submergence. He suggested that there was a threshold period of 2-3 days needed for the seedlings to develop sufficient roots to withstand subsequent tides. Clapham *et al.* (1942) suggested that the threshold period free from tidal inundation required for successful establishment of *Aster tripolium* was 5 days. *Puccinellia* fragments are buoyant and very susceptible to disturbance by tidal action during establishment (Brereton 1971), and wave and tidal action on seedlings and plantlets also prevents the natural seaward spread of *Spartina* (Gray, in Toft and Maddrell, NRA 1995). *Spartina* clumps at the marsh front in Skeffling, Humber Estuary, produce scouring as they intercept the incoming tide so that they eventually sit in waterlogged hollows (Brown 1998). Although there has been vertical accretion at the marsh front here over the last 7 years, there has been no seaward extension of the pioneer zone, and it is hard to imagine how small seedlings could survive the rapid tidal advance that occurs across the wide flat mudflat in front of this marsh.

Managed realignment sites created by breaching the embankment are likely to have some degree of natural shelter, unless the sites are very large. Realignment sites created by full bank removal may need some form of artificial protection initially (e.g. brushwood fences) to encourage establishment and survival of seedlings.

Experimental work by West (2001) found that *Salicornia* seedling establishment is helped by good drainage to a water content of <54% at low tide, deposition of not more than 1cm in four weeks at the seedling stage, sufficient wave energy attenuation, and soil with a dry bulk density ratio > 0.87. The presence of invertebrates such as the polychaete *Hediste (Nereis) diversicolor*, may delay the development of *Salicornia* cover (West 2001, Paramor and Hughes, in Reading *et al.* 2002, Gerdol and Hughes 1993, Hughes 2001), by herbivory, granivory and bioturbation, and influence the lower limits of plant colonisation out on to the mudflat.

Pretreatment of a realignment site

Experiments at Tollesbury where surfaces were either ploughed, left bare, left to cereal stubble, or seeded with ryegrass, found that colonisation of *Salicornia* was higher in areas of grass and stubble, probably because the dead vegetation afforded protection against seeds being removed by tidal currents or by invertebrates. These effects disappeared in later years once the surface became covered with accreted sediment (Garbutt *et al.*, in Reading *et al.* 2002).

Pollutants

Many coastal areas and estuaries are heavily populated and industrialised. Salt marshes are at the receiving end of a variety of pollutants from land based activities (industrial discharges, sewage outlets, agricultural run off, catchment clearance *etc.*) and from the sea (acute and chronic oil pollution, plastics and litter).

Chemicals and heavy metals – industrial effluents, sewage sludge

Salt marshes act as a sink for chemicals and heavy metals that become adsorbed onto clay minerals in the sediments. Some may be immobilised under anaerobic conditions that are often found below the surface of the mud, precipitated as insoluble sulphides. Disturbance may result in re-suspension of sediments and toxic chemicals, and re-mobilisation (resolution) under oxidised conditions.

Some toxic elements may be taken up by vegetation, but there is little information on toxicity to the plants. However, plant uptake and uptake by benthic filter or deposit feeders, creates potential for accumulation in the food chain. In 1979, a large number of estuarine birds died in the Mersey estuary, England, apparently as a result of accumulation of trialkyl lead by the benthic fauna, which were eaten by the birds.

Sewage, and agricultural run off –fertilisers (excess nutrients), herbicides

Excessive nutrients from agricultural run off (e.g. fertilisers, piggery effluent) and sewage inputs may result in large blooms of algal mats, which are subsequently lifted off by incoming tides and deposited higher up the shore on marsh vegetation, smothering it and causing it to die off. This is one mechanism that has been suggested for secondary salt pan formation (bare pans in the upper and middle marsh).

Marshes are often found adjacent to large areas of agriculture, much of which has been created from salt marshes in the past by reclamation to produce very fertile productive soil for market gardening. Good examples of this can be found in the Netherlands, the Wash (east coast), and south east coast of England.

Recently, it has been suggested that herbicide run off from agriculture may have an adverse effect on salt marsh plants, and may be partly responsible for die off of some salt marsh vegetation in southeastern England, and playing a part in increased erosion in this areas as the stabilising effects of salt marsh plants are lost (Mason *et al.* 2003).

Laboratory studies and field trials showed that herbicide concentrations within the range found in the aquatic environment reduced photosynthetic efficiency and growth rates of both epipellic diatoms and vascular salt marsh plants, and herbicide treated sediments showed decreased stability. Diatoms produce extracellular polymeric substances (EPS), which bind and stabilise sediments (Paterson 1994), enhancing accretion and assisting colonisation by pioneer salt marsh plants (Underwood 2000).

Oil pollution

Oil contamination may occur as the result of acute pollution from a major incident or in the form of chronic pollution from occasional discharge from land based oil industries. The susceptibility of salt marsh vegetation to oil in its different forms varies according to the plant species, and the time of year that contamination occurs. The more volatile fractions of oil are usually the most toxic. Chronic pollution may cause long-term loss

of some salt marsh species. *Salicornia* is sensitive to a single oiling, whereas *Spartina anglica* survives most single oil spillages by producing new growth, but it does not tolerate chronic pollution (Baker *et al.* 1990). *Puccinellia maritima* and *Atriplex portulacoides* are both sensitive to oil pollution when tested in monoculture, but in mixed cultures oil, acting a stress factor, influences the direction of competition (Scholten *et al.* 1987) when interacting with nitrogen in limited supply.

A salt marsh may recover after a single spillage. In general, allowing the oil to weather naturally is likely to be less damaging than using chemical dispersants, burning or cutting the vegetation, or stripping the sediment. If sediment removal is the only option after a major incident, some replanting should be carried out to stabilise the exposed sediment.

Excessive sediment input –catchment clearance, stormwater drains

Increased sedimentation in the pioneer (front) zone of a marsh may result in marsh expansion, but excessive sediment input on to higher levels can smother and kill the vegetation. Alterations in freshwater input, for example from stormwater drains, may result in a modified salinity regime and changes to the composition of estuarine and salt marsh biota.

Plastics and other litter from ports, ships, and illegal refuse dumping, destroy the aesthetic value of salt marshes and gives the impression that salt marshes are wasteland of little value.

Site History

The most suitable areas for managed realignment are those which were originally salt marsh before enclosure (reclamation). Burd (1995) states that such sites indicate that conditions at this point in the estuary are more likely to be suitable for development of salt marsh, and she points out that if no marsh was present, either the physical environment is unsuitable, or the estuary has not reached a stage in its evolutionary history where salt marshes would develop naturally. It is generally accepted that where appropriate, the more recent the reclamation of a site, the more suitable it is to be returned back to the sea. This is primarily because the site would not be as low relative to the tidal frame as those reclaimed a long time ago (due to compaction and continued marsh accretion in front of the site). It is also assumed that the soil structure and chemistry of the underlying substrate is more likely to be suitable for salt marsh formation than an area which was not originally marsh (Burd 1995, Huggett 2003, draft report to RSPB). However, soils may have ‘ripened’ (dried out irreversibly), their density increased and porosity decreased (Dent *et al.* 1976), and may not be suitable for salt marsh plant colonisation until covered with newly deposited sediments. The physical properties of the old agricultural soil also influence the subsequent development of creeks (Hazelden and Boorman 2001), an important factor for successful salt marsh creation (see ‘drainage’ above), and which may need to be created artificially. The old pattern of creeks may be still visible on the site to guide the construction of a suitable drainage network.

Tidal Prism and Estuary Morphology

To avoid creating problems of erosion downstream of a managed realignment site, the effect of increasing the tidal prism needs to be carefully assessed, and managed realignment sites should aim to maintain, or return an estuary to, its natural funnel shape (Burd 1995, see her report for further detail) which has often been altered significantly by extensive land claim.

LAND CONSERVATION VALUE

Sites selected for salt marsh creation should not currently have a high conservation value (such as SSSIs, mature grazing marsh *etc.*). The Inventory of UK Estuaries (JNCC 1993,1996,1997) lists and maps conservation status in each estuary area, but more detailed and up to date information needs to be gathered during the site selection process.

ECONOMIC ACTIVITIES – SHELL FISHERIES

All current activities such as oyster and mussel farms on mudflats in the vicinity of a proposed site should be mapped and checked that they are not likely to be adversely affected by the creation of a managed realignment site. All stakeholders involved need to be informed. At Abbots Hall, locals involved with shellfisheries were consulted and the breaches were designed to avoid any potential problems (information given on tour of Abbots Hall site). Although well advertised at Frieston (Wash Banks managed realignment site), possible implications to an oyster farm were missed. A problem was encountered immediately after the breach at Frieston, where large volumes of water draining off the site caused rapid channel deepening and erosion, taking suspended sediment through an oyster farm out on the mudflats south of the site. This caused siltation and burial of the oyster racks, which had to be moved in an expensive operation.

SUMMARY OF KEY FACTORS FOR SITE SELECTION

There are many environmental factors, several of them interacting, which influence the colonisation and distribution of salt marsh flora. These include elevation (and consequently tidal submergence), sediment supply, estuary size, exposure or fetch, tidal range, currents and wave action, latitude, gradient, drainage characteristics, sediment stability and water content, salinity, aeration and redox potential, pH, organic content and mineral nutrients, propagule supply, freshwater inputs, and some environmental levels of pollutants of which herbicide run-off may prove to be important.

As far as existing knowledge and current UK experience shows, the following is a summary of the key factors affecting the success of salt marsh creation, which should be considered in selecting sites. The process of site selection should also aim to ensure that there would be no adverse impacts on the environment or activities in the surrounding estuary or other areas.

- As a general guide, the **presence of natural salt marshes in the proposed area** would indicate that overall conditions are suitable for salt marsh creation, providing the following important parameters are met
- **Elevation** must be suitable for salt marsh vegetation colonisation. The minimum elevation should be around the level of MHWN *in the location of the proposed site*, which is equivalent to a level which would experience approximately 450-500 tidal inundations per year. Levels lower than this would be likely to develop mudflat, which may be required as part of the scheme
- **Gradient:** in order to encourage adequate drainage, and provide conditions for the development of the range of salt marsh communities from pioneer to upper marsh (eventually) and driftline, a gently sloping site is generally recommended. The US experience recommends various gradients, but between 1% and 3% would seem to be considered optimum (from a review of the US literature and UK reports, although the latter may have taken figures from the US recommendations). However, some of the large marshes on parts of the British east coast in the Wash and Lincolnshire have gradients lower than 1%. Providing that the gradient is more than zero to prevent ponding, and some drainage system is in place, we cannot rule out any gradients between >0.1% - 3% at this stage. Sites backed by naturally sloping land behind are ideal for creation of rare upper transitional habitats.
- **Drainage:** creeks supply the marsh surface with sediment and nutrients, and drain the marsh, increasing sediment stability. As natural development of a creek system is slow, and appears to only develop in newly accreted sediment, excavation of a drainage system should be considered, particularly for large sites. In site selection, therefore, accessibility for earthmoving vehicles needs to be considered.
- **Sediment supply** needs to be sufficient to maintain an accretion rate sufficient to offset predicted sea level rise. The presence of healthy marshes close to a proposed site would indicate a suitable location in terms of sediment supply.
- **Soil grain size** is not an important factor for site selection, as the site will accumulate marine sediments which should be of an appropriate grade if hydrodynamic conditions are suitable for salt marsh development. However, if the proposed site needs the artificial addition of sediment to produce the right configuration, the use of sediment finer than sand is preferable
- **Propagule supply:** the presence of a natural salt marsh in the vicinity will provide a source of propagules to the new site, although colonisation at Saltram has shown that salt marsh can develop at some distance from the nearest salt marsh. If natural colonisation is slow, some assisted seeding of the site can be considered
- **Contamination:** areas away from major pollutant sources are preferable, and it may be necessary to provide ways of diverting any excessive herbicide input if used on adjacent agricultural land.

- **Site history:** sites reclaimed from salt marsh are likely to be the most suitable, particularly if reclamation was relatively recent (in terms of elevation differences) so that the proposed site meets the required elevation levels
- **Tidal prism:** the effect of increasing tidal prism (particularly for large sites in high tidal ranges) needs careful prediction to ensure no detrimental effects on adjacent areas of coast
- **Conservation status of proposed site:** sites selected for salt marsh creation should not involve damage to existing sites of high conservation value
- **Local economic activities -shellfisheries:** any activities in the area, such as shellfisheries, should be determined and efforts made to ensure that there will be no detrimental impacts from a realignment scheme.

NVC SALT MARSH COMMUNITIES

The dominant species that determines each community is described briefly, with information on habitat. For further details and information on associated species in these communities see Rodwell (2000).

SM1 *Zostera* communities –more details on the three species of *Zostera* with maps of their distribution are given in the report section on eelgrasses.

The three species of eelgrass, *Z.marina*, *Z.angustifolia* and *Z.noltii* form stands in the sub-littoral and sulittoral zones of sand and mud flats.

Z.marina is essentially sub-littoral, extending from 1-4m below to just above LWS Tides. In Britain *Z.marina* grows on a firm substrate, usually sand or sandy mud, sometimes with fine gravel. It is abundant in The Solent, west coast of Scotland and Outer Hebrides, and the Moray Firth.

Z.angustifolia grows in the lower and middle eulittoral zone, extending well above LWN Tides, and may form mosaics with *Z.noltii*. It is characteristic of muds and muddy sands, which may be quite firm, although *Z.angustifolia* is typically associated with sloppy mud. It is widespread along south and east coasts of England and the east coast of Scotland. There are extensive stands in the Cromarty Firth and along the Essex and North Kent coasts.

Z.noltii generally grows in the middle and upper eulittoral zone, on mud-sand mixtures from very soft to quite firm consistency. Its British distribution is similar to *Z.angustifolia*.

SM2 *Ruppia maritima* salt marsh community

R.maritima is a monocotyledonous perennial which can occur as a dominant in a submerged aquatic community, locally in permanently filled pans and creeks on coastal salt marshes, at some inland saline sites and in brackish counter-dykes behind sea walls, and also as a plant of estuarine flats (e.g. it is abundant in the Cromarty Firth, sometimes overlapping with *Salicornia* and *Zostera noltii*).

SM3 *Eleocharis parvula* salt marsh community

E.parvula is very rare in Britain with records in Hampshire, Dorset, Devon and Gwynedd. At Beaulieu, Hampshire, stands occur at the limit of tidal influence, with some input of fresh-water from land drainage at low tide.

SM4 *Spartina maritima* salt marsh community

Once abundant in late nineteenth and early twentieth centuries in Hampshire, parts of Sussex, Kent, Essex, and around the Wash (Marchant and Goodman 1969a), but now declined and remaining in areas around the Solent and parts of Essex and the Wash (near Frieston managed realignment site – personal observation by S.Brown &

A.Garbutt). A pioneer community in its European range, its decline in Britain is not fully understood but may be partly due to competition with *S.anglica*, and now seems to survive best where *S.anglica* is less aggressive, on drier sites above MHWS (Marchant and Goodman 1969a). It is at the northern limit of its range in Britain and small fluctuations in climate may also have played some part in its decline (Marchant 1967). Little viable seed is produced at the present time (Marchant and Goodman 1969a).

SM5 *Spartina alterniflora* salt marsh community

A naturalised alien, first recorded in Britain in 1829 from the river Itchen, Hampshire, and spread around Southampton Water east to Chichester (Marchant and Goodman 1969b). Hybridisation between the north American *S.alterniflora* and *S.maritima* produced *S.townsendii* and subsequently the fertile form, *S.anglica* (Gray *et al.* 1991). *S.alterniflora* now only survives at Marchwood, Hampshire, and as transplants in Poole Harbour, Dorset (Marchant and Goodman 1969b, Gray *et al.* 1990).

SM6 *Spartina anglica* salt marsh community

Constant species: *Spartina anglica*

Rare species: *Arthrocnemum perenne* (*Sarcocornia perennis*)

S.anglica (fertile form) arose from *S.townsendii*, a hybrid produced between the native *S.maritima* and the introduced North American *S.alterniflora*, which was first seen in Southampton Water in 1870. *S.anglica* was transplanted to many areas around Britain (and other parts of the world), and also spread rapidly around the coast. Large areas have died back since the 1930s, but it is widespread around the English and Welsh coasts, and still spreading around the Solway in Scotland.

S.anglica is found mainly at the seaward edges of salt marshes (lowest pioneer zone), and colonising old pans in the upper marsh zone. Substrates are varied, from very soft mud to shingle, although it appears to spread more on finer sediments. The pH is generally above 7.0 and loss-on-ignition (organics) varies from 0.2% to 36.3% (Adam 1976). The sediment is often strongly reduced (black layer), and *S.anglica* is very tolerant of tidal immersion, having colonised a 'vacant niche' in many areas, too low for other salt marsh plants to survive. In general its lower limit is around MHWN, with about 6 hours submersion per day during spring tides (Goodman *et al.* 1969, Dalby 1970, Morley 1973, Proctor 1980), but extends down to MLWN in the narrow tidal range of Poole Harbour, with up to 23.5 hours submersion per day on neap tides (Hubbard 1969). The lower limit of colonisation is probably controlled by wave or tidal action, and may also be related to the nature of the substrate. *S.anglica* can tolerate high salinities, up to about 2.5% chloride (Ranwell *et al.* 1964, Proctor 1980).

S.anglica spreads by rhizome fragmentation and seed, and small patches expand into clumps which may persist for long periods, or may spread and join together to form a continuous sward. Accretion of sediments in *Spartina* areas varies between 0.5 and 10cm per year (Ranwell 1964a, Bird and Ranwell 1964).

SM7 *Arthrocnemum perenne* (*Sarcocornia perennis*) stands

A perennial halophyte with restricted distribution, occurring around the coast of south-east England from the Wash to Poole Harbour, with isolated records from North Wales and Teesmouth (Perring and Walters 1962). It occurs as an occasional in both low and high marsh, on sand or firm silt or firm clays with gravel and shell fragments, and on drift litter over shell banks at a few sites, particularly around Chichester Harbour, Hampshire.

SM8 Annual *Salicornia* salt marsh community

Constant species: *Salicornia* aggregate

Rare species: *Arthrocnemum perenne* (*Sarcocornia perennis*)

There are several taxa, and three groups: *S.europaea*, *S.procumbens*, and *S.pusilla*; all annual species described here under *Salicornia* agg.

Widely distributed in marshes around the British coast, but local in western Scotland due to lack of suitable habitat (many loch-head marshes are fronted by cobble beaches rather than sand flats). Annual *Salicornias* germinate from seed in April/May. Found in the pioneer zone at lower limits of the vegetation, the lower marsh and throughout the marsh surface where there are gaps. The lower limit of seedling establishment is likely to be set by the time necessary for seedlings to become firmly established, and 2-3 days between tidal flooding is needed for sufficient root growth to occur to anchor the seedlings. *Salicornia* is tolerant of frequent tidal submersion, to about 600 flooding tides a year at its lower limits. The plants can grow on a variety of substrates from hard clay to shelly sand, and occasionally on shingle, but very soft sediments are only rarely colonised. Growth may be dependent on sediment nutrients, particularly nitrogen (Pigott 1969, Stewart *et al.* 1972), and addition of nutrients to *Salicornia* stands higher on the marsh stimulates growth characteristic of lower marsh stands. Plants can survive some burial by wind blown sand. *Salicornias* are highly susceptible to oil and refinery effluent spills.

SM9 *Suaeda maritima* salt marsh community

Constant species: *Suaeda maritima*

S.maritima is an annual, tolerant of a wide range of soil types subject to various submersion regimes. Chapman (1947) reported it dominant on Norfolk marshes with between 290 and 430 submergences per year. Like *Salicornia*, Its growth appears dependent on sediment nutrients, especially nitrogen (Pigott 1969, Stewart *et al.* 1972). *S.maritima* is characteristic of open situations free of competition from established perennials, it often forms mosaics on the lower marsh with stands of annual *Salicornia* (where the pioneer zone comprises raised areas dissected by shallow channels the *Suaeda* is usually seen on the slightly higher better drained areas, with *Salicornia* on the gently sloping sides – S.Brown, observation). Also found on piles of dumped sediment from construction of sea walls, creek sides, on drift litter at the foot of sea walls, and brackish areas behind sea walls.

Distribution is widespread but many stands are fragmentary; *Suaeda maritima* is most frequent in south-east England and locally in west Scotland.

SM10 Transitional low-marsh vegetation with *Puccinellia maritima*, annual *Salicornia* species and *Suaeda maritima*.

Constant species: *Puccinellia maritima*, annual *Salicornia* spp., *Suaeda maritima*

Rare species: *Arthrocnemum perenne* (*Sarcocornia perennis*)

This transitional community is widespread around Britain, except for western Scotland, but stands are often small. At its lower limit, this community probably experiences a similar level of flooding tides to the lower part of the *Puccinellia maritima* community (SM13). Sediment varies from firm clays to coarse sands with a pH range of 7.0-8.0 and high levels of free calcium carbonate. On sandy substrates the community may occur as a pioneer community, forming patches in a mosaic with the *Salicornia*, *Spartina anglica*, or *Puccinellia maritima* communities. On sandy grazed hummocky *Puccinellia* marshes this transitional community may be found on the hummock tops; on muddier marshes in south-east England, it occurs in slight depressions within the *Puccinellia*, *Spartina*, *Aster* and *Halimione* communities. It is also widespread on the sides of large creeks in a zone above the *Salicornia*, often on grazed marshes where the creek sides are inaccessible to grazing cattle or sheep.

SM11 *Aster tripolium* var. *discoideus* salt marsh community

Constant species: *Aster tripolium* var. *discoideus* (rayless form of *Aster tripolium*), *Puccinellia maritima*, annual *Salicornia* spp.

Rare species: *Arthrocnemum perenne* (*Sarcocornia perennis*)

This association occurs as an extensive zone in the low marsh or on creek sides at varying levels in the marsh. At the lower limits, this community tolerates about 500 or more submergences per year (Chapman 1960a), with maximum development around 350 submergences per year (Clapham *et al.* 1942). The sediments are mostly firm clays or silts low in organic matter, with fine shell fragments and a pH between 7.0 and 8.0. Most sites are ungrazed or only lightly cattle grazed. In the low marsh this community forms a zone above the *Salicornia* or *Spartina* zone or, occasionally, at the most seaward limit. Landwards it passes into the *Puccinellia* or *Halimione* (now called *Atriplex portulacoides*) zones.

Geographical distribution is mostly south-eastern and it is frequent in the Wash, north Norfolk and Essex. It is local on the south coast and in the Bristol Channel. Its general absence from the west coast may reflect climatic limitations, the scarcity of muddy marshes or the higher incidence of grazing.

SM12 Rayed *Aster tripolium* on salt marshes

Stands dominated by the rayed form of *Aster tripolium* have been found in situations with some freshwater influence, such as brackish ditches behind sea walls, but habitat

distinctions between the rayed and rayless forms are not yet clear, or indeed whether the different forms merit separate community distinctions.

SM13 *Puccinellia maritima* salt marsh community

Constant species: *Puccinellia maritima*

Rare species: the following occur occasionally – *Arthrocnemum perenne*, *Limonium bellidifolium*, *L. binervosum*, *Salicornia pusilla*, *Spartina maritima* and *Suaeda vera*.

This community mostly occurs as a closed species-poor grassland, but can also occur as open pioneer vegetation and herb-dominated stands in which *Puccinellia* is of minor importance. The sward varies from a low turf 1-2cm high to a rank mattress up to 50cm tall. Some provisional sub-communities have been proposed (see Rodwell 2000 for details), found in different habitats and levels in the salt marsh zonation: *Puccinellia maritima* dominant; *Glaux maritima*; *Limonium vulgare*-*Armeria maritima*; *Plantago maritima*-*Armeria maritima*; *Puccinellia maritima*-turf furoid; *Puccinellia maritima*-*Spartina maritima*.

The *Puccinellia maritima* salt marsh community is the most widespread perennial community of the lower salt marsh in Britain, occurring both as a discontinuous pioneer zone and as a continuous sward in the zone above the pioneer vegetation. It is also common on slumped creek-sides, in old pans and on disturbed sites in the upper marsh. The community is found on a wide range of substrates including clays and silts, calcareous sands and soils with high organic content and, more rarely, on gravel and shingle. It is a frequent pioneer community on sandy marshes of western England and Wales, and the north-west shore of the Wash. The pH is usually basic, with most soils between 6.0 and 8.5. Soils are often intermittently waterlogged, with a moderate to high submergence rate and salinity. The lower limit of *Puccinellia* may experience more than 350 submergences per year. In Morecambe Bay, a mean rate of 220 submergences per year was recorded by Gray and Scott (1977b). Salinities of 12-30g l⁻¹ were found in this zone in the Exe estuary (Proctor 1980), but levels higher than sea-water can develop in the higher marsh following evaporation. Grazing affects the species composition of the sward. *Puccinellia* declines with repeated oil pollution (Baker 1979).

Puccinellia establishes itself by rooting of vegetative fragments, especially where it is a pioneer community on sandier substrates. It can also set abundant seed. In the south east, it is rarely a pioneer community, and its position in the salt marsh zonation varies, either above or below the Halimione zone, and it can be found right up to the tidal limit. In the upper reaches of estuaries where the soil salinity in the lower marsh is lowered by freshwater dilution, this community can be found in upper marsh depressions where evaporation produces high salinities (Adam 1976).

The *Puccinellia* dominated community is frequent on all coasts except west Scotland and the northern Isles.

SM14 *Halimione portulacoides* salt marsh community

Constant species: *Halimione portulacoides* (now called *Atriplex portulacoides*)

Rare species: *Arthrocnemum perenne* (*Sarcocornia perennis*), *Frankenia laevis*, *Inula crithmoides*, *Limonium bellidifolium*, *Suaeda vera*.

A closed species-poor association in which *Halimione* is constant, either as a bushy canopy up to 50cm high, or as a prostrate carpet. *Puccinellia* is also constant and frequently some *Suaeda maritima* occurs. There are three distinct sub-communities: *Halimione portulacoides* dominant (usually >90%); *Juncus maritimus* (present as scattered shoots or patches); and *Puccinellia maritima* (*H.portulacoides* and *P.maritima* co-dominant).

This salt marsh community is most extensive and widespread in south-east England, covering approximately 30% of the salt marshes in the Wash. Its northern limit occurs in south Scotland, which may be related to severe frosts rather than summer temperatures (Ranwell 1972, Beeftink 1977a,b; Chapman 1950). It grows on a variety of substrates including clays, sands, shingle and occasionally soils with high organic content. Most commonly found on silty clay of low organic content, with some free Calcium carbonate and pH ranging 7.0-8.0. Tolerant of a range of submersion regimes, e.g at Scolt Head, Norfolk, from 100-400 submergences per year (Chapman 1950, 1960a; O'Reilly and Pantin 1957). In the Exe, Devon, the community tolerates chloride levels at 10-24 g l⁻¹ (salinity 16-36 g l⁻¹). There are two distinct situations: an extensive belt of variable position in the general salt marsh zonation, or as narrow ribbons on the better-drained creek levees and low ridges on the marsh surface. *H.portulacoides* appears to need a well-drained aerobic soil environment, at least for seed germination (Chapman 1950), and /or the levees positions may reflect a preference for a good supply of soil nutrients, particularly nitrogen and phosphate.

The *Juncus maritimus* and *Puccinellia* sub-communities occur throughout the habitat range of the association, but the bushy *H.portulacoides* dominated sub-community is confined to sandy substrates e.g where the marsh abuts dunes or, less often, on the lower marsh. The community is generally absent from sheep-grazed marshes, except for inaccessible creek-sides, but is found on cattle grazed marshes (e.g. around the Wash) and it will tolerate some rabbit grazing.

The position of this community is variable: either above or below the *Puccinellia* community, and boundaries are often mosaics of the two. It can occur from the upper limit of the pioneer zone up to the sea wall. The creek levee *Halimionetum* may cut across the boundaries of several marsh communities. *Halimione* is sensitive to frost and trampling and grazing.

SM15 *Juncus maritimus*-*Triglochin maritima* salt marsh community

Constant species: *Juncus maritimus*, *Plantago maritima*, *Triglochin maritima*.

Tall tussocks of *J.maritimus* are always dominant in this community, but it differs from SM18 *Juncus maritimus* salt marsh in the frequencies of associated component species.

The most widespread community dominated by *J.maritimus* in Britain, common on the west coast (with extensive stands at Cefni marsh, Anglesey) and is the major *J.maritimus* community in south-east England.

J.maritimus is tolerant of a wide range of salinities and soil moisture conditions (Ranwell et al. 1964, Gillham 1957b) and occurs at all levels on salt marshes, and on a variety of substrates. Soil pH is generally around 7.0; loss on ignition varies from 3% to over 40%. The most species-poor stands are found on the low marsh, usually on soft anaerobic mud. The lowest stand for which submergence data have been given experiences 220 submergences per year, but many stands occur at lower levels. SM15 occurs on grazed and ungrazed marshes, and tends to be avoided by grazing stock.

There is a considerable difference between the relative position in the salt marsh zonation on marshes in the south-east and those elsewhere. On the west and channel coasts, this community occurs at relatively low levels near the *Spartina* or, more often, at the upper limit of the *Puccinellia* community; in the south-east it occurs higher.

SM16 *Festuca rubra* salt marsh community

Constant species: *Festuca rubra*, *Plantago maritima*, *Glaux maritima*

There are various sub-communities: *Puccinellia maritima*; with *Juncus gerardii* dominant; *Festuca rubra*-*Glaux maritima*; *Leontodon autumnalis*; *Carex flacca*; with tall *Festuca rubra* dominant.

The *Festuca rubra* salt marsh community covers extensive areas of salt marsh especially in the north and west of Britain where it is the main community of the mid- and upper marsh. It is found on a range of substrates from marsh levels that are subjected to several hundred submergences per year to the upper tidal limit. Usually grazed, and much of the site-specific variation within this community is probably related to the grazing history of each site. In the south-east it is local, and some of the sub-communities are very sparsely distributed.

The transitional *Puccinellia* sub-community usually extends furthest down-marsh and may experience more than 250 submergences per year, though it can also occur in slight hollows in the upper marsh, and down near the *Puccinellia* community (SM13) on knolls and creek levees. The *Festuca-Glaux* sub-community is also found in similar situations although the lower limit of continuous sward is between approximately 150-200 submergences per year. The *Leontodon* community grows at higher levels, with up to 100-120 submergences per year. The *Carex flacca* community is best developed at the storm tide level, with usually only one or two flooding tides per year with extremes of up to 25 submergences per year.

The *Festuca rubra* community in general occurs on various substrates, including clays, silts, sands, shingle and soils of high organic content. The *Puccinellia* sub-community covers the whole range of substrate variation, while other sub-communities are more restricted: the tall *Festuca rubra* sub-community tends to occur on clays, silts and sands while the *Festuca-Glaux* and *Leontodon* sub-communities are usually confined to sandier material with some occurrences on more organic soils. The *Juncus gerardii*

sub-community occurs on various substrates but in the south-east there is often shingle below the top horizon, and in some areas this vegetation can be found directly on shingle banks. The *Carex flacca* sub-community is usually found on soils with high organic content, at least in the upper part of the profile. The pH of substrates with the *Festuca rubra* community varies between 5.0 and 7.0, with finer material without organic enrichment being more basic.

The degree of waterlogging and salinity probably affect the proportions of associated species in the vegetation.

Among the associated grasses, *A.stolonifera* seems more resistant to oil pollution than *F.rubra* or *P.maritima*. Of the other associated species, *Armeria maritima*, *Plantago maritima* and *Triglochin maritima* are able to tolerate oil spillage because of their underground storage organs.

In general, *Festuca rubra* communities occur above the *Puccinellia maritima* community in the salt marsh zonation, but its extent in the south east is much more limited than elsewhere and it occurs only at high levels in the marsh. In the north and west it is usually very extensive in both the mid- and upper marsh. Within the community there is usually a zonation of the different sub-communities in relation to their tolerance to submersion.

SM17 *Artemisia maritima* salt marsh community

Constant species: *Artemisia maritima*, *Festuca rubra*, *Halimione portulacoides*, *Plantago maritima*.

Rare species: *Limonium binervosum*, *L.humile*, *Suaeda vera*.

A species-poor community with stands which are generally small and fragmentary. Its distribution is widespread in East Anglia and along the south coast. It extends north to Scotland and does occur on the west coast of Britain, but is scattered and restricted mainly to ungrazed marshes. It grows on the upper marsh on a variety of substrates, but often in association with tidal litter and shell fragments. It occurs most usually on creek levees; also on ridges and mounds on the upper marsh and sometimes as a fringe along the foot of sea walls. Mostly found on ungrazed marshes but this may reflect the predominantly south-eastern distribution of this community. It is usually seen as a patchy zone between the *Halimione* and *Atriplex-Elymus* communities.

SM18 *Juncus maritimus* salt marsh community

Constant species: *Agrostis stolonifera*, *Festuca rubra*, *Glaux maritima*, *Juncus gerardii*, *J. maritimus*.

Sub-communities: *Plantago maritima*, *Oenanthe lachenalii*, *Festuca arundinacea*

Widespread on the west coast as far north as Arran but very local in south-east England, although it may occur here on derelict reclaimed land. In Norfolk, the association is replaced by the *Juncus maritimus*-*Triglochin maritima* salt marsh.

This community is predominantly an upper marsh community but the sub-communities differ in their tolerance of tidal submersion. The lowest recorded site for the *Festuca arundinacea* sub-community was subjected to 25 submergences per year, while the *Oenanthe* sub-community appears to tolerate at least 150 submergences per year. The *Plantago* sub-community is normally found seaward of the *Oenanthe* sub-community and so its tolerance is presumably greater.

A variety of substrates can be colonised and pH is usually around 7.0 but has been recorded down to 5.1 (Bridges 1977). There is normally an accumulation of organic matter in the top 10-20cm of soil, often with superficial litter trapping, and this material provides a suitable substrate for colonisation by weed species, which are associated with this community. Common on grazed marshes, but *J.maritimus* is unpalatable, and can also be an aggressive invader, for example transforming a zone of *Puccinellia maritima* in 20 years (Packham and Liddle 1970).

Oenanthe is resistant to repeated oil and refinery effluent spillage (Baker 1979).

SM19 BLYSMUS RUFUS SALT MARSH COMMUNITY

Constant species: *Blysmus rufus*, *Agrostis stolonifera*, *Glaux maritima*, *Juncus gerardii*, *Triglochin maritima*.

Rare species: *Blysmus rufus*

A northern salt marsh community (Ratcliffe 1977) which is locally distributed on the west coast in generally small stands (except at some Scottish sites). It occurs from mid-Wales northwards, and is commonest in west Scotland.

The community is found on a variety of substrates. Sites are often poorly-drained or subject to flushing by brackish or fresh water. The typical situation is in small depressions in the upper marsh, and in west Scotland small stands are widespread in rocky flushes in the salt marsh/mire transition on raised beaches, and among coastal rocks (Gillham 1957b, Birks 1973, Adam *et al.* 1977). Usually on grazed salt marshes although *B.rufus* itself does not seem to be much eaten. Stands of this community are usually surrounded by the *Festuca rubra* community.

SM20 ELEOCHARIS UNIGLUMIS SALT MARSH COMMUNITY

Constant species: *Eleocharis uniglumis*, *Agrostis stolonifera*.

A rare community on British salt marshes locally along the west coast from the Dovey estuary northwards. It occurs patchily within other upper marsh associations such as the *Festuca rubra* community, and most often in depressions in the upper marsh. Some of the most extensive stands are in brackish marshes by the river Gilpin, Cumbria.

SM21 *Suaeda vera*-*Limonium binervosum* salt marsh community

Constant species: *Armeria maritima*, *Halimione portulacoides*, *Limonium binervosum*, *Puccinellia maritima*, *Suaeda vera*.

Rare species: *Frankenia laevis*, *Limonium bellidifolium*, *L.binervosum*, *Suaeda vera*.

Sub-communities: *Suaedeto-Limonietum binervosi* (typical); *Frankenia laevis*

This community is endemic to Britain and restricted to the north Norfolk coast, although the constituent species of the community, although restricted in occurrence, are not, apart from *L.bellidifolium*, confined to north Norfolk. Open vegetation generally dominated by bushes of *Suaeda vera* and *Halimione portulacoides* (*Atriplex portulacoides*) up to 40cm high with a patchy cover of herbaceous halophytes between. The community occupies the uppermost end of the salt marsh zonation, and is characteristic of salt marsh/dune interfaces, spit laterals, eroded dunes and sand dune lows where a base of shingle is covered with blown sand and inwashed silt (Chapman 1934, 1960b, Tansley 1939). The typical sub-community is usually found at or above the tidal limit where inundation occurs only during severe storms. The *Frankenia* sub-community extends further downshore where there may be a thick layer of clay over the shingle base. High soil salinities may be experienced during summer. Grazing, especially by rabbits, has been important in maintaining an open cover in this community.

SM22 HALIMIONE PORTULACOIDES-FRANKENIA LAEVIS SALT MARSH COMMUNITY

Constant species: *Armeria maritima*, *Frankenia laevis*, *Halimione portulacoides* (*Atriplex portulacoides*)

Rare species: *Frankenia laevis*, *Inula crithmoides*, *Arthrocnemum perenne* (*Sarcocornia perennis*).

Confined to the south coast of Sussex, particularly East Head, Chichester Harbour. Occurs on mixtures of silt, sand and shingle at the salt marsh/sand dune interfaces. Similar vegetation, but without *H.portulacoides*, has been reported from chalk undercliffs and rubble (Brightmore 1979).

SM23 *Spergularia marina*-*Puccinellia distans* salt marsh community

Constant species: *Spergularia marina*, *Puccinellia distans*, *P.maritima*.

An association of the three species above with variable amounts of *Agrostis stolonifera*, other salt marsh species and ruderal glycophytes. Fragmentary stands occur on coastal marshes throughout, and on inland saline areas. Characteristic of disturbed areas with soils of variable but generally high salinity. Found on coastal marshes in dried-up pans, in old turf cuttings, along paths and cattle-poached areas, and on and behind sea walls.

SM24 *Elymus pycnanthus* salt marsh community

Constant species: *Elymus pycnanthus* (now called *Elytrigia atherica*)

Most abundant in south-east England, stands on the west coast are local and small. The northern limit in Britain for this species is the Solway.

An upper marsh community growing on a variety of substrates including organically enriched clay, sand and shingle, and older partly decayed drift litter. Substrates are generally well-drained, often with considerable free calcium carbonate from inwashed shell fragments. The pH is generally above 7.0. This community may be confined to a narrow strip around the tidal limit, or form large stands in the upper marsh, occasionally forming mosaics with other communities. It may extend down the marsh on creek levees and also above the tidal limit, for example on unmown sea walls. Most stands occur on ungrazed or cattle-grazed marshes. This community often ends the zonation at the upper limit of British salt marshes.

SM25 *SUAEDA VERA* DRIFT-LINE COMMUNITY

Constant species: *Halimione portulacoides* (*Atriplex portulacoides*), *Suaeda vera*

Rare species: *Arthrocnemum perenne* (*Sarcocornia perennis*), *Suaeda vera*

This community is found in north Norfolk and Essex. The two association constant species are sometimes co-dominant as a relatively closed shrubby cover, or they occur as scattered bushes in a grassy ground cover.

Sub-communities: *Elymus pycnanthus*, and *Halimione portulacoides*

This association is most characteristic of drift-lines at salt marsh/shingle interfaces. The *Elymus* sub-community can run down the marsh on ridges of drier silt, and stands of the *Halimione* sub-community can tolerate up to about 120 submergences per year. The community marks a type of transition from the upper marsh to other maritime communities. The lower level stands of the *Halimione* sub-community overlap the habitat of the *Frankenia laevis* sub-community of the *Suaeda vera*-*Limonium binervosum* salt marsh where, at some sites in north Norfolk, there may be a mosaic of the two communities; the balance between them may be controlled by rabbit grazing (Chapman 1960b).

SM26 *Inula crithmoides* on salt marshes

Inula crithmoides is a maritime perennial mainly confined to southern England and Wales, recorded from Essex to Anglesey, with an isolated occurrence in south-west Scotland. It occurs in maritime cliff communities throughout this range, but in salt marsh vegetation it is restricted to south-east England from Essex to Hampshire. Stands in which *Puccinellia maritima*, annual *Salicornia*, and *Limonium vulgare* are constant in small amounts occur on low marsh sites with coarse sand; stands with abundant *Elymus*

pycnanthus occur on moderately organic soils with drift litter on the upper marsh (the most common occurrence on salt marshes).

SM27 Ephemeral salt marsh vegetation with *Sagina maritima*

Small stands of ephemeral vegetation with often an open cover of annuals and short-lived perennials occur in patches, in breaks in the turf of mid- and upper salt marsh, such as old turf cuttings and on disturbed ground around reclamation banks (Gray 1977, 1979; Adam and Akeroyd 1978).

SM28 *Elymus repens* salt marsh community

Constant species: *Agrostis stolonifera*, *Atriplex prostrata*, *Elymus repens*, *Festuca rubra*.

Rare species: *Allium scorodoprasum*, *Hordeum marinum*.

A closed grassy sward up to 1m tall, generally dominated by *Elymus repens* (*Elytrigia repens*) with usually smaller amounts of other species in this association. The community is characteristic of similar habitats to those occupied by the *Elymus pycnanthus* (*Elytrigia atherica*) salt marsh community, that is upper marsh areas often with disturbance, drift litter deposition and some freshwater influence, but is less consistently confined to well-drained areas and occasionally grows on heavy waterlogged clays. It is also found on recently excavated material on banks of drainage channels, and on some brackish marshes at the tidal limit in estuaries it may form extensive stands. Like the *Elymus pycnanthus* (*Elytrigia atherica*) community, this community often terminates the salt marsh vegetation at its upper limit, and can be viewed as the north-western equivalent of the *Elymus pycnanthus* (*Elytrigia atherica*) community, being particularly frequent around the Irish Sea coast.

2.0 MUDFLATS

Where sites are too low in the tidal frame for salt marsh vegetation to grow (generally >500-600 tidal inundations per year), but where there is sufficient width of intertidal sediments, intertidal sandflats or mudflats can be created. The structure of the benthic community that develops (epifauna and burrowing infauna, both macrofauna and meiofauna, with various feeding strategies e.g. deposit feeding, suspension or filter feeding, carnivores) is influenced by various interrelated factors including the hydrodynamic conditions (tidal currents and wave action) and resulting substrate type, which in turn will determine factors such as substrate mobility, suspended sediment load, sediment organic content and redox potential, and so on. Where there are suitable surfaces for attachment, mussel beds may develop. Shore level (elevation), fresh water inputs and salinity also affect community type and distribution. These physical and chemical factors combined with biotic factors such as competition, predation, larval settlement, mobility and mortality of juveniles, act together to produce a complex picture (Little 2000).

The fauna must withstand changes in salinity and problems of desiccation, therefore there are many burrowing forms of invertebrates that can escape desiccation at low tide. The sediments are inhabited by meiofauna (e.g. nematodes, ostracods, copepods) and larger macrofauna (including molluscs, various small crustaceans, polychaetes and oligochaetes). The microphytobenthos and mudflat fauna make these environments extremely important feeding grounds for both resident and migrant birds.

Sandflats are characteristic of more wave-dominated environments than mudflats, which occur on coasts sheltered from wave action where fine particles can settle. Clay particles in seawater form flocs, increasing the settling rate compared with that of individual particles, and extracellular mucoid substances produced by diatoms, worms and molluscs also help to bind the sediment once it is deposited. Cohesive sediments on mudflats are therefore relatively stable, requiring greater tidal velocities to erode them than is needed to shift unconsolidated sand (Little 2000).

In general, intertidal mudflats and sheltered sandflats with shallow gradients reflect low energy conditions which are characterised by particles of small to medium diameter, shallow slope, high water content, high sorting coefficient, low permeability and generally low porosity, high organic content and therefore high reducing conditions, high carbon to nitrogen ratio, high microbial population and high sediment stability (Elliott *et al.* 1998).

Land-claim for agriculture and industry in Britain has removed considerable areas of mudflat (and salt marsh) and losses of coastal and estuarine wetlands to land-claim have been estimated as between 25 and 50% (Davidson *et al.* in Jones 1995). In the Tees estuary, developed for industry and port facilities, the 2740ha of mudflats and salt marsh existing in the 1850s was reduced to 470 ha by the 1970s (Davidson *et al.* 1991). Reductions in intertidal area alter the tidal regime and reduce productivity and bird feeding areas, with possible consequences to fish and bird populations (Little 2000). Sea level rise will add to the losses of intertidal areas and it is likely that creation of mudflats as well as salt marshes will become increasingly necessary to conserve these important productive ecosystems.

Whereas some site features can be improved to encourage salt marsh development, including the possibility of contouring a site to encourage establishment of particular vegetation communities within the salt marsh zonation, there seems to be less scope to engineer sites selected for intertidal flat creation, except to ensure that the elevation and site profile is suitable. Areas selected for intertidal flat creation will develop according to local conditions and the type and amount of sediment that will accumulate on the site. The benthic community types that will establish will depend upon prevailing conditions such as exposure, position on shore, substrate type and salinity. The various community types that are found according to these and other environmental characteristics are shown in Tables A11 and A12.

Factors affecting faunal distribution and densities in intertidal flats

The distribution and zonation of communities that will naturally colonise intertidal flats vary according to the particular site conditions of water depth and exposure during the tidal cycle, tidal currents, salinity, and pollutants, as well as the important substrate-related parameters such as particle size and cohesiveness, but the precise determinants are still far from clear (Little 2000).

Shore level (elevation) and sediment particle size

Shore level and sediment grain size are two key environmental factors (Anderson 1990; Goss-Custard and Yates 1992) determining species distributions.

Elevation:

Intertidal flats occur below the level of salt marsh, from approximately MHWN down to the limit of low spring tides. As discussed in the salt marsh section the level of MHWN in terms of height above ODN, varies around the coast.

Different organisms inhabit different levels on the shore according to their tolerance to the physiological stresses imposed by exposure to air, or their abilities to avoid them by burrowing into the sediment. Exposure at low tide exposes the benthos to various stresses including temperature and salinity fluctuations, UV radiation and desiccation.

Grain size:

Sediment grain size and composition varies according to hydrodynamic conditions and along the shore profile. On mudflats sediment tend to be coarsest at mean tide levels (MTL) because tidal velocities are highest at mid tide.

Sediment grain size preferences relate to behavioural and feeding methods of the invertebrates. Particle size composition affects the characteristics of the sediment substrate in several ways. For example, affecting drainage through its porosity and permeability (hence extent of drying out at low tide), sediment behaviour under disturbance (thixotropic sediments are easy to burrow in; dilatant sediments are not), organic content and microbial biomass (inversely related to particle size) and oxygen content, redox potential and depth of reduced sediments (Little 2000). Highly anoxic sediments with high sulphide content are unsuitable for many organisms unless they are adapted to this environment, for example those living in permanent burrows with connection to the surface (e.g. the lugworm *Arenicola marina*) or deposit-feeding

bivalves such as *Scrobicularia plana*, and *Mya arenaria* with long feeding siphons that reach the surface.

Coarse, mobile sand is unsuitable for permanent macrofaunal burrows, and contains little associated organic matter needed by deposit feeders. In contrast, very fine soft muds that are easily resuspended and create turbid conditions can be unsuitable for filter feeders where suspended particles clog their gills. In studies of the communities of intertidal sandflats in Morecambe Bay, Anderson (1990, cited in ABP, 1998) showed that sediments with silt content of 30% or more provided the best conditions for development of abundant benthic invertebrates. The size range of sediment classifications are as follows: sands: 63-2000 μ m; silts 4-63 μ m; clays 1-4 μ m.

Current Speeds and Bed Stress

Current speeds and bed stress determine the character of the substrate and affect benthic community type. Current speeds change within an estuary as well as changing along an intertidal flat profile. For example, maximum current speed and bed stress increase towards the head of a funnel-shaped estuary such as the Severn and species communities change with increasing bed stress (Warwick and Uncles 1980).

Turbidity

Turbidity levels influence the distribution of species. As noted previously, high turbidity may interfere with feeding and respiratory apparatus of many suspension feeding species, and it also reduces light penetration and therefore primary production. Highly turbid estuaries may therefore tend to be dominated by deposit feeding infauna, with few suspension feeders except for those which have mechanisms to deal with unwanted particles, such as binding them with mucus.

Salinity

Estuarine/marine invertebrate diversity declines with decreasing salinity within an estuarine gradient, and are gradually replaced by freshwater species. For example, in the Tay Estuary, McLusky (1989) reported that marine species die out over a 30 km distance from the sea and a minimum number of species occurs at about 25 km from the sea. Little (2000) states that this minimum in species diversity at some point seems consistent for most estuaries. During this review of the literature we have not found the salinity level at which most of the marine species start to decline (although it may exist), however in the US (Zedler 1996) the abundance of most marine species in estuaries decreases with extended periods of salinity of less than 1/3 that of seawater (approximately 10psu). The size of marine organisms such as bivalves and lugworms also decrease along a salinity gradient (Remane, in Little 2000; Mettam 1980), which may be due to a direct effect of salinity or to other factors such as food supply, biotic interactions, or age structure (more young individuals) of the population (Little 2000). However, some typical estuarine intertidal species such as the ragworm, *Hediste diversicolor* and the burrowing shrimp, *Corophium volutator*, can thrive under variable and low salinity conditions (Anderson 1990).

Gradient

Mudflats can be very flat, with slopes of 1 in 1000, although their cohesive nature allows steep banks to form, such as on the side of creeks (Little 2002). There appear to be little information in the literature on actual gradients of typical mudflats, therefore we asked the Environment Agency if they would calculate the average gradients of intertidal flats on the East Anglian coast (Table A11) down to Mean Low Water (MLW) from the EA profiles which are measured every Kilometre on this part of the east coast. The mudflat surface type on the transects is usually denoted as Mud (M) or Mud & Sand (MS), and in general profiles denoted as mud were used in the selection of three profiles in each region (Except for Norfolk: 1 profile). As our original remit was to determine site selection criteria for mudflats (rather than mudflats and sandflats) we do not have the equivalent information on gradient for sandier parts of the coast.

Table A11. Average Percentage Slope on the East Anglian Coast (EA data)

Site	Average % Slope
Washlands (3 transects)	0.242
The Wash (3 transects)	0.177
Norfolk – Stiffkey (1 transect)	0.245
Essex – Mersea Flats (3 transects)	0.258
Essex – Dengie Flats (3 transects)	0.172
Essex – Foulness (3 transects)	0.270

Sediment accretion

In selecting sites suitable for intertidal flat creation, sediment accretion in the area should be sufficient to keep up with sea level rise, otherwise it will not be sustainable, but a higher accretion rate would be preferable for early colonisation by a variety of benthic infauna, as those inhabiting permanent burrows are unlikely to burrow into the terrestrial soils of the flooded area.

If only marine sediments are suitable for burrowing infauna, it is likely that the colonisation rates of a new area of intertidal flats by different species will vary according to the level of accretion at a new site because of the different depths within the sediment that they. For example, the amphipod *Corophium* and the cockle (*Cerastoderma/Cardium*) with its short siphons, live at shallow depths in the sediment. The deposit feeding bivalves such as *Tellina* and *Macoma* are found slightly deeper in the mud. Deeper burrowers such as the bivalves *Mya*, *Ensis*, *Solen*, *Scrobicularia*, and the lugworm *Arenicola* are presumably unlikely to colonise a new site until the required depth of sediment has accumulated.

Extremely high accretion rates could result in smothering of fauna if they cannot respond to the change in sediment level. However, deposition rates on natural mudflats tend to be highly variable, and the elevation of a mudflat represents a balance between phases of deposition and erosion. Mudflat levels in front of Welwick marsh on the north side of the Humber estuary showed typical fluctuations of 5cm per year (Brown *et al.* 1998). Invertebrate fauna colonised the Tollesbury site rapidly within the first year and densities continued to increase throughout the 6 years of the initial monitoring

programme (Reading *et al.* 2002). The average annual accretion rate on the developing mudflat was calculated from the total accretion over 6 years/6, measured at stations below the 1.5mOD contour (stations 1-4, 6-11, 13-16, and 18, ignoring stations 24 and 25 by the breach which eroded) and was found to be 27.5mm per year (range: 7.8-43.0).

A relatively high accretion rate may also be necessary for drainage channels to develop relatively quickly. At Tollesbury, creek formation only began to occur once the depth of marine accreted sediments had reached 20-30cm. As noted in the section on salt marshes, the formation of an aquaclude (barrier to water) at the terrestrial soil / marine sediment interface may depend upon the soil type and constituents e.g. calcium content. Observations of creek development at recently breached sites such as Frieston and Tollesbury will provide more information on development of drainage channels.

Water quality- nutrient levels

Excessive nutrient levels can result in dense algal mats on the surface of the sediment which can reduce the diversity and biomass of some mud-dwelling invertebrates such as ragworm, *Hediste diversicolor*, and lugworm, *Arenicola marina*. In Langstone Harbour, Hampshire, the spread of algal mats reduced the area available to feed for some estuarine waders (Tubbs and Tubbs 1980, Nicholls *et al.* 1981). Furthermore, where mudflats are bordered by salt marshes, the algal mats can be washed up onto the marsh surface, smothering and killing the vegetation.

Pollutants

A few infaunal species are tolerant to relatively high levels of heavy metals and other chemical pollutants, so that the biomass may remain high, but the diversity of fauna is drastically reduced. There is little information on the effects of low concentrations of toxic elements on salt marsh and mudflat fauna or on food chain transfer.

Biotic factors

Biotic factors are also important influences on the distribution and abundance of intertidal benthos. These include interspecific competition, predation and mortality from other causes, mobility of adults and distribution of larval forms by currents. Food supply may also be important, particularly in coarse sediments, although in mudflats the supply of the microphytobenthos such as benthic diatoms, microbial populations, and detritus is generally thought not to be limiting, but may be more variable than is currently assumed (Little 2000). In terms of invertebrate colonisation of a new site, species which are mobile as adults such as *Corophium volutator* (Hughes and Gerdol 1997) will be able to disperse into the site on flood tides. Some mobile adult species however, disperse at different states of the tide (Little 2000) which could affect the colonisation potential of a realignment site. Many benthic species have pelagic larvae which are dispersed by water movements and will settle provided that the substrate is suitable. However, the speed of colonisation of a new site will depend upon the timing of the breach and deposition of suitable sediment in relation to the seasonal reproductive behaviour of the species in question. The supply of larvae will also influence colonisation potential. Predation of larval forms either in the water column or after settling can have a major effect on recruitment to a population. Many bivalves, such as *Macoma balthica* for example, show considerable variation in larval settlement and establishment between years (Little 2000) and such variations will affect colonisation rates at managed realignment sites. Species without planktonic larvae with limited powers of dispersal may be excluded from new sites for many years and in terms of a

site providing feeding areas for birds, slow growing species may take years to grow to a suitable size for bird predators (Atkinson *et al.* 2001).

Timing of intertidal flat creation

In view of many of the factors outlined above, such as the time needed for accumulation of suitable depths of sediment for different species of burrowing invertebrates, and the time for growth from larval to adult forms of many invertebrates, it would be prudent to plan and select sites for intertidal flat creation early if they are to provide compensation for current losses of important intertidal flat habitats as feeding areas for birds.

Invertebrate colonisation in managed realignment sites, regulated tidal exchange, and sediment recharge schemes

Notes on invertebrate colonisation where this was monitored in some UK case studies are tabulated in Appendix Table A12

Managed realignment sites that include low lying areas suitable for development of intertidal sandflats or mudflats, have shown generally to have undergone rapid colonisation by a range of benthic invertebrates. At Tollesbury, Essex, 16 of the 20 species recorded after 6 years were present in the year following the breach. Although varying between species, the diversity, density and size of the benthic fauna in the realignment site were comparable with those in a nearby site. At Orplands, polychaetes and *Hydrobia* were well established within 4 years, although bivalves had not colonised successfully despite populations present just beyond the old sea wall. At Seal Sands (discussed briefly below), the bivalve *Macoma* was still rare after 7 years. The case studies on managed realignment sites and recharge schemes reviewed by Atkinson *et al.* (2001) suggest that the reasons why invertebrate colonisation is rapid in some cases but delayed in others are poorly understood.

The study of the recreation of mudflats at Teesmouth National Nature Reserve (Seal Sands), by regulated tidal exchange since 1993, found a delay in successful colonisation and overwintering survival by *Nereis* and *Corophium*, which was suggested to be due in part to compaction of the intertidal muds by earthmoving equipment used to contour the site that prevented these organisms from burying deeply enough to avoid frosts. The slow increase in *Hydrobia* density may have been due to the low organic content of the compacted mud. The study concluded that it takes at least three years for mudflats to develop a permanent population of marine invertebrates and provide successful feeding ground for shorebirds (Evans *et al.* 1998, 2000; Environment Agency 2003).

Intertidal recharge schemes have resulted in some initial reductions in species due to smothering, for example at Hamford Water and the North Shotley mud placement scheme, but densities increased subsequently (Atkinson *et al.* 2001). Many recharge schemes using coarser sediments, such as Hamford Water and Pewit Island in Essex, and Parkstone Bay in Poole Harbour, Dorset, resulted in a change in invertebrate communities to those associated with larger sediment grain sizes, with reduced densities but increased diversity. At Pewit Island an increase in invertebrate diversity was recorded 18 months after discharge (ABP, 1998). However, these schemes were still considered successful, for example Hamford Water was rapidly colonised by king ragworm, *Nereis virens*, which support a bass fishery and bird populations (ABP 1998).

Table A12 Summary of some UK Sites containing areas for mudflat creation or recharge schemes which were monitored to some degree for invertebrates

Site, and type of scheme	Date (Inundation)	Invertebrate colonisation -examples	Comments	Source
Orplands, Essex, managed realignment (lower part mudflat -not colonised by vegetation)	1995	Densities very low, even in reference sites. Polychaete worms and <i>Hydrobia</i> well established by 4 years. Bivalves not successfully colonised despite populations on intertidal mudflats just beyond old seawall	Area not colonised by bivalves - anoxic	Taken from Atkinson <i>et al.</i> 2001, HR Wallingford 1999
Tollesbury, Essex, managed realignment (most mud flat, upper fringe sufficient elevation for salt marsh)	1995	Rapid initial colonisation of site. After 2 months, 14 species in realignment site, 13 in adjacent marsh, with 10 in common. Densities in natural marsh much higher. After 3years, 19 species in realignment site, 11-13 in natural marsh. 3 species at higher densities in marsh; seven at higher densities in realignment area; 2 species equal densities in both. Densities continued to increase during the 6 years between 1995 and 2001. Bivalves <i>Abra tenuis</i> and <i>Macoma balthica</i> occurred at higher densities in the realignment area than in adjacent marsh.	More species in realignment site thought to reflect the greater diversity of sediment types. Most intertidal invertebrates in the realignment area were concentrated at sites that remained wet at low water. Invertebrate colonisation only in the newly accreted sediment, not in original agricultural substrate. The site is used by a variety of birds.	Reading <i>et al.</i> 2002 ABP 1998
Parkstone Bay, Poole Harbour. Mudflat Creation, using dredged material	1995	Surveys undertaken by local school. New mudflat on western end appeared to support more polychaete worms than the original foreshore	During construction, additional dredged material was placed on to the eastern edge of the breakwater, raising the level of the tidal flats too high, resulting in less tidal inundation, surface sediments are coarser and the flats are less developed ecologically than those on the western half of the breakwater.	ABP 1998

Seal Sands, Teesmouth, water entry via sluice	Sept 1993	<i>Corophium volutator</i> , autumn 1993, gone by each winter until survived over winter 1996. <i>Hydrobia</i> , summer 1994, densities still well below adjacent estuary in 1997 <i>Nereis (Hediste) diversicolor</i> , summer 1995, not abundant until 1996 Macoma still rare after 7 years, but Nereis and Hydrobia more common on created mudflats by 2000	Delay in successful colonisation by <i>Nereis</i> and <i>Corophium</i> may be due in part to compaction of the intertidal muds by earthmoving equipment used to contour the site. Slow increase in <i>Hydrobia</i> density may be due to low organic content of mud. In general – at least 3 years before area profitable for feeding waterfowl.	Evans <i>et al.</i> 1998; 2000
Parkstone marshes, Stour Estuary, intertidal recharge scheme		Within 2 years a diverse benthic community has recolonised the dredged material	Replacement with coarser material caused a change in invertebrate species and communities, with increased diversity but reduced biomass.	ABP 1998
Pewit Island, Blackwater estuary, intertidal recharge scheme	Sediment recharge in Dec. 1992 and Feb. 1995	Coarser materials in recharge sediments support a reduced invertebrate biomass. An increase in diversity of the invertebrate species colonising the coarse material was recorded 18 months after recharge.	Reduced invertebrate biomass in coarser materials means a decrease in potential food supply to waders. Fine materials are being deposited over the top of the coarser recharge materials in the lower intertidal. The structure of fish communities changed – flounder replaced by bass and sole, which favour the coarser sediments. Some parts of the existing salt marsh were smothered due to roll-back of the sand/gravel ridge at the edge of the salt marsh.	ABP 1998
North Shotley Mud placement		Initial reduction in species due to smothering, but increase after.	Placement increased the value of the intertidal, probably because foreshore prior to mud placement consisted of consolidated mud.	Taken from Atkinson <i>et al.</i> 2001. Attempting to get original reports cited (some not in bibliography)
Essex Foreshore recharge works, 1998-2002 (Horsey Island, Cobmarsh Island, Old Hall Point, Tollesbury Wick, Wallasea Ness	1998-2002	At Horsey Island, much greater abundance and diversity at control site. At Trimley marsh, control site much lower in both diversity and abundance. Others intermediate between these two	Attempts to get original reports unsuccessful	Taken from Atkinson <i>et al.</i> 2001. Not clear on which is Trimley in site description, or on dates of colonisation. Many refs cited in this report not in

		extremes		its bibliography.
Hamford Water intertidal recharge scheme (and Horsey Island salt marsh restoration – see salt marsh section)	1990, first trial estuarine recharge scheme in UK	Abundance of typical mud dwelling invertebrates reduced initially due to smothering. Colonisation was then by species associated with coarser materials not found elsewhere on the site. Dredged material became ‘rapidly colonised’ with benthic invertebrates, particularly king ragworm, <i>Nereis virens</i> , which support bass fishery and bird populations.	Change in sediment character due to recharge using coarser materials, and therefore marked changes in marine invertebrates colonising the sediments. Project considered successful, site now recognised for its ornithological importance. A new marsh habitat is developing behind the recharged material	ABP 1998

Site Selection Criteria

Many physical, chemical and biological factors influence the distribution, type and abundance of benthic species, as discussed above. Different organisms will colonise under different conditions that prevail, but may still be a valuable food source for different shorebirds. The various community types that are found according to exposure, zone, substrate, salinity and other environmental characteristics are shown in Tables A13 and A14.

The following criteria appear to be the most important in site selection.

Presence of existing intertidal flats within the estuary or coastal zone: The presence of existing intertidal flats with abundant invertebrates would suggest that a proposed site would achieve conditions suitable for intertidal flat creation by managed realignment.

Elevation: For intertidal mudflats or sandflats to develop, the site needs to be at an elevation between low spring tides and the level at which salt marsh develops, i.e. the site should experience at least 450-500 tidal inundations per year, or be below the height of MHWN at the location.

Gradient: Common sense and observations of natural intertidal flats suggest that the gradient of a site should be gradual, not concave, and sufficient to allow drainage. Data from some selected EA profiles show mudflats on the East Anglian coast to have average gradients between 0.17 and 0.27%.

Accretion: The accretion of sediments in the area should be sufficient to keep up with sea level rise, otherwise it will not be sustainable, but a higher accretion rate would be preferable for early colonisation by a variety of benthic infauna, as those inhabiting permanent burrows are unlikely to burrow into the terrestrial soils of the flooded area.

Salinity: Since the literature shows that marine species diversity, abundance and size decreases with declining salinity gradients in estuaries, sites in the lower parts of estuaries are likely to provide the best feeding grounds for shorebirds. We have not found any precise information on salinity levels from UK literature reviewed, but US information suggests that salinity less than 1/3 of seawater may be a reasonable guide.

Pollutant levels: Contaminated soils within a site would not be recommended as inundation by seawater can result in mobilisation of toxic elements. Sites close to sources of undesirable chemical pollutant levels are also not recommended as it is likely that invertebrate species diversity would be low and for some pollutants there may be consequences for food chain transfer. Excessive nutrient levels can produce dense algal mats which may smother invertebrates.

Table A13. Biotopes typical of intertidal mud and sandflats.

Taken directly from Elliott *et al.* 1998, Appendix II

Biotope definition and code	Environmental characteristics	Characterising species
<p><i>Hediste diversicolor</i> and <i>Macoma balthica</i> in sandy mud shores LMU.HedMac</p> <p>Subtypes of this biotope: LMU.HedMac.Are – least sheltered, abundant <i>Arenicola marina</i> and frequent <i>Cerastoderma edule</i>;</p> <p>LMU.HedMac.Pyg – contains less <i>A.marina</i>;</p> <p>LMU.HedMac.Mare – contains <i>Mya arenaria</i> in high densities</p>	<p>Full-variable salinity Sheltered, very sheltered, extremely sheltered Sandy mud – mud</p> <p>Eulittoral</p> <p>Mid shore, lower shore</p> <p>Anoxic layer present</p>	<p>-Polychaetes, typically <i>Hediste diversicolor</i></p> <p>-Other smaller polychaetes include <i>Eteone longa</i>, <i>Nephtys hombergii</i>, <i>Tharyx marioni</i>, <i>Pygospio elegans</i>, <i>Arenicola marina</i> and <i>Manayunkia aestuarina</i>.</p> <p>-Oligochaete worms include <i>Tubificoides</i> spp.</p> <p>-Amphipod, <i>Corophium volutator</i></p> <p>-Mud snail, <i>Hydrobia ulvae</i></p> <p>-Bivalves include <i>Macoma balthica</i></p> <p>-Green algae, e.g. <i>Enteromorpha</i></p>
<p><i>Hediste diversicolor</i> and <i>Scrobicularia plana</i> in reduced salinity mud shores LMU.HedScr</p>	<p>Variable – reduced/low salinity</p> <p>Sheltered, very sheltered, extremely sheltered</p> <p>Mud-sandy mud</p> <p>Eulittoral</p> <p>Upper shore, mid shore, lower shore</p> <p>Anoxic layer present</p>	<p>- Polychaete, <i>Hediste diversicolor</i> and bivalve, <i>Scrobicularia plana</i> are abundant</p> <p>- Other polychaetes include <i>Eteone longa</i></p> <p>- Oligochaete, <i>Tubificoides benedeni</i></p> <p>- Isopod, <i>Cyathura carinata</i></p> <p>-Other bivalves include <i>Macoma balthica</i> and <i>Cerastoderma edule</i></p>
<p><i>Hediste diversicolor</i> and <i>Streblospio shrubsolii</i> in sandy mud or soft mud shores LMU.HedStr</p>	<p>Variable –low salinity</p> <p>Very sheltered – extremely sheltered</p> <p>Mud – sandy mud</p> <p>Eulittoral</p> <p>Mid shore, lower shore</p>	<p>- <i>Streblospio shrubsolii</i>, <i>Tharyx killariensis</i> and <i>Manayunkia aestuarina</i></p> <p>- <i>Hediste diversicolor</i>, <i>Nephtys hombergii</i>, <i>Pygospio elegans</i></p> <p>- <i>Corophium volutator</i>, <i>Hydrobia ulvae</i>, <i>Macoma balthica</i> and <i>Abra tenuis</i></p>

	Black, possibly nutrient enriched	- <i>Tubificoides</i> spp.
<i>Hediste diversicolor</i> and oligochaetes in low salinity mud shores LMU.HedOI	Reduced – low salinity Extremely sheltered Mud – sandy mud Littoral fringe, Eulittoral Upper shore, mid shore, lower shore	- Oligochaetes, incl. <i>Tubificoides</i> spp. and <i>Hediste diversicolor</i> are abundant - <i>Corophium volutator</i> - reduced polychaetes and absence of bivalves
Barren coarse sands LGS.BarSnd	Full salinity Exposed – mod. Exposed Coarse – medium sand Supralittoral, Eulittoral Strandline, Upper shore, mid shore, lower shore	- Sparse macrofauna - Low abundances of burrowing amphipods <i>Bathyporeia</i> spp. or <i>Pontocrates</i> spp. and <i>Eurydice pulchra</i>
Burrowing amphipods and <i>Eurydice pulchra</i> in well drained clean sand shores LGS. AEur	Full salinity Exposed – moderately exposed Medium sand Eulittoral Upper shore, mid shore, lower shore	- Burrowing amphipods - <i>Eurydice pulchra</i> - Impoversihed polychaetes only <i>Scolelepis squamata</i>
Burrowing amphipods and polychaetes in clean sand shores LGS.AP Sub biotopes are LGS.AP.P and LGS.AP.Pon , depending on the amphipod to polychaete ratio	Full salinity Exposed, mod. Exposed, sheltered Medium-fine sand Eulittoral Mid shore, lower shore	- Burrowing amphipods and polychaetes incl. <i>Pontocrates</i> and <i>Bathyporeia</i> spp. and <i>Nephtys cirrosa</i> , <i>Scolelepis squamata</i> , <i>Paraonis fulgens</i> and <i>Arenicola marina</i> - Occasional bivalves e.g. <i>Angulus tenuis</i> - Isopod, <i>Eurydice pulchra</i>
Dense <i>Lanice conchilega</i> in tide-swept lower shore sand LGS.Lan	Full – variable salinity Moderately exposed, sheltered, very sheltered Strong – moderately strong tidal streams Medium sand – fine sand	- Dense populations of <i>Lanice conchilega</i> - Other polychaetes incl. <i>Nephtys cirrus</i> , <i>Nephtys hombergii</i> and <i>Pygospio elegans</i> - few crustaceans

	Eulittoral Mid shore, lower shore	- bivalve <i>Cerastoderma edule</i>
<i>Bathyporeia pilosa</i> and <i>Corophium</i> spp. in upper shore slightly muddy fine sand shores LMS.BatCor	Variable salinity Mod. Exposed, sheltered, very sheltered Muddy fine sand Eulittoral Upper shore, mid shore	- Amphipods, <i>Bathyporeia pilosa</i> , <i>Corophium arenarium</i> and <i>Corophium volutator</i> - Polychaetes and bivalves (with exception of <i>Macoma balthica</i>) are limited in their abundance and variety
Polychaetes and <i>Cerastoderma edule</i> in fine sand or muddy sand shores LMS.PCer	Full salinity Moderately exposed – sheltered Fine sand or muddy sand Eulittoral Mid shore, lower shore	- <i>Cerastoderma edule</i> and other bivalves - Reduced amphipod populations, <i>Bathyporeia sarsi</i> - Polychaetes, <i>Nephtys hombergii</i> , <i>Scoloplos armiger</i> , <i>Pygospio elegans</i> , <i>Spio filicornis</i> and <i>Capitella capitata</i> - Oligochaetes
<i>Macoma balthica</i> and <i>Arenicola marina</i> in muddy sand shores LMS.MacAre	Full – variable salinity Mod. Exposed, Sheltered, very sheltered, extremely sheltered Fine sand or muddy sand Eulittoral Upper shore, mid shore, lower shore Anoxic layer present	- <i>Arenicola marina</i> and <i>Scoloplos armiger</i> - <i>Macoma balthica</i> and <i>Cerastoderma edule</i> - <i>Corophium volutator</i> can be common

Table A14. Typical infauna found in intertidal sandflats according to their exposure, and in intertidal mudflats (sheltered areas).

Table from Elliot *et al.* 1998

Infauna	Intertidal Sandflats: Exposed	Intertidal Sandflats: Moderately Exposed	Intertidal Sandflats: Sheltered	Intertidal Mudflats
<i>Amphipoda</i>	<i>Haustorius arenarius</i> <i>Bathyporeia</i> spp. <i>Urothoe</i> spp.	<i>Perioculodes longimanus</i> <i>Bathyporeia pelagica</i> <i>B.elegans</i> <i>B.pilosa</i> <i>Pontocrates novegicus</i> <i>P.arenarius</i>		<i>Corophium volutator</i>
Isopoda	<i>Eurydice pulchra</i>	<i>Eurydice pulchra</i>		
Polychaetes	<i>Nerine cirratulus</i> <i>Ophelia rathkei</i> <i>Paraonis fulgens</i> <i>Spio filicornis</i> <i>Scolelepis squamata</i> <i>Nephtys cirrosa</i>	<i>Chaetozone setosa</i> <i>Owenia fusiformis</i> <i>Exogone hebes</i> <i>Arenicola marina</i> <i>Nephtys caeca</i> <i>N.cirrosa</i> <i>N.hombergii</i> <i>Scoloplos armiger</i> <i>Lanice conchilega</i> <i>Nerine cirratulus</i> <i>Ophelia rathkei</i> <i>Paraonis fulgens</i> <i>Spio filicornis</i>	<i>Arenicola marina</i> <i>Lanice conchilega</i> <i>Nerine foliosa</i> <i>Notomastus latericeus</i> <i>Scolelepis fuliginosa</i> <i>Nephtys</i> spp.	<i>Nereis diversicolor</i> <i>Nephtys hombergii</i> <i>Arenicola marina</i> <i>Pygospio elegans</i> <i>Manayunkia aesturina</i>
Molluscs	Donax vittatus <i>Fabulina fabula</i> <i>Ensis siliqua</i>	<i>Fabulina fabula</i> <i>Angulus tenuis</i> <i>Donax vittatus</i>	Ensis ensis <i>Macoma balthica</i> <i>Mya arenaria</i> <i>Cerastoderma edule</i> <i>Venus</i> spp.	<i>Macoma balthica</i> <i>Cerastoderma edule</i> <i>Retusa obtusa</i> <i>Hydrobia ulvae</i> <i>Scrobicularia</i>

			<i>Abra alba</i>	<i>plana</i>
			<i>Nucula turgida</i>	
Megafauna	<i>Echinocardium cordatum</i>		<i>Echinocardium cordatum</i>	
	<i>Ammodytes</i> spp.			
Meiofauna	Nematodes			
	Harpacticoid copepods			

3.0 EELGRASS (*Zostera*)

INTRODUCTION

The UK Biodiversity Action Plan for seagrasses recognises the need to restore areas of *Zostera* beds, many of which have not recovered well from wasting disease several decades ago. Large-scale transplantation trials have been carried out around the south coast of England, but with little success in the long-term. As yet there appear to be no examples of managed realignment sites that have included creation of habitat suitable for eelgrass in their objectives, but this may be considered in the future.

This report includes a brief review on the geographical distribution, habitat requirements, biology and ecology of UK species, and sensitivity of eelgrass to natural and anthropogenic disturbances, extracted mainly from a comprehensive review of *Zostera* biotopes by Davison and Hughes (1998), with some additional material from other literature. Most of the information, including a section on site selection, is appended to the main report, but the most important parameters for site selection are summarised below. Experience with eelgrass restoration in the United States suggests that lack of success with restoration attempts is often because of the failure to apply basic ecological principles and lack of understanding of habitat requirements, rather than problems with transplanting techniques. In particular, mistakes in appropriate site selection have been made (Fonseca *et al.* 2002). Transplanting and restoration methods are beyond the scope of this report, but if required at a future realignment site, some useful information can be found in the literature, for example starting with recent papers by Calumpong and Fonseca (2001), Fonseca *et al.* (2002), Davison 1997, Fonseca *et al.* (1994).

Eelgrasses are marine flowering plants of sheltered environments anchored to shallow subtidal and intertidal sands and muds by a rhizome and root system, often growing in extensive beds and providing shelter, nursery areas, and food web support for a numerous organisms, including crustaceans and juvenile commercial fish species. They also provide and feeding grounds for over-wintering wildfowl, particularly Brent geese and wigeon, and food web support for waders. In higher energy environments the beds tend to be smaller and patchier. Eelgrass beds are productive and an important source of organic matter to the detrital food web. The root networks increase sediment stability, reducing erosion (Fonseca and Fisher 1986, Gambi *et al.* 1990), while the canopy buffers water movement, reducing current flow and trapping suspended sediment and organic particulates. Seagrasses also help to maintain water quality as the canopy and epiphytic algae scrub nutrients and toxins from land run-off (Lee Long and Thom, 2001). The ecological value of eelgrass beds results in economic benefits: stabilization of foreshore topography lowers costs of foreshore protection; water quality maintenance and support of recreational fisheries helps to maintain tourism economies; and nursery habitat for commercial fish populations helps to support fisheries economies (Lee Long and Thom, 2001). Eelgrass beds are therefore of considerable economic and conservation importance (Davison and Hughes 1998), but have unfortunately undergone significant declines due to human pressures and a severe outbreak of wasting disease in the 1930s, and to a lesser extent in the 1980s, affecting particularly the common eelgrass, *Z.marina*. Substantial declines were recorded on the East Anglian and north Kent coasts and around the Solent (Butcher 1934, 1941). It has recovered quite well in the Solent, but seems to have remained rare elsewhere in the southeast. The fungal

pathogen (*Labyrinthula macrocystis*), responsible for causing the loss of over 90% of *Zostera marina* beds in the 1920s and 1930s (according to the UK Marine SACs project website: www.ukmarinesac.org.uk) and may persist as a low-level parasite subject to periodic population explosions, which was particularly large in the 1930s (Tubbs 1995). The factors triggering the disease epidemics are not fully understood, but plants may be more susceptible when stressed by some environmental factor such as increased water temperatures, low light levels, or pollution (Short *et al.* 1988).

There are three species of *Zostera* in the UK, common eelgrass *Z.marina*, narrow-leaved eelgrass, *Z.angustifolia*, and dwarf eelgrass, *Z.noltii*. *Z. marina* shows morphological variation with a decrease in leaf size and density upshore (Rodwell 2000) and may be confused with *Z.angustifolia*. Because *Z.angustifolia* is not consistently distinguished from narrow-leaved forms of *Z.marina*, it is often regarded as a variant of *Z.marina* outside the UK, but here they are treated as distinct species, first described as *Z.hornemanniana* by Tutin in 1936 (Tutin 1942). On the shore, *Zostera angustifolia* and *Z.noltii* often occur in the same zone, but according to the sediment drainage characteristics, with *Z.noltii* on the hummocks or ridges and *Z.angustifolia* in hollows that retain standing water at low tide. *Z.marina* inhabits the lower zone of the three species. Although once abundant and widespread around the coast, all three UK species are now classed as nationally scarce (Stewart *et al.* 1994). Seagrass beds are a high priority for conservation measures in the UK (Davison and Hughes 1998). In the NVC classification (Rodwell 2000) *Zostera* communities are designated as NVC Salt Marsh Community SM1: *Zostera* communities. Notes on NVC classification for *Zostera* and salt marshes are given in the salt marsh section above

Short *et al.* (2001) provide a useful overview of the many parameters critical for the occurrence of seagrasses in general (including *Zostera* spp.). These comprise physical parameters that affect physiological activity (temperature, salinity, waves, currents, depth, substrate, day length), natural factors that limit photosynthetic activity (light, nutrients, epiphytes, diseases), and anthropogenic inputs such as nutrient and sediment loading. More detail on these is given in the Appendix, but the critical factors for site selection are summarised below. Methods for the measurement of physical parameters, sediment characteristics, and light and water quality, which may be necessary for site selection, sampling and monitoring techniques, and management measures to improve habitat quality, can be found in various chapters in Short and Coles (2001). However, once the appropriate basic conditions of water depth/surface elevation and substrate type of a potential site are known, the best guide to whether there is a good chance for successful establishment of *Zostera* is the presence of existing beds in the region of the proposed site (see section on site selection).

Habitat and environmental requirements of Zostera species and their geographical distribution

Zostera marina forms stands with a cover of trailing leaves up to 1m long (Rodwell 2000). It is essentially a sub-littoral species, growing in the subtidal zone, on a firm relatively coarse substrate of sand or sandy mud, sometimes with an admixture of fine gravel, protected from full exposure, from slightly above LWST to a depth of about 4m below LWST in Britain (10m or more in the clear waters of Ventry Bay, Ireland, Whelan and Cullinane 1985; and in the Mediterranean). Light is the limiting factor for growth in deeper water, and its upper limits are probably controlled by susceptibility to desiccation. Around the Solent, plants are exposed for only 1 ½ hours even at LWST

(Rodwell 2000). *Z.marina* in the UK is reported to be found in bays, sea lochs and estuaries with little land drainage (Tutin 1942), and lagoons, preferring marine conditions with salinities not much below 35 g l⁻¹ (chloridity 24 g l⁻¹). Stewart *et al.* (1994) also refer to British *Z.marina* as preferring saline conditions, stating that it avoids brackish water. However, there appear to be some discrepancies in UK reports on the salinity requirements of *Z.marina*. For example, the UK Marine SACs project website gives a range of salinity ‘requirements’ (full, variable, reduced, low) and notes that in ‘brackish waters along the Atlantic coast’, *Z.marina* behaves as an annual plant shedding its leaves in winter, citing Jacobs (1982; although no single author reference by Jacobs is given in the references for the website). This work is probably from studies by Jacobs and colleagues on the French Atlantic coast. The literature reports various optimum salinity conditions and tolerances relating to *Z.marina*, showing that mature plants can have a wide tolerance to salinity changes. Data from field studies, cited in the UK Marine SACs website and in the report by Davison and Hughes (1998) on *Zostera* Biotopes (which was prepared for the UK Marine SACs project) indicate that germination occurs over a range of salinities and temperatures. They also cite a laboratory study which showed that maximum germination occurs at a very low salinity of 1 part per thousand. Davison and Hughes (1998) note that this low figure is surprising as *Z.marina* (in the UK) occurs almost exclusively in fully saline conditions.

A number of reasons may account for apparent discrepancies. There seems to be some confusion between tolerance, habitat requirements and actual conditions where *Z.marina* is found. Different ecotypes may well be adapted to different conditions and have different requirements. The locations of some of the cited work are often omitted and it is not possible within this project to go back to all the numerous original papers to select UK only data. A further source of confusion may arise from disagreements on the taxonomic status of *Zostera* species, for example outside the UK *Z.angustifolia* is classified as a variation of *Z.marina* and not as a separate species. For the purpose of the current review on site selection we will use saline conditions as a habitat requirement for British *Z.marina*, as concluded by Davison and Hughes (1998) who state that this species occurs almost exclusively in fully saline conditions in the UK.

Zostera marina is patchily distributed around the coast with concentrations in southwest England and particularly on the west coast of Scotland and around the Outer Hebrides (Fig. A9, from the ‘New Atlas of the Flora’ by Preston *et al.* 2002), and in the Moray Firth. It may be under-recorded, and the Atlas map may not reflect precisely the distribution of the species as many records are based on stranded, uprooted plants.

Z.angustifolia forms stands with a cover of trailing leaves up to about 25cm long. It grows on sheltered tidal mudflats, in estuaries and coastal lagoons, higher on the shore, in shallower more turbid water than *Z.marina*, typically on mud or muddy sands, between mid- and low-tide marks, extending up to well above low water of neap tides, sometimes to high water of neap tides. The substrate can be quite firm and contain some fine gravel, but this species can also grow on sloppy mud (Rodwell 2000). It has a more easterly distribution than *Z.marina*, widespread along the south and east coasts of England and the east coast of Scotland (Perring and Walters 1962), with concentrations in The Solent, Thames Estuary, and Moray and Cromarty Firths (Fig. A10). It can tolerate

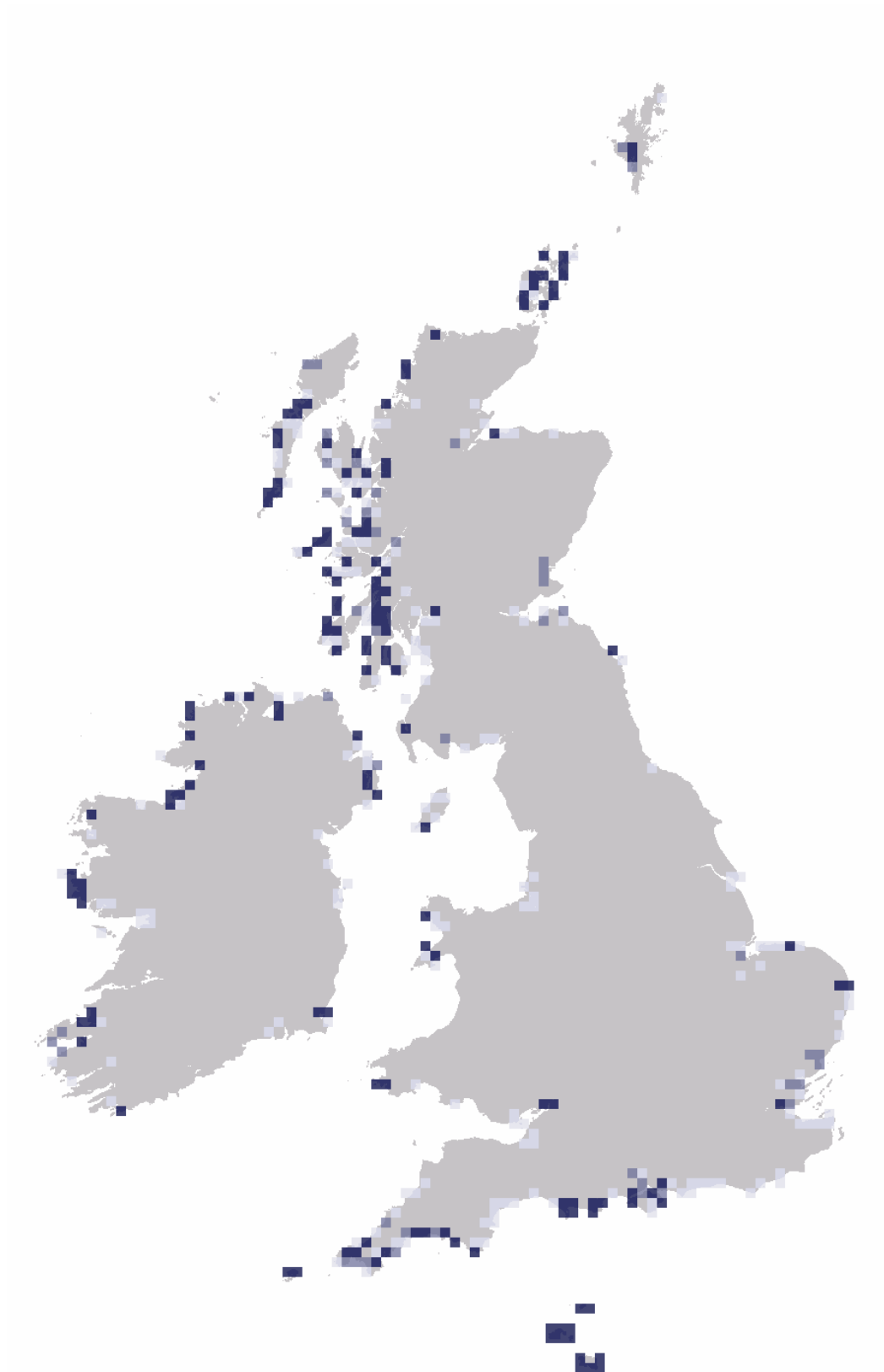


Figure A9. Distribution map of *Zostera marina* from Preston *et al* (2002)
Legend: 1987-1999 Native: Dark blue; 1970-1986 Native: Mid Blue; Pre-1970 Native: Pale blue; (Pre-1970 Alien: Light Red)

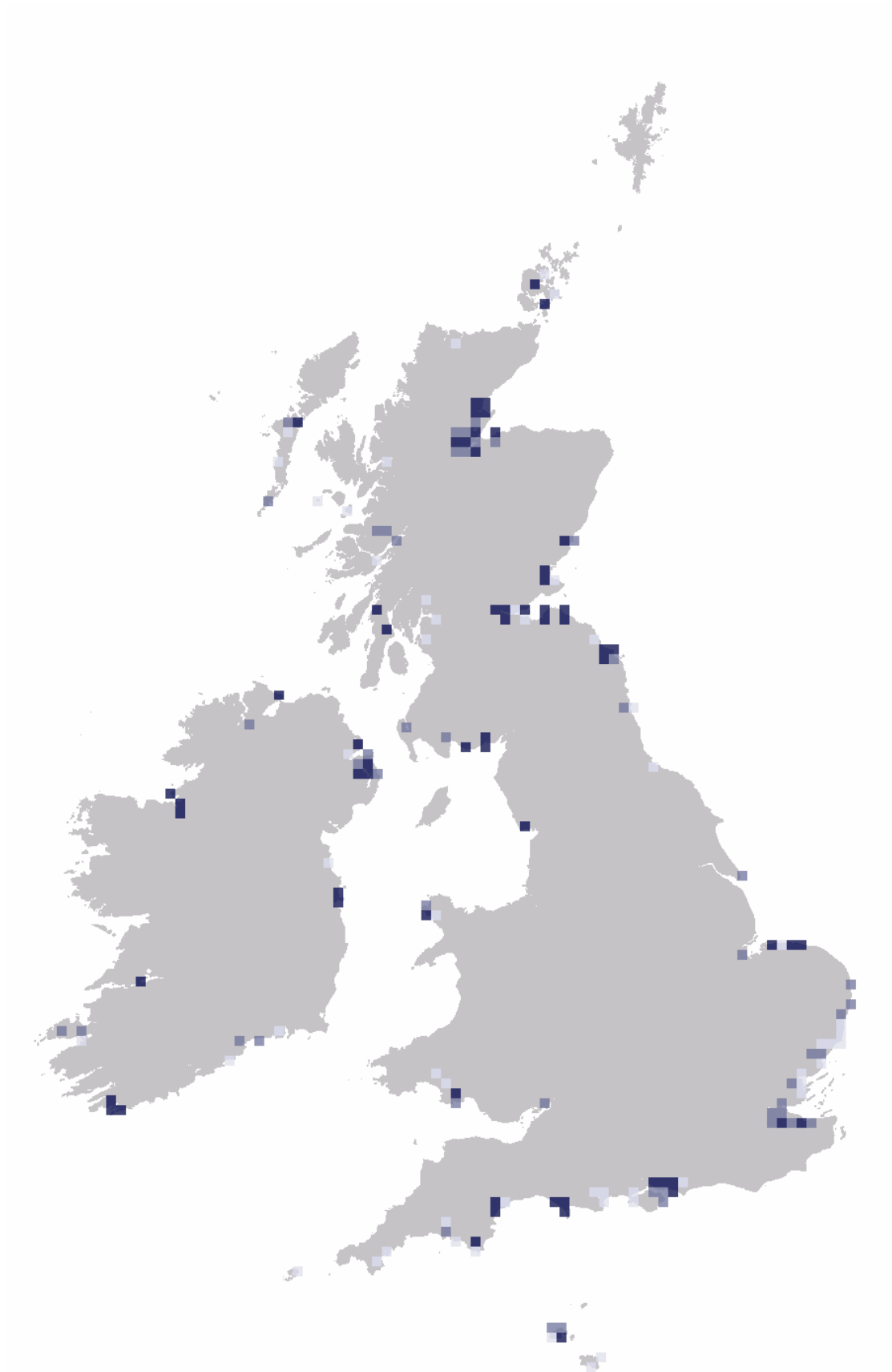


Figure A10. Distribution map of *Zostera angustifolia* from Preston *et al* (2002)
Legend: 1987-1999 Native: Dark blue; 1970-1986 Native: Mid Blue; Pre-1970 Native: Pale blue; (Pre-1970 Alien: Light Red)

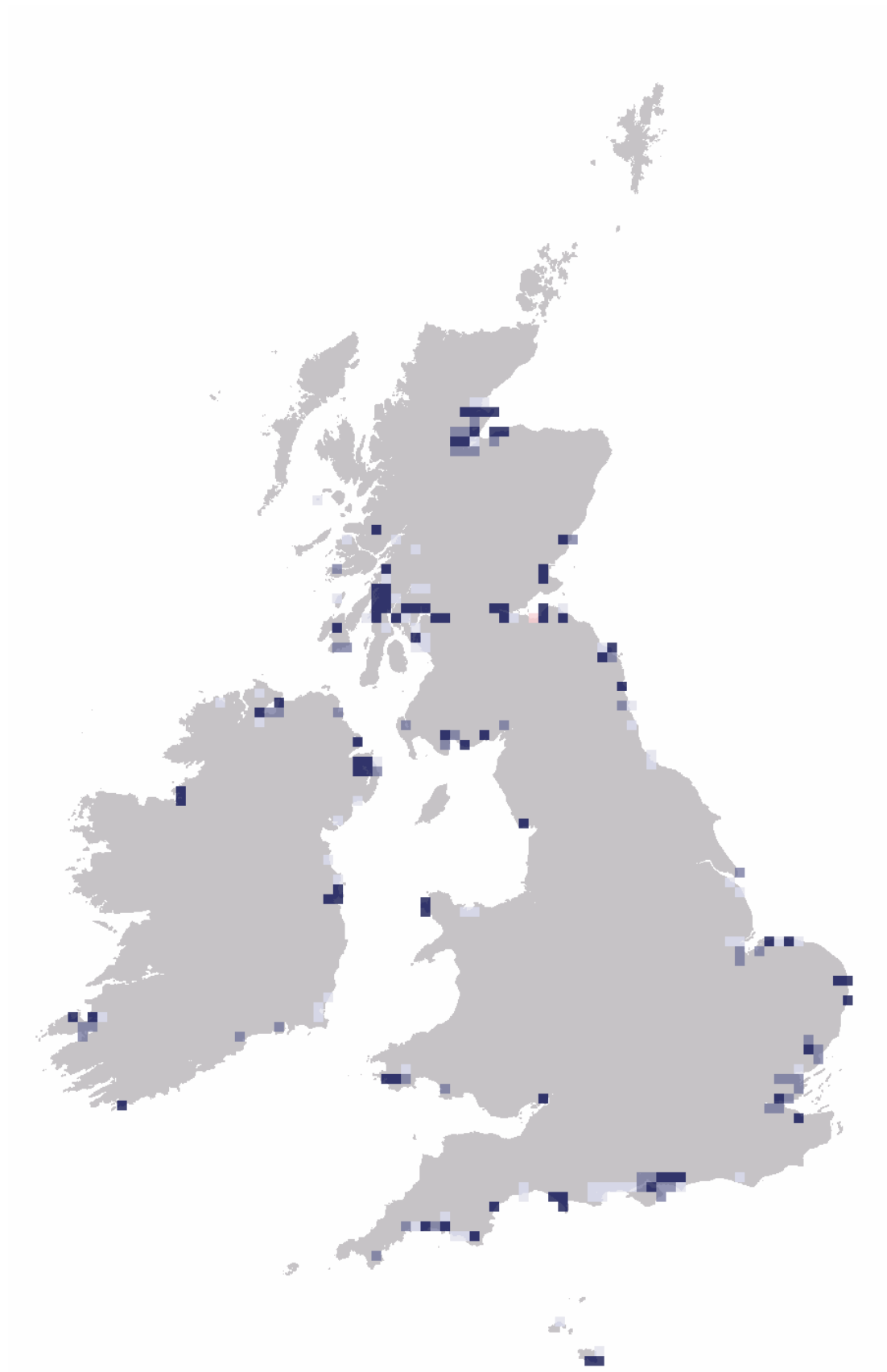


Figure A11. Distribution map of *Zostera noltii* from Preston *et al* (2002)

Legend: 1987-1999 Native: Dark blue; 1970-1986 Native: Mid Blue; Pre-1970 Native: Pale blue; (Pre-1970 Alien: Light Red)

variable salinity but optimal salinity is between 25-34 g l⁻¹ (chloridity 16-20g l⁻¹) according to Proctor (1980). As with *Z.marina*, its limits seem to be controlled by light requirements at the lower limits and susceptibility to desiccation at the upper limit. In the Solent it is exposed for a maximum of 6½ hours on spring tides. It grows best in sites, which are never deeply submerged at high tide, nor ever fully dry at low tide, and is characteristic of shallow depressions on tidal flats, often with some standing water at low tide (Rodwell 2000). Here, it may form mosaics with *Z.noltii* as noted above, with *Z.noltii* preferring the drier tops of ridges or mounds.

Z.noltii forms stands with a cover of delicate trailing narrow leaves up to about 20cm long. It is a more southerly species than *Z.marina* and better adapted to exposure to air. It can colonise higher up the shore than the other two species, in sheltered estuaries and harbours on mixed substrates of sand and mud of varying consistencies from very soft to quite firm, often in pools or runnels on the shore. It is most characteristic of situations where the substrate dries out a little on exposure and it may occur pure or in mosaics with *Z.angustifolia*, with pioneer salt marsh plants such as annual *Salicornia* spp. or *Spartina anglica* (Rodwell 2000), or with *Ruppia maritima* (in the Cromarty Firth). It appears to have declined in the Solent, but extensive stands occur along the Essex and north Kent coasts (Thames estuary) and Cromarty Firth, and is also common in the Moray Firth and in Argyll (Fig. 1c). It has been reported to occur in full to variable (8-30ppt) salinities (Connor et al. 1997). Its lowest salinity limit is reported to be about 15g l⁻¹ (chloridity 9g l⁻¹) by Rodwell (2000).

As noted above, the three British species differ slightly in some of their habitat requirements (Stewart *et al.* 1994). These differences are summarised by Davison and Hughes (1998; who include information from the Marine Nature Conservation Review biotope classification by Connor *et al.* 1997) and shown in Table A15, with additional details added from Rodwell (2000):

Table A15. Habitat requirements for the 3 species of *Zostera*

	<i>Zostera marina</i>	<i>Zostera angustifolia</i>	<i>Zostera noltii</i>
Substratum	Coarse sediments, sand, sandy mud, sand-fine gravel, firm	Mud or muddy sand, from quite firm with some fine gravel to very sloppy mud	Typically on mixtures of sand and mud, from very soft to quite firm
Depth	Subtidal, typically to 4m	Intertidal, mid- to low-tide mark (above LWN). Rarely down to 4m	Intertidal, not below low-tide mark
Salinity	Avoids brackish water. Full salinity close to 35g l ⁻¹ ⁵	Typically in conditions of variable salinity. Optimum 25-34g l ⁻¹	Can occur in variable salinities, lower limit about 15g l ⁻¹
Desiccation resistance	Intolerant of desiccation	Intertidal, but typically in poorly-draining sediments	Most tolerant to desiccation, occurs higher on shore than the other species

⁵ [The UK Marine SACs project website gives a range of salinity ‘requirements’ from full to low, but this seems to relate more to tolerance rather than to actual conditions in which it is found in the UK]

All three species require sandy to muddy substrates and shelter from strong tides, currents and wave exposure. Dense swards can develop in sheltered inlets, bays, estuaries and saline lagoons, but in more exposed sites the beds are usually smaller and patchier and vulnerable to storm damage. *Zostera* sp. cannot tolerate excessive sedimentation, which can smother the plants, or high turbidity, which inhibits growth by reducing light penetration for photosynthesis and has been cited as a cause of decline of *Z.marina* (Giesen *et al.* 1990a&b).

Different species of seagrasses have varying light requirements, but in general, the minimum requirement is around 10-20% of surface light (Duarte 1991). In the intertidal, photosynthesis and production are inhibited by high light intensity (see references in Short *et.al* (2001), but this may not be an important consideration in the UK.

Tidal range and associated water depth fluctuations influences light availability and the amount of exposure and potential stresses experienced by *Zostera* species at low tide. This is an important factor in the UK where most estuaries and coast experience macro- or meso-tidal ranges. Various methods can be used to measure light in seagrass habitats (Carruthers *et al.* 2001). A quick and simple method for measuring water clarity, or light penetration, is the Secchi disk, a round, black and white disk, which is lowered through the water until the distinction between black and white quadrants on the disk are no longer visible. According to Dennison and Kirkman's seagrass survival model (1996), seagrass will survive in intertidal habitats as long as astronomic tides are larger than barometric tides, and Secchi depth is greater than the astronomical tidal range. Subtidal seagrass meadows are calculated to survive when Secchi depth is greater than the astronomic tidal range and greater than the minimum light required for growth. Whether this model can be applied directly to the UK situation is not known.

Water movement affects seagrass biomass and habitat structure (see references in Short *et al.* 2001), for example, biomass and height may increase with increasing velocity (but within limits). Water movement is also important for pollination.

The optimum temperature range for growth and germination of UK *Zostera* species is considered to be between about 10-15°C, although plants can tolerate sea temperatures between 5-30°C (Davison and Hughes 1998) . Active growth in *Z.marina* begins when sea temperatures reach approximately 10°C (generally end of April / beginning of May in southern England) and flowering begins when sea temperatures reach 15°C (usually July in southern England). Seeds mature and are shed mainly in August and September, but may be found into October (Tutin 1942).

Mature *Zostera* plants can tolerate some variations in salinity, and according to Davison and Hughes (1998), even *Z.marina*, which is the most marine in its occurrence, may be stimulated to produce flowering shoots by some exposure to reduced salinities (e.g. van Katwijk *et al.*1999).

Although nitrogen is usually the limiting nutrient, and growth may be stimulated by slight enrichment, excessive inputs may be harmful, causing blooms of algae that may smother the plants. Also, high nitrate levels may cause metabolic imbalances in *Zostera* (Davison and Hughes 1998).

Biology and ecology

Growth occurs from April to September. Propagation is by vegetative growth of rhizome fragments, or by sexual reproduction and seed production. Temperatures above 15°C appear to be necessary for flowering and seed germination, and in northern latitudes subtidal *Zostera marina* beds are perennial and thought to persist by vegetative means rather than by seed production (Davison and Hughes 1998), and will be less genetically diverse than where sexual reproduction occurs. Summer leaves shed in the autumn are generally replaced with smaller winter leaves. *Z.angustifolia* and *Z.noltii* are propagated by a combination of vegetative growth and seed set. Leaf cover in these two species begins to decline during autumn and winter.

Flowers and seeds are produced between early summer and early autumn and *Zostera* is hydrophilous (water pollinated). Seeds are dispersed by water currents, and possibly on birds' feet.

Dense *Zostera* meadows bind the sediment, reducing resuspension and erosion, and root penetration aerates the upper layers of sediment improving the habitat for burrowing animals. Primary production is high and the plants are used directly for food, and support detritus based food webs *in situ* and *via* export to adjacent waters. Eelgrass beds support a rich community of associated flora and fauna, particularly in the subtidal perennial populations of *Z.marina*, that include numerous epiphytic algae, non-epiphytic algae, invertebrates (gastropods, bivalve molluscs, polychaete worms, burrowing anemones, amphipod and mysid crustaceans), fish, and grazing wildfowl (see Davison and Hughes 1998). *Zostera* is important in the diet of Brent geese *Branta bernicula*, wigeon *Anas Penelope*, mute swans *Cygnus olor*, whooper swans *C.cygnus*, and Teal *Anas crecca* (feed on eelgrass seeds). The decline in the European population of dark-bellied Brent geese followed the decline in *Zostera marina* by wasting disease (Ogilvie and Matthews 1969), and there were declines also of wigeon. Since this time, *Z.noltii* has replaced *Z.marina* as the preferred food for over-wintering Brent geese.

Epiphyte grazing, for example by gastropods, may be important to maintain the health of eelgrass (Phillipart 1995, Nelson 1997), and wildfowl grazing may help to prevent excessive accumulation of sediment around the plants (Jacobs *et al.* 1981).

Sensitivity to natural events

Zostera marina is very susceptible to drought and the upper limit to growth is determined by the degree of desiccation to which the plant is subjected at low tide. A short (e.g.30 minutes) exposure to air on a sunny or windy day is sufficient to kill the flowers, and may be sufficient to kill the base of the shoot. On sandy substrates that dry out rapidly when exposed, it grows where it is exposed only at Low Water Spring Tides, but can grow above LWST on muddier substrates and in shallow pools of water (Tutin 1942). The upper limit of *Z.marina* is related to the time of LWST, which affects the degree of drying out during exposure. It grows lower down shore where LWST occurs at mid-day, in south Devon, for example, than on the west coast of Scotland where LWST is about 6am and 6pm.

Z.angustifolia is less intolerant to desiccation and occurs in the inter-tidal, although generally in waterlogged sediment, and *Z.noltii* is least affected by aerial exposure (Davison and Hughes 1998).

Extreme weather conditions such as heavy storms and increased wave action, or floods, can damage *Zostera* beds. The more inter-tidal species are exposed to greater extremes of heat and cold at low tide, and plants may be damaged by ice and killed or defoliated by severe frosts.

Wasting disease has been the most significant natural cause of decline in *Zostera*, particularly sublittoral *Z.marina*. A major outbreak occurred in the 1920s and 1930s, as noted above, and recovery has been slow and partial. The pathogen does not appear to cause disease in conditions of low salinity and so tends to affect *Z.marina* far more severely than the other two UK *Zostera* species which appear to have been relatively unaffected by the outbreaks (Rasmussen 1977; Muehlstein *et al.* 1988, 1991).

Grazing wildfowl can remove considerable biomass of *Zostera* (up to 90% in some cases), but the plants are normally able to tolerate normal grazing pressures unless under some other stress (Davison and Hughes 1998).

Zostera leaves become coated by epiphytic algae, which can cut down light available for photosynthesis, and have been smothered by *Enteromorpha* (Den Hartog 1994). Invertebrate algal grazers such as the gastropod *Hydrobia ulvae* help to maintain healthy *Zostera* plants and so any factors, which cause eutrophication and algal blooms, or which reduce grazer populations may have an indirect effect on eelgrass survival (Davison and Hughes 1998).

Sensitivity to human activities

Eelgrass beds are susceptible to human activities including land reclamation, coastal developments, discharge schemes, water pollution, physical disturbance including mobile bottom fishing gear, cockle and mussel fisheries, and alien introductions (Davison and Hughes 1998, de Jonge *et al.*1996). Coastal developments such as construction works, dredging and pipe-laying may affect the hydrographic regime and sediment dynamics. If the consequences are increased sedimentation, erosion, or water turbidity, then the viability of the beds may be threatened.

Climate change and sea-level rise may cause long-term consequences for *Zostera*, for example if the frequency and intensity of severe storms increases. In warmer parts of its world distribution (particularly the tropics), increased temperatures and UV-B radiation may cause stress and distribution shifts in eelgrass populations, but increased water temperatures would not be expected to cause problems in the UK, where water temperatures are presumably not near upper limits for UK genotypes. However, other possible consequences, such as increased disease activity or epiphytic growth, may have deleterious effects. Elevated carbon dioxide may increase plant productivity, but outcomes are difficult to predict due to possible effects on competitive interactions (e.g. between eelgrass and algal species). Sea level rise will affect the distribution along the shore profile, and whether the plants will be able to colonise upshore will depend on niche availability. For example, migration may be blocked by man-made structures, or

the presence of salt marsh may prevent this if die-off of pioneer marsh vegetation does not occur at a similar rate as the need for *Zostera* to relocate into this zone to stay within its tolerance limits.

A variety of toxic contaminants have the potential to cause harmful effects, including herbicide run off, antifoulants, heavy metals, oil pollution and dispersants, and excessive nutrient inputs from sewage or agricultural sources. In general there is little evidence of significant damage from environmental levels of heavy metals or antifoulants. Chemical dispersants used to treat oil spills are more damaging than the oil itself, both to the *Zostera* and to the associated faunal communities. Terrestrial herbicide run-off may damage eelgrass, as can high nitrate concentrations and excessive nutrient inputs if they cause eutrophication (van Katwijk *et al.* 1997, 1999). This may result in increased growth of epiphytic and blanketing algae, increased turbidity from phytoplankton blooms, or increased susceptibility to wasting disease (see Davison and Hughes 1998).

Invasion of intertidal mudflats by *Spartina anglica* has diminished the area available for *Zostera* colonisation (see references in Adam 1990) and encroachment of *Zostera* habitat by *Spartina anglica* and changes in sediment patterns has also been suggested as another factor in the decline in *Zostera* cover around Lindisfarne (Percival *et al.* 1998). 'Made in Britain', but a hybrid product of British and American parents, *Spartina anglica* was both planted and spread naturally around the British coast in the last century. Concern about adverse affects of *Spartina* on the *Zostera* resource for grazing wildfowl has motivated attempts to control *Spartina* with various methods such as herbicides, rotovation (rotoburial), and mechanical disturbance with a tracked vehicle, for example, at Beal (across from Lindisfarne) and Morecambe Bay (Frid *et al.* 1999, Harwood and Scott, 1999). *Spartina anglica* has also colonised eelgrass beds in southern England, as has the Japanese brown alga *Sargassum muticum* which has spread since it appeared in Europe in 1971, and there is some speculation, although little hard evidence, that they may compete with *Zostera* or prevent *Zostera* recolonisation after die back. However, neither species yet appears to be a serious threat to healthy eelgrass beds (Davison and Hughes 1998).

Eelgrass beds are sensitive to physical disturbance e.g. from channel dredging, trampling, anchoring, powerboat propeller wash and jet ski wash, and bivalve harvesting (e.g. mussels, de Jonge and de Jong 1992), particularly by suction dredging. Reintroduction of eelgrass beds is possible (e.g. de Jonge *et al.* 1996) and attempts have been made in the UK (e.g. Ranwell *et al.* 1974), but according to Davison and Hughes (1998), long-term success has been very limited so far.

The fact that eelgrass beds have not recovered well naturally following wasting disease, except in a few sites in the UK, suggests that simply selecting the correct theoretical habitat conditions may not be sufficient for their natural establishment in many areas of the UK coast. As indicated in the following section, it is likely that any site selected for eelgrass bed creation would need to be in reasonably close proximity to existing eelgrass beds. This would indicate that all requirements for the species are met in the area, but measurements of the important parameters should be made to ensure that conditions match those of the healthy existing beds. As it may be necessary to actively assist restoration by transplanting vegetative stock it would be advisable to ensure that suitable donor stock is available to harvest without causing damage to existing beds.

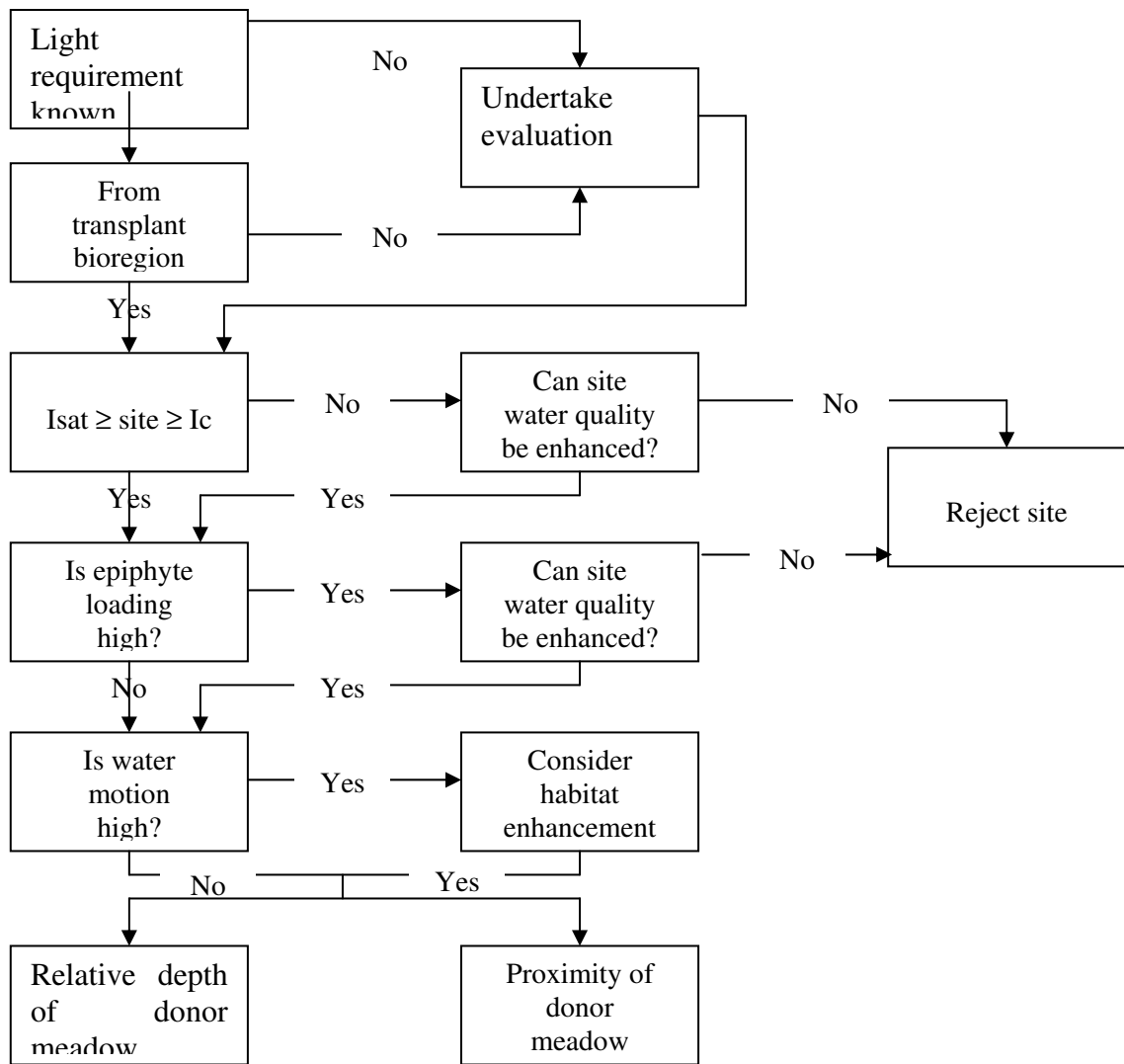
Site Selection

According to Fonseca *et al.* (2002), failure of eelgrass restoration projects is frequently a consequence of inappropriate site selection, and many sites either cannot support seagrass, or only support low levels. They state that Fredette *et al.*'s (1985) condition 'If seagrass does not grown there now, what makes you think it can be established?' best sums the problem. This suggests that sites selected to encourage natural colonisation or for transplantation of eelgrass should be close to existing areas of eelgrass beds. The current distribution and known extent of the *Zostera* biotope in the UK are summarised in Davison and Hughes (1998), and distribution maps are shown in Fig1. Matching water depths, temperature, salinity, water clarity and plant size are good general guidelines for matching donor and recipient beds (Addy 1947). Fonseca *et al.* (2002) state that it is essential to study the substrate and exposure regime, and water clarity of a restoration area so that suitable source materials can be identified, and that areas exposed at low tides should be carefully mapped in order to place transplants with minimal exposure to air, unless the plants regularly occur in the intertidal zone. This will be important in regard to the different UK species, which have different tolerances to exposure and desiccation.

Campbell *et al.* (2000) have constructed a decision flow diagram for site selection for restoration (see Fig. A12), that include considerations of light, water quality: nutrient and epiphyte loading, water motion, depth and proximity of donor site.

A selection procedure for suitable transplantation sites in the Netherlands has been drawn up by de Jonge *et al.* (2000), based on factors such as sediment composition, exposure time, current velocity and wave action, integrated in a GIS-based map (Table A17).

To improve the GIS-based model, de Jonge *et al.* (2000) note that parameters for salinity and ammonium still need to be added as they may affect eelgrass establishment potential, and that further quantification of nutrient requirements, nutrient toxicity and the role of wave action as a stress factor need more detailed investigation. To create conditions suitable for eelgrass re-establishment in the Wadden Sea, these authors recommend that structures are built to reduce wave action and enhance shelter, that eutrophication (particularly nitrogen load) needs to be reduced, and that the number of freshwater discharge points that have been reduced in the past, need to be increased again to meet the requirements of eelgrass. This, and also grain size requirements and the optimum emersion times given in Table A16, would appear to be in contradiction to the sublittoral habitat and salinity and substrate requirements for *Z.marina* as noted in Table A15 previously, and may be a reflection of the fact that the two of the three *Zostera* species in Britain, *Z.marina* and *Z.angustifolia* are recognised as distinct species in the UK, but not in Europe. Two different populations of eelgrass are indicated to have been present in the littoral zone of the Wadden Sea between mean high water and mean low water, separated by a bare zone (van Katwijk *et al.* 2000), and de Jonge *et al.* (2000) state that presumably, the middle and high littoral populations consisted mainly of annual plants, while the low littoral and sublittoral populations were perennial. These two populations may correspond to what is recognised in Britain as being *Z.angustifolia* and *Z.marina* respectively. Davison and Hughes (1998) emphasise the need for clarification of the taxonomic status of *Zostera* species to improve understanding of their distribution, habitat requirements and management needs.



Isat = saturation irradiance, Ic = compensation irradiance

Fig. A12 Decision flow diagram for site selection for seagrass restoration (Campbell *et al.* (2000))

Table. A16 Class ranges of several factors used to make GIS maps for site selection for suitable transplantation sites for *Zostera marina* in the Netherlands. From de Jonge *et al.* (2000)

Parameter	Range	Chance of occurrence (%)	Reference
Orbital velocity in waves ($m s^{-1}$)	0-0.15 0.15-0.2 0.2-0.3 >0.3	100 100-50 50-0 0	Best estimates based on field observations and model calculations
Current velocity of flowing water ($m s^{-1}$)	0-0.5 0.5-0.9 0.9-1.2 >1.2	100 100-5 5-0 0	Fonseca <i>et al.</i> 1983 Fonseca and Kenworthy 1987
Sediment composition (% <64 μm)	0-2.5 2.5-5 5-60 60-75 75-100	0 1-100 100 100-50 50-10	D.J. de Jong, personal observation
Emersion time (%day $^{-1}$)	100-70 70-65 65-40 40-28 28-17 17-12 <12	0 0-100 100 100-50 50-10 10-0 0	De Jonge and de Jong 1992 Feekes 1936 Harmsen 1936 Hermus 1995 Van Katwijk <i>et al.</i> 2000

So, in summary, for these parameters, the optimum conditions to produce at least a 50% chance of occurrence of eelgrass beds (*Z.marina*) are:

- Orbital velocity in waves: 0-0.2m S $^{-1}$
- Current velocity of flowing water: 0 to just over 0.5m S $^{-1}$
- Sediment composition: just less than 5 to 75% <64 μm grain size
- Emersion time: approximately 28-65% (but would seem to contradict subtidal habitat (see below))

Fonseca *et al.* (2000a) and Calumpong and Fonseca (2001) give the following criteria for selecting a restoration site away from the original injury site:

- It is at depths similar to nearby seagrass beds,
- It has a history of seagrass growth (note: this is not likely to apply to a realignment site unless fronted by eelgrass beds),
- The seagrass bed was lost due to anthropogenic activities and these disturbances have ceased,
- It exists in areas that are not subject to chronic storm damage or sand movements,
- It is not undergoing rapid and extensive natural recolonisation by seagrasses,
- Seagrass restoration has been successful at similar sites,

- There is sufficient area to conduct the project,
- Similar quality habitat would be restored as was lost.

Harvesting stock from donor beds may cause damage and would require spacing (of harvesting) to ensure recovery of the donor bed (Fonseca *et al.* 2002), or should only be done when the beds are in imminent danger of removal (e.g. dredging) or under some anthropogenic source of physiological stress that cannot be abated. Details of restoration techniques are beyond the scope of this report. However, there are numerous papers on this subject, and those cited in Fonseca *et al.* (2002) would be a useful starting point.

Having selected a site with the necessary basic habitat requirements of substrate, water clarity, depth, salinity, exposure, current and wave conditions as summarised in Tables 1 and 2 above, other biological factors and sensitivities discussed in this report are relevant to success of *Zostera* recovery or restoration. These are summarised in Table A17 below, taken directly from Davison and Hughes 1998.

Table A17. Factors that may affect *Zostera* bed recovery

Factors that may limit bed recovery	Factors that may facilitate bed recovery
Removal of habitat	Artificial transplantation
Unstable substrata	Stable substrata
Fragmenting and destabilised <i>Zostera</i> beds, caused by factors such as changes to coastal processes, physical damage or stochastic weather events	Stable <i>Zostera</i> beds
Reduced rhizome growth, seed production, germination success and seedling development into patches	Increased rhizome growth, seed production, germination success and seedling development into patches
Reduced light penetration caused by increased turbidity, eutrophication, some forms of pollution, or epiphyte smothering	Improved light penetration caused by reductions in turbidity, eutrophication, pollution, epiphyte and algal smothering
Nutrient enrichment	Reductions of, or limited increases to, nutrient inputs
Declines in epiphyte grazer populations	Healthy and stable epiphyte grazer populations
Unusual increases in wildfowl grazing pressure	Wildfowl grazing activities may prevent excessive sediment build up in <i>Zostera</i> beds
Competition with non-native species, <i>Spartina anglica</i> and <i>Sargassum muticum</i>	Absence of non-native species, <i>Spartina anglica</i> and <i>Sargassum muticum</i>
Environmental stress (e.g. extreme temperatures or pollutants), which may increase susceptibility to wasting disease infection	Absence of environmental stresses and low populations of <i>L.macrocystis</i> , the causative fungal pathogen for wasting disease.

Recent work has indicated that the activities of infauna, particularly the polychaete *Hediste (Nereis) diversicolor* may restrict natural colonisation by *Zostera* and reduce success of transplanting trials, through herbivory and disturbance (Hughes *et al.* 2000). Transplants of *Z.noltii* protected from the effects of the polychaetes by netting had higher survival, lower root damage and greater biomass than unprotected transplants.

There appears to be little information on tolerance to surface accretion or erosion, although Ranwell *et al.* (1974) suggested that *Z.noltii* growth is favoured in areas where a close balance between the forces of erosion and accretion occurs. They found that *Z.noltii* could be transplanted on suitable mudflats where the mud surface changes in level were at least ± 7 cm per year, or ± 3 cm per week.

Summary of conditions needed for appropriate site selection

As discussed above, a number of physical, chemical and biotic factors affect the distribution of eelgrass beds. For site selection the following criteria appear to be the most important:

- **General:** Areas close to existing beds would be the best indication that requirements for the species are met in the area. Match water depth, clarity (light penetration /low turbidity), temperature, and salinity.
- **Wave exposure:** sheltered to extremely sheltered conditions are necessary for *Zostera* survival
- **Tidal streams:** *Zostera sp.* require weak to very weak tidal streams
- **Substrate requirements:** These are different for the different species:
Z.marina: sand, sand-fine gravel, muddy fine sand, mud; firm
Z.angustifolia: mud or muddy sand with some fine gravel; quite firm to sloppy mud
Z.noltii: sand and mud mixtures, quite firm to very soft
- **Elevation:** These are different for the different species:
Z.marina: lower shore, largely subtidal, slightly above LWST to approximately 4m (typically) below, depending on water turbidity and light penetration.
Z.angustifolia: lower shore, intertidal / infralittoral, between mid- and low tide, from above LWN, sometimes to HWN, rarely down to 4m below tide level, generally in waterlogged sediment.
Z.noltii: upper shore-mid shore, intertidal / eulittoral, up to about HWN, not below low tide mark, can withstand some drying out.
- **Salinity:** These are different for the different species:
Z.marina: saline, avoids brackish water. *Z.marina* is reported to have a wide tolerance to salinity changes, but in the UK it occurs almost exclusively in fully saline conditions
Z.angustifolia: variable salinity, optimum 25-34g l⁻¹
Z.noltii: variable salinity, 2 reports from the literature state ‘down to 15g l⁻¹’ and ‘8-30 ppt’ (parts per thousand)

- **Water turbidity:** low turbidity levels are required by all species. Avoid areas where there may be increased turbidity or physical disturbance from human activities (unless disturbances can be prevented)
- **Water quality / contamination:** although there is little evidence of significant damage by environmental levels of pollutants, avoid contaminated areas (sediments and water) including areas with excessive nutrient inputs (particularly nitrogen load)
- **Alien /invasive species:** avoid areas with *Spartina anglica* or *Sargassum muticum* growing at similar elevations as eelgrass requirements as these may compete with *Zostera* and prevent good colonisation
- **Current velocities and wave action:** some protection may be required to promote colonisation.

Information on transplanting is beyond the scope of this report. However, it is quite likely that some transplanting may need to be done on any site selected for creation of *Zostera* beds. If transplanting is to be carried out, areas exposed at low tides should be mapped first to place transplants with minimum exposure to air. In a newly flooded area it may be necessary to wait until the site has ‘settled down’ for a while and appropriate conditions are met. Information on accretion or erosion rates of the new site, and resuspension of the newly accreting surface, should be gathered first, and checked with the literature on *Zostera* transplantation to ensure that conditions will be suitable for transplant survival.

PB 11547

Nobel House,
17 Smith Square,
London SW1P 3JR

www.defra.gov.uk

