Suitability criteria for habitat creation – Report II: Tools to aid site selection for habitat creation
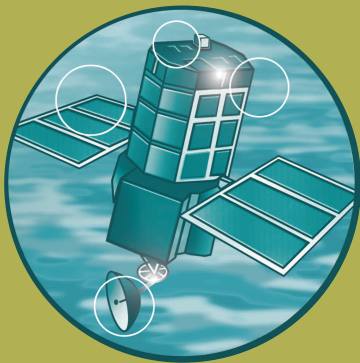
R&D Technical Report FD1917TR2

Environment Agency

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Department for Environment
Food and Rural Affairs

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

Suitability criteria for habitat creation – Report II:
Tools to aid site selection for habitat creation

R&D Technical Report FD1917TR2

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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

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www.defra.gov.uk/environ/fcd

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

SUITABILITY CRITERIA FOR HABITAT CREATION

This research project brings together the present scientific understanding of the physical, chemical and ecological factors controlling habitat creation (saltmarsh, intertidal flats and *Zostera* 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 an electronic decision tool for users to assess the potential of specific sites for habitat creation schemes. This involves an estuary scale (screening tool) using a Geographical Information System (GIS) approach and testing on a site-by-site basis using an influence diagram tool[1].

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 appear in a Report I (complementary to this report) and facilitated the identification of parameters (criteria) and relevant limits, which can describe potential realignment sites with regard to habitat creation. This information provides a clear audit trail for incorporation into decision tools (GIS based and influence diagram) for policy makers and managers concerned with managed realignment and habitat creation or restoration.

The project outputs comprise two reports and an associated influence diagram file:

Report I (previous 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 that will interact to control habitat creation at a given location. Not all the parameters reviewed were selected as suitable criteria for the decision tools.

Report II (this report) : Tools to Aid 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).

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[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.

EXECUTIVE SUMMARY

<u>**REPORT II**</u> **(this report):** TOOLS TO AID SITE SELECTION FOR HABITAT CREATION

Two approaches designed to facilitate site selection for habitat creation are presented in this report. These are:

- A demonstration of a GIS screening tool which is capable of identifying sites for habitat creation at a wider spatial scale and using readily accessible spatial data relevant to suitability criteria.

- A generic influence diagram model designed to assess each site within a short-list in more detail.

Both tools build on the findings of the comprehensive reviews detailed in Report I in terms of utilising the criteria and associated thresholds that were derived from the scientific reviews of the physical, chemical and ecological controls on habitat creation (FD1917 - Report I). In this way the tool(s) represent an attempt to unravel the complexity of interdependent processes and factors controlling habitat creation as discussed in Report I and incorporate them into a framework which will direct an end-user or site selector to the key issues (criteria) in a systematic way.

One of the main practical uses of the tools is to lead the end-user or site selector through the range of issues to consider. This process will include highlighting the factors amenable to predictive assessment, and also those that may be important but where the scientific understanding is not yet sufficient to allow incorporation into the tools.

The tools are designed to be applied in succession in terms of initial screening site selection using the larger scale, screening GIS tool and then application of the influence diagram tool to a short list on a site-by-site basis. Together the tools provide a framework that is user-friendly, accessible, and transparent and provide a good audit trail for decision-making and site selection.

At present there are still scientific limitations on understanding of key processes and controlling factors related to habitat creation and this has limited the quantitative predictive capability of the tools to some extent. Future research on more habitat creation sites, in particular focussing on site characteristics and controls on habitat establishment with time will lead to improved understanding of the cause and effect pathways, responses and outcomes relevant to site selection. This will enable improvement and development of tools such as these that are now in place.

A summary of the main points specific to the tools presented in section of this report appears below.

GIS screening tool:

GIS is increasingly being applied to coastal zone management situations either in terms of purely integrating relevant spatial information which facilitate site selection or in terms of applying GIS and models to help habitat predictions.

A demonstration of a GIS screening tool was developed for the Blackwater Estuary, Essex. GIS layers were developed for three of the criteria relevant to habitat creation (elevation, slope and proximity to existing habitat) and filtered using thresholds to provide suitability maps at estuary and site scales. These layers were combined by various methods to give maps of potentially suitable sites for saltmarsh and also some estimates of relative suitability. Some of the predicted sites were compared to existing managed realignment sites (Tollesbury, Abbotts Hall) to see how the tool compared. For the demonstrated example of saltmarsh habitat the tool predictions compared well to the actual habitat creation sites.

The GIS screening tool is capable of providing a rapid overview of potential sites for habitat creation (saltmarsh in this case). These sites can either, be identified as suitable or not depending on whether they satisfy a range of criteria, or can be ranked in relation to their mean suitability (derivative mapping) against the same criteria. Either method provides a short-list of sites to be tested using the influence diagram tool on a site-by-site basis.

The GIS application performed was limited to some extent by the lack of scientific information which could define the habitat/ criteria / threshold relationships and also by available spatial digital data. As knowledge of the controlling factors on habitat creation and availability of data improves this can be taken further.

Application of this procedure in other geographical areas will require some adaptation of criteria and thresholds in relation to local habitat data but also tidal level information to Chart Datum (CD) or Ordnance Datum (OD). An end-user can therefore tailor the approach presented here to a specific area using local data or site selection aims.

Use of GIS needs to be critically applied and the reasons for selection or deselection of sites must be transparent. The accuracy and uncertainty of each layer needs to be understood so weighting can be appropriately applied.

The criteria used in the GIS overview were specifically targeted towards the physical, chemical and ecological controlling factors of habitat creation. However, other socio-economic, political or logistical constraints may also impact site selection. The GIS framework is flexible enough that given site selection on this basis it is possible to add further layers which can aid filtering from other perspectives such as, grade of coastal defence, Ordnance Survey spatial data (roads, footpaths), agricultural land grade, land availability, strategic plans, conservation restrictions i.e. SSSIs, SACs etc. Within a GIS framework the bigger picture is important not only in terms of scale but to also fit within strategic coastal plans. It is important to look at this large scale as an initial process of identifying potential sites within the context of long-term development of an estuarine or coastal system.

Influence diagram model:

The generic influence diagram model is designed to assess each site within a short-list identified by the GIS screening tool, in more detail. The model is intended to act as a guide to assessing a site for potential suitability for habitat creation. It has been developed from the outputs of 'Suitability criteria for habitat creation – Report I' (R&D Technical Report: FD1917). This report facilitated the identification of physical, chemical and ecological parameters (criteria) and relevant limits, which describe potential realignment sites with regard to habitat creation. These outputs provide the basis for the influence diagram's habitat area and suitability calculations. The model helps steer the user towards the type of data needed to meaningfully investigate a potential site and to identify the most important factors in generating new saltmarsh, intertidal flats or eelgrass (*Zostera marina*) habitat. Although generic the model has the potential to be adapted to individual sites, and to be expanded and developed as criteria are more accurately parameterised with future research.

The influence diagram model is run using *Analytica* software that is freely available through the Lumina website and the model can be both browsed and edited for 30 days. After this period the software allows only the browse mode to be used.

A guide to entering data and using the model is provided. The physical site parameters and suitability criteria of the model are described and defined, with units and threshold information supplied where appropriate. Frieston, The Wash is used as an example of a managed realignment site and the model's predicted habitat area is shown to correspond with the actual area of saltmarsh created on the site.
Guidance and information on weighting criteria and on calculating confidence are provided to help make the model more sensitive to specific sites.

The model has been tested against data for a range of sites with differing locations and purposes; e.g. coastal realignment, estuarine realignment, recharge sites. A strong correlation exists between the model's predicted habitat areas for each site and the area of habitat that actually created following inundation. The model will also be tested against data for sites which failed to create habitat. This will further examine the sensitivity of the model's predicted suitability calculations.

The model can be adapted and expanded once users are familiar with the structure of Analytica's software and have site-specific information available to incorporate into the model's calculations. In this way it acts as an effective audit trail for decisions on final site selection.

Conclusions:

This report covers the demonstration of two tools to aid site selection in terms of habitat creation; a GIS screening tool and a site-specific model. Both use the combination of physical, chemical and ecological controlling factors identified in Report I. These tools are flexible and can be adapted, refined and expanded, to provide greater accuracy and site-specific results. As knowledge improves and criteria are more precisely quantified the tools will become more sensitive and accurate in their prediction of suitability. Together they act as an effective audit trail for decision-making and site selection.

The outputs from this project together with the monitoring guidance provided by DEFRA/EA-FD1918 (2004) and CIRIA (2004) provide a continuum of site evolution and a mechanism for improved understanding of habitat creation in terms of site selection, site design and site monitoring over various timescales. These tools provide a user friendly and auditable framework to encapsulate present day understanding of habitat creation, but they do not deal with all issues related to site selection and are limited to some extent by scientific understanding to date and also variability observed at present example habitat creation sites. The tools are a good starting point to help guide site-selectors through the key issues but a more fundamental study is required to develop increasingly robust tools for future site selection applications.

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1.0 Introduction:

This research project is intended to bring together the present scientific understanding of physical, chemical and ecological criteria controlling habitat creation (saltmarsh, intertidal flats 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 diagram[2] model and GIS demonstration:

- **Report I** (a previous 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** (this report) 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.

This report describes the two decision approaches developed within this project to aid the selection of sites for habitat creation from an ecological perspective. By formalising the procedure of criteria combination and parameterisation within a user-friendly framework it is aimed to make the decision process transparent, comparable and auditable.

The two approaches designed to facilitate site selection are;

- A demonstration of a GIS screening tool which is capable of identifying sites at a wider spatial scale and using readily accessible spatial data relevant to suitability criteria.

- A generic influence diagram model designed to assess each site within a short-list in more detail.

Both tools build on the main outputs of the scientific reviews undertaken in Report I, which determined factors (criteria and associated thresholds) that are relevant to site selection in terms of habitat creation. The criteria and thresholds derived from the review process on present site selection criteria and practise and also on scientific reviews of the physical, chemical and ecological controls (Report I) are summarised in Tables 1 and 2. The main aim of the tools is to build the present scientific understanding and practise into a framework that is user-friendly, accessible, transparent and gives a good audit trail for decision making and site selection. Building on the scientific understanding from Report I, one of the main practical uses of the tool is to lead the end-user or site selector through the range of issues to

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[2] 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.

consider. This process will include highlighting the factors amenable to predictive assessment, and also those that may be important, but where the scientific understanding is not yet sufficient to allow incorporation into the tools. In this way the tool(s) represent an attempt to unravel the complexity of interdependent processes and factors controlling habitat creation as discussed in Report I and incorporate them into a framework which will direct the user to the key issues (criteria) in a systematic way.

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 (*Z. marina*)	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

Table 2: Summary of criteria, thresholds and habitat determined from the reviews in Report I and applied in the influence diagram.

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	
	Lower than MHWN	Intertidal flats	General saltmarsh and intertidal flats texts, e.g. Adam, 1990; Packham and Willis, 1997; Long and Mason, 1983; Gray, 1992; Gray *et al*, 1995;
	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 *Zostera marina* only. Thresholds for eelgrass (*Z. marina*), 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 *et al.*, 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 *et al.*, 1981. Algae may also smother and kill saltmarsh vegetation; e.g. Adam, 1990; or eelgrass; e.g., Davison and Hughes, 1998; van Katwijk *et al.*, 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 *et al.*, 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 *et al.*, 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 *et al.*, 1983; de Jonge *et al.*, 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	Saltmarsh Intertidal flats Eelgrass	No references (T. Chesher, personal experience)

	in newly accreted material is slow - consider excavating channels pre-breach		
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 *et al*., 1987; Rand, 2000; Huiskes *et al*., 1995; Garbutt *et al*., in Reading *et al*., 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 *et al*., 2000, 2002; Calumpong and Fonseca, 2001

*Eelgrass refers to subtidal *Zostera marina* only.

2.0 Geographical Information System (GIS) screening approach demonstration:

2.1 Aim and approach:

The demonstration described in this section was undertaken to illustrate how GIS can be applied as a tool to provide a rapid overview of potential sites for habitat creation within an estuary or coastline area. The GIS acts as a framework to bring together spatial data on different criteria relevant to site selection and then integrate them using the associated criteria thresholds to specify the sites that have characteristics that fit the requirements. The GIS will therefore utilise the desired site characteristics to screen and spatially display prospective successful managed realignment sites over a given area. It therefore should fit easily into wider strategic plans and site selection in line with SMPs, CHaMPs etc.

GIS is increasingly being applied to coastal zone management situations either in terms of purely integrating relevant spatial information which facilitate site selection (EA HESMP, 2000; EA HEEBS, 1998) or in terms of applying GIS and models to help habitat predictions.

As elevation is such a controlling factor in habitat creation, Digital Terrain Models (DTMs), often derived from the radar system Light Detection and Ranging (LiDAR), are routinely used to give good elevation information for a site and may be displayed in a GIS format. Critically, the GIS environment allows examination of this type of data at various spatial scales, including sites, area or region and so facilitates decisions across the scale of management strategies or site selection.

Increasingly though, GIS is being used in conjunction with scientific knowledge of habitat creation to identify sites and aid site selection. Coombes (2003) investigated habitat creation and loss in the context of managed realignment within the Humber estuary by using GIS to look at changing land-use and historic maps of the coastline. Also in the Humber, Frost et al., (2004) have used a combination of hydrodynamic modelling and GIS approaches to predict the changes that would occur to key habitat types and invertebrate communities in response to changes in the physical environment (predictor variables) following long-term natural changes in the morphology and hydrodynamics of the estuary. These models made use of multivariate statistical methods to define relationships between physical environment and habitat response and the results were output in the GIS. The approach presented here however, uses the GIS itself to filter the data and identify prospective sites. Also it incorporates more variables relevant to habitat creation in addition to elevation.

The process of application of the GIS to aid site selection is demonstrated here, with the various stages being designed to show end-users how GIS can be implemented and what sort of outputs can be produced in terms of varying complexity.

2.2 Demonstration:

2.2.1 Methods:

The demonstration area is the Blackwater Estuary, Essex (Figure 1a). This was selected because there were several managed realignment sites within the estuary which could be used to test the prediction of the GIS tool. Sites such as Orplands, Tollesbury and Abbotts Hall in the Blackwater were used to cross check the output of the GIS. Site selection is an on-going issue in this region and it was an aim that a tool could provide insight to managers in this area. Also it was likely that the digital spatial information that was needed would be available.

Using a GIS system (in this case Arcview 3.3 and Spatial Analyst 3.2), the delineation and spatial extent of potential sites for habitat creation can be selected or screened using a suite of physical, chemical and biological data (criteria) and the associated thresholds for each of the criteria.

The location of potential sites can be derived using a robust GIS methodology for mapping and data handling, known as derivative mapping (mean suitability). The derivative process produces a new map output based on a range of underlying data layers describing an environmental variable which is determined as controlling a site suitability for habitat creation e.g. elevation, wave exposure, salinity etc. The GIS is used to interrogate and query each data (criterion) layer using information that describes the environmental requirements of sites suitable for habitat creation. Interrogation is based on Boolean logic (i.e. AND, OR statements). For example, if a suitable site is defined by bed levels >x, prefer tidal ranges between y AND z, and chemical parameters a, b AND c, then a new map is derived depicting the occurrence of these predefined areas. The limitation of this approach is that data for the each GIS layer needs to be in a grid format in order to provide synoptic coverage of each environmental parameter and so the number of criteria that can be included in site selection may be limited by data availability at a suitable spatial resolution. Figure 1b shows the process of derivative mapping in full. In this case the suitability indices could not be fully developed due to the lack of quantitative scientific relationships between site characteristics (criteria), associated thresholds and resultant habitat or by restricted resolution of available data, but the process has been demonstrated given three selected criteria that are applied within the site-by-site tool and as listed in Table 3.

2.2.1.1 Criteria Layers (themes):

The GIS output demonstrated here includes a few selected layers (themes) related to creation of saltmarsh and intertidal habitats. Given the limitation of some of the availability of spatial data these were the data that were most readily available at appropriate resolution within the timescales of the project. As a demonstration, these layers illustrate the possibilities in terms of GIS manipulation of layers and also combination of layers to aid site selection.

The layers of data used for the demonstration were elevation, slope and proximity to existing habitat. These layers were not only selected because there was the most readily available spatial data but also the processing of the data illustrates a number of

ways of varying complexity in which GIS could be applied to site selection. The details of source data and treatment/implementation for each of the layers is summarised in Table 3.

Additional GIS layers on criteria that have been identified as controlling habitat creation such as inundation (modelling output), land pollution/contaminated land, soil type, water quality / salinity (contours from monitoring), turbidity, exposure and freshwater flows could be added. But with these three contrasting layer types the process to achieve site selection has been well demonstrated.

Figure 1a: The Blackwater Estuary Essex, Salcott creek focus area and managed realignment sites used in GIS tool testing.
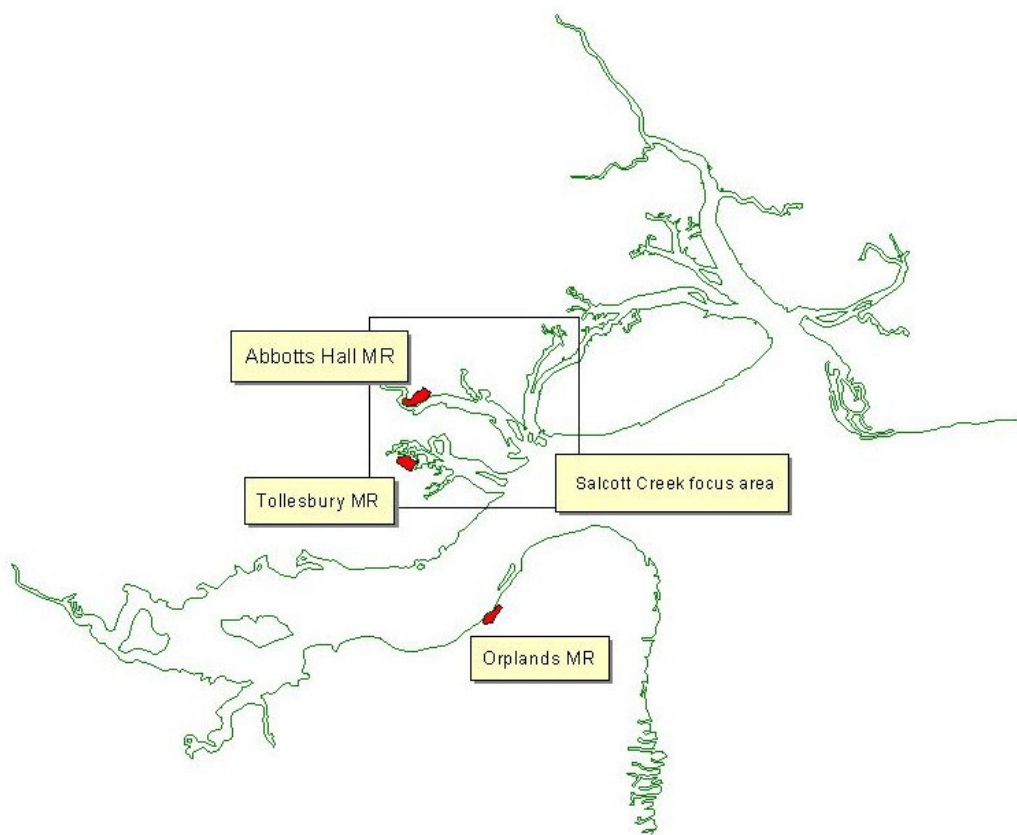
Figure 1b: Process of GIS derivative mapping applied to site suitability for habitat creation.

Modelled habitat criteria thresholds

Digital environmental maps recoded with suitability indices (SI's)

elevation

inundation

salinity

substrate type

Habitat suitability index map

Suitable

Medium suitability

Low suitability

Unsuitable

$$HSI = \left(\begin{array}{c} \text{Temperature SI map} \\ \text{X} \\ \text{Depth SI map} \\ \text{X} \\ \text{Salinity SI map} \\ \text{X} \\ \text{Substrate SI map} \end{array} \right)^{1/4}$$

Table 3: Criteria information, thresholds, data sources and GIS approach summarised for example GIS layers.

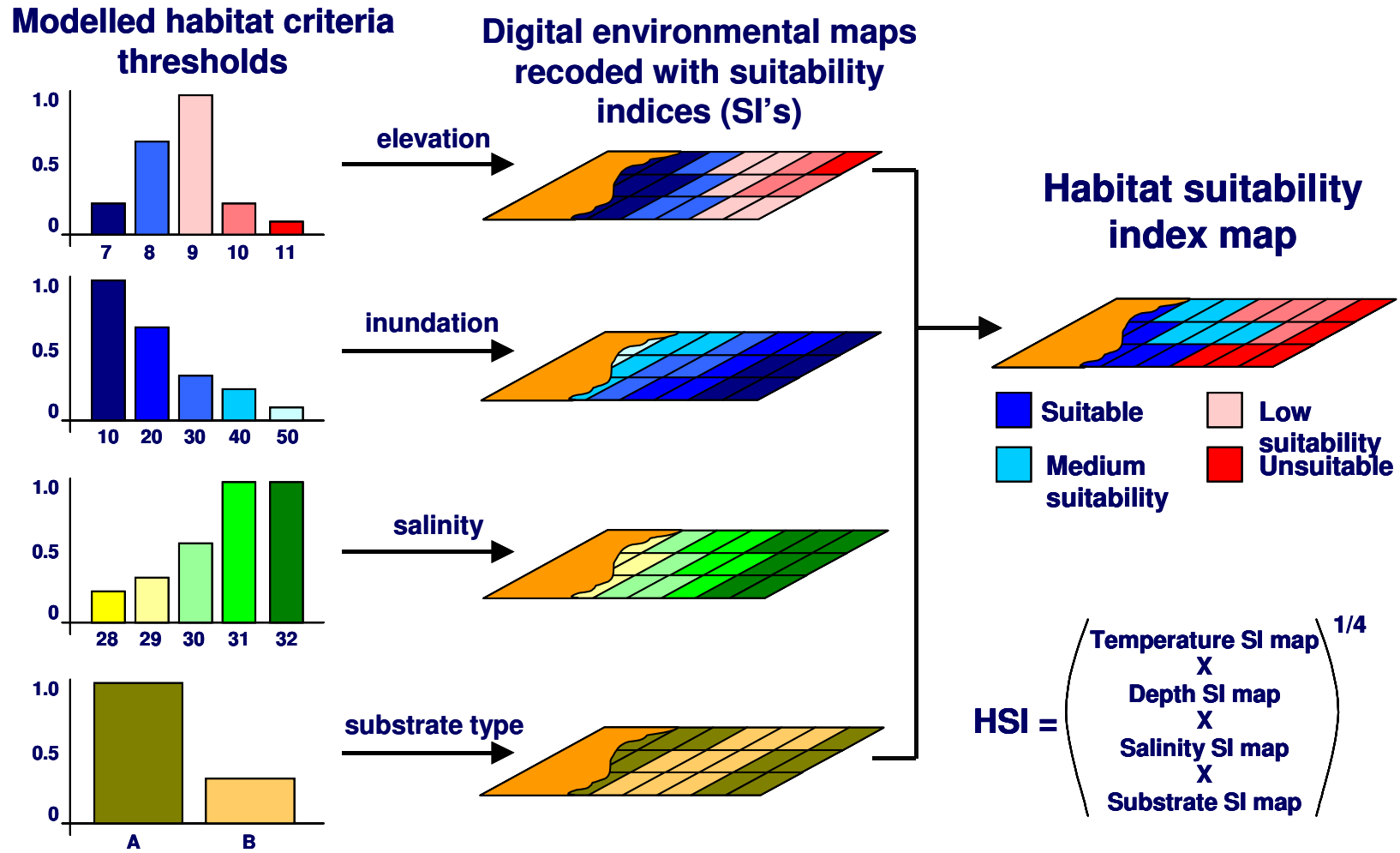| Criteria/layer	Criteria information	Thresholds applied	Data source	GIS approach
Elevation	Elevation must be suitable for salt marsh vegetation colonisation. The minimum elevation should be around the level of MHWN *in the location of the proposed site,* or at a level that would experience 450-500 tidal inundations per year. 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 MHWN. Elevation also helps with estimates of connectivity.	Saltmarsh = MHWS - MHWN Mudflat = MHWN - MLWS, Eelgrass (*Z. marina*) = <MLWS.	EA LIDAR data (mOD).	Mapping of gridded data. Map calculations in spatial analyst.
Slope	Gradient should be sufficient 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. Optimum slope has drainage and also creates good succession of habitat and increases potential diversity.	For Saltmarsh ideal = 1-2% (1:0-1:64) 0-7% (1:0-1:18) possible Intertidal ideal = gradual, not concave, sufficient for drainage	Calculated within the GIS framework from elevation data.	Calculation within GIS framework from gridded elevation data. Derivative layer
Proximity / 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, Devon 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 Sources of propagules (e.g. seeds, rhizomes) nearby, up/down estuary / coast available for natural transport to the site.	In close proxmity: adjacent for infauna or within a tidal excursion.	Essex estuaries ChaMP GIS overview of saltmarsh.	Buffering technique around existing saltmarsh habitats.

2.2.1.2 Data collation and processing for site selection criteria:

Elevation:
Elevation is such an important parameter in determining the distribution of habitats and invertebrates within the intertidal zone, the GIS grid cells were refined to a high resolution using data from the radar system Light Detection and Ranging (LiDAR). Several LiDAR tiles ($5Km^2$) in the form of ArcView grids which covered the Blackwater, Mersea and Colne regions were obtained from the Environment Agency, National Centre for Environmental Data and Surveillance. This data had previously been filtered to remove buildings and vegetation from the surface, leaving a bare earth DTM (digital terrain model). Each LiDAR tile includes gridded data of elevations referenced to Ordnance Datum (OSGB36) at a resolution of 2 x 2m. The height accuracy of point measurements (z) for the LIDAR system for a WGS84 product (including instrument errors, calibration errors and GPS errors) is ± 9 – 15 cm. The accuracy after transformation to OSGB36 (inclusive of LIDAR system errors) is ± 11 – 25 cm. The plan accuracy of point measurements (x,y) for the LIDAR system for a WGS84 product (including instrument errors, calibration errors and GPS errors) is ± 40 cm. The accuracy after transformation to OSGB36 (inclusive of LIDAR system errors) is ± 45 cm. The quoted error is ± one standard deviation which means that 66% of the values lie within the defined error bands.

Other sources of elevation information could be Panorama DTM data from Digimap (http://www.digimap.co.uk). This is a grid of height values interpolated from O.S contour data and are accurate to a minimum of 3 metres root mean square error, although this can vary according to the complexity of the terrain.

Figure 2 illustrates a LiDAR tile of raw data from the areas of Tollesbury and Abbotts Hall (Salcott). The legend is in metres OD and poor data in terms of return during sampling can be clearly seen as black. Such data could be filtered out before progressing to site selection. This data is carried through the GIS process and stands out clearly in subsequent layers as anomalous.

All the separate LiDAR tiles covering the required area (Figure 3) were joined together using a Spatial Analyst 'spatial tool' extension which creates a single layer (theme) from all the tiles which facilitates mapping exercises across the whole area. This 'mosaic' of all the LiDAR tiles forms one GIS elevation layer (theme) of the Blackwater/Colne region (Figure 4). Close-ups of prospective areas in this form can also illustrate the connectivity of a site. The coastline theme used here is approximately mean low tide and is added to this and subsequent figures to act as a guide. However, site selection in terms of elevation acts as a continuum seaward of this line to MLWS and so the data is left past this line. Poor data mid estuary is due to LIDAR flights during higher water which created contrasting elevation information.

The criteria thresholds for habitat type limits with respect to elevation in this study and others (as in Table 1) are given in relation to tidal levels (e.g. MHWS, MHWN, MLWS) which are given in CD. To compare elevation (derived from LIDAR in mOD) and tide level data, the tidal levels derived from Admiralty Tide Tables needed to be converted into mOD. Table 4 below shows the information that was used. It should be noted that although Walton-on-the-Naze is not in the Blackwater, but it is the Standard Port that tide levels are referred to. The bottom row in Table 4 are the

OD(m) numbers used in the GIS tool to identify habitat boundaries in terms of mean tide levels. These are consistent with the levels applied in the site-by-site influence diagram tool.

It should be noted that the offset of Chart Datum to Ordnance Datum and heights of tidal levels are variable within the estuary and the rate of change is most extreme in the upper reaches (NB change at Maldon). It is possible to overlay a surface for each tide level over the DTM provided by the LiDAR information within the GIS environment to output the spatial extent of the tidal level boundaries (MHWS etc.) more accurately.

The layer of relative datum levels can be created within the GIS using a Thiessen polygons method which creates a network of polygons based on spot data (i.e. offset from metres OD/CD from ports). There is an extension for creating Thiessen polygons on the ESRI website (www.esri.com) which can be downloaded to do this. It is also possible to couple outputs of a hydrodynamic model with data from LiDAR which would allow prediction of changes in physical parameters, including water levels, for each individual grid cell (Frost et al., 2004).

Table 4: Mean tide levels (CDm) for ports within the Blackwater Estuary. From Admiralty Tide Tables (2004).

Site	CD relative to OD (m)	LAT	MLWS	MLWN	MSL	MHWN	MHWS	HAT
Walton on the Naze	-2.16	0.0	0.4	1.1	2.2	3.4	4.2	4.6
Bradwell waterside	-2.68		0.4	1.3	2.7	4.2	5.2	
Osea	-2.63		0.4	1.2	2.7	4.3	5.3	
Maldon	0.11		-	-		2.3	2.9	
W.Mersea			0.5	1.2	2.7	3.8	5.1	
Overall Blackwater								
CD(m)	0		0.5	1.3		4.2	5.3	
OD(m)	-2.65 (-2.7)		-2.2	-1.4		1.5	2.6	4.0

These techniques were not employed here due to little variance in mean tide levels and CD/OD conversion within the main part of the estuary and limitations still of this approach given 3 or 4 points within the estuary. If this technique was to be applied in future then more detailed information for a specific estuary both in terms of average tidal levels and CD/OD offset and also in terms of habitat boundaries as determined by habitat mapping such as has been performed in the Humber (Table 1, this study; EA, 1998), could be applied. For the purposes of this study, an average offset (CD/OD) and level of various mean tidal heights (MHWS etc.) has been assumed. The error that this averaging introduces (mainly overestimation of areas in the upper estuary towards Maldon) is determined to be acceptable given the scope of the project, the accuracy (vertical and horizontal) of the LiDAR data and also given the implementation of a testing phase to check site predictions.

Figure 2: Example of raw LiDAR tile used for elevation data in GIS tool.
(Legend gives the LiDAR tile reference (TI91se) and categories are assigned by default in the GIS in metres OD (–2.6mOD to +30.1mOD).
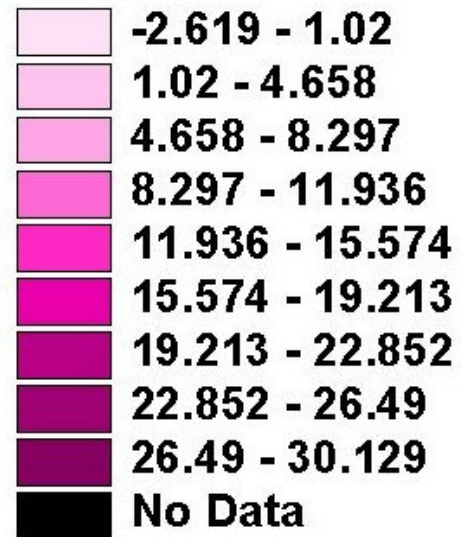
Figure 3: Composite of individual (5Km^2) LiDAR tiles used to make up single mosaic elevation GIS layer (theme) for the Blackwater.
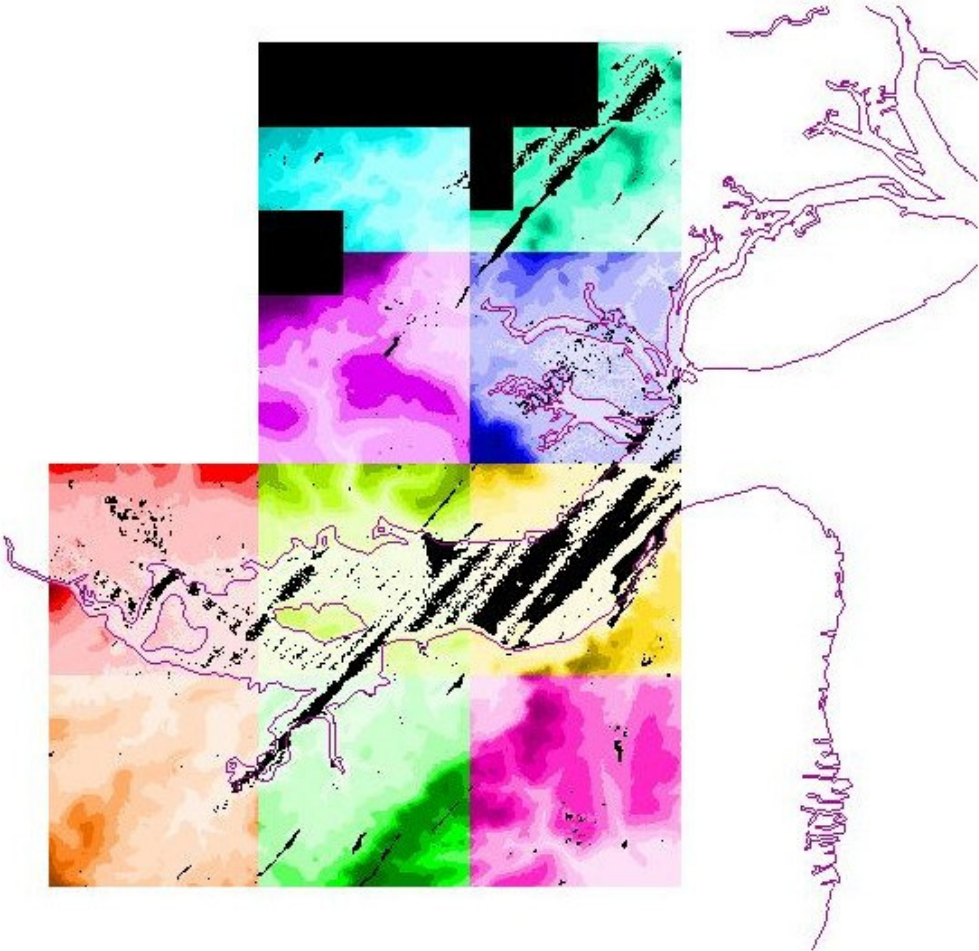
Figure 4: Mosaic of all LiDAR tiles (elevation mOD legend as assigned by GIS).
(Legend gives the layer displayed (mosaic of all tiles) and categories are assigned by default in the GIS in metres OD (–2.96mOD to +73.3mOD). The intervals are equal in height difference from the minimum to maximum heights.

Mosaic
- -2.959 - 5.522
- 5.522 - 14.004
- 14.004 - 22.485
- 22.485 - 30.967
- 30.967 - 39.448
- 39.448 - 47.93
- 47.93 - 56.411
- 56.411 - 64.893
- 64.893 - 73.374
- No Data
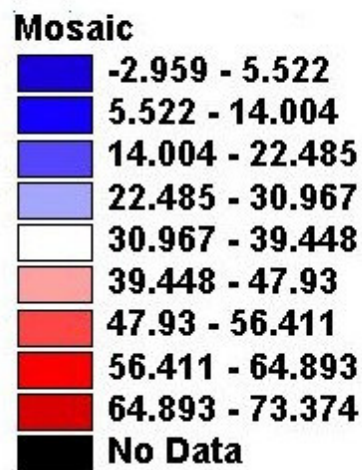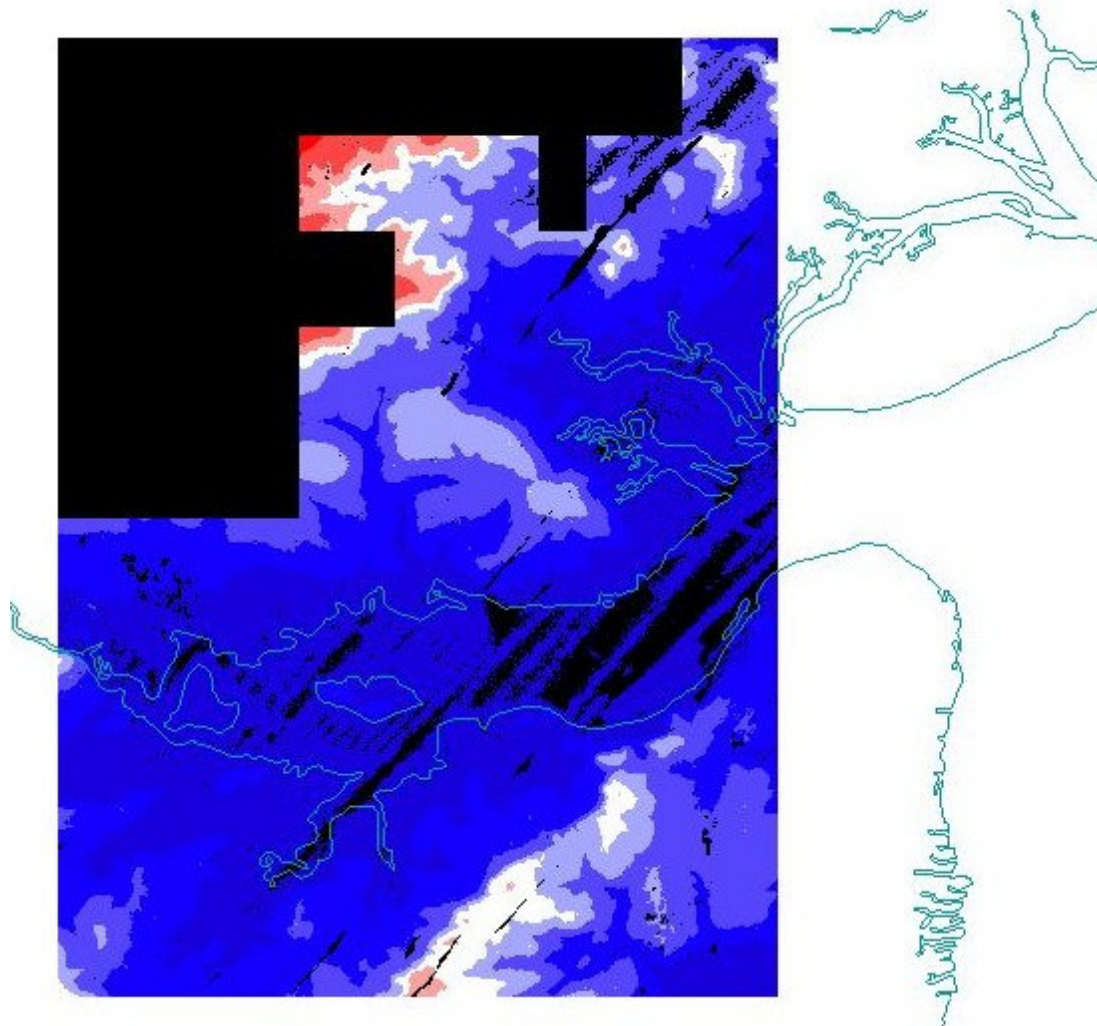
Slope:

The slope or gradient of a site has implications for drainage and also creates good succession of habitat and increases potential diversity. Slope can be determined by transect/profile information which is surveyed along a fixed bearing and extends from a predetermined point inland, to at least MLWS. Estuary profiles in the Blackwater are tailored to meet specific requirements for timing, extent of survey and concentration of survey lines so do not provide a complete coverage. They are very good though for site-by-site detail, for example Orplands data, and would be very useful information for the influence diagram model assessment of slopes.

In this demonstration, slope was derived from the GIS theme of elevation using a function within Spatial Analyst. The tool identifies the slope, or maximum rate of change, from each cell to its neighbours. The output slope grid theme represents the degree of slope (e.g., 10 degree slope) for each cell location. This can be converted into % slope i.e. 1-2% slope = 0.45 – 0.9 ˚, 2 to 7% slope = 0.9 to 3.15˚.

The only problem with this approach is that it does not differentiate the direction of slope in terms of an ideal towards the breach (i.e. higher land behind) but as an initial screen this is useful. Figures 5 and 6 show the output from the overall mosaic (regional) slope calculations and also a more magnified view (around Salcott) of the slopes calculated by this approach. Both figures show the comparatively low slopes in this area (< 2˚) and the capability of this method of picking out gradient changes related to seawalls, field boundaries and slope variability associated with existing saltmarsh areas.

Proximity to established habitat/propagule supply:

Presence of a habitat close in proximity (adjacent, within natural transport ranges within the estuary or up/down coast) to a new site can provide sources of propagules (e.g. seeds, rhizomes) or recolonising infauna. Such sites also demonstrate good water quality conditions. This is especially relevant for saltmarsh and eelgrass (*Z. marina*) and although colonisation at Saltram, Devon has shown that saltmarsh can develop at some distance from the nearest salt marsh habitat, for most sites and habitat types a minimal distance would be preferable to increase chances of recolonisation. The approach taken here was to apply a buffering method within the GIS which highlights an area within a certain distance of an existing habitat.

A GIS shapefile of saltmarsh distribution within the Blackwater Estuary was downloaded from the English Nature web-site (http://www.english-nature.org.uk/pubs/gis/gis_register.asp) , the original data layer is presented in Figure 7. Similar information is available for other intertidal and subtidal habitats and also conservation designations (SSSI, SAC etc) which may be used for screening of site selection. Similar information could also be derived from The Institute of Terrestrial Ecology (ITE) (now CEH) land-cover data which shows land-use such as saltmarsh and intertidal mud but also potentially gives some historic information on previous land-use which may be relevant. It also gives information on areas which could be excluded from selection by their land-use (Urban, Suburban etc).

A buffer was applied to this saltmarsh layer (theme) with a radius of 0.5Km to enable selection of sites within this distance. Figure 8 illustrates the buffer radius at 500m

intervals up to 1.5Km. Clearly, sites too far landward (>1Km) would not be considered and can be clipped from a layer. Here, intervals of 0.5Km have been demonstrated but this could be altered in extent relevant to tidal excursions within an estuary or residual flows, or some combination of propagule viability and transport within an estuary along a coastline. If infauna or eelgrass (*Z. marina*) are being considered, sites may need to be restricted to adjacent sites, in which case the procedure could be adapted accordingly.

Other layers relevant to habitat creation criteria:
Other layers (themes) could be added to this demonstration. Examples of sources of information are given below relevant to the criteria not demonstrated here.

Salinity, water quality and turbidity:
This type of information can be derived mainly from monitoring data and literature. Figure 9 illustrates the regular shellfish sampling sites monitored by the Environment Agency in the Blackwater. At these sites salinity, turbidity and some water quality parameters are measured. Although these sites are insufficient for compilation of a robust GIS layer the data illustrate the range of measurements of the variables of interest. For example: information for the sites have average suspended loads of around 100mg/l, which is considered turbid and likely to limit light in terms of eelgrass (*Z. marina*) requirements.

This type of data can be augmented by additional information from other monitoring programmes or literature values. For example various publications have reported average salinity values in the main Blackwater Estuary ranging from 28 to 34 (Talbot, 1967; Fox et al., 1999; Fox and Aldridge, 2000), which are adequate for creation of the habitats considered here (criterion threshold is >18).

Inundation:
An estimate of level of frequency of inundation can be calculated using a modelling approach of imposing the tidal curves over spring/neap cycles onto a DTM to determine how often a given cell is wet/dry. This can be done in the GIS environment as has been applied by Aldridge et al., (2004) in terms of looking at inundation in relation to nutrient supply to intertidal macroalgae. It is also possible to couple outputs of a hydrodynamic model with a DTM which would allow prediction of inundation for each individual grid cell (Frost et al., 2004).

Land contamination and soil type:
Land pollution/contaminated land should be able to be derived from the register of contaminated land held by local authorities and also from the EA. The EA publishes Soil Guideline values and fact sheets on contaminated land and Groundwater and Contaminated Land publications. (www.environment-agency.gov.uk/subjects/landquality/). Complete coverage of soil survey data is only available for England and Wales at a scale of 1:250,000 (Potter et. al. 1993; Avery, 1973) and soil information at this scale is presented in terms of soil association (geographically associated soils) rather than a true soil series (describing soils alike in soil characteristics behaviour). Drift geology maps can be used as a surrogate for soil survey data (Ghiaffari et al., 2000), because these maps provided better spatial resolution (1:50,000) than soil survey maps (1:250,000) and drift geology is

convertible into a soil survey criterion. Drift geology maps are published by the Geological Survey of Great Britain (England and Wales). Maps of this type would need to be digitised prior to use as GIS layers.

Exposure:
Exposure in terms of wave impact which can affect accretion, can be expressed in terms of fetch, wave heights, distance of sites from the mouth of an estuary but it is difficult to integrate into a spatial layer on a resolution relevant to site selection. Some assessment of relative exposure has been made in GIS as part of a SNIFFER project on estuarine and coastal typologies around the UK and could be used for comparison of sites around the UK. Examples of the type of designations from this document (Rogers et al., 2003) for the UK and the Blackwater area appear in Figure 10a and b. This approach mainly differentiates between estuarine and coastal areas so further information would be needed on a specifc site or to compare sites within an estuary or stretch of coastline.

Freshwater flows:
Freshwater flows into a site are important for sources of contaminants/nutrients from the land behind but also in terms of soil salinities as this is obviously a key factor in saltmarsh creation. At present the EA shoreline management data catalogue does not hold this type of data. Electromagnetic conductivity mapping of foreshore and supra shore areas could provide a wealth of information, not least blanket coverage of substrate salinities, saline intrusion, fresh water flows, water content of saltmarsh and relative saturation levels (Justin Ridgewell pers. Comm.). These can provide important information which can assist in not only in the site selection process for habitat creation but also the assessment of the relative 'health' of existing saltmarshes.

Overall, with more time to apply the GIS methodology to an area, datasets and maps which can provide additional layers of information on habitat creation criteria would be available. This will enhance the predictive capability and robustness of site selection within a GIS screening tool but the three layers used here are sufficient to demonstrate the approach.

Figure 5: GIS layer of slope (degrees) derived from LiDAR elevations of whole Blackwater area.
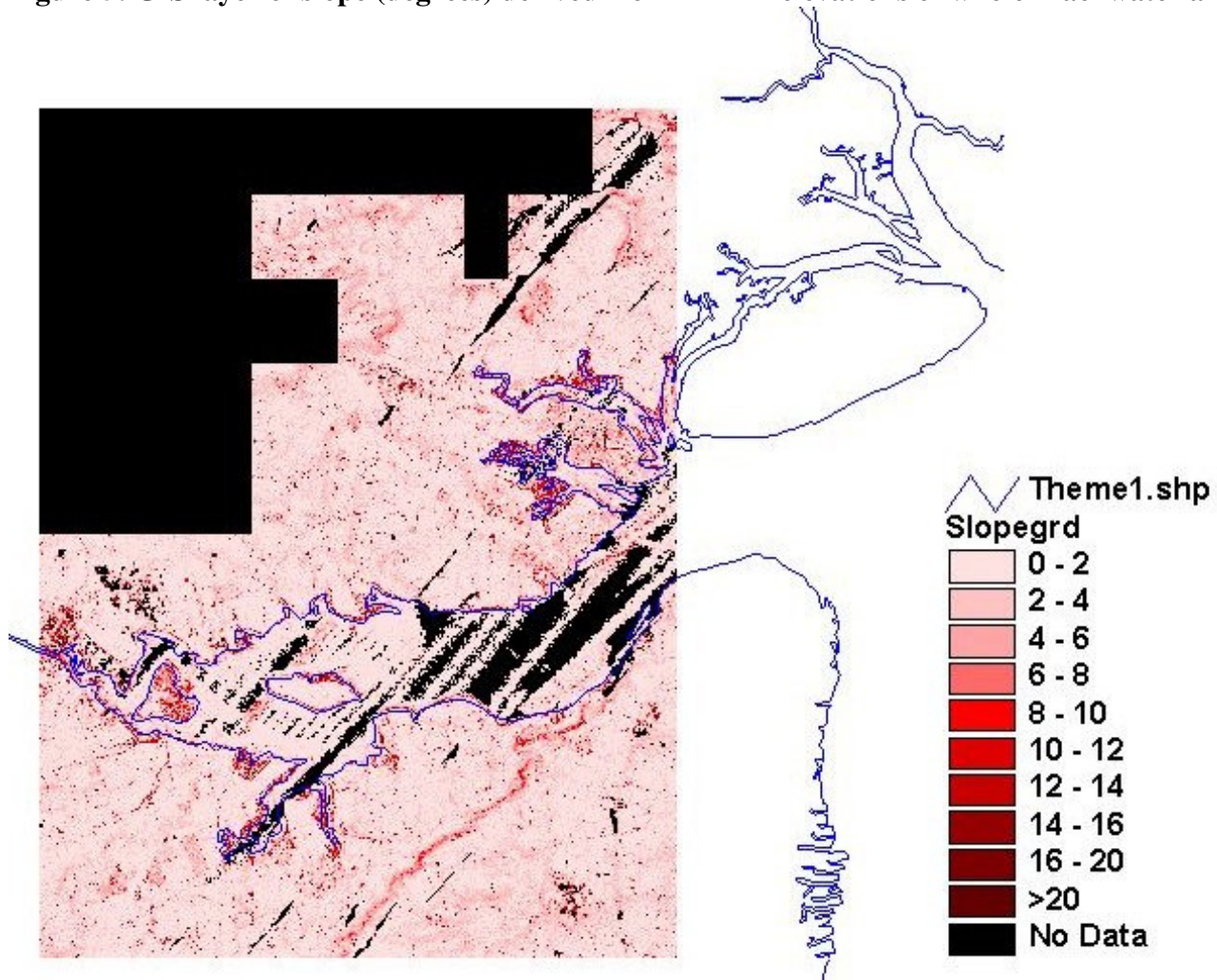
Figure 6: Magnified GIS layer of slope output (degrees) derived from LiDAR elevations for the Salcott Creek area.
Area of higher slope (sea walls, field boundaries, saltmarsh and associated creeks) are visible as darker red areas.
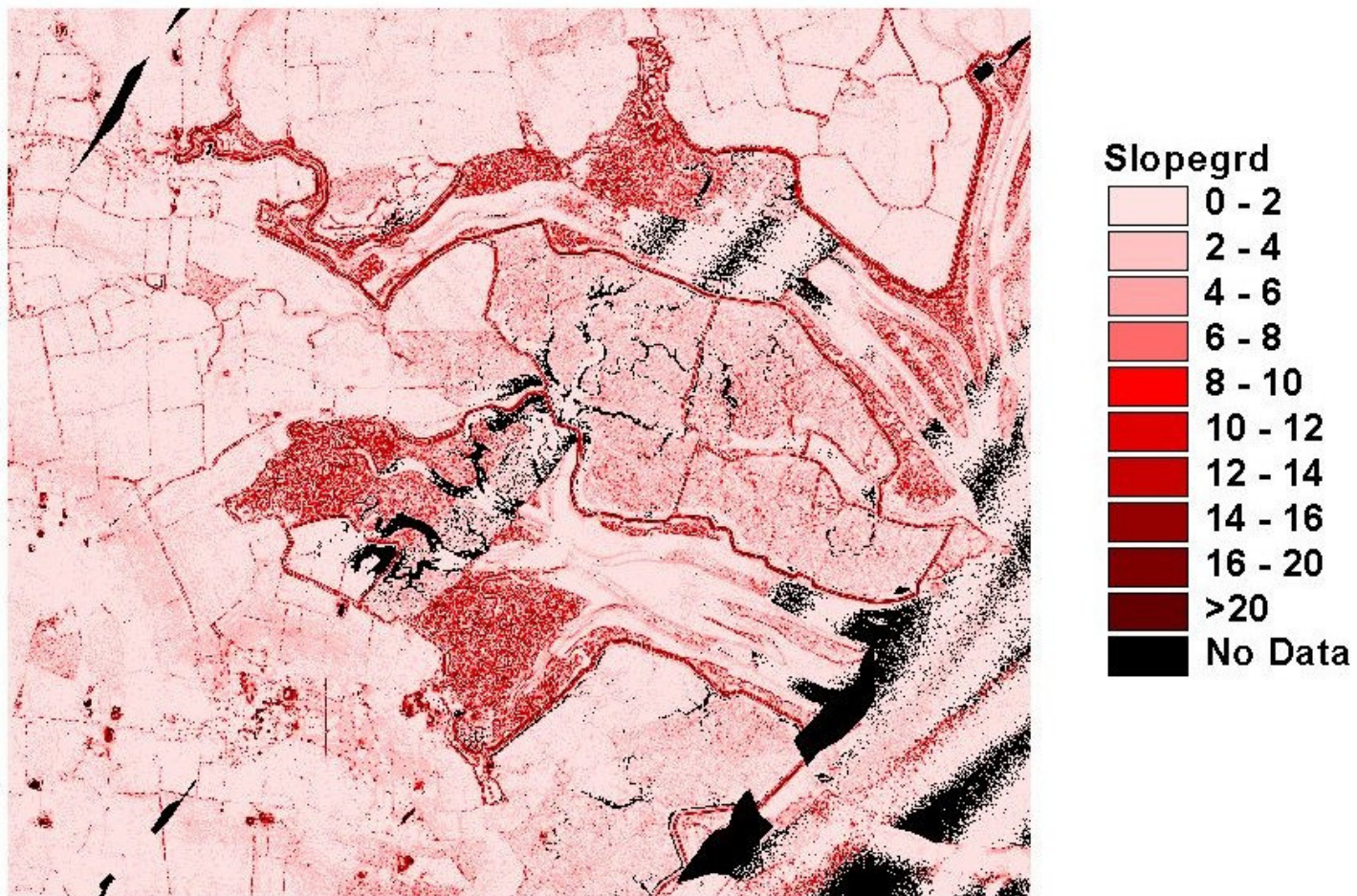
Figure 7: GIS layer of saltmarsh habitat in the Blackwater Estuary and surrounds (English Nature GIS web-site)
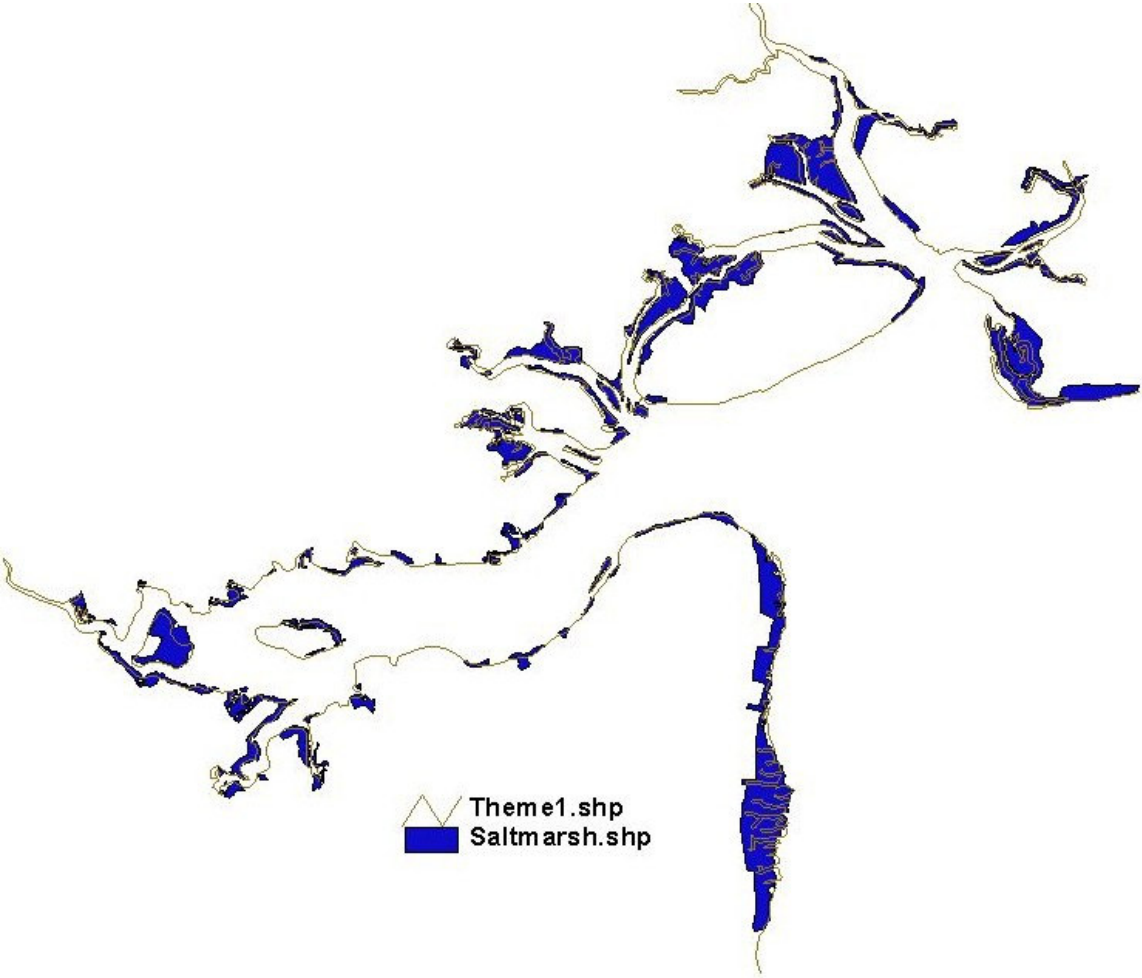
Figure 8: Saltmarsh distribution and buffering radii applied at 0.5Km intervals
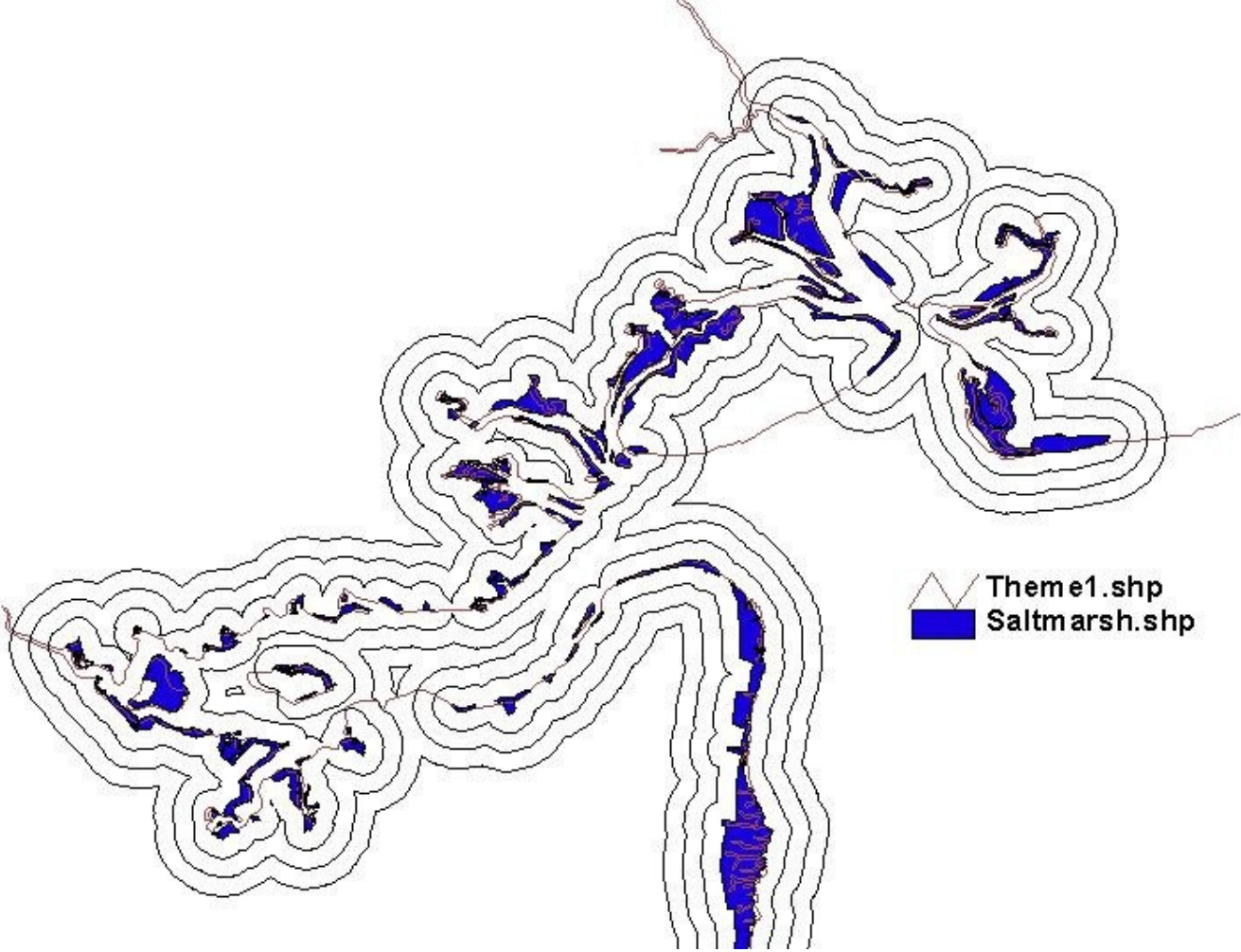

Theme1.shp
Saltmarsh.shp

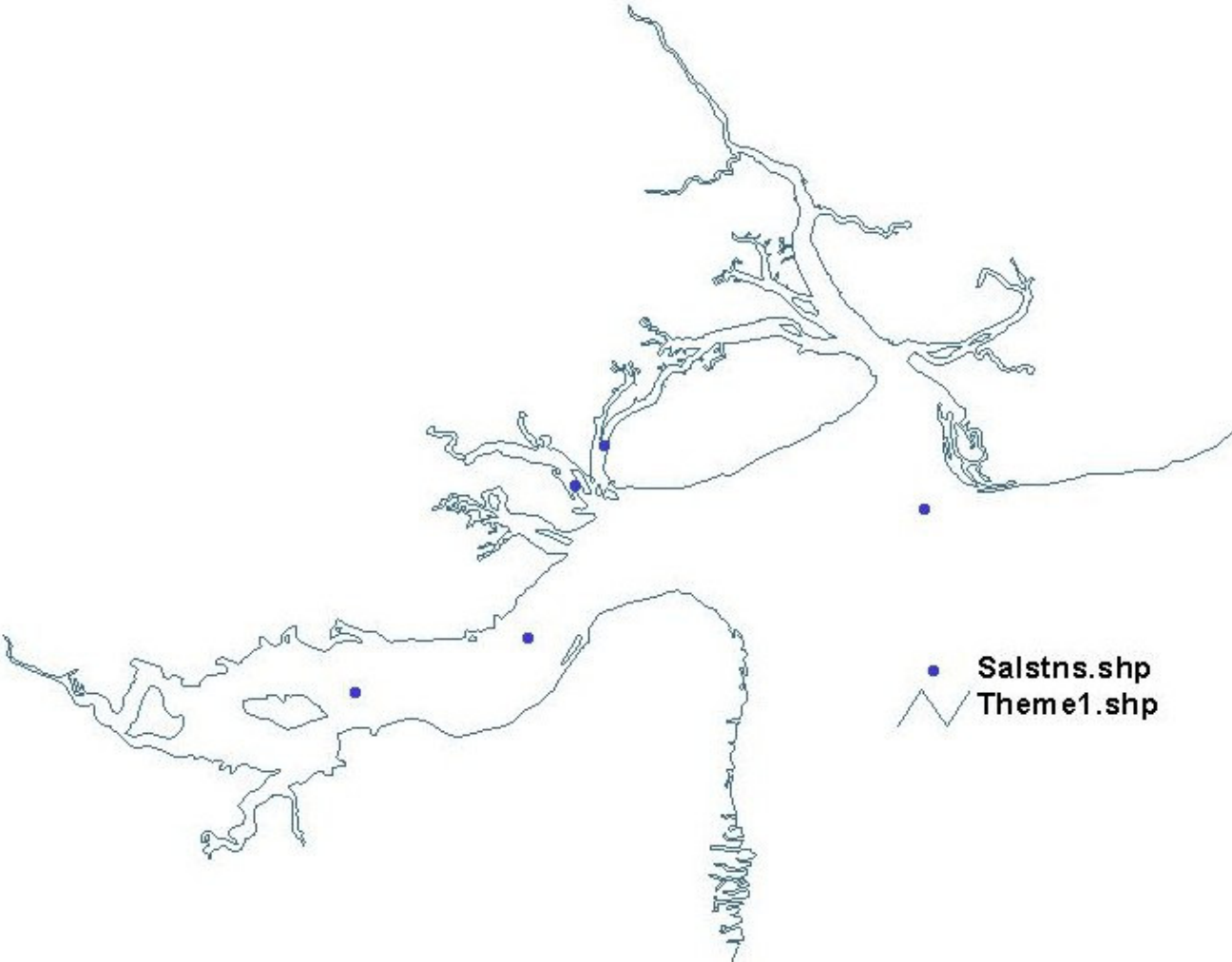**Figure 9: Shellfish sampling sites on the Blackwater Estuary**

Figure 10A: GIS layer of relative exposure around the UK (Rogers et al., 2003).
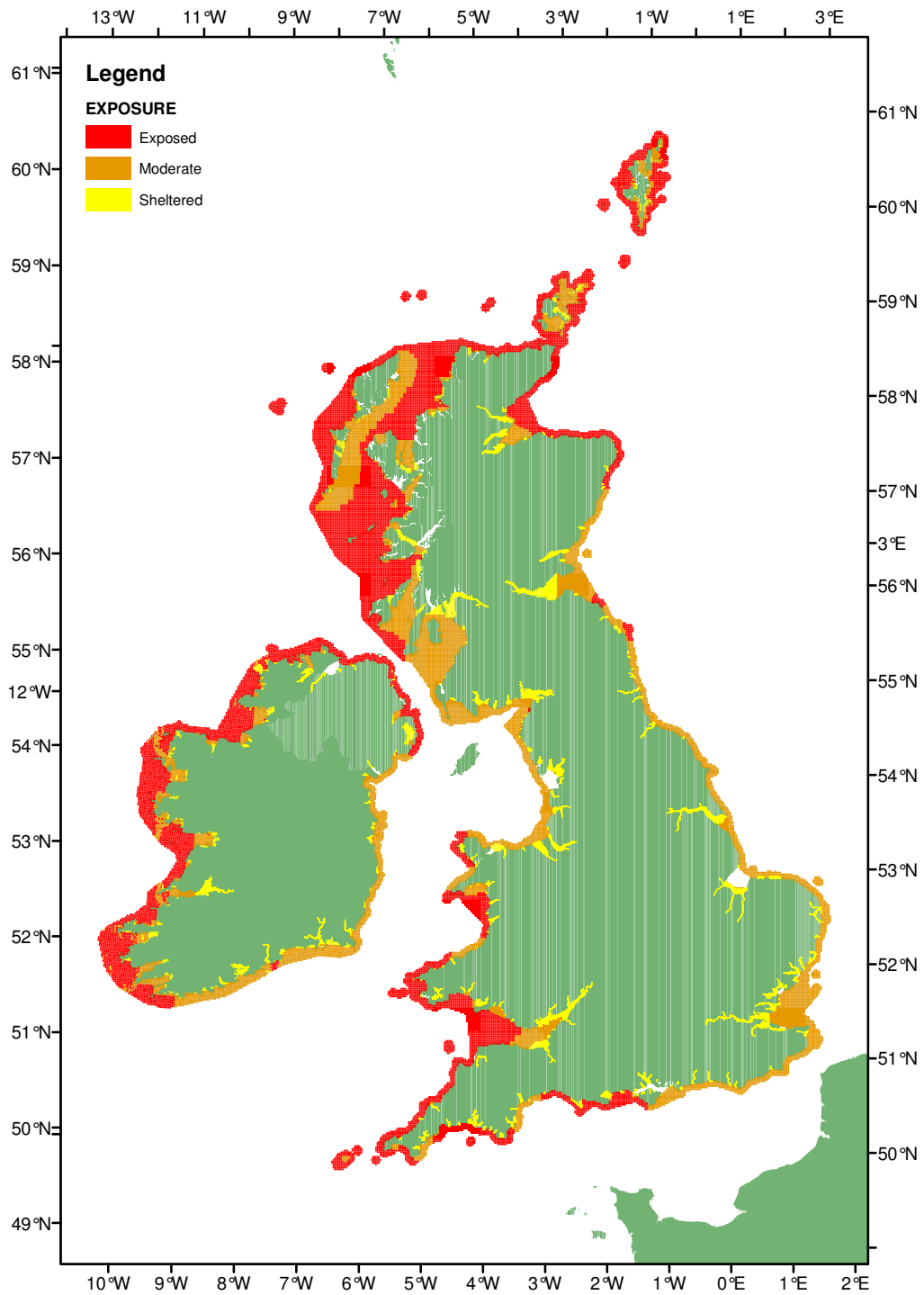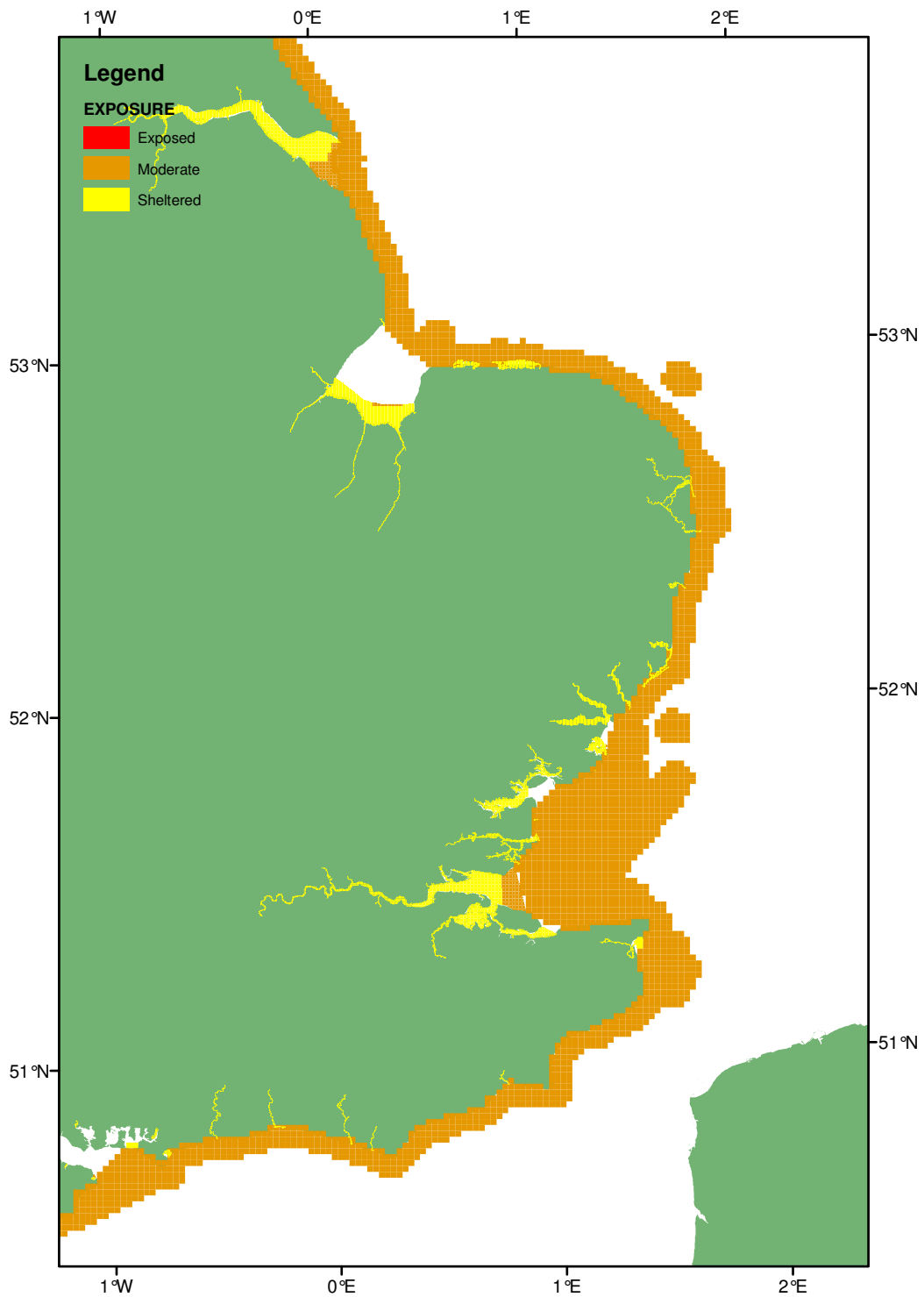
Figure 10b: GIS layer of relative exposure around East Anglia (Rogers et al., 2003)

2.2.2 Results:

This section demonstrates various GIS outputs in the form of layers after application of the habitat creation criteria thresholds as listed in Table 3. The application of the thresholds relevant to saltmarsh and intertidal mud-flat for each criteria (GIS layer) is demonstrated first and then the combination of the criteria layers is illustrated which forms the screening process to identify potential sites. A short test of the tool predicted sites against managed realignment sites and established saltmarsh is also presented.

2.2.2.1 Elevation:

Using elevation layers alone there are several techniques that can be used to indicate areas which from elevation thresholds are suitable or unsuitable for habitat creation. Figure 11 illustrates a complete elevation layer with legend in mOD up to +4.0m which is highest astronomical tide (HAT) and therefore should be the upper limit of any transitional habitats above MHWS. Also marked are the three managed realignment sites (Abbotts Hall, Tollesbury and Orplands) which will be used to test the overall screening tool performance in terms of site selection.

As a first cut, from this elevation map simply changing the theme legend to reflect the boundaries of elevation (mOD) relevant to habitat types for intertidal mudflat (MHWN - MLWS) and saltmarsh (MHWN to MHWS) can help give some preliminary indication of the distribution of potential habitats. In this case cells where LiDAR elevations (mOD) were above the predicted lower limit and below the upper limit of saltmarsh were described as saltmarsh. Those cells within the intertidal area, which contained elevations greater than the estimated upper limit of saltmarsh but less than HAT were classified as transitional marsh/ grassland.

The area outside (seaward) of the guide coastline is not accurate for elevation due to the presence of water which affects the determination of elevation by LiDAR, hence the classification of intertidal mudflat extending across the estuary is not correct. Normally, this would be screened out of LIDAR data. Figure 12 shows the habitat areas predicted from elevation alone for the whole estuary and Figure 13 illustrates for an area around the Tollesbury and Abbotts Hall sites.

In the close ups, the impact of poor LiDAR data can be seen but the overview layer illustrates clearly the areas of possible intertidal mudflat, saltmarsh and transitional sites suitable in terms of elevation. In more detail, the transition of habitats expected within a site (Figure 13) are visible and the approximate area of habitat types created.

Figure 14 illustrates the GIS layer that was used for elevation in the derivative mapping exercise. Green is suitable for saltmarsh in terms of elevation and red is unsuitable. This gives an index of 1 or 0 for suitable and unsuitable respectively. By expanding the thresholds used in the GIS, selection of areas as suitable for saltmarsh or intertidal mudflat can be illustrated (Figure 15). The layer for saltmarsh alone (Figure 14) was used in the GIS mapping exercise which used multiple criteria layers as this was most relevant to the buffering technique to saltmarshes.

Figure 11: Elevation (mOD) of the Blackwater Estuary with managed realignment sites (Mrsites – in red) used to test site predictions.
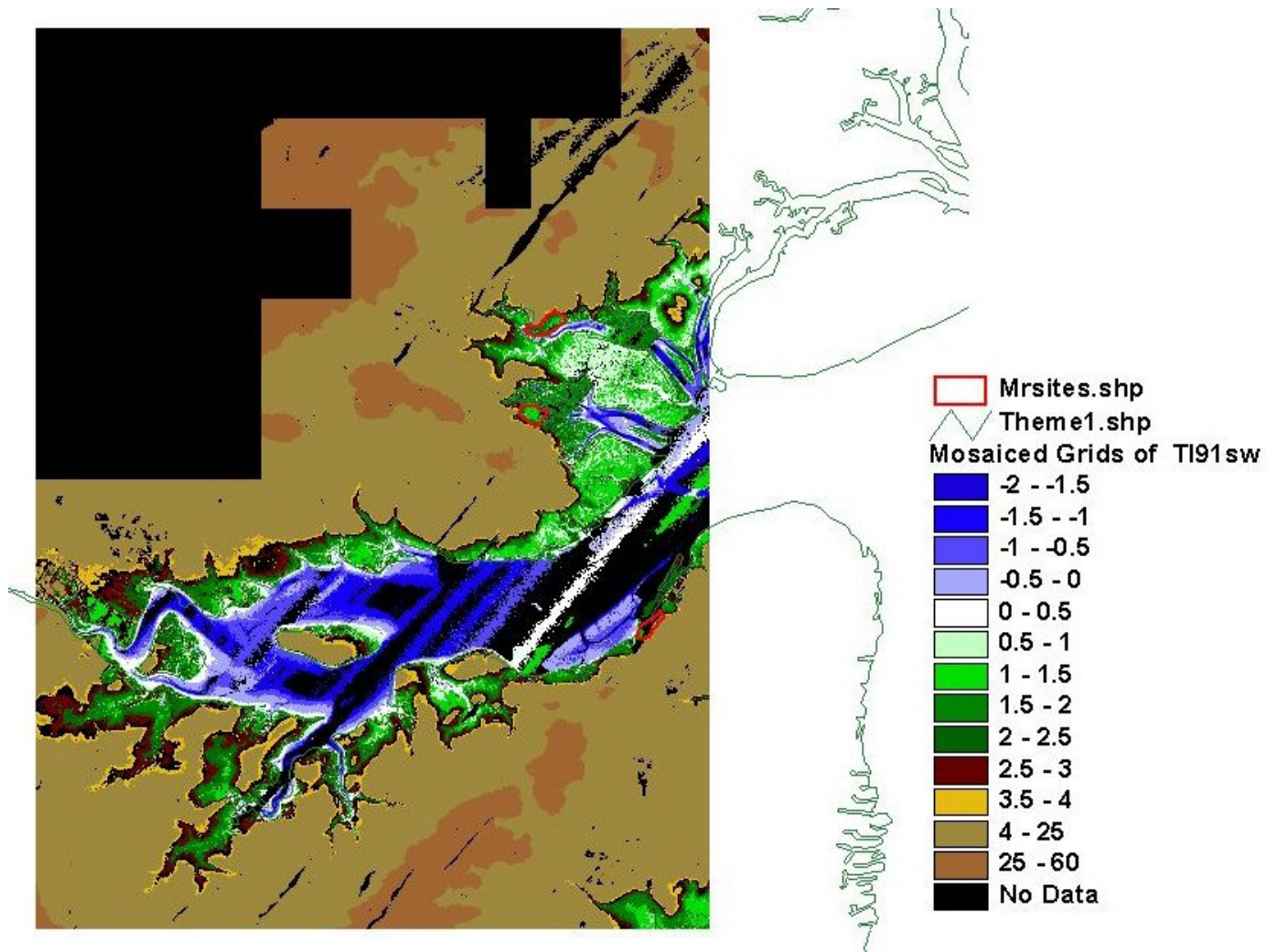
Figure 12: Habitat type predictions from elevation alone (whole estuary)
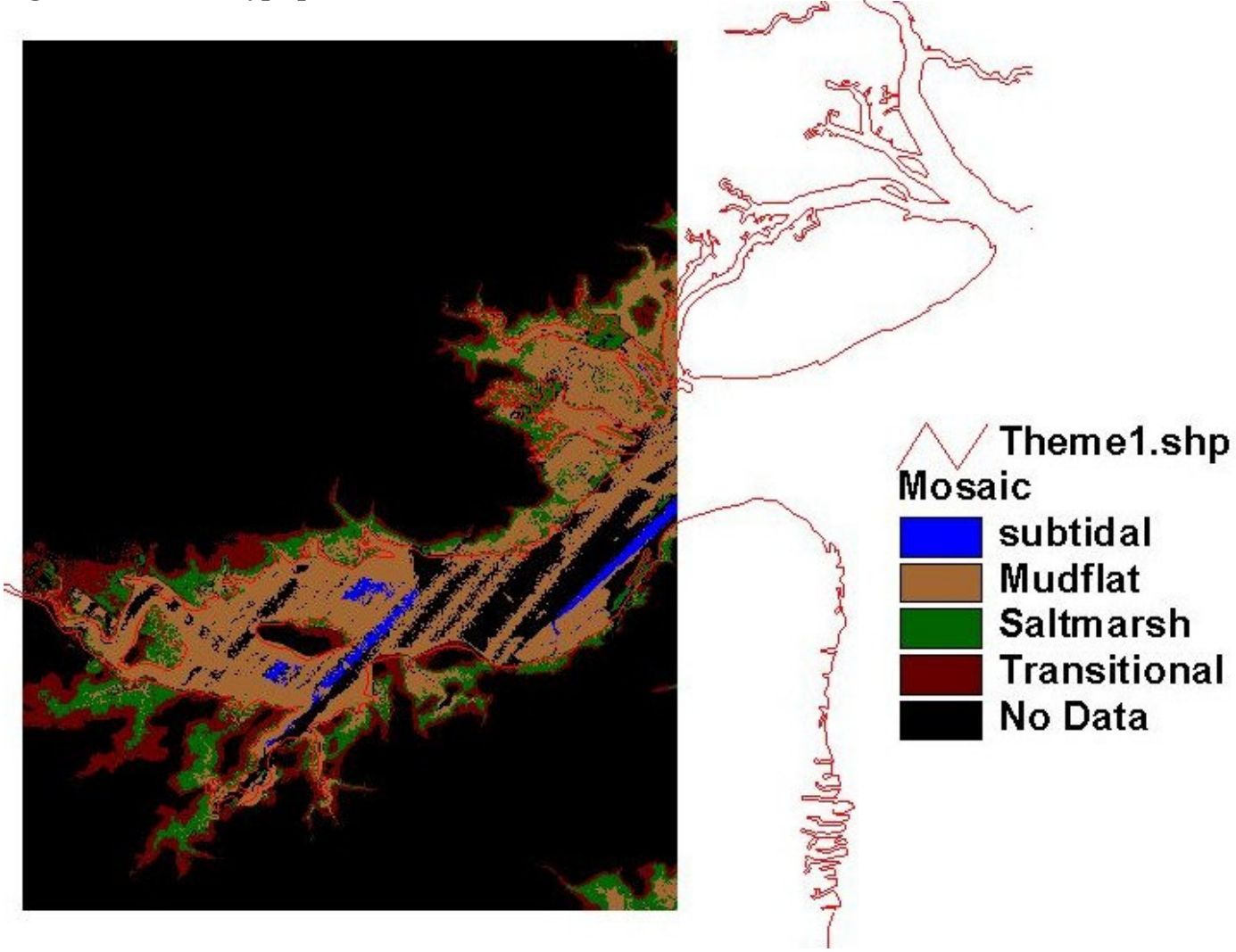
Figure 13: Habitat type predictions from elevation alone around the area of Tollesbury and Abbotts Hall managed realignment sites
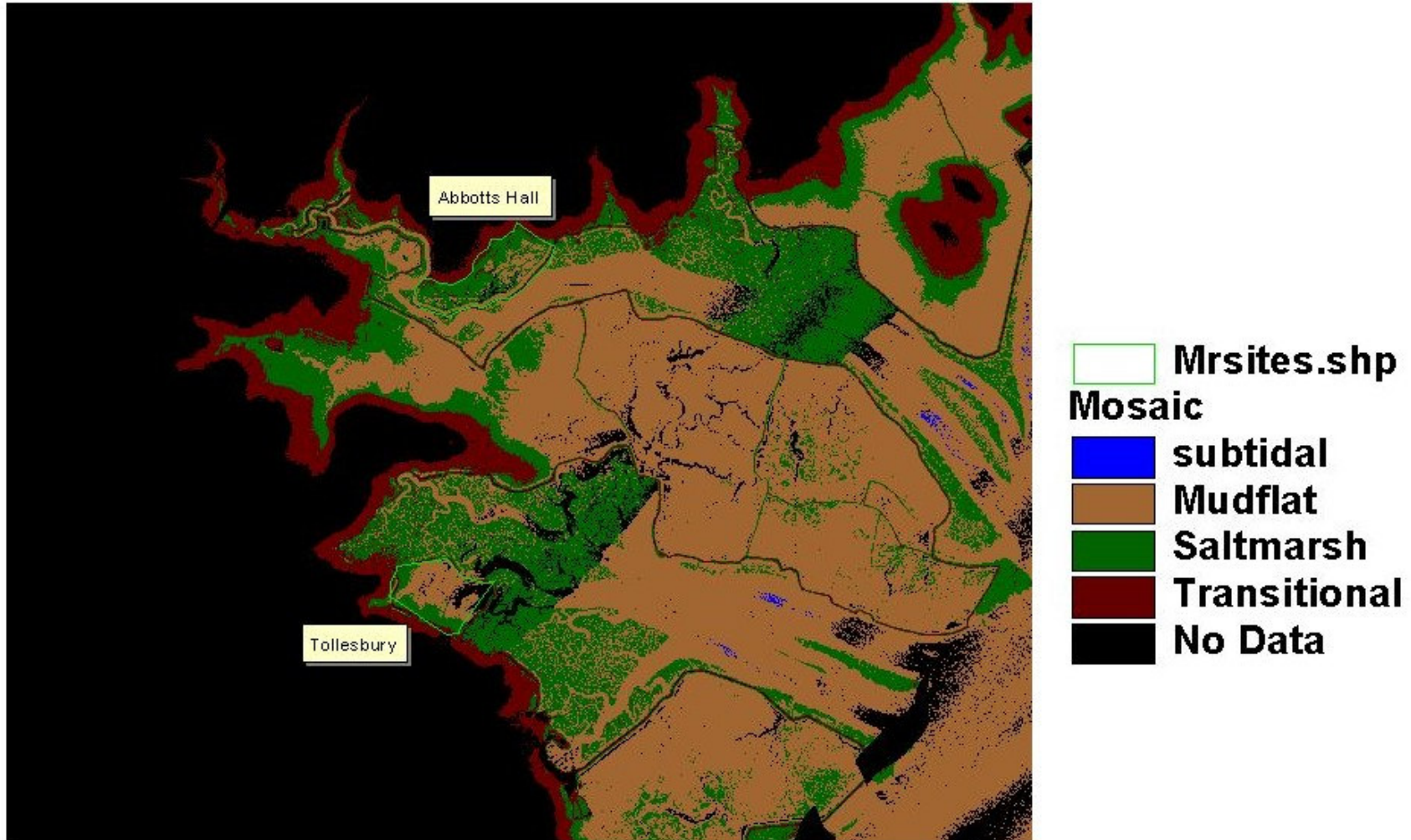
Figure 14: GIS layer of large-scale elevation suitability for saltmarsh habitat.
Areas with elevation that is unsuitable for saltmarsh are marked red and those that are suitable in terms of elevation are marked green.
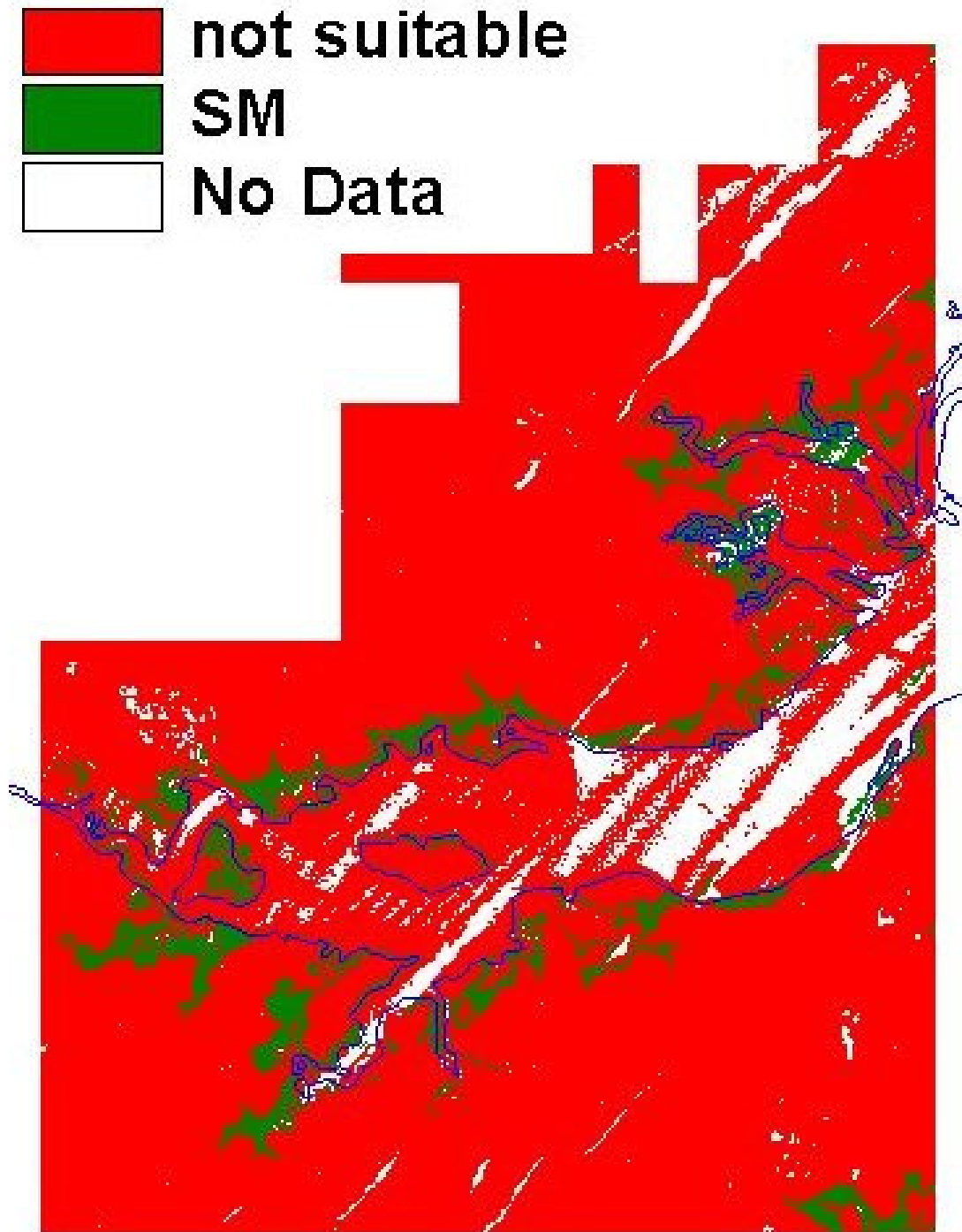
Figure 15: GIS layer of large-scale elevation suitability for saltmarsh and/or intertidal mudflat.

Areas with elevation that is unsuitable for either mudflat or saltmarsh are marked red and those that are suitable in terms of elevation are marked green.

2.2.2.2 Slope:

Figure 16 shows a suitability layer (theme) for site gradient (slope). The cells which fit the criteria suitability thresholds of 0 to 7% slope are coloured green (1), those that have steeper slopes are coloured red (0). This layer is used in the overall site selection composite. Figure 17 shows the distribution of slope in more detail from the optimum slope for saltmarsh (1-2% - green) to the medium suitability (2 to 7% - amber) and unsuitable areas (> 7% -red).
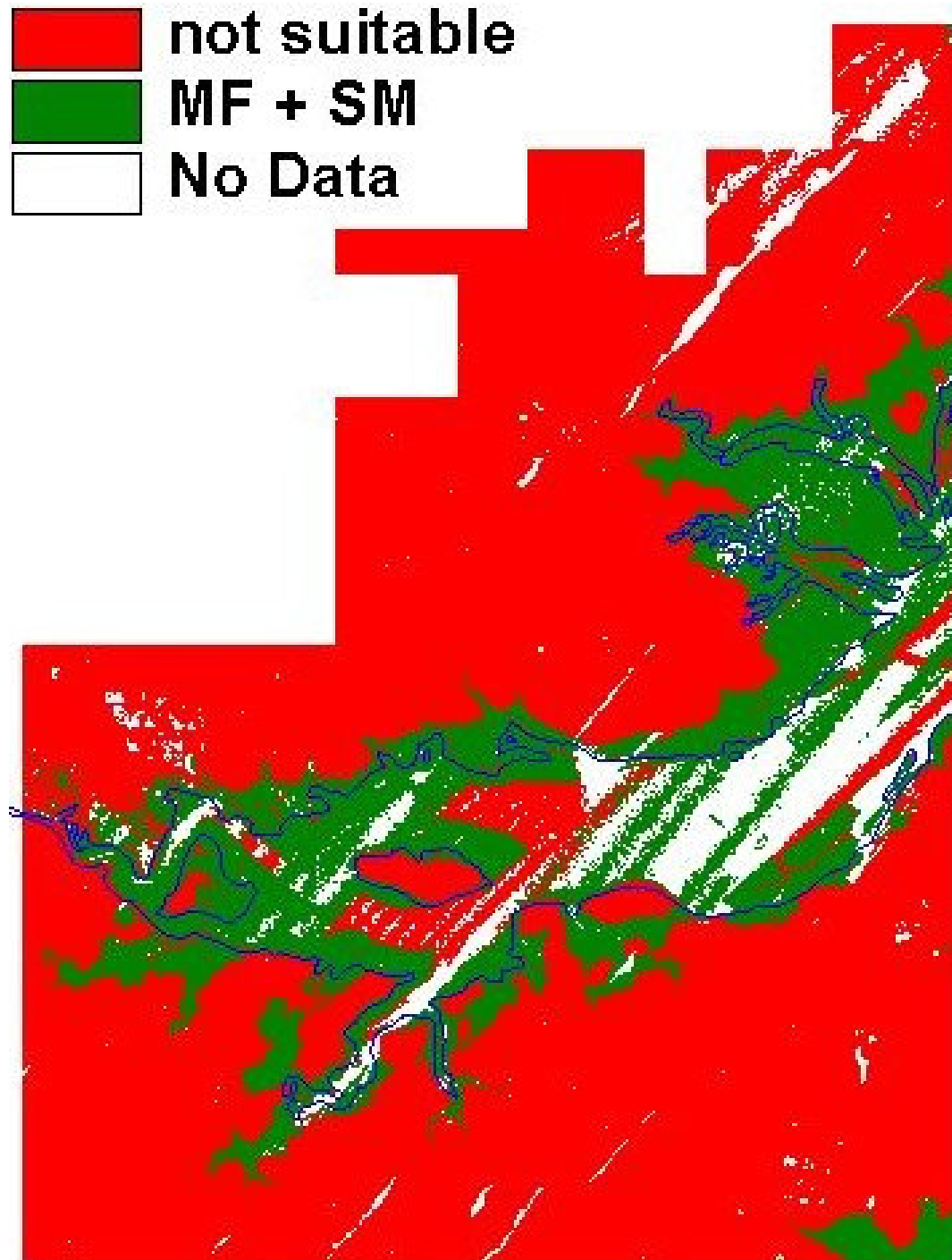
2.2.2.3 Proximity:
Figure 18 illustrates the nominal buffer of 0.5Km set around the mapped established saltmarsh in the Blackwater. This 'inclusion' area i.e. the area within the buffer is closer to an established habitat, is labelled suitable for habitat creation (green). Sites (cells) further away are deemed unsuitable using this particular filter (red).

2.2.2.4 Overview site selection:

The suitability layers (red/green) illustrated above are brought together in several ways within the GIS framework to screen the whole area for potential sites suitable for the creation of saltmarsh. Two methods are demonstrated here;

- Within the GIS framework using the map calculator to select cells which satisfy all the criteria as suitable in terms of threshold values (yes/no).
- Within the GIS framework to undertake limited derivative mapping which combines all suitability scores of a given cell into an overall index of suitability (0 to 1) as described in Figure 1 i.e. mean suitability.

Figure 19 shows the layer of selected cells which satisfy all the criteria in relation to elevation, slope and propagule supply for saltmarsh (derived from the layers presented in Figures 14, 17 and 18). The red areas are cells which do not have all the required conditions and the green cells are ones that do. It is clear that there is potentially a high number of sites suitable for saltmarsh creation. Comparison with Figure 14 of saltmarsh sites derived purely from elevation illustrates the areas that have been excluded (mainly due to unsuitable slope).

This approach could be expanded to identify sites suitable both for saltmarsh and intertidal mudflat by using suitability layers for all intertidal habitats (as in Figure 15) and also layers for suitability of slope and habitat proximity relevant to both saltmarsh and intertidal mudflat.

This methods identifies only sites that are suitable or not in terms of the criteria layers used. However, as is often the case, sites are not so clearly defined. The derivative mapping techniques enables the suitability of a site relevant to each criteria to be used and combined into an overall score so sites can be weighted in terms of likely suitability (0 to 1).

Figure 16: GIS suitability layer (theme) for site gradient (slope).
Suitability is determined in three categories, highest: 1-2% (green) , medium: 0-1 and 2-7% (amber), unsuitable: >7% (red).
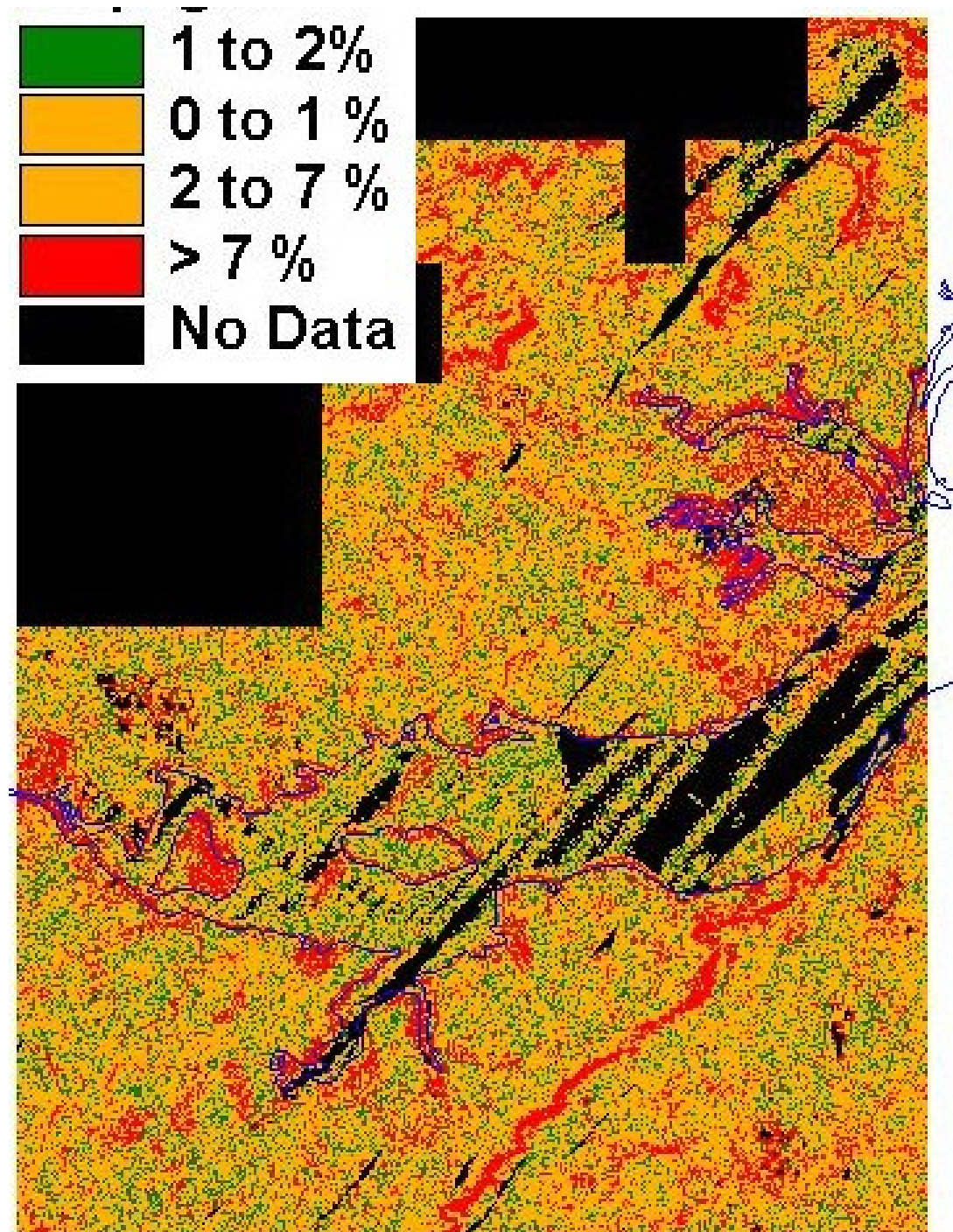
Figure 17 shows the distribution of slope in more detail from the optimum slope for saltmarsh
(Suitable slope is <7% - green, unsuitable is >7% - red)
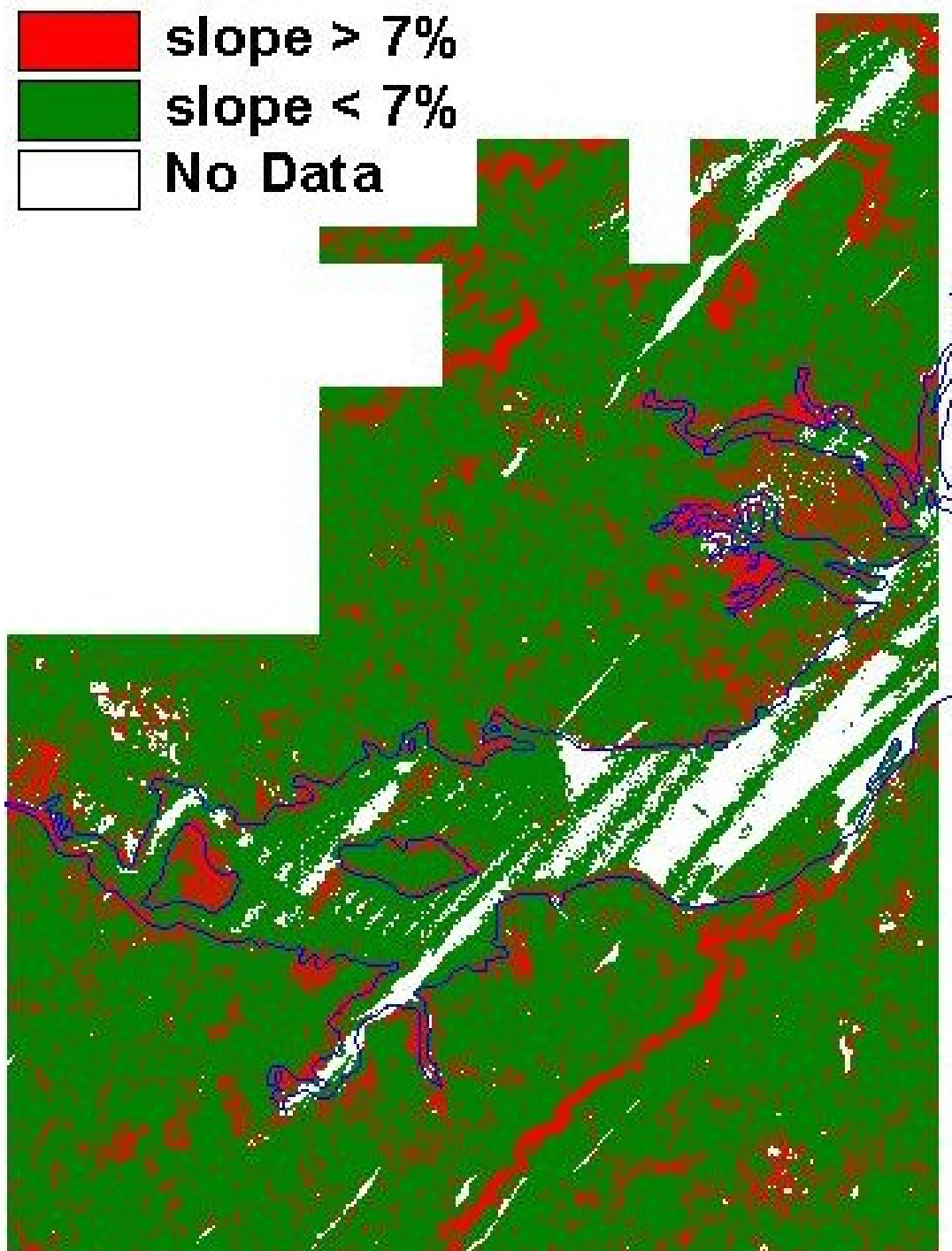
Figure 18: GIS suitability layer for saltmarsh proximity of 0.5Km set around the mapped established saltmarsh in the Blackwater.

The suitable areas which are <500m from established saltmarsh are marked green and unsuitable areas (>500m) are marked red.
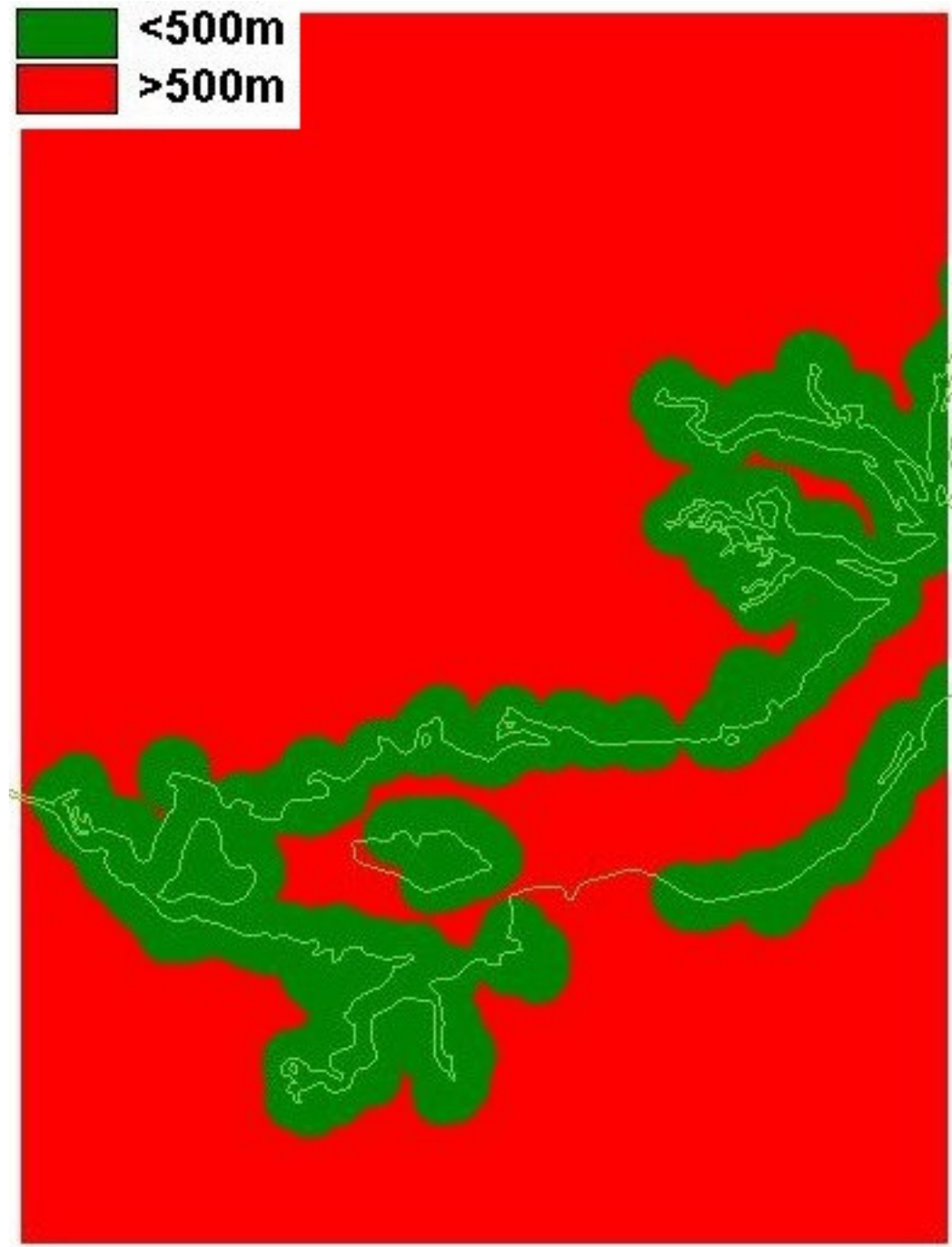
Figure 19: Saltmarsh sites identified from a composite of criteria layers (elevation, slope and proximity).

Suitable areas are marked in green and unsuitable areas are marked in red.
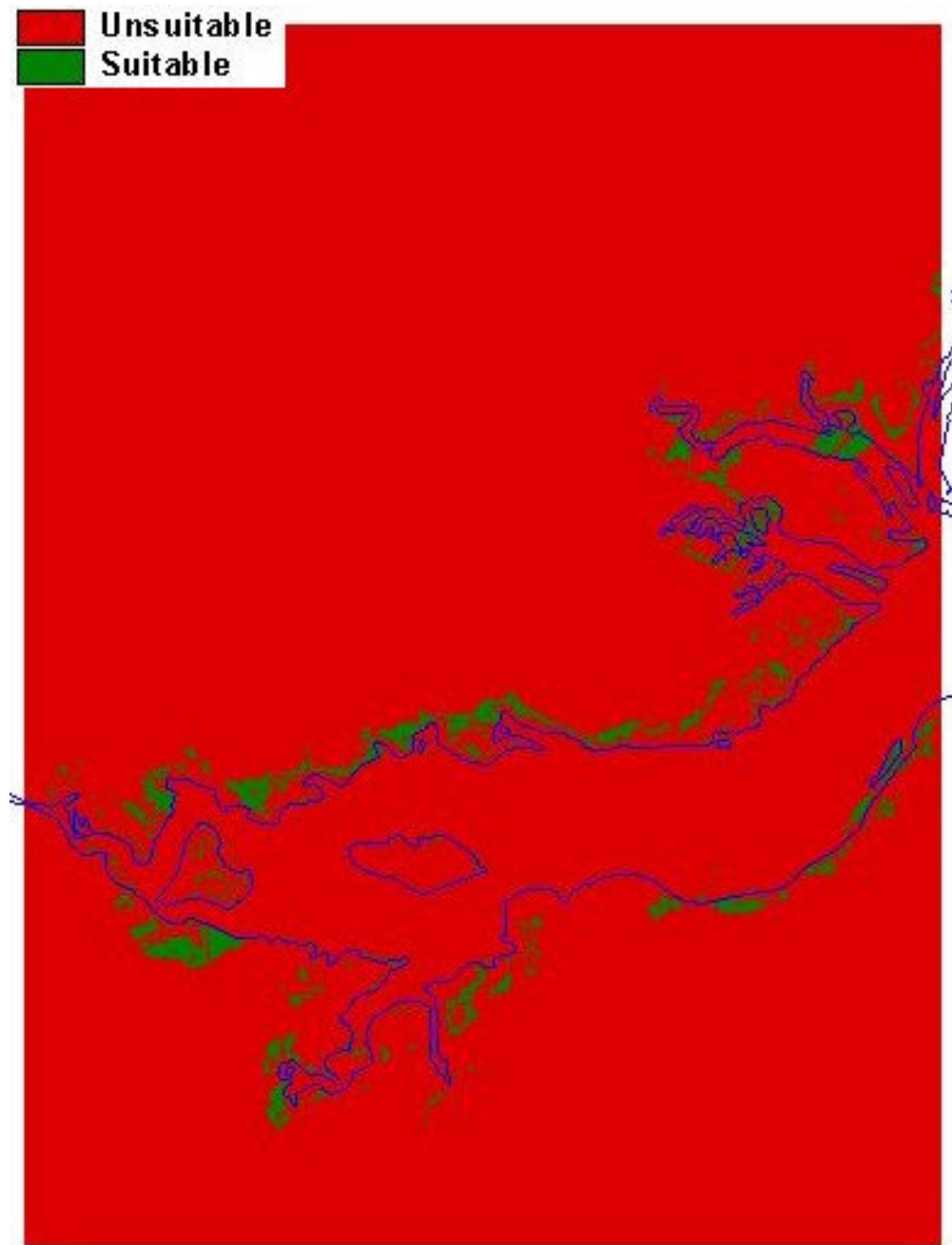
The overview of the derivative mapping approach (similar to a mean suitability) is illustrated in Figure 20. This provides more detail in terms of site selection by looking at sites that satisfy one, two or all three of the criteria used here rather than only all of them and so gives some idea of the spectrum of sites available. This would be useful when more criteria layers are used and there may be a range of suitable sites but for different reasons. This technique allows ranking of various sites (0 to 1) and also weighting of different criteria as in the influence diagram tool (although the weighting here is equal).

Figure 20: Saltmarsh sites and comparative ranking in suitability derived from elevation, slope and proximity layers but using derivative mapping/mean suitability.

Mean suitability (0-1)

	0 - 0.333
	0.333 - 0.667
	0.667 - 1
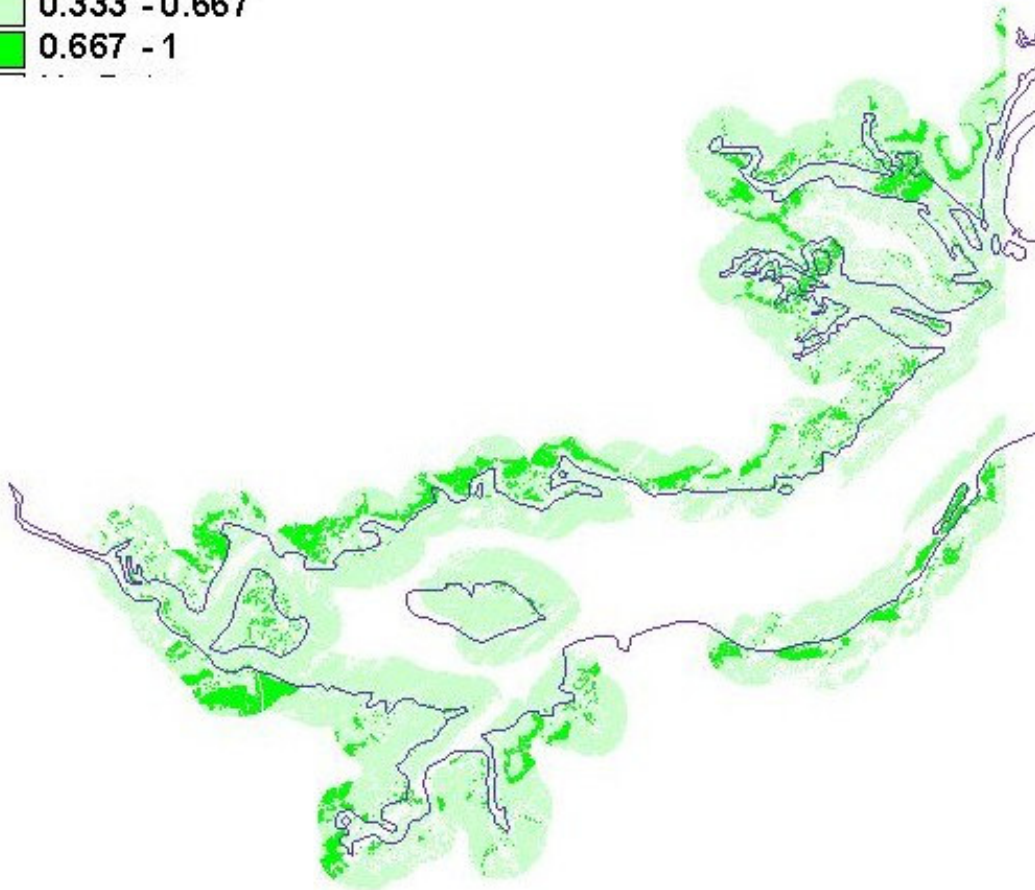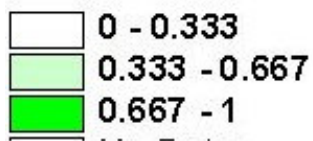
2.2.3 Testing:

Although this is a demonstration of a GIS approach it is important still to test the sites predicted to see if the tool is performing well. This can be done by looking at present managed realignment sites and also existing saltmarshes.

The test sites used in the Blackwater area were Tollesbury, Orplands and Abbotts Hall. Unfortunately, there was problems with LiDAR data over the bulk of the Orplands site but the areas within the site where data was good were identified as suitable for mudflat and saltmarsh habitats.

Figure 21 illustrates in more detail the areas around Abbotts Hall and Tollesbury where suitable sites were identified. It is possible to see that the two managed realignment sites are predicted as suitable, with saltmarsh towards the back of the Tollesbury site and also Abbotts Hall behind existing saltmarsh (stippled green areas). The area in front has been predicted to be intertidal mudflat. The band of apparently 'suitable' areas in a band across the two creek areas is due to poor LiDAR data as is clearly seen in Figure 22. With more time this data could be screened out to clarify the identified sites.

Figure 21: Close-up of predicted sites for saltmarsh in comparison to the test sites and existing saltmarsh habitat.
(suitable sites are marked in green and unsuitable sites are marked in red)

The screening tool rightly discards areas of present-day saltmarsh (mainly due to the unsuitability of the slopes) as these are not possible areas for site selection. However, Figure 22 shows the tool does identify sites generally adjacent to existing saltmarshes which gives more confidence in the tool predictions and using elevation alone saltmarshes are clearly visible. Testing against more sites would be helpful and would give increased confidence in the outputs. However, for a large-scale, first look at site identification the tool seems to perform well.

Figure 22: Predicted sites (green) for saltmarsh using elevation alone in comparison to existing saltmarshes.
(suitable sites are marked in green and unsuitable sites are marked in red)

2.3 Conclusions:

This demonstration GIS screening tool is capable of providing a rapid overview of potential sites for habitat creation (saltmarsh in this case). These sites can either, be identified as suitable or not depending on whether they satisfy a range or criteria, or can be ranked in relation to their mean suitability (derivative mapping) against the same criteria. Either method provides a short-list of sites to be tested using the influence diagram tool on a site-by-site basis.

The extent of the complexity of the derivative mapping performed here was limited to some extent by the lack of scientific information which could define the habitat/ criteria/threshold relationships. As knowledge of the controlling factors improves this can be improved. At present the site suitability as determined here by three criteria of which elevation is probably the most significant factor. As more criteria are added into such a tool it is possible to alter weighting of each criteria to give more realistic assessments as is done in the site-by–site model presented in Section 3.0 of this report.

This demonstration was designed to illustrate the GIS approach in terms of a broad scale tool for site selection. Although, given the testing, this tool seems to be doing a good job there are several things that should be noted in terms of limitations and application;

- The accuracy of the LiDAR elevation data is variable both spatially and vertically which can lead to errors in boundary designations which must be appreciated. As can be seen in some of the tiles in the Blackwater there is also errors in terms of poor return data or over water which must be identified and discarded. However, for this application it is fit for purpose and alone or combined with other criteria it provides a good overview for short listing of sites.

- Given some time and data availability (digital or spatial information) constraints this demonstration only included three layers of criteria for habitat creation. Site determination would be improved given the addition of more criteria layers.

- Application of this procedure in other geographical areas will require some adaptation of criteria and thresholds. For example the height of MHWS relative to mOD is not the same everywhere. The relevant levels can be found in the Admiralty Tide Tables. Similarly, in a given estuary or coastal location the criteria thresholds used here may be different and end-users should refine the GIS tool to the area they are working in terms of habitat of interest or habitat distributions.

- Resolution is an issue that must be addressed initially not only in terms of the data required, grid size of GIS layers, computing time but also the detail of site differentiation required. In this case the grid size was determined by the grid size (2 x 2m) of the original LiDAR data.

- This demonstration has illustrated various levels of complexity and scale which can be utilised in GIS to aid site selection. At simplest can be used to map elevation as a main forcing factor for habitat creation with legend changes to indicate predicted habitat type. At most complex it can be used to identify and rank sites for suitability by combining various layers of information on controlling criteria. Each approach has associated implications for time and resource needed and the precision of output. An end-user will need to match the complexity required to the purpose and resource available.

- Use of GIS and the selection or deselection of sites needs to be critically applied throughout. This demonstration provides a good 'first-cut' for site identification and many sites here were deselected in terms of inappropriate slope variability (i.e. existing saltmarshes). The accuracy and uncertainty of each layer needs to be understood so weighting can be appropriately applied and also the selection/deselection of sites can be fully understood.

2.4 Future developments and applications:

This overview was provided using criteria specifically targeted towards the physical, chemical and ecological controlling factors of habitat creation. However, although these and the other criteria in the reviews may identify many suitable sites, in actuality other socio-economic, political or logistical constraints may restrict the number of choices even further. The GIS framework is flexible enough that given site selection on this basis it is possible to add further layers which can aid filtering from other perspectives such as grade of coastal defence, Ordnance Survey spatial data (roads, footpaths) agricultural land grade, land availability, strategic plans, conservation restrictions i.e. SSSIs, SACs etc. A GIS framework can deliver a perspective on the bigger picture not only in terms of scale but within objectives of strategic coastal plans. It is important to look at this large scale as an initial process of identifying potential sites within the context of long-term development of an estuarine or coastal system.

The availability of digital spatial data is always an issue in this type of GIS work. However, initiatives are underway that are aimed at improving access to GIS terrestrial and marine data (Coastmap - http://www.cefas.co.uk/coastmap/ ; FutureCOAST - http://www.abdn.ac.uk/geospatial/agi/future/index1.htm ; ICZMap - Integrated coastal zone –data research http://www.iczmap.com/) and resolving issues on datums, scale, projections and common coastline etc., will facilitate the future use of GIS in coastal management decision-making.

As scientific understanding of the relationships between controlling factors, site characteristics and habitat creation improves and becomes more quantitative, improved and more complex modelling of potential sites will be possible. Under these circumstances GIS and associated mapping tools will become more powerful and can be linked to other assessment tools or models to aid site selection (Socio-economic, hydrodynamic, morphological etc) such as has been performed by Coombes (2003), Frost et al., (2004) and Hanslip (2003) in the Humber. Whatever developments are made within GIS to aid site selection there will still be the need for robust understanding of how sites are selected/deselected and a detailed site-by-site assessment as is demonstrated in section 3.0 of this report.

3.0   Influence Diagram Model Report

3.1 Aim and approach:

This influence diagram model is targeted to habitat creation criteria. It has been developed from the outputs of 'Suitability criteria for habitat creation – Report I' (R&D Technical Report: FD1917). The report facilitated the identification of parameters (criteria) and relevant limits describing potential realignment sites with regard to habitat creation. These outputs provide the basis for the influence diagram habitat area and suitability calculations.

There are a variety of existing tools and guides available to aid site selection for habitat creation purposes. English Nature's 'Coastal Habitat Restoration – Towards Good Practice' website provides guidance on 8 habitats (http://www.english-nature.org.uk/livingwiththesea/project_details/good_practice_guide/habitatcrr/ENRestore/home.htm). English Nature's Lappel Bank and Fagbury Flats Compensatory Measures project (ABPmer, 2002) involved a multi-criteria analysis for site selection and suitability. Halcrow have developed an 'Evaluation of Potential Re-alignment Sites' Matrix with tick boxes for a variety of criteria. The influence diagram model attempts to provide a more generic tool that can be tailored and expanded.

The model is intended to act as a guide to assessing a site for potential suitability for habitat creation. One generic model cannot answer the myriad questions likely to arise from the unique set of circumstances surrounding each site, but the model has the potential to be adapted to individual sites, and to be expanded and developed as criteria are more accurately parameterised with future research. It helps steer the user towards the type of data needed to meaningfully investigate a potential site and to identify the most important factors in generating new saltmarsh, intertidal flats or eelgrass (*Z. marina*) habitat. Throughout the model the term 'mudflats' has been used to refer to all types of intertidal flats – although mudflats are the most common in the UK As research moves forward and criteria are parameterised more accurately the model can be expanded or the qualitative descriptors made more quantitative to improve accurate prediction of habitat creation.

Initially, a list of 38 criteria of potential importance for habitat creation was brainstormed and a mind-map diagram was developed to illustrate the complex interaction between only those physical components identified (Appendix I, Figure 32). This highlights some of the many issues that may need to be considered in a managed realignment project. In order to address some of these, resources will likely need to be allocated for further site-specific investigations to better understand site conditions and the potential habitat created. During the research phase of the project it became apparent that many of these criteria could not be satisfactorily parameterised with existing research data, other than at a site-specific level, or that the scientific evidence was not sufficiently robust to give a clear response. A tool for site selection needs to be more generic; i.e. more widely applicable to many sites. As a result 11 common criteria were identified as key controls in the suitability of a site for habitat creation; these are incorporated into the model and summarised in Table 5. They take the form of a choice of descriptive options rather than quantitative values. The descriptors are assigned values within the model in the range 0 – 100, with 0 as unsuitable and 100 as completely suitable. The 11 criteria have generic applicability

to site selection, and it is incumbent upon the users of the model to adapt, refine and assign weightings to these in line with available data, and to identify and incorporate other site-specific

Table 5: Influence diagram model; (a) site parameters for calculation of habitat areas, and (b) suitability criteria, options in model, suitability calculations and thresholds

5(a)

Site parameters	Units	Calculation
Length of site	**Metres**: Length of site along shore, parallel with waterline.	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.
Width of site	**Metres**: Width of site across shore, perpendicular to waterline.	
Mean High Water Springs (MHWS)	**Metres**: Saltmarsh=MHWS - MHWN Intertidal flats = MHWN - MLWS, Eelgrass* = <MLWS. Either Ordnance Datum (OD) or Chart Datum (CD) - All data in any model run must be consistent to the same Datum.	Inundation controls the type of habitat it is possible to create on particular areas of a potential site. 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 intertidal flats 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 intertidal flats. This does not take account of the splash-zone about MHWS where a transition between saltmarsh and grassland may develop.
Mean High Water Neaps (MHWN)		
Mean Low Water Springs (MLWS)		
Mean Low Water Neaps (MLWN)		
Mean elevation	**Metres**: Mean elevation of site to OD or CD (see above).	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. 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.
Mean slope	**Ratio** of 1:*x* e.g. Saltmarsh 1-2% (1:0-1:64) ideal but 0-7% (1:0-1:18) possible*	

* Eelgrass is to be used to refer to *Zostera marina* and not intertidal species

5(b)

Criteria	Options in model	Suitability calculation	Threshold
Is the land polluted?	Yes/ No	If **Yes** then 'needs detailed appraisal' appears. If **No**, then 'contamination is absent'.	Levels should be within the Environment Agency's published guidances on contaminated land, and the local authority's Contaminated Land Register may provide further information on specific sites.
Light Climate	Limited light penetration / High light penetration	Limited penetration = 0 High penetration = 100	Eelgrass (*Z. marina*) habitats are very sensitive to suspended solids and low turbidity; high light environments are essential to establishment. If there is strong light attenuation eelgrass habitat will not establish even if other criteria are suitable. Presence of eelgrass immediately adjacent to the site indicates high light environment.
Water salinity	<18 / >18	>18 = 100 <18 = 0	Although there are ideal salinity ranges for individual species, generally below 18 halophytic plants will not establish.
Water Quality	No pollution/ Within acceptable limits/ Unacceptable	No pollution = 100 Within limits = 50 Unacceptable = 0	Eutrophication suggests unacceptable water quality for habitat creation. 'Acceptable' Water Quality will be within EA standards. 'Unacceptable' will be outside EA standards.
Eelgrass propagules supply to site	Adjacent source/ Distant source	Adjacent source = 100 Distant source = 0	Eelgrass communities usually spread vegetatively and unless established habitat is immediately adjacent new habitat is highly unlikely to create on the new site.
Saltmarsh/ intertidal flats; propagules, larvae & invertebrates	Adjacent source/ Distant source within range/ Distant source out of range	Adjacent source = 100 Distant, within range = 50 Distant out of range = 0	Adjacent (within the same estuary or along the same stretch of coastline) sites with established saltmarsh or intertidal flats habitat are likely to provide biology (propagules and larvae or invertebrates) that will 'kick start' habitat creation, if the transport direction is appropriate. May vary between coastal and transitional sites and with season; e.g. in Saltram, Devon the nearest substantial saltmarsh was >10 km away, and new habitat created at the breach site.

Habitat Location	Muddy estuary/ Sandy estuary/ Open coast with adjacent habitat/ Open coast without adjacent habitat	Muddy estuary = 100 Sandy estuary = 25 Coast with habitat = 100 Coast without habitat = 0	Muddy estuarine locations are most suitable, as they are likely to be more sheltered and allow accretion to take place. Sandy estuarine locations are less likely to accrete even when sheltered. Open coastlines are often exposed, limiting habitat creation. However, existing habitat adjacent to a proposed coastal location indicates likely success of a new site with similar location.
Exposure	High exposure Moderate exposure Low exposure	High exposure = 0 Moderate exposure = 50 Low exposure = 100	New habitats are most successful in sheltered locations. High-energy areas close to the breach in the seawall or in creeks of significant size, disturbance of the seabed surface may prevent colonisation of vegetation. Deposition of fine sediment and flora seeds in the more quiescent areas of the realignment site promotes vegetation growth.
Connectivity inside site	Good/Poor	Good = 100 Poor = 0	Connectivity estimates how uniform or contiguous are the low areas of the site. Good connectivity means low-lying areas connect and drain. Poor connectivity means low-lying areas at the rear of site remain wet and ponding occurs.
Freshwater flows	High/Low	High = 0 Low = 100	Freshwater can be a pollutant to saltmarsh/halophytic plants and eelgrass habitats by influencing salinity. Freshwater inflows to the site may decrease the salinity and increase extent to which the site is waterlogged/submerged.
Bed stability	Strong/firm, or Weak/friable	Strong/firm = 100 Weak/friable with low exposure = 50 Weak/friable with Moderate exposure = 25 Weak/friable with high exposure = 0	Bed Stability includes strength and resistance to erosion. Strong or firm means firm sediment, e.g. soil compressed by livestock, and is valued as suitability of 100. Weak loose, friable soils are more at risk of erosion (especially if the exposure is high) and are valued as suitability of 0.
Soil type	Sandy/ Clay/ Clay loam / > coarse sand	Clay loam is the most suitable grain size to retain carbon (suitability 100)	Saltmarsh and intertidal flats will establish on sediment size less than coarse sand. Suitability 75 for clay, 50 for sandy soils and 0 for coarser sediments
			Eelgrass prefers firm sediment and not extremes of fine clay or coarse sand. Suitability is 50 for sandy soils and 0 for coarse sediment or clay.
ALL CRITERIA	*All criteria have a 'no data' option*	*0 suitability*	*Selecting 'no data' limits the ability of the model to predict suitability of a site for habitat creation and will reduce the calculated suitability value.*

criteria. In this way the influence diagram model is tailored site-by-site and becomes capable of predicting results more precisely. Consequently, it acts as an effective audit trail.

The success or quality of a habitat may be defined in several ways and are difficult to quantify or predict. In part, quality is dependent on the drivers behind the attempted habitat creation and its intended purpose. Also quality will change over time as a site becomes more established. In the short term the best guide to the likely quality that can be achieved is to investigate an adjacent, established habitat's quality. Habitat can be monitored for such change and the Habitat quality measures and monitoring protocols (DEFRA/EA, 2004) report provides further detail on this.

3.2   Using the influence diagram model

In order to run the model Analytica software needs to be installed: http://www.lumina.com/software/influencediagrams.html. The software can be downloaded free from http://www.lumina.com/reg/AnaTrialReg.htm Once installed the software will allow the user to browse and edit the model or to create new models, for 30 days. Once this period has expired only the browse mode is available unless the software is purchased from Analytica.

Once using the model the hand symbol from the tool bar at the top of the screen will be highlighted. In this, the browse mode, site-specific data may be input and habitat areas and site suitability calculated, as directed in the following sections. Once familiar with the model the user can switch to the edit mode, to adapt the model and make it more specific to the site under investigation; e.g. by incorporating more criteria, expanding the descriptive choices within criteria or by altering calculations and equations (Section 3.4).

3.2.1 Opening screen

INTRODUCTION
Welcome to the Habitat Suitability Influence Diagram.

This Influence Diagram aims to aid calculation of potential saltmarsh, intertidal flat and/or eelgrass habitat, based on inundation information.

Inundation is calculated from length, width, tidal heights, slope and elevation data entered by the user (Screen One).

In Screen Two further site criteria may then be entered to calculate the suitability of the site for habitat creation on a scale of 0 (no suitability criteria met) to 100 (all suitability criteria met). These criteria may be weighted in importance relative to each other. In Screen Three the user may grade their confidence in their data as 'high', 'moderate' or 'low'.

ENTER

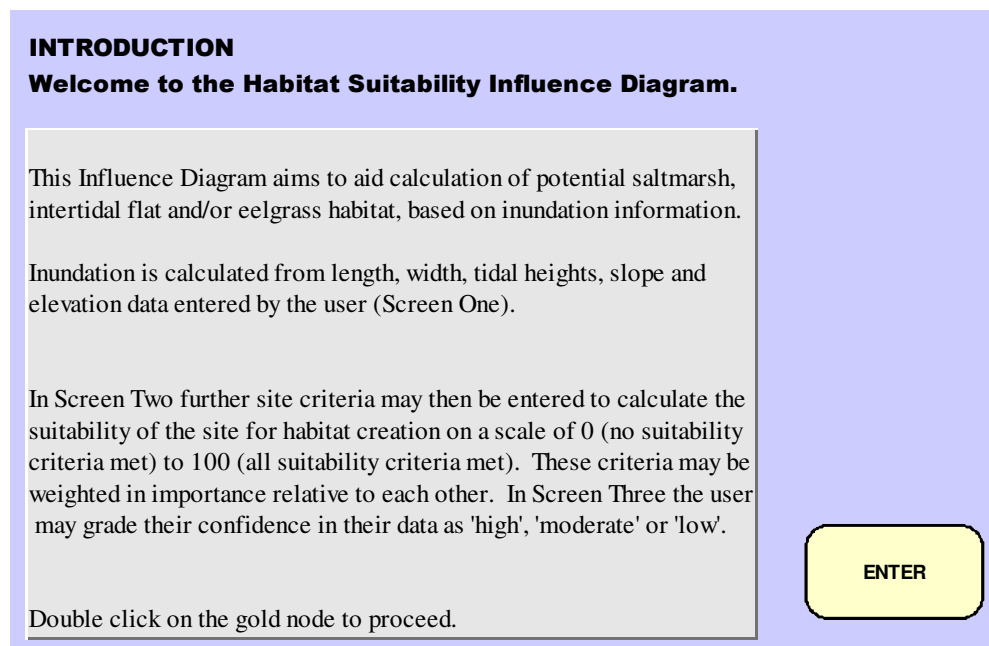Double click on the gold node to proceed.

Figure 23: Opening Screen – Influence Diagram

The first screen of the model (Figure 23) is a brief introduction and the user may read the information and proceed to the MAIN SCREEN by double clicking on the ENTER node.

3.2.2 Main Screen

The user will find they return to this screen (Figure 24) at each stage of using the model. It contains the access nodes (gold) to screens requiring data entry. Following data entry in each screen (gold nodes One, Two and Three) results are calculated in the Main Screen, by clicking on the pink 'calc' buttons.
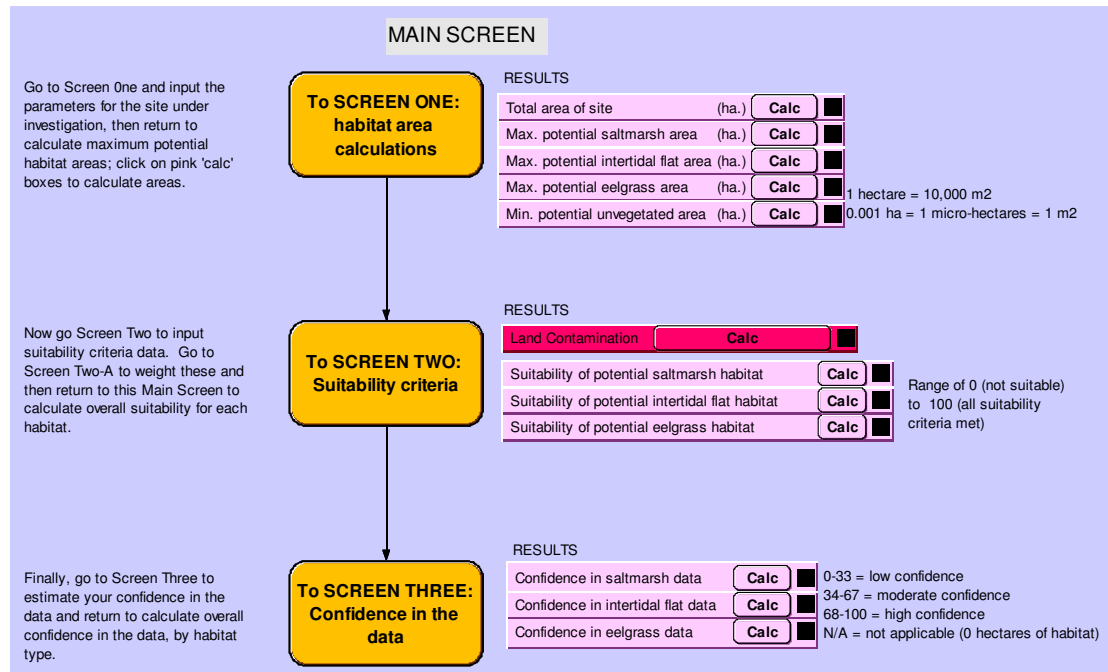

Figure 24: Main Screen – Influence Diagram

3.2.3 Screen One: habitat area calculations

Throughout the model the term 'mudflats' has been used, but this refers to all types of intertidal flats – although mudflats are the most common in the UK.

Few sites are truly rectangular in shape, but the model requires data to be input in this form (Figure 25). It may be appropriate to sub-divide a site into roughly rectangular sub-areas and to run the habitat area calculations of the model for each sub-area. If other precise data are available for sub-areas of a site, e.g. LIDAR elevations or slope gradients, then separate model runs for each one will more accurately predict the maximum potential habitat area as a sum of each sub-area's potential habitat extent.

Figure 25: Habitat area calculations – Influence Diagram

Throughout the model green boxes require the user to input data, either as a numeric value or by choosing from drop-down boxes.

NB: Double-clicking on a green box reveals a parameter's description, definition and the units required (Figure 26). 'Outputs' lists the other parameters and/or criteria influenced by this parameter. All parameters and criteria should be investigated in this way before data are input into the model.

Figure 26: Example of parameter or criterion definitions – Influence Diagram

3.2.3.1 Length and Width of site

Allow calculation of total site area and maximum potential area of each habitat type. These parameters will not determine the suitability of a site; they are simply dimensions from which the estimated proportions of saltmarsh/intertidal flats/eelgrass can be calculated, based on inundation (see Table 5 for more detail). Data are input in metres.

3.2.3.2 Slope

A site is likely to consist of a series of sub-areas with varying slopes. In this situation the model may be run separately for each sub-area to give a more accurate prediction of potential habitat area. For a first-cut rough approximation the model may be run with one mean slope for the whole site. The model is simplified by assuming slope is downwards from land to water's edge. It may be possible to alter the slope of a potential site by recharge or excavation. The long-term sustainability of this is unpredictable within the framework of this project. Slope has a direct influence on both inundation and habitat type.

Data are input as a ratio of 1:x, e.g. 1:400.

3.2.3.3 Elevation

Mean elevation and mean slope gradient allow calculation of inundation area. It may be possible to alter the elevation of a potential site by recharge or excavation. The long-term sustainability of this is unpredictable within the framework of this project. Values may be referenced either to Chart Datum (CD) or Ordnance Datum (OD). The same datum must be used consistently for each model run.

3.2.3.4 Mean Spring and Neap Tidal Heights

Site elevations at the seaward and landward edge are calculated from width of slope, mean elevation and mean slope gradient. The area calculations are based on these elevations and the extent of inundation between tidal heights. Tidal height data must be in metres referenced to either CD or OD. Habitat areas calculations are based on the inundation required by each habitat type. It should be stressed that the separation of habitat zones based on inundation (e.g. into saltmarsh between MHWS and MHWN) is a simplification. These are gross figures and do not take account of any suitability criteria. 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.

Once data are entered in the green boxes the user may either view the model of area calculations (double click on the yellow node), or return to Main Screen and display calculation results. Closing or minimising Screen One performs the latter. The areas are displayed in hectares (ha.). Figure 27 is an example of the input data for Frieston in Screen One and the calculated maximum potential habitat area in the Main Screen. The model calculates this site as only suitable for saltmarsh habitat (in fact this is the only habitat which established).
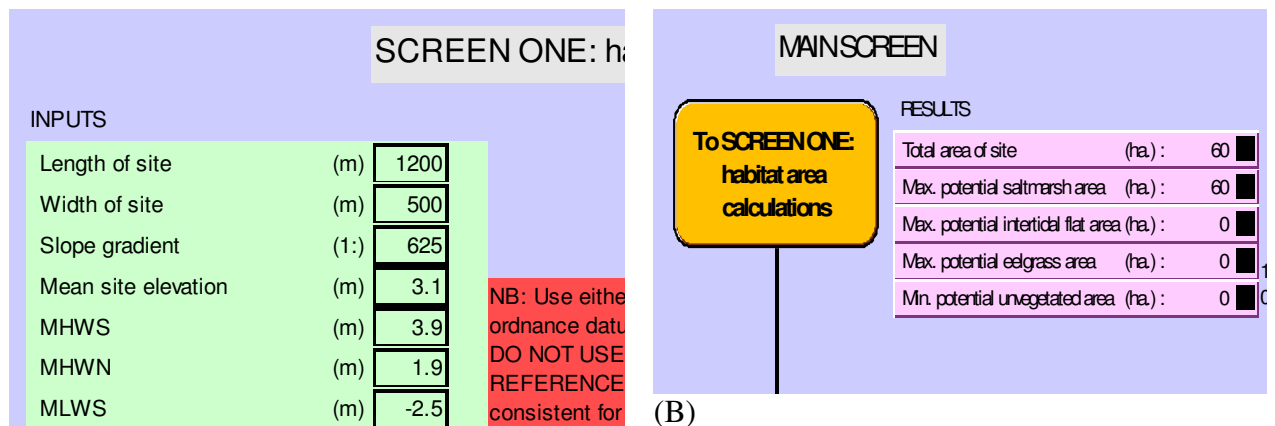
Figure 27: Frieston, The Wash example: (A) Input data in Screen One; (B) Habitat area calculations in Main Screen

The calculations of habitat areas are included here for completeness:

- Total Area = Length of site x width of site
- Saltmarsh area = Length of site x (width to MHWS - width to MHWN)
- Intertidal flats area= Length of site x (width of site to MHWN - Width of site to MLWS)
- Subtidal eelgrass, *Zostera marina** area = Length of site x width of site to MLWS
- Unvegetated area = Length of site x (width of site - width to MHWS)

* Eelgrass species are highly sensitive and there is no guarantee they will establish within the identified sub-tidal area. As yet there appear to be no examples of managed realignment sites that have included creation of habitat suitable for eelgrass in their objectives. Eelgrasses predominantly spread vegetatively so potential new subtidal habitat sites need to be directly adjacent to existing eelgrass beds. 'The World Atlas of Seagrasses', Green & Short may be a useful start-point for locating eelgrass beds near potential habitat creation sites (http://www.unep-wcmc.org/marine/seagrassatlas/index.htm), or 'Atlas of the British Flora', Perring & Walters, 1962 (see Appendix II, Figure 33).

Intertidal eelgrass can grow between mid and low tidal heights, from above MLWN sometimes to MHWN (*Z. angustifolia*), or up to approximately MHWN above the low tide mark (*Z. noltii*). However, intertidal *Zostera* is unlikely to grow in the presence of saltmarsh as *Spartina anglica* and *Sargassum muticum* grow at similar elevations and usually out-compete *Zostera*, preventing good colonisation.
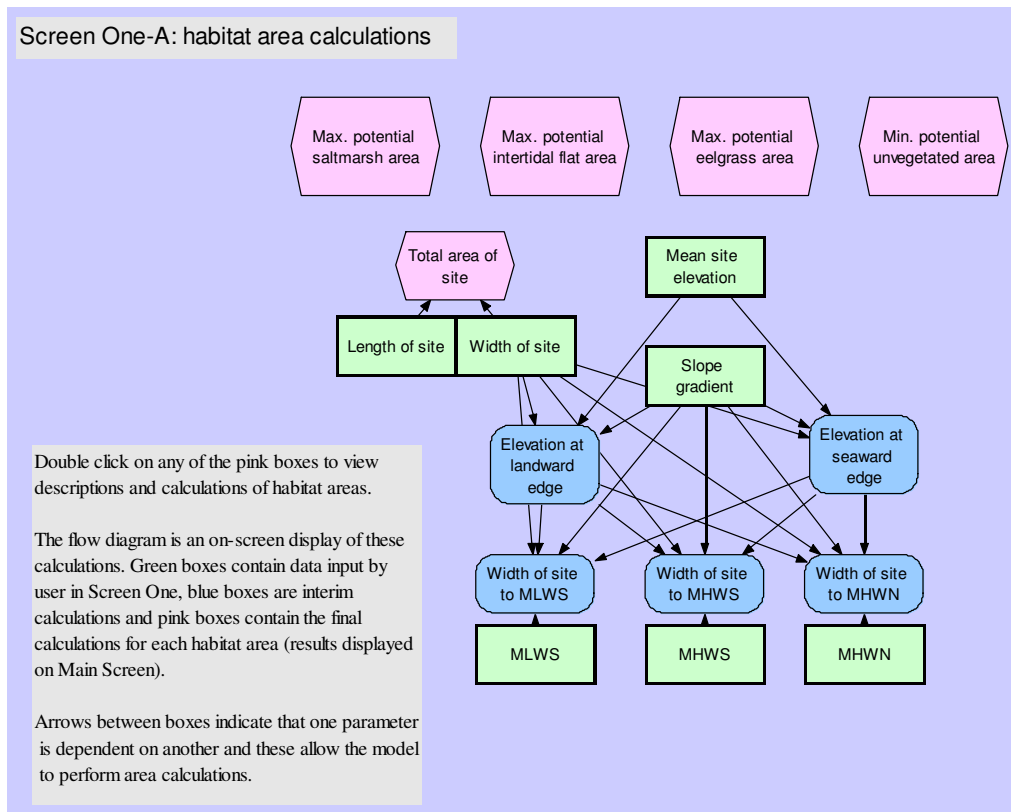
3.2.3.5 Model of area calculations

Figure 28: Model of area calculations – Influence Diagram

Double-clicking on the 'Model of area calculations' node in Screen One displays the model diagram (Figure 28). There is no requirement for the user to enter this node, as data do not need to be input in this screen. The model uses the various parameters and their inter-dependencies (black arrows) to perform area calculations.

NB: Double-click on any coloured box (pink, green or blue) to view descriptions and definitions/calculations.

Close or minimise Screen One-A and then Screen One to return to the Main Screen, and calculate habitat areas by clicking on the pink 'calc' buttons.

3.2.4   Screen Two: suitability criteria

Figure 29: Screen Two – Influence Diagram

In Screen Two (Figure 29) 11 suitability criteria have drop-down boxes for the user to choose the most appropriate descriptor for the site under investigation.

3.2.4.1 Land Pollution

Double-click on this red box read a detailed description of contaminants, pollutants and how best to judge the extent of land pollution at the site.

The Environment Agency (EA) publishes Soil Guideline Values and fact sheets on contaminated land and also Groundwater and Contaminated Land publications: www.environment-agency.gov.uk/subjects/landquality/. The EA's Contaminated Land Exposure Assessment (CLEA) provides guidance on potential risk of land to human health and also a local authority is likely to hold a Contaminated Land Register. These should be referred to when assessing a potential site. In the model Land Pollution may be selected as 'No' if contamination is absent or within recommended guideline values, or 'Yes' if contamination is elevated. This criterion is not part of the suitability calculation, as some toxics may be rendered inactive in estuaries. Instead the comment "Land contamination needs detailed appraisal" is flagged on the Main Screen if contaminants are present.

Combinations of the following criteria are used to calculate suitability of a site for saltmarsh, intertidal flats and eelgrass (*Z. marina*) habitats. In the model qualitative statements for each criterion are transformed into a value between 0 and 100 (see Table 5b). In all cases 'no data' defaults to 0. These values are then combined along with criterion weightings (see below) to give an overall suitability of the site for habitat creation, between 0 and 100. Weighting of these criteria is discussed in section 3.2.5.

3.2.4.2 Light Climate

Subtidal eelgrass habitats are very sensitive to suspended solids and require low turbidity, high light environments to establish. Without an appropriate light climate eelgrass habitat will not be created, despite other criteria being suitable. Consequently it acts as a showstopper. High light penetration is calculated as 100 suitable. Low light penetration is calculated as 0 suitable and this over-rides all other criteria for eelgrass suitability. Presence of existing eelgrass at a directly adjacent site indicates a high light environment.

Saltmarsh and intertidal flats habitats are less sensitive due to lower inundation levels and can tolerate a range of turbidity. Therefore this criterion is excluded in calculations for saltmarsh and intertidal flats habitats.

3.2.4.3 Water Salinity

Suitability may vary for each habitat; there are not enough available data at present to specify separate thresholds for each habitat. Measure salinity of the water that will inundate the site; if salinity is less than 18 habitats are unlikely to become established. Salinity '>18' is calculated as 100 and salinity '<18' is calculated as 0. Salinity data assigned by water-body are available from SNIFFER typologies (Rogers *et al*, 2003).

3.2.4.4 Water Quality

The quality of the water that will inundate the site will be evident from adjacent sites, which will either be supporting healthy habitats (saltmarsh, intertidal flats or eelgrass), or will show signs of pollution such as absence of habitat, or elevated nutrients and eutrophication, such as high opportunistic green algal growth (e.g. *Enteromorpha* or *Ulva* spp). Presence of pollution/eutrophication may limit the suitability of a site for habitat creation. It is not possible to define absolutely what thresholds each habitat can tolerate. Refer to the Environment Agency's Environmental Quality Standards for water quality guidance www.environment-agency.gov.uk/subjects/waterquality/. 'No water pollution' is calculated as 100, 'within acceptable limits' as 50 and 'unacceptable' as 0.

3.2.4.5 Propagules or Biological Supply

For habitat to create on a newly inundated site there needs to be a source of 'biology' naturally transported to the site; i.e. propagules such as seeds, rhizomes and tiller fragments, and intertidal organisms such as larvae, and adult invertebrates. In the model these are all encompassed in this criterion. It is important to identify the nearest established habitat likely to supply propagules and organisms, which may be up-stream or down-stream in the estuary or along the coast. Proximity of established habitat is crucial for eelgrass, and unless the site is directly adjacent to eelgrass beds the likelihood of new habitat creation is negligible. For saltmarsh and intertidal flats the nearest established habitat may be as much as 10 km away and new habitat will create from a received source of biological supply, assuming transport direction permits; e.g. Saltram, Devon.

The suitability of this criterion for eelgrass is calculated as 100 if propagule supply is from 'adjacent habitat' and 0 if distant. For saltmarsh and intertidal flats suitability is calculated as 100 if 'adjacent source', 50 if 'distant source within range' and 0 if 'distant source out of range'.

3.2.4.6 Habitat Location

Saltmarsh, intertidal flats and eelgrass are most commonly, but not exclusively, found in estuarine locations. They are successful here due to the combination of sediment supply, shelter and potential for colonisation. Sites in muddy environments can undergo rapid accretion and 'warp up' if there is a high degree of shelter. 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 habitats can grow in the vertical and also expand in the horizontal dimensions. In sandy estuaries accretion is more limited. New habitats are unlikely to create at open coastal sites unless there is evidence of established habitats indicating local conditions are suitable.

Suitability is calculated as 100 for 'muddy estuary', 25 for 'sandy estuary', 100 for 'open coast with adjacent habitat' and 0 for 'open coast without adjacent habitat'.

3.2.4.7 Exposure

High exposure would tend to limit the degree of accretion and inhibit creation of habitats, whereas sheltered sites promote settling of sediment and vegetation growth. Exposure typologies are available from SNIFFER (Rogers *et al*, 2003). There are 3 choices in the model calculated as 0 for 'high', 50 for 'moderate' and 100 for 'low' exposure. UK examples for each type of exposure are provided in the criterion's description to aid the user in deciding how best to categorise the site under investigation.

This criterion is linked to bed stability (section 3.2.4.10).

3.2.4.8 Connectivity in site

Connectivity is a measure of homogeneity of the land on the site: e.g. 'good' connectivity suggests low-lying areas are all interconnected so that the site drains thoroughly, 'poor' connectivity would indicate sub-areas of low-lying land not connected to the main breach that would inundate, but then pond. In the model connectivity is calculated differently for each habitat: for saltmarsh, 100 for 'good' and 0 for 'poor'; for intertidal flats 100 'good' and 25 for 'poor'. Subtidal eelgrass habitats are not directly affected by this criterion.
Natural development of creeks is slow, but creeks may be constructed prior to inundation of a site and for this reason it may be appropriate to assign a low weight to the criterion if the site is to be anthropogenically adapted before inundation (see section 3.2.5).

3.2.4.9 Freshwater Flows

Inundation by freshwater flow reduces salinity and can act as a pollutant to halophytic plants. Freshwater also affects the extent to which a site is waterlogged/submerged. This may result in more intertidal flats than saltmarsh. When evaluating this criterion it is necessary to consider high flows from high rainfall, storm sewers opening onto site, and discharges. Provided the minimum salinity level at all parts of the site remains above 18, and there is good connectivity, freshwater flow may be considered 'low' and is valued as 100.

3.2.4.10 Bed Stability

Very firm, worked soil that has been compressed by livestock is more resistant to erosion, and a weaker natural site has a tendency to erode (especially if the exposure is high). Success of managed realignment depends on the ability of the soil within the site to resist erosion by the action of waves and to allow the accretion of sediment at least at the rate of the effective sea level rise. However, in friable soils stability is likely to naturally increase post breach, so weak stability will not prevent long-term site success, provided exposure is low. Therefore, this criterion is linked to Exposure and calculated as follows:

100 for 'strong/firm' beds, 50 for 'weak/friable' beds with low exposure, 25 for 'weak/friable' beds with moderate exposure and 0 for 'weak/friable' beds with high exposure. It may be appropriate to assign a low weighting to 'Bed Stability' as weak soils will not prevent habitat from establishing in the longer term.

3.2.4.11 Soil Type

The model provides a choice of 4 soil types. 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. Saltmarsh and intertidal flats will establish on sediments finer than 'coarse sand', though species composition is likely to vary with sediment type. Initially, clay loam is the most suitable for all habitats as this is a silty-clay sand mix that provides a reasonable grain size to retain carbon. The lower nutrient content of sandier sediments may reduce colonisation potential. Another possibility is that there is greater seedling washout 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.

Post-inundation of the site, however, new sediment is likely to accrete and the original sediment-type of the site becomes less important. Although soil grain size for saltmarsh is not a critical factor for site selection, if the proposed site needs the artificial addition of sediment to produce the right configuration, the use of sediment finer than sand is preferable. These factors are reflected in the suitability values. Eelgrass (*Z. marina*) prefers firm sand, sand-fine gravel, or sandy mud. Clay loam provides suitable grain size and retention of carbon. Too fine or too coarse sediment will be unsuitable.

Suitability for saltmarsh and intertidal flats is set at 50 for sandy soils, 75 for clay soils, 100 for clay loam and 0 for sediment size greater than coarse sand. Suitability for eelgrass is 50 for sandy soil, 100 for clay loam and 0 for clay or sediment size >coarse sand. If a site's existent soil type appears unsuitable, but there is strong evidence for new and more suitable sediment to be deposited post-inundation, this criterion may be assigned an appropriately low weighting.

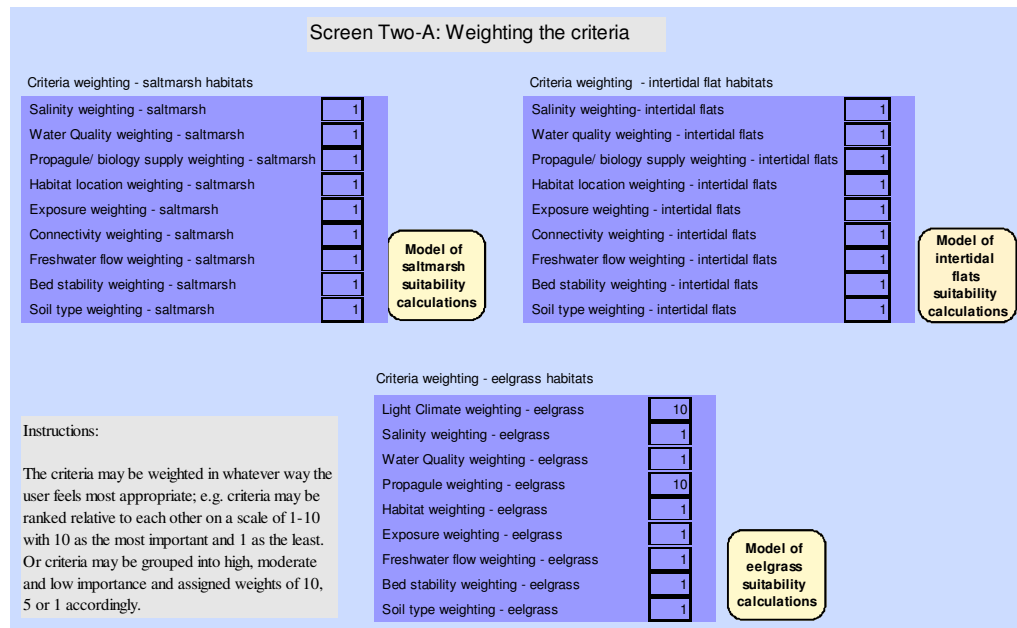### 3.2.5 Screen Two-A: weighting the criteria

Figure 30: Screen Two-A – Influence Diagram

The user must move into Screen Two-A to weight the criteria (Figure 30), before returning to Main Screen to perform calculations. Each habitat type lists the criteria involved in its suitability calculation. Some criteria can be considered as having greater influence on the likelihood of creating habitat at a newly inundated site. General guidance has been given in some criterion descriptors above as to influence on overall habitat creation, but this will vary site-by-site. Therefore the user has the opportunity to decide on criterion weighting appropriate to the site under investigation and the degree of engineering to be used on the site in preparation for inundation; e.g. if a site's natural connectivity is unsuitable for habitat creation but the site is due to be recharged or excavated, this criterion may be given a very low weighting as existent connectivity will have no/low impact on habitat generation.

There are several different ways of weighting the criteria and the model-user may choose their own weighting scale. For example, criteria may be ranked on a scale of 1 – 10 and weightings assigned with 10 as the most important criterion and 1 as the least. A more simple approach may be to group the criteria into high, moderate and low importance and assign all high importance 10, moderate 5 and low 1. Criteria weightings in the model default to 1, but Figure 30 illustrates 'Light climate' and 'Propagules supply' weightings for eelgrass as 10 as an example of how these 2 criteria are of greatest influence on the likelihood of this habitat type establishing.

3.2.5.1 Model of saltmarsh/Intertidal flats/eelgrass suitability

Double-clicking on any of the 3 yellow nodes in Screen Two-A displays models of each habitat's suitability calculations. There is no requirement for the user to enter these nodes, as data do not need to be input in this screen. The models use the various parameters and their inter-dependencies (black arrows) to perform suitability calculations. The overall suitability for a habitat is calculated as a mean of the weighted criteria.

NB: Double-click on any coloured box (green, white, purple or the central pink node) to view descriptions and definitions/calculations.

Close or minimise the suitability model screens and return to the Main Screen to calculate habitat areas (by clicking on the pink 'calc' buttons).

Having weighted criteria appropriate to the site under investigation, close or minimise Screen Two-A and then Screen Two to return to the Main Screen, and calculate suitability of the site for each habitat type on a scale of 0 – 100, by clicking on the pink 'calc' buttons.

NB: If a habitat's area calculation is 0 ha., then suitability will also be 0.

3.2.6 Screen Three: confidence in the data

Figure 31: Screen Three – Influence Diagram

The opportunity is provided for users to record confidence in their data and to make an overall calculation of this confidence (Figure 31). There are drop-down boxes for each habitat's criteria providing the choices of low, moderate or high confidence in the data used for each criterion of the site under investigation. In the model low confidence is valued as 0, moderate as 50 and high as 100. The user should define these 3 categories and then allocate a category to each criterion based on the provenance of the available data.

NB: If a habitat's area is calculated as 0 hectares then confidence will appear as 'N/A' (not applicable) for that habitat. If 'no data' is selected as a criterion's suitability (Screen Two) then confidence will automatically default to 0 for that criterion, regardless of which level of confidence the user selects from the choices.

3.2.6.1 Models of confidence calculations in saltmarsh / intertidal flats/ eelgrass data

Double-clicking on any of the 3 yellow nodes in Screen Three displays models of each habitat's confidence calculations; though there is no requirement for the user to enter these nodes, as data do not need to be input in this screen. The models calculate a mean confidence for each habitat's data based on the confidence assigned to each criterion and the weighting previously allocated in Screen Two-A. For example, if there is high light penetration at a potential eelgrass bed based on very robust data from a reliable source, then the high confidence assigned to this heavily weighted criterion will skew the overall calculated confidence value (Main Screen) away from 0 towards 100. This means if there is high confidence in the most heavily weighted criteria and low confidence in the lowest weighted criteria, overall confidence may still fall in the 67 – 100 range (high).

NB: Double-click on any coloured box (green, white, purple or the central pink node) to view descriptions and definitions/calculations.

Close or minimise the confidence model screens and return to the Main Screen to calculate overall confidence in the range 0 (no confidence) to 100 (full confidence), by clicking on the pink 'calc' buttons.

3.3 Editing and adapting the model

Once familiar with the construction of the influence diagram the user may switch to edit mode by highlighting the upwards-pointing arrow at the top of the screen. It is worthwhile reading information and downloads provided on the Lumina website, before attempting to edit the Analytica influence diagram; http://www.lumina.com/ana/whatisanalytica.htm. New criteria may be built into the model as additions or replacements for the existing criteria. As research grows published literature may provide data quantifying other physical, chemical or ecological parameters, e.g. the effect of internal waves on habitat creation, the precise chemical tolerances for saltmarsh plants, or the period required for habitat to become established. Alternatively local issues such as land ownership or local regulations governing land-use could be quantified and incorporated into the model. Such new criteria can be weighted and in this way the influence diagram becomes tailored to the specific site under investigation and provides an effective audit trail supporting final decisions on site selection.

3.4   Model testing and validation

The resolution of the model is limited by the lack of available data to accurately quantify suitability criteria. Nevertheless it can be used to predict maximum potential habitat areas and a level of suitability in the range of 0 (no suitability criteria met) to

100 (all suitability criteria met). The following table is the result of model testing on 7 sites, comparing predicted habitat with actual habitat created.

Table 6: Model predictions for habitat areas, compared with actual areas. (N/A = not applicable – where predicted habitat is 0 ha.)

Site		Frieston, The Wash	Tollesbury, Blackwater, Essex	Orplands, Blackwater, Essex	Shotley, Orwell, Essex	Horsey Island, Hamford Water, Essex	Westwick, Crouch, Essex	Abbotts Hall, Blackwater, Essex	Humber, Humberside
Site type and location		Coastal managed realignment site	Estuarine managed realignment – sheltered site	Estuarine managed realignment – very sheltered creek site	Beneficial use recharge site – adjacent to intertidal flats	Beneficial use recharge site – adjacent to saltmarsh and shingle bank.	Beneficial use recharge sit – within saltmarsh system, Crouch	Estuarine Managed realignment – very sheltered creek site	New site
Saltmarsh	Actual (ha)	Developing	6.0	~40.0 pioneer plants	0.0	3.0 Quickly developed saltmarsh	0.0	Expanding vegetation on most parts of site	Not available
	Predicted (ha)	60.0	6.4	33.0	0.0	2.5	0.0	8.3	800.0
	Predicted suitability	94.4	50.0	61.1	N/A	55.6	N/A	38.9	38.9
Intertidal flats	Actual (ha)	60 ha developing into saltmarsh	14.0	Extensive, developing into saltmarsh	Whole site is intertidal flats	0.0	0.1	Extensive, but developing into saltmarsh	Not available
	Predicted (ha)	0.0	14.6	5.6	3.0	0.0	0.1	9.4	0.0
	Predicted suitability	N/A	52.8	61.1	27.8	N/A	61.1	38.9	N/A
Eelgrass	Actual (ha)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Predicted (ha)	0.0	0.0	0.0	0.009	0.0	0.0	0.0	0.0
	Predicted suitability	N/A	N/A	N/A	9.3	N/A	N/A	N/A	N/A

A range of site types has been used for model testing and validation. Table 5 illustrates a spectrum of suitability, as the model is able to sufficiently differentiate suitability between sites, using the available site-specific data. For the areas in which saltmarsh was created there is a strong correlation between predicted and actual habitat areas; $R^2 = 0.9872$. There are too few data to statistically compare predicted with actual habitat areas for intertidal flats or eelgrass. There are always likely to be variations between actual and predicted habitat areas caused by a wide range of site-specific variables. For example, a splash-zone is likely to exist above MHWS, creating a transition zone between saltmarsh and grassland habitats; small-scale variations in surface slope will affect habitat creation; unexpected events such as storm surges or high freshwater runoff will influence establishment of habitat; habitat will take a number of years to become fully established so the timing of post-breach monitoring and recording of habitat area must be considered when comparing with the model's predicted area. Even so, the model does give good estimates for these known sites and testing is due to be conducted on unsuccessful site data.

The model is designed to be a generic tool and as such it cannot be used definitively for all potential sites in its current form. Its strength lies in its adaptability to site-specific conditions, its provision of an effective audit-trail and its potential to be developed and refined in the future, as criteria become more accurately quantified.

4.0 Conclusions:

This report (Report II) covers the demonstration of two tools to aid site selection in terms of habitat creation. The broader scale GIS screening tool and a site-by-site influence diagram tool can identify a possible short list of sites ranked in terms of likely success governed by physical, chemical and ecological controlling factors. They are flexible in terms of end-user adaptation, have been tested against existing sites and provide an auditable trail for site selection purposes. The entire process of this project (Reports I and II) should help to lead an end-user through the process of site selection and issues that need to be considered in terms of habitat creation. The decision tools presented in this report aim to summarise and facilitate this process.

Both of these tools have had to remain generic in nature to some degree given the several unresolved factors. These are:

- The natural variability in the nature of estuarine and coastal systems and the comparatively short list of habitat creation sites in which controlling criteria have been monitored. Although many features and criteria are common to these sites, the actual criteria and thresholds may vary.

- Despite a comprehensive review (Report I) of the controlling factors of habitat creation there are still significant limitations in scientific understanding of the cause and effect pathways, responses and outcomes involved.

Due to these uncertainties it was not possible to produce a 'one-size fits all' approach but within both of the tools presented there is scope for refinement of the criteria and thresholds given specific local data availability or species knowledge. Some of the controlling factors for specific species of plants are much better known but it terms of whole habitat creation this is complex and there are still large uncertainties. For example, the definition of success or habitat quality will often depend on the original objective and end-user. In this way the tools are not as quantitative as originally proposed but incorporate the best scientific knowledge to date and are flexible enough for adaptation as increased knowledge and understanding occurs. The outputs from this project together with the monitoring guidance provided by DEFRA/EA-FD1918 (2004) and CIRIA (2004) should provide a continuum of site evolution and a mechanism for improved understanding of habitat creation in terms of site selection, site design and site monitoring over various timescales.

The evolution and sustainability of a site given unknowns in sea level rise, rate of colonisation etc. is beyond the scope of this project. The tools are designed to identify potential sites as suitable in terms of initial conditions with only minor changes. Although it is accepted that sites will evolve over time and like other saltmarsh or intertidal flats habitat be subject to coastal squeeze the prediction of this is very difficult and should be covered within any SMP or other coastal plan.

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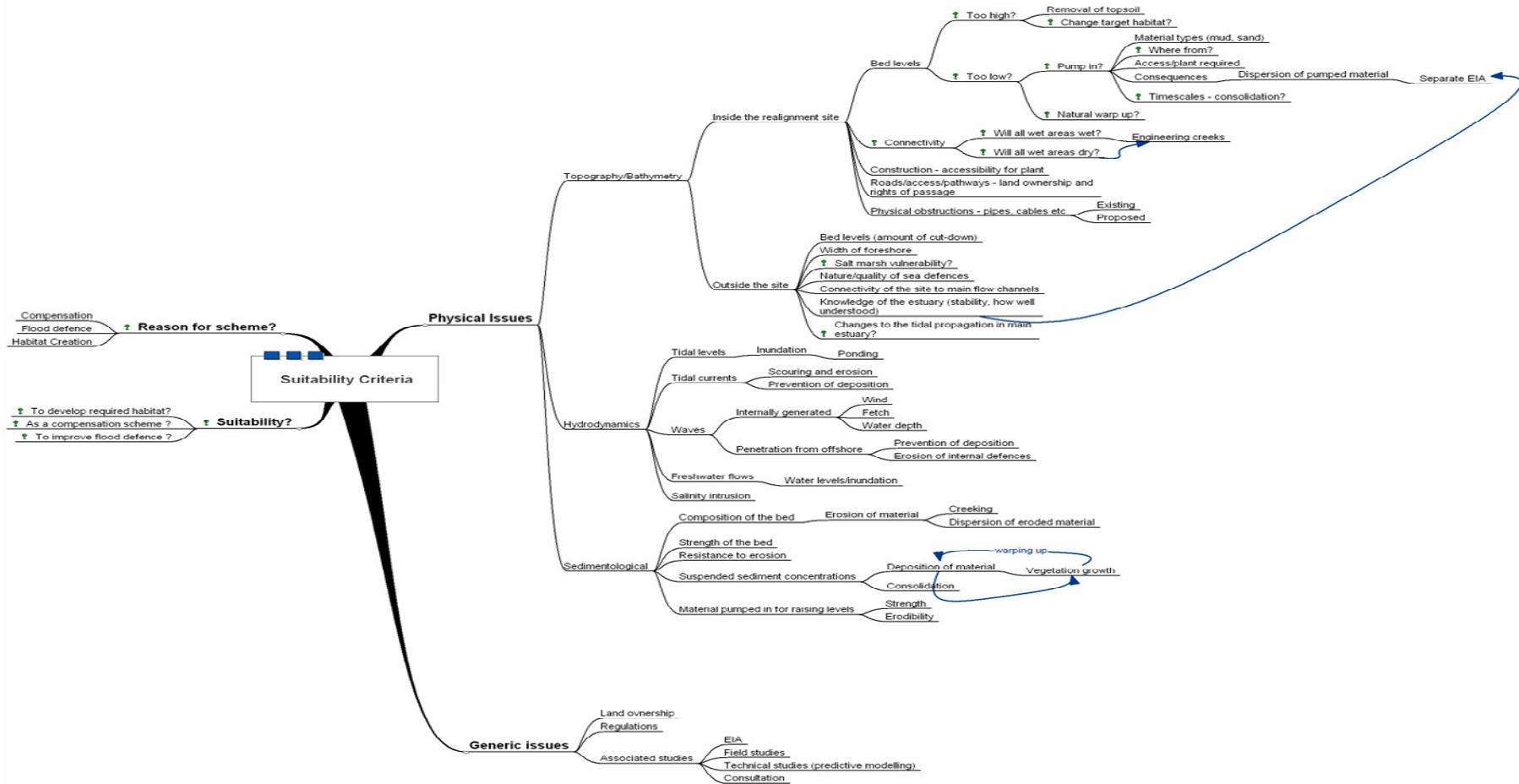
APPENDIX I

Figure 32: Mind-map of physical components for habitat suitability

APPENDIX II

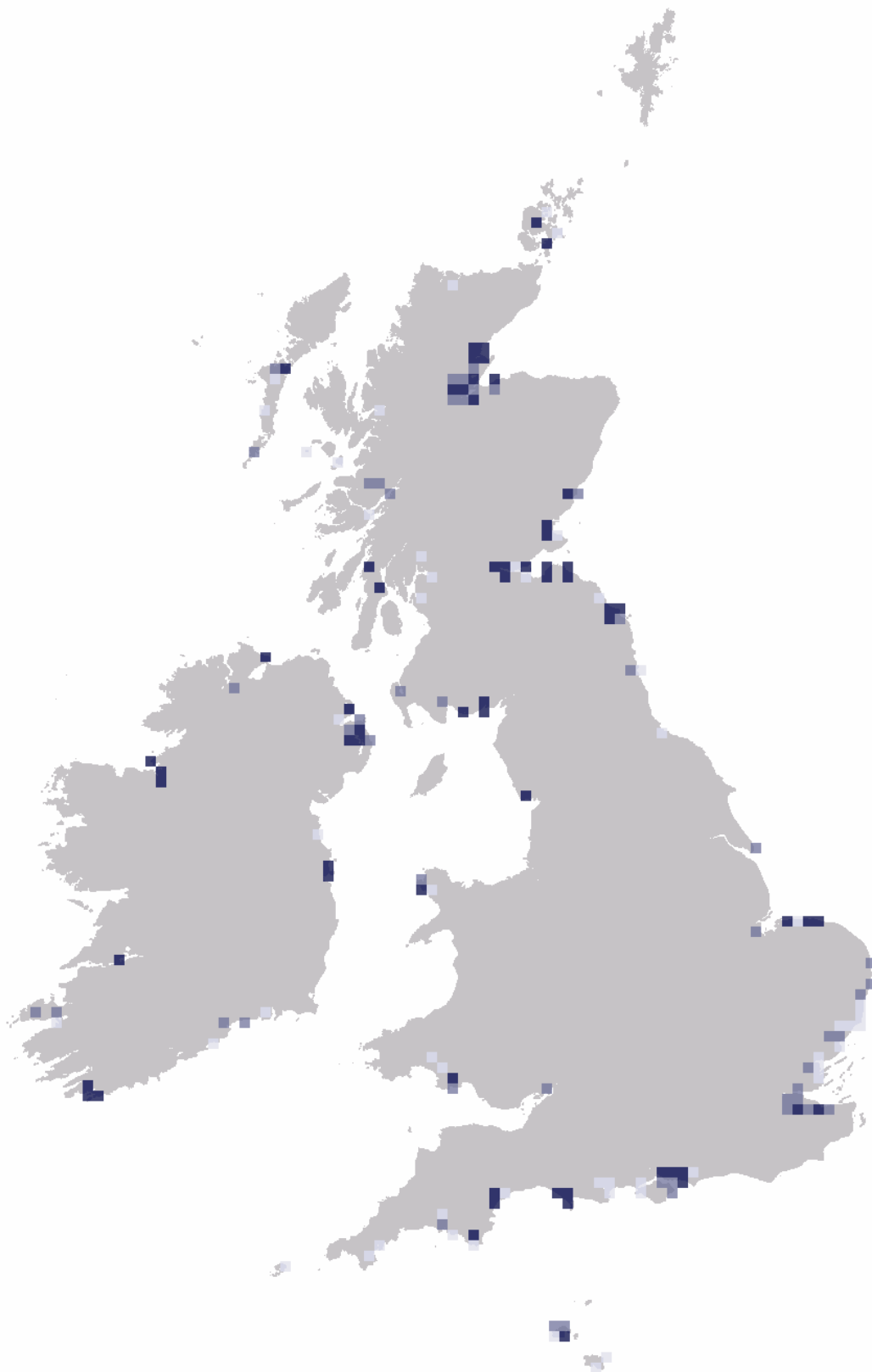**Figure 33a. Distribution map of *Zostera marina***

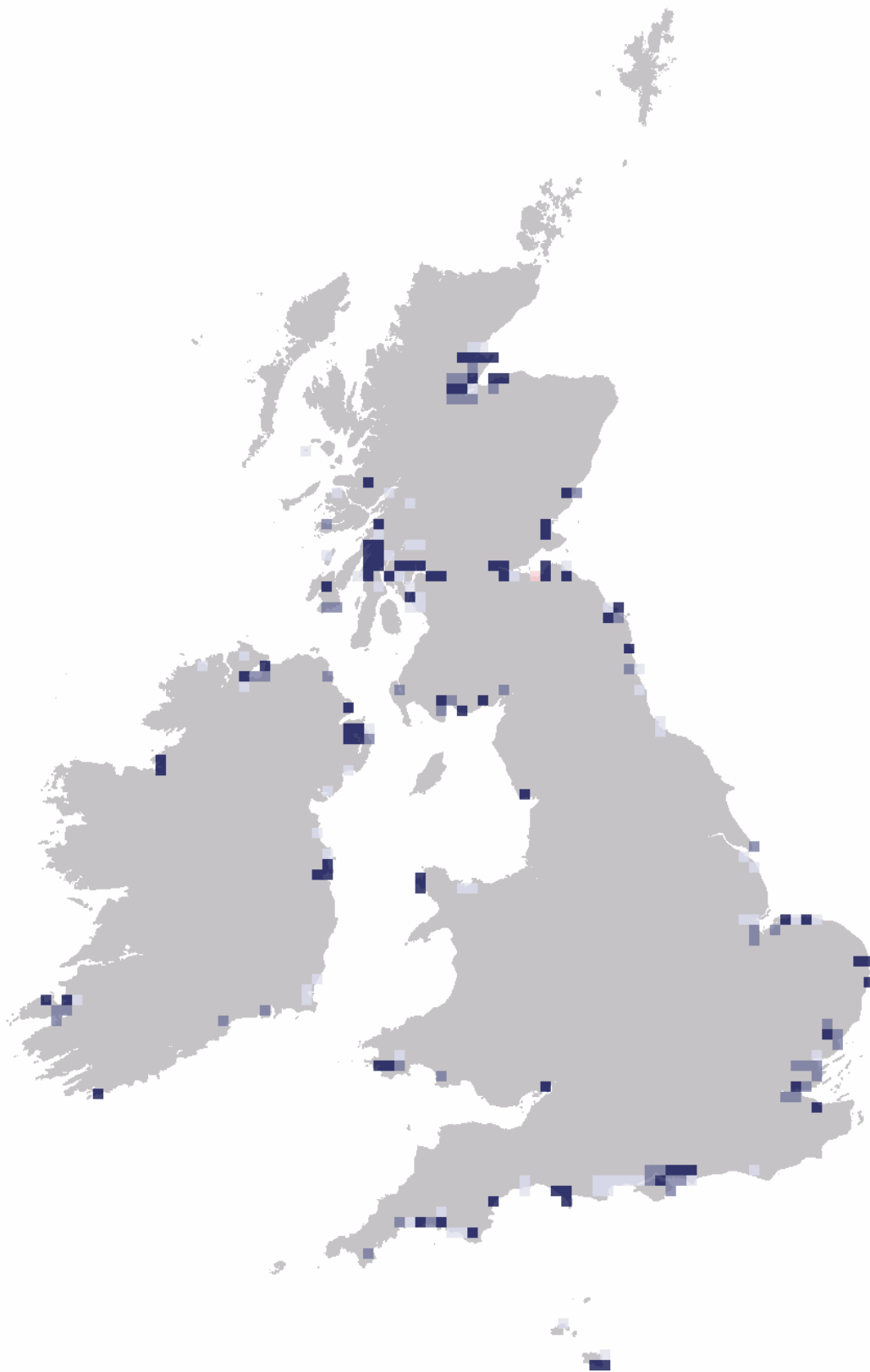**Figure 33b. Distribution map of *Zostera angustifolia***

Figure 33c. Distribution map of *Zostera noltii*

Figure 33: Geographic distribution maps of (a) *Z.marina*, (b) *Z.angustifolia* and (c) *Z. 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)

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