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Coastal evolution in Suffolk: an evaluation of geomorphological and habitat change

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Coastal evolution in Suffolk:
an evaluation of geomorphological and habitat change

Specialist contributors
Dr Pat Doody
Dr Mark Lee
Professor John Pethick

Edited by
Sue Rees

English Nature Project Officers:
Sue Rees,
Maritime Team, Peterborough.

Patrick Robinson,
Suffolk Team, Bury St Edmonds

Tim Collins
Maritime Team, Peterborough

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Foreword

English Nature has recently published a Maritime Strategy *our coasts and seas* setting out its vision and objectives for the 21st Century. This process involved a process of consultation and awareness-raising with a wide range of stakeholders. A central theme of this strategy is adaptation to change, and the need to build on current conservation mechanisms to ensure they continue to deliver benefits for wildlife, habitats and geology. One of the most challenging communication aspects about coastal conservation is the need to understand that the coast is, and always has been, an ever-changing environment; this is a critical part of its scientific and aesthetic interest. The predictions of the impacts of climate change are additional drivers in ensuring the adaptation of conservation measures for sites at the coast. This includes the role of designated sites taking a more forward look and to ensure that they can accommodate future changes in distribution of species, habitats or geomorphological features of special interest.

Acknowledgements

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Executive summary

This report contains the results of commissioned studies to increase the scientific understanding of a Site of Special Scientific Interest (SSSI) in the Suffolk Coast and Heaths Natural Area, with particular regard to coastal evolution and predictions of future change.

The Suffolk Coast supports coastal habitats and geological features of national and international significance. These designations need to be supported by scientific information about these features of special interest, as required by the guidelines for selection of SSSIs.

The studies cover two main aspects: a vegetation survey of the shingle at Benacre Ness and the evaluation of the likely coastal evolution of the shingle structure and the cliff line. The vegetation studies confirmed that the shingle vegetation had changed since it was last surveyed in 1988, with a range of vegetation communities represented at the site. The distribution and extent of these communities has evolved in response to the re-working of the sediment and the northward migration of the shingle, which provided new areas for colonisation.

The coastal evolution studies were based on a review of current coastal studies and data about the historic changes that have taken place. Using modelling techniques, these provided a prediction of future change for both the northward migration of Benacre Ness and the likely recession rates for the cliff sections of the site. The impact of climate change and sediment budgets are uncertainties that need to be taken account of in future. A simple probabilistic model has been used to generate predictions of the cliff top position in 50 years time. The model takes account of uncertainty in the rate of future sea-level rise and the variability of the recorded recession rates along each cliffline. A conceptual model has been developed to provide a prediction of the migration rate of Benacre Ness over the next 50 years. This model considers ness migration as involving a combination of long periods of gradual change (13.3m/year) together with short periods of rapid change (100m/year) during rare storm events. Ness migration of up to 1500m is predicted for this period. However, it must be stressed that rising sea levels may limit the long-term reliability of this model.

The studies have contributed to an increasing body of knowledge about coastal change, and the link between geomorphological processes at the coast and the habitats of shingle structures. The information will be applied in the development of conservation measures for the site and will also be useful for broader aspects of coastal management.

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1. Introduction

1.1 Aims of this report

This report contains the results of a series of commissioned studies to enhance the scientific understanding of some of the interest features of a Site of Special Scientific Interest (SSSI) in the Suffolk Coast and Heaths Natural Area, with particular regard to coastal evolution and predictions of future change. These studies, from 2003 to 2004, were carried out by specialist contractors, using both field survey and literature reviews, and drawing on other current specialist studies. There are two main sections to the report; a study of the shingle vegetation and changes since 1988, and analysis and predictions of coastal geomorphological evolution for both the cliffs and the shingle structure. Both sets of information were used to develop a new and revised site boundary for the Pakefield to Easton Bavents SSSI to ensure that the current interests were included when the site was re-notified and that there was space for migration of the special interest features over the next 50 years. There are other interest features of the site, but these are not covered by this report. The remainder of this section provides a brief introduction to the relevant background for these studies.

1.2 Sites of Special Scientific Interest

SSSIs are the country's very best wildlife and geological sites. They include some of our most spectacular and beautiful coastal areas including the active cliffs and shingle beaches so typical of the Suffolk coastline.

The purpose of SSSIs is to safeguard for present and future generations a series of sites which are individually of high natural heritage importance. They make a vital contribution to the ecological processes upon which we all depend. Many areas designated as SSSIs make important contributions to the local economy, for example through tourism and recreation, and can provide opportunities for people to enjoy and appreciate nature.

Wildlife and geological features are under pressure from development, pollution, climate change and unsustainable land management. SSSIs are important as they support plants and animals that find it more difficult to survive in the wider countryside.

Notification as a SSSI gives legal protection to the best sites for wildlife and geology in England. The first SSSIs were identified in 1949 when the then Nature Conservancy notified local authorities of SSSIs, so their conservation interest could be taken into account during the planning process. English Nature now has responsibility for identifying and protecting the SSSIs in England under the Wildlife and Countryside Act 1981 (as amended by the Countryside and Rights of Way Act 2000).

If the special scientific interest of a SSSI changes, English Nature may change the details of the notification. An SSSI can also be extended if land nearby is found to be of scientific interest. Proposals to vary or extend SSSIs are treated in the same way as new notifications.

1.3 Coastal evolution

England's coast supports an abundance of wildlife habitats and physical features. These features are not static and depend on the interactions between wind, waves, tides, sediments and geology to shape and sustain their nature conservation interest. Over time coastal habitats and features change, so enough space is needed to allow them to move and evolve in response to the action of the sea.

Much of England's coastline is also responding to rising sea levels and other aspects of climate change, such as increased storminess. In areas where the coast has not had any artificial structures to stabilise it, the coast can evolve as it has done historically. There is often a link between the sediment eroded from cliffs and the size and shape of sand and shingle beaches and foreshores.

English Nature has set out a vision for the coasts and seas in its Maritime Strategy: *Our coasts and seas-making space for people, industry and wildlife* (English Nature 2005). The importance of coastal evolution is highlighted specifically in this vision in the following points:

- plans and management measures are in place to allow habitats to adapt to long-term coastal evolution;
- designated site boundaries can accommodate coastal change and are managed within the context of the coastal ecosystem

A critical element of the scientific interest of coastal SSSIs is the natural functionality and dynamic nature of coastal systems. It is important to continue to raise awareness of the inherently changeable nature of the coastline, the scale of those changes and the advantages of working with coastal processes. We need better understanding of the way the coast is changing now, how it changed in the past, and how it is likely to evolve in the future. Coastal SSSIs provide opportunities to study and understand the scientific evidence of these changes

1.4 Natural Areas in Suffolk

Natural Areas are a landscape classification. As an approach it allows the whole of England, including coastal and marine areas, to be described by the characteristic association of wildlife and natural features. Each Natural Area has a unique identity resulting from the interaction of wildlife, landforms, geology, land use and human impact. Natural Areas provide an effective framework for the planning and achievement of nature conservation objectives and are used for targeting of action with partners to conserve our biodiversity and earth heritage assets.

The purpose of this approach is to provide a wider context for nature conservation action. Natural Area descriptions take into account not only the wildlife and natural features of the landscape, but also incorporate a ‘sense of place’ into the descriptions of these areas so that people who live and work in them can relate to them. Natural Areas can help to set objectives, define national priorities and local targets, and help with the focus of resources to best effect for nature conservation. A result of this is that national targets can be converted into local action, helping us and others to ‘think globally and act locally'.

Examples of their use include targeting of the agri-environment schemes and the breakdown of national targets or priorities, such as those set out in the UK Biodiversity Action Plan to a more local Natural Area level.

Suffolk has six natural areas; two of these are at the coast (English Nature 1997). The coastal habitats of the Suffolk Coasts and Heaths and the Suffolk Coast Natural Areas are of national and international importance for nature conservation. The estuaries and grazing marshes support waders and wildfowl in great numbers, reedbeds support breeding bitterns and bearded tits, and saline lagoons support specialist and rare invertebrates. The coast is rapidly eroding along much of its length. Cliffs are retreating inland by several metres each year, and saltmarshes are steadily shrinking. Gradual erosion of these habitats will occur as a normal outcome of coastal processes, and is exacerbated by sea level rise caused by global warming and as slow lowering of land level continues.

The shingle structures of Orfordness and Benacre Ness are actively moving, through the continual erosion and deposition of shingle. The southern end of the Orfordness spit varies rapidly in shape, with new shingle often appearing or being washed onto the shore at Shingle Street. Benacre Ness is slowly moving northwards, as new material accretes on its northern side and shingle erodes from its southern side. As well as their geomorphological significance, the shingle structures support rare undisturbed vegetation communities and nationally important breeding bird populations.

1.5 Geological features of the Natural Area

The Suffolk Coast and Heaths Natural Area is a generally low-lying area underlain almost exclusively by the shelly, muddy and sandy sediments known as Crag. In a few places Tertiary deposits of London Clay underlie the Crag or are at the surface.

The geology tells the story of the changes that have occurred in the area, and these deposits are an important reference section against which sediments of this age from other areas of Europe are compared. The London Clay was deposited in shallow tropical seas around 50 million years ago. It is well exposed at Wrabness Cliff and on the foreshore at Harwich. The latter site is notable for its Tertiary fossil flora. Septaria platforms at Wrabness Cliff and at Nacton are of great interest.

The Crag deposits are marine sediments deposited near the western margin of the southern North Sea in relatively shallow water, of a cool or temperate nature. The Crag deposits have abundant marine fossils, which indicate how the relatively mild climatic conditions of preglacial times (Pliocene to mid Pleistocene) degenerated through several oscillations of temperature into the cold glacial climates of the Middle and Late Pleistocene. The Crag is generally divided into three broad groups: the Coralline Crag Formation, the Red Crag Formation and the Cromer Forest Bed Formation. Of these, the first two are widespread in the Natural Area and the third is absent. The most extensive of these is the Early Pleistocene Red Crag Formation (deposited about 2.3 million years ago).

Following the deposition of the Crag sands, ice sheet movement during the subsequent Anglian glaciation (at around 400,000 to 470,000 years ago) removed vast quantities of chalk and clay from the North Sea basin and deposited these on land as chalky till and boulder clay. The chalky till is best seen in coastal sections in the north of the Suffolk Coast and Heaths Natural Area, although it is also found in excavations such as quarries.

So the sediments in these cliffs form a key part of our understanding of how climates and environments changed over the last 2 million years. If we put this information together with studies of other sites in East Anglia, we are now able to work out where rivers flowed, how far the ice reached, and how our coastlines have changed, and continue to change. This is currently a very important area of scientific research, which is also relevant to the debates about climate change and predictions about global warming.

1.6 Pakefeld to Easton Bavents SSSI

The Site of Special Scientific Interest (SSSI) site is considered to be of special interest for:

- Habitats
    - Coastlands
        - Vegetated shingle beaches
        - Coastal Lagoons
    - *Phragmites* swamp and tall fen
- Species/Groups
    - Number of breeding birds
    - Number of wintering birds
- Geological features:
    - Coastal geomorphology interest at Benacre Ness
    - Vertebrate Palaeontology
    - Pleistocene/Quaternary of East Anglia

The SSSI also includes Benacre National Nature Reserve.

To ensure the continued inclusion of the geological interest of the three sites mentioned in the Geological Conservation Review the site needs to be enlarged by the process of re-notification. Due to a combination of coastal erosion and other coastal processes a significant area of the geological interest lies outside the previously notified (1989) SSSI boundary.

The site also supports a range of internationally important habitats and species. It has been classified as a Special Protection Area (SPA) under Article 4.1 of the EC Birds Directive by regularly supporting bittern *Botaurus stellaris*, marsh harrier *Circus aeruginosus* and little tern *Sterna albifrons*.

Part of the existing SSSI has been designated as a Special Area of Conservation (SAC) on account of the presence of European Annex I habitats. These include lagoons, a priority habitat. These are areas of shallow coastal saltwater of varying salinity separated from the sea by sandbanks or shingle or, less frequently, by rocks.

2. Benacre to Easton Bavents, Suffolk (TM 540860) - Assessment and survey of shingle vegetation

Dr J P Doody

2.1 Background

Assessment and survey of shingle vegetation was carried out in 2004 to update the 1988 survey (Sneddon & Randall 1994). It also covered newly formed areas of shingle that had been more recently colonised by shingle vegetation.

2.2 Method

2.2.1 Site visit

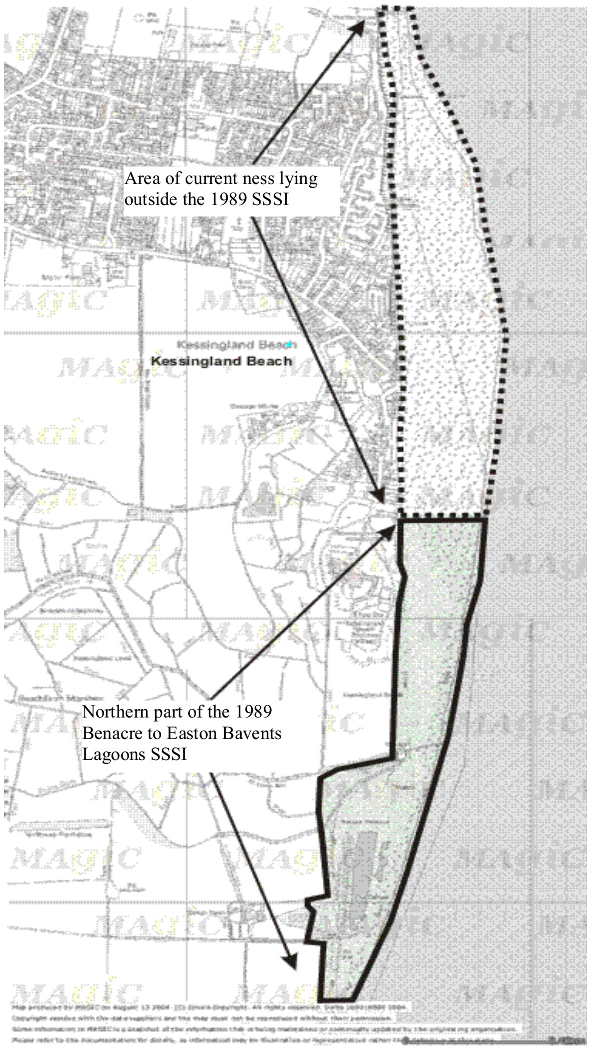
Visits to the site and vegetation survey were undertaken between 14 August 2004 and 19 August 2004. The whole foreshore from the northern edge of the NNR in the south to the limits of Kessingland village in the north (Map 1) was visited.

2.2.2 Survey

The total area surveyed was approximately 50ha.

Recent oblique aerial photographs from the Defra Futurecoast study were inspected and comparisons made with the 1988 Sneddon and Randall survey. The vegetation was surveyed in two main blocks: the northern part of the site and the southern part of the site. The northern part of the site had more sand in the shingle matrix than the southern part. A preliminary assessment of the range of vegetation types was followed by a more detailed survey using NVC methods (Rodwell 2000) for the identification of the plant communities, but also taking account of the Sneddon and Randall classification for shingle vegetation.

Map 1 Area of site

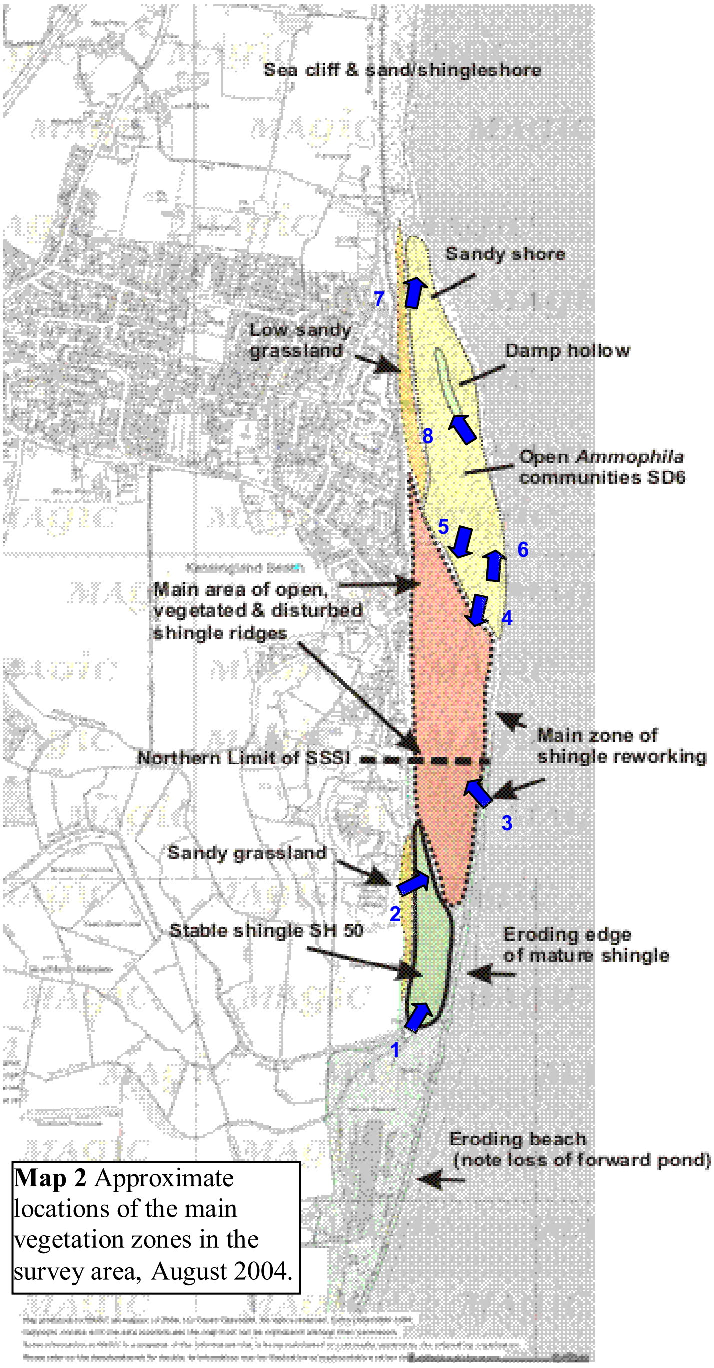


In total, 31 quadrats were recorded during the survey, representing samples of the main vegetation types. Each quadrat is described by a species list with cover abundance (Domin scale) and a photograph of the quadrat. Additional information was collected on the range of plant species on the site and additional habitats. This is described in three main sections and presented below. The location of quadrats and results of the survey work are summarised in Annex 2.1. This annex shows the approximate location and type of vegetation recorded. It gives a reasonable illustration of the general pattern of the communities present. Annexes 2.2-2.7 provide the more detailed quadrat records for the areas surveyed. In the more sandy habitats, 10 quadrats were recorded.

2.3 Site description

Moving from the south to the north of the site there is a sequence of vegetation types. The description that follows provides an overall view of the nature of the site and its vegetation. More detailed information is provided on the communities present in three principal sections (the colours in brackets refer to the colours on Map 2):

1. sand dune, stable shingle surfaces and eroding shingle at the southern end of the site (green);
2. main area of vegetated shingle, principally SH 11 & 21 (red);
3. sandy, *Ammophila* dominated northern section (yellow).



Map 2 Approximate locations of the main vegetation zones in the survey area, August 2004.

Map 2 also shows the northern limit of the 1989 SSSI boundary with a thick dashed line and areas to the north of this where there has been shingle sediment deposition on the foreshore. The blue arrows on Map 2 indicate the location and direction of the photographs used to illustrate the type of vegetation occurring in each section.

The descriptions that follow provide notes on the areas surveyed. These should be read in connection with the more detailed vegetation records provided in the annexes. All the vegetation types with the prefix 'SH' are based on the shingle vegetation types described in the 1994 Joint Nature Conservation Committee report (Sneddon & Randall 1994). Descriptions of these communities are also included in Annex 2.8.

National Vegetation Classification (NVC) types prefixed with 'SD' are based on the strandline and shingle community descriptions in the NVC volume on maritime communities (Rodwell 2000).

2.3.1 Southern section 1

A sequence of habitats occurs from north to south of the site. On stable shingle in the south, **SH 50** *Festuca rubra* - *Aira praecox* - *Plantago coronopus* grassland occurs extensively. It consists of species-poor grassland with a short sward. The location of the quadrats is shown in Annex 2.1 and the details of the vegetation presented in Annex 2.2. The area lies within the SSSI boundary notified in 1989. The disturbed open shingle surfaces occasionally include plants of *Senecio jacobea* and *Glaucium flavum*. Photograph 1 shows a general view of the vegetation.

Photograph 1 Sandy grassland in the foreground, stable vegetated shingle surfaces to landward and the active shingle shoreline.

The sandy grassland in the foreground is relatively rich in species though this part of the vegetation sequence was not surveyed.

Photograph 2 shows the general nature of the shingle surface towards the northern limit of this section. Included in this area is the location of the vegetation recorded by Sneddon in 1988 described as **SH 50,** *Festuca rubra* - *Aira praecox* - *Plantago coronopus* grassland. It proved difficult to compare the survey results of the 1988 survey with the situation in August 2004. People taking a short cut across the vegetation from the adjacent caravan park have disturbed the vegetation. Combined with erosion from the sea, the vegetation has been considerably fragmented. Five quadrats were recorded here (Annex 2.3) of vegetation classed as **SH 50**.

Photograph 2 Areas of stable vegetated shingle towards the northern margin of **SH 50**. Note the paths through the vegetation, which leads from the caravan park to the beach. Section 2 begins in the middle distance.

The shingle foreshore in this area is eroding. Here the vegetation consists of a mixture of tussocks of *Ammophila arenaria* and individual plants of *Beta vulgaris* ssp *maritima*, *Crambe maritima*, *Glaucium flavum*, *Rumex crispus* and *Raphanus maritimus*.

At this point the shingle vegetation becomes much dissected and it is difficult to discern any pattern that can be equated with distinct shingle ridges. It would appear that at this point the original trend of the ridges from north west to south east has been broken up.

2.3.2 Middle section 2

This section makes up the bulk of the open and vegetated shingle. In this central part of the Kessingland shingle shore, the shingle ridges become more obvious. They are orientated obliquely to the coast and lie on a north west to south east direction. The nature of the shingle at this point is best shown by the southern most ridges illustrated in Photograph 3. This shows the trend of two ridges either side of a low (termed the *Ammophila*) hollow. Five Quadrats were recorded from the vegetation between these ridges (Annex 2.4). They indicate a complex series of vegetation types, namely:

SH 50 *Festuca rubra - Aira Praecox - Plantago coronopus* grassland.
SH 48 *Festuca rubra - Hypnum cupressiforme - Lotus corniculatus - Plantago lanceolata* community.
SH 21 *Ammophila arenaria - Rumex crispus - Senecio viscosus* community.

Photograph 3 looking north west from the shore. Note the trend of the shingle and the position of the mobile beach in the foreground. The beach is moving in a northerly direction truncating the ridges.

In addition to the communities noted above there is a stand of *Crithmum maritimum* just beyond the eroding shingle indicating exposure to salt spray. [Note: this species is rare on the site.]

The beach itself has frequent scattered *Glaucium flavum* with *Ammophila arenaria* and individual plants of *Beta vulgaris* ssp *maritima* and *Crambe maritima* continuing the open foreshore community found to the south. Although no quadrats were recorded here the community was assessed as falling within the NVC community **SD 1** *Rumex crispus-Glaucium flavum* shingle community and can be equated to **SH 8** *Senecio viscosus – Glaucium flavum – Rumex crispus* community (not recorded on this site by Sneddon in 1988).

Much of the rest of this section supports a series of shingle ridges with varying amounts of vegetation occurring in patches between the bare shingle areas. The communities are mostly composed of **SH 11** *Lathyrus japonicus* pioneer community with *Rumex crispus* as a conspicuous component of the vegetation. Five quadrats were recorded here (Annex 2.5) and although assigned to **SH 11** the presence of a wide variety of species including *Raphanus maritimus* as a conspicuous component of some vegetation stands, suggest there may be a wider range of variation types present than those described in this report or identified during the survey in 1988.

Photograph 4 General view looking south across the main shingle ridges

A further series of communities were recorded to the north of this area (Annex 2.6). These are equally, if not more complex than the ones shown in the picture above and recorded in Annex 5. A general view of this area is shown in Photograph 5. Pockets of *Lathyrus japonicus* in open shingle lie alongside taller vegetation. Some of the areas are relatively species rich. Quadrat 3, for example, had 14 species. By contrast, in other areas *Arrhenatherum elatius* was virtually the only species. This community, which probably equates closest to **SH 41** *Arrhenatherum elatius – Festuca rubra – Plantago lanceolata – Silene maritima* grassland was not recorded in the 1988 survey.

Photograph 5 A Shingle ridge extending in a narrow linear form into Section 3. This photograph was taken towards the middle of the site (between the seawall and the sea) looking south. Immediately to the left and behind this location the extensive *Ammophila* communities begin.

Toward the north and east the shingle ridges become less evident. Here the substrate becomes composed of smaller pebbles and has a much sandier matrix. In the transition between the two zones *Lathyrus japonicus* stands occur as discrete patches within a community dominated by tussocks of *Ammophila arenaria*.

As the substrate becomes sandier in nature the community is almost completely dominated by tussocks of *Ammophila arenaria*. Photograph 6 shows the transition between these two communities looking north.

2.3.3 Northern section 3

This section of the site is almost completely dominated by *Ammophila arenaria* except for the transition between it and the shingle communities to the south. Photograph 6 clearly shows the nature of the northern section of the shore. The tussocky *Ammophila* community extends northwards to the point where the ness narrows again.

Photograph 6 *Lathyrus japonicus* growing in amongst tussocks of *Ammophila arenaria*. The picture shows the view north towards the extensive zones of *Ammophila* (probably **SD 6a**).

In order to give a more complete picture Photograph 7 shows the small area of sandy grassland lying alongside the cliff with the *Ammophila* beyond.

Photograph 7 Sandy grassland at the limit of the sea wall stretching below the low cliffs and towards Lowestoft. The beach reduces the impact of wave impact on the cliff face and it has become vegetated.

To the south east of Photograph 7, in the approximate centre of the sandy area, there is a small depression. This appears to have been created as the beach has moved northwards to enclose what may have been an ephemeral tidal inlet. Species typical of areas with a saline influence, such as *Salsola kali*, *Suaeda maritima*, *Puccinellia* spp. and *Spergularia marina* were recorded. The presence of *Phragmites communis* as shown in Photograph 8 suggests that the saline influence has diminished as the sand has accumulated, cutting the area off from tidal inundation.

Photograph 8 *Phragmites communis* in a depression in the dune/beach interface, looking towards the vegetated cliff.

NB although quadrats were recorded in the *Ammophila* community it soon became apparent that this was relatively simple community type and the results are not included in this report.

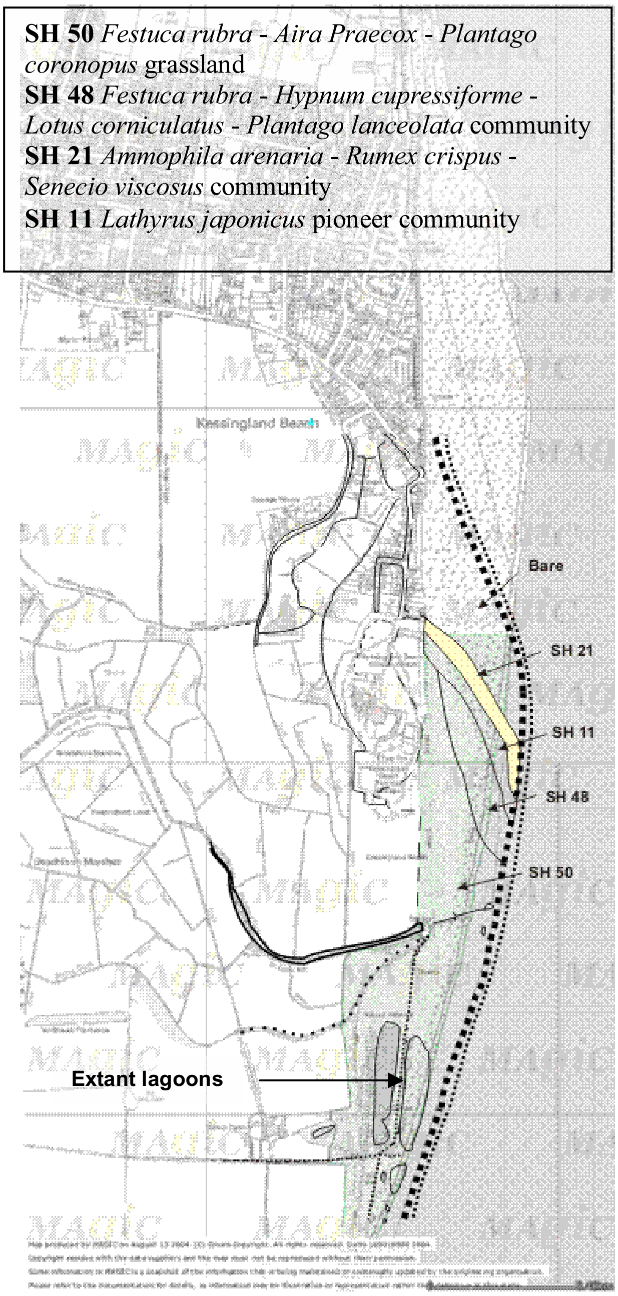
2.4 General conclusions and recommendations

2.4.1 Evolution of Benacre Ness

Benacre Ness is an **updrift accretion ness**, comprising a series of sand and shingle ridges. The structure has been migrating northwards along this coastline in response to a combination of accretion on the updrift side and erosion on the southern side. It stretches for nearly 2km along the shore adjacent to the village of Kessingland. At its widest point it is approximately 250 – 300m from the sea wall to the edge of the sea. It may be the product of long-term shortening of a spit system, which could have extended as far south as Dunwich. The ness has moved northwards by about 4.4km since 1766 (See Section 4 of this report). Since 1988 the ness has continued its northward migration and erosion and reworking of the sediment and re-deposition continues. Section 4 of this report predicts a northward movement of 1,500m over the next 50 years.

2.4.2 Comparison with the shingle survey of 1988

The result of the survey of the shingle vegetation of Kessingland Beach undertaken by P Sneddon in 1988 is shown in Map 3. This has been superimposed on an OS map derived from the DEFRA web site http://www.magic.gov.uk/



Although the date of the map is not given it is clearly more recent than the survey and shows the ness to have moved a considerable distance northwards in line with the work done by Lee and Pethick.

The background map represents a reasonably accurate picture of the current (2004) location of the ness in relation to its position in 1988. Note in particular the area of bare shingle, which is now the main zone of vegetated shingle.

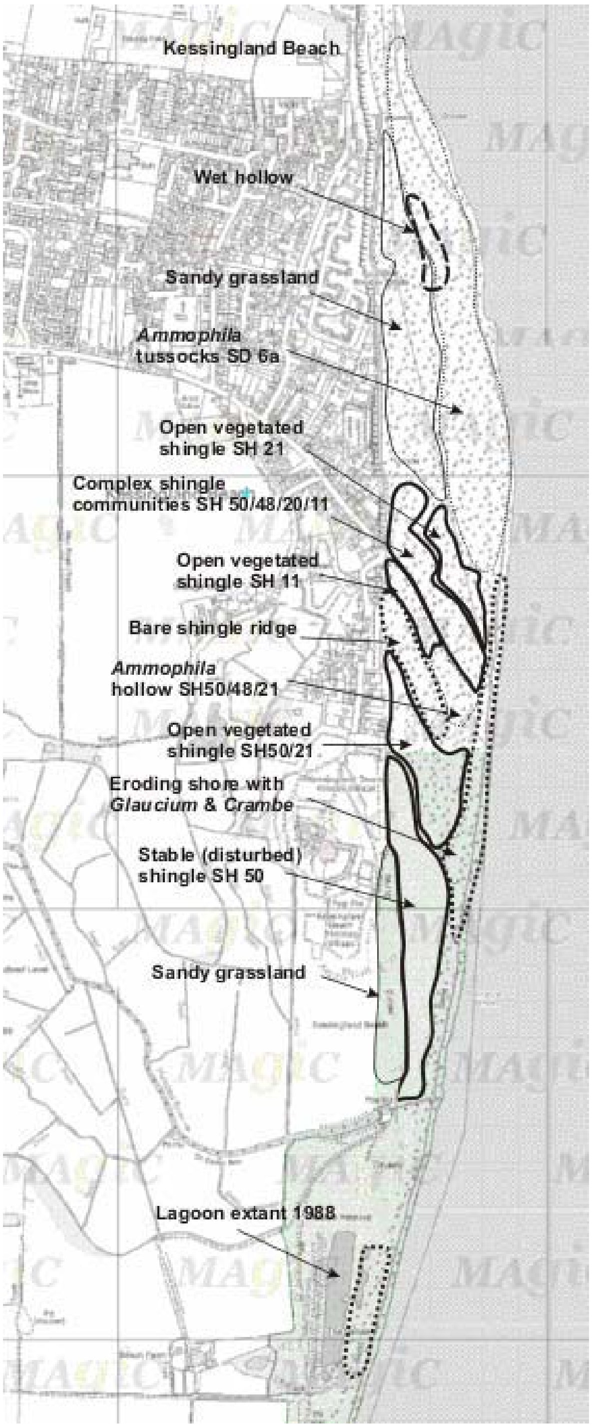
In the 2004 vegetation survey, it proved more or less impossible in the field to relocate the communities mapped in 1988 because of the extensive reworking and disturbance to the shingle, particularly at the seaward edge of the ridges. The only area that appeared to be more or less extant was the stable shingle plateau at the southern end of the site (Section 1). Even here although there are similar communities present, the degree of redistribution has resulted in the development of a very different vegetation mosaic as the ness has migrated northwards.

Map 3. Location of shingle communities as identified and mapped by P Sneddon in July 1988 (Sneddon & Randall 1994). Map produced by Magic on August 13th 2004 © Crown Copyright.

2.4.3 Vegetation

The more detailed study of vegetated shingle structures carried out in 1988 (Sneddon & Randall 1993) identified four communities:

SH 50 *Festuca rubra* - *Aira Praecox* - *Plantago coronopus* grassland.
SH 48 *Festuca rubra* - *Hypnum cupressiforme* - *Lotus corniculatus* - *Plantago lanceolata* community.
SH 21 *Ammophila arenaria* - *Rumex crispus* - *Senecio viscosus* community.
SH 11 *Lathyrus japonicus* pioneer community.



The survey in 2004 confirmed the presence of these communities but suggests that there may be several more not recorded in the 1988 survey. More detailed survey would be required to establish the nature of these communities. The NVC community **SD1** *Rumex crispus*-*Glaucium flavum* shingle community was also confirmed, both in the form of the typical sub-community and the *Lathyrus japonicus* sub-community.

Map 4 shows the approximate locations of the vegetation types recorded in the 2004 survey. As can be seen from the map, shingle communities are present north of the original area surveyed. In 1988 this location was identified as bare shingle.

Lathyrus japonicus occurs as a conspicuous and widespread species on the open sand/shingle throughout the site.

A large part of the rest of the site has high proportion of sandy substrate in the shingle matrix. The detailed quadrat results are given in the annexes.

The 2004 map shows that there is a substantial area of vegetated shingle that lies outside the SSSI boundary notified in 1989. This map also shows that there has been a substantial extension of the sand and shingle beach and with it *Ammophila* dominated communities since 1988.

Map 4 Approximate location of the main shingle communities identified in the survey of August 2004. The 1989 SSSI boundary is shown in green.

2.4.4 Recommendation

The shingle that has migrated northwards beyond the 1989 northern boundary of the Benacre to Easton Bavents SSSI supports shingle vegetation and communities that are developing into sand dune vegetation. These areas are considered to meet the SSSI selection criteria for shingle habitats. In particular it should be noted that:

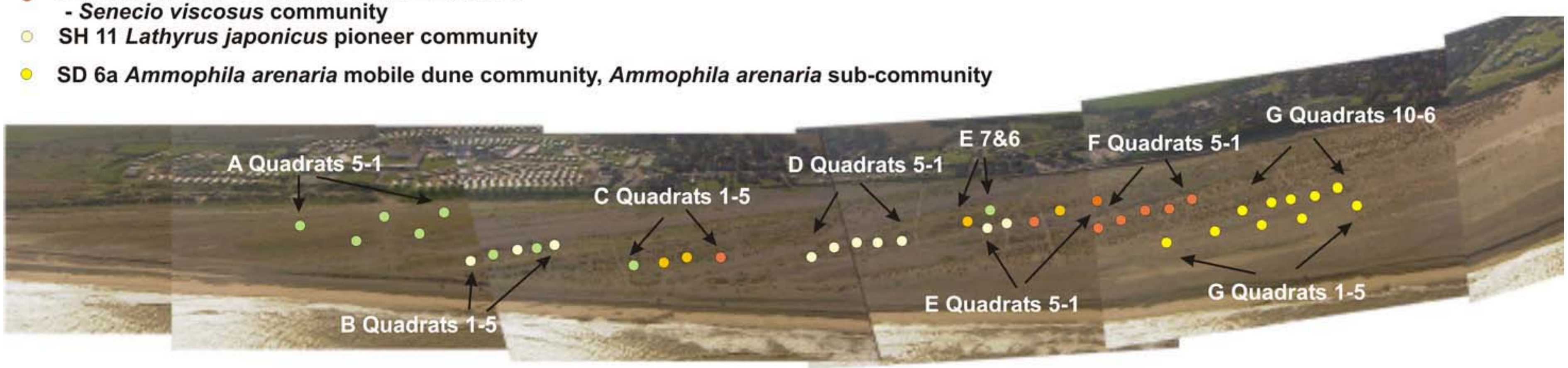
1. the shingle communities form part of the zonation of vegetation. The areas of older sandy grassland margins, which are in effect low sand dune habitat, support typical dune grassland valuable in their own right. This represents a combination of sedimentary coastal habitats;
2. the northern area of the site will, over time, be colonised by pioneer shingle vegetation as the ness continues its predicted progression northwards . This represents a wide range of pioneer and mature vegetation types and reflect the geomorphological changes occurring on the Ness.

Revising the site boundary would not only ensure that all the features appropriate to this highly dynamic system are encompassed, but also allow for the predicted movement of the shingle ridges in the future. Consideration should also be given to extending the site along the shore towards Lowestoft. The beach below the cliff line has valuable communities typical of this part of England with *Lathyrus japonicus*, a rare species, as a significant component of the sandy/shingle shoreline. Note *Corynephorus canescens* was also noted in several locations throughout the site, a local species of special interest in this part of England. The extent of this addition to the SSSI will need to be determined but could extend from Grid Ref. TM 536868 to TM 544916, a distance of approximately 4km. The beach represents a continuation of that shown in Photograph 7. Photographs from 1984 show the area around TM 536870 to have a more obvious shingle shore, with *Crambe maritima* prominent. Both of the shingle communities identified in the EU Habitats Directive, 'Annual vegetation of drift lines' and 'Perennial vegetation of stony banks' equate to the communities present on the site. Further descriptions of these habitats can be found on the Joint Nature Conservation Committee website http://www.jncc.gov.uk/page- 23

The site exhibits some disturbance from human activity. Management of this activity would be difficult on such an open beach. Measures similar to the existing walkways already placed along the beach to facilitate access to the shore could be considered.

Annex 2.1 Location of quadrat records 14 & 19 August 2004

- SH 50 *Festuca rubra - Aira Praecox - Plantogo coronopus* grassland
- SH 48 *Festuca rubra - Hypnum cupressiforme - Lotus corniculatus - Plantago lanceolata* community
- SH 21 *Ammophila arenaria - Rumex crispus - Senecio viscosus* community
- SH 11 *Lathyrus japonicus* pioneer community
- SD 6a *Ammophila arenaria* mobile dune community, *Ammophila arenaria* sub-community



NB Because of the distortion created by the oblique photos the location of the quadrats is a ‘best guess’ based the relationship of the shingle surface with features on the land. For each set of quadrats, the following sections provide a detailed plant list, Domin cover score and photograph. The numbering sequence reflects the direction in which the quadrats were recorded; the letters and numbers have no other significance than to enable the record to be located in the report.

Annex 2.2 Series A quadrats

A Quadrat 01 SH 50

	Domin
Festuca rubra	3
Hypochaeris radicata	1
Plantago coronopus	7
Ceratodon purpureus	4
Bare ground	4

Date of record: 19-08-04 **Recorder**: JP Doody

A Quadrat 02 SH 50

	Domin
Desmazeria marina	2
Plantago coronopus	4
Poa pratensis	1
Sedum acre	3
Trifolium arvense	4
Ceratodon purpureus	3
Bare ground	4

Date of record: 19-08-04 **Recorder**: JP Doody

A Quadrat 03 SH50

	Domin
Desmazeria marina	3
Elymus farctus	2
Honckenya peploides	5
Plantago coronopus	4
Poa pratensis	4
Sedum acre	4
Ceratodon purpureus	2
Bare ground	

Date of record: 19-08-04 **Recorder**: JP Doody

A Quadrat 04 SH 50

	Domin
Lotus corniculatus	3
Plantago coronopus	4
Sedum acre	4
Trifolium arvense	3
Hypnum cupressiforme	4
Ceratodon purpureus	3
Bare ground	3

Date of record: 19-08-04 **Recorder**: JP Doody

A Quadrat 05 SH50

	Domin
Corynephorus canescens	3
Elymus farctus	4
Hypochaeris radicata	1
Plantago coronopus	3
Sedum acre	2
Trifolium arvense	2
Ceratodon purpureus	4
Bare ground	5

Date of record: 19-08-04 **Recorder**: JP Doody

This area of shingle vegetation is the most mature of the vegetation types. The shingle matrix consists of small pebbles and it has high humus content. It is characterised by having a very short, closed-cropped turf. It is species poor.

It appears to be most closely related to the area identified by Sneddon in the 1998 survey as **SH 50** though more fragmented. Thus all the quadrats have been assigned to:

SH 50 *Festuca rubra - Aira Praecox - Plantago coronopus* grassland

Human trampling (the area has a caravan park immediately to landward) associated with rabbit grazing appears to be the principle reason for the close-cropped nature of the sward.

Annex 2.3 Series B quadrats

B Quadrat 02 SH 50

	Domin
Arrhenatherum elatius	2
Cerastium fontanum	2
Hypochaeris radicata	2
Leontodon autumnalis	1
Lathyrus japonicus	3
Plantago coronopus	4
Rumex acetosella	2
Sedum acre	3
Trifolium arvense	2
Hypnum cupressiforme	4
Ceratodon purpureus	2
Cladonia furcata	5
Bare ground	4

Date of record: 19-08-04 **Recorder**: JP Doody

B Quadrat 04 SH 50

	Domin
Arrhenatherum elatius	2
Cerastium fontanum	3
Lathyrus japonicus	3
Plantago coronopus	5
Rumex acetosella	5
Senecio viscosus	1
Hypnum cupressiforme	2
Cladonia furcata	3
Bare ground	4

Date of record: 19-08-04 **Recorder**: JP Doody

B Quadrat 01 SH 11

	Domin
Arrhenatherum elatius	2
Cerastium fontanum	3
Elymus farctus	2
Lathyrus japonicus	5
Phleum arenarium	2
Plantago coronopus	3
Plantago lanceolata	2
Rumex acetosella	4
Rumex crispus	1
Sedum acre	2
Senecio viscosus	2
Sonchus arvensis	1
Bare ground	5

Date of record: 19-08-04 **Recorder**: JP Doody

B Quadrat 03 SH 11

	Domin
Arrhenatherum elatius	3
Cerastium fontanum	3
Glaucium flavum	4
Lathyrus japonicus	6
Lupinus arboreus	3
Rumex crispus	2
Sedum acre	4
Hypnum cupressiforme	2
Bare ground	5

Date of record: 19-08-04 **Recorder**: JP Doody

B Quadrat 05 SH 11

	Domin
Arrhenatherum elatius	4
Atriplex hastata	2
Elymus farctus	2
Festuca rubra	3
Holcus mollis	1
Lathyrus japonicus	4
Plantago coronopus	2
Plantago lanceolata	2
Rumex crispus	2
Senecio viscosus	2
Ceratodon purpureus	3
Bare ground	5

Date of record: 19-08-04 **Recorder**: JP Doody

Just beyond the main zone of SH50 there are areas of fragmented vegetation, which conform to SH50 and SH 11. These communities lie in the zone appearing to equate to the area recorded as having a community dominated by **SH 48** *Festuca rubra - Hypnum cupressiforme - Lotus corniculatus - Plantago lanceolata* community in the 1988 survey. During the 2004 survey this community was not recorded here but fragmentary examples of **SH 50** and **SH 11** were. It seems possible that reworking and/or disturbance of the shingle surface have resulted in the loss of **SH 48** and that this was replaced by bare shingle and **SH 11**.

Quadrats 02 & 04

SH 50 *Festuca rubra - Aira Praecox - Plantago coronopus* grassland

Quadrats 01, 03 & 05

SH 11 *Lathyrus japonicus* pioneer community

Annex 2.4 Series C quadrats

Set C Quadrat 01 SH 50

	Domin
Festuca rubra	3
Plantago coronopus	4
Sedum acre	2
Trifolium arvense	4
Ceratodon purpureus	6
Cladonia furcata	3
Evernia prunastre	4
Bare ground	5

Date of record: 19-08-04 **Recorder**: JP Doody

C Quadrat 02 SH48

	Domin
Daucus carota	1
Festuca rubra	2
Honckenya peploides	5
Plantago coronopus	3
Plantago lanceolata	3
Sedum acre	3
Hypnum cupressiforme	4
Cladonia furcata	5
Bare ground	4

Date of record: 19-08-04 **Recorder**: JP Doody

C Quadrat 03 SH 48

	Domin
Ammophila arenaria	4
Carex arenaria	2
Daucus carota	4
Festuca rubra	3
Honckenya peploides	4
Hypochaeris radicata	2
Lathyrus japonicus	6
Plantago lanceolata	2
Sedum acre	3
Trifolium arvense	2
Hypnum cupressiforme	4
Cladonia furcata	2
Bare ground	2

Date of record: 19-08-04 **Recorder**: JP Doody

C Qu 04 SH21

	Domin
Ammophila arenaria	6
Carex arenaria	2
Daucus carota	2
Honckenya peploides	2
Hypochaeris radicata	2
Lathyrus japonicus	2
Rumex crispus	2
Senecio jacobaea	2
Sonchus arvensis	1
Bare ground	4

Date of record: 19-08-04 **Recorder**: JP Doody

The sequence of quadrats opposite shows the progression of plants communities from the seaward edge of the hollow towards the sea wall. As with elsewhere on the site there is complex mixture and the match between the community types and the quadrat records is not close.

SH 50 *Festuca rubra - Aira Praecox - Plantago coronopus* grassland.

SH 48 *Festuca rubra - Hypnum cupressiforme - Lotus corniculatus - Plantago lanceolata* community.

SH 21 *Ammophila arenaria - Rumex crispus - Senecio viscosus* community.

The presence of the more mature stable communities (SH 50 and SH 48) could be relict from those present in the first survey in 1988 as they occur in approximately the same location. However, here as elsewhere there has been reworking by the sea (note the trend of the ridges in relation to the shoreline in Figure 5 of the main report) and probably as a result of human disturbance.

Annex 2.5 Series D quadrats

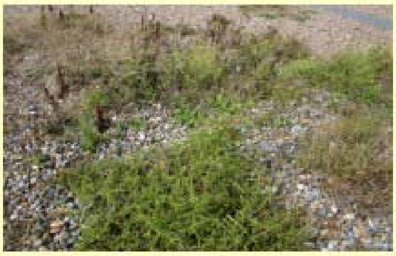
D Quadrat 01 SH 11

	Domin
Achillea millifolium	2
Glacium flavum	2
Lathyrus japonicus	4
Sonchus arvensis	4
Rumex crispus	2
Bare shingle	5

Date of record: 19-08-04 **Recorder**: JP Doody

D Quadrat 02 SH 11

	Domin
Beta maritima	5
Lathyrus japonicus	2
Raphanus maritimus	4
Rumex crispus	3
Senecio viscosus	2
Bare shingle	4



Date of record: 19-08-04 **Recorder**: JP Doody

D Quadrat 03 SH 11

	Domin
Arrhenatherum elatius	4
Glacium flavum	2
Epilobium hirsutum	4
Lathyrus japonicus	1
Raphanus maritimus	4
Rumex crispus	3
Sonchus arvensis	3
Bare ground	5

Date of record: 19-08-04 **Recorder**: JP Doody

D Quadrat 04 SH 11

	Domin
Arrhenatherum elatius	7
Beta maritima	4
Lathyrus japonicus	1
Raphanus maritimus	1
Rumex crispus	2
Bare ground	4

Date of record: 19-08-04 **Recorder**: JP Doody

D Quadrat 05 SH 11

	Domin
Glacium flavum	4
Elymus farctus	2
Lathyrus japonicus	5
Rumex crispus	2
Bare ground	4

Date of record: 19-08-04 **Recorder**: JP Doody

This series of quadrats has been assigned to **SH 11** *Lathyrus japonicus* pioneer community because the dominance of larger sized pebbles and the constant presence of *Lathyrus japonicus*. Compare this with **SH 21** *Ammophila arenaria* - *Rumex crispus* - *Senecio viscosus* community which has more sand and the presence of *Ammophila arenaria* as a constant). However, as the species list shows, the variation is considerable and detailed survey and analysis would be required to more accurately identify and assign these vegetation stands.

The quadrat records suggest that amongst these community types are variations of *Raphanus maritimus* dominated communities **SH 12** and **SH 13**, not recorded during the survey of 1988.

Recorder JP Doody 19-08-04

Annex 2.6 Series E quadrats

E Quadrat 04 SH 11

	Domin
Beta maritima	3
Daucus carota	4
Festuca rubra	4
Lathyrus japonicus	4
Raphanus maritimus	3
Rumex crispus	4
Bare shingle	8

Quadrate 4 is a typical example of this semi-open community though less species rich

Date of record: 14-08-04 **Recorder**: JP Doody

E Quadrat 05 SH 11

	Domin
Crambe maritima	5
Daucus carota	1
Festuca rubra	4
Lathyrus japonicus	3
Plantago lanceolata	5
Raphanus maritimus	3
Rumex crispus	2
Senecio jacobaea	3
Bare shingle	4

The community can become quite dense; Qu 05 gives an illustration

Date of record: 14-08-04 **Recorder**: JP Doody

E Quadrat 01 SH 21

	Domin
Arrhenatherum elatius	5
Crambe maritima	2
Daucus carota	2
Lathyrus japonicus	3
Plantago lanceolata	4
Raphanus maritimus	3
Rumex crispus	3
Bare shingle	8

Date of record: 14-08-04 Recorder: JP Doody

E Quadrat 03 SH 21

	Domin
Ammophila arenaria	3
Beta maritima	3
Cerastium fontanum	1
Daucus carota	2
Dactylis glomerata	3
Festuca rubra	4
Leontodon autumnalis	3
Lathyrus japonicus	4
Plantago lanceolata	2
Poa pratensis	2
Raphanus maritimus	4
Rumex crispus	3
Sedum acre	3
Senecio jacobaea	2
Bare shingle	5

Date of record: 14-08-04 Recorder: JP Doody

These quadrats were recorded to the landward of the Series D Quadrats. They show an equally diverse and complex series of vegetation types.

Quadrats 4 & 5

Quadrats 4 & 5 have been assigned to **SH 11** *Lathyrus japonicus* pioneer community again because the dominance of larger sized pebbles and the constant presence of *Lathyrus japonicus*.

The quadrat records suggest that these community types could be variations of *Raphanus maritimus* dominated communities **SH 12** and **SH 13**, not recorded during the survey of 1988.

Quadrats 1 & 3

The next two quadrats 1 and 3 have been assigned to **SH 21** *Ammophila arenaria - Rumex crispus - Senecio viscosus* community largely because of the presence of *Ammophila* as a constant species and the sandy nature of the shingle matrix. Again however, the species list and photographs do not correlate absolutely with SH 21, it may be more closely allied to **SH 41** *Arrhenatherum elatius – Festuca rubra – Plantago lanceolata – Silene maritima* grassland.

E Quadrat 02 SH 48

Species	Domin
Achillea millifolium	1
Carex arenaria	2
Daucus carota	3
Festuca rubra	4
Honckenya peploides	3
Hypochaeris radicata	2
Leontodon autumnalis	2
Lathyrus japonicus	4
Plantago lanceolata	3
Rumex crispus	1
Sedum acre	4
Senecio jacobaea	3
Ceratodon purpureus	2
Bare shingle	3

Date of record: 14-08-04 **Recorder**: JP Doody

E Quadrat 07 SH 48

Species	Domin
Festuca rubra	4
Hypochaeris radicata	3
Leontodon autumnalis	4
Lolium perenne	3
Plantago coronopus	2
Sedum acre	5
Trifolium arvense	1
Cladonia furcata	7
Evernia prunastre	3
Bare shingle	2

Quadrat 07 SH 48 is the only one encountered with lichens in the northern non SSSI part of the site.

Date of record: 14-08-04 **Recorder**: JP Doody

Quadrats 2 & 7

The presence of *Festuca rubra* as a key component of these quadrats has resulted in their being assigned to **SH 48** *Festuca rubra* - *Hypnum cupressiforme* - *Lotus corniculatus* - *Plantago lanceolata* community. However as can be seen from the species composition the match is not exact.

E Quadrat 06 SH 50

Species	Domin
Ammophila arenaria	3
Carex arenaria	3
Festuca rubra	3
Honckenya peploides	4
Hypochaeris radicata	2
Plantago coronopus	3
Rumex acetosella	3
Sedum acre	4
Trifolium arvense	2
Hypnum cupressiforme	4
Bare shingle	6

Date of record: 14-08-04 **Recorder**: JP Doody

Quadrat 6

This quadrat that lies towards the inner landward section of the shingle zone fits closely with the mature shingle vegetation at the southern end of the site and has been assigned to **SH 50** *Festuca rubra* - *Aira Praecox* - *Plantago coronopus* grassland.

As the species lists and comments above indicate, the variation in vegetation type is considerable. It is felt that further detailed survey and analysis would more accurately identify and assign these vegetation stands. Note the comments in the record; these were made at the time of recording. It was clear then that the range of variation in this part of the site was such as to require more detailed quadrat recording than time would allow in this contract. As a consequence only samples of the main types only were taken.

Recorder JP Doody 14-08-04

Annex 2.7 Series F quadrats

F Quadrat 01 SH21/11

	Domin
Ammophila arenaria	3
Carex arenaria	1
Daucus corota	1
Festuca rubra	4
Hypochaeris radicata	1
Leontodon autumnalis	1
Lathyrus japonicus	5
Trifolium arvense	1
Bare ground	5

Date of record: 14-08-04 **Recorder**: JP Doody

F Quadrat 02 SH21

	Domin
Ammophila arenaria	2
Carex arenaria	1
Cerastium fontanum	2
Daucus corota	3
Festuca rubra	6
Hypochaeris radicata	3
Leontodon autumnalis	1
Lathyrus japonicus	5
Plantago lanceolata	3
Senecio jacobaea	1
Hypnum cupressiforme	4
Ceratodon purpureus	4
Bare ground	4

Date of record: 14-08-04 **Recorder**: JP Doody

F Quadrat 03 SH 21

	Domin
Ammophila arenaria	3
Carex arenaria	2
Daucus corota	2
Festuca rubra	5
Hypochaeris radicata	2
Lathyrus japonicus	7
Hypnum cupressiforme	3
Ceratodon purpureus	2
Bare ground	4

Date of record: 14-08-04 **Recorder**: JP Doody

F Quadrat 04 SH 21

	Domin
Ammophila arenaria	3
Daucus corota	3
Festuca rubra	4
Hypochaeris radicata	3
Lathyrus japonicus	7
Lotus corniculatus	2
Trifolium arvense	2
Bare ground	7

Date of record: 14-08-04 **Recorder**: JP Doody

F Quadrat 05 SH 21

	Domin
Ammophila arenaria	1
Crambe maritima	2
Daucus corota	1
Festuca rubra	4
Hypochaeris radicata	2
Lathyrus japonicus	5
Plantago lanceolata	2
Ceratodon purpureus	3
Bare ground	5

Date of record: 14-08-04 **Recorder**: JP Doody

These quadrats have all been assigned to **SH 21** *Ammophila arenaria - Rumex crispus - Senecio viscosus* community largely because of the presence of *Lathyrus japonicus* and *Ammophila arenaria* as constant species. This together with the sandy nature of the shingle matrix also reflected in the presence of *Carex arenaria* another characteristic species of sandier situations.

The Series F quadrats were taken along a ridge line lying approximately parallel to the shore and on the landward side. To seaward the vegetation is dominated by *Ammophila arenaria* tussocks which sweep round to the north and west.

Quadrat 1 has appears to lie somewhere between **SH 21** and **SH 11** *Lathyrus japonicus* pioneer community again because the dominance of larger sized pebbles and reduced amount of sand.

The presence of *Festuca rubra* as a key component of some of these quadrats also suggests they may be moving towards **SH 48** *Festuca rubra - Hypnum cupressiforme - Lotus corniculatus - Plantago lanceolata* community. However, without much more comprehensive survey the match cannot be established.

Recorder JP Doody 14-08-04

Annex 2.8 Shingle Community Descriptions/NVC equivalents of shingle vegetation found in both the 1988 and 2004 survey of Benacre Ness from Coastal Vegetated Shingle Structures of Great Britain (1993)

Mature grassland communities – *Festuca rubra*

SH50 (NVC equivalent MC5: *Armeria maritima – Cerastium diffusum ssp. diffusum* maritime therophyte community)
In this case *Festuca rubra* and the herbs *Aira praecox, Plantago coronopus* and *Silene maritima* comprise the major indicator species. There is evidence that this may represent a sandy version of the more mature *Festuca rubra* grassland as illustrated in the frequent presence of arenicolous species such as *Sedum acre, Carex arenaria, Desmazeria marina, Brachythecium albicans* and *Ammophila arenaria* within the assemblage. In addition, *Armeria maritime, Ceratodon purpureus* and *Lotus corniculatus* are also commonly found in association. This assemblage is distinguished from other mature *Festuca rubra* grasslands by the lack of a lichen content with the only occasional presence of *Cladonia verticillata* and *C. furcata* found in small quantities. This assemblage is also southern in extent, found from Blakeney in north Norfolk to the Isles of Scilly in the south west. This may be an example of an earlier stage in the development of the *Festuca rubra* grassland described above.

SH48 (NVC equivalent: SD7 *Ammophila-arenaria – Festuca rubra* semi-fixed dune community
Another major *Festuca rubra* shingle grassland is defined by the constant presence of *Festuca rubra, Hypnum cupressiforme* and *Lotus corniculatus* with *Plantago lanceolata, Sedum acre* and *Aira praecox* as the prime associates. Although the lichen content in this assemblage is not as diverse as in the others nor, indeed, as important, in places *Cladonia furcata* and *C. verticillata* become locally important. Additional associates are herbaceous with particular emphasis on *Hypochoeris radicata, Senecio jacobaea, Plantago coronopus* and *Cerastium diffusum* as the minor associates. This community is represented at many sites which are largely southern in distribution. This herb rich assemblage is separated from another mature grassland community at the final level of division.

Mature grassland – *Arrhenatherum elatius*

SH41 (NVC equivalent: No clear match. The closest is SD7 *Ammophila-arenaria – Festuca rubra* semi-fixed dune community)
A more maritime, less mature version of the grassland described above emerges at the ninth level of division where the two communities are divided. In this case, *Arrhenatherum elatius, Festuca rubra, Plantago lanceolata, Silene maritima* and *Rumex crispus* are the key indicators with a major herb element among the associates. The key associates include *Hypochoeris radicata, Cerastium semidecandrum, Lathyrus japonicus* and *Geranium robertianum*. Clearly this assemblage is closely related to the previous community with many of the same constants and major associates. However, it is the absence of any lichens or bryophytes which distinguishes this community and which may indicate the less mature nature of this unit. This, along with the constant presence of maritime herbs, may indicate that this is an earlier stage in the development of this type of grassland. The distribution of this community is largely northern, although it is also found at one southern location, which incidentally also supports the previous community. This community is also less rich in

species than the former with an average of ten species per quadrat as opposed to sixteen in the former.

SH21 (**NVC equivalent:** SD1 *Rumex crispus – Glaucium flavum* shingle community)
The first is a widespread community found across many shingle sites. It is an example of a secondary pioneer community typical of shingle sites with a high proportion of sand within the shingle matrix. This assemblage is characterised by the constant presence of *Ammophila arenaria* which is often found to dominate in terms of the cover it provides. However, this is not typical throughout the community which is distinguished by its major associates, *Rumex crispus* and *Senecio viscosus*, both of which are found frequently throughout the assemblage although neither has a Domin score greater than 4. Additional arenicolous species which may occasionally be found in association include *Honkenya peploides, Glaucium flavum, Desmazeria marina* and *Carex arenaria. Festuca rubra, Cirsium vulgare* and the rare shingle species *Lathyrus japonica* are also found as occasional community components. On average each quadrat contains only eight species.

Herb-dominated pioneer communities

SH11 (NVC equivalent: SD1b *Rumex crispus – Glaucium flavum* shingle community, *Lathyrus japonicus* sub-community)
A southern community which emerges in this section of the classification is defined by the dominance of the nationally rare *Lathyrus japonicus.* This represents a shingle pioneer community in which overall cover is usually low and mostly *Lathyrus japonicus*. There are very few associates in this assemblage with on average, three species per quadrat. *Rumex crispus, Cirsium arvense, Glaucium flavum* and *Sonchus asper* are the species most commonly found in association with *Lathyrus japonicus*. This community is typical of many southern shingle sites reflecting the distribution of *Lathyrus japonicus*.

SH8 (**NVC equivalent:** SD1 *Rumex crispus – Glaucium flavum* shingle community)
Another pioneer community is identified at the eighth level of division, although in this case *Crambe maritima* is a less important component, being found as a minor associate. This community is characterised by the constant presence of *Senecio viscosus,* which is found with the major associates *Glaucium flavum, Solanum dulcamara* and *Rumex crispus.* There are on average six species per quadrat in this assemblage with *Arrhenatherum elatius* and *Senecio jacobaea* as minor associates along with *Crambe maritima*. The community is commonly found on southern shingle sites, although it has also been recorded on sheltered Scottish sites. This reflects the distribution of *Senecio viscosus.*

3. Benacre to Easton Bavents SSSI: prediction of coastal change

Dr M Lee

3.1 Introduction

This section provides an assessment of the following:

- a prediction of the likely position of the coastline in 2054;
- an indication of the extent of the GCR interest at Benacre Ness.

The following assessment is based on a field visit (13 August 2003), together with a review of the following documents:

- *Lowestoft to Harwich Shoreline Management Plan, sediment sub-cell 3c. Volume 4: Shoreline Management Plan*. Halcrow (1998);
- *Lowestoft to Thorpeness Coastal Process and Strategy Study Volume 2: Coastal Processes.* Halcrow (September 2001);
- *Suffolk Coast and Estuaries Coastal Habitat Management Plan Final Report.* Posford Haskoning (October 2002).

The coastline comprises a series of 5-10m coastal cliffs developed in weak Pleistocene sands and gravels (Norwich Crag), separated by low-lying marsh and lagoon areas (Broads) that are fronted by low sand/shingle barrier beaches. The northern end of the coastal section is dominated by a series of sand and shingle ridges that form a low promontory known as Benacre Ness.

3.2 Coastal cliffs

The coastline contains five separate cliff sections:

1. **Benacre cliffs.** (Grid reference TM534836 to TM532831): a 0.5km long cliffline developed in Norwich Crag sediments. The cliffs are generally 3-5m high, with a near-vertical profile and are fronted by a partitioned sand and shingle beach.
2. **Covehithe cliffs** (Grid reference TM530826 to TM523809): a 7-10m high cliffline developed in Norwich Crag sediments (current bedded gravels and sands of the Westleton Beds), extending from Benacre Broad to Covehithe Broad (1.9km). The cliffs have a near-vertical profile and a discontinuous talus apron of rockfall and debris slide material at the cliff foot. The cliffline is fronted by a partitioned sand and shingle beach.
3. **Easton Wood cliffs** (Grid reference TM522805 to TM519798): a 0.8km long cliffline developed in Norwich Crag sediments, extending from Covehithe Broad to Easton Broad. The 5-10m high cliffs have a near-vertical profile and are fronted by a partitioned sand and shingle beach.

4. **Easton Broad cliffs (North Warren Cliffs)** (Grid reference TM516791 – TM515788): a short (0.35km) section of low cliffs (<5m high) within the Easton Broads and Easton Marshes complex. The cliffs are developed in Norwich Crag sediments, have a near vertical upper profile and an almost continuous talus cone at the cliff foot. The partitioned sand and shingle beach is part-vegetated to the rear.

5. **Easton Bavents cliffs** (Grid reference TM514785 to TM512773): a 1km long section of cliffs extending from Easton Marshes to the northern end of the Southwold sea defences. The cliffs are developed in Norwich Crag sediments, with mixed sand-shingle of the Westleton Beds and clay with sand laminae of the Easton Bavents Clay.

In addition, two sections of cliff near Kessingland have been identified as being affected by the movement of Benacre Ness. These are:

Patefield Cliffs (Grid reference TM536885 to TM535880;
Kessingland Cliffs (Grid reference TM537880 to TM535871).

3.2.1 Cliff recession to date

The cliff line is undefended and has experienced very severe recession over the last century (see Table 1):

Table 1. Cliff recession 1884-1976 and 1991-1999

Cliff section	Cumulative recession* (1884-1976)	Cumulative recession** (1991-1999)
Benacre cliffs	436m	57m
Covehithe cliffs	421m	64m
Easton Woods cliffs	390m	9m
Easton Broad cliffs	354m	58m
Easton Bavents cliffs	276m	9m

Notes: * recession rates determined from comparison of the cliff top positions on different Ordnance Survey map editions (Halcrow 2001).
** recession at SDMS section/EA profile along the cliffline with the largest recorded recession. Note that the data is for HWM retreat – as the cliffline retreats by landward translation of the entire cliff-beach profile, it was assumed that, over the medium-term, HWM retreat is equivalent to cliff top retreat.

It is clear that Benacre cliffs and Covehithe cliffs have experienced the highest recession rates over the period 1884-present day. This is believed to be a response to the progressive increase in exposure of these cliffs to wave attack following the gradual northward migration of Benacre Ness.

3.2.2 Prediction of future cliff recession

Considering the cliff behaviour over the next 50 years, it is expected that there will be on-going recession at an accelerated rate due to the effects of sea-level rise.

A simple indication of the cliff position in 50-years time can be gained by extrapolating the historical trends:

Table 2. Extrapolation of historic trends to 2053

Cliff section	Medium-term recession rate (m/year)* (1946-1976; 1991-1999)	Simple extrapolation: predicted recession (2003-2053)
Benacre cliffs	4.89	244.5m
Covehithe cliffs	7.75	387.5m
Easton Woods cliffs	6.63	331.5m
Easton Broad cliffs	7.69	384.5m
Easton Bavents cliffs	4.32	216m

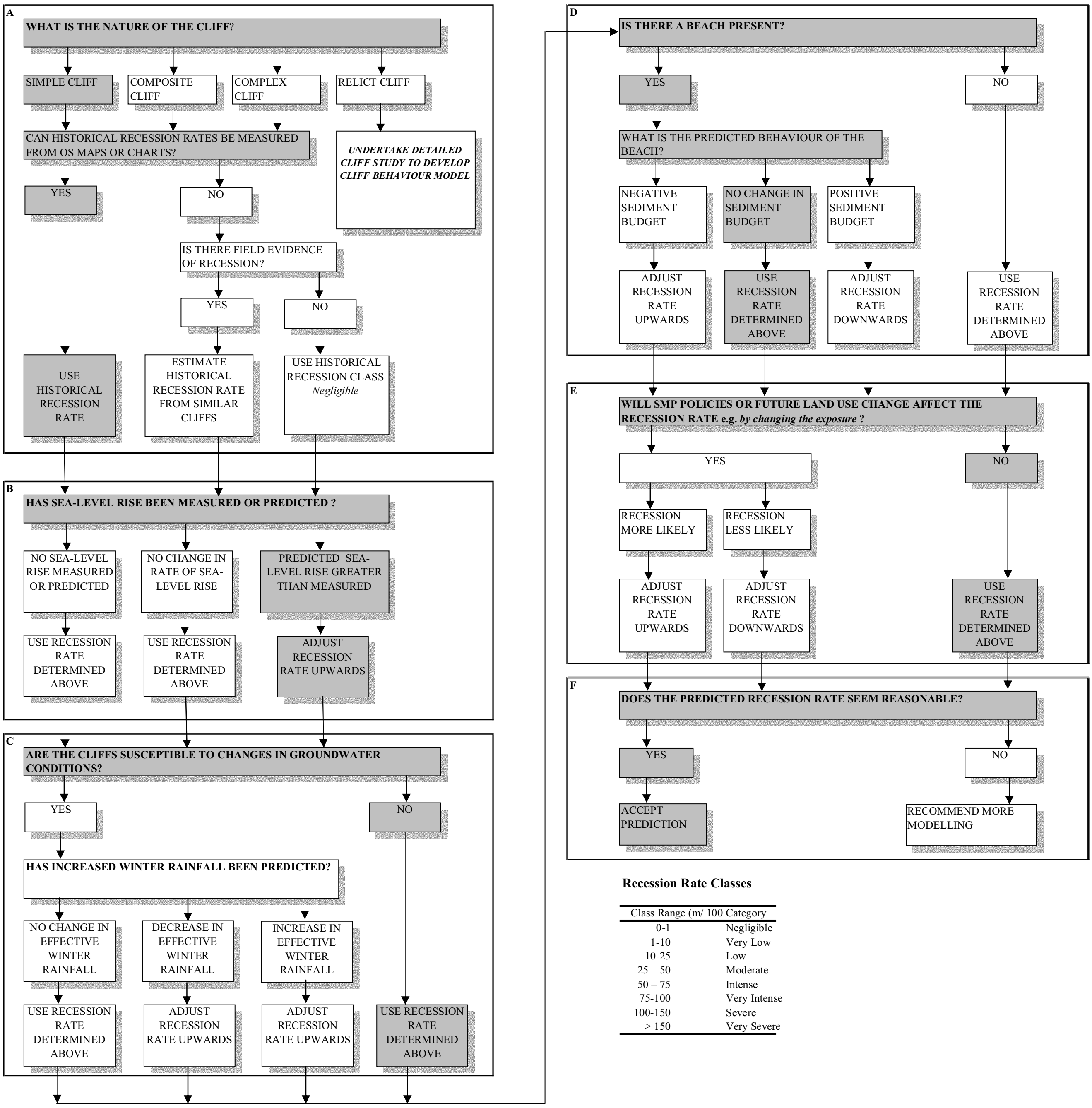
Note: * a medium-term recession rate that has operated over the last 50 years has been established by combining the 1946-1976 cumulative recession and the 1991-1999 cumulative recession and dividing by the number of years of the record (38 years)

However, Lee and Clark (2002) have pointed out that there can be significant limitations to this extrapolation approach. Predictions of cliff recession that are based on extrapolation of past trends do not reflect the potential uncertainty and variability in the cliff recession process. The sources of uncertainty include:

- the rate of future sea-level rise;
- the degree of natural cliff protection provided by the beach;
- the response of the cliffline to higher winter rainfall predicted to result from climate change;
- the response of the cliffline to local changes in shoreline orientation, ie the gradual loss of a headland (ie a ness) that protects the adjacent cliff sections;
- the variability of the materials exposed in the cliff face at a particular time.

Probabilistic methods offer an improvement on conventional deterministic predictions because they aim to acknowledge and take account of these sources of uncertainty. Probabilistic methods are essentially sophisticated sensitivity tests in which single data values (ie recession rates) are replaced by probability distributions that cover all possible values or outcomes.

A probabilistic cliff recession model (Annex A) has been used to develop a probability distribution, rather than a single recession rate, for each cliffline (Lee 2003, Lee 2005). The framework for this model is presented as Figure 1 and involves a series of separate stages at which judgements, based on the available knowledge of the site conditions, are made about the need to adjust the historical recession rate because of changing future conditions, especially future sea-level rise.



Recession Rate Classes

Class Range (m/ 100	Category
0-1	Negligible
1-10	Very Low
10-25	Low
25 – 50	Moderate
50 – 75	Intense
75-100	Very Intense
100-150	Severe
> 150	Very Severe

Shading indicates the logic route taken through the model in this example

Figure 1 Framework for the probabilistic cliff recession model (after Lee 2003; Lee and Jones, in press)

The model is described in more detail in Annex A. In this study, the model takes account of the two following sources of uncertainty:

sea-level rise: four alternative scenarios are considered – the low, medium-low, medium-high and high scenarios developed by the UKCIP:

Table 3. Change in sea level (mm) with respect to mean of 1961 to 1990

Scenario	2020s	2050s	Probability
Low	70	120	0.1
Medium-low	80	180	0.4
Medium-high	120	250	0.4
High	380	670	0.1

(Source: Hulme & Jenkins, 1998; MAFF-PAGN, 1995).

A judgement has been made on the relative likelihood of each of these scenarios, reflecting the UKCIP view that the medium-low and medium-high are more likely (eg Hulme and others 1998).

the historical (medium-term) recession rate for each cliffline: as indicated in Table 1 (Annex A) there is considerable variation in the recorded recession rates between the various measuring points (SDMS sections and Environment Agency/Waveney District Council Profiles; see Box 1) along each cliffline. However, it is clear that the clifflines have been retreating in a relatively uniform manner (ie parallel retreat), rather than fragmenting into a series of separate bays as a result of differential recession rates.

Although it is clear that individual lengths of a particular cliffline actually erode at similar rates, there is uncertainty over which recorded rate presents the most reliable measure of the historical recession. It was assumed that each recorded historical recession rate for a cliffline was equally likely.

In addition, for this study the assumption has been made that over the next 50 years there would be no change in the regional sediment budget.

Box 1 Sea Defence Management Study

In the late 1980's, NRA Anglian Region (the predecessor of the Environment Agency) began the implementation of its Sea Defence Management Study (SDMS), to provide an overview of prevailing coastal processes and to gain a basic coastal geomorphological understanding from the Humber to the Thames.

Phases IV and V of the SDMS monitoring programmes have comprised: region-wide bi-annual beach profile surveys at 1km centres; bathymetric survey on a 5 Year rolling programme and aerial surveys delivering 1:5000 stereoscopic black/white pairs.

Beach profile survey locations SWE5 to SWD10 lie on the shoreline between Lowestoft and Southwold. Locations are given in Annex A Table A1.

The migration of Benacre Ness has probably had an important influence on beach levels and cliff recession rates along this coastline (see Annex B). As the ness migrates northwards, beach levels on the northern margins will have gradually increased and cliff recession declined. However, on the southern margin, the reverse would have been true. It is expected that the cliffs within the SSSI now lie beyond the southern zone of influence of the ness. Some confirmation of this is provided by the fact that beach levels in front of Benacre and Covehithe cliffs are already very low. As a result it is not expected that there will be significant changes in shoreline exposure over the next 50 years.

A range of possible cases has been developed for each cliffline, reflecting different combinations of sea-level rise predictions and historical recession rate. Each of these cases result in a different predicted average annual recession rate and can be assigned a conditional probability:

Prob. (Case *n*) = Prob. (Sea level rise scenario) x Prob. (Historical recession rate)

For a particular cliffline, the sum of the conditional probabilities for all possible cases adds up to 1.0. The results of the modelling are presented as a simple plot of the predicted 50-year recession distance (predicted annual recession rate x 50) against its probability or the cumulative probability of a particular 50-year recession distance (Figures 1-5 Annex A).

The results are summarised in Table 4 in terms of the percentage confidence that the 50-year recession would be less than a particular 'upper bound' value. For example, at Benacre cliff, there is a 95% chance that the cumulative recession over the next 50 years would be less than 300m (ie a 5% chance it would be greater than this value) and a 75% chance that the cumulative recession would be less than 250m.

Table 4. Percentage confidence of predicted 50 year recession distances

Cliff Section	'Upper bound' recession: 95% cumulative probability distance (m)	75% cumulative probability distance (m)
Benacre cliffs	<300	<250
Covehithe cliffs	<400	<350
Easton Woods cliffs	<350	<300
Easton Broad cliffs	<425	<400
Easton Bavents cliffs*	<225	<200

Note: * The southern part of this cliffline is currently protected by a bank of dumped material. At this section the 50-year recession distances will probably be less than that indicated above. Annex C provides further consideration of the impacts of this bank.

Material has been dumped on the beach to protect the southern part of the Easton Bavents cliffs (south of Grid Ref TM 51261 77482). Whilst the material has prevented cliff recession it is unclear as to how long it will remain effective in future. As a result there is considerable uncertainty regarding the likely 50-year recession distance in this area. It could range from close to 0m (if dumping of material continues) to over 200m (if the dumping of material halts and it begins to erode). Further consideration of this issue is presented in Annex C.

It is suggested that the 95% cumulative probability distances above could be used to define the landward extent of the SSSI boundary behind each eroding cliffline, as this figure reflects some of the uncertainties associated with future shoreline changes. While the figures provided currently represent the best possible estimates of future cliff recession, there is a limit to the predictability of cliff recession and it is suggested that these figures should be reviewed at regular intervals to ensure that the predictions of recession rates remain reasonable.

3.3 Coastal lagoons

The clifflines are separated by a series of brackish coastal lagoons, known locally as 'Broads', fronted by sand and/or shingle beach barriers:

1. **Benacre Broad (TM 529828)**: a low natural dune ridge, vegetated by marram grass, approximately 60m wide, fronts Benacre Broad.
2. **Covehithe Broad (TM 523808)**: the broad is protected by a low natural sand-shingle ridge. In front of this ridge the beach width is approximately 100m. There is a low vegetation cover of marram grass on the ridge.
3. **Easton Broad (TM 516794)**: the broad and low-lying marshes are protected by a substantial sand and shingle ridge, which is currently artificially maintained by the Environment Agency. The maintenance by bulldozing results in the ridge being about 2m high and along much of its length between 10 to 15m wide, with steep landward and seaward faces. To the south the ridge is replaced by a man-made bund, which is up to 3m in height. The management of the ridge and bund is currently under review and may change in future.

The barrier beaches have been rolling inland at similar rates to the recession of the adjacent clifflines:

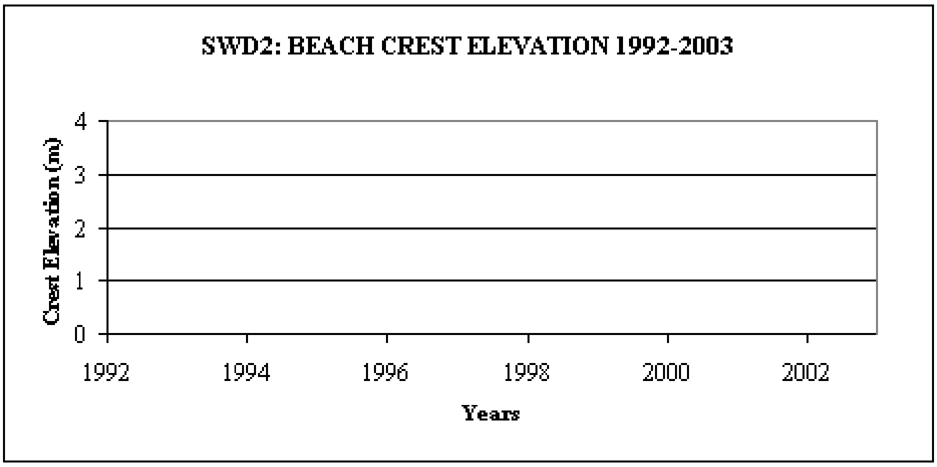
Table 5. High Water Mark (HWM) retreat rates to 1976.

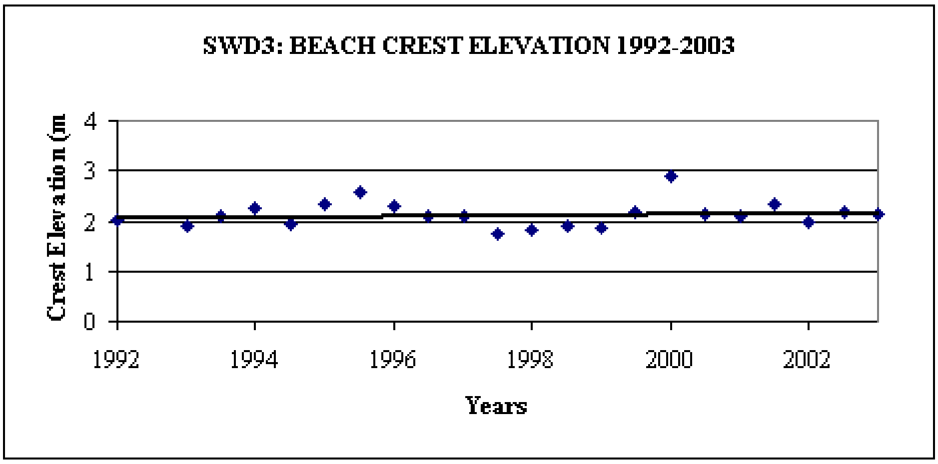
Barrier Beach	HWM Retreat Rate* (m/year) 1946-1976	Cumulative HWM Retreat*(m) 1884-1976	HWM Retreat Rate* (m/year) 1884-1976
Benacre Broad (SDMS Section 533)	3.59	415.97	4.52
Covehithe Broad (SDMS Section 525)	6.68	333.69	3.63
Covehithe Broad (SDMS Section 525)	4.9	298.58	3.24
Easton Broad (SDMS Section 520)	4.8	294.6	3.2
Easton Broad (SDMS Section 519)	8.18	342.6	3.72
Easton Broad (SDMS Section 518)	7.8	329.2	3.58

Notes: * retreat rates determined from comparison of the HWM positions on different Ordnance Survey map editions (Halcrow 2001)

The barrier behaviour over the next 50 years is expected to be as follows:

- **Ongoing retreat at an accelerated rate controlled by the recession of the adjacent cliffs**.
- **Increased susceptibility to breaching**. This is because the gradual decline in beach crest elevations over the period 1992-2003 (despite accelerated cliff recession and supply of beach sediment), together with the effects of rising sea-level can be expected to result in an increase in potential for overwashing events in the future (see Box 2 and Figure 2).


SWD2: BEACH CREST ELEVATION 1992-2003
Crest Elevation (m)
0
1
2
3
4
1992
1994
1996
1998
2000
2002
Years


SWD3: BEACH CREST ELEVATION 1992-2003
Crest Elevation (m
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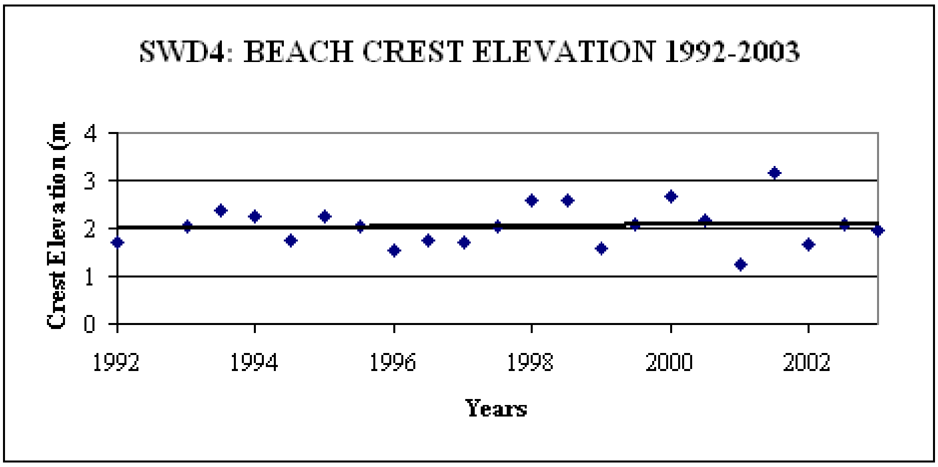
2
3
4
1992
1994
1996
1998
2000
2002
Years


SWD4: BEACH CREST ELEVATION 1992-2003
Crest Elevation (m
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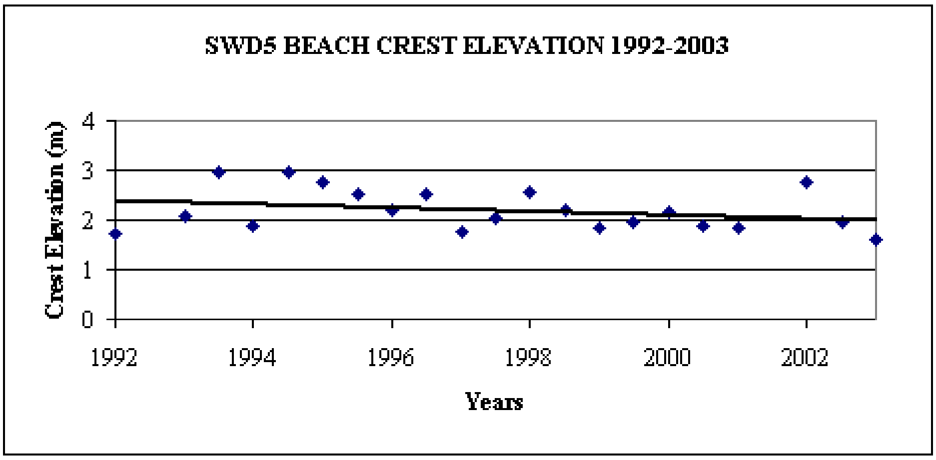
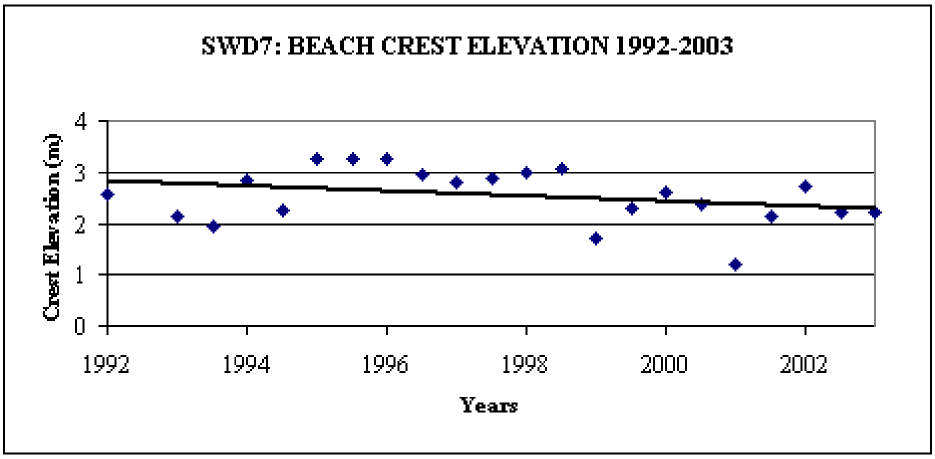




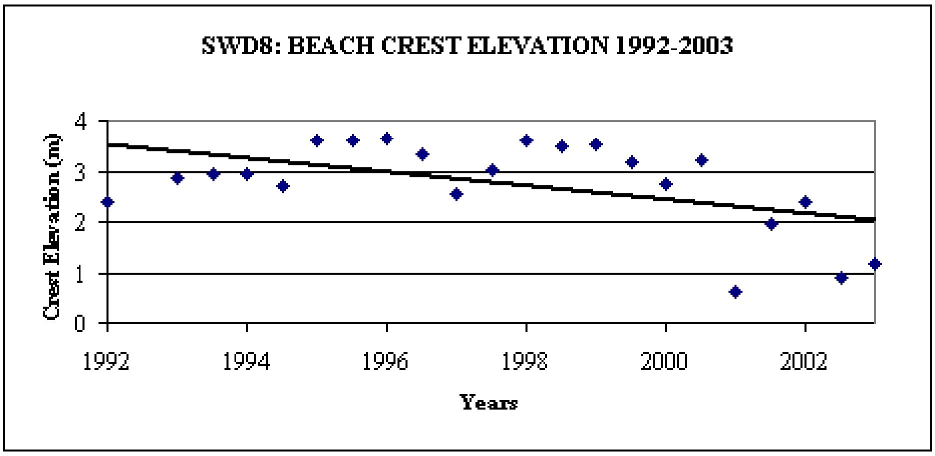


Figure 2 Beach Crest Trends 1992-2003

Box 2 Overwashing and breaching of shingle beaches

Surging wave flows up the beach face include:

- overtopping surge that transports material up the beach face and leads to increase in crest height;
- overwashing surge that carries gravel over the crest and towards the back-beach. This involves a greater magnitude of surge than overtopping events. Breaching may occur during overwashing events.

Beach behaviour involves brief episodes of overwashing and crest lowering, followed by longer periods of recovery during which the 'damage' to the beach crest caused by storm events is 'healed' during overtopping surge events.

The **overwashing ratio (OWR)** is the proportion of waves of sufficient magnitude to generate overwash events; it is a function of the wave climate and the barrier crest height **relative** to sea-level (Orford and others 1995). It is a measure of the potential for breaching. A number of conditions can be defined:

	Barrier Crest Constant	Barrier crest Increase	**Barrier crest decrease**
Sea-level fall	OWR decrease	OWR decrease	OWR constant*
Sea-level constant	OWR constant	OWR decrease	OWR increase
Sea-level rise	OWR increase	OWR constant*	**OWR increase**

Note: * assumes that crest height change is equivalent to sea-level change. The expected future condition is highlighted in bold.

3.4 Benacre Ness

Benacre Ness is an **updrift accretion ness**, comprising a series of sand and shingle ridges. The structure has been migrating northwards along this coastline in response to a combination of accretion on the updrift side and erosion on the southern side. It may be the product of long-term shortening of a spit system, which could have extended as far south as Dunwich. As the feature has contracted in size it has undergone a number of name changes, including Easton Ness and Covehithe Ness. Recent behaviour has involved (Halcrow 2001):

- northward migration of around 2.5 km since 1884, equating to an average annual rate of 22m/year;
- comparison of the MHW position for 1880, 1900, 1950, 1970 and 1992 Ordnance Survey maps and aerial photographs suggests that the rate of northward migration is around 10m/year;
- recent topographic surveys suggest that between 1995 and 1997 there was a net increase in the volume of material stored within the Ness;
- as the Ness has moved further northward it has become more elongate.

The outcome of the evaluation of the movement of the Ness over the next 50 year (see section 4) suggests that ness migration probably involves a combination of long periods of gradual change (13.3m/year), together with short periods of rapid change (100m/year) during rare storm events. Northwards ness migration of up to 1500m is predicted for the next 50 years. However, there are considerable uncertainties associated with the extrapolation of past rates to provide a future rate of migration, especially:

- the rate of sea-level rise and the impact it has on the pattern of wave refraction (ie longshore wave power) and the rate of cliff recession (ie sediment inputs);
- the behaviour of the offshore banks between Kessingland and Lowestoft.

The Ness is an important geomorphological feature as it has been actively migrating in the opposite direction to the regional sediment transport pattern. The interest at the site includes the following elements of the coastal system:

- the **supply zone**; ie the eroding clifflines to the north of the Ness – the Pakefield and Kessingland cliffs;
- the **transport zone**, ie the shingle beaches north of the Ness;
- the **accumulation zone**, ie the swash aligned northern margin where sediment is building up because of the reduced transport potential;
- the **eroding zone**, ie the southern margin where sediment is actively removed because of the increased transport potential;

The Geological Conservation Review (GCR) boundary (May & Hansom 2003) extends to Kessingland Beach and, hence, incorporates most of the features of immediate interest. However, the 1989 SSSI boundary does not include the accumulation zone. Section 4 of this report addresses this issue.

3.5 Impact of ness migration on cliff recession and shoreline erosion

There is a wide range of beach volumes along the shoreline. This is reflected in marked variations in recession rate, from 0m/year, where the cliffs or back-shore is protected by Benacre Ness, to over 7m/year on the open coast (see Annex B).

The migration of Benacre Ness along the shoreline will result in major changes in beach volume and, hence, cliff recession rate (see Annex B). Three zones can be defined:

- Zone 1; clifflines beyond the northern and southern margins of the ness; open coast beaches with beach profile areas above HWM (the "beach wedge") of less than $10m^2$ (eg SDMS sites D2-D5; Table B.3, Annex B), current recession rates up to 7m/year;
- Zone 2; clifflines at the margins of the ness; significantly higher beach wedge areas and (>$30m^2$; eg SDMS site E7) and current recession rates of around 0.3m/year;
- Zone 3; cliffs and back shore areas fronted by the ness complex; beach wedge areas in excess of 100-$500m^2$ (eg SDMS sites E8-E10, D1) and no recession.

As the ness migrates northwards, so a point on the shoreline passes from Zone 1, through Zone 2 and into Zone 3, before returning through Zone 2 to Zone 1. As the 4km long ness structure can be expected to move at an average rate of around 30m/year (Lee and Pethick 2004), so this entire process (Zone 1 to Zone 3 to Zone 1) will take around 130 years.

Table 6. Expected changes in cliff recession rates by 2053 at SDMS sites

Cliff Section	SDMS Profile	Year 0	Year 25	Year 50	Trend
Pakefield Cliffs	E6	Zone 1	Zone 2	Zone 3	Gradual cessation of recession
	E7	Zone 2	Zone 3	Zone 3	Gradual cessation of recession
Benacre Ness	E8	Zone 3	Zone 3	Zone 3	No change*
(Kessingland Cliffs)	E9	Zone 3	Zone 2/3	Zone 1/2	Increase in shoreline erosion
	E10	Zone 3	Zone 2	Zone 1	Increase in shoreline erosion
	D1	Zone 2	Zone 1	Zone 1	Increase in shoreline erosion
Benacre cliffs	D2	Zone 1	Zone 1	Zone 1	No change*
Covehithe cliffs	D3	Zone 1	Zone 1	Zone 1	No change*
	D4	Zone 1	Zone 1	Zone 1	No change*
Easton Woods cliffs	D5	Zone 1	Zone 1	Zone 1	No change*
Easton Broad cliffs	D6	Zone 1	Zone 1	Zone 1	No change*
Easton Bavents cliffs	D7	Zone 1	Zone 1	Zone 1	No change*

Notes: Zone 1; current cliff recession rate >3m/year. Zone 2; current cliff recession rate 0.3m/year. Zone 3; cliff recession rate 0m/year. These rates will increase over time due to the effect of sea-level rise.
* Although the trend will remain the same, the rates are predicted to increase due to the effects of sea-level rise.

Table 6 provides an indication of the changes that may be expected to occur over the next 50 years at SDMS sites around the current ness location. The key points to note are:

- a gradual reduction in recession rates along the Pakefield cliffs, currently to the north of the ness (Figure 3 and 4a). It is predicted that there will be a decline from the current average annual rate of 3.78m/year (SDMS profile SWE6) to 10% of this figure within 25 years. Recession is expected to have ceased within 50 years. The predicted 50-year recession distance at SWE6 (map co-ordinates 653687 288954) and SWE7 (map co-ordinates 653541 287990) is around 50m and 10m, respectively (Figures 3b and 4b).
- the onset of rapid erosion of the back-shore ground currently protected by the southern flanks of the ness, ie the Denes and Kessingland Levels. Shoreline retreat of between 300-400m could be expected over the next 50 years.

Ness migration is not expected to have an impact on the recession rates on the cliffs to the south, ie Benacre cliffs to Easton Bavents cliffs.

There is a relationship between changing beach conditions and cliff recession rates. This is illustrated in Figure 5, which is based on detailed analysis of beach-cliff profile surveys in Suffolk since 1992 (Lee 2004b and Lee 2005).

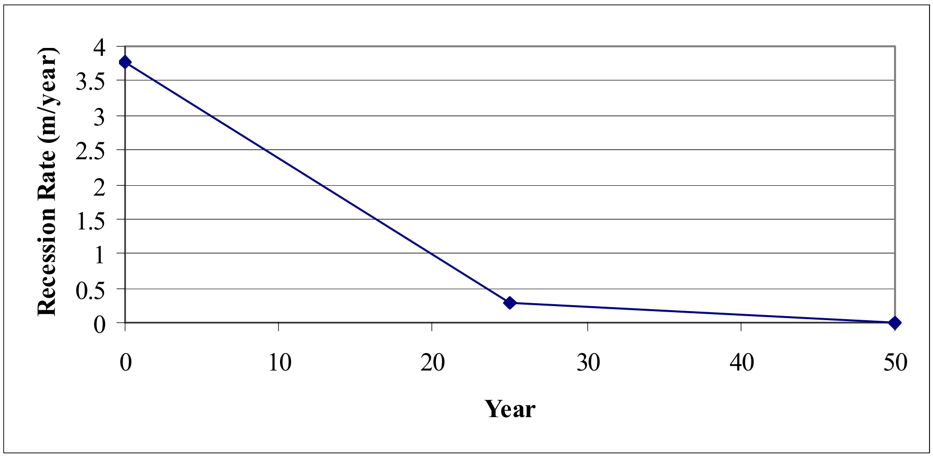


Figure 3a Pakefield Cliffs: Gradual decline in cliff recession rates (SWE6)

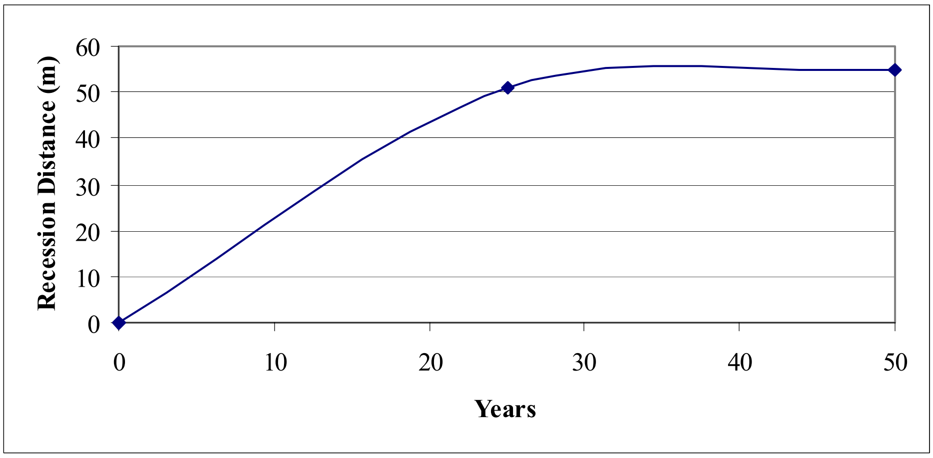


Figure 3b Pakefield Cliffs: Predicted recession distance (SWE6)

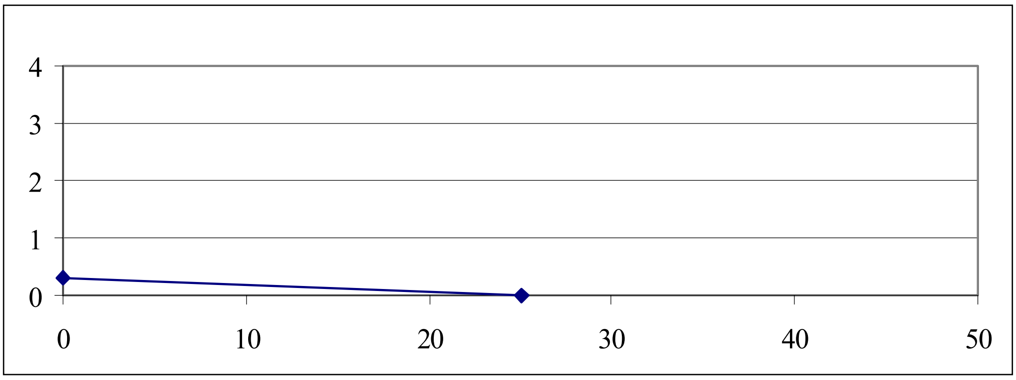


Figure 4a Pakefield Cliffs: Gradual decline in cliff recession rates (SWE7)

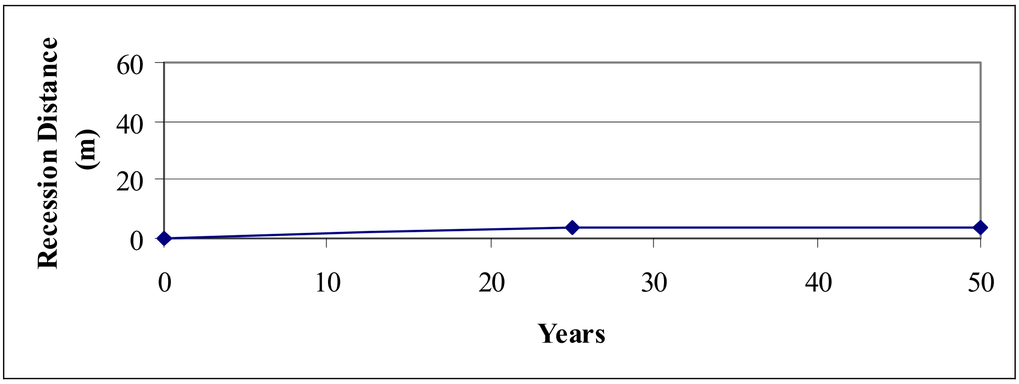


Figure 4b Pakefield Cliffs: Predicted recession distance (SWE7)

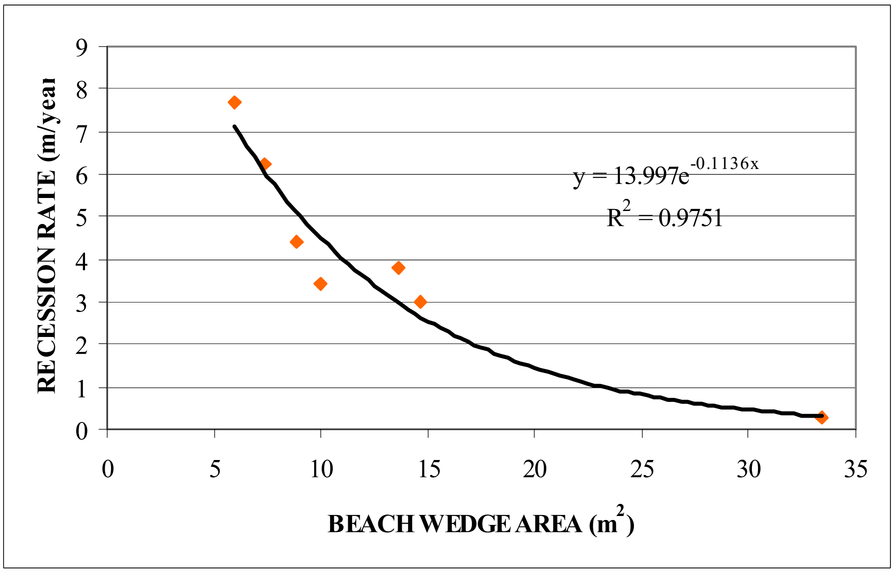


Figure 5 Suffolk Cliffs: Recession Rate and Beach Volume (Unprotected) (from Lee 2004, 2005)

3.6 Summary

A simple probabilistic model has been used to generate predictions of the cliff top position in 50 years time. The model takes account of uncertainty in the rate of future sea-level rise and the variability of the recorded recession rates along each cliffline. The results are expressed as a probability distribution for the 50-year recession and in determining the revised SSSI boundary it is recommended that this should be located as set out in Table 7 from the current cliff top position:

Table 7. Recommended inland location of SSSI boundary from current (2003) cliff top position.

Cliff section	Predicted 50-year recession (m)*
Benacre cliffs	<300
Covehithe cliffs	<400
Easton Woods cliffs	<350
Easton Broad cliffs	<425
Easton Bavents cliffs**	<225

* Note: there is a 5% chance that the cliff top recession would be greater than these figures. ** Lower recession distances will probably apply for the southern part of the Easton Bavents cliffs, as they are currently protected by dumped material.

It is expected that there will be on-going retreat of the barrier beaches fronting the broads, at an accelerated rate controlled by the recession of the adjacent cliffs.

The size of each of the Broad areas is constrained by the surrounding topography, ie the features are subject to natural coastal squeeze. There would be no significant retreat of the landward margin of the Broads.

Benacre Ness has been migrating northwards along this coastline in response to a combination of accretion on the updrift side and erosion on the southern side. It seems likely that the Ness will continue to migrate northwards over the next 50 years, possibly in the order of 1500m. However, there are considerable uncertainties associated with the rate of migration.

Ness migration will have a significant impact on the rate of cliff recession and shoreline erosion. It is predicted that beach accretion in front of the Pakefield and Kessingland Cliffs will result in a gradual decline in cliff recession rates over the next 50 years. However, the Denes and Kessingland Levels areas will become increasingly exposed to marine erosion.

The Ness is an important geomorphological feature as it has been actively migrating in the opposite direction to the regional sediment transport pattern. The GCR boundary extends to Kessingland Beach and, hence, incorporates most of the features of immediate interest. However, the SSSI boundary appears to coincide with the Hundred River outfall. As a result the SSSI does not currently include the accumulation zone.

4. Benacre Ness: Prediction of coastal change.
Dr M Lee and Professor J Pethick

4.1 Introduction

Benacre Ness comprises a series of low sand dunes and shingle ridges behind a partitioned sand and shingle beach. Historical evidence indicates that the ness has migrated northwards. It was important to understand how far north Benacre Ness is likely to 'migrate' over the next 50 years.

This assessment is based on a review of the following documents and information sources:

- *The Anglian Sea Defence Management Study – Stage III. Study Report*. Report prepared for the NRA Anglian Region. Halcrow (1991).
- *Lowestoft to Harwich Shoreline Management Plan, sediment sub-cell 3c. Volume 4: Shoreline Management Plan.* Halcrow (1998).
- *SDMS Profile Measurements 1992-1997*. Beach and Bathymetric Profiles (see Box 1 and Annex A Table A1 for Profile locations).
- *Lowestoft to Thorpeness Coastal Process and Strategy Study Volume 2: Coastal Processes.* Halcrow (September 2001);
- *Suffolk Coast and Estuaries Coastal Habitat Management Plan Final Report.* Posford Haskoning (October 2002).
- *FutureCoast.* Halcrow (2002).
- *Southern North Sea Sediment Transport Study, Phase 2 Sediment Transport Report.* HR Wallingford, CEFAS/UEA, Posford Haskoning and Dr Brian D'Olier. Report EX 4526 August 2002.
- *Coastal Geomorphology of Great Britain (GCR Volume No 28).* (V. May and J. Hansom 2003).

4.1.1 Definitions

In this report the Benacre Ness system is defined as

- the *northern face* ie where sediment is building up because of the reduced transport potential (SDMS Profiles SWE7 – SWE8);
- the *southern face* where sediment is actively removed because of the increased transport potential (SDMS Profiles SWE8 – SWD1).

The northern end of the ness is defined as the transition point between the narrow fringing beaches in front of the Pakefield cliffs and the broad accumulation of sand and shingle (currently around SWE7).

The ness lies within a broader coastal cell comprising:

- the *northern supply and transport zone*; ie the eroding clifflines and beaches to the north of the Ness – the Pakefield cliffs; (SDMS Profiles SWE5 – SWE7);

- the *southern supply and transport zone*; ie the eroding clifflines and beaches to the south of the Ness – the Benacre to Southwold cliffs; (SDMS Profiles SWD2 – SWD10).

For background, Table 8 below presents the principal tidal levels along the Lowestoft-Southwold shoreline.

Table 8. Principal tidal levels for the study area (source: Admiralty Tide Tables, 2000).

	Lowestoft	Southwold
HAT	1.4	-
MHWS	0.9	1.1
MHWN	0.6	0.7
MSL	0.10	0.25
MLWN	-0.5	-0.4
MLWS	-1.0	-0.8
LAT	-1.5	-
Chart Datum	-1.5	-1.3

4.1.2 Historical migration rates

Halcrow (2001, 2002), Posford Haskoning (2002) and May and Hansom (2003) provide brief reviews of the evidence of ness migration, based on inspection of historical maps and aerial photographs:

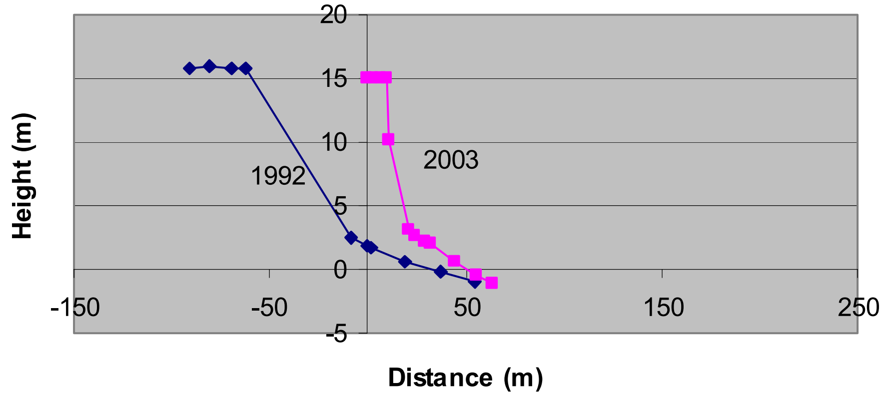
- around 4.4km of northwards movement since 1766, at an average annual rate of 23m/year. Note that in the period 1766 to 1783, the ness is shown to have moved northwards at 98m/year (May and Hansom 2003).
- around 2.5km of northwards movement since 1884, at an average annual rate of 22m/year. Over recent years, the migration rate is reported to have been around 10m/year.
- recent accretion on the northern face of up to 25m/year;
- surveys indicate that between 1995 and 1997 the Ness was accreting at a rate of around 66,000m^3/year (Birbeck College and Babtie 2000). Sediment eroded from the Ness is believed to be transferred offshore, accumulating below the 12m contour.

Note that Hardy (1964) suggested that there had been southwards migration of the ness since the beginning of the 20th century. However, there appears to be no map or monitoring evidence to support this view.

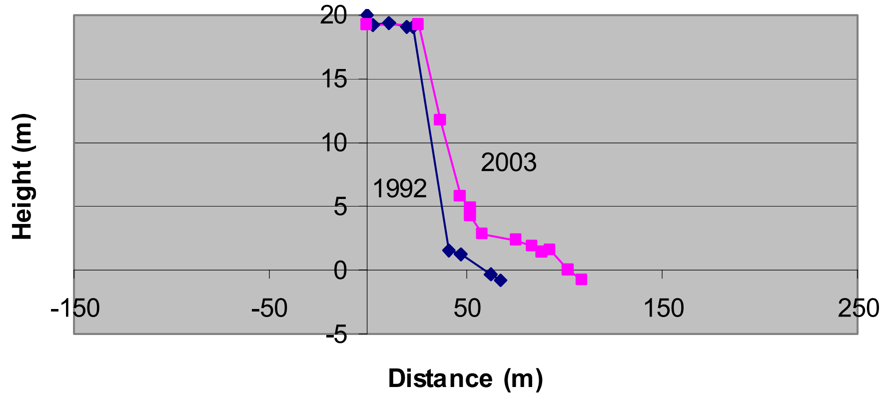
4.1.3 Recent migration rates

As part of this review the Environment Agency SDMS bathymetric and beach profiles were analysed (Profiles SWE6-E10; SWD1-D2; see Figure 6).

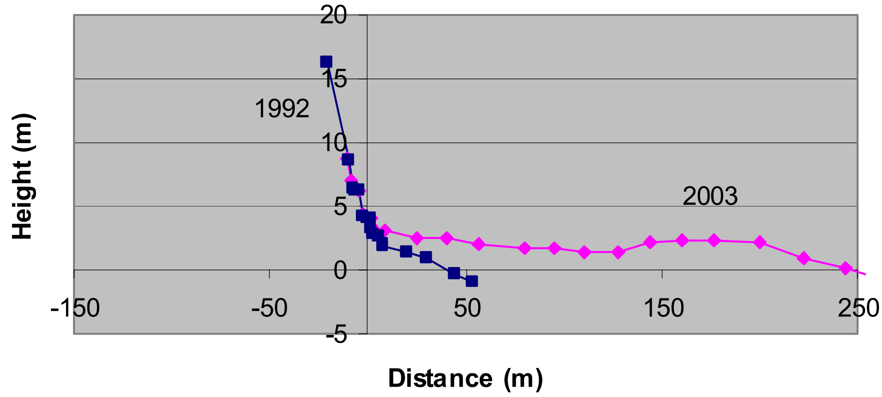
SDMS Profile SWE6: 1992-2003



SDMS Profile SWE7: 1992-2003



SDMS Profile SWE8: 1992-2003



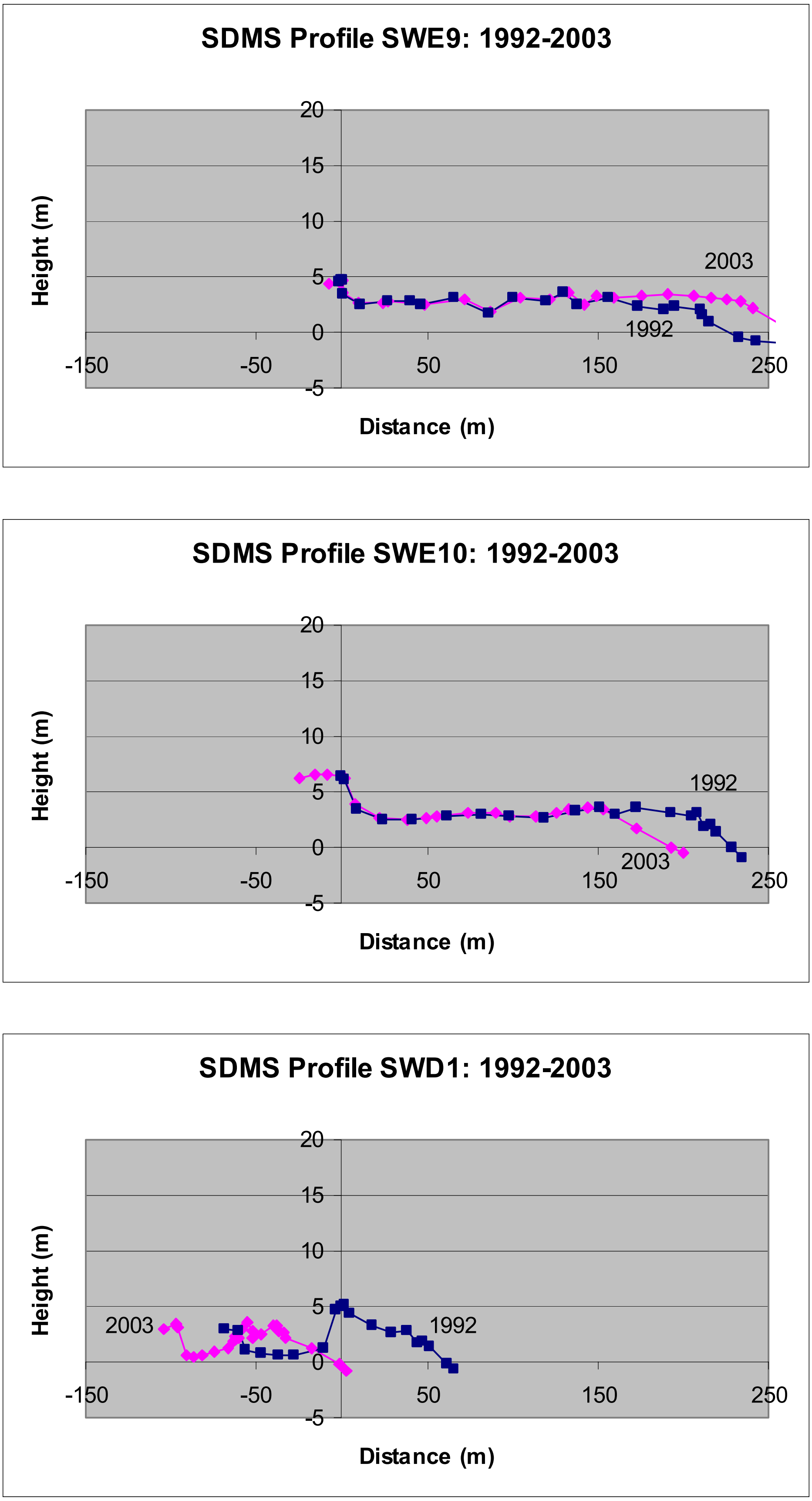


Figure 6 Analysis of SDMS bathymetric and beach profiles

The pattern of beach erosion and accretion between these dates is shown in Table 9.

Table 9. SDMS Profile beach changes (1992-2003)

Profile	Erosion (m)	Accretion (m)
SWE6		18.4
SWE7		40.49
SWE8		200.02
SWE9		38.04
SWE10	35.1	
SWD1	61.39	
SWD2	74.2	

Figure 7 presents the changes to the 0m OD contour between 1992 and 2003, as recorded at the SDMS profiles. This indicates that the northern face of the ness migrated northwards by between 920m and 1063m during this period, yielding an average annual migration rate of **83-106m/year**. Comparison of the 2003 0m contour with the 1980 Ordnance Survey shoreline position (HWMST, around 1m OD) suggests a northwards migration of around **72m/year** over that period.

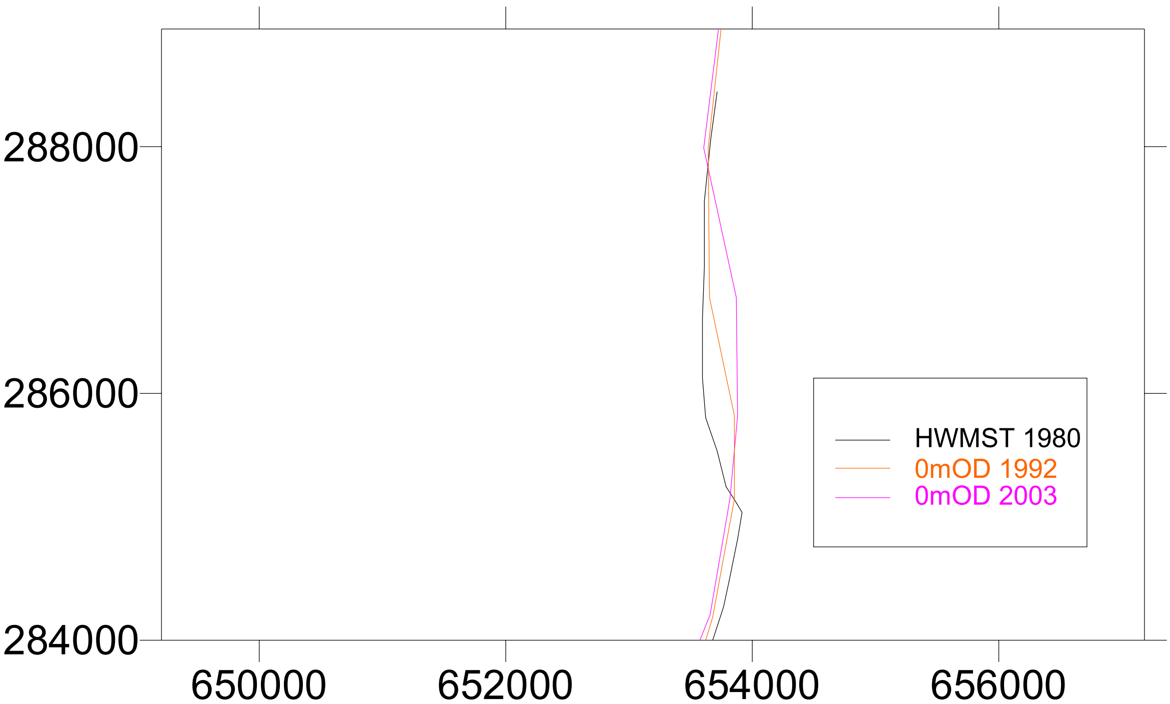


Figure 7 Benacre Ness: Comparison of the 0m OD contour position (1992 and 2003) and the 1980 HWMST position (1m OD)

Figure 8 presents the bathymetric changes between 1992 and 1997. This reveals a pronounced accumulation of material on the seabed off the northern face of the ness, as indicated by the north-facing "bulge" in the -4m contour. The northward tip of this bulge has moved north during this period by around 825m (ie **165m/year**).

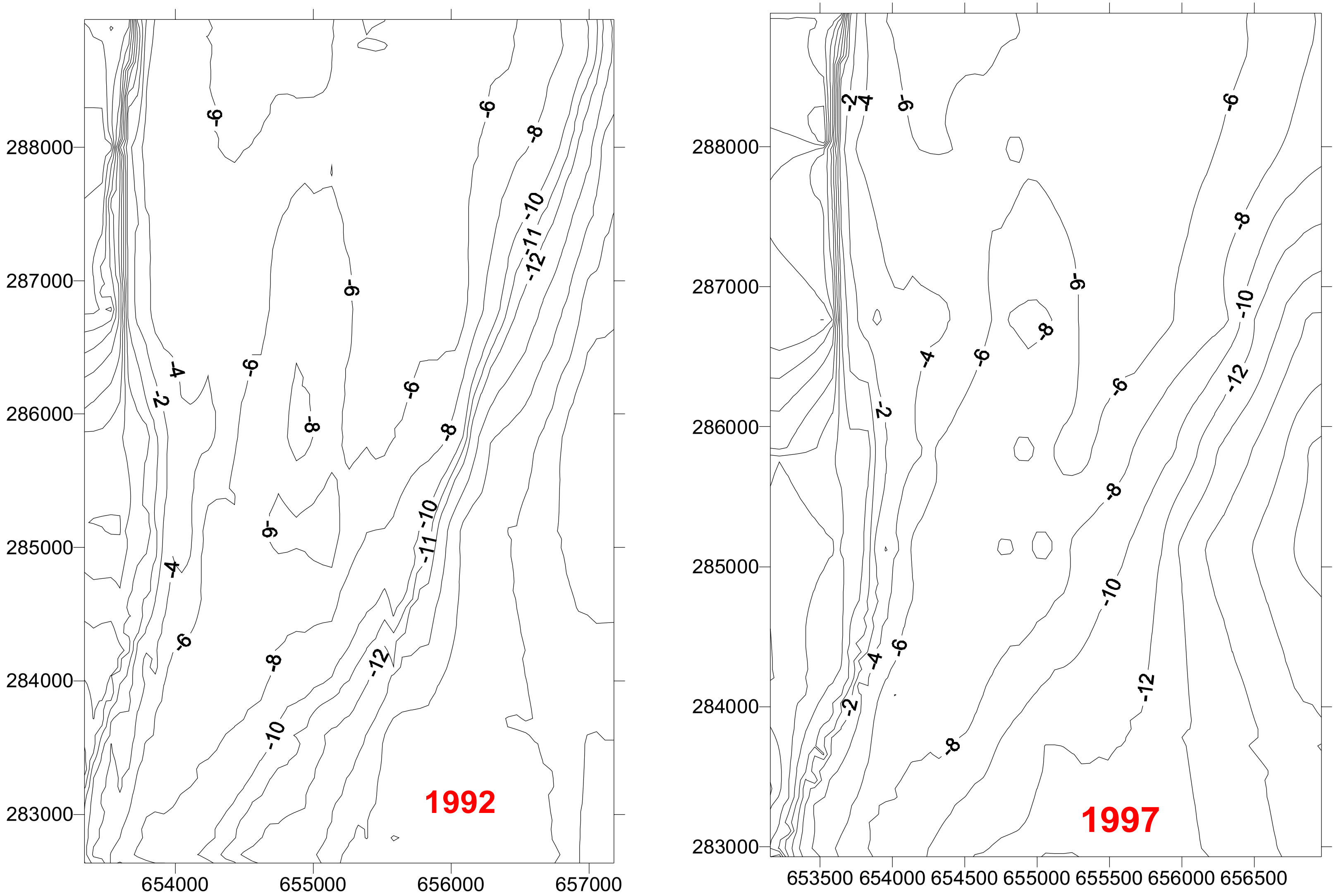


Figure 8 Benacre Ness: Bathymetric changes (1992 and 1997)

4.1.4 Ness migration model

A number of interpretations have been put forward to explain the northwards migration of the ness, including:

- the product of northwards sediment transport following surges (Williams 1956);
- a balance between accretion on the northern face and erosion on the southern face (Russell 1956);
- the response to the northward migration of an offshore tidal channel (Robinson 1966).

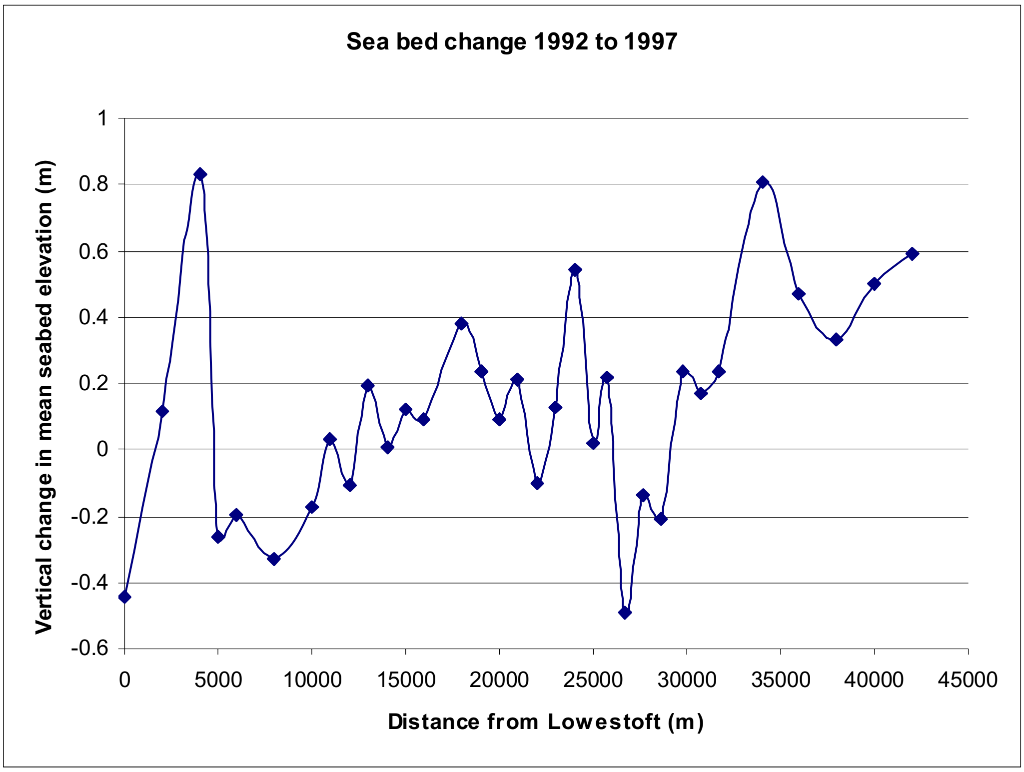
In our view, the behaviour of the ness needs to be explained in the context of the long-term evolution of the Suffolk coast. It may be the product of long-term shortening of a shingle barrier beach system, which could have extended as far south as the Orford Ness complex. Recent unpublished work by one of the authors has suggested that over historical times the orientation of the Suffolk coast may have changed from **drift-alignment** towards **swash-alignment**. It is believed that this process has been in response to declining longshore sediment supply and has been accompanied by the fragmentation of the shoreline into a series of headland-bay cells. This re-alignment of the Suffolk shoreline can be seen in the pattern of recent seabed accretion and erosion (Figure 9).

In broad terms this interpretation means that:

- the Suffolk coast continues to evolve in response to changes in the dominant environmental controls, such as sediment availability, sea-level and land reclamation.
- local historical changes (eg accelerated cliff recession at Dunwich or ness migration) are related incidents and need to be seen in the context of how the regional shoreline has evolved. Future patterns of erosion and accretion will a reflection of the on-going evolution of the regional shoreline.

Analysis of longshore wave power gradients between Lowestoft and Southwold suggests that the ness appears to act as a mobile headland (*a-e* boundary) separating two sub-cells (Lowestoft-Benacre Ness; Benacre Ness to Southwold; see Box 2). The predicted behaviour can be summarised as follows:

- **Northern face** (SWE7 – SWE8); dominant **accretion**;
- **Ness tip** (SWE8); dominant **accretion**, except during waves from 15^{o} and 30^{o} when erosion occurs;
- **Southern face** (SWE8 – SWD2); erosion during southerly waves, accretion during northerly waves.



Cell 1: Lowestoft to Southwold
Cell 2: Southwold to Minsmere
Cell 3: Minsmere to Thorpness

Each cell is characterised by seabed erosion in the north (ie negative values) and seabed accretion to the south (ie positive values)

Figure 9 Cell fragmentation on the Suffolk coast

Table 10 provides a summary of the predicted trends at different SDMS profile locations along the Benacre Ness frontage. This simple analysis tends to support the view that the ness moves north by differential erosion of the southern face and accretion on the northern face.

Table 10. Longshore power gradients on the Benacre Ness frontage (see Box 2 and Figure 10 for a definition of the points *a-e*)

Profile	**Wave direction**			
	15^o	**30^o**	**165^o**	**180^o**
SWE5	*b*; max. erosion	*b*; max. erosion	*d*; max. accretion	*d*; max. accretion
SWE6	*c*; no change	*c*; no change	*c-d*; accretion	*c-d*; accretion
SWE7	*d*; max. accretion	*d*; max. accretion	*c-d*; accretion	*c-d*; accretion
SWE8	*b*; max. erosion	*b*; max. erosion	*c-d*; accretion	*c-d*; accretion
SWE9	*c-d*; accretion	*c-d*; accretion	*b*; maximum erosion	*b*; maximum erosion
SWE10	*c-d*; accretion	*c-d*; accretion	*a-b*; erosion	*a-b*; erosion
SWD1	*c-d*; accretion	*c-d*; accretion	*a-b*; erosion	*a-b*; erosion
SWD2	*d*; max. accretion	*d*; max. accretion	*a-b*; erosion	*a-b*; erosion

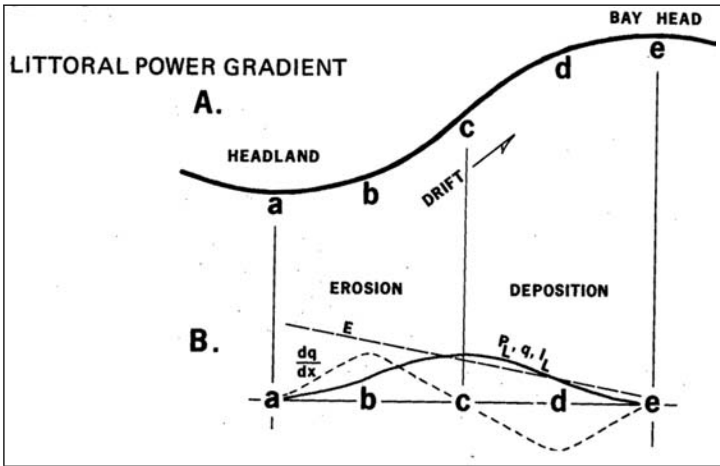


Figure 10 The May and Tanner (1973) longshore sediment transport model (see Table 11 for definition of points *a-e*)

Box 2. Shoreline alignment and longshore wave power: a summary

Coasts tend to become orientated in relation to the dominant wave direction:

- **drift-aligned coasts** where the shoreline is oriented parallel to the line of maximum sediment transport ie adjusted to maximise sediment transport. These cells are open systems and associated with a continuous sediment supply from updrift. Increases in the wave approach angle cause a reduction in the transport rate and leads to deposition, so that the alignment is restored (ie **dynamic equilibrium**);
- **swash-aligned coasts** where scarcity of sediment results in a tendency for plan-form adjustment of the morphology to the refraction of the dominant wave system, so as to minimise the sediment transport potential. Eventually the readjustment leads to a stable bay within which longshore sediment transport potential is zero at all points (ie **static equilibrium**).

Patterns of erosion and accretion can be explained in terms of changes in the longshore component of wave power (P_L), reflecting localised changes in shoreline orientation relative to the wave approach angle:

$$P_L = 0.5\ (EC)\ \sin 2\beta$$

(β is the angle between the wave crest and the shoreline; $E = 1/8\ \rho g H^2$ and $C = (2gH_b)^{0.5}$).

Considering a headland-bay unit (Figure 10) it is possible to recognise a number of points that define the nature of the sediment transport system (Table 11). A positive power gradient (ie increasing P_L) indicates shoreline erosion, whereas a negative gradient indicates deposition.

Table 11. Longshore power gradients and sediment transport (derived from May and Tanner 1973)

Point (Figure 10)	Wave Energy (E)	Longshore Wave Power (P_L)	dQ/dX	Beach Trend
a	Maximum	Minimum	Zero	No change
b			Maximum	Erosion
c		Maximum	Zero	No change
d			Minimum	Deposition
e	Minimum	Minimum	Zero	No change

Note: dQ/dX is the change in sediment transport (Q), dX is the change in distance (X) along the shoreline. Where dQ/dX is zero there is no change in the amount of sediment in transit.

Figure 11 shows the variations in longshore wave power (P_L) along the Lowestoft to Southwold frontage, for the dominant wave approach angles (15^o, 30^o, 160^o and 180^o; Halcrow 2001). Figure 12 presents a plot of dQ/dX for the shoreline.

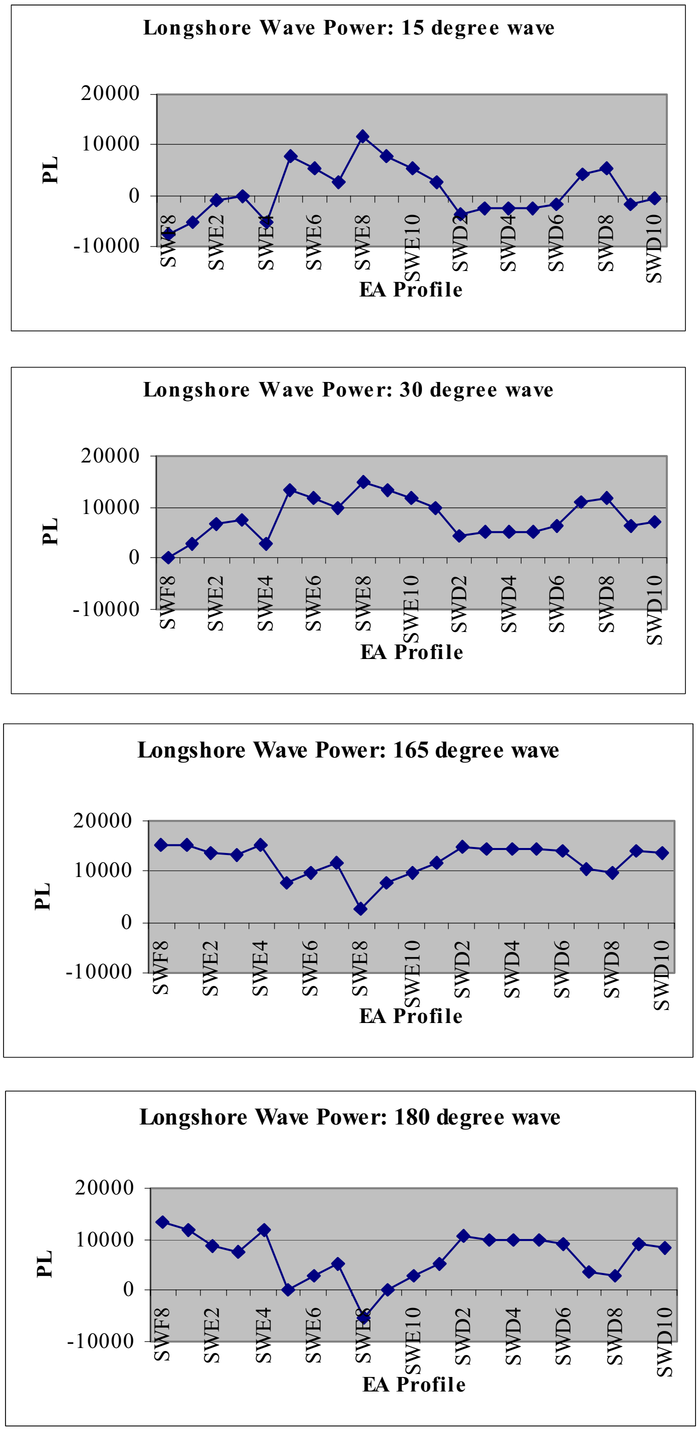


Figure 11 Benacre Ness: Variations of Longshore Wave Power (PL) with different wave directions

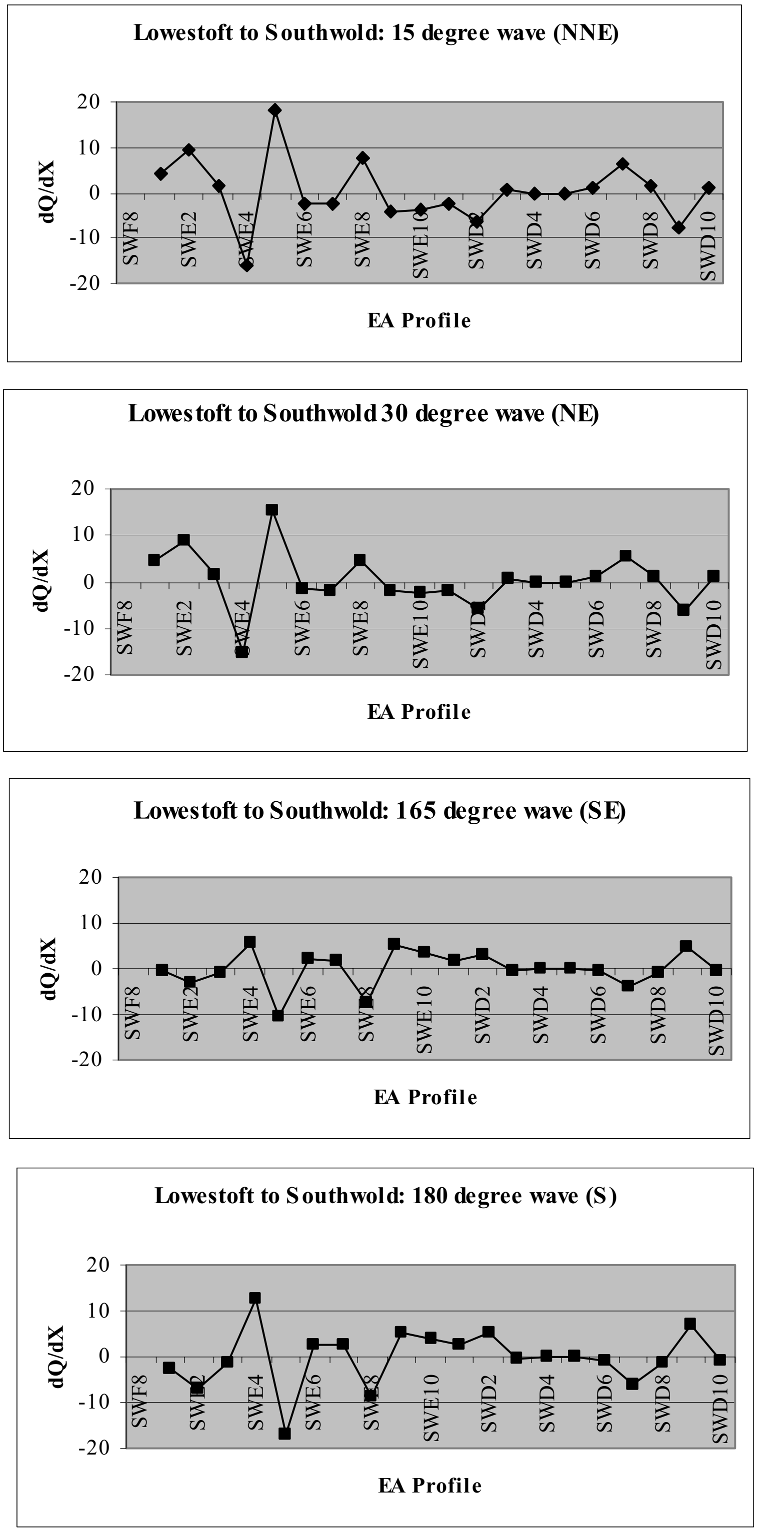


Figure 12 Lowestoft-Southwold: Longshore variations in dQ/dX

4.1.5 Migration potential: a sediment budget model

Figure 13 presents a conceptual sediment budget for the ness. Northward migration of the ness can occur in response to deposition of sediment transported from the north during waves from 15^{o} and 30^{o} and from the south during waves from 165^{o} and 180^{o}.

The migration rate (M) can be seen to be a function of the balance between sediment inputs and outputs on the northern face:

M = Inputs (from North) + Inputs (from South) – Outputs

The inputs included are shown in Table 12.

Table 12. Sediment inputs and outputs included in sediment budget.

Source	Inputs (north)	Inputs (south)
Cliff Recession	Pakefield Cliffs	Benacre to Southwold Cliffs
Ness Erosion		Southern Face of Ness
Regional Longshore Transport	Probably limited by Lowestoft defences	Probably limited by Southwold defences
Offshore	Sand/shingle banks	Sand/shingle banks

The outputs include longshore transport away from the ness (north or south) and offshore transfers to the banks between Kessingland and Lowestoft (eg Birbeck College and Babtie 2000).

Assuming that regional inputs have been constrained by coastal defences at Lowestoft and Southwold, then the migration rate can be seen to be dependent on:

- sediment supply from the eroding cliffs to the north (Pakefield cliffs) and the south (Benacre to Southwold cliffs);
- sediment supply from erosion of the southern face of the ness;
- onshore/offshore sediment exchanges.

Changes in migration rate will be in response to changes in either or both the sediment inputs and outputs.

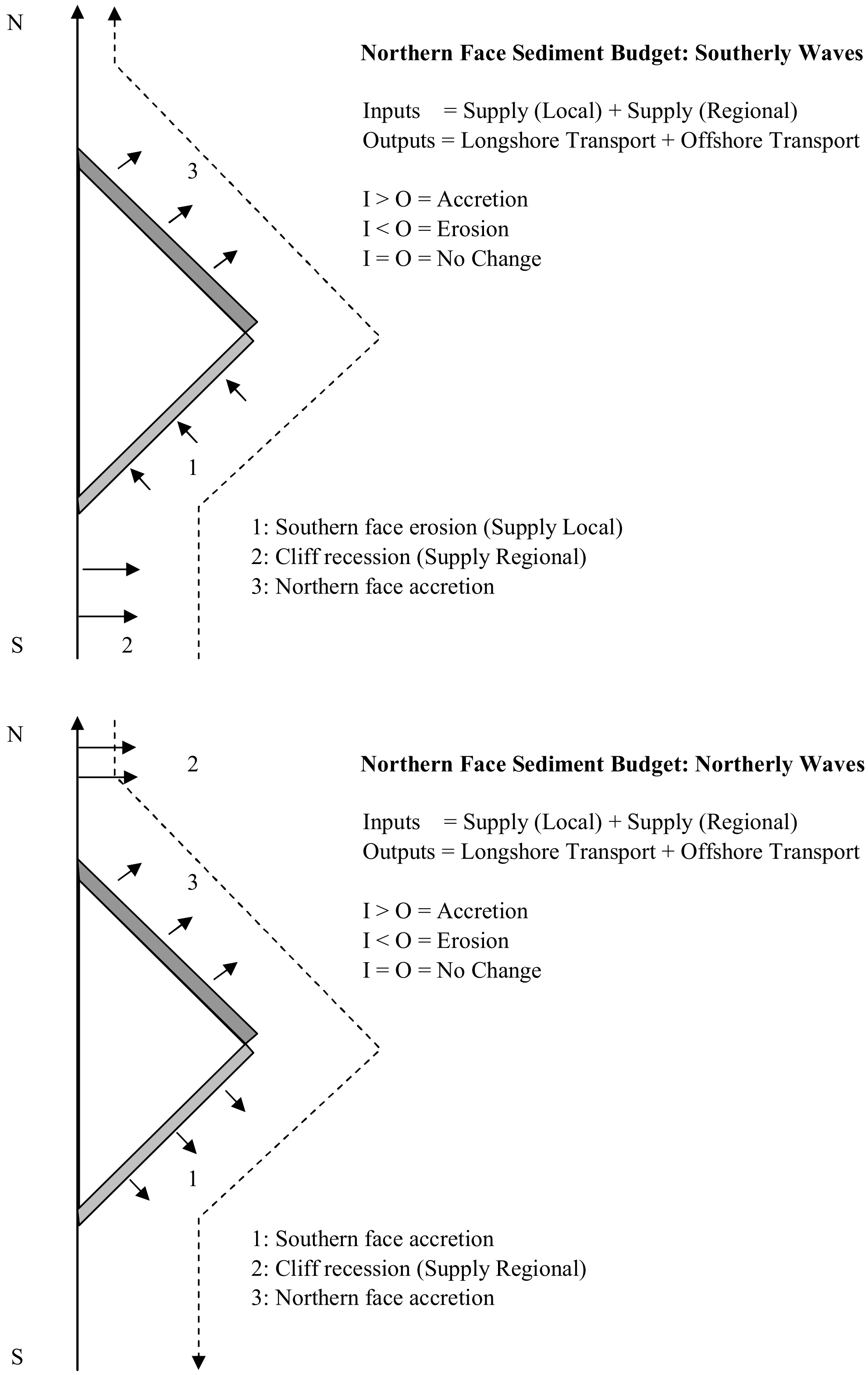


Figure 13 Benacre Ness: Conceptual Sediment Budget

4.1.6 Future migration rates

There are considerable problems in attempting to predict the future rate of migration. Of particular concern is the large variation in historical rates:

- the 'medium-term' migrations rates of around 22-23m/year, determined from analysis of historical maps and aerial photographs covering the period 1766 to 1992;
- the 'short-term' rates of around 70-100m/year, calculated from analysis of SDMS beach profiles for the period 1992-2003.

Such variability is not uncommon in geomorphological systems. The high recorded rates between 1992 and 2003 do not necessarily imply a sudden and dramatic acceleration in the migration rate that would be applicable over a 50-year period. Indeed, there does not appear to have been a significant change to the sediment budget during this period, such as dramatically increased cliff recession rates. An alternative view would be that ness migration involves a combination of long periods of gradual change, together with short periods of rapid change.

This alternative view can be used to develop a simple conceptual model of the past migration rate. It has been assumed that the average migration over the course of a century (2200m; 100 x 22m) was a reflection of:

- a 10-year period during which rates of up to 100m/year can occur (ie net migration of 1000m during this period). Note that this rate is comparable to the rate recorded between 1766 and 1783;
- a 90-year period during which the remaining 1200m of migration will occur, at average annual rates of 13.33m/year. Note that this is comparable to the 'slowed down' rate of 10m/year reported by Halcrow (2001).

This model has been used to provide an estimate of the migration rate over the next 50 years. Migration over this period could involve:

- up to 1000m during a 10-year period of rapid change;
- around 500m during the remaining 40 years of gradual change.

This suggests that it would be prudent to plan for ness migration of up to 1500m over the next 50 years (note that this is 400m further than a simple extrapolation of the average annual rate of 22m/year). This migration rate would result in:

- the northern extent of the ness occurring between SWE6 and SWE7, fronting the Kessingland cliffs (around OS Grid ref 653550 288500);
- the southern extent of the ness occurring around SWE9 (OS Grid ref 653600 285800).

It should be stressed that there are considerable uncertainties associated with the extrapolation of past rates to provide a future rate of migration, especially:

- the rate of sea-level rise and the impact it has on the pattern of wave refraction (ie longshore wave power) and the rate of cliff recession (ie sediment inputs);
- the behaviour of the offshore banks between Kessingland and Lowestoft.

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Annex A: Probabilistic cliff recession model

Simple extrapolation of the measured trends can provide an indication of the timescale over which particular assets would be threatened by cliff recession. This approach relies on the assumption that the historical rate can provide a reliable indication of the future recession rate. However, it is recognised that there could be considerable uncertainty associated with the cliff recession over the next 50 years. The sources of uncertainty include:

- the rate of sea-level rise;
- the degree of natural cliff protection provided by the beach;
- the response of the cliffline to higher winter rainfall and storminess predicted to result from climate change;
- the response of the cliffline to local changes in shoreline orientation, ie the gradual development or loss of a headland that protects the adjacent cliff sections;
- the variability of the materials exposed in the cliff face at a particular time, in terms of their strength and resistance to erosion.

A simple probabilistic model has been developed to provide a structured framework for adjusting the historical recession rate to reflect future changes in a number of the key factors that control the recession process (Lee 2003; Lee 2004). This model is presented as Figure 1 and involves a series of separate stages at which judgements, based on the available knowledge of the site conditions, are made about the need to adjust the historical recession rate because of changing future conditions.

For example, a cliff has been retreating at an average annual recession rate of 1.0m/year. Available knowledge suggests that in the future the rate of sea-level rise will be greater than the historical rate, there will be an increase in the effective winter rainfall, beach levels will decline and there will be an increase in shoreline exposure. The predicted recession rate for this particular case would be:

Predicted recession rate: = Historical recession rate x sea level rise factor
x winter rainfall factor x beach levels factor
x shoreline exposure factor

Where:

the **sea level rise factor** is a factor that represents the change in average annual cliff recession rate related to change in the rate of sea level rise (Box B in Figure 1);

the **winter rainfall factor** is a factor that represents the change in average annual cliff recession rate related to change in effective winter rainfall (Box C in Figure 1);

the **beach level factor** is a factor that represents the change in average annual cliff recession rate related to change in the degree of cliff protection provided by the beach (Box D in Figure 1).

the **shoreline exposure factor** is a factor that represents the change in average annual cliff recession rate related to the change in shoreline protection provided by a ness or natural headland (Box E in Figure 1).

However, as there is uncertainty about the future conditions it is possible to develop numerous possible cases, each with different combinations of future condition changes. For example:

- case 1, rate of sea-level rise greater than the historical rate, an increase in the effective winter rainfall, a decline in beach levels and an increase in shoreline exposure;
- case 2, rate of sea-level rise the same as the historical rate, no change in the effective winter rainfall, a decline in beach levels and an increase in shoreline exposure;
- case 3, rate of sea-level rise greater than the historical rate, no change in the effective winter rainfall, no change in beach levels no change in shoreline exposure.

Each of these cases will result in a different average annual recession rate and can be assigned a conditional probability:

Prob. (case *n*) = prob. (sea level rise) x prob. (winter rainfall) x prob. (beach levels) x prob. (shoreline exposure)

The sum of the conditional probabilities for all possible cases adds up to 1.0 and can be presented as a simple plot of average annual recession rate against its probability.

This model has been adapted for use in this study. Note that it was assumed that over the next 50-years the cliffs would not be sensitive to changes in winter rainfall, there would be no change in the regional sediment budget and there would be no increase in shoreline exposure (eg as a result of ness migration or change in wave refraction due to changing bathymetry). Hence, the **winter rainfall, sediment budget and shoreline exposure** factors were omitted from this application of the model.

The objective has been to establish a probability distribution for the average annual recession rate that would be applicable over the 50-year time periods for each of the five clifflines.

The development of the model has involved:

1. **Determination of historical recession rates:** Table 1 summarises the historical recession data derived from SDMS sections and EA/WDC profiles. It is clear that there is considerable variability between sites along the same cliffline and between measurement periods. A medium-term historical recession rate was established by combining the cumulative recession over the periods 1946-1976 and 1991-1999 and dividing by the number of years in the combined periods (38 years). This recession rate takes account of both the recent high recession rates and the longer term trends. It also provides a recession rate that is applicable over the period of recorded sea-level change (1956-1995, see below).

   A number of medium-term recession rates were established for each cliffline. Rather than establishing an average value for the clifflines, it was assumed that that each value was equally likely. Each separate rate was used in a series of different cases for each cliffline.

2. **Establishing appropriate adjustment factors** that reflect the available knowledge the specific conditions at the site:

Sea-level rise: although there is much uncertainty about future rate of sea level rise, it is expected to accelerate and to result in increased recession rates (eg Bray and Hooke 1997). Sea level rise can be assumed to result in the parallel retreat of the cliff profile (Bruun 1962), albeit with a corresponding rise in elevation of the cliff foot. This geometric relationship forms the basis of the Bruun Rule for deriving the shoreline response to sea level rise. The Bruun Rule is essentially two-dimensional (onshore-offshore) and assumes that longshore sediment inputs and outputs are equal and equivalent, a condition rarely achieved in reality. To model reliably the three-dimensional situation, a full sediment budget needs to be calculated for the littoral cell being considered. If it is assumed, however, that the historical recession rate represents the net contribution to the sediment budget, then the Bruun Rule can be modified to predict the recession increase due to sea level rise (R) as follows (Dean 1991):

$$R = R_1 + Sc \times \frac{L}{P(B+h)}$$

where:
R_1 = historical recession rate
Sc = change in rate of sea level rise
P = sediment overfill
L = length of cliff profile
B = cliff height
h = closure depth

The overall validity of this general model has been confirmed for the eroding cliff shores of the Great Lakes (Hands 1983). Rising lake levels have produced a transfer of material from the cliff to the nearshore bed resulting in recession rates that were very close to those predicted by the model.

The **change in sea level rise** is the difference between the historical and future sea level rise at the site. The historical rate is 1.81mm per year (1956-1995; standard error of ∀ 0.48mm; Woodworth and others 1999). Although there is uncertainty about the future rate of sea-level rise over the next century, the local change in rate is expected to be between 2-13.4mm per year.

The **closure depth** is the boundary of the profile beyond which there is little loss of sediment. The closure depth can be estimated as being twice the maximum wave height for a 50 year return period (Bruun 1988), ie 14.8m for this coastline (Halcrow 2001).

The **sediment overfill** function is the proportion of sediment eroded that is sufficiently coarse to remain within the equilibrium profile. This was derived from the study of cliff recession inputs carried out by the BGS (1996) and was calculated as the combined sand and gravel yield from each cliffline.

The **length of active cliff profile** was measured from the hydrographic charts by using the closure depth to indicate the seaward limits, taken here as 1500m (assuming a 1 in 100 bed gradient).

3. **Assigning subjective probabilities** to each of the possible future coastal conditions:

- the probability that each of the different historical recession rates on each cliffline reflects the actual recession rate. As mentioned earlier, each rate was considered to be equally likely.
- the probability of the sea-level rise being the low, medium-low, medium-high or high scenario.

Tables 2-6 present the model results for the clifflines. The results provide a probability distribution for the average annual recession rate that would be applicable over the 50 year time period. Projecting these average annual rates over the relevant time period (ie 50 years) yields a probability distribution of the cliff top position at the end of that time period (Figures 2-6).

Table A SDMS Profile Locations

Profile	Map co-ordinates		Grid reference
SWE4	654020	290622	TM540966
SWE5	655784	289910	TM557899
SWE6	653687	288954	TM536889
SWE7	653541	287990	TM535879
SWE8	653608	286776	TM536867
SWE9	653623	285822	TM536858
SWE10	653627	285143	TM536851
SWD1	653556	284226	TM535842
SWD2	653362	283322	TM533833
SWD3	652728	281957	TM527819
SWD4	652411	281200	TM524812
SWD5	652005	279925	TM520799
SWD6	651661	279089	TM516790
SWD7	651377	278189	TM513781
SWD8	651241	277395	TM507756
SWD9	651110	276489	TM511764
SWD10	650798	275663	TM507756
SWD11	650488	274888	TM504748

Table 1 Cliff recession information (derived from Halcrow 2001, Appendix B)

			Cliff Recession Rates (m/year)*								
Cliffline	SDMS Section Number	EA/WDC Profile Location	1884-1905	1905-1946	1946-1976	Cumulative Recession (m) 1884-1976	Long-term Recession Rate 1884-1976	Cumulative Recession (m) 1991-1999	Short-term Recession Rate 1991-1999	Medium-term Recession Rate 1946-1976; 1991-1999**	Proportion of beach building material***
Benacre Cliffs	536		3	4.8	3.7	370.8	4.03			4.42	
	535		4.09	5.4	4.3	436.29	4.74			4.89	
		SWD2						56.8	7.1		0.782
Covehithe Cliffs	531		5	3.8	5.3	419.8	4.56			5.87	
	530		4.09	4.09	5.59	421.28	4.58			6.10	
	529		4.68	3.2	5.68	399.88	4.35			6.17	
	528		4.59	2.3	7	400.69	4.36			7.21	
	527		4.4	1.4	7.68	380.2	4.13			7.75	
	526		4	1.2	7.4	355.2	3.86			7.53	
		SWD3						64	8		0.977
		SWD4						9.6	1.2		
Easton Wood Cliffs	523		4.9	1.2	6.59	349.8	3.80			5.43	
	522		2.3	2.4	8.1	389.7	4.24			6.63	
	521		2.09	2.59	7.8	384.08	4.17			6.39	
		SWD5						8.8	1.1		0.939
Easton Broad Cliff	517		1.4	2.2	7.8	353.6	3.84			7.69	
	516		1.5	2.3	6.5	320.8	3.49			6.67	0.649
		SWD6						58.4	7.3		
Easton Bavents Cliffs	514		3	1.4	5.18	275.8	3.00			4.32	
	513		3.8	1.1	4.59	262.6	2.85			3.86	
	512		3.8	1.2	3.59	236.7	2.57			3.07	
	511		4	0.7	3.2	208.7	2.27			2.76	
	510		4.3	0	3.2	186.3	2.03			2.76	0.935
		SWD7						8.8	1.1		
		SWD8						3.2	0.4		

Notes: * It is assumed that cliff top recession rates are equal to HWM recession rates
** Medium-term recession rate is the cumulative recession over the periods 1946-1976 (30 years) and 1991-1999 (8 years) divided by the total number of years (38 years)

Table 2 Benacre Cliff: prediction of cliff recession rates

Bruun Rule model of the effect of sea-level rise

1. Low sea-level rise scenario (Probability = 0.1)

Section	R1	S1	S2	P%	L*	h*	B	S2-S1	P(B+h*)	Recession Factor	R2	50-Year Recession (m)	Conditional Probability
536	4.42	0.00181	0.0034	0.782	2000	14.8	5	0.00159	15.4836	0.205	4.62	231	0.05
535	4.89	0.00181	0.0034	0.782	2000	14.8	5	0.00159	15.4836	0.205	5.09	255	0.05

2. Medium-low sea-level rise scenario (Probability = 0.4)

Section	R1	S1	S2	P%	L*	h*	B	S2-S1	P(B+h*)	Recession Factor	R2	50-Year Recession (m)	Conditional Probability
536	4.42	0.00181	0.0046	0.782	2000	14.8	5	0.00279	15.4836	0.36	4.78	239	0.2
535	4.89	0.00181	0.0046	0.782	2000	14.8	5	0.00279	15.4836	0.36	5.25	262	0.2

3. Medium-high sea-level rise scenario (Probability = 0.4)

Section	R1	S1	S2	P%	L*	h*	B	S2-S1	P(B+h*)	Recession Factor	R2	50-Year Recession (m)	Conditional Probability
536	4.42	0.00181	0.006	0.782	2000	14.8	5	0.00419	15.4836	0.54	4.96	248	0.2
535	4.89	0.00181	0.006	0.782	2000	14.8	5	0.00419	15.4836	0.54	5.43	272	0.2

4. High sea-level rise scenario (Probability = 0.1)

Section	R1	S1	S2	P%	L*	h*	B	S2-S1	P(B+h*)	Recession Factor	R2	50-Year Recession (m)	Conditional Probability
536	4.42	0.00181	0.0144	0.782	2000	14.8	5	0.01259	15.4836	1.63	6.04	302	0.05
535	4.89	0.00181	0.0144	0.782	2000	14.8	5	0.01259	15.4836	1.63	6.52	326	0.05

Table 3 Covehithe Cliff: prediction of cliff recession rates

Bruun Rule model of the effect of sea-level rise

1. Low sea-level rise scenario (Probability = 0.1)

Section	R1	S1	S2	P%	L*	h*	B	S2-S1	P(B+h*)	Recession Factor	R2	50-Year Recession (m)	Conditional Probability
531	5.87	0.00181	0.0034	0.977	1500	14.8	5	0.00159	19.3446	0.123	5.99	300	0.0167
530	6.10	0.00181	0.0034	0.977	1500	14.8	8	0.00159	22.2756	0.107	6.20	310	0.0167
529	6.17	0.00181	0.0034	0.977	1500	14.8	8	0.00159	22.2756	0.107	6.28	314	0.0167
528	7.21	0.00181	0.0034	0.977	1500	14.8	8	0.00159	22.2756	0.107	7.32	366	0.0167
527	7.75	0.00181	0.0034	0.977	1500	14.8	7	0.00159	21.2986	0.112	7.86	393	0.0167
526	7.53	0.00181	0.0034	0.977	1500	14.8	5	0.00159	19.3446	0.123	7.65	382	0.0167

2. Medium-low sea-level rise scenario (Probability = 0.4)

Section	R1	S1	S2	P%	L*	h*	B	S2-S1	P(B+h*)	Recession Factor	R2	50-Year Recession (m)	Conditional Probability
531	5.87	0.00181	0.0046	0.977	1500	14.8	5	0.00279	19.3446	0.216	6.08	304	0.0667
530	6.10	0.00181	0.0046	0.977	1500	14.8	8	0.00279	22.2756	0.188	6.29	314	0.0667
529	6.17	0.00181	0.0046	0.977	1500	14.8	8	0.00279	22.2756	0.188	6.36	318	0.0667
528	7.21	0.00181	0.0046	0.977	1500	14.8	8	0.00279	22.2756	0.188	7.40	370	0.0667
527	7.75	0.00181	0.0046	0.977	1500	14.8	7	0.00279	21.2986	0.196	7.94	397	0.0667
526	7.53	0.00181	0.0046	0.977	1500	14.8	5	0.00279	19.3446	0.216	7.74	387	0.0667

3. Medium-high sea-level rise scenario (Probability = 0.4)

Section	R1	S1	S2	P%	L*	h*	B	S2-S1	P(B+h*)	Recession Factor	R2	50-Year Recession (m)	Conditional Probability
531	5.87	0.00181	0.006	0.977	1500	14.8	5	0.00419	19.3446	0.325	6.19	310	0.06667
530	6.10	0.00181	0.006	0.977	1500	14.8	8	0.00419	22.2756	0.282	6.38	319	0.06667
529	6.17	0.00181	0.006	0.977	1500	14.8	8	0.00419	22.2756	0.282	6.45	323	0.06667
528	7.21	0.00181	0.006	0.977	1500	14.8	8	0.00419	22.2756	0.282	7.49	375	0.06667
527	7.75	0.00181	0.006	0.977	1500	14.8	7	0.00419	21.2986	0.295	8.04	402	0.06667
526	7.53	0.00181	0.006	0.977	1500	14.8	5	0.00419	19.3446	0.325	7.85	393	0.06667

4. High sea-level rise scenario (Probability = 0.1)

Section	R1	S1	S2	P%	L*	h*	B	S2-S1	P(B+h*)	Recession Factor	R2	50-Year Recession (m)	Conditional Probability
531	5.87	0.00181	0.0144	0.977	1500	14.8	5	0.01259	19.3446	0.976	6.84	342	0.01667
530	6.10	0.00181	0.0144	0.977	1500	14.8	8	0.01259	22.2756	0.848	6.95	347	0.01667
529	6.17	0.00181	0.0144	0.977	1500	14.8	8	0.01259	22.2756	0.848	7.02	351	0.01667
528	7.21	0.00181	0.0144	0.977	1500	14.8	8	0.01259	22.2756	0.848	8.06	403	0.01667
527	7.75	0.00181	0.0144	0.977	1500	14.8	7	0.01259	21.2986	0.887	8.63	432	0.01667
526	7.53	0.00181	0.0144	0.977	1500	14.8	5	0.01259	19.3446	0.976	8.50	425	0.01667

Table 4 Easton Wood Cliff: prediction of cliff recession rates

Bruun Rule model of the effect of sea-level rise

1. Low sea-level rise scenario (Probability = 0.1)

Section	R1	S1	S2	P%	L*	h*	B	S2-S1	P(B+h*)	Recession Factor	R2	50-Year Recession (m)	Conditional Probability
523	5.43	0.00181	0.0034	0.939	1500	14.8	8	0.00159	21.4092	0.111	5.55	277	0.0333
522	6.63	0.00181	0.0034	0.939	1500	14.8	8	0.00159	21.4092	0.111	6.74	337	0.0333
521	6.39	0.00181	0.0034	0.939	1500	14.8	8	0.00159	21.4092	0.111	6.50	325	0.0333

2. Medium-low sea-level rise scenario (Probability = 0.4)

Section	R1	S1	S2	P%	L*	h*	B	S2-S1	P(B+h*)	Recession Factor	R2	50-Year Recession (m)	Conditional Probability
523	5.43	0.00181	0.0046	0.939	1500	14.8	8	0.00279	21.4092	0.195	5.63	281	0.1333
522	6.63	0.00181	0.0046	0.939	1500	14.8	8	0.00279	21.4092	0.195	6.82	341	0.1333
521	6.39	0.00181	0.0046	0.939	1500	14.8	8	0.00279	21.4092	0.195	6.58	329	0.1333

3. Medium-high sea-level rise scenario (Probability = 0.4)

Section	R1	S1	S2	P%	L*	h*	B	S2-S1	P(B+h*)	Recession Factor	R2	50-Year Recession (m)	Conditional Probability
523	5.43	0.00181	0.006	0.939	1500	14.8	8	0.00419	21.4092	0.294	5.73	286	0.1333
522	6.63	0.00181	0.006	0.939	1500	14.8	8	0.00419	21.4092	0.294	6.92	346	0.1333
521	6.39	0.00181	0.006	0.939	1500	14.8	8	0.00419	21.4092	0.294	6.68	334	0.1333

4. High sea-level rise scenario (Probability = 0.1)

Section	R1	S1	S2	P%	L*	h*	B	S2-S1	P(B+h*)	Recession Factor	R2	50-Year Recession (m)	Conditional Probability
523	5.43	0.00181	0.0144	0.939	1500	14.8	8	0.01259	21.4092	0.882	6.32	316	0.0333
522	6.63	0.00181	0.0144	0.939	1500	14.8	8	0.01259	21.4092	0.882	7.51	375	0.0333
521	6.39	0.00181	0.0144	0.939	1500	14.8	8	0.01259	21.4092	0.882	7.27	364	0.0333

Table 5 Easton Broad Cliff: prediction of cliff recession rates

Bruun Rule model of the effect of sea-level rise

1. Low sea-level rise scenario (Probability = 0.1)

Section	R1	S1	S2	P%	L*	h*	B	S2-S1	P(B+h*)	Recession Factor	R2	50-Year Recession (m)	Conditional Probability
517	7.69	0.00181	0.0034	0.649	1500	14.8	4.5	0.00159	12.5257	0.190	7.89	394	0.05
516	6.67	0.00181	0.0034	0.649	1500	14.8	4.5	0.00159	12.5257	0.190	6.86	343	0.05

2. Medium-low sea-level rise scenario (Probability = 0.4)

Section	R1	S1	S2	P%	L*	h*	B	S2-S1	P(B+h*)	Recession Factor	R2	50-Year Recession (m)	Conditional Probability
517	7.69	0.00181	0.0046	0.649	1500	14.8	4.5	0.00279	12.5257	0.33	8.03	401	0.2
516	6.67	0.00181	0.0046	0.649	1500	14.8	4.5	0.00279	12.5257	0.33	7.00	350	0.2

3. Medium-high sea-level rise scenario (Probability = 0.4)

Section	R1	S1	S2	P%	L*	h*	B	S2-S1	P(B+h*)	Recession Factor	R2	50-Year Recession (m)	Conditional Probability
517	7.69	0.00181	0.006	0.649	1500	14.8	4.5	0.00419	12.5257	0.50	8.20	410	0.2
516	6.67	0.00181	0.006	0.649	1500	14.8	4.5	0.00419	12.5257	0.50	7.17	359	0.2

4. High sea-level rise scenario (Probability = 0.1)

Section	R1	S1	S2	P%	L*	h*	B	S2-S1	P(B+h*)	Recession Factor	R2	50-Year Recession (m)	Conditional Probability
517	7.69	0.00181	0.0144	0.649	1500	14.8	4.5	0.01259	12.5257	1.51	9.20	460	0.05
516	6.67	0.00181	0.0144	0.649	1500	14.8	4.5	0.01259	12.5257	1.51	8.18	409	0.05

Table 6 Easton Bavents Cliff: prediction of cliff recession rates

Bruun Rule model of the effect of sea-level rise

1. Low sea-level rise scenario (Probability = 0.1)

Section	R1	S1	S2	P%	L*	h*	B	S2-S1	P(B+h*)	Recession Factor	R2	50-Year Recession (m)	Conditional Probability
514	4.32	0.00181	0.0034	0.935	1500	14.8	10	0.00159	23.188	0.103	4.42	221	0.02
513	3.86	0.00181	0.0034	0.935	1500	14.8	10	0.00159	23.188	0.103	3.96	198	0.02
512	3.07	0.00181	0.0034	0.935	1500	14.8	10	0.00159	23.188	0.103	3.17	158	0.02
511	2.76	0.00181	0.0034	0.935	1500	14.8	10	0.00159	23.188	0.103	2.86	143	0.02
510	2.76	0.00181	0.0034	0.935	1500	14.8	10	0.00159	23.188	0.103	2.86	143	0.02

2. Medium-low sea-level rise scenario (Probability = 0.4)

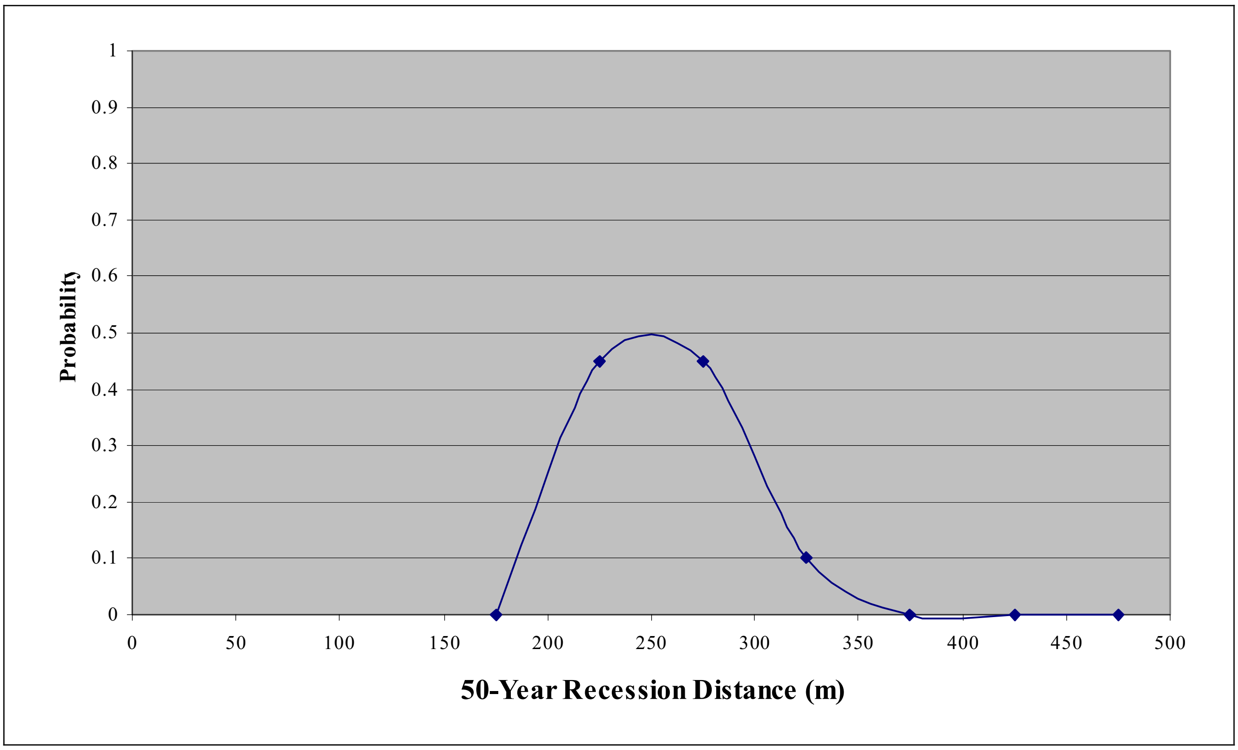
Section	R1	S1	S2	P%	L*	h*	B	S2-S1	P(B+h*)	Recession Factor	R2	50-Year Recession (m)	Conditional Probability
514	4.32	0.00181	0.0046	0.935	1500	14.8	10	0.00279	23.188	0.180	4.50	225	0.08
513	3.86	0.00181	0.0046	0.935	1500	14.8	10	0.00279	23.188	0.180	4.04	202	0.08
512	3.07	0.00181	0.0046	0.935	1500	14.8	10	0.00279	23.188	0.180	3.25	162	0.08
511	2.76	0.00181	0.0046	0.935	1500	14.8	10	0.00279	23.188	0.180	2.94	147	0.08
510	2.76	0.00181	0.0046	0.935	1500	14.8	10	0.00279	23.188	0.180	2.94	147	0.08

3. Medium-high sea-level rise scenario (Probability = 0.4)

Section	R1	S1	S2	P%	L*	h*	B	S2-S1	P(B+h*)	Recession Factor	R2	50-Year Recession (m)	Conditional Probability
514	4.32	0.00181	0.006	0.935	1500	14.8	10	0.00419	23.188	0.271	4.59	230	0.08
513	3.86	0.00181	0.006	0.935	1500	14.8	10	0.00419	23.188	0.271	4.13	206	0.08
512	3.07	0.00181	0.006	0.935	1500	14.8	10	0.00419	23.188	0.271	3.34	167	0.08
511	2.76	0.00181	0.006	0.935	1500	14.8	10	0.00419	23.188	0.271	3.03	151	0.08
510	2.76	0.00181	0.006	0.935	1500	14.8	10	0.00419	23.188	0.271	3.03	151	0.08

4. High sea-level rise scenario (Probability = 0.1)

Section	R1	S1	S2	P%	L*	h*	B	S2-S1	P(B+h*)	Recession Factor	R2	50-Year Recession (m)	Conditional Probability
531	4.32	0.00181	0.0144	0.935	1500	14.8	10	0.01259	23.188	0.814	5.14	257	0.02
530	3.86	0.00181	0.0144	0.935	1500	14.8	10	0.01259	23.188	0.814	4.67	233	0.02
529	3.07	0.00181	0.0144	0.935	1500	14.8	10	0.01259	23.188	0.814	3.88	194	0.02
528	2.76	0.00181	0.0144	0.935	1500	14.8	10	0.01259	23.188	0.814	3.57	179	0.02
527	2.76	0.00181	0.0144	0.935	1500	14.8	10	0.01259	23.188	0.814	3.57	179	0.02



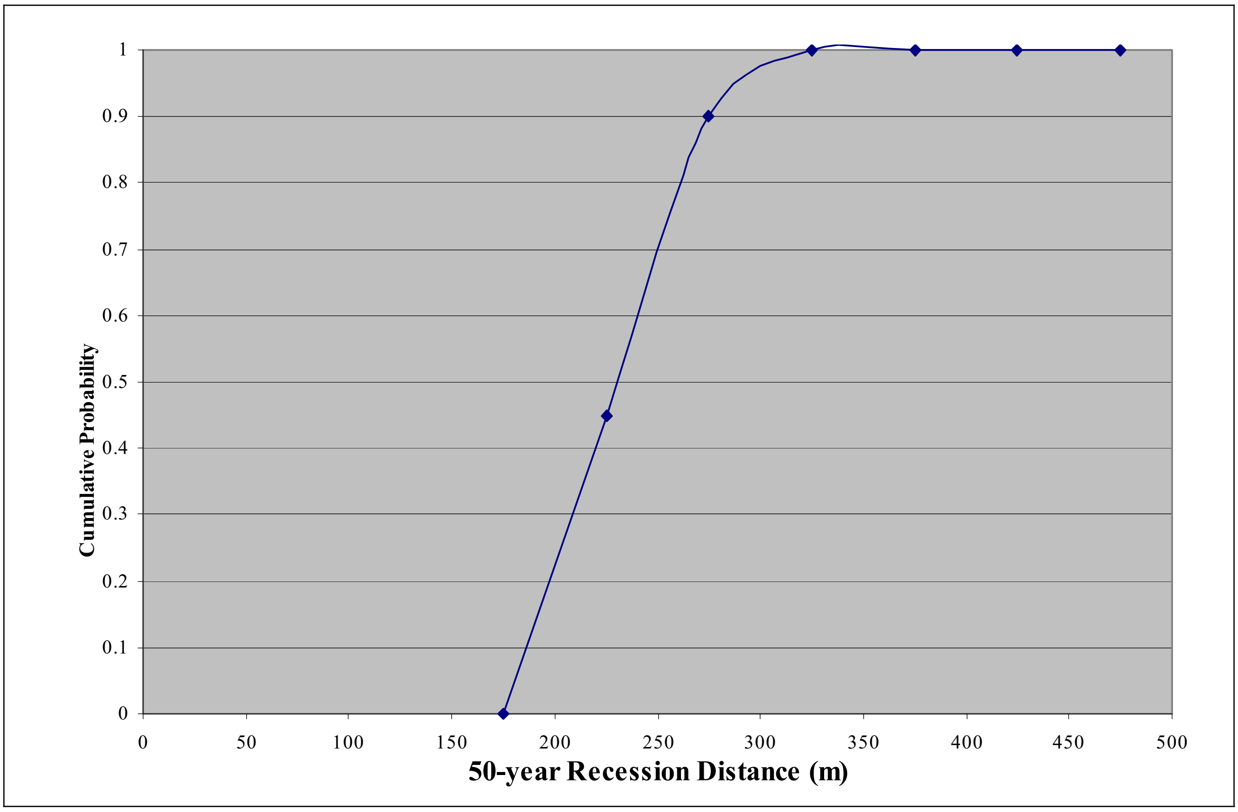
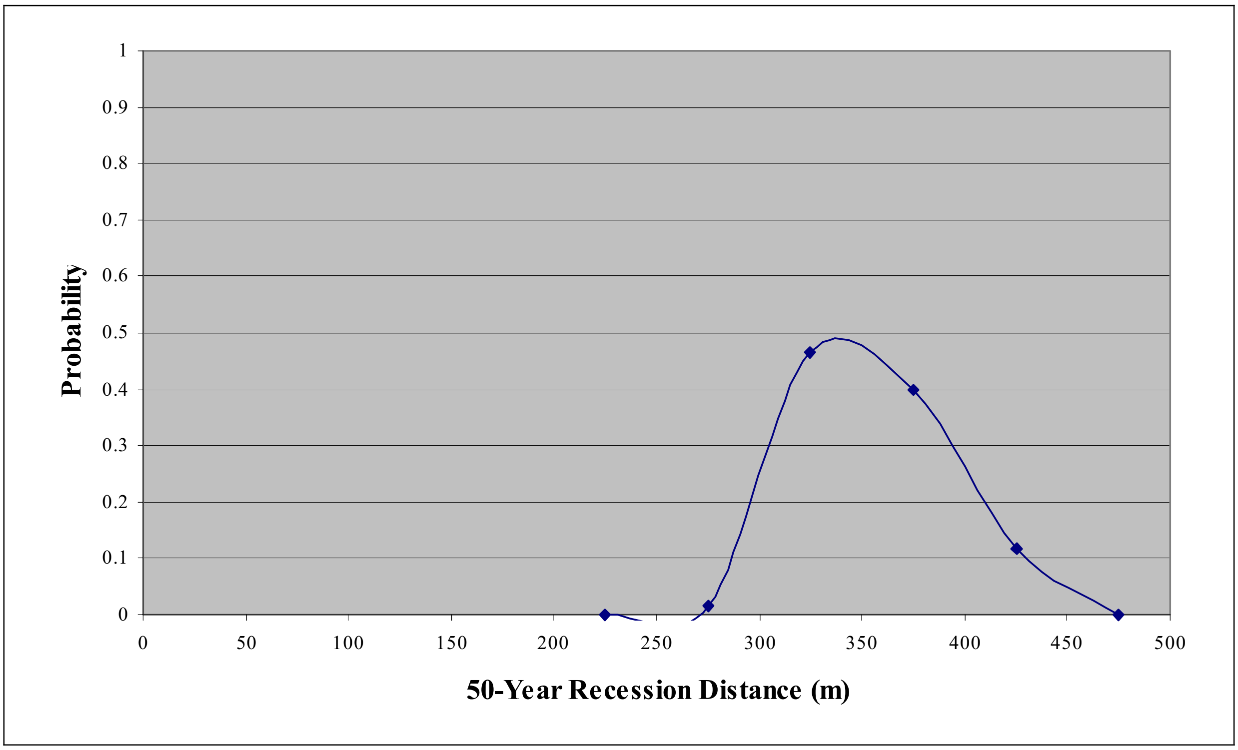


Figure 1 Benacre Cliff: Predicted 50-year Recession Distance



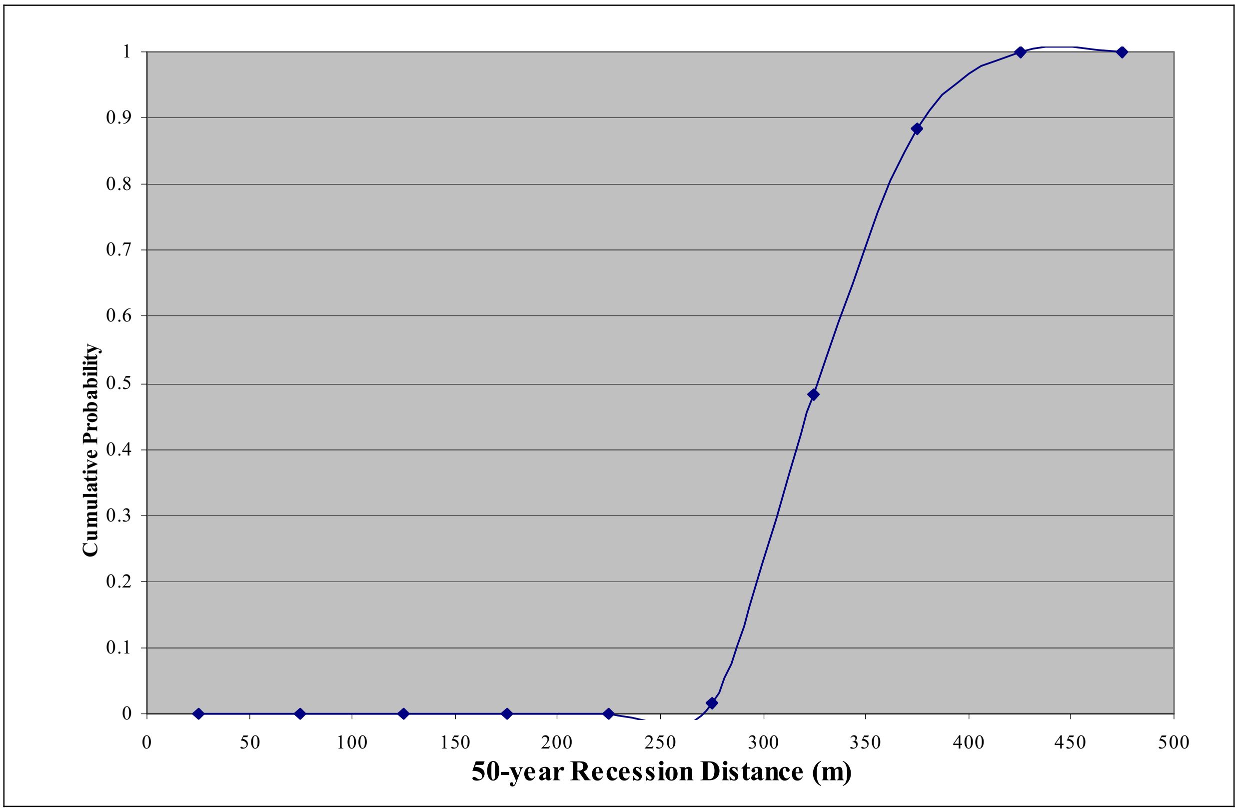
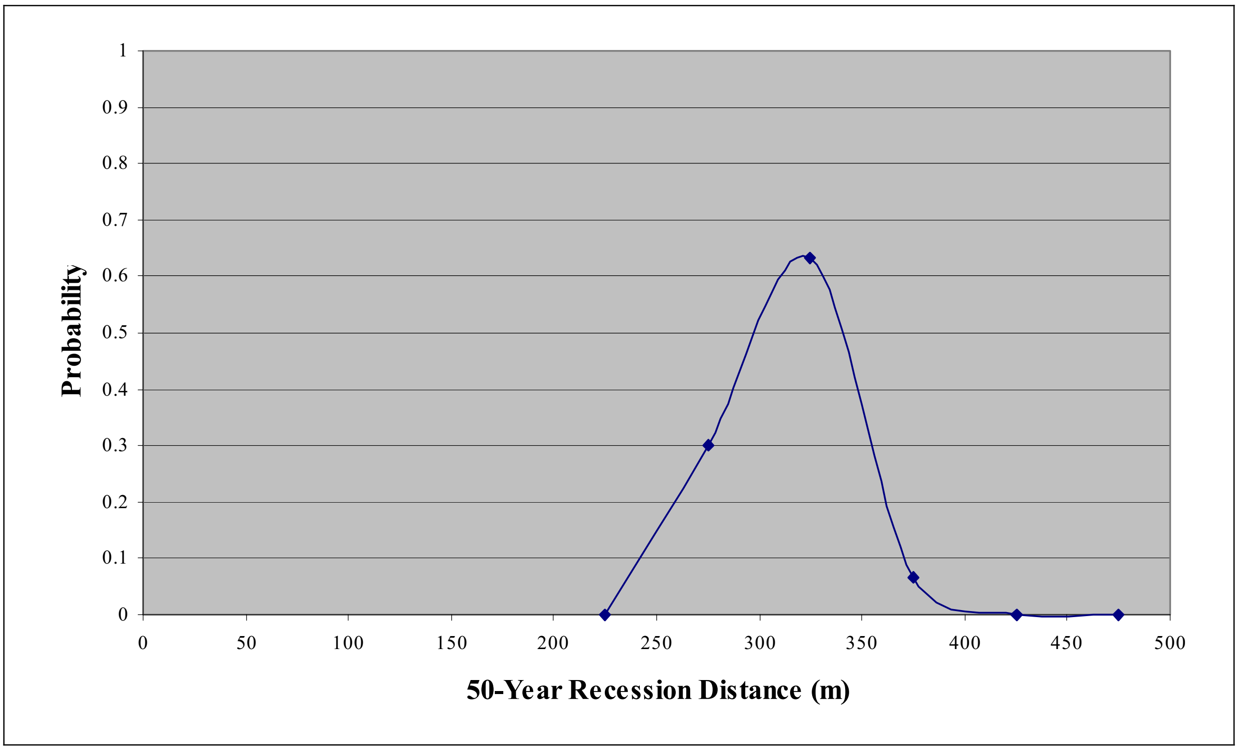


Figure 2 Covehithe Cliff: Predicted 50-year Recession Distance



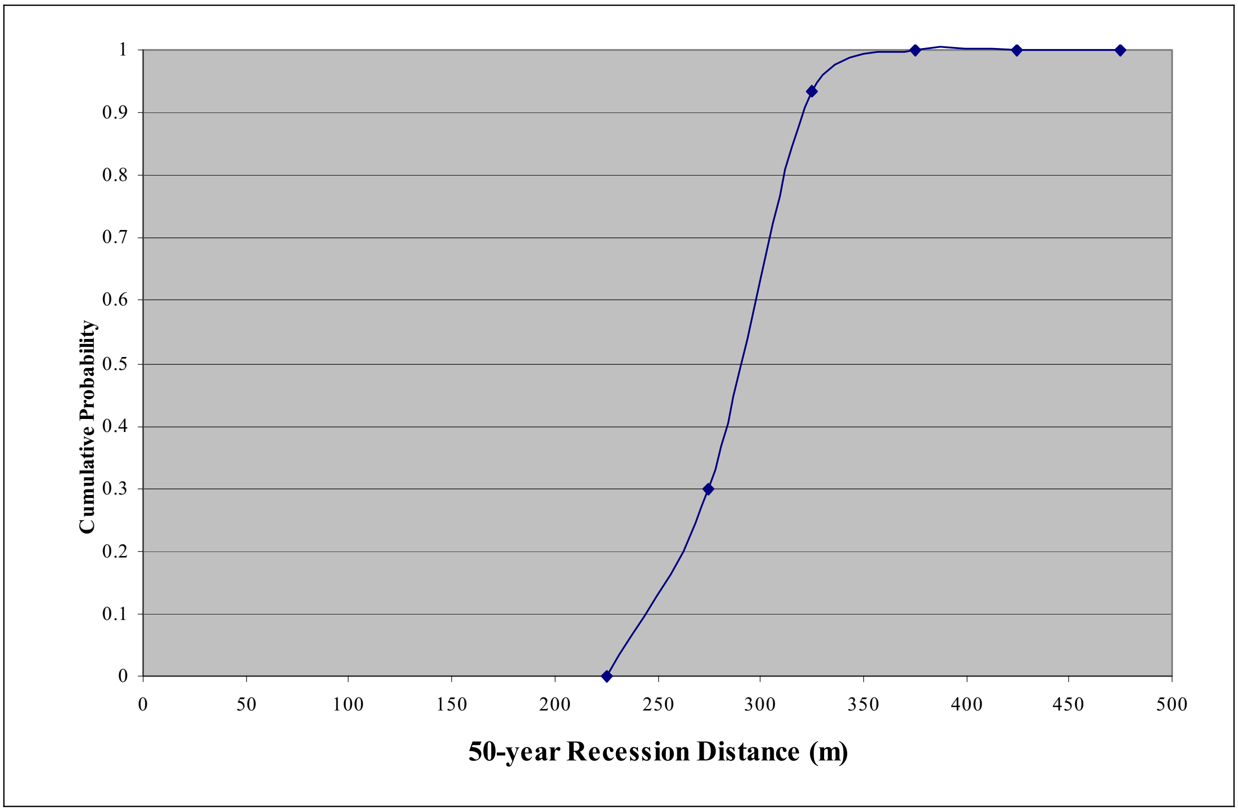
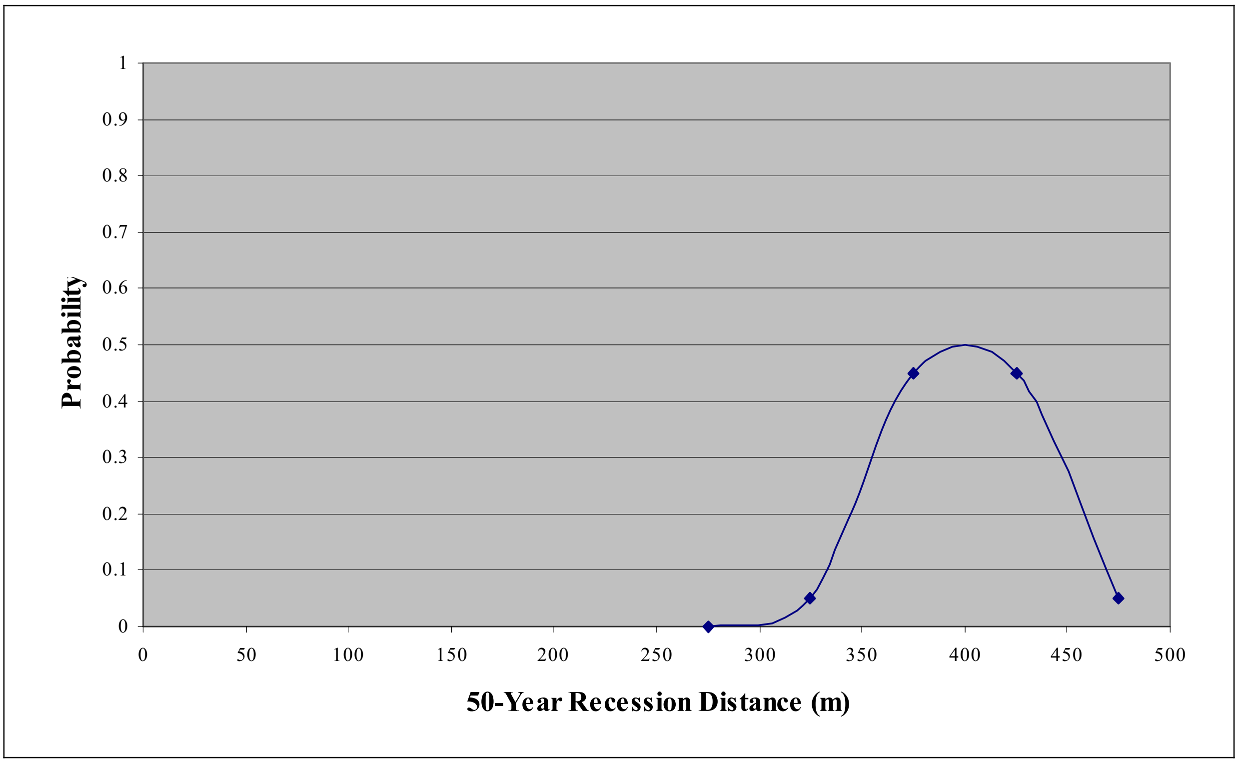


Figure 3 Easton Wood Cliff: Predicted 50-year Recession Distance



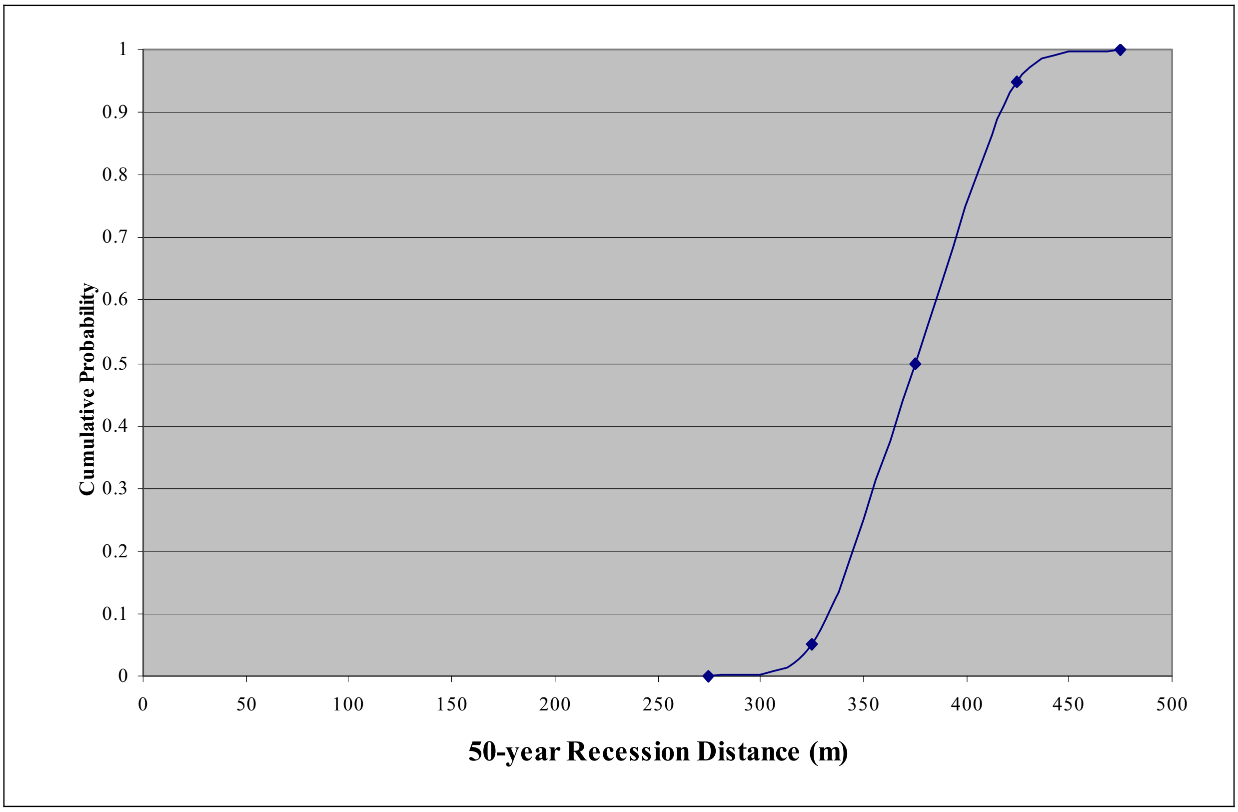
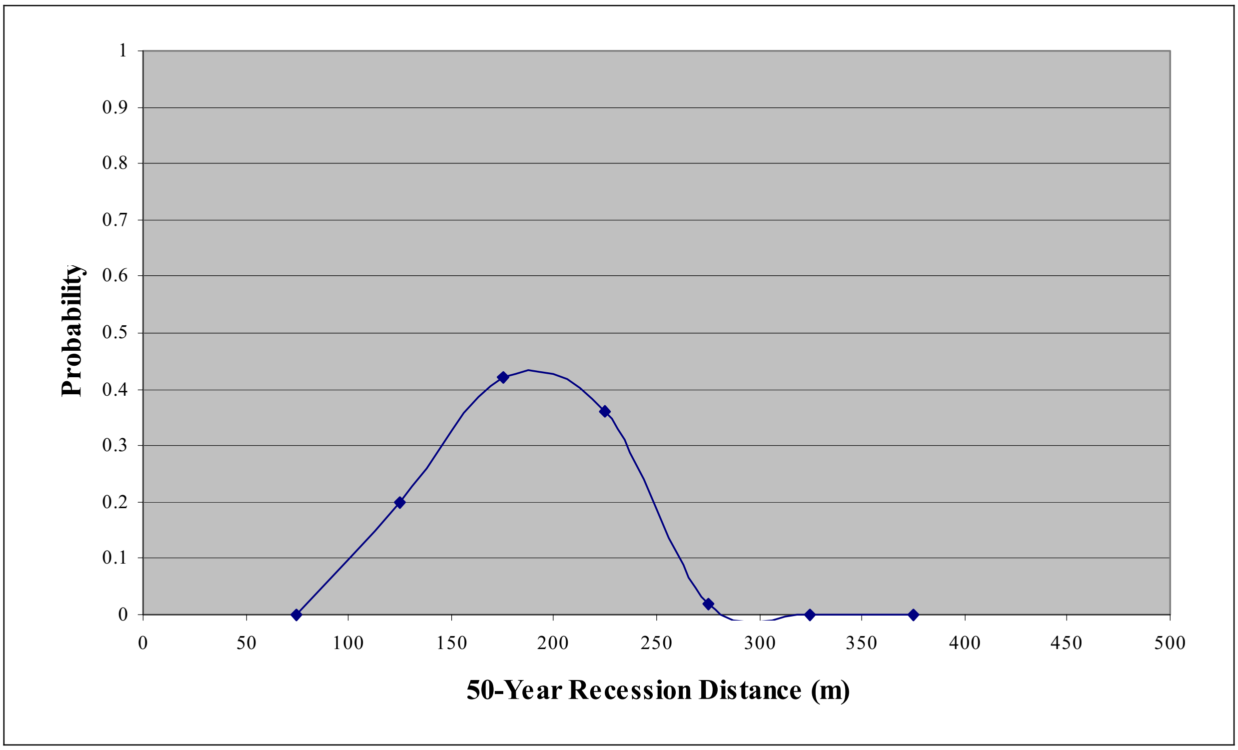


Figure 4 Easton Broad Cliff: Predicted 50-year Recession Distance



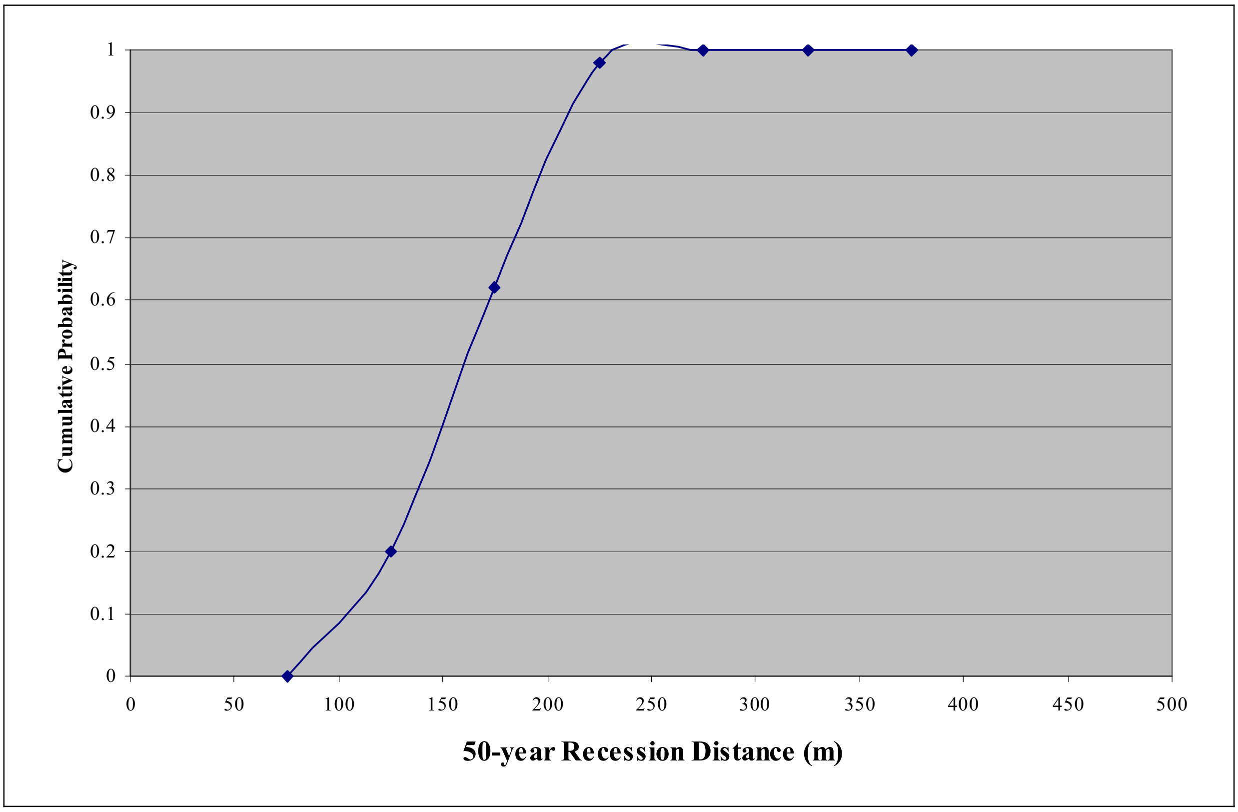


Figure 5 Easton Bavents Cliff: Predicted 50-year Recession Distance

Annex B: Cliff recession and beach levels

Beaches control wave energy dissipation on the foreshore and, as a result, can provide complete protection from marine erosion. In California, Everts (1991) demonstrated that a beach width (above mean sea level) of 20-30m affords significant protection, whereas one of 60m provides complete protection.

The relationship between the average beach volume (measured as the beach profile area above High Water Mark – the 'beach wedge') and annual cliff recession rate for the Suffolk clifflines has been defined by Lee (2004b, 2005), based on the analysis of SDMS profile site surveys between 1992 and 2003. Each survey profile was analysed to determine:

- **annual cliff recession**: calculated as the change in position of the cliff top between survey dates;
- **average annual recession rate**: the cumulative cliff top recession (1992-2003) divided by the number of years in the record;
- **beach wedge area**: calculated for each SDMS profile as a triangle defined by the width and maximum height of the beach above MHWS (0.9m at Lowestoft; 1.1m at Southwold);
- **average beach wedge area**: the sum of the beach wedge area for each winter profile (1992-2003), divided by the number of years in the record.

The average beach wedge area and recession rate for each of the unprotected SDMS profile sites is plotted on Figure 5. The results suggest an exponential relationship, with recession rates increasing rapidly as beach volumes fall (ie 'wedge area'):

Recession rate = $13.997e^{-0.1136x}$ where x is the beach wedge area.

This relationship provides the basis for predicting the effects of changing beach conditions on recession rates. Tables B.1 and B.2 provide an indication of the reduction in recession rate that could be expected with particular beach level changes (10-25% accretion or depletion).

Table B.1 Suffolk cliffs: predicted effect of beach accretion on recession rate

Initial beach wedge area	Accretion	Predicted recession rate (m/year)	Recession reduction factor
10	0	4.494	
	10%	4.012	0.89
	25%	3.383	0.75
20	0	1.443	
	10%	1.150	0.80
	25%	0.818	0.57
30	0	0.463	
	10%	0.330	0.71
	25%	0.198	0.43

Table B.2 Suffolk cliffs: predicted effect of beach depletion on recession rate

Initial beach wedge area	Depletion	Predicted recession rate (m/year)	Recession increase factor
10	0	4.494	
	10%	5.035	1.12
	25%	5.971	1.33
20	0	1.443	
	10%	1.811	1.26
	25%	2.547	1.76
30	0	0.463	
	10%	0.652	1.41
	25%	1.086	2.34

Table B.3 Cliff recession rates and beach wedge areas at SDMS sites

SDMS profile	Cliff recession rate (m/year)	Beach wedge area (m^2)
E6	3.78	13.61
E7	0.3	33.38
E8	0	~200
E9	0	~500
E10	0	~500+
D1	0	~100
D2	7.71	5.95
D3	6.23	7.36
D4	3.44	10.008
D5	4.41	8.87
D7	3.005	14.61

TableB.4 SDMS profile locations

Profile	Grid reference	
SWE6	653687	288954
SWE7	653541	287990
SWE8	653608	286776
SWE9	653623	285822
SWE10	653627	285143
SWD1	653556	284226
SWD2	653362	283322
SWD3	652728	281957
SWD4	652411	281200
SWD5	652005	279925
SWD6	651661	279089
SWD7	651377	278189
SWD8	651241	277395
SWD9	651110	276489
SWD10	650798	275663
SWD11	650488	274888

Annex C: Benacre to Easton Bavents SSSI: Easton Bavents Bank

Introduction

This short report has been prepared in response to the request for advice relating to the proposed re-notification of the Suffolk coastal SSSI between Benacre Ness and Easton Bavents. At the southern end of the site English Nature wish to refine the proposed boundary to allow for the presence of the hard point created by the northern end of the Southwold sea defences. The situation at this point is complicated by the construction of a fill bank immediately to the north of the existing Southwold coastal defences; it is understood that this structure will extend along the Easton Bavents frontage towards Easton Marshes.

The coast protection bank comprises an 8m high soil-fill revetment that extends around 15m seawards from the cliff foot. The seaward edge of the revetment is intended to erode and maintain the coarse sediment inputs to the shoreline ie it is a *sacrificial fill*. The fill material lost each year would be replaced as part of an ongoing maintenance programme.

Photo 1 View southwards along the coast protection bank in front of the Easton Bavents Cliffs (2.9.2005)

The specific casework questions to be addressed were defined as:

- On the basis that the defences are maintained predict a 50 year 'most likely' line of coastal recession; assuming that the bank is removed and the coast is free to erode normally (defined here as the *Active Removal Option*).

- A similar projection but on the basis that the bank stays in place but is not added to or defended. In other words this bank would have to erode first before natural cliff recession could resume (defined here as the *Do Nothing Option*)
- Consideration is also given to the long-term (ie 50-year) impact of maintaining the bank (defined here as the *Hold the Line Option*).

The following assessment is based on a field visit (2 September 2005) during which there was a short conversation with the bank operator. The report is, in part, an addendum to sections of the following report:

- Lee E M 2004a. Benacre – Easton Bavents SSSI: Prediction of Coastal Change. Report to English Nature.

In that Report, 50-year recession predictions were presented in terms of the percentage confidence that the recession would be less than a particular "*upper bound*" value (Table 1). For example, at Easton Bavents Cliff, there is a 95% chance that the cumulative recession over the next 50 years would be less than 225m (ie a 5% chance it would be greater than this value) and a 75% chance that the cumulative recession would be less than 200m.

Table 1 50-Year Cliff Recession Predictions (from Lee 2004a)

Cliff Section	*Upper Bound* Recession: 95% Cumulative Probability distance (m)	75% Cumulative Probability distance (m)
Benacre cliffs	<300	<250
Covehithe cliffs	<400	<350
Easton Woods cliffs	<350	<300
Easton Broad cliffs	<425	<400
Easton Bavents cliffs	<225	<200

Background

The coastline north of Southwold contains a number of separate cliff sections:

1. *Easton Bavents cliffs*; a 1km long section of cliffs extending from Easton Marshes to the northern end of the Southwold sea defences. The cliffs are developed in Norwich Crag sediments, with mixed sand-shingle of the Westleton Beds and clay with sand laminae of the Easton Bavents Clay.
2. *Easton Broad cliffs*; a short (0.35km) section of low cliffs (<5m high) within the Easton Broads and Easton Marshes complex. The cliffs are developed in Norwich Crag sediments, have a near vertical upper profile and an almost continuous talus cone at the cliff foot. The partitioned sand and shingle beach is part-vegetated to the rear;
3. *Easton Wood cliffs*; a 0.8km long cliffline developed in Norwich Crag sediments, extending from Covehithe Broad to Easton Broad. The 5-10m high cliffs have a near-vertical profile and are fronted by a partitioned sand and shingle beach;

The cliffline has experienced very severe recession over the last century, from ranging 2.76-4.32m/year (Easton Bavents cliffs) to 6.67-7.69m/year (Easton Broad cliffs) and 5.43-6.63m/year (Easton Wood cliffs; see Table 2).

Figure 1 illustrates how the *medium-term* recession rate increases northwards with distance from the Southend Warren groyne at the north end of the Southwold coastal defences. A linear trendline plotted through the data suggests an increase in average annual recession of around 1.1m for every 1km north between Easton Bavents and Easton Wood cliffs (3.5km distance). Between Easton Bavents and Easton Broad, the rate of increase is 3m for every 1km north (Figure 2).

These variations in recession rate are likely to be related to difference in beach volume and, hence, the "natural" protection against wave erosion. The relationship between the average beach volume (measured as the beach profile area above High Water Mark – the "beach wedge") and annual cliff recession rate for 7 profile monitoring sites the Suffolk clifflines has been defined by Lee (2004b, 2005) and is shown in Figure 3. This indicates that recession rates increase exponentially as beach volumes fall (ie "wedge area"). At Easton Bavents, the average beach wedge area between 1992 and 2003 was $14.61m^2$; at Easton Wood cliffs the beach wedge area was $8.87m^2$.

The higher beach volumes in front of Easton Bavents cliffs are probably a reflection of the interruption of the longshore sediment transport pathway by the Southwold coastal defences:

- the Southwold groynes act as partial barriers to southwards sediment transport, promoting a build up of beach material on the updrift (northern) side;
- the contrast between the ongoing recession of the Easton Bavents cliffs and the static shoreline along the Southwold frontage has resulted in a local change in shoreline orientation ie the defended section has become a "headland". This local change in shoreline orientation has probably resulted in a reduction in the sediment transport rate along the shoreline between Easton Marshes and Southwold and, hence, a tendency for beach accretion (ie sediment inputs to this section are greater than the outputs).

Closer inspection of Figure 1 suggests that the influence of the Southwold coastal defences on the average recession rate (ie the *zone of reduced recession rates*) may extend around 1000-1500m northwards. After this distance, recession rates appear to be broadly constant, varying between 5.5-7.7m/year.

Table 2 Cliff Recession Measurements (from Lee 2004a)

			Cliff Recession Rates (m/year)							
Cliffline	SDMS Section Number	EA/WDC Profile Location	1884-1905*	1905-1946*	1946-1976*	Cumulative Recession (m) 1884-1976*	Long-term Recession Rate 1884-1976	Cumulative Recession (m) 1991-1999**	Short-term Recession Rate 1991-1999**	Medium-term Recession Rate 1946-1976; 1991-1999**
Easton Wood Cliffs	523		4.9	1.2	6.59	349.8	3.80			5.43
	522		2.3	2.4	8.1	389.7	4.24			6.63
	521		2.09	2.59	7.8	384.08	4.17			6.39
		SWD5						8.8	1.1	
Easton Broad Cliffs	517		1.4	2.2	7.8	353.6	3.84			7.69
	516		1.5	2.3	6.5	320.8	3.49			6.67
		SWD6						58.4	7.3	
Easton Bavents Cliffs	514		3	1.4	5.18	275.8	3.00			4.32
	513		3.8	1.1	4.59	262.6	2.85			3.86
	512		3.8	1.2	3.59	236.7	2.57			3.07
	511		4	0.7	3.2	208.7	2.27			2.76
	510		4.3	0	3.2	186.3	2.03			2.76
		SWD7						8.8	1.1	
		SWD8						3.2	0.4	

Notes:

* * recession rates determined from comparison of the cliff top positions on different Ordnance Survey map editions (Halcrow 2001)
** It is assumed that cliff top recession rates are equal to HWM recession rates
*** Medium-term recession rate is the cumulative recession over the periods 1946-1976 (30 years) and 1991-1999 (8 years) divided by the total number of years (38 years)

Figure 1 Variation in Medium-term Recession Rate with Distance north from the Southwold Defences (Easton Bavents cliffs to Easton Wood cliffs)

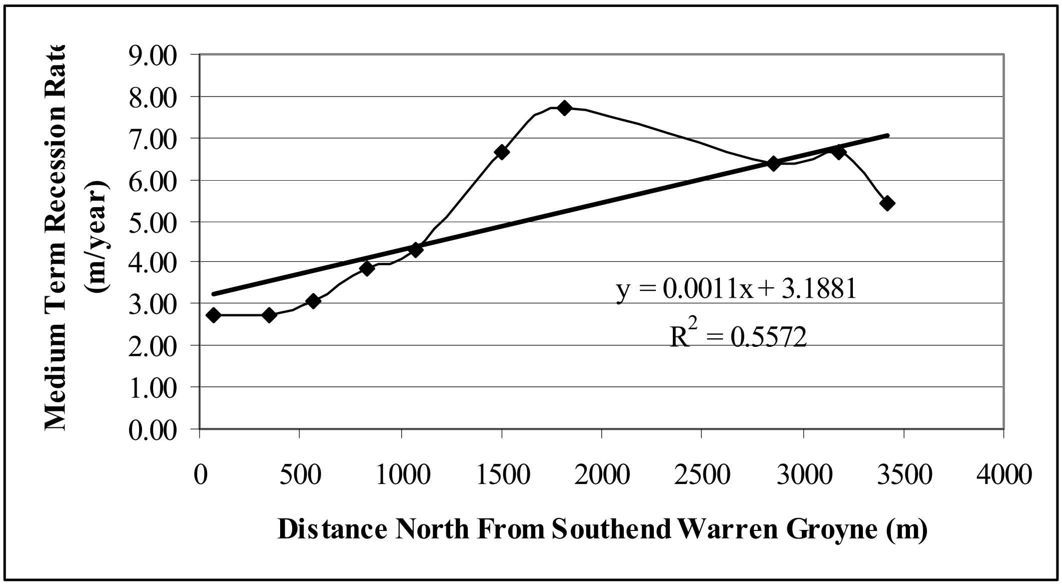


Figure 2 Variation in Medium-term Recession Rate with Distance north from the Southwold Defences (Easton Bavents cliffs to Easton Broad cliffs)

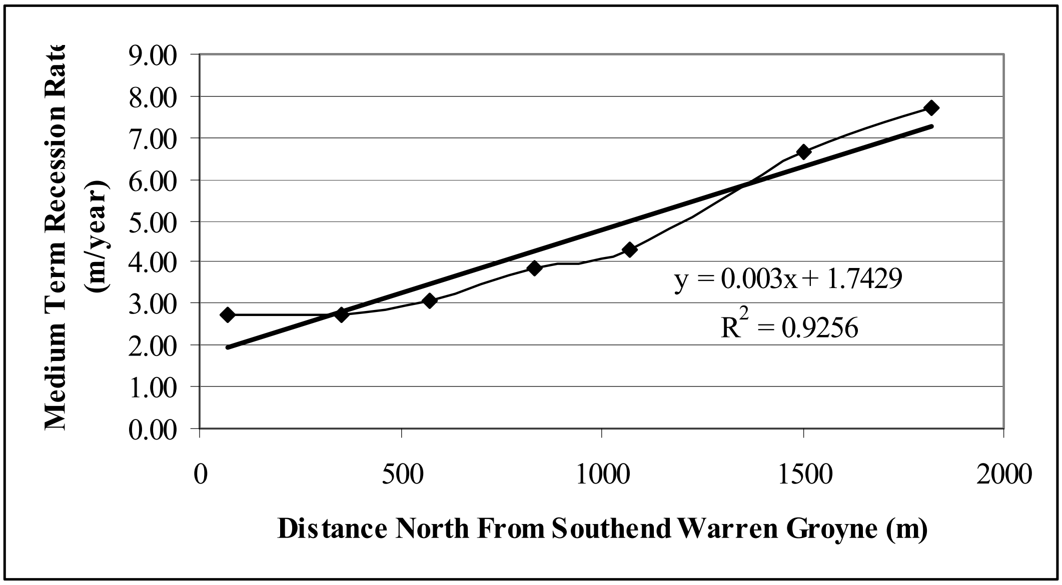
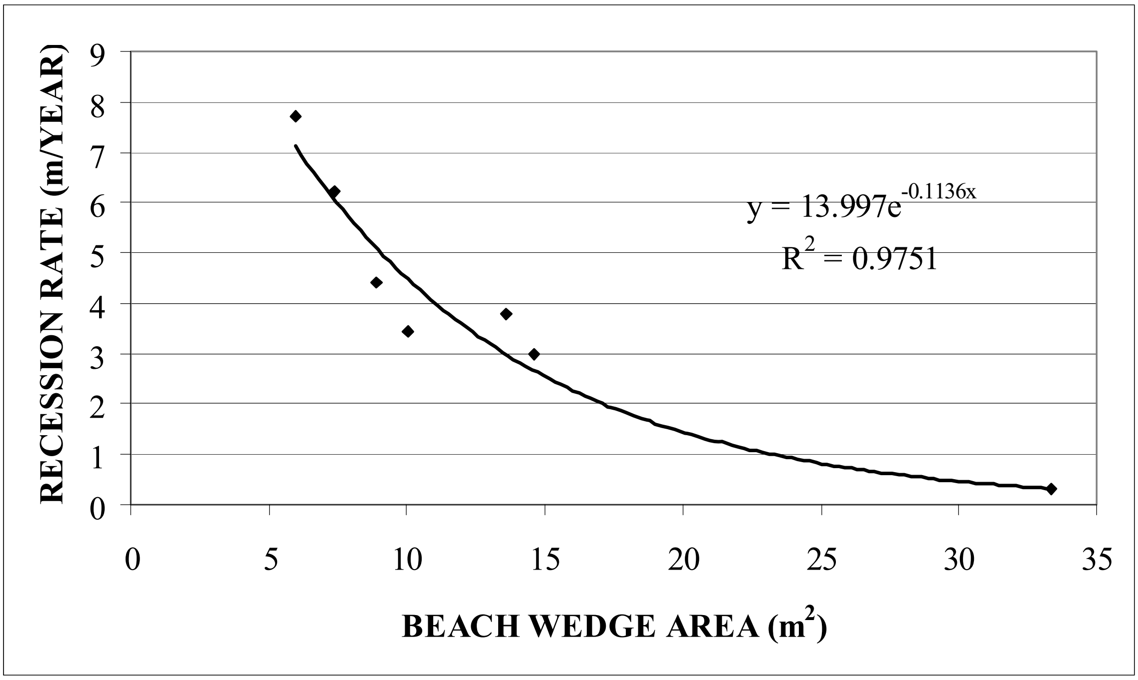


Figure 3 Suffolk cliffs: the relationship between average annual cliff recession rate and beach volume (expressed as the beach profile area above HWM - the "beach wedge") (from Lee 2004b)



Impact of the Coast Protection Bank: Do Nothing Option

The seaward edge of the revetment is currently eroding at a reported rate of around 5m/year (source: P Boggis). The fill material lost each year is replaced, ensuring that there is no/minimal *net* shoreline retreat.

If the fill replacement programme ceased, then it is expected that the fill bank would be removed by wave attack within 5 years. The precise time until the natural cliffline is exposed is difficult to predict as it will be very sensitive to the frequency and severity of storms over that period.

The cliffs may then be expected to retreat at roughly the 50-year rates predicted in the previous report (see Table 1; Lee 2004a). This judgement takes into account a possible balance between the 5-year delay in re-establishing recession and the possibility that there would be accelerated recession in the short-term. It is understood that part of the beach material at the cliff foot was removed during the bank construction. This could result in lower beach volumes when the cliffline is re-exposed and, as a result, higher short-term recession rates (eg over the first 10 years after the onset of erosion). This period of rapid erosion could offset the loss of 5 years of recession during the time that the fill is lost.

Impact of the Coast Protection Bank: Active Removal Option

If the fill material was mechanically removed, then the re-establishment of cliff recession will be immediate. As mentioned above, in the short-term the rate is likely to be higher because of the lower beach volumes. However, the significance of this impact is likely to decline over time as the cliffline retreats.

It is suggested, therefore, that the 50-year recession rate for either of the Do Nothing and Active Removal options will be roughly similar to the previous predictions made for the unprotected cliffline ie around 200-225m over the next 50 years.

Impact of the Coast Protection Bank: Hold the Line Option

If the coast protection bank is effectively maintained, then there will be no significant retreat of the Easton Bavents Cliffs over the next 50 years. However, allowance needs to be made for minor spalling of the cliff face and top; this might be around 5-10m over that period.

Prevention of cliff recession will result in the Easton Bavents frontage gradually emerging as a "headland" relative to the eroding sections of shoreline to the north. As described earlier for the Southwold groynes, this will lead to beach accretion updrift of the northern end of the bank and the development of a *zone of reduced recession*. This zone could be expected to extend around 1000-1500m, causing reduced recession rates along the Easton Marshes and Easton Broad Cliff shorelines.

The impact on the Easton Broad Cliff 50-year recession rate is difficult to quantify. However, it is possible that the beach volumes and recession rates might be similar to the *unprotected* East Bavents Cliffs ie around 200-225m over the next 50 years. This would represent a 50% decline from the previously predicted rates of around 400-425m.

The coast protection bank is not expected to influence the recession of the Easton Woods Cliffs.

Summary

Table 3 summarises the expected impacts of the coast protection bank on the 50-year recession rates of the clifflines north of Southwold. Predicted recession distances for three different shoreline management options are presented in Table 4.

Table 3 Expected Impact of the Coast Protection Bank on the Previous 50-Year Recession Predictions (see Table 1)

Option	Predicted Impact on 50-Year Recession Rate		
	Easton Bavents Cliffs	Easton Broad Cliff	Easton Woods Cliffs
Do Nothing	No Impact	No Impact	No Impact
Active Removal	No Impact	No Impact	No Impact
Hold the Line	No significant recession (almost 100% reduction in predicted recession rates)	50% reduction in predicted recession rates	No Impact

Table 4 50-Year Cliff Recession Predictions

Cliff Section	Option	*Upper Bound* Recession: 95% Cumulative Probability distance (m)	75% Cumulative Probability distance (m)
Easton Woods cliffs	Do Nothing	<350	<300
	Active Removal	<350	<300
	Hold the Line	<350	<300
Easton Broad cliffs	Do Nothing	<425	<400
	Active Removal	<425	<400
	Hold the Line	<225	<200

Easton Bavents cliffs	Do Nothing	<225	<200
	Active Removal	<225	<200
	Hold the Line	<10	<10

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Research information note

English Nature Research Report, No.647

**Coastal evolution in Suffolk:
an evaluation of geomorphological and habitat change**

Edited by Sue Rees   January 2006

Keywords: Coastal Shingle vegetation, Cliff recession

Introduction

England's coast supports an abundance of wildlife habitats and physical features. These special places depend on the interactions between wind, waves, tides, sediments and geology to shape and sustain their nature conservation interest. Over time, coastal habitats and features change, so their effective conservation involves providing sufficient space to allow them to move and evolve in response to the action of the sea. This report contains the results of a series of commissioned studies to enhance the scientific understanding of a Site of Special Scientific Interest (SSSI) in the Suffolk Coast and Heaths Natural Area, with particular regard to coastal evolution and predictions of future change.The Suffolk coast is rapidly eroding along much of its length. Cliffs are retreating inland by several metres each year, and saltmarshes are steadily shrinking. The great shingle structures of Orfordness and Benacre Ness are actively moving, through the continual erosion and deposition of shingle. Benacre Ness is slowly moving northwards, as new material accretes on its northern side and shingle erodes from its southern side. As well as their great geomorphological significance, the shingle structures support rare undisturbed vegetation communities.

What was done

These studies, from 2003 to 2004, were carried out by specialist contractors, using both field survey and literature reviews, and drawing on other current specialist studies. There are two main sections; a study of the shingle vegetation and changes since 1988, and analysis and predictions of coastal evolution for both the cliffs and the shingle structure. The studies included a vegetation survey of the shingle at Benacre Ness and evaluation of the likely coastal evolution of the shingle structure and the cliff line. The vegetation studies confirmed that the shingle vegetation had changed since it was last surveyed in 1988, with a range of vegetation communities still represented at the site. The distribution and extent of these communities has changed in response to the re-working of the sediment and the northward migration of the shingle of Benacre Ness. The coastal evolution studies were based on a review of current coastal studies and data about the historic changes that have taken place. Using modelling techniques, these provided a prediction of future change for both the northward migration of Benacre Ness and the likely recession rates for the cliff sections of the site. The impact of climate change and sediment budgets are uncertainties that need to be taken account of in future.

Results and conclusions

The survey in 2004 confirmed the presence of a series of shingle vegetation communities recorded in 1988, as well as others not recorded in the 1988 survey. The site is of importance for this nationally scarce type of vegetation.

For the cliff geomorphological study, a simple probabilistic model has been used to generate predictions of the cliff top position in 50 years time. The model takes account of uncertainty in the rate of future sea-level rise and the variability of the recorded recession rates along each cliffline. The results are expressed as a probability distribution for the 50-year recession. These range from 225m to 425m inland of the current cliff position, depending on the section of cliff. For the movement of the shingle structure at Benacre Ness, a conceptual model has been developed to provide a prediction of the migration rate over the next 50 years. This model considers ness migration as involving a combination of long periods of gradual change (13.3m/year) together with short periods of rapid change (100m/year) during rare storm events. Ness migration of up to 1500m is predicted for this period. However, it must be stressed that rising sea levels may limit the long-term reliability of this model.

English Nature's viewpoint

The studies have contributed to an increasing body of information about coastal evolution, vital for the conservation measures needed for this area of coast and the predictions of future coastal change. It highlights the link between geomorphological processes at the coast and the habitats of shingle structures.

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Middle left: Co_2 experiment at Roudsea Wood and Mosses NNR, Lancashire.
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