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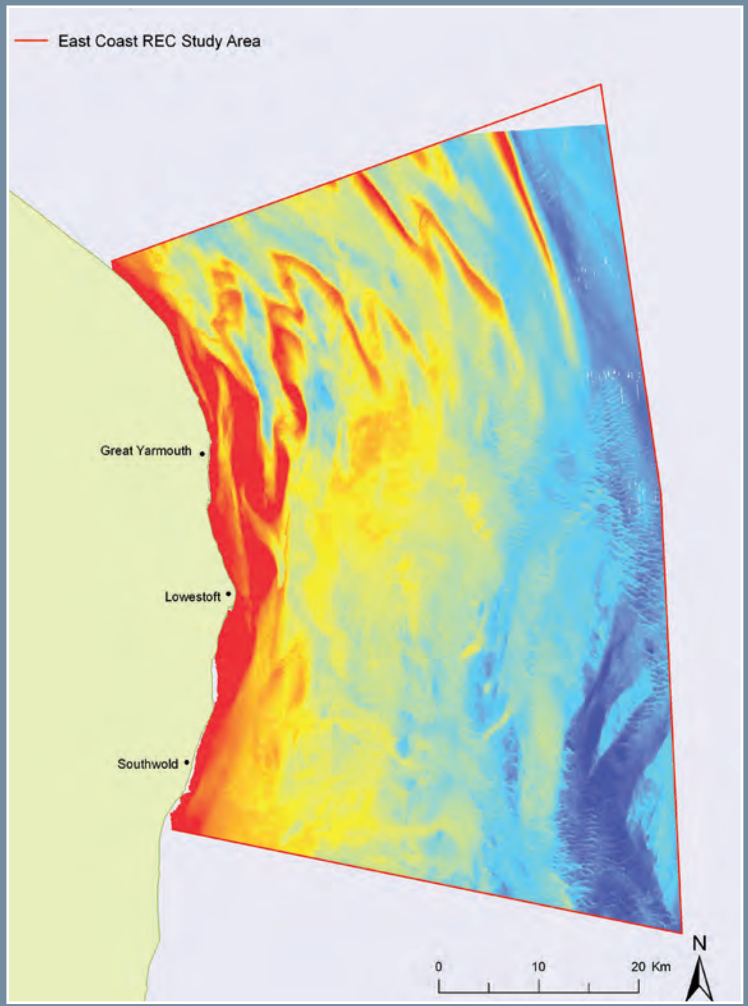
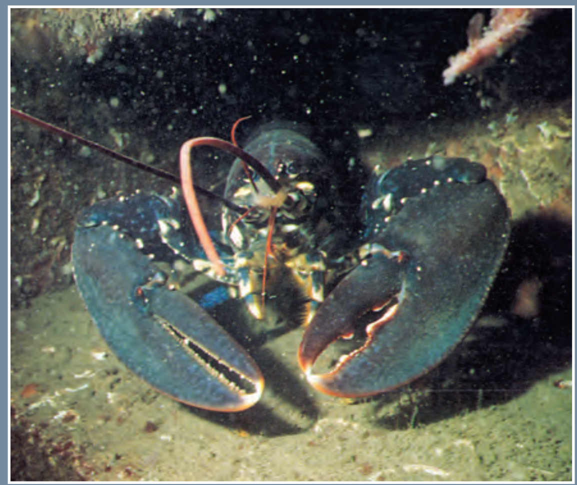
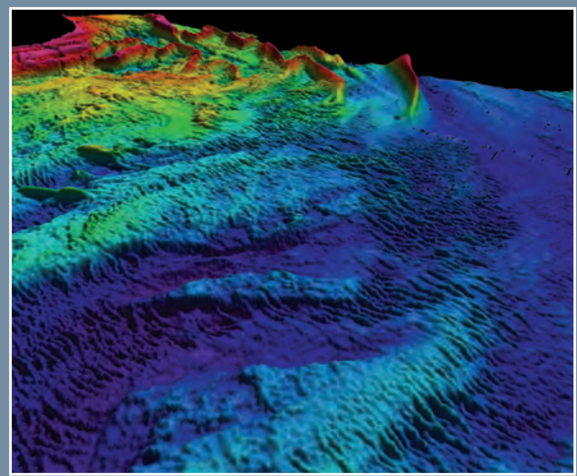
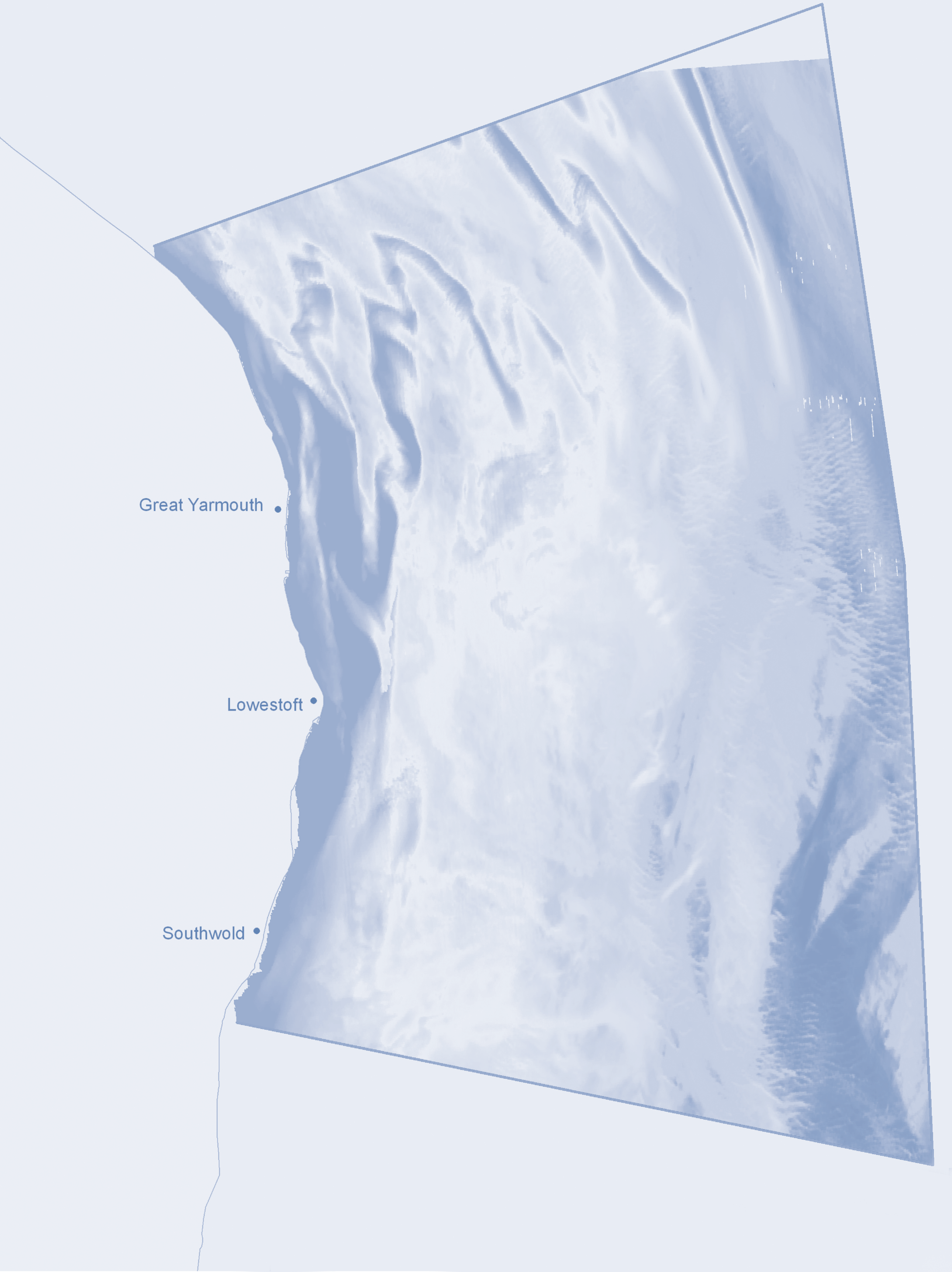
The East Coast Regional Environmental Characterisation









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The East Coast
Regional Environmental Characterisation

Marine Aggregate Levy Sustainability Fund (MALSF)

Administered by:

Report written by:

March 2011

CENTRE FOR ENVIRONMENT, FISHERIES AND AQUACULTURE SCIENCE OPEN REPORT

MEPF 08/04

CLIENT CONTACT DETAILS
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This report is available at www.alsf-mepf.org.uk
Project shape files and other MEPF data are available from www.marinealsf.org.uk
Further information on East Coast REC outputs can be found in Section 1.3.

Project Funding
This work was funded by the **MALSF** and commissioned by the **MEPF**.

Background to the Fund
In 2002, the Government imposed a levy on all primary aggregates production (including marine aggregates) to reflect the environmental costs of winning these materials. A proportion of the revenue generated was used to provide a source of funding for research aimed at minimising the effects of aggregate production. This fund, delivered through Defra, is known as the Aggregate Levy Sustainability Fund (ALSF); marine is one element of the fund.

Governance
The Defra-chaired MALSF Steering Group develops the commissioning strategy and oversees the delivery arrangements of the Fund.

Delivery Partners
The **MALSF** is currently administered by two Delivery partners – the **MEPF** (based at Cefas, Lowestoft) and **English Heritage**.

Contents

Figures

Tables

Appendices on DVD-ROM

Executive summary

1 The East Coast Regional Environmental Characterisation (REC) Programme is a multidisciplinary investigation that has employed "state of the art" techniques to develop a broad understanding of the habitats and areas of archaeological interest over an extensive area of approximately 3,300 km^2 of the seabed off East Anglia. The study was conducted over a three-year period and has been funded by the Marine Aggregate Levy Sustainability Fund.

2 The overall aim of this study was to provide integrated broad-scale maps to underpin marine spatial planning and to enable the sustainable management of offshore resources now and into the future. As such, the data and mapped products from this study will help support the Marine Management Organisation's efforts for delivering statutory Marine Plans for the area encompassed by the East Coast REC Study Area. These plans will apply the Government's Marine Policy Statement and implement tailored and locally specific marine policy objectives and targets to enable the sustainable development of marine activities.

3 In parallel, the UK Government together with its Statutory Nature Conservation advisors is seeking to identify Marine Conservation Zones, which will contribute to an ecologically coherent and well-managed network of Marine Protected Areas. One of the main outputs from the East Coast REC programme is a series of biotope (habitat) maps that delineate areas of seabed that are distinct in terms of their physical properties and associated biological communities. Such maps also highlight the location, extent and character of the EC Habitats Directive Annex I features (ie, subtidal reefs and sandbanks) within the East Coast REC Study Area and therefore can be used to refine or supplement evidence required as part of the identification and selection of Natura 2000 sites.

4 High-quality geophysical, geological, archaeological and biological data-sets have been acquired during the project, and these have been combined with existing data to produce interpreted mapped outputs. These provide the context for providing a regional assessment of the physical, biological and archaeological environment. Such assessments are presented individually and are also integrated to provide a holistic view of the seabed and important features of nature conservation or heritage importance. As such, this information will provide an essential underpinning for decisions aimed at ensuring the sustainable management of offshore resources and protecting the marine historic environment.

5 There is increasing demand on marine space and resources in the East Coast REC Study Area, partly because of the expansion of some maritime industries and also newer developments such as offshore windfarms. Within the area, there are a wide range of marine activities including marine aggregate extraction, port and shipping activities, dredged material disposal, offshore windfarms, oil and gas exploration, and commercial and recreational fisheries. In the future, this area is also likely to experience a step change in wind-turbine deployment and an increasing demand for marine aggregate materials to support large-scale infrastructure projects and coastal defence programmes.

6 Historically, marine sand and gravel extracted from the area has made an important contribution to meeting the UK's demand for construction aggregate materials in London and the south-east of England. In 2009 the East Coast region produced 6.93 million tonnes, which accounted for 34.3% of the total marine aggregate production in England and Wales. The total area licensed for aggregate extraction in the East Coast region (of which the East Coast REC Study Area forms a part) in 2009 was 266.52 km^2, and of this 158.17 km^2 was actively dredged. Currently, there are 14 active marine aggregate extraction licences in the East Coast REC Study Area, with applications submitted for a further 7 licences and 11 prospecting areas.

7 A variety of fixed and mobile fishing gears are employed to catch a range of target species in the East Coast REC Study Area. Longlines are used to target cod, thornback ray, smoothhound, spurdog and, seasonally, sea bass. Gill and trammel nets are set for cod and whiting in the winter, and tangle and trammel nets target sole, plaice, turbot and rays in the spring, with sole being of particular commercial importance. Beam trawlers are also used to catch brown shrimp, along with a variety of finfish species such as plaice and sole. Drift netting takes place for herring, and crabs and lobsters are caught using parlour pots. The East Coast REC Study Area has eight ports into which fish are regularly landed, namely Winterton-on-Sea, Great Yarmouth, Lowestoft, Southwold, Dunwich, Sizewell, Aldeburgh and Orford. The majority of vessels are <10 m in length, but larger vessels of >10 m length may also land their catches in Great Yarmouth and Lowestoft. In addition to these large ports, many longshore boats operate from beaches throughout the area.

8 Geologically, the East Coast REC Study Area is characterised by recent (Holocene) deposits, which are often highly mobile. These sediments exist as a relatively thin veneer overlying the erosional surface of the Quaternary strata, and are largely derived from glaciogenic or fluvial sources, being composed primarily of sandy materials. Gravel deposits are also relatively widespread and locally important in producing features such as the gravel lag deposits identified in the central section of the East Coast REC Study Area. These deposits are the target for the marine aggregate extraction industry.

9 In the western part of the East Coast REC Study Area, there are several occurrences of uneven seabed resulting from the outcrop of older strata. Although referred to as bedrock outcrop, the outcropping material is uncemented and poorly consolidated. The most dramatic of these outcrops is the Cross Sands Anomaly, a feature of maximum length of 165 m, protruding west from the Middle Cross Sands sandbank into the Barley Picle Channel. First discovered in 1987, this feature

has been mapped during the East Coast REC study and is thought to be a glaciotectonic rafted block transported by an ice sheet, deposited during meltwater drainage.

10 The East Coast REC Study Area is known to have a generally high sensitivity in respect of the marine historic environment. Remains indicative of *in situ* archaeological sites have been identified within existing aggregate extraction areas on a number of occasions, and the wider region is also known to contain significant sites, including wrecks and inundated/eroded terrestrial sites. The East Coast REC study has provided a regional geological and environmental context in relation to previously recovered Palaeolithic finds. In addition, a flint flake was recovered from a Clamshell grab sample during the East Coast REC survey. Amongst the sites discovered during surveying of the area or through aggregate extraction activities are:

- the internationally important discovery of 75 Palaeolithic artefacts, including hand axes, cores and flakes in an aggregate extraction area
- peat and wood fragments indicating Mesolithic land surfaces
- wrecks dating from the early nineteenth century, including the *SS Seagull* and *Xanthe*, as examples of c. nineteenth-century sail-assisted steam paddle vessels and steam screw vessels, respectively
- evidence of the remains of Second World War aircraft, which are protected under the Protection of Military Remains Act 1986.

11 Several locations of archaeo-environmental potential were also discovered during the East Coast REC study. These were determined by integrating data and evidence from archaeological studies with geological, geophysical and palaeo-environmental interpretations to characterise the submerged prehistoric resource. Through this analysis, the archaeological potential has been demonstrated of deposits in the East Coast REC Study Area associated with the key periods of occupation, from the earliest known sites, such as Pakefield and Happisburgh, through the Palaeolithic to the Mesolithic.

12 The maritime archaeological resource has been spatially mapped, and enhanced through the collection of additional geophysical data-sets collected across the East Coast REC Study Area. This characterisation has improved our understanding of the maritime heritage resource and provides a reliable guide to the quantity, preservation and age of wrecks that lie in the East Coast REC Study Area.

13 The environment in East Coast REC Study Area is characterised by a highly dynamic system, with strong tidal currents and mobile sandy bedforms, that generally supports impoverished biological assemblages. The seabed within the area consists mainly of sandy gravels and gravelly sands. Sandwaves with maximum amplitudes of 6–8 m are found in the north-western and north-eastern parts of the region. In addition, there are sandbanks that are located offshore from Great Yarmouth and as far south as Lowestoft. These are large-scale flow-parallel bedforms orientated in a N–S direction and are approximately 5.8 km in length by 0.8 km in width. Within the Norfolk Banks, towards the north-east of the East Coast REC Study Area, the sediment transport patterns are complex and are often associated with circulatory patterns around the banks, driven by tidal forces. Nevertheless, the sediment transport vectors along the northern edge of the Cross Sands marine aggregate extraction block indicate a southerly movement in the form of bands of sandwaves, probably driven by surge or storm-related events. These southerly flows are generated from the banks further to the north and are orientated against the mean current flow, suggesting that surge/storm events are dominant. Conversely, the southern edge of the marine aggregate extraction block has indications of a northerly migration of sediment, and the sediment transport vectors are aligned with the mean current flow.

14 Sediment type, water temperature and tidal currents, combined with wave action in shallower water, appear to be the most influential variables determining the distributions of biological assemblages in the area. These are generally not independent variables as the consequences of water movements may be expressed through effects on the stability, sorting and scouring of sediments across a range of particle sizes. In particular, the sand fraction appears to be strongly correlated with the distribution of biological assemblages in the area. Near-bed temperature also appeared to be an important determinant of community structure. This is perhaps unsurprising, since many benthic species have well-known temperature tolerances.

15 In general, the benthic fauna of the East Coast REC Study Area is sparse and is characterised by polychaete worms and hard-shelled molluscs. The limited range and density of benthic fauna in this region is attributed to the effects of shifting sands under strong tidal currents and storm action. Locally, there are also reefs of the polychaete worm *Sabellaria spinulosa*, and these biogenic structures act to stabilise mobile sediments by utilising sand in the construction of their tubes, permitting a greater range of species to become established. In addition, there are local reefs of the blue mussel *Mytilus edulis*.

16 Fourteen distinct biological assemblages were described from across the East Coast REC Study Area. Although these assemblages were assessed to be distinct, some differ only in the relative proportions of their shared species. The distribution of these assemblages was compared with the physical data associated with each sample, allowing the relationships between each assemblage and the physical environment to be determined. Preference ranges were identified for each biological assemblage, leading to predictive distributions of the assemblages and thus identifying other areas with the same environmental characteristics. This allowed maps to be produced for each biotope that showed both their known and predicted distributions.

17 Biotope distribution maps were produced for the area using both “top-down” European Nature Information System (EUNIS) and “bottom-up” classification methods. The map resulting from the “top-down” EUNIS approach shows a relatively simple ordered

gradient of change in biotope distributions from west to east across the East Coast REC Study Area. This apparent simple gradient is an artefact of the decision-making process used to generate the EUNIS biotope map. Therefore, whilst the inherent simplicity of this EUNIS biotope map is appealing for management purposes, it may be unsuitable in this area for differentiating between certain sedimentary biotopes, given that allocation of an area into one or other biotope is based on differences in water depth (used as a proxy for unmeasured variables thought to affect the distribution of benthic species, such as photic zone and wavebase). In contrast, the more complex map produced using the "bottom-up" classification process is a more detailed biotope map of this area, and although inaccuracies will inevitably exist, this map utilises available data in a scientifically rigorous way. Where outputs from both mapping approaches agree is in the identification of features of notable conservation importance (eg, *Sabellaria* and *Mytilus*).

18 A number of nationally rare or scarce species were encountered across the East Coast REC Study Area, including the erect colonial hydroid *Obelia bidentata* and the mantis shrimp *Rissoides desmaresti*. The discovery of this shrimp in this area represents a new scientific record, extending the known range of this species to the East coast of England from what was previously thought to be a relatively confined area on the south and Welsh coasts of the UK.

19 Potentially important Annex I biogenic reef habitats and sandbanks were found across the East Coast REC Study Area. The main reef-building species identified during this study are the Ross worm *S. spinulosa* and the blue mussel *M. edulis*. Maps have been produced showing both the known and predicted distribution of *Sabellaria* reef across the East Coast REC Study Area. Dense brittlestar aggregations were identified in the area, and whilst they are not considered to constitute a biogenic reef in themselves, they have been identified as sub-features of reef habitats. In the northern part of the East Coast REC Study Area, there are also a number of significant sandbank features, and these form the southern half of the Haisborough, Hammond and Winterton candidate Special Area of Conservation.

1 Introduction

The East Coast Regional Environmental Characterisation (REC) is a multidisciplinary study encompassing the geology, biology and archaeology of an area covering approximately 3,300 km^2 of the seabed off East Anglia (Figure 1.1). The seabed off East Anglia is comprised of coarse material – that is, various proportions of sand and gravel (Humphreys *et al*., 1996; see also BGS's DigSBS250 map). Where these resources are present in sufficient quantity, are of the right composition, and are accessible to commercial dredgers, they have been considered for extraction as a source of sand and gravel (aggregate) for the construction industry. This may be undertaken either to supplement land-based sources, or as a source of material for beach nourishment (Singleton, 2001). Planning constraints are tending to restrict the extraction of aggregate from terrestrial sources, and therefore attention is increasingly focused on the importance of seabed resources to satisfy part of the demand for aggregates (Mankelow *et al*., 2008). The seabed is also recognised as the only viable source of material for beach recharge in coastal defence schemes. In recognition of this, the extraction of marine aggregate resources is supported by the UK Government, subject to environmental safeguards (UK Her Majesty's Government, 2010). As dredged material can often be landed close to the point of demand, this can also secure an environmental advantage by reducing the need for onward transport on the road network.

Historically, the East Coast Region has been an important source of marine aggregate, with a total of 88,973 million tonnes of marine sand and gravel dredged from Crown Estate licensed areas between 1998 and 2007 (The Crown Estate and BMAPA, 2008). However, many marine aggregate extraction licences off the East Anglian coastline are now nearing the end of their terms, and, as a result, the marine aggregate extraction industry is in a phase of licence renewals. In recent years, dredging companies have also released dredging licences (or Zones) for areas off the East Anglian coast which no longer yield significant returns. Additionally, in the awarding of many new licences, systems of zoning of dredging activity have been agreed in order both to limit the geographical scale of environmental impact during any one period, and to minimise disruption to fishing or other marine activities. In the future, demand for marine dredging in the region could increase, particularly to support large-scale infrastructure projects (eg, new nuclear power stations and offshore wind gravity base structures) and coastal defence programmes.

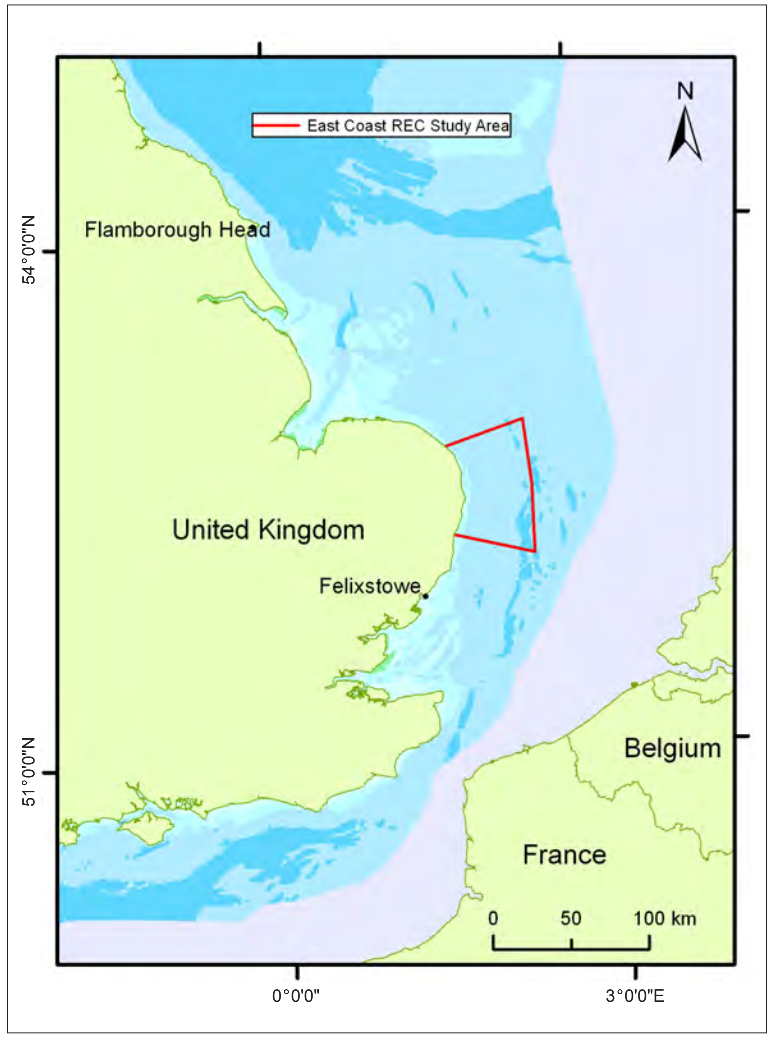

Figure 1.1 Location of East Coast REC Study Area. Digital bathymetry data © British Crown and SeaZone Solutions Ltd. All rights reserved. Data Licence 052008.012.

To support the process of licence renewals, the marine aggregate extraction industry has embarked on a programme of Regional Environmental Assessment (REA). The REA aims to provide a description of the current regional environmental information, enhanced through the collection of new survey data. Its remit includes improving our ability to predict and understand the potential for cumulative and in-combination effects arising from marine aggregate extraction as a result of existing and prospective aggregate extraction licences. Gaps in knowledge or data identified by the REA are also being targeted as part of the data and evidence collection process during individual licence applications or renewals. The East Coast REC study is designed to complement this process by offering a broader context for these assessments through the provision of regional-scale geological, biological and archaeological data and interpretations.

Since the inception of the East Coast REC study, the regulatory framework for considering marine offshore activities including marine aggregate extraction has changed. The Marine and Coastal Access Act 2009 (the "Act") received Royal Assent on 12 November 2009 and aims to help the UK Government achieve its vision of integrated coastal zone management by putting in place better systems for delivering sustainable development of the marine and coastal environment. The Act intends to do this through a new system of marine planning, streamlining the licensing processes and improving marine conservation and marine fisheries management. These processes will all be overseen by the new delivery body, the Marine Management Organisation (MMO), established in April 2010. The MMO is responsible for delivering statutory Marine Plans in the areas that make up the English inshore and offshore regions. Production of statutory Marine Plans is due to start in April 2011. This will involve applying the Government's Marine Policy Statement (expected to be released in Spring 2011) and implementing tailored and locally specific marine policy objectives and targets for each of the English Marine Plan areas. Their overall objective is to contribute to the achievement of sustainability in the marine area by enabling strategic management of marine activities, achieving integration of different objectives, managing conflicts and complementarities and taking account of how ecosystems function. As such, they will be akin to the marine spatial plans already formulated in other countries (Douvere, 2008; Crowder and Norse, 2008; Douvere and Ehler, 2009). This initiative will also significantly contribute towards the UK vision of clean, healthy, safe, productive and biologically diverse oceans and seas (UKMMAS, 2010). The East Inshore and East Offshore areas, located off the coast between Flamborough Head and Felixstowe, are the first areas in England to be selected for marine planning (www.marinemanagement.org.uk/marineplanning/areas.htm). As well as being an important area for marine aggregate extraction activities, recent analysis by the MMO shows that the East Inshore and East Offshore Marine Planning Areas will experience the majority of the step change in forecast wind turbine construction to help meet the UK's 2020 energy targets.

The current programme is therefore very timely, since the East Coast REC Study Area (also referred to as survey area) lies within both the East Coast Inshore and Offshore Marine Planning Areas. As such, the outputs from this study should have wide utility. Specifically, they could be used to underpin the future statutory Marine Plans within this Region. Indeed, the study has been designed to produce mapped outputs and a regional context to inform such marine spatial planning processes, particularly in relation to designation of sites of conservation/heritage significance and for rational management of important marine aggregate resources that are located in the area. For example, the seabed maps from the East Coast REC study could be used to aid decision making in terms of guiding dredging towards preferred areas in a transparent, sustainable and objective manner. Such evidence-based decision making may help to promote more confidence in decisions that are later made in the context of the statutory Marine Plans and create greater certainty for marine users, assisting with medium- to long-term planning and investment decisions. Such plans (and the underpinning seabed maps) can also provide stakeholders and regulators with a framework within which dredging applications, renewable energy developments or other marine activities can be considered. Apart from the obvious economic advantages, Marine Plans, supported by detailed maps, also offer the possibility of enabling, for example, the aggregate extraction and offshore renewable energy industries to be managed at a much finer spatial scale than was previously possible, whilst affording greater protection to sensitive habitats.

The Act also provides for the establishment of Marine Conservation Zones (MCZs), which is one of the proposed measures that seeks to minimise impacts on marine ecosystems whilst allowing sustainable use of marine resources. MCZs will complement European Marine Sites as part of a network of flexible, objective-based, marine protected areas. The UK Government intends that the network will help halt the decline of biodiversity by including the full range of UK habitats and species and conserving areas where there are rare or threatened species to "*ensure that the marine environment is healthy and able to deliver the many goods and services that we rely on*" (UK Her Majesty's Government, 2010). Again, the East Coast REC study may assist here, by producing high-resolution biotope maps of the seabed that can provide some of the necessary information and data to help the Statutory Nature Conservation Agencies and wider stakeholder groups such as the Net Gains Project (www.netgainmcz.org/). In particular, such biotope maps may inform judgements as to whether there are any sites within the Region suitable as potential MCZs. They may also have value in providing additional evidence to help delimit and/or refine the boundaries of sensitive heritage or nature conservation features (including those within Special Areas of Conservation), and/ or provide a wide spatial context for any future environmental monitoring programme(s) in the Region.

1.1 Objectives

The overarching objective of this study is to develop a broad understanding of the habitats and areas of archaeological interest present in the East Coast REC Study Area and to provide an insight into the processes that influence them. To achieve this, we have set out to acquire high-quality physical, geophysical, archaeological and biological data-sets and use them to produce interpreted outputs that will enable the subsequent assessment of regional influences.

The **principal objectives** of the East Coast REC study stipulated by the Marine Environment Protection Fund (MEPF) are provided below:

1 Desk-based research:
To critically review all pertinent scientific data for the Region and identify gaps in knowledge, and to use this to refine the survey-work scope to ensure that acquired data are sufficient to be suitable for the likely avenues of interpretation.

2 Geophysical survey data acquisition:
(a) To collect additional data through the conduct of new geophysical surveys in the Region to target knowledge gaps.
(b) To produce a detailed acquisition report in line with those provided for previous REC studies.

3 Biological survey data acquisition:
(a) To collect additional data through the conduct of new sediment sampling and biological surveys in the Region to target knowledge gaps.
(b) To produce a detailed acquisition report in line with those for previous REC studies.

4 Mapping R&D:
To integrate new and existing geophysical, geological and biological data to provide comprehensive maps of:
(a) the distribution of marine species and habitats (including those of conservation significance and fisheries importance)
(b) seabed sediments
(c) archaeological features and deposits/areas of increased archaeological potential in the Region.

5 Additional R&D:
To test causal relationships/correlations between the physical environment and associated fauna.

6 To identify and record the nature and location of any obvious human impacts in the Region (eg, dredge tracks, disposed or discarded material and trawl marks).

7 To provide data and products to support the integrated management of offshore resources in each Region and to provide a better basis for marine spatial planning.

8 Dissemination:
To disseminate interpreted data, maps and new knowledge directly to stakeholders via the World Wide Web, reports, scientific publications, multimedia and other means.

The East Coast REC study provides a unique opportunity to target the collection of co-located data-sets and integrate these with existing information to produce a holistic assessment of the seabed for the Region. In doing this, we have broadly followed the approach adopted in previous REC programmes (see, eg, James *et al.*, 2007; Emu Ltd & University of Southampton, 2009; James *et al.*, 2010). Throughout the study, a multidisciplinary approach has been adopted, and this has been supplemented by introducing novel methods of analysing and interpreting the available data. The report begins with an account of the regional setting in terms of the physical, biological and archaeological environment and is followed by a description of socio-economic activities that take place within the study area. An appraisal of such data was undertaken to inform new survey strategies in a way that maximised the value of newly acquired data-sets. New approaches have also been developed in terms of providing a comprehensive assessment of heritage issues, and these have been integrated with the Quaternary geology, as appropriate. Analysis of the infaunal and epifaunal data-sets have been integrated with an evaluation of the associated physical environment. Concerted effort is also applied to deliver biotope maps using the more traditional European Nature Information System (EUNIS) “top-down” classification and a novel “bottom-up” classification approach. The latter classification is dependent on adopting an *a-priori* approach, through establishing the relationships between environmental and biological variables that are then used to describe and delineate the habitat map units. Recognising that the outputs from this study have wide utility, the study has also sought to identify and map features of potential nature and heritage significance.

1.2 Study team

The study team and the preparation of this report were led by the Centre for Environment, Fisheries and Aquaculture Science (Cefas). This partnership – comprising Cefas, The British Geological Survey (BGS), Wessex Archaeology (WA), Marine Ecological Surveys Ltd (MES) and Envision Mapping Ltd (see Table 1.1) – applied its combined skills to address the multidisciplinary aims of this project in a scientifically robust way.

The partnership are grateful for the support of the Marine Aggregate Levy Sustainability Fund (MASLF), the Steering Group and its advisors, including Dave Carlin, Mike Cowling, Patricia Falconer, Euan McNeil, Julianna Measures, Richard Newell, Shaun Nicholson, Simone Pfeiffer, Ian Reach, Mark Russell, Ian Selby, Philip Stamp and Gareth Watkins.

1.3 Outputs

The results, interpretations and conclusions of the East Coast REC study are published in this report. Also attached to the back cover of this report is a DVD-ROM that includes appendices of data and analysed or interrelated results, plus a pdf copy of this report in high resolution and the East Coast REC survey report (Cefas, 2010). A low resolution version of this report will also be available on the MEPF website.

The ALSF Marine GIS database (www.marinealsf.org.uk) provides access to the marine aggregate research project metadata information and digital reports. The database holds a copy of this report and the survey data from the East Coast REC 2010 survey for download. Interpreted data are also available via the database. The database can be accessed using text and GIS map-based searches.

Organisation	Team
Cefas	Kelly Baker Christopher Barrio Froján Andrew Birchenough Sonia Kirby Robin Law David Limpenny (Project lead August 2008 to October 2010) Siân Limpenny (Project lead November 2010 to March 2011) Bill Meadows Sara Pacitto Julia Rance Jon Rees David Stephens Christian Wilson Sarah Walmsley
British Geological Survey NATURAL ENVIRONMENT RESEARCH COUNCIL	Carol Cotterill Sophie Green David Long (Partner organisation lead)
MES	Jackie Hill Bryony Pearce (Partner organisation lead)
ENVISION envision.uk.com	Bob Foster-Smith (Partner organisation lead)
Wessex Archaeology	Stephanie Arnott Kitty Brandon Stuart Churchley Patrick Dresch Antony Firth Matt Leivers Jack Russell Chris Stevens Louise Tizzard (Partner organisation lead) Sarah Wyles

Table 1.1 The East Coast Regional Environmental Characterisation study team.

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2 Regional perspective

2.1 Physical setting

The East Coast REC Study Area lies within the southern North Sea, which forms part of a shallow-water embayment of an epeiric sea on the European Continental Shelf (Figure 2.1). Water depths in the southern North Sea are generally between 40 and 80 m, although locally water depths may exceed 130 m in infilled/open meltwater-incised valleys.

The oldest strata that outcrop in the southern North Sea are of Cretaceous age, but Cenozoic sediments dominate the pre-Quaternary. Underlying this, the strata of the Mesozoic and Permian are represented by a sequence of sedimentary rocks derived from a range of marine and terrestrial environments of deposition. The oldest strata found in this area are the crystalline metamorphic basement rocks of the London–Brabant massif, which were most recently deformed during the late Silurian.

The North Sea has been an area of active subsidence since the Permian, developing the large hydrocarbon basin exploited today. Rates of subsidence have fluctuated over this time, having increased since the Pliocene (Kooi *et al.*, 1991). In combination with global sea-level fluctuations associated with Quaternary climatic changes, this has caused dramatic changes in the geometry and morphology of the North Sea seafloor. In addition, glacial isostacy has influenced the area since the mid-Quaternary, and in certain areas – such as the southern part of the Dogger Bank between 53°50′N and 54°30′N – salt movement (halokinesis) has had an effect.

The Quaternary period is characterised by considerable global climatic instability, with repeated cycles of glaciation, reflected in the cyclical depositional nature of the formations. The base of the Quaternary is considered to be 2.588 Ma ago, coincident with a major change in the fauna of north-west Europe, and the establishment of the Quaternary ice age, seeing permanent ice

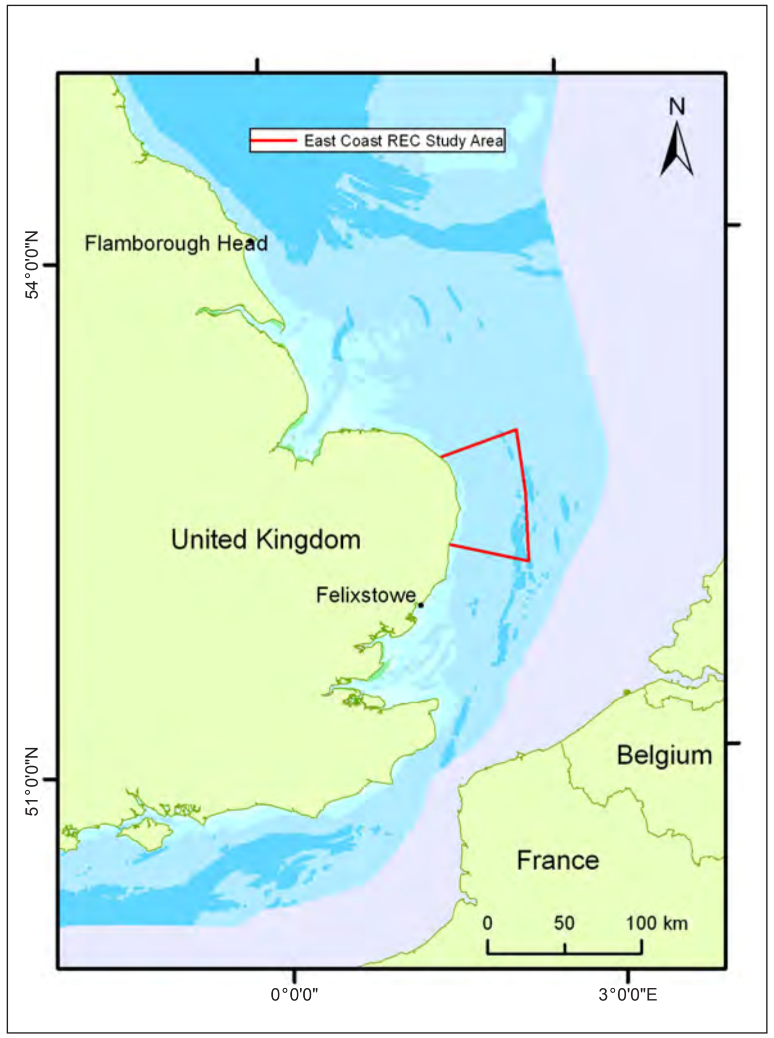


Figure 2.1 **Regional location of the East Coast REC Study Area.**

sheets established on Antarctica and Greenland, and major cooling over Europe. Over the Quaternary formations lies a Holocene drape, composed primarily of mobile re-worked glacial sediments, deposited during the marine transgression. There is limited fluvial input to the area, but erosion rates of the coastal sections are high (eg, Brooks and Spencer, 2010).

The East Coast REC Study Area covers approximately 3,300 km², extending ~44 km east of Ness Point (most Easterly point) and ~75 km from north to south (Figure 2.1). Within this area, water depths generally do not exceed 50 m. However, there are some deeper bathymetric lows within the East Coast REC area, reaching depths of 61 m (Figure 2.2). The Quaternary geological formations underlying the Holocene sediment drape have a predominantly N–NE dipping trend, whilst the modern seabed itself gently deepens eastwards, with a few isolated deeps located in the nearshore waters.

The Holocene sediments generally form a thin drape over the underlying Pleistocene deposits. Therefore, the modern seabed, in general, approximates to the pre-Holocene landscape. However, in certain areas – including the Wash, Humber and Thames estuaries, and the developing offshore sandbank features – significant sediment accumulation combined with significant coastal erosion mask the older topographic signature.

There are a number of significant sandbank features, including North, Middle and South Scroby Sands, Holm Sand, Corton Sand, Winterton Ridge, Smith's Knoll, North and Middle Cross Sands and Newcome Sand (Figures 2.3 and 4.1). These form the Great Yarmouth Banks (Cooper *et al.*, 2008), a sub-set of the Norfolk Banks, which have often been cited as being amongst the best offshore examples of the "classic" sandbank bedform. Associated with these N–S to NW–SE trending positive features are a number of channels such as Barley Picle, Holm Channel and Stanford Channel, which provide shipping ways between the sandbanks into Lowestoft and Great Yarmouth.

2.2 Geology

2.2.1 Solid geology

The North Sea basin is a Palaeozoic–Holocene multi-stage rift zone located within the north-west European craton. Table 2.1 summarises the stratigraphic Eras, Periods, Epochs and Ages mentioned whilst discussing the main formations identified across the southern North Sea.

From the early Carboniferous to the early Cretaceous, a basin-marginal upland area called the London–Brabant Massif extended from East Anglia across the Southern Bight into Belgium. The origins of this structure date back to the Proterozoic and Palaeozoic.

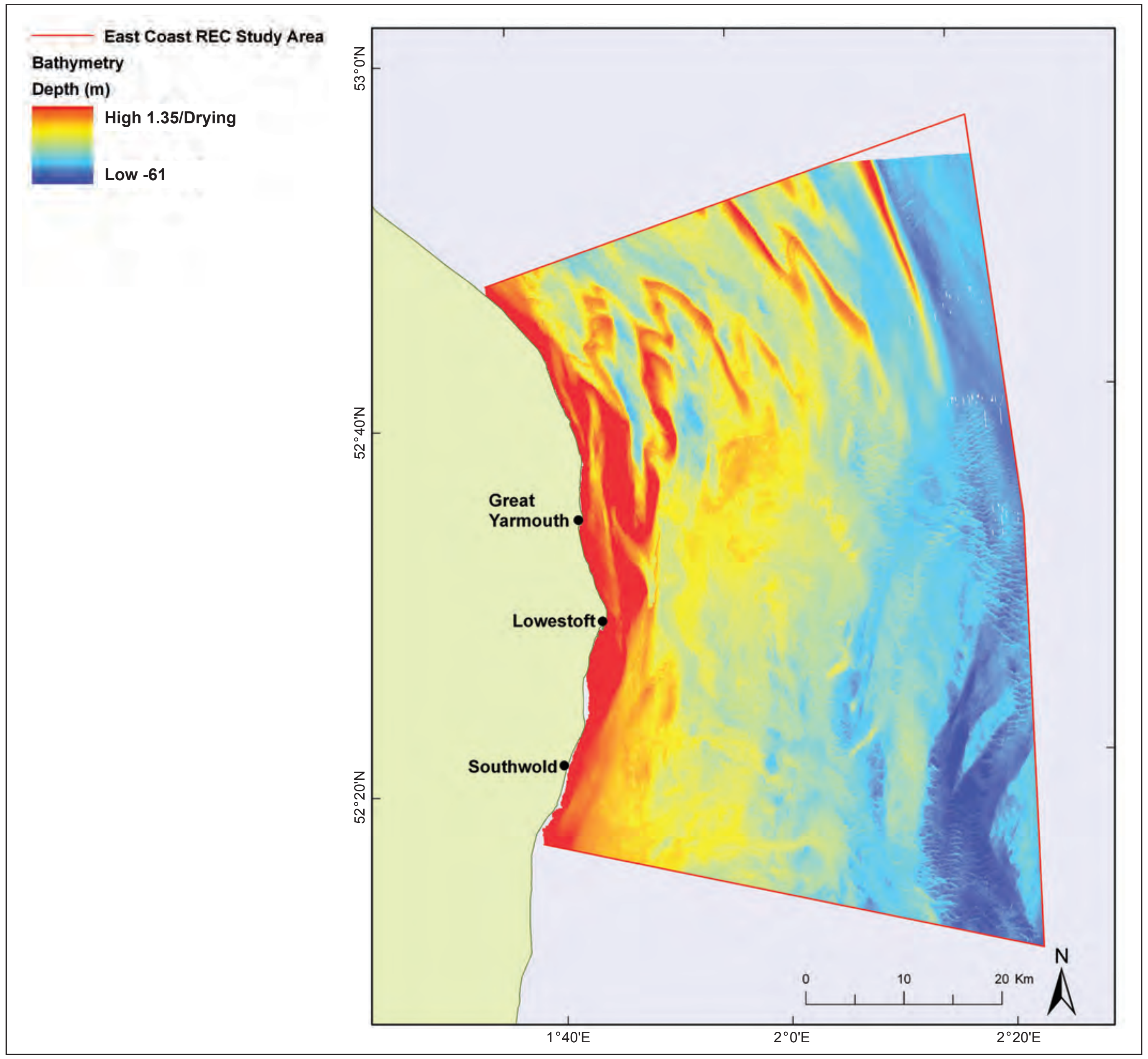


Figure 2.2 **Seabed morphology of the East Coast REC study area (values given in metres relative to CD). The positive value indicates areas that can dry out during very low tides. Digital bathymetry data © British Crown and SeaZone Solutions Ltd. All rights reserved. Data Licence 052008.012.**

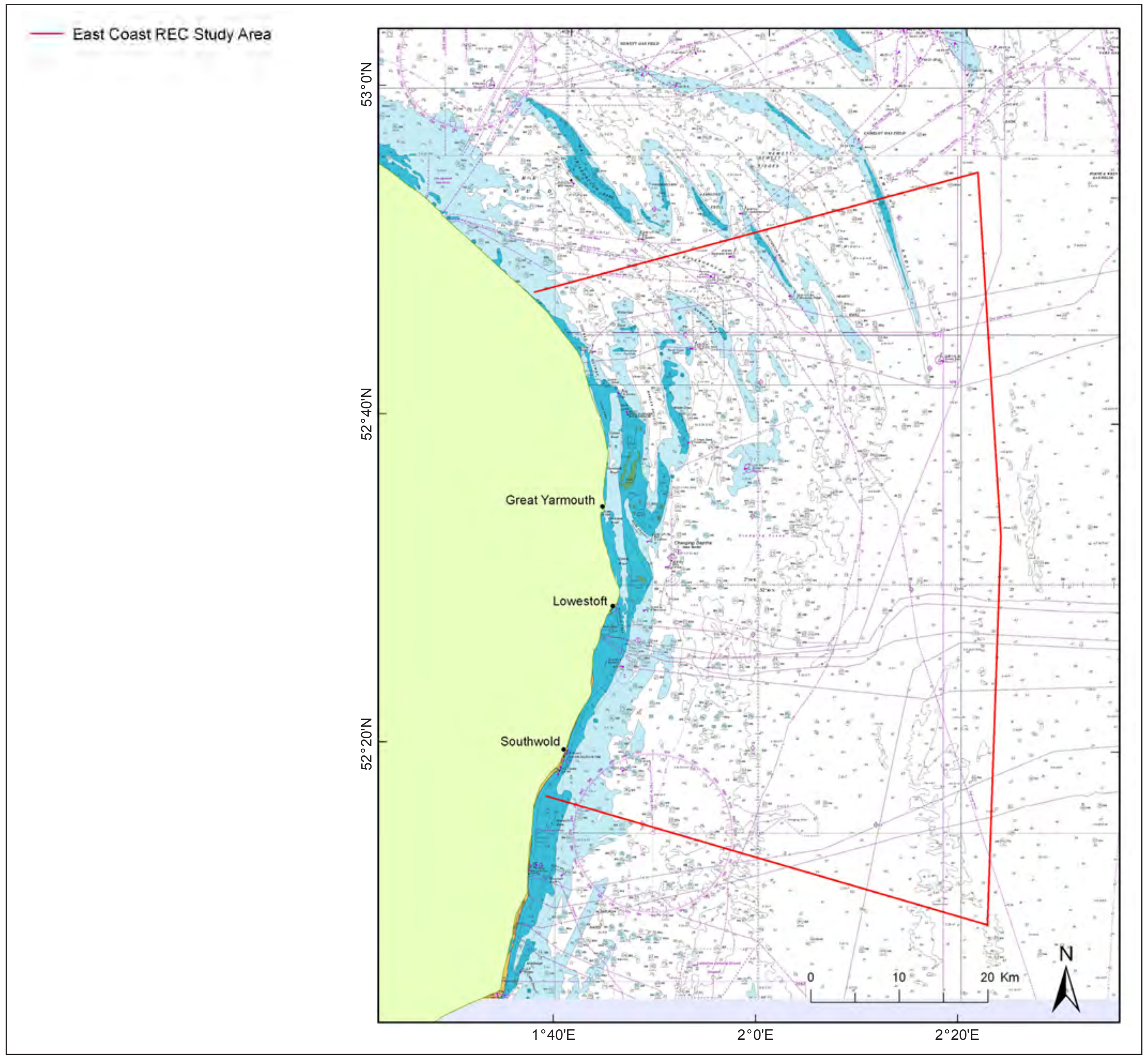


Figure 2.3 **Representation of the East Coast REC Study Area. This figure has been derived in part from material obtained from the UK Hydrographic Office (UKHO) with the permission of Her Majesty's Stationery Office and UK Hydrographic Office (www.ukho.gov.uk).** ***Not to be used for navigation.***

Pre-Cambrian cratonic crystalline basement rocks forming part of the former microcontinent Eastern Avalonia (Soper *et al.*, 1987) were deformed and metamorphosed during both the Cadomian Orogeny (~600 Ma) and the Caledonian Orogeny (~420 Ma). During the Silurian period, this massif became covered with turbidite rocks comprising alternating siltstones, silty shales and silica-cemented, very fine grained, micaceous sandstones (Cameron *et al.*, 1992).

Throughout the Permian and Triassic, the southern North Sea lay within a gently subsiding Variscan foreland basin. The London–Brabant Massif began to sink as western Britain uplifted as part of the Variscan Orogeny. This resulted in the formation of a shallow sea in the broad basin that formed north of the London–Brabant Massif and south of Scandinavia. Five distinct marine transgressions occurred across the basin during the late Permian, depositing a complex series of marine and evaporite deposits, reaching up to 1,000 m in thickness in places. Triassic deposits reflect a range of environments, encompassing playa-lake, floodplains, fluvial and semi-marine, before fully marine conditions extended across the whole southern North Sea in the late Triassic. Triassic sediments up to 1,650 m thick are observed in some localities across the southern North Sea, comprising of marine mudstones, sandstones and limestones.

During Oligocene and early Miocene times, the rift experienced low rates of subsidence, followed by a period of uplift during the mid- to late Miocene. Rapid subsidence followed during the Pliocene and Pleistocene (Kooi *et al.*, 1991), with isopachs showing an accumulation of sediments between 100 and 200 m thick across the East Coast REC Study Area during the Pleistocene (Cameron *et al.*, 1987). The late Pleistocene depositional systems were dominated by glacial activity – erosion and deposition – with two significant glaciations reaching the East Coast REC Study Area, namely the Elsterian and Weichselian glacial stages.

These cyclical glacial and interglacial climatic fluctuations significantly shaped the southern North Sea seafloor, with transgressions and regressions causing erosion and the formation of ravinement surfaces, down-cutting into older deposits and deposition of glacially derived materials. Following the Last Glacial Maximum (LGM) and subsequent transition into an interglacial stage, a strong tidally dominated marine environment now controls deposition and erosion across the southern North Sea and the East Coast REC Study Area.

Within the East Coast REC Study Area, the geological formations imaged sub-cropping beneath the Holocene deposits are predominantly Quaternary in age. Onshore, the subdivision of the Quaternary is based on lithostratigraphic and biostratigraphic evidence. Offshore stratigraphy is derived primarily from seismostratigraphic evidence, and a different set of names has been adopted. The entire Quaternary succession has recently been divided in three major subdivisions (Stoker *et al.*, 2010):

- Southern North Sea Deltaic Group, from Lower Pleistocene to Lower Middle Pleistocene.
- Dunwich Group – delta top sequence of Lower Middle Pleistocene age.
- Californian Glacigenic Group, from Middle Pleistocene to Holocene.

Sections 4.3 (Solid Geology) and 4.4 (Quaternary) give in more detail the specific formations identified, and their depositional environments, in the East Coast REC Study Area.

2.2.2 Holocene deposits

The seabed geology of the East Coast REC Study Area is comprised of recent (Holocene) deposits, which are often highly mobile. These sediments exist as a relatively thin drape overlying the erosional surface of the Quaternary strata and are largely derived from glaciogenic or fluvial sources, being composed primarily of sandy materials. Gravel deposits are also relatively widespread and locally important in producing features such as the gravel lag deposits identified in the central section of the survey area (see Section 4.6.3, Physical Region 3 – Central). Muds and carbonate sediments are limited in the southern North Sea and the East Coast REC Study Area, only occurring in some intertidal areas. The carbonate component of sediments is usually less than 10%, although locally it may be significantly higher, reflecting deposition of carbonate shells or a more carbonate-rich parent rock.

The seabed sediment distribution within the East Coast REC Study Area is of great importance due to the impact of the upper ~0.5–1 m of sediment deposits on the distribution and development of marine biotopes and habitats. However, equally important is the distribution of bedforms, as this also impacts on the distribution of marine life, with the larger bedform features having a significant impact on localised hydrodynamics.

Era	Period	Epoch	Age (Ma)
Cenozoic	Quaternary	Holocene	< 0.0117
		Pleistocene	2.588 to 0.0117
	Neogene	Pliocene	5.332 to 2.588
		Miocene	23.03 to 5.332
	Paleogene	Oligocene	33.9 ± 0.1 to 23.03
		Eocene	55.8 ± 0.2 to 33.9 ± 0.1
		Paleocene	65.5 ± 0.3 to 55.8 ± 0.2
Mesozoic	Cretaceous		145.5 ± 4.0 to 65.5 ± 0.3
	Jurassic		199.6 ± 0.6 to 145.5 ± 4.0
	Triassic		251 ± 0.4 to 199.6 ± 0.6
Paleozoic	Permian		299 ± 0.8 to 251 ± 0.4
	Carboniferous		359.2 ± 2.5 to 299 ± 0.8
	Devonian		416 ± 2.8 to 359.2 ± 2.5
	Silurian		443.7 ± 1.5 to 416 ± 2.8
	Ordovician		488.3 ± 1.7 to 443.7 ± 1.5
	Cambrian		542 to 488.3 ± 1.7
Precambrian			> 542

Table 2.1 Geological timescale

The seabed sediments occur in a number of different forms as a result of the differing hydrodynamic and erosional processes acting upon them:

- Re-worked deposits in which the finer sediment sand and mud fractions have been removed/reduced due to winnowing by tidal currents, producing a seabed sediment distribution that differs in composition from the underlying source rocks or glacial deposits.
- Gravel lag deposits formed by the removal of finer sediment fractions, leaving a gravel-rich deposit overlying the Quaternary formations.
- Sand-rich areas, often shaped by tidal currents into sandbanks, sandwaves, megaripples and sand ribbons, depending on the water depth, amount of source sediment and the tidal velocities. These features can form as groups (sandbanks) or fields (sandwaves and megaripples) or exist as solitary features. They can be long-standing features formed over many years (eg, sandbanks) or ephemeral, driven by storms and locally strong current conditions (eg, sand ribbons).

2.3 Hydrodynamic processes

2.3.1 Tides and currents

Along the east coast, the mean spring tidal range varies from north to south, being 5.7 m at SpurnHead, 1.95 m at Lowestoft, and 3.8 m at Walton-on-the-Naze. This is due to the location of the amphidromic point east of the East Coast REC Study Area between the East Anglian and Dutch coasts. The range of tidal elevations likely to be encountered at Lowestoft is shown in Table 2.2.

The tidal currents are dominated by the astronomical tides and are generally parallel to the local bathymetry or coast. Figure 2.4 shows the spring tidal ellipses for the region (Cefas, 2001) and the variation in orientation, strength and the ellipticity or degree of rectilinearity over the area. Spring tidal currents can reach 1.9 m s^{-1} near Winterton-on-Sea (approximately 9 miles north of Great Yarmouth), north of Great Yarmouth (Southern North Sea Sediment Transport Study – SNSSTS 2, 2002) but decrease both southerly and offshore.

As well as astronomically driven tidal variations, the east coast of England is impacted by tidal surges or coastally trapped waves which, under certain meteorological conditions, can propagate in an anticlockwise manner around the southern North Sea (Pugh, 1987). The frequency and scale of the highest 10 positive and negatives surges are shown in Table 2.3 and demonstrate the importance of surges in relation to astronomical tidal variations and the relative frequency of such large events. The negative events may also be significant at times, for example, if negative surges coincide with wave events (from storms or wind events), the smaller waves can resuspend sediments.

2.3.2 Waves

The waves in the region are dominated by northeasterly winds, with occasional long-period swells that propagate southward along the English coastline. Whilst a south-westerly wind component exists, inshore this is insignificant due to the short fetch. The nearest WaveNet (www.cefas.co.uk/wavenet) mooring to the East Coast REC Study Area is that at the West Gabbard just to the south of the area (51°58′87N, 002°4′.78E, in 34 m water depth). A detailed analysis of this long-term site (UKMMAS, 2010) shows mean monthly summer significant water heights of 0.9 m but with maximum summer values of 3.2 m. In winter, the mean monthly values increase to 1.5 m with peaks of 5.2 m (see Figure 2.5).

2.3.3 Temperature

Surface temperatures recorded at the West Gabbard site show a range from 5°C in March for cold years, increasing to a maximum of 20°C in August in warm years (Figure 2.6). Inter-annually, temperature variations can be large, especially during the spring warming period with monthly variations ranging from 8 to 14.6°C in May.

Tidal level	Height (m) above CD
Highest astronomical tide (HAT)	+2.9
Mean high water spring (MHWS)	+2.5
Mean high water neap (MHWN)	+2.15
Mean sea level	+1.6
Mean low water neap (MLWN)	+1.08
Mean low water spring (MLWS)	+0.55
Lowest astronomical tide (LAT)	+0.02
Ordnance datum Newlyn	+1.5
Note: CD = chart datum	

Table 2.2 **Summary tidal elevation data from Lowestoft (National Tidal Sea Level Facility [NTSLF] – www.pol.ac.uk/ntslf/tgi/portinfo.php?port=lowe.html).**

Top 10 positive	Surge (m)	Top 10 negative	Surge (m)
14/02/1989 08:00	2.51	19/12/1982 15:00	-1.94
21/02/1993 05:00	2.37	31/01/1995 13:00	-1.68
09/11/2007 03:00	2.09	19/02/1997 21:00	-1.66
12/12/1990 12:00	2.02	25/12/1990 15:00	-1.52
03/01/1976 17:00	1.97	03/11/1979 16:00	-1.39
10/01/1995 06:45	1.92	04/04/1973 14:00	-1.37
31/10/2006 20:30	1.87	05/01/1995 16:30	-1.36
06/03/1968 08:00	1.76	27/02/1967 23:00	-1.33
05/02/1999 08:00	1.75	14/12/1969 18:00	-1.32
29/09/1969 07:00	1.72	04/02/1968 23:00	-1.3

Table 2.3 **Top ten positive and negative surges (ie, above predicted astronomical tide) recorded at the Lowestoft Tide Gauge (NTSLF – www.pol.ac.uk/ntslf/surgehilo.php?port=lowestoft).**

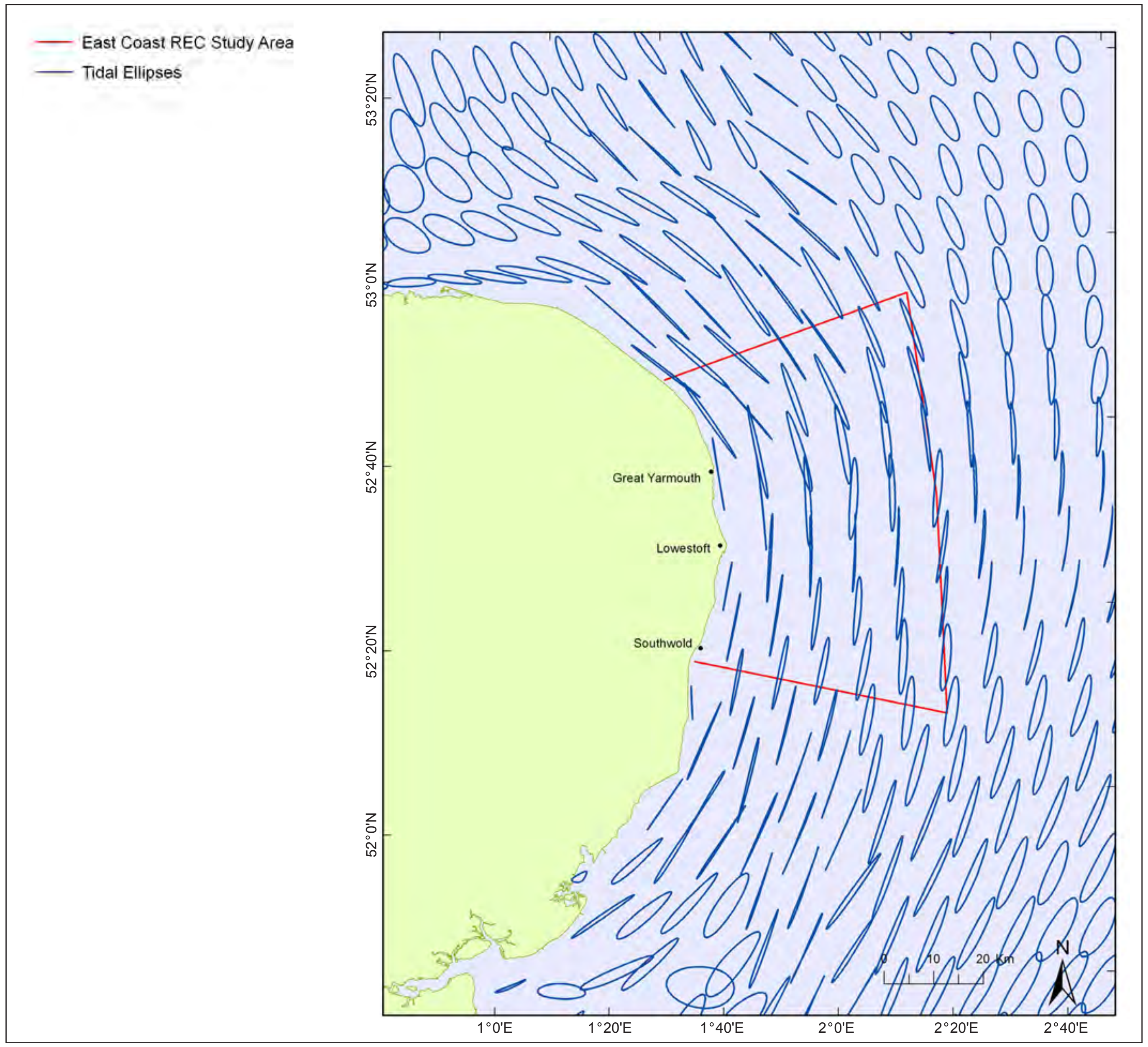


Figure 2.4 Tidal ellipses along the East Anglian coastline from the Cefas Plume numerical model. Reproduced from Admiralty Chart 1408 by permission of the Controller of Her Majesty's Stationery Office and the UK Hydrographic Office (www.ukho.gov.uk). Arcs Chart Licence F46558002C2B4F56. ***Not to be used for navigation*.**

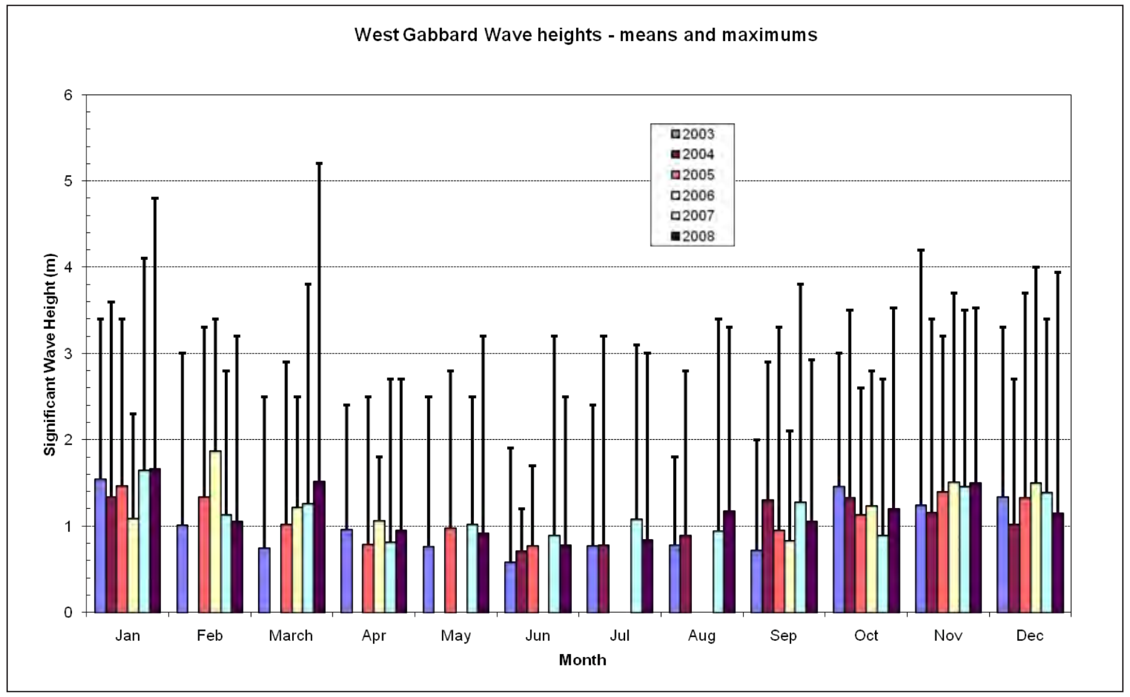


Figure 2.5 West Gabbard wave heights – means and maximums (www.cefas.co.uk/wavenet) (from UKMMAS, 2010).

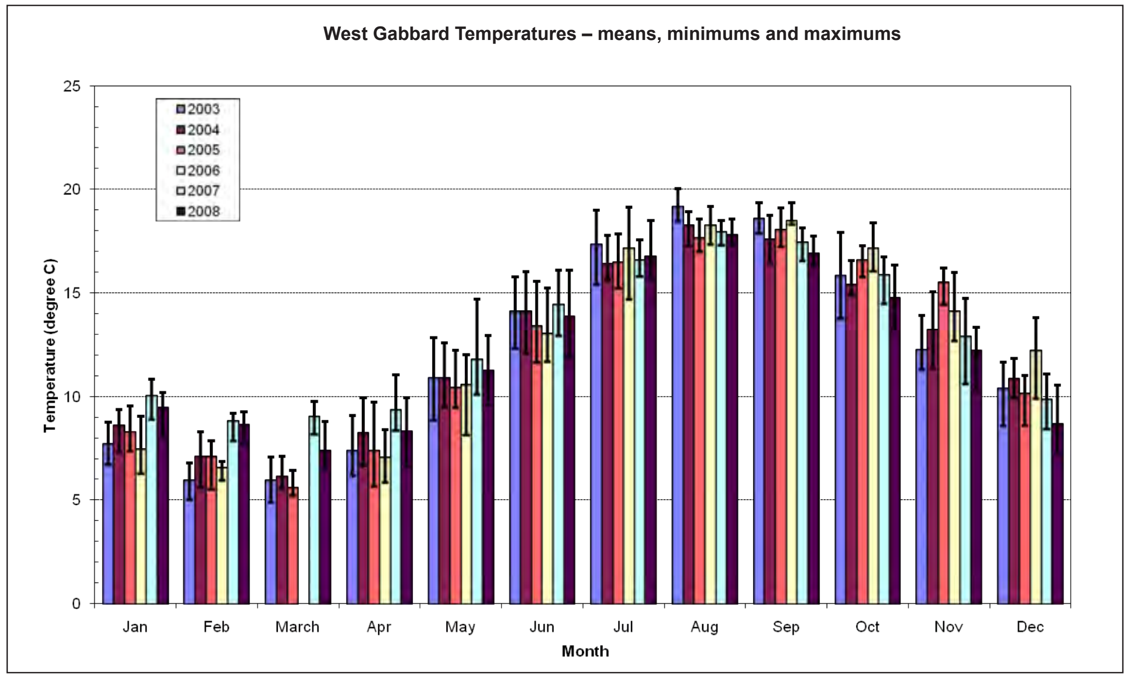


Figure 2.6 West Gabbard monthly mean, minimum and maximum surface water temperatures for 2003–08 (UKMMAS, 2010).

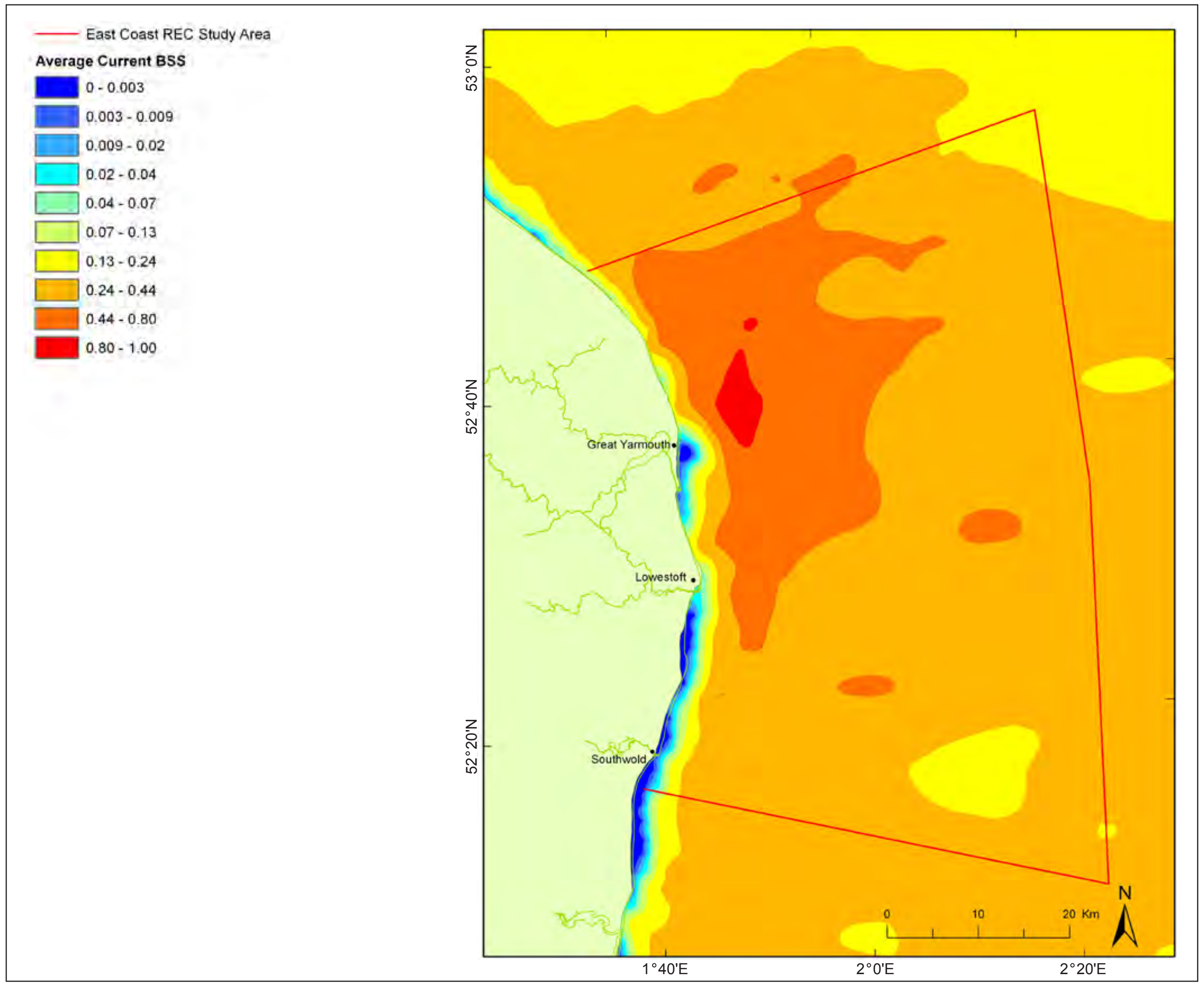


Figure 2.7 **Mean tidal bed shear stress (N m^{-2}) computed from a high-resolution numerical model for the East Coast REC Study Area (Eggleton *et al.*, 2011).**

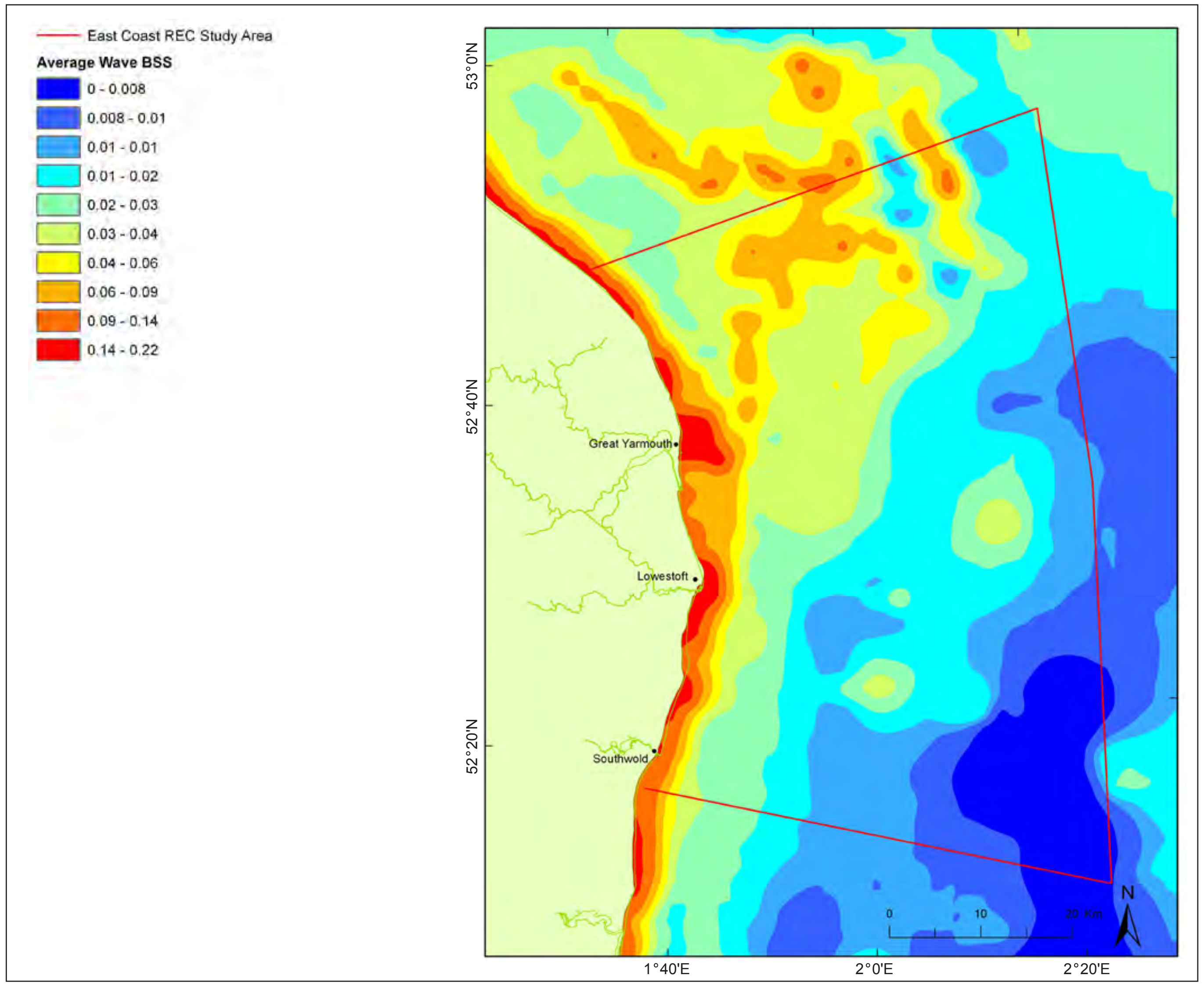


Figure 2.8 **Mean wave bed shear stress (N m^{-2}) computed from a high-resolution numerical model for the East Coast REC Study Area (Eggleton *et al.*, 2011).**

2.3.4 Bed shear stress

To give an indication of the wave and tidal conditions on the seabed in the East Coast REC Study Area, the bed shear stress has been calculated taking into account the bed roughness, current velocities, wave height, wave period and water depth. Bed shear stress is an essential parameter in assessing both sediment transport dynamics and benthic habitat distributions. Eggleton *et al.* (2011) calculated the mean bed shear stress for currents alone, waves alone and currents/waves combined using non-linear interaction. Figure 2.7 shows the tidal bed shear stress contour map (using an original grid of 2 nautical miles) for the East Coast REC Study Area and reflects the higher currents found off Winterton Ness (which is 19 miles north of Great Yarmouth), which result in a mean bed shear stress of just under 1 N m^{-2}. Similarly, Figure 2.8 shows the wave bed shear stress for 1999, with higher values near the coast due to shallow water and a complex pattern in the north of the area associated with the Norfolk Sand Banks (Cross Sands). The total bed shear stress (ie, waves plus tides) map shown in Figure 2.9 indicates that the tidal signal is dominant in the majority of the region but is enhanced by wave activity, especially along the northern boundary of the East Coast REC Study Area.

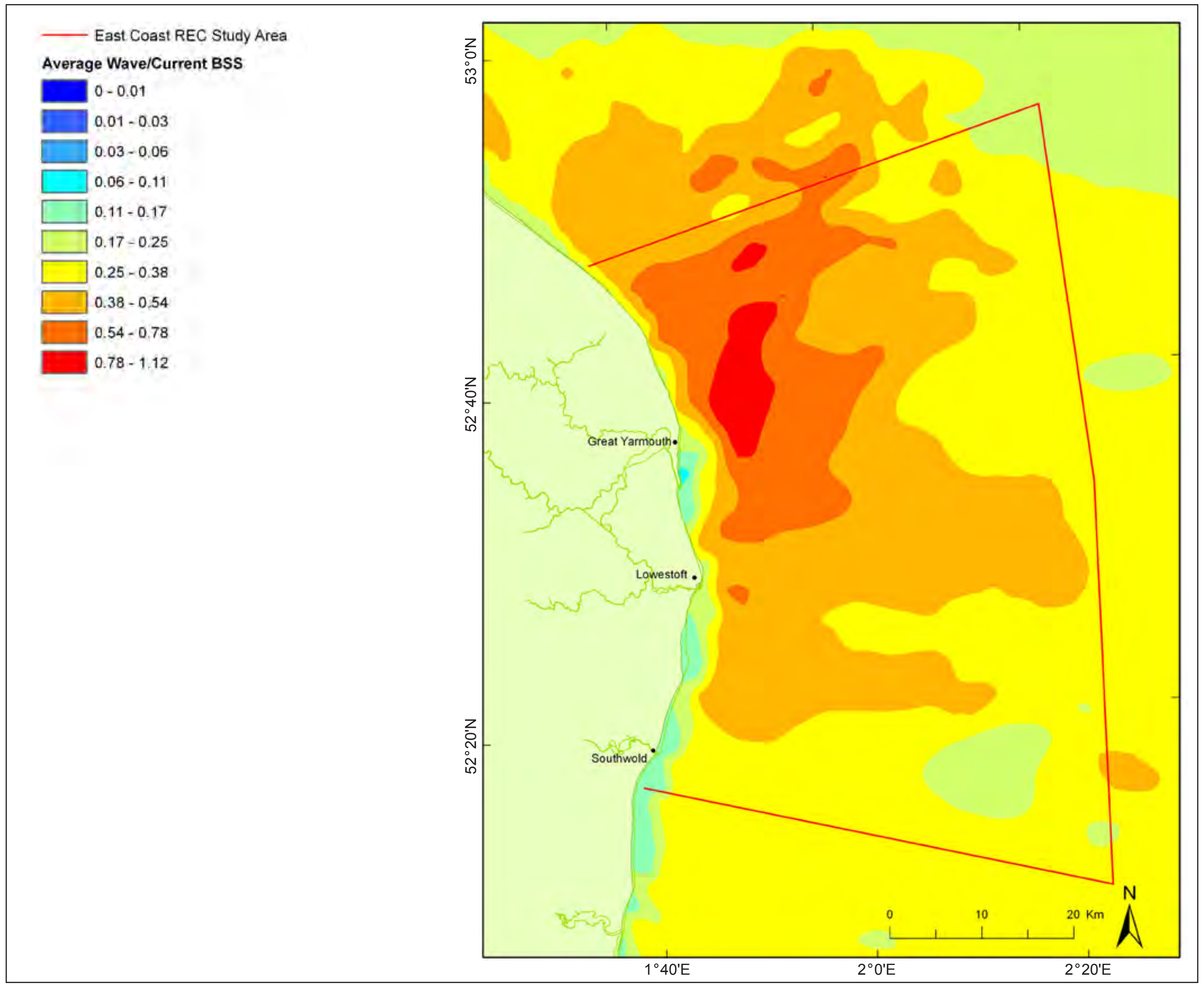


Figure 2.9 Combined wave and current mean bed shear stress (N m^{-2}) computed from a high-resolution numerical model for the East Coast REC Study Area (Eggleton *et al.*, 2011).

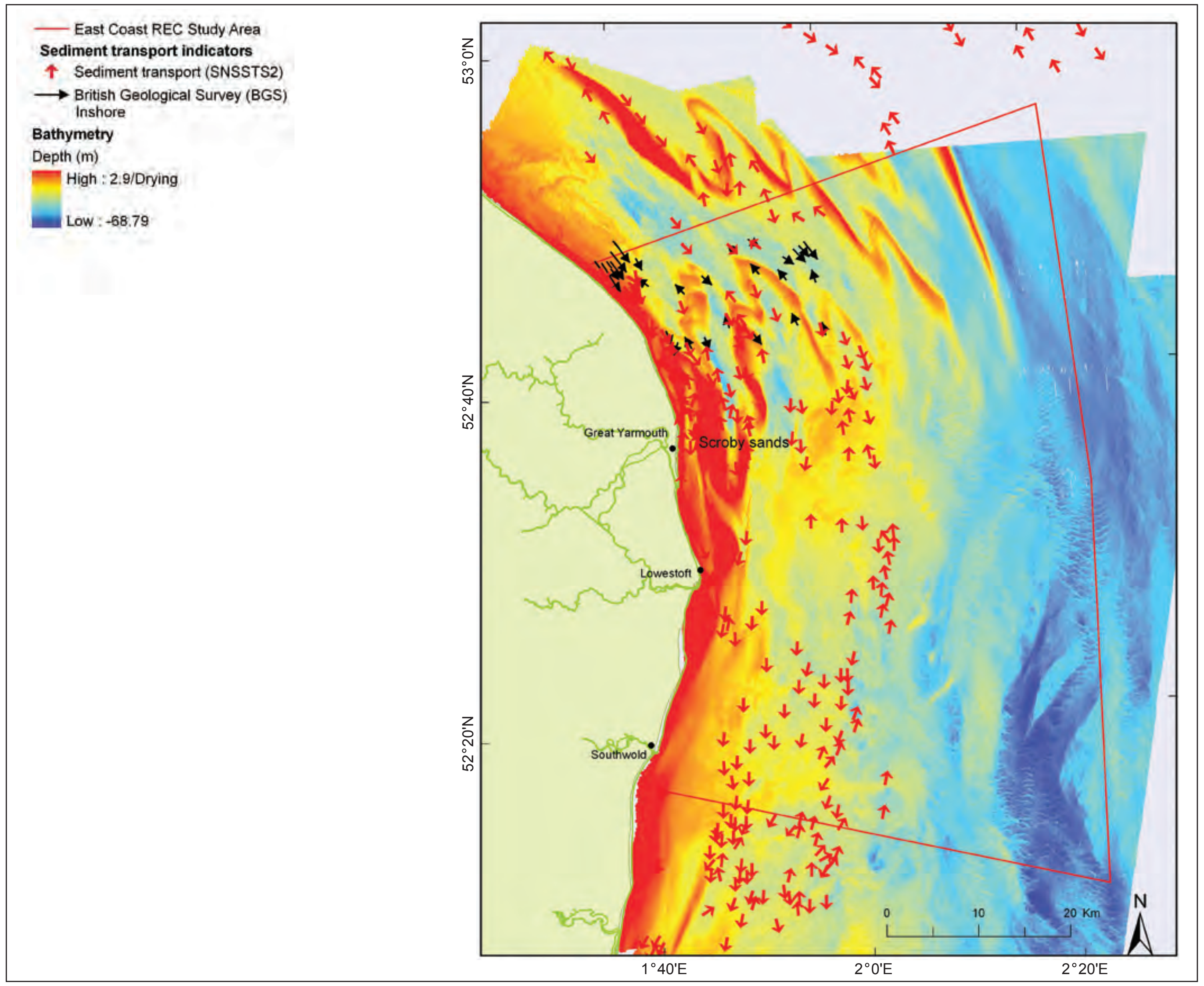


Figure 2.10 Sediment (sand) transport pathways as inferred from sediment bedforms, sandwave asymmetries etc (values given in metres relative to CD; SNSSTS 2, 2002). Digital bathymetry data © British Crown and SeaZone Solutions Ltd. All rights reserved. Data Licence 052008.012.

2.4 Sedimentary processes

2.4.1 Sediment transport pathways

A number of studies have been undertaken in order to investigate the sediment transport patterns within the East Coast REC Study Area. The BGS inshore seabed sediment and transport indicators maps (Evans *et al.*, 1998), created using an interpretation of side-scan sonar records, identified a number of sand sediment transport vectors. A later study, SNSSTS 2 (2002), used these and a number of other data-sets to create maps with a wider spatial coverage. Figure 2.10 shows these two data-sets for the East Coast REC Study Area along with the contour bathymetry. Interpretation is complex and associated with local bathymetry but with generally southerly transport vectors from Great Yarmouth in the inshore zone and northerly offshore. Within the Norfolk Banks system, sediment transport vectors are normally clockwise around the banks (eg, Haisborough Bank). The twin sinusoidal nature of the seabed elevations of the Norfolk Banks is clearly visible. Note that within the Norfolk Banks system, care needs to be exercised in establishing the periods of observations in both sediment transport vectors and bathymetry due to the mobile nature of the sandbanks in the area.

2.4.2 Suspended sediments

Sources of suspended sediment include both tide and wave resuspension mechanisms as well as export from the Thames Estuary to the south, especially during periods of large river runoff (SNSSTS 2, 2002). The coastline also contributes to the suspended sediment climate, especially along the Winterton and Benacre–Southwold frontage (Shoreline Management Plan 2, 2010).

Local resuspension adds to the suspended sediment climate, especially in shallow areas (eg, sandbanks) and also in strong wave or current regimes. For instance, on Scroby Sands (see Figure 4.1) for a 2 mm sand particle, the likelihood of resuspension increases from 5% in summer to 10% in winter. In contrast, a 62.6 μm sand particle will remain in suspension almost continuously in both seasons (see Figure 2.11).

The high-resolution (1 km) monthly suspended sediment climatology (Dolphin *et al.*, 2011), created using a 9 yr database of satellite images, shows the variation in surface suspended sediment concentrations over the whole of the southern North Sea. Those for June and January (Figures 2.12 & 2.13) show the extent of the plume of suspended sediments extending eastwards from the East Anglian coastline. In January, monthly mean concentrations close to the coast near Scroby Sands can reach 100 mg l^{-1}, reducing to typically only 10 mg l^{-1} in summer. Even during summer months, suspended sediment concentrations vary from tens of mg l^{-1} close to the coast to approximately 1 mg l^{-1} offshore within the East Coast REC Study Area region.

2.4.3 Depth of sediment reworking

Eggleton *et al.* (2011) computed the potential depth of reworking by either tidal currents or waves of two types of sediments (sands and gravels) for the southern North Sea (Figures 2.14 & 2.15). These show that, if sand is going to be reworked, it tends to be reworked to typically a layer depth of 300 mm over relatively large areas. In contrast, gravels tend to be only reworked in small areas (reflecting their coverage) and also in a more gradual manner. Gravel reworking reaches similar levels of depth (300 mm), but only in a small area off Great Yarmouth.

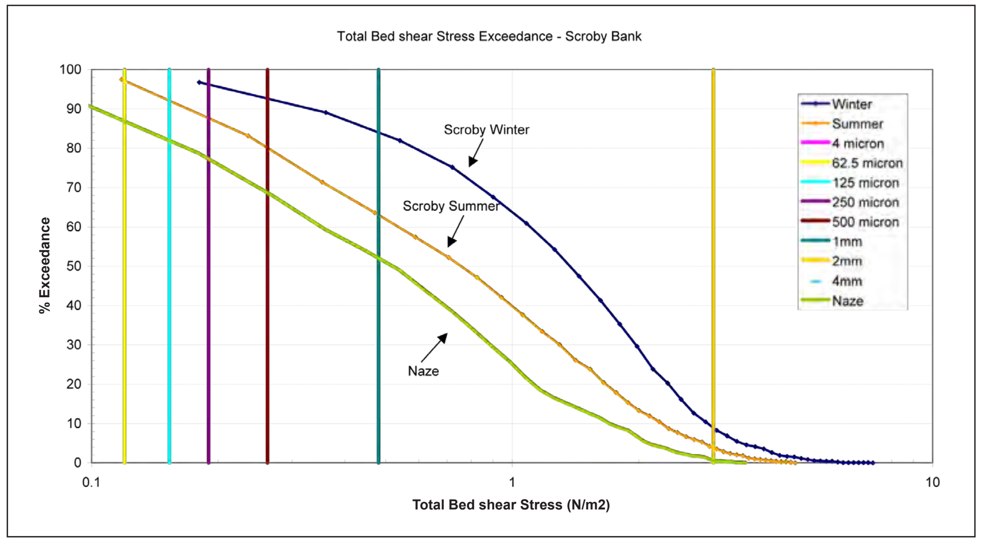


Figure 2.11 Bed shear stress exceedance diagram for Scroby Sands (Cefas, 2004) in 5 m water depth. The Naze Line is a monitoring point off Harwich used in SNSSTS 2.

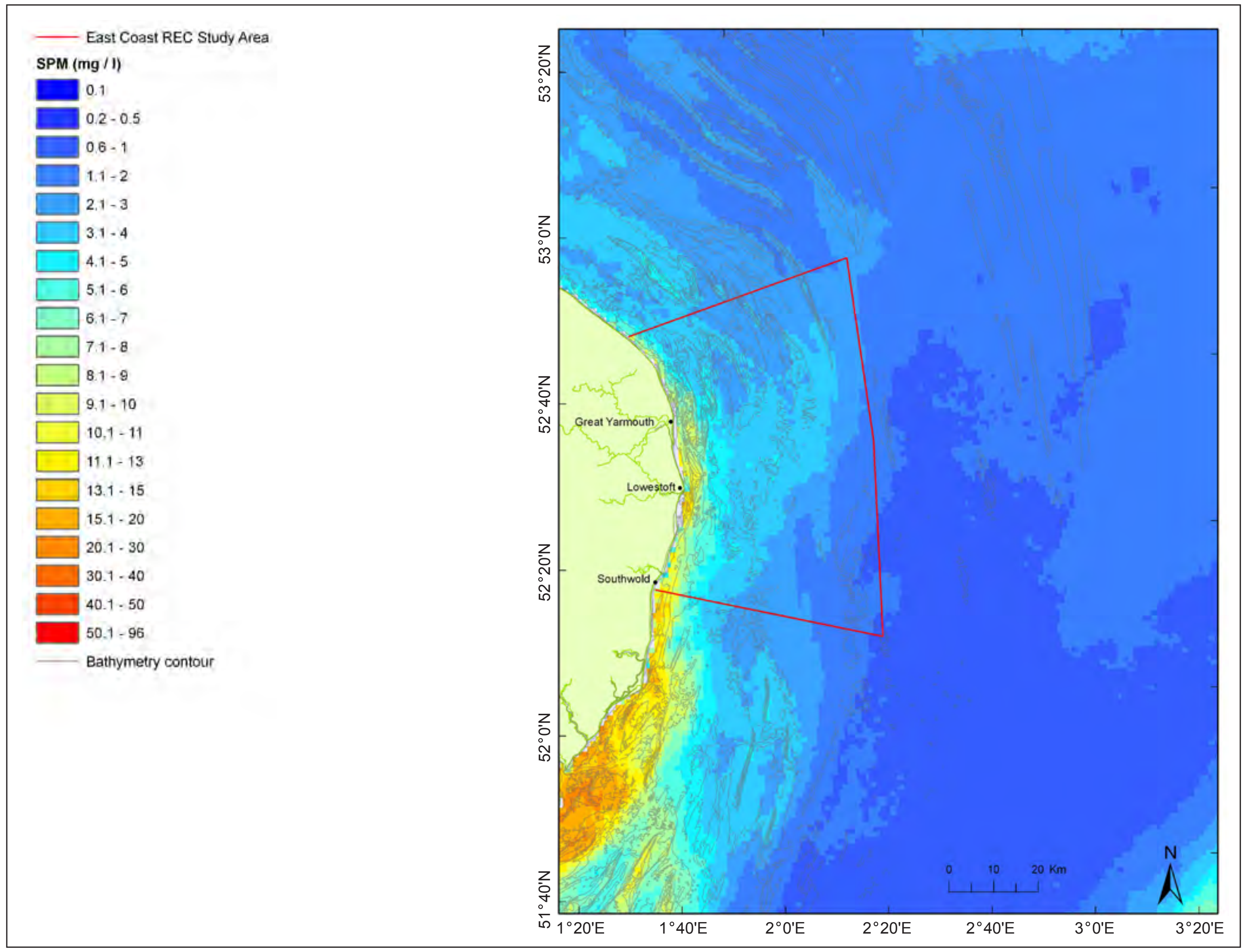


Figure 2.12 Surface climatological mean suspended sediment concentrations in summer (June) (Dolphin *et al.,* 2011; SPM = suspended particulate matter).

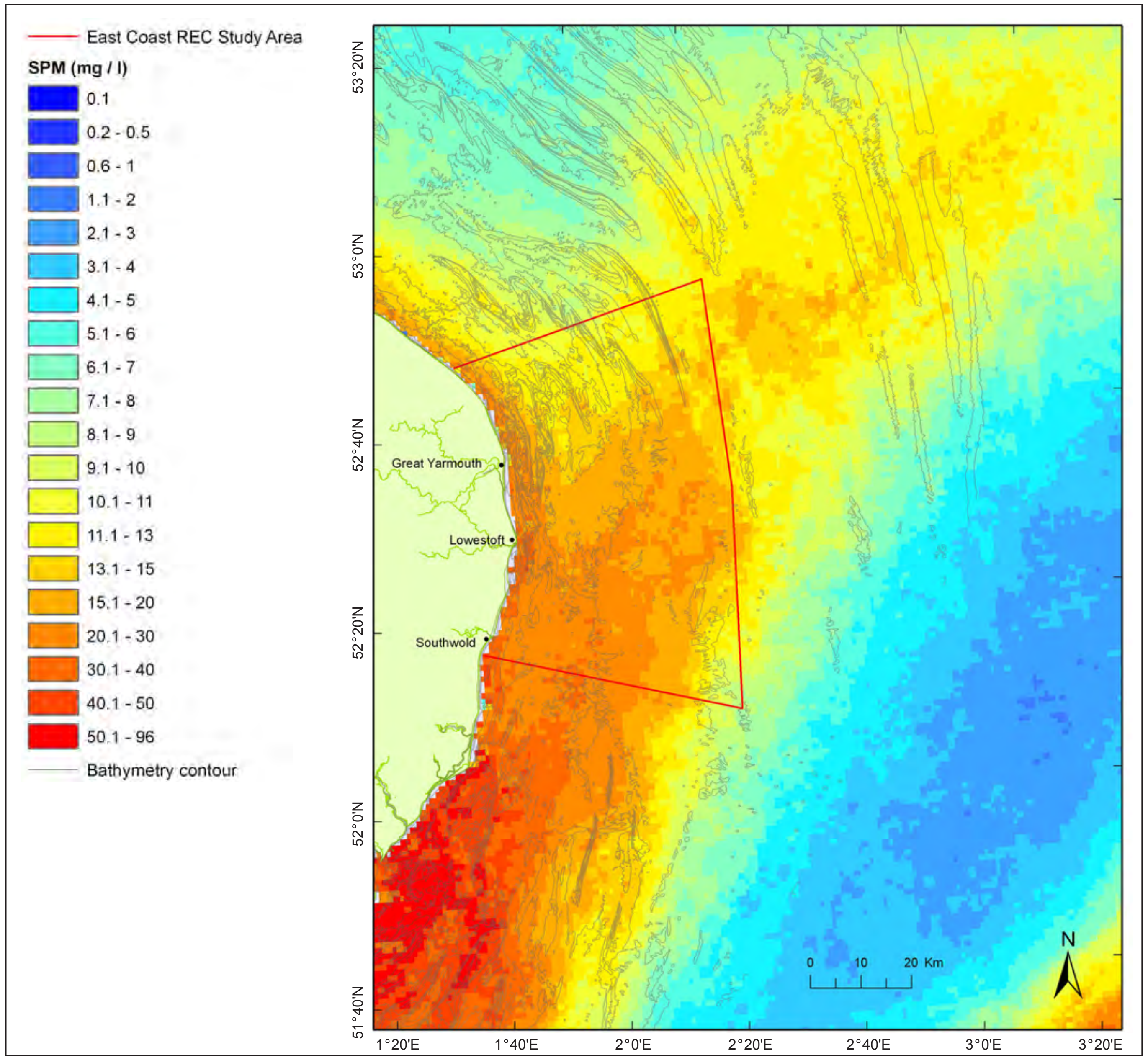


Figure 2.13 **Surface climatological mean suspended sediment concentrations in winter (January) (Dolphin *et al.*, 2011).**

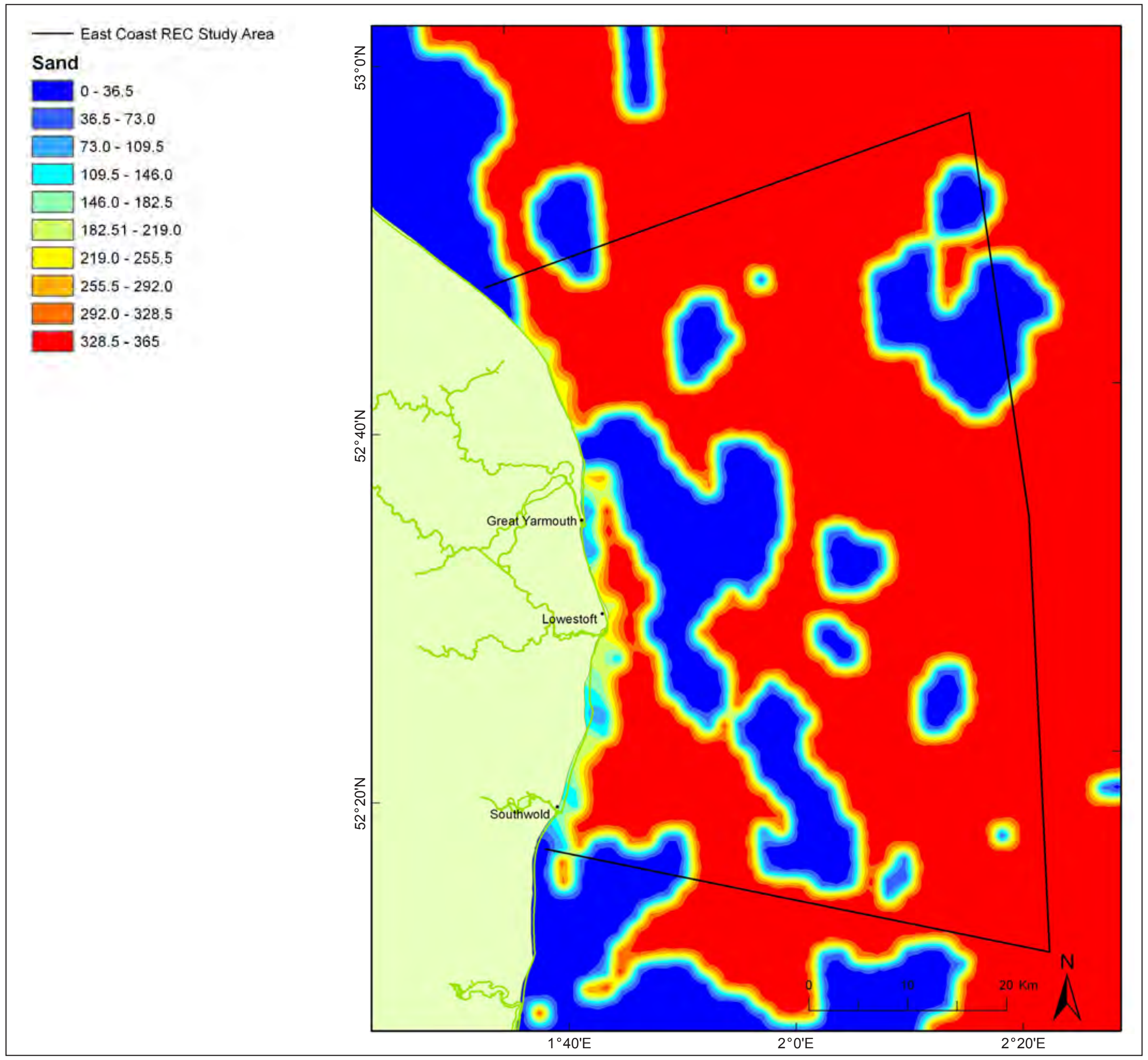


Figure 2.14 **Potential depth (mm) of reworking for sand (after Eggleton *et al.*, 2011).**

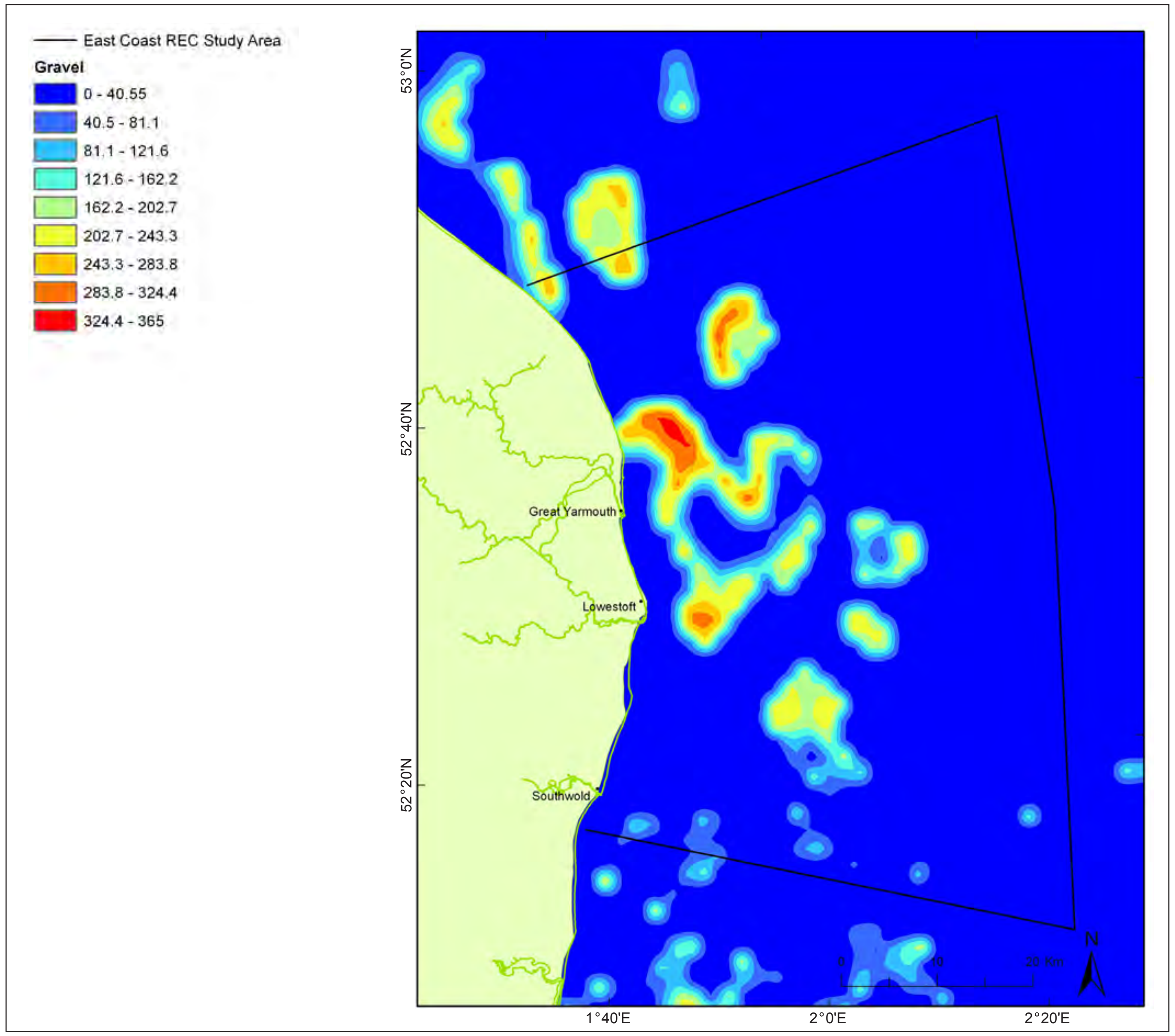


Figure 2.15 **Potential depth (mm) of reworking for gravel (after Eggleton *et al.*, 2011).**

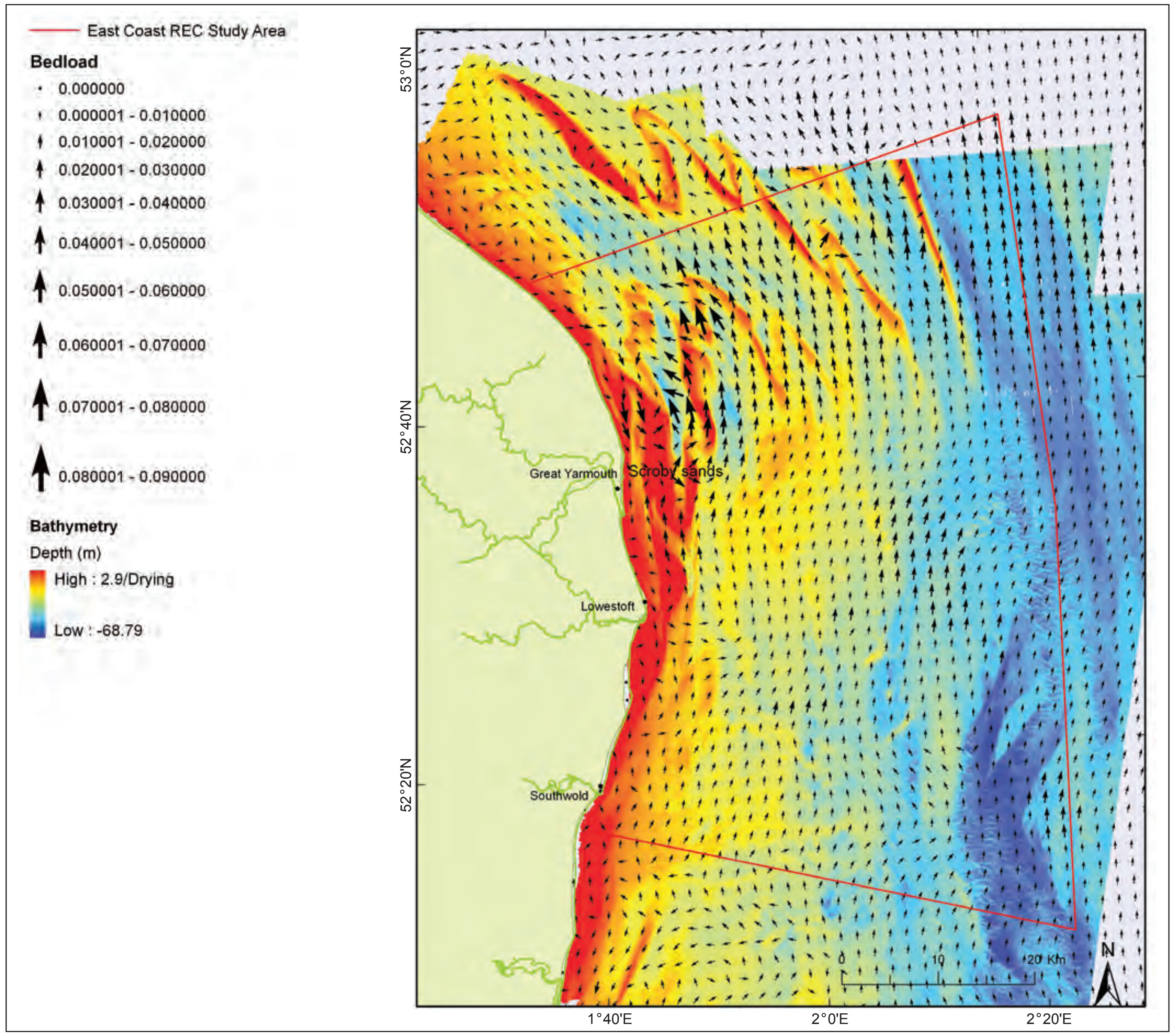


Figure 2.16 **Potential bedload transport patterns for the East Coast REC Study Area (values given in metres relative to CD; after Eggleton *et al.*, 2011). The positive value indicates areas that can dry out during very low tides. Digital bathymetry data © British Crown and SeaZone Solutions Ltd. All rights reserved. Data Licence 052008.012.**

2.4.4 Bedload sediment transport

Eggleton *et al.* (2011) also computed the potential bedload ransport for the East Coast REC Study Area (Figure 2.16) for 1999. These show a northward tidally driven sediment transport pattern over the majority of the area and the complex transport patterns associated with the Norfolk Banks, especially those around Scroby and Cross Sands (see Figure 4.1). Whilst the numerical model grid resolution is only 2 nautical miles, southward sediment transport can be observed in Yarmouth Roads and an enhanced northerly pattern in the Cross Sands area. It should also be noted that surge/storm-related transport is southerly over virtually the whole area (SNSSTS 2, 2002). The relative balance between these two driving mechanisms varies on a yearly basis, with the gravel transport dominated by the southerly storm/surge events.

2.5 Marine archaeology

The marine historic environment comprises all forms of physical evidence of people's activities in the past. Marine historic material of the east coast of Britain ranges from the earliest known occupation of Britain, >850,000 years ago to the Second World War.

The archaeological material of the East Coast REC Study Area can be divided into three categories: prehistory, maritime and aviation. The first category relates to the prehistory of the region from the earliest occupation >850,000 years ago to approximately 6000 BC when the East Coast REC Study Area was fully inundated. The character of the archaeological material may include isolated artefact find spots or extensive spread of material (either discrete or dispersed). Indirect evidence, such as the remnants of land surfaces and associated features, are also used to characterise the prehistory of the region.

The maritime category relates to the remains of vessels that have been lost as a result of, for example, stranding, floundering, collision etc. or to sites that consist of material related to the use of vessels but not of the vessel itself – for example, material lost overboard or deliberately jettisoned. The aviation category comprises material associated with aircraft crash sites. The character of the archaeological material may include isolated artefact find spots or extensive spread of material (either discrete or dispersed).

The circumstances in which the archaeological material is found can also be used to characterise the finds. In broad terms, archaeological sites can be found in either primary or secondary context. Archaeological sites discovered in a primary context can be defined by those in which the spatial relationship of finds has not altered (*in situ* finds) since they were deposited, or where the overall artefact movement is small on a regional scale. Secondary context refers to material that has been derived or moved from their original positions, which may be associated with fluvial re-depositing, glacial processes or marine transgressions and regressions.

2.5.1 Prehistoric archaeology

The Quaternary (Pleistocene and Holocene) has been a period of fluctuating climate with corresponding oscillations in sea level. During interglacial periods sea levels were relatively high, sometimes comparable to the present day, whereas at the climax of glacial periods the sea levels fell to more than 100 m below present levels. During these multiple cycles of transgressions and regressions various areas of the southern North Sea have been repeatedly exposed. These palaeo-land surfaces would have been available for hominins to traverse and exploit, leaving similar prehistoric material as found in present-day terrestrial settings. The shallow geology of the southern North Sea includes sediments dating from the earliest occupation through to the Mesolithic, although not as a complete sequence (Cameron *et al*., 1992). Although these deposits have undergone a certain amount of erosion and re-working, remnants of these land surfaces can be identified offshore and allow the identification of areas that have the potential for the recovery of archaeological material.

Happisburgh and Pakefield on the Norfolk and Suffolk coasts provide evidence of the earliest occupation in Britain, possibly as early as approximately 970,000 BP (Parfitt *et al*., 2010). The evidence includes hand axes and flint flakes, as well as a rich fauna of elephants, deer and other large mammals, suggesting that food sources would have been available for early hominins (Wymer, 1999; Parfitt *et al*., 2005). These finds are generally associated with the fluviatile and estuarine deposits of Early Pleistocene Ancaster and Bytham river systems and include finds in both primary and secondary contexts.

Stone artefacts have long been found in sediments associated with such river channels, either in sand and gravel layers or in associated fine-grained sediments and peats (eg, Wymer, 1999). The presence and survival of these artefacts are closely linked to the environmental processes that caused the associated deposits to be formed.

Along the course of the River Yare, meandering eastwards through Norfolk towards Great Yarmouth, single, isolated finds comprising mainly hand axes and stone flakes have been found (Wymer, 1999). These finds are considered to be Lower Palaeolithic and are predominantly found in re-worked fluvial or glacial sediments, rather than in an *in situ* context (Wymer, 1985). For a large percentage of the Pleistocene, rivers extended beyond present-day shorelines onto the continental shelf, and these extensions of existing rivers, enlarged by confluences that are now submerged, and swollen by glacial meltwater, would have been drainage systems of considerable size (Bridgland, 2002). It should also be borne in mind that remnants of river systems may be submerged which have no direct correlation onshore today.

The recovery of Palaeolithic stone artefacts and Pleistocene faunal remains from the southern North Sea has a long history predominantly associated with the fishing industry and, more recently, the marine aggregate extraction industry (Godwin and Godwin, 1933; Glimmerveen *et al*., 2004; Mol *et al*., 2006). Numerous Early and Middle Pleistocene mammal remains have been reported from the southern North Sea (van Kolfschoten and Laban, 1995; De Wilde, 2006). Isolated finds of artefacts such as flints, bone spearheads and reworked or carved fossil mammal bones are also documented (Long *et al*., 1986; Coles, 1998; Flemming, 2002). Finds and faunal remains have been, and continue to be, reported from marine aggregate extraction licensed areas via the marine aggregate industry protocol for reporting finds of archaeological interest (BMAPA and English Heritage, 2005). One such significant report involved the discovery of 75 Palaeolithic artefacts, including hand axes, flakes and cores, and a number of bones (including woolly mammoth, bison, horse and reindeer) in stockpiles of gravel at the SBV Flushing Wharf, dredged from a discrete area within marine aggregate extraction licence Area 240, situated 11 km off the coast of Great Yarmouth. At least some of the material is considered to be dredged from a primary context.

Although prehistoric material reported in this way reflects isolated finds with little or no context, the material has the potential to provide insights into patterns of past hominin land use and demography (Ashton and Lewis, 2002; Hosfield *et al.*, 2009). To understand prehistoric material found on the continental shelf, it is necessary to look beyond traditional UK sources and recognise that, at times, the region would have formed part of a continuous lowland plain connecting Britain and mainland Europe (Firth, 2004).

2.5.2 Maritime archaeology

The North Sea is a large marine basin with numerous tidal rivers flowing into it from all directions: the Elbe and Rhine to the east, the Forth and the Humber from the north, and the Thames from the south of the East Coast REC Study Area. Such rivers have commanded the flow and transport of people and their belongings throughout the sequence of human habitation in Northern Europe over many thousands of years. Within the vicinity of the East Coast REC Study Area, numerous cultural and technological developments have occurred that have established a tangible record of how humans have inhabited and adapted to the marine environment.

Simultaneously, during the Early Mesolithic period (approximately 8000 BC), as the northern ice sheet melted further and the sea level rose, cutting off Britain's dry-land connections with the Continent, a flourishing forested environment gradually spread throughout the region. This meant that communities would have had to modify their behaviour towards harnessing such conditions. Human settlement patterns around the North Sea and associated river inlets suggest the use of vessels. For example, there is evidence of wood clearing and settlement close to rivers such as the Little Ouse, near Theftford to the west of the East Coast REC Study Area (Wymer, 2005). Although there has yet to be any archaeological evidence for boat building at this time within the region, it is possible, due to discoveries in the Netherlands and France, that wood working took place for a variety of equipment, such as water craft.

The landscape of the Neolithic and early Bronze Age (4000–700 BC) encompassed the clearing of broad areas of woodland with settlement amongst the rich marshlands and estuarine environments. The east coast is an area well known for coastal erosion, and its catastrophic impact suggests that the long stretches of sandy coast that typify this region would have extended further offshore than observed today. Overall, conditions would have provided a diverse resource for humans to exploit; however, archaeological evidence for settlement in this region is relatively scarce compared to the county of Essex to the south (Brown and Murphy, 1997).

The earliest examples of British Middle to Late Bronze Age watercraft represent a functional development of adapting timber into planks in order to utilise the varying environments for their owners' benefit, either for ferrying within fast-flowing estuaries or simply searching for foodstuffs within quiet upper reaches and creeks (McGrail, 2004).

The Iron Age that followed (700 BC to AD 43) would see a similar structure of lifestyle to that of the Late Bronze Age, with a low density of activity along river valleys and sustained woodland clearance close to and within the East Coast REC Study Area (Bryant, 1997). Late Iron Age artefacts of European significance from the *La Tène* I to III cultures that were deposited as offerings have all been discovered within wet contexts to the west of the East Coast REC Study Area (Bryant, 1997). This not only represents a further connection to the Continent through trade, but also a community motivated towards water environments for more than simply transport and subsistence (Hegarty and Newsome, 2004).

A closer unity between Britain and the southern North Sea margin was established during the Romano-British period (AD 43–410), which expanded and diversified trade with the Continent further. In particular, by AD 50 the port of Londinium attracted a vast density of shipping and merchant carriers (Merrifield, 1983).

Direct maritime archaeological evidence also represents diverse cultural impacts and impressions during the Romano-British period. For instance, a number of vessels discovered around England illustrate cross-Channel contacts through the manner of the constructional traditions utilised. As the Roman dominance of Europe diminished, vulnerable areas such as East Anglia became under threat from opportunistic seafaring communities from the east. This saw the establishment of Roman garrisons along the Norfolk and Suffolk coast, known as the "Saxon Shore" sea defence. Indeed, the fortified sites of Caister and Burgh Castle are well documented (Darling and Gurney, 1993; Gurney, 2005).

The Saxon settlers that succeeded the Roman occupation introduced a network of trade and migration routes that extended throughout the southern North Sea, as evidenced by Scandinavian-style clinker-built vessels during the Early Medieval period (AD 410–1066). A wooden boat was discovered in an old watercourse close to Ashby Dell in 1830, to the west of the East Coast REC Study Area. The vessel is thought to be from the fourth or fifth century and to be similar to the Nydam 2 ship from Jutland from between AD 310 and AD 350. Additionally, the famous ship burial of Sutton Hoo 2 (just to the south of the East Coast REC Study Area) of approximately AD 630 is also similar to a continental ship find, the Kvalsund Ship, of AD 700, found in western Norway (McGrail, 2004). Although the Nydam 2 boat and the Sutton Hoo 2 boat may not reflect ocean-going cargo vessels, they do represent the ability of shipwrights to build strong sailable vessels during this period. The Anglo-Saxon burial mounds of Sutton Hoo, discovered on a promontory overlooking the River Deben in Suffolk, not only represent the type of Northern European shipbuilding practices in use during this period, but also demonstrate the much broader social or cultural importance of ships and seafaring for the communities living within the vicinity of the East Coast REC Study Area at this time (Bruce-Mitford, 1972; Evans, 1994).

During the early medieval period there was a series of Viking raids and settlements along the eastern shores of England, causing cultural influences to gradually converge and envelop the vibrant Saxon communities of East Anglia. After a further invasion in 1066, by the Normans of northern France, stability returned to the region, which finally provided the impetus for the area to benefit from its strategic geographical position. The documented ship (and casualty) losses from this period infer an international nature of shipping networks from the eleventh to sixteenth centuries, which encompassed the Baltic to Mediterranean seas, all passing through the southern North Sea area. The close proximity of rich marine resources would see Norfolk and Suffolk establish the largest fleet of ships compared to any other region of England at this time, with the towns of Dunwich, Southwold, Lowestoft and Great Yarmouth as particular examples of this prosperity (Williams, 1988).

Although such regional developments transformed the coastal medieval towns of the East Coast REC Study Area into vibrant economic centres, there were larger scale developments occurring throughout Europe, culminating in a chaotic period in maritime history. The success of returning open-ocean explorers of the late fifteenth and early sixteenth centuries were the catalyst for such change, driving the large merchant centres of northern and southern Europe, who would compete to develop new trans-oceanic network links between the North Sea and the East and West Indies. Paradoxically, such turbulent links ultimately contributed to the beginning of a “Golden Age” in northern European fortunes (Glete, 1999) and the impetus to protect financial interests abroad.

Within a century the advance in shipbuilding technological capabilities and cheap ordnance meant that conflicts at sea became organised, larger in scale and more destructive. The East Coast REC Study Area would be the stage for two significant naval battles during the seventeenth century: the Battle of Lowestoft – the opening engagement of the Second Anglo-Dutch War in 1665 – and the Battle of Sole Bay (Southwold Bay) in June 1672 during the Third (and final) Anglo-Dutch War. A total of 20 Dutch ships and 2 English vessels were lost in the course of the Battle of Lowestoft. Losses suffered at the Battle of Sole Bay included 3 Dutch ships and 4 ships from the combined English and French fleet, which included the English First Rate, *Royal James*, a wreck within the East Coast REC Study Area.

Towards the end of the post-medieval period (AD 1509–1815), East Anglia was at the forefront of the “Agricultural Revolution”, with grain the principal export of Norfolk and Suffolk’s diverse trade. A number of Parliamentary Acts were passed in order to further expand trade communications that served the farming economy (Gilman, 1997). The developed quays of Lowestoft and Southwold and the established ports of Great Yarmouth and King’s Lynn played particular roles during this time, along with the Icelandic cod fishing fleets during the mid-seventeenth and eighteenth centuries (Gould, 1997).

During the Industrial Revolution the Broads of Norfolk and Suffolk transformed into a patchwork of model farms. Local industries of ironworks, lime works (for building and fertilising) and brickworks emerged in order to supply the demand for local developments. Much of this had to be transported by water, until a reliable railway network was developed by the 1860s (Gould, 1997).

Generally, timber-built vessels continued to dominate on such regional scales, with iron structural elements and fittings becoming more popular as the nineteenth century progressed. Further technological innovations of the Industrial Revolution brought fundamental changes in shipbuilding traditions with the development of steam propulsion together with iron- and steel-constructed hulls (Greenhill, 1993; Ville, 1993).

The necessary continuation of the movement of cargo to and from London meant the east coast was en route from the industrial heartland and northern coalfields throughout the First and Second World Wars. Both conflicts developed separate strategies with which to disrupt shipping, based around the available technologies of the time, with the East Coast witnessing a large proportion of maritime wartime casualties during both conflicts.

During the First World War, the German U-Boat and minefields were to become a fundamental factor in shipping losses, compared to the natural elements of weather and navigational hazards. To combat this strategy, the British Navy established convoy networks with escorting minesweepers that were usually local fishing trawlers acquired and customised by the Admiralty. Recorded losses from the First World War are predominantly situated in close proximity to the coastline, and in particular the major ports, and potentially reveal the German strategy in the southern North Sea.

During the Second World War, convoy vessels were lost by torpedoes from submarines, with the additional threat of German motor torpedo boats, known as E-Boats, and fighter/bomber aircraft (Larn and Larn, 1997). The distance between the coast of Norfolk and Suffolk and the coasts of German-occupied France and Holland was relatively short, and ships were lost off Norfolk almost daily between 1939 and 1941 (Larn and Larn, 1997). The archaeological record of the East Coast REC Study Area therefore has a disproportionate focus towards twentieth-century shipping losses that, although important in its own right, belie the technological advances of shipbuilding made in the previous 100 years.

2.5.3 Aviation archaeology

Within the context of the marine environment, aviation archaeology is a study of the wreckage of aircraft crash locations. Considering the well-documented record of military air force activity in the United Kingdom throughout the twentieth century, the exact number and positioning of such a significant heritage resource is still poorly understood. It is, however, reasonable to estimate that losses from the Second World War provide the majority of such aviation sites (Wessex Archaeology, 2008c), and therefore the East Coast REC Study Area is likely to encompass a number of diverse national influences and cultural remains. Therefore, the east coast of England has a large potential for aircraft remains, especially with respect to the strategic positioning of airfields in Norfolk and Suffolk for the bombing raids of both combatants during the Second World War.

2.6 Benthic biology

The whole of the North Sea falls within the Atlantic biogeographic region (European Topic Centre on Biological Diversity, 2006), which provides the ecological context for the resident fauna. Research looking specifically at the distribution of benthic species across the North Sea has been considerable over recent years, most notably and comprehensively by the recent ICES Working Group on North Sea Benthos (see Rees *et al*., 1999; Eleftheriou and Basford, 1989; Heip *et* *al*., 1992; Künitzer *et al*., 1992; Heip and Craeymeersch, 1995; Eggleton *et al*., 2007; Rachor *et al*., 2007; Vanden Berghe *et al*., 2009). This research effort has found that many of the benthic species inhabiting the North Sea have a widespread distribution, ranging over much of the north Atlantic continental shelf. Examples include the polychaete worms *Pholoe* sp., *Goniada maculata* and *Spiophanes bombyx*, and the brittlestar *Amphiura filiformis*. Other species are more northern in their distribution, preferring cold water and not occurring further south than the northern edge of the Dogger Bank, which corresponds to the 50 m depth contour. Examples of these include the polychaete *Minuspio cirrifera*, the brittlestar *Ophiura affinis* and the tuskshell *Antalis entalis.* Species with a more southern distribution and a preference for warmer water tend not to be found north of the 100 m depth contour. Examples of these include the common brittlestar *Ophiura albida*, the sea potato *Echinocardium cordatum*, the striped venus clam *Chamelea gallina* and the bivalve *Tellimya ferruginosa* (Künitzer *et al*., 1992).

The East Coast REC Study Area falls under the Natural Area[1] of the southern North Sea. The Southern North Sea Marine Natural Area has been recognised, defined and coarsely characterised as a distinct biogeographic entity by several authors – including Glémarec (1973), Dyer *et al*. (1983), Duineveld *et al*. (1991), Heip and Craeymeersch (1995), Künitzer *et al*. (1992) and Jennings *et al*. (1999) – and extends from the inflows of the English Channel around the Straits of Dover in the south to the 50 m isobath at Flamborough Head in the north (Figure 2.17).

As well as biogeographic context, temperature and the influence of different water masses (eg, Atlantic water), a further factor affecting benthic species distribution is sediment type. Some species occur on all types of sediment, but most are restricted to a particular type and

[1] Marine Natural Areas take account of natural processes and the interaction between them, the underlying geology and wildlife. They offer a biogeographic framework within which an ecosystem approach to managing human uses of the marine environment can be developed and implemented (Jones *et al*., 2004).

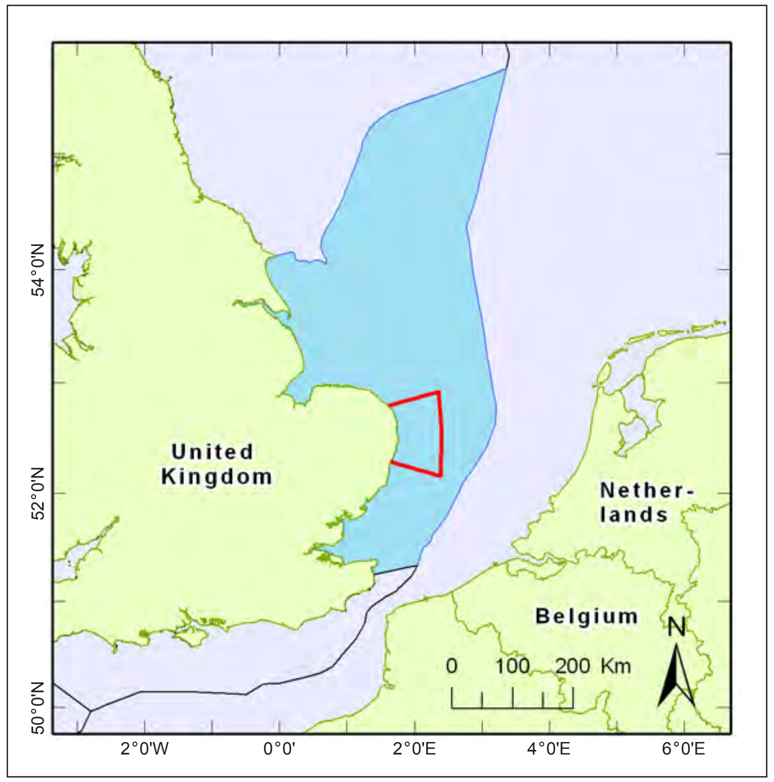


Figure 2.17 Map illustrating the limits of the Southern North Sea Marine Natural Area (highlighted in blue).

therefore these species are limited in their distribution. Within the southern North Sea region, the seabed is largely composed of mixed sand and gravel sediments; their distribution is largely influenced by hydrodynamics, geological processes and the present topography of the underlying seafloor. The pattern and distribution of the sediments is a key factor controlling the distribution of benthic habitats, masking the influence of the deeper geology on habitat distribution. Large offshore sandwaves are a conspicuous feature over the seabed within the region. They are no longer mobile and may host habitats different from those on the smaller mobile or more inshore sandwaves. Much of the inshore part of the southern North Sea region has shallow water, rarely exceeding 10 m in depth. This extends to approximately 65 m towards the south-eastern limit of the East Coast REC Study Area. Depths exceeding 80 m have been recorded in some areas of the southern North Sea (eg, from Skate Hole to the Outer Silver Pit). The relatively shallow waters of the East Coast REC Study Area are generally well mixed and show practically no stratification. This lack of stratification allows for the majority of the primary production (ie, phytoplankton) to reach the seabed for consumption by the benthos.

There has been previous targeted sampling of the benthic fauna in the East Coast REC Study Area prior to the conduct of this project (eg, Millner *et al*., 1977; Marine Ecological Surveys Limited, 2000; Cooper *et al*., 2007; Barrio Froján *et al*., 2008). Those studies have, in general, described the fauna as being relatively impoverished and characterised by the polychaete worm *Ophelia borealis*, a typical inhabitant of mobile sandy sediments (eg, Vanosmael *et al*., 1982). The limited range and density of fauna in this area has been attributed to the abrasive effects of shifting sands under strong tidal currents and storm action (Kenny *et al*., 1991) and also the sustained effects of marine aggregate extraction in the central part of the area (Cooper *et al*., 2007; Barrio Froján *et al*., 2008). Locally, there are also reefs of the Ross worm *Sabellaria spinulosa*. These reefs act to stabilise mobile sediments by utilising sand in the construction of their tubes, permitting a greater range and diversity of species to become established.

As a result of the mosaic of different sediment types and bedforms on the seabed of the region, there are a number of habitats found there. These are considered in turn, starting with gravel habitats, followed by sand, mud, rock and biogenic reef habitats.

2.6.1 Gravel habitats

Sublittoral sand and gravel sediments are the most common habitats found below the low water mark around the coast of the United Kingdom. North Sea sands and gravels tend to be formed from rock material, although shell fragments and whole shells may form 30% or more of the gravel sediment off the coast of Suffolk. The particle structure of gravel habitats ranges from various combinations of sand and gravel to pure gravel. The diversity and types of community associated with this habitat type are determined primarily by the sediment type, and also by a variety of other physical factors such as the relative exposure of the coast and differences in the depth, turbidity and salinity of the surrounding water.

Towards the southern end of the southern North Sea region, a discontinuous belt of gravel and sandy gravel extends offshore from Aldeburgh in Suffolk to the vicinity of Clacton-on-Sea in Essex. To the north of the area, many of these sediments generally form a surface layer less than 1 m thick, with the underlying glacial deposits or bedrock often exposed locally. The gravel habitats found in deeper offshore areas (>30 m) generally tend to be less perturbed by natural disturbance than those found closer inshore. These areas also tend to support a diverse marine fauna which may include a wide range of anemones, polychaetes, bivalves and amphipods, and both mobile and sessile epifauna.

2.6.2 Sand habitats

Sand habitats are widespread and are the dominant habitat type found in the southern North Sea. They tend to be mobile but accumulate in areas of moderate to strong tidal currents. In such situations the sands are coarse and clean with little silt/mud. More mobile sand habitats tend to be characterised by robust and sometimes impoverished faunas, dominated by organisms that are capable of rapid burrowing, such as certain mobile polychaete worms (eg, *O. borealis*) and thick-shelled bivalves.

The communities supported by sublittoral sandbanks are determined by the sediment type and a variety of other physical factors, including geographic location, the relative exposure of the coast and differences in the depth, turbidity and salinity of the surrounding water. Resident benthic communities can include large aggregations of the brittlestar *Ophiothrix fragilis*, polychaete worms such as the sand mason worm *Lanice conchilega*, and venerid bivalves. In areas of silty fine sands the community is characteristically rich and includes the bivalve *Abra alba*, bristleworms *Scoloplos armiger* and *S. bombyx*, and brittlestars *Ophiura ophiura* and *O. albida*. In tide-swept areas, mobile, rippled sand with occasional cobbles, pebbles or gravel are characterised by colonies of the hydroid *Hydrallmania falcata*. These grow on the stones and are tolerant of periodic burial in the shifting sands. The infaunal component usually consists of spionid worms and deposit-feeders. Such tide-swept shallow areas may also have dense beds of the sand mason worm *L. conchilega* (which further stabilises the sediment) with other polychaetes such as *S. armiger* and *Chaetozone setosa*. In addition, sublittoral sandbanks provide important nursery grounds for young commercial fish species, including plaice *Pleuronectes platessa*, cod *Gadus morhua* and sole *Solea solea*.

2.6.3 Mud habitats

The presence of mud mixed in with other sediment types usually indicates an area of relative shelter from wave exposure or from tidal currents. It is under such conditions that silt can settle onto the seafloor and become incorporated into the sediments. Because of the exposed nature of much of the southern North Sea, few areas of mud-dominated sediment can be found, except in deeper water such as in “troughs” or “deeps”. Polychaete worms, bivalve molluscs and brittlestars often dominate the fauna of muddy sediments.

2.6.4 Rock habitats

The only rock habitats of note in the southern North Sea are chalk reefs, which occur at two locations: in the south within the Thanet coast Special Area of Conservation (SAC), and in the north within the Flamborough Head SAC. There are no noteworthy chalk or other rocky outcrops within the East Coast REC Study Area.

Chalk reef habitats, where they do occur, characteristically support a wide range of species, some of which are unique to this type of substrate. Subtidal chalk at Thanet is bored by piddocks *Barnea* spp, *Pholas dactylus*, *Hiatella artica* and *Petricola pholadiformis*. The chalk reefs at Flamborough support kelp *Laminaria hyperborea* forests with an associated fauna that typically colonises the holdfasts. They also support a variety of faunal “turf” communities. They range from low encrusting forms, such as sea mats and sponges, to tall erect forms, such as soft corals and sea fans, plus mobile organisms such as crustaceans, echinoderms, molluscs and fish.

2.6.5 Biogenic habitats

Biogenic habitats are often associated with specific broad habitats – for example, maerl is usually associated with gravel, and seagrass beds with sand – though reefs formed by animals such as the Ross and honeycomb worms *Sabellaria* spp. can be associated with a range of habitats such as sand, gravel, pebbles and cobbles, and bedrock. The most notable biogenic habitats in the southern North Sea are reefs.

Biogenic reefs are where species aggregate to form a hard substratum and allow a community of other species to develop. Biogenic reef-forming species include the tubeworm *Serpula vermicularis*, the honeycomb worm *Sabellaria alveolata*, the Ross worm *S. spinulosa*, cold-water coral *Lophelia pertusa*, edible blue mussel *Mytilus edulis* and the horse mussel *Modiolus modiolus*. In the southern North Sea the main biogenic reef-forming species are *S. spinulosa*.

S. spinulosa reefs are solid structures, at least several centimetres thick, raised above the surrounding seabed, which persist for many years. As such, they provide a biogenic habitat that allows many other associated species to become established. *S. spinulosa* does not always form reefs but can occur as solitary individuals or in small groups encrusting pebbles or shells. Where conditions are favourable, thin crusts can be formed, sometimes covering extensive areas of the seabed. However, these crusts are ephemeral in nature, being broken up during winter storms. As a result, these crusts do not constitute true *S. spinulosa* reef habitats. *Sabellaria* reefs are present within the southern North Sea, in particular offshore from The Wash (Foster-Smith and White, 2001) and in an aggregate licence area (401/2) which is approximately 13 nautical miles east of Great Yarmouth (Marine Ecological Surveys Limited, 2000). It is likely that this habitat is also present in the surrounding offshore waters.

2.7 Marine mammals

There are two major groups of marine mammals: Cetaceans – whales, dolphins and porpoises – and Pinnipeds or seals. The Cetacea is further divided into two suborders: the Mysteceti or baleen whales, and the Odontoceti or toothed whales. The baleen whales have two blow holes and possess no teeth, feeding by means of comb-like baleen plates that hang from the roof of the mouth. The baleen acts as a filter, sifting out crustaceans and small fish from the water column. The toothed whales, dolphins and porpoises possess teeth and a single blow hole. The Pinnipedia includes the eared seals, true seals and the walrus (Shirihai and Jarrett, 2006; Walker and Cresswell, 2008).

Marine mammals inhabit seas and oceans throughout the world, but individual species often have a fragmented distribution according to their "preferred" areas. These areas are usually determined by ocean temperature, but also by competition with other species (Learmonth *et al.*, 2006). Many marine mammals take seasonal migrations determined by prey resources, habitat availability, predation pressures, competition and breeding (Learmonth *et al.*, 2006).

Marine mammals can be difficult to observe because of their elusive nature and wide-ranging distribution, and so knowledge of their behaviour and distribution is incomplete. It is known, however, that the waters surrounding the United Kingdom provide year-round habitats for numerous species of marine mammals (Reid *et al.*, 2003). Habitat preferences often reflect the distribution of prey species, determined by topographic variables such as water depth, nature and distance to the shelf edge and the physical and chemical characteristics of the water (Hall *et al.*, 1998; Learmonth *et al.*, 2006; MacLeod *et al.*, 2007).

Marine mammal data collected during dedicated surveys (effort-related sightings) is supplemented by ad-hoc sightings data collected by volunteers and fishermen (incidental sightings). Such opportunistic observations, however, can lead to inconsistencies in data-sets. Observation numbers are also a function of the distribution of effort and of the sighting conditions (Hammond *et al.*, 2002a). Some inaccuracies may also result from mistaken identity of marine mammals as several species are easily confused. For example, surfacing minke whales can look very similar to sei or fin whales, and sometimes fish species such as tuna can be mistaken for dolphins (Walker and Cresswell, 2008). Strandings data and accidental encounters also contribute significantly to our understanding of marine mammals although they do not necessarily imply population levels or reflect true distributions (Reijnders and Lankester, 1990; Santos *et al.*, 2001, 2004).

2.7.1 The protected status of marine mammals

Effective conservation of marine mammals depends on an understanding of many aspects of their population ecology including population size, structure and distribution. As much of this information is lacking, the best means of protecting many cetacean species is difficult to assess (Reid *et al.*, 2003). Conservation efforts are further complicated because marine mammals migrate across political and geographic borders, requiring global cooperation in conservation and management issues. Numerous national and international conventions and initiatives have been put in place to tackle this problem, and those applicable to species occurring in the East Coast REC Study Area are summarised in Table 2.4.

UK populations of many marine mammals have declined over the course of the last 200 years, largely as a result of anthropogenic influences (Reid *et al.*, 2003). Population numbers have been impacted by direct and indirect fishing pressure, collisions with shipping and the effects of pollution and anthropogenic noise (Dietz *et al.*, 2001; Henriksen *et al.*, 2001; Dolman *et al.*, 2003; Reid *et al.*, 2003; Hammond, 2006). The majority of marine mammal species now receive legal protection through both European and UK legislation.

All of the marine mammals that are known to regularly occur in the east coast region (Table 2.4) are listed in the European Directive on the Conservation of Natural Habitats and of Wild Fauna and Flora 92/43/EEC (the EC Habitats Directive) which was incorporated into UK law as the Conservation (Natural Habitats etc) Regulations in 1994. Cetaceans are listed under Annex IV of the Directive, which prohibits all forms of deliberate capture or killing and the disturbance or destruction of the animals themselves or the habitats that they use for breeding or resting. Similarly, it is illegal under the UK Wildlife and Countryside Act 1981 to intentionally kill, injure or harass any cetacean species in UK waters (Reid *et al.*, 2003).

Conservation efforts are likely to be greatly enhanced as more data become available and our understanding of the ecology of marine mammals improves. In recent years there has been a trend towards co-ordinated sea surveys, which yield valuable information on the distribution and population dynamics of marine mammals. Examples of such surveys include the Small Cetaceans in the European Atlantic and North Sea (SCANS) survey, conducted by the Sea Mammal Research Unit (University of St. Andrews), a survey dedicated to all small cetaceans in the North Sea and adjacent waters (Hammond *et al.*, 2002a; Hammond, 2006). Observational data from a number of sources have also been collated and are published in the Atlas of Cetacean distribution in north-west European waters (Reid *et al.*, 2003).

Data from the Reid *et al.* (2003) Atlas has been used to map distributions of cetaceans in the East Coast REC Study Area (see Figures 2.19, 2.21, 2.23, 2.25, 2.27). Three sources contributed to these collated data: the Small Cetacean Research Unit – SCANS 1994 and SCANS-II 2005 – and the Sea Watch Foundation and the European Seabirds at Sea (ESAS) database held by the Joint Nature Conservation Committee (JNCC). Although these data are collected from several sources, they are still thought to be outdated and may not accurately reflect cetacean distribution and relative abundance in UK waters (Dunn, 2010). There are also inconsistencies within marine mammal literature and publicly available data. These data are, however, the best available data covering UK waters (Dunn, 2010) and are supplemented by data from the National Biodiversity Network Gateway (NBN, 2010).

The JNCC are currently leading a collaborative project, the Joint Cetacean Protocol, which aims to assess the cetacean reporting requirements of various European directives and to identify all relevant NW European cetacean data available for reporting on cetacean conservation status. The project will investigate what power these data have to assess trends in abundance and range and how to improve that power. It also will determine what standards data must attain to enable high-quality reporting. Finally, it aims further to facilitate the sharing of standardized cetacean data-sets via the worldwide web and to generate tools for the production of cetacean distribution and abundance summary data (Dunn, 2010).

Legislation / conservation initiative	Details	Harbour porpoise	White-beaked dolphin	Bottlenose dolphin	Common dolphin	Minke whale	Harbour seal	Grey seal
EC Habitats Directive	All cetacean species are protected from capture, killing, disturbance (particularly during periods of breeding) or the destruction of them or their habitat under Annex IV of the Habitats Directive. The United Kingdom is also required to designate areas of particular importance to the common dolphin, harbour porpoise and grey and common seals under Annex II. Incidental captures and killing of the common dolphin and harbour porpoise must also be recorded and monitored under Article 12. The Habitats Directive is transposed to UK law by the Conservation (Natural Habitats etc.) Regulations 1994.	*	*	*	*	*	*	*
Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)	CITES aims to protect certain plants and animals, including cetaceans, by regulating and monitoring their international trade to prevent it reaching unsustainable levels.	*	*	*	*	*		
The Convention on the Conservation of European Wildlife and Natural Habitats (the Bern Convention)	The principal aims of the Bern Convention are to ensure conservation and protection of all wild plant and animal species and their natural habitats (listed in Appendices I and II of the Convention); to increase cooperation between contracting parties; and to afford special protection to the most vulnerable or threatened species (including migratory species) (listed in Appendix III). To this end the Convention imposes legal obligations on contracting parties, protecting over 500 wild plant species and more than 1,000 wild animal species.	*	*	*	*	*		
Convention on the Conservation of Migratory Species of Wild Animals (CMS or Bonn Convention)	Migratory species that would significantly benefit from international co-operation of conservation efforts are listed in Appendix II of the Bonn Convention. This encourages member states to conclude global or regional Agreements for the conservation and management of individual species or, more often, of a group of species listed in Appendix II of the Convention. The Wildlife & Countryside Act and the ASCOBANS agreement are the main mechanisms adopted by the UK in order to implement the recommendations of the Bonn Convention (see below).	*	*	*	*		*	*
Wildlife & Countryside Act 1981	Act of Parliament which makes it an offence (subject to exceptions) to intentionally kill, injure, take, possess or trade in any wild animal listed in Schedule 5, and prohibits interference with places used for shelter or protection, or intentionally disturbing animals occupying such places. The common dolphin, bottlenose dolphin and harbour porpoise are also listed under Schedule 6, which prevents them from being killed by certain methods.	*	*	*	*	*		
Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS)	Regional agreement covering all species of the toothed whales (Odontoceti), with the exception of the sperm whale (*Physeter macrocephalus*). A conservation and management plan forms part of the agreement, and this obliges parties to engage in habitat conservation and management, surveys and research, pollution mitigation and public information.	*	*	*	*			
Section 74 Countryside Rights of Way (CRoW) Act 2000	The CRoW act amends the law relating to nature conservation and protection of wildlife. Section 74 of the act requires the preparation and maintenance of lists of priority species and habitats. The CRoW act also strengthens the legal protection for threatened species with regard to killing, injuring, disturbing or destroying places used for shelter and protection.	*	*	*	*	*		
Conservation of Seals Act 1970	Provides for a closed season during which it is an offence to take or kill any seal except under licence in particular circumstances. The closed season for grey seals is 1 September to 31 December inclusive and for common seals, 1 June to 31 August inclusive, coinciding with their respective pupping seasons. The Act provides an exception that makes it lawful to kill a seal to prevent it from causing damage to fishing nets or tackle, or to any fish in the net, provided that the seal is in the vicinity of the net or tackle at the time.						*	*
UK Biodiversity Action Plan (BAP)	The UK List of Priority Species and Habitats contains 1,150 species and 65 habitats that have been listed as priorities for conservation action under the UK BAP.	*	*	*	*	*	*	

Table 2.4 **The national and international conventions and initiatives that apply to the marine mammals of the East Coast REC Study Area.**

2.7.2 Cetaceans of the East Coast REC Study Area

The most commonly observed marine mammals within the East Coast REC Study Area are the harbour porpoise *Phocoena phocoena*, the white-beaked dolphin *Lagenorhynchus albirostris* and the common bottlenose dolphin *Tursiops truncatus.* The short-beaked common dolphin *Delphinus delphis*, minke whale *Balaenoptera acutorostrata*, fin whale *Balaenoptera physalus*, sperm whale *Physeter macrocephalus* and white-sided dolphin *Lagenorhynchus acutus* are also observed or found stranded, although they are very rare in the southern North Sea (Das *et al.***,** 2003).

Harbour porpoise, *Phocoena phocoena*

Harbour porpoises are small, inconspicuous and undemonstrative animals that are hard to detect (Figure 2.18). This means that sighting numbers can be low and that opportunistic observations may not be very useful (Jung *et al*., 2009). There are also problems with duplicate identification – that is, a porpoise may be counted more than once in a single observation (Hammond *et al.*, 2002a). These factors need to be considered, as reported distributions of porpoises may not be truly representative.

Nevertheless, the North Sea is reported to be one of the most important habitats in the world for the harbour porpoise (Das *et a*l., 2003; ICES, 2008). In 1994, the North Sea population of harbour porpoises was estimated to be 268,000 (Hammond *et al*., 2002a, 2002b; Reid *et al*., 2003). Abundance is higher in the southern North Sea than in northern areas, and this is probably a reflection of prey distribution (Hammond *et al*., 2002a; Reid *et al*., 2003; Hammond, 2006; ICES, 2008). Evans *et al.* (2003) report that sub-populations may exist in the northern and southern North Sea. Porpoises are known to have a shelf tendency (distance to coast or water depth), preferring coastal waters and depths around 60 m (MacLeod *et al*., 2007), although deep-water sightings are not uncommon (Northridge *et al*., 1995).

Figure 2.18 Harbour porpoise, *Phocoena phocoena.* © Marine Wildlife Department of Gardline Environmental.

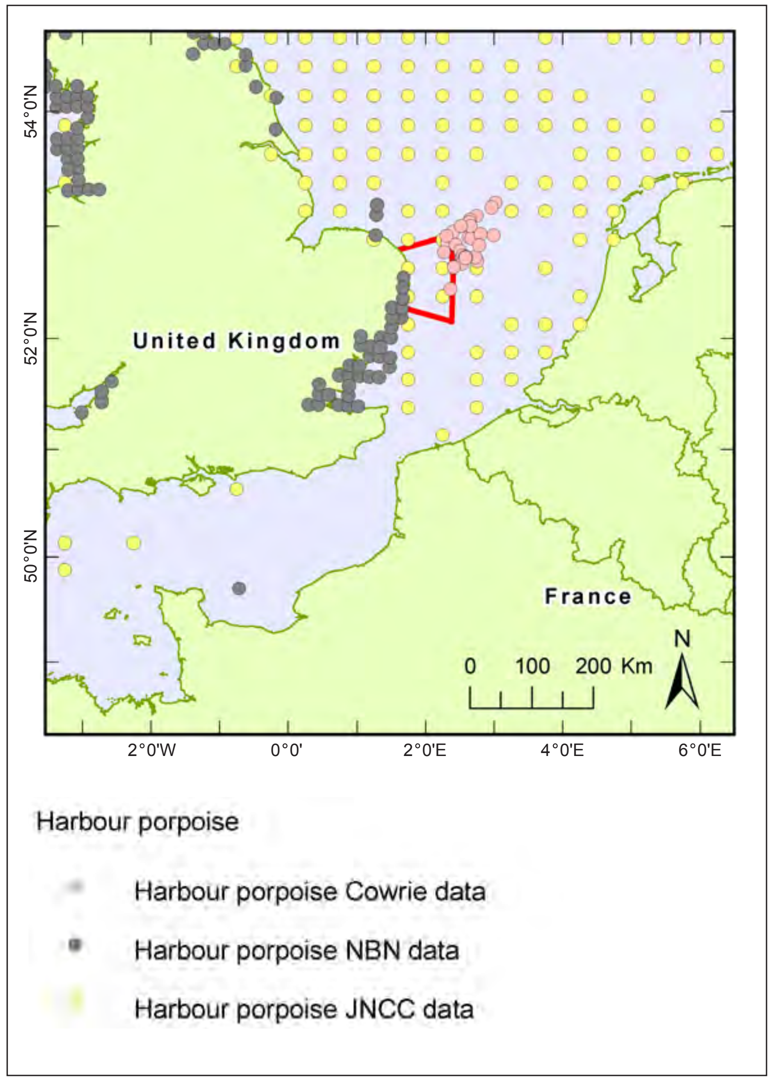


Figure 2.19 Recorded sightings of harbour porpoise, *Phocoena phocoena*, in the East Coast REC Study Area (Hexter, 2009; NBN, 2010; Reid *et al*., 2003).

Harbour porpoises are frequently sighted around the East Coast REC Study Area (see Figure 2.19), and despite the lack of literature it is apparent from observational results that they are by far the most common cetacean in the East Coast REC Study Area and indeed in the United Kingdom.

In the North Sea the harbour porpoise is badly affected by bottom set gillnet fisheries (Reijnders and Lankester, 1990; Hammond, 2006). In the early 1990s the bycatch of Danish gillnet fisheries was approximately 6,000–7,000 porpoises in the central and southern North Sea (Gislason, 1994; Vinther, 1999; Hammond, 2006). The minimum estimated mortality of porpoises per year is around 5,500, which is believed to exceed sustainable levels and is considered a significant factor in the population decline of this species (Hammond *et al*., 2002a; Evans *et al*., 2003; Reid *et al.***,** 2003). Although the status of porpoises has been of concern, recent studies indicate that stable populations appear to be establishing after a recent decline (Hammond *et al*., 2002a; Hammond, 2006; Jung *et al*., 2009).

White-beaked dolphin, *Lagenorhynchus albirostris*

The white-beaked dolphin *L. albirostris* (Figure 2.20) is the most abundant dolphin species to be recorded in the North Sea, with population estimates of 7,900 individuals, indicating the North Sea

Figure 2.20 White-beaked dolphin, *Lagenorhynchus albirostris.* © Marine Wildlife Department of Gardline Environmental

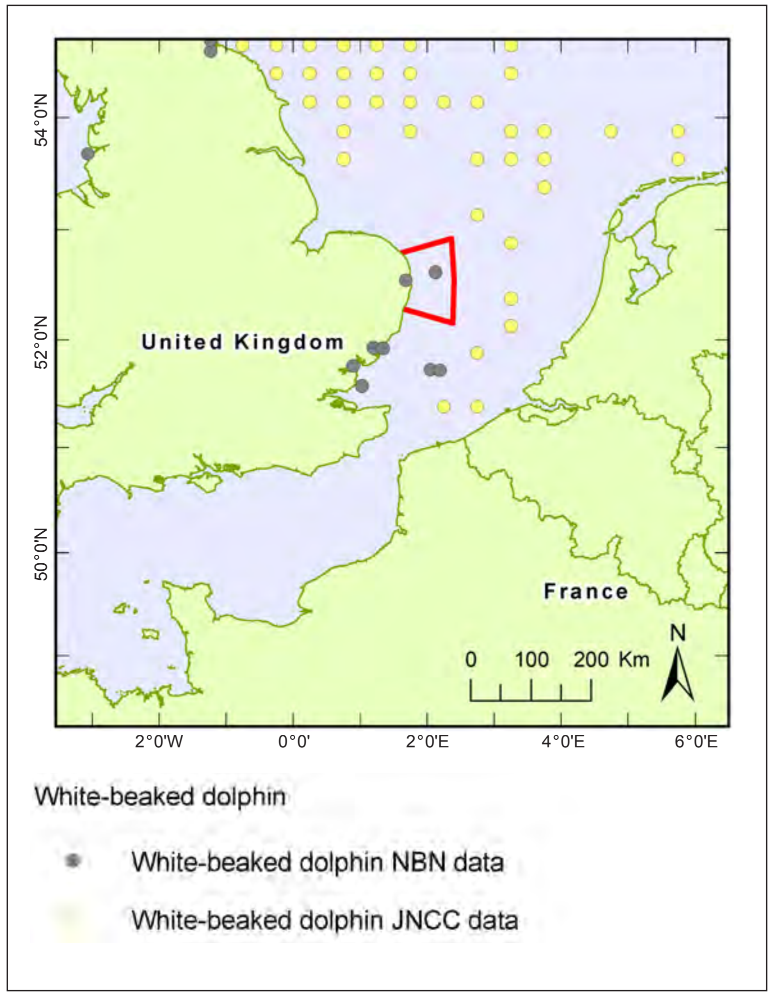


Figure 2.21 Recorded sightings of white-beaked dolphins, *Lagenorhynchus albirostris*, in the East Coast REC Study Area (NBN, 2010; Reid *et al.*, 2003).

as a major habitat for this species (Hammond, 2006; ICES, 2008). The white-beaked dolphin is frequently sighted along the eastern coast of the United Kingdom (Northridge *et al.*, 1995; Das *et al.*, 2003; Evans and Hammond, 2004), predominantly around Scotland but also as far south as the Thames (see Figure 2.21) (Evans, 1980; Canning *et al.*, 2008). *L. albirostris* is usually seen in pods of around 10–50 individuals, although pods of up to 100–500 animals have been observed in the North Sea (Evans, 1980; Reid *et al.*, 2003).

The distribution of the white-beaked dolphin is thought to be linked to sea temperature, with larger groups associated with lower temperatures and so possibly restricted to the cooler northern areas in the summer months (Weir *et al.*, 2007; Canning *et al.*, 2008). Northridge *et al.* (1995) found that *L. albirostris* is confined to shelf areas, with a general increase in sightings towards land in summer months (Northridge *et al.*, 1995; Canning *et al.*, 2008). Canning *et al.* (2008) analysed *L. albirostris* strandings data and found a segregation of the sexes in the North Sea. In the months June to September all strandings and sightings were found to be either females or calves (Weir *et al.*, 2007; Canning *et al.*, 2008). This suggests that females move inshore to give birth in summer months, with males following later (Canning *et al.*, 2008).

Other factors such as prey density may also influence the distribution of this species (Weir *et al.*, 2007; Canning *et al.*, 2008; Weir *et al.*, 2009). The white-beaked dolphin is said to belong to the “southern North Sea food-web” consuming fish and squid including cod, whiting, hake, mackerel and herring (Evans, 1980; Evans *et al.*, 1987; Kinze *et al.*, 1997; Das *et al.*, 2003; Canning *et al.*, 2008). Peak numbers of individuals occur off the east coast of England between May-June (Evans *et al.*, 2003).

The distribution of *L. albirostris* within the East Coast REC Study Area is limited to two observations, one close to the coast and another towards the central region of the study area (see Figure 2.21). Although these numbers are low the observations do indicate a white-beaked dolphin presence within the area.

Bottlenose dolphin, *Tursiops truncatus*

The bottlenose dolphin *T. truncatus* (Figure 2.22) is commonly found in shallow coastal habitats, tending to aggregate around entrances to estuaries, lagoons and bays and often concentrating in areas of fast tidal currents and uneven bottom relief (Ingram and Rogan, 2002; Evans *et al.*, 2003; Reid *et al.*, 2003). *T. truncatus* is a known resident of the North Atlantic, with resident populations in the Moray Firth (Scotland), Cardigan Bay (Wales) and the Shannon Estuary (Ireland) (Ingram and Rogan, 2002; Reid *et al.*, 2003).

Figure 2.22 Bottlenose dolphin, *Tursiops truncatus*. © João Nuno Gonçalves, CIRCÉ – Portugal.

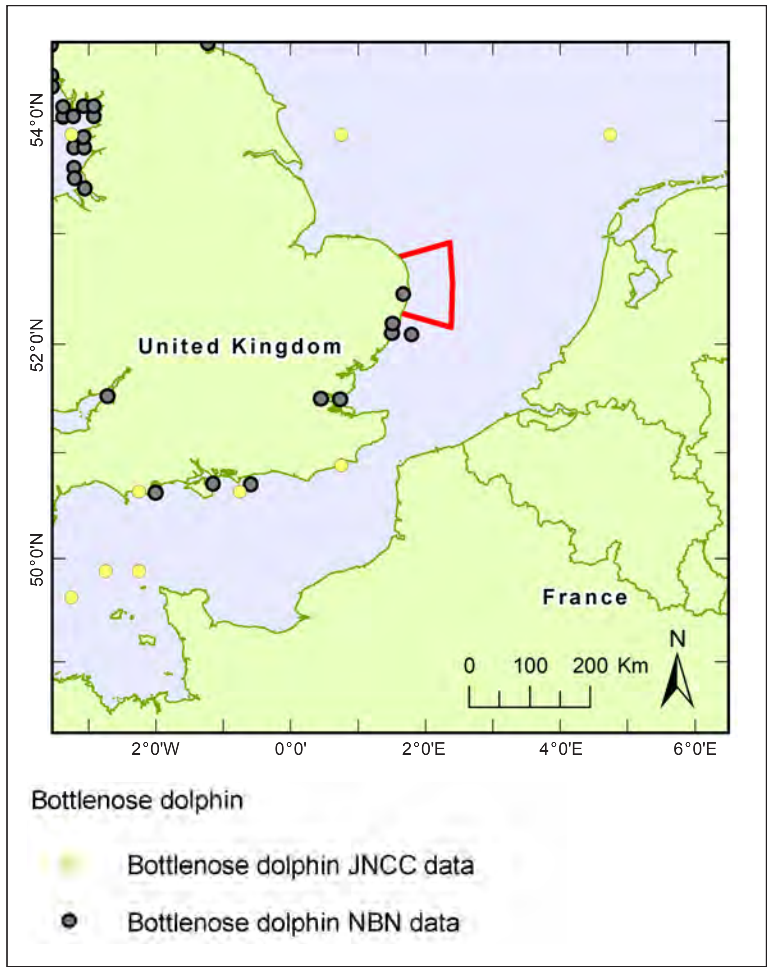


Figure 2.23 Recorded sightings of bottlenose dolphins, *Tursiops truncatus*, in the East Coast REC Study Area (NBN, 2010; Reid *et al.*, 2003).

In the eastern and southern waters of Britain there has been a decline in bottlenose dolphin populations compared to northern and western regions (Wood, 1998). Evans (2002) reports very occasional observations of bottlenose dolphins off the east coast of England, with only one sighting of *T. truncatus* observed in the East Coast REC Study Area (see Figure 2.23). Peak numbers at coastal sites of the United Kingdom are generally greatest between July and October (Evans, 2002). Whilst the bottlenose dolphin is known to pass through the East Coast REC Study Area, there is no evidence to suggest the area holds any special significance for this species.

Short-beaked common dolphin, *Delphinus delphis*

The short-beaked common dolphin (Figure 2.24) is a fast, acrobatic and highly active species commonly found in tropical and temperate waters (Hammond *et al*., 2002b; Carwardine, 2003; Shirihai and Jarrett, 2006; Walker and Cresswell, 2008). *D. delphis* have criss-cross "hourglass"-shaped markings with a tan or yellow arching patch from head to mid-body, crossing over a pale grey flash that continues to the tail stock. The rest of the body and the prominent dorsal fin are dark grey.

Figure 2.24 Common dolphin, *Delphinus delphis.* © João Nuno Gonçalves, CIRCÉ – Portugal.

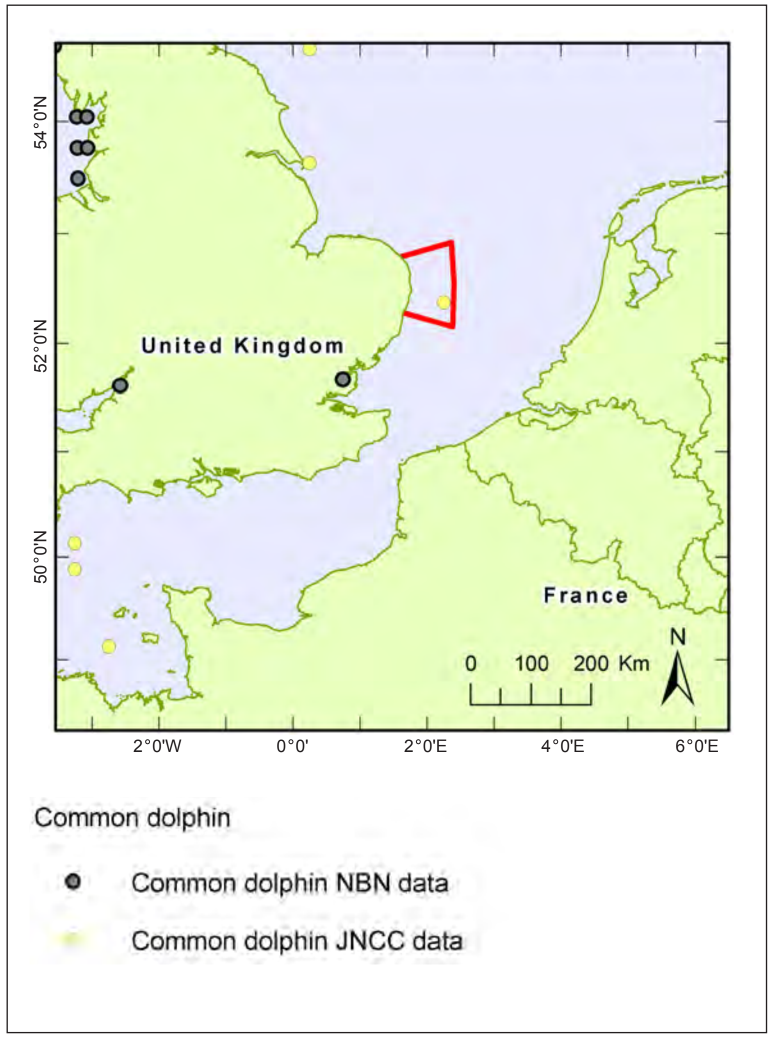


Figure 2.25 Recorded sightings of common dolphin, *Delphinus delphis*, in the East Coast REC Study Area (NBN, 2010; Reid *et al.*, 2003).

Short-beaked common dolphins are generally found in oceanic and shelf-edge waters and occasionally in coastal waters (Hammond *et al*., 2002b). They tend to occur in waters of 200–500 m depth, although seasonally they will occur in waters of 50–100 m depth, with distributions linked to undersea topography such as sea mounts and escarpments (Evans *et al*., 2003).

D. delphis is generally rare in the central and southern North Sea (Evans *et al*., 2003; Reid *et al*., 2003), being more commonly observed in the western approaches to the Channel and the southern Irish Sea (Evans, 2002; Hammond *et al*., 2002b). There are infrequent sightings in eastern England, which are most likely to occur in the summer months (Evans *et al*., 2003). There is a recorded observation of the short-beaked common dolphin in the East Coast REC Study Area, though such sightings are rare (Figure 2.25).

Minke whale, *Balaenoptera acutorostrata*

The minke whale *B. acutorostrata* (Figure 2.26) is the most frequently recorded baleen whale in the North Sea (Howes *et al.*, 1987; Carwardine, 2003; Northridge *et al*., 1995) and is thought to be the most important marine mammal in terms of biomass (ICES. 2008). In 1994, it was estimated that there were 7,200 minke whales around the east coast of Scotland and in the central/southern North Sea (Hammond *et al*., 2002b). Sightings of minke whales in the North Sea have only been recorded from May to October, and this seasonality is thought to be related to offshore movements in colder months (Hammond *et al*., 2002b; Anderwald and Evans, 2008). Evans (1980) suggests that minke whales migrate north-eastwards of Britain in summer months. Minke whales are usually rather solitary, although they have been

Figure 2.26 Minke whale, *Balaenoptera acutorostrata.* © Marine Wildlife Department of Gardline Environmental.

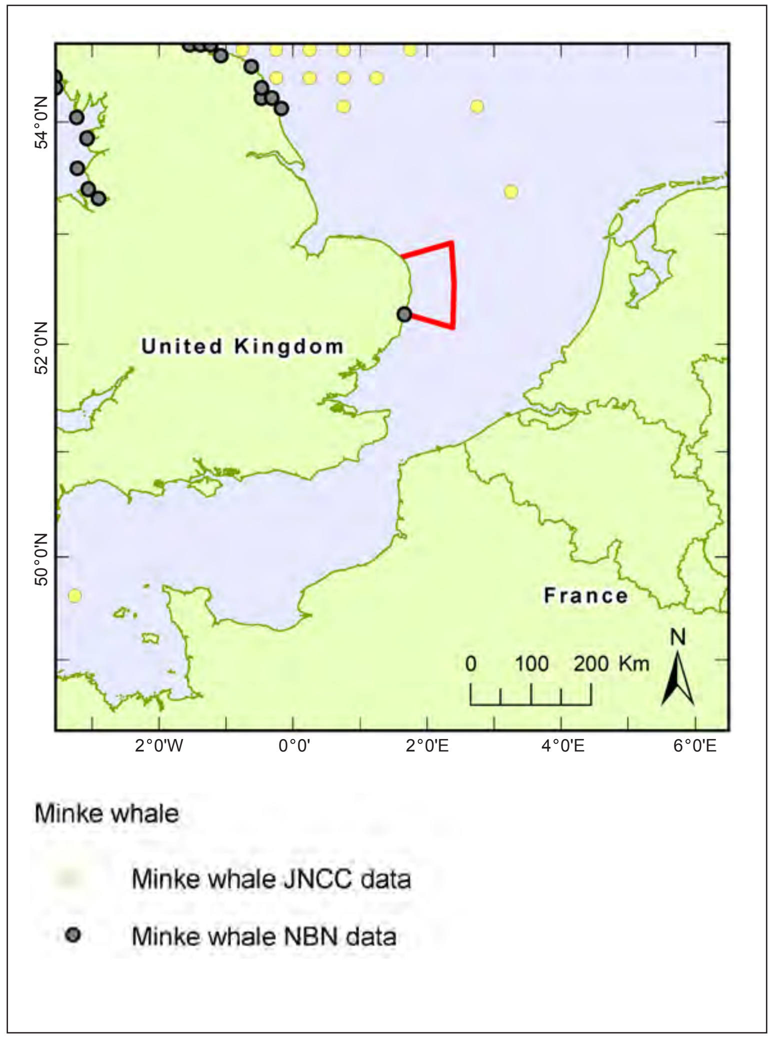


Figure 2.27 Recorded sightings of minke whale, *Balaenoptera acutorostrata*, in the East Coast REC Study Area (NBN, 2010; Reid *et al.*, 2003).

occasionally observed in groups of around 5–15 individuals (Anderwald and Evans, 2008).

The highest sighting rates for *B. acutorostrata* occur off the Hebrides and down the western edge of the North Sea from the Orkneys to Flamborough Head in Yorkshire (Northridge *et al.*, 1995). Although minke whales are reported to be rare off the east coast of England, there are occasional sightings around the East Coast REC Study Area (Figure 2.27).

2.7.3 Pinnipeds of the East Coast REC Study Area

Harbour seal, *Phoca vitulina*

The harbour seal *Phoca vitulina* (Figure 2.28) is the most widely distributed pinniped in the North Sea (Hammond *et al.*, 2002b), although it is not the most abundant. It occurs in all coastal waters around the North Sea, with an estimated minimum population of 38,000 – over half of the total estimated northeast Atlantic population (Hammond *et al.*, 2002b). The North Sea provides major haul-out sites on tidally exposed rock, sandbanks and mud, where animals come ashore for pupping and moulting (Hammond *et al.*, 2002b; Das *et al.*, 2003). Aerial surveys estimate that on the English east coast, 3,700 individuals haul out onto land for the moult and pupping seasons (Hammond *et al.*, 2002b).

The east coast of England hosts major populations of harbour seals in areas such as the Humber Estuary (Donna Nook, Lincolnshire), the Wash and Blakeney Point (Norfolk). The colonies at these three locations are thought to make up over 90% of the total English population of harbour seals (Lonergan *et al.*, 2007) (see Figure 2.29). Pupping occurs from June to July, and the moult occurs from around August to September (Hammond *et al.*, 2002b).

Figure 2.28 Harbour seal, *Phoca vitulina.* © Marine Wildlife Department of Gardline Environmental.

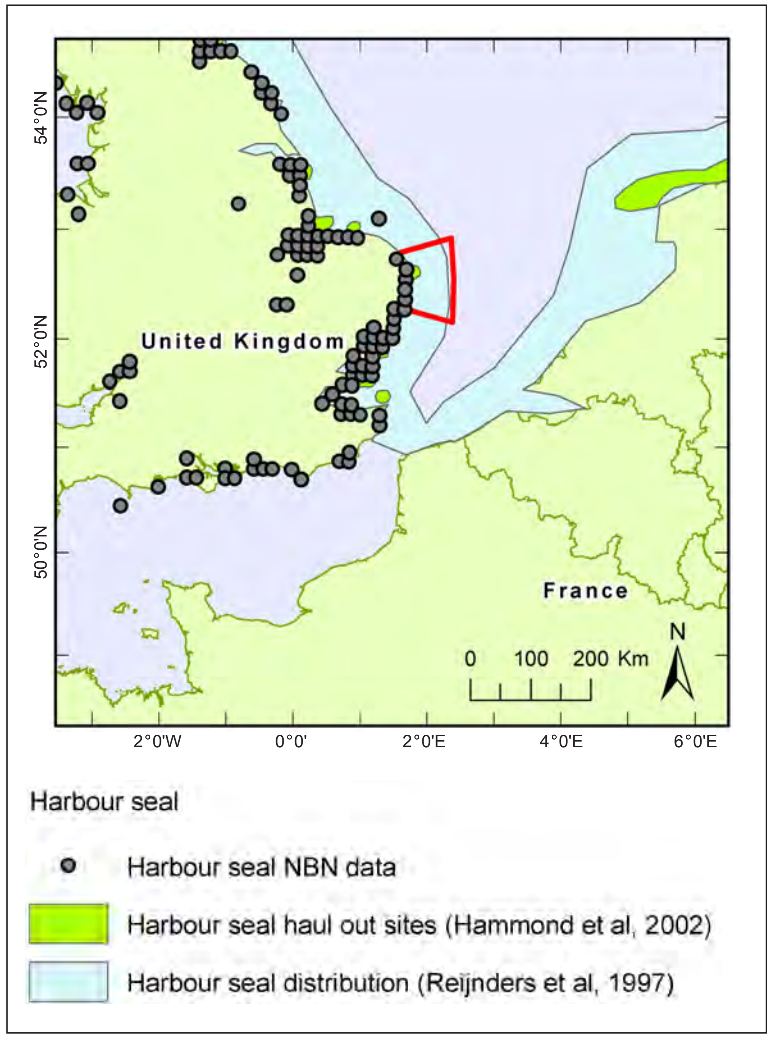


Figure 2.29 Recorded sightings, distribution and haul-out sites of harbour seals, *Phoca vitulina*, in the East Coast REC Study Area (Hammond *et al.*, 2002b; NBN, 2010; Reijnders *et al.*, 1997).

Grey seal, *Halichoerus grypus*

The grey seal *Halichoerus grypus* (Figure 2.30) is the most abundant seal in the North Sea, with an estimated population of 300,000. Of these, 14,100 are estimated to reside on the UK coastline (Hammond *et al.*, 2002b). Hauling and breeding sites for *H. grypus* are mostly found around the northern UK coast. However, more recent sightings and strandings in the southern region of the North Sea suggest that this species is extending southwards. Grey seal movements from haul-out sites are

Figure 2.30 Grey seal, *Halichoerus grypus*. © Marine Wildlife Department of Gardline Environmental.

localised over gravel and sand beds that are linked to sandeel habitat (Das *et al*., 2003).

North-west of the East Coast REC Study Area is Donna Nook (River Humber, Lincolnshire), one of three major grey seal colonies in Britain where breeding occurs (Abt *et al*., 2002). An estimated 400 individuals frequent this area every year, and approximately 120 pups are born each December (Prime and Hammond, 1990; English Nature, 2003). Prime and Hammond (1990) estimate a 135 km feeding radius from Donna Nook, encompassing the northern part of the East Coast REC Study Area (see Figure 2.31). Grey seals are recorded across the entire East Coast REC Study Area, so it is very likely that there are numerous haul-out sites across this coastline.

Both harbour and grey seals are important predators in the North Sea, commonly consuming prey such as sandeels, gadoids and

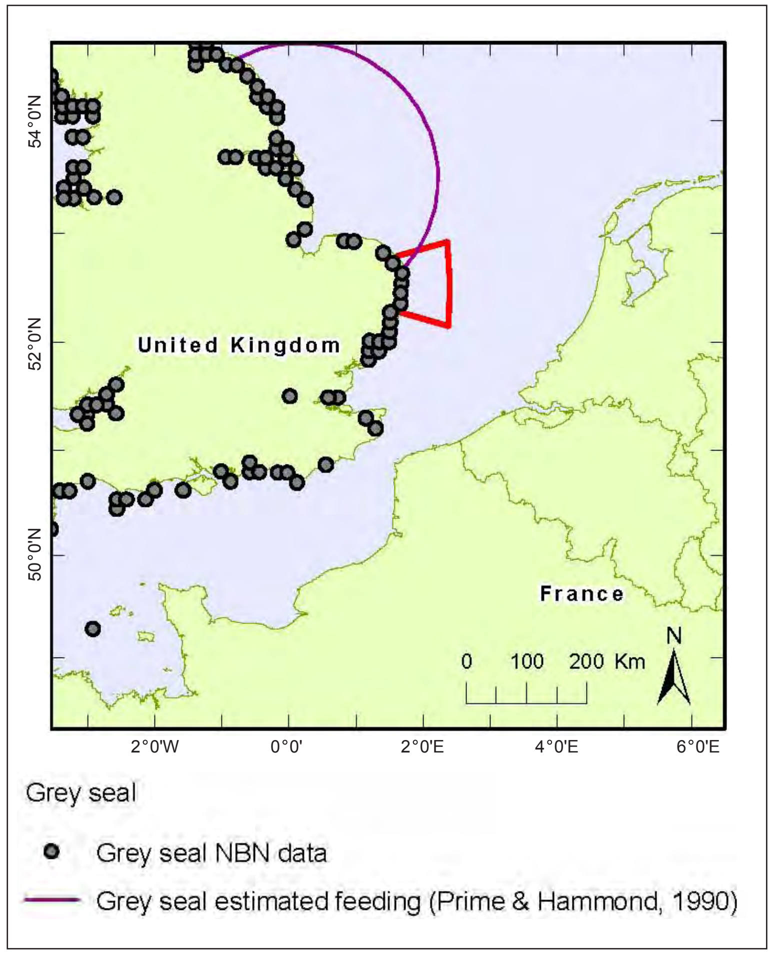


Figure 2.31 Recorded sightings and estimated feeding radius of grey seal, *Halichoerus grypus*, in the East Coast REC Study Area (NBN, 2010; Prime and Hammond, 1990).

flatfish. Harbour seals also predate other clupeoid fish and cephalopod species (Prime and Hammond, 1990; Hall *et al*., 1998; Pierce and Santos, 2003). Along with the white-beaked dolphin and cod, they occupy the highest trophic position in the North Sea, with very few natural predators of their own (Das *et al*., 2003). In the North Sea, the grey seal has been estimated to consume approximately 130,000 tonnes of prey each year, and the harbour seals' estimated annual prey consumption is 65,000 to 95,000 tonnes (Hammond *et al*., 2002b). Grey seals are often considered a nuisance as their fish consumption competes with commercial fisheries (Reijnders and Lankester, 1990; Matthiopoulos *et al*., 2008).

Multispecies associations

Cetaceans and seabirds forge multispecies feeding associations in the North Sea. Marine mammals act as "beaters", forcing fish balls to the surface, providing seabirds with access to prey such as sandeels and clupeoid fish that would otherwise be too deep below the surface to catch (Camphuysen and Webb, 1999; Frederiksen *et al*., 2006). Camphuysen and Webb (1999) observed a "typical association" of Atlantic white-beaked dolphins and harbour porpoises displaying this beating behaviour for Northern gannets (*Morus bassanus*) and black-legged kittiwakes (*Rissa tridactyla*). Minke whales are associated with auks, kittiwakes, large gulls, Manx shearwaters (*Puffinus puffinus*) and shags (*Phalacrocorax* spp.) (Anderwald and Evans, 2008). Cetaceans can also provide scraps of prey and faeces for scavenging birds (Camphuysen and Webb, 1999). These multispecies feeding associations are important in assisting the "visual food-finding" abilities of seabirds (Camphuysen and Webb, 1999).

The East Coast REC Study Area hosts a variety of marine mammal species, providing habitat, feeding grounds and haul-out sites. It is particularly important for harbour porpoises *P. phocoena*, harbour seals *P. vitulina*, and grey seals *H. grypus*.

2.8 Ornithology

The East Coast REC Study Area has a varied coastline that is highly important for marine birds. Just inland are five Important Bird Areas (IBAs): Broadland, Great Yarmouth North Denes, Breydon Water Nature Reserve, Benacre to Eastern Bavents National Nature Reserve (NNR) and the Minsmere–Walberswick Reserves (Figure 2.32). The region's importance to birds is also reflected in the number of Special Protection Areas (SPAs) and Ramsar sites. For example, Broadland and Minsmere–Walberswick are Ramsar sites, and Breydon Water, Great Yarmouth North Denes, Benacre to Eastern Bavents and Minsmere–Walberswick are SPAs (see Figure 2.40). All of the SPAs are protected by the Birds and Habitats Directive, the Habitats Regulations and the Countryside and Right of Way Act 2001 (Jones *et al.*, 2004). In addition to these designations, there are a number of Sites of Special Scientific Interest (SSSI), NNRs and Special Areas of Conservation (SACs) (see Figures 2.40 & 2.41).

Seabirds are long-lived, often easily observed birds (Oro and Furness, 2002), making it relatively easy to monitor populations. Concerted and co-ordinated seabird monitoring in the United Kingdom has occurred since 1986, when the Seabird Monitoring Programme (SMP) started to collect annual data (Sims *et al.*, 2006; Mavor *et al.*, 2008). Other surveys that have helped our understanding of bird trends in the United Kingdom are Operation Seafarer, Seabirds 2000 and Seabird Colony Register (Eaton *et al.*, 2009). Avian data acquisition is mainly concentrated around coastal and inland areas, although boat data are available though databases such as ESAS. ESAS was set up to standardise bird surveying techniques and data formatting for studies conducted around the North Sea (Camphuysen and Garthe, 2004). Bird data are also available from the NBN gateway, which collates and presents biodiversity data for the United Kingdom. Surveying techniques include boat and aerial surveys as well as land-based observations (Gibbons *et al.*, 2009). The data points, representing bird observation data, presented in this report have been divided into general observations and nest sites. Sightings by aerial surveys have also been highlighted. Much of the species information used in the report was taken from the website of the Royal Society for the Protection of Birds (RSPB) (www.rspb.org.uk/wildlife/birdguide/name).

The range of data collected helps to build a picture of population trends that are used to define the conservation status of birds in the United Kingdom and Europe. The Birds of Conservation Concern (BoCC) categorises birds into red, amber and green status, according to quantitative criteria that are used by organisations such as the RSPB (Gibbons *et al.*, 2009). The majority of the seabirds observed in the East Coast REC Study Area have been given amber status by the RSPB for one or more of the following criteria: European conservation status, historical decline (red-listed) followed by recent recovery (more than doubled in the last 25 years); moderate (>25% but <50%) breeding population decline; moderate non-breeding population decline; moderate breeding range decline; rarity (breeding population <300 pairs or non-breeding population <900 individuals); localisation (at least 50% of breeding or non-breeding population in 10 or fewer sites); and international importance (at least 20% of the European breeding or non-breeding population found in the United Kingdom) (Eaton *et al.*, 2009; RSPB, 2009).

Bird species of interest

Gulls are by far the most common group of seabirds in the East Coast REC Study Area, with the most regularly sighted species being black-headed gulls, great black-backed gulls, herring gulls, black-legged kittiwakes, lesser black-backed gulls, Mediterranean gulls and mew (common) gulls. These species are observed throughout the year but most commonly during the winter months. Some species of tern are commonly observed in the summer months, particularly the little tern, and are present at internationally important breeding sites. During the winter months, auks such as the common guillemot and the Atlantic puffin are often observed offshore. The northern fulmar is commonly observed in the East Coast REC Study Area throughout the year, and cormorants, divers and gannets have also been observed, especially in the winter (Parkin and Knox, 2010; RSPB, 2010).

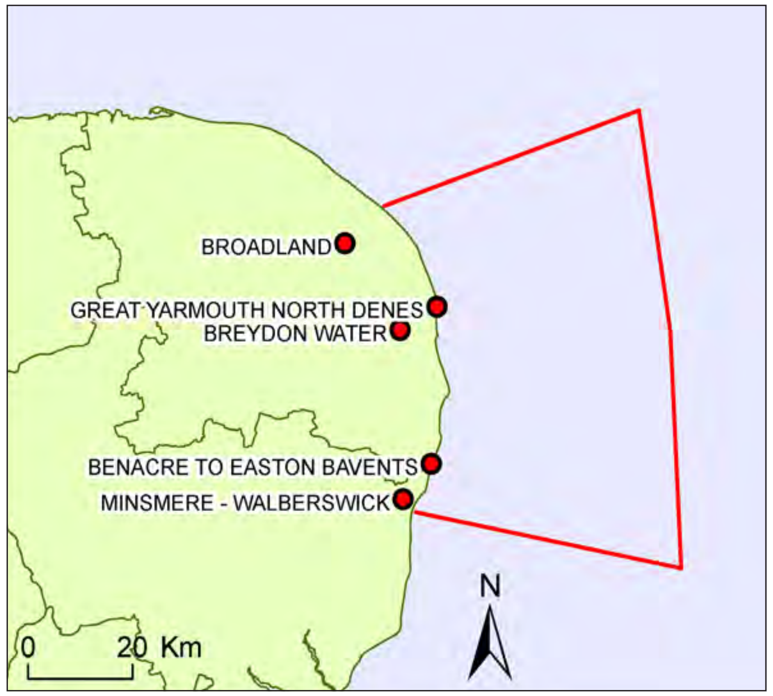


Figure 2.32 **Important Bird Areas within or close to the East Coast REC Study Area (RSPB, 2010).**

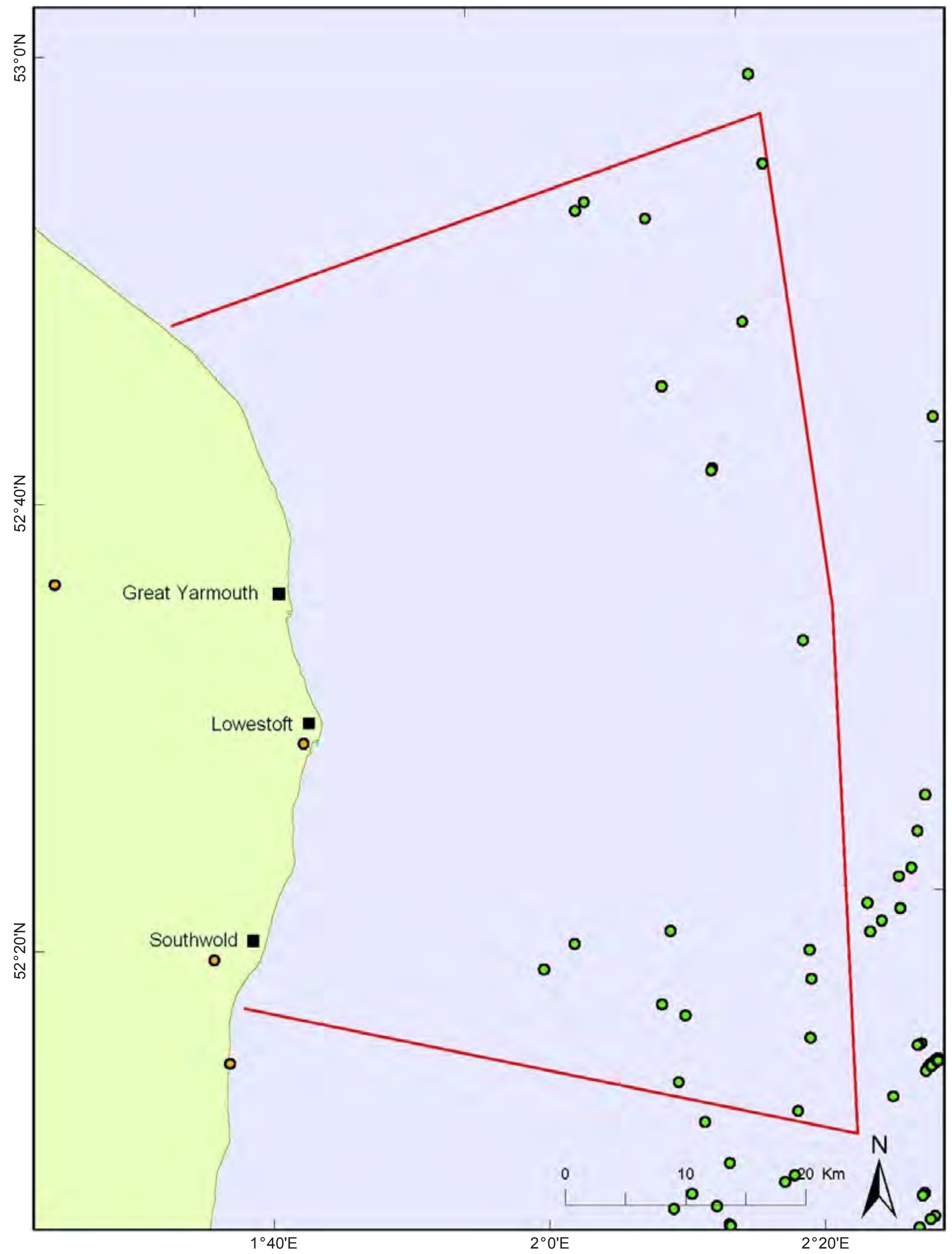
Gulls (Laridae)

Most gull species are on the RSPB amber list, with the herring gull on the red list due to severe declines in breeding and non-breeding populations (Eaton *et al.*, 2009; RSPB, 2009). There are a number of coastal and inland gull nesting sites in Norfolk and Suffolk, including a few within the East Coast REC Study Area (Figure 2.33). Species nesting at these sites are: black-headed gulls *Larus ridibundus*, great black-backed gulls *Larus marinus*, lesser black-backed gulls *Larus fuscus*, Mediterranean gulls *Larus melanocephalus*, mew or common gulls *Larus canus*, herring gulls *Larus argentatus* and black-legged kittiwakes *R. tridactyla*. Available data show black-legged kittiwakes were only recorded at Lowestoft in 1986 and at Sizewell in 1995. Aerial surveys show that gulls are widespread across the offshore east coast area including the East Coast REC Study Area (Figure 2.33), but such surveys are not effective at identifying gulls to species level. NBN data (NBN, 2010), which is not included in Figure 2.33, showed gulls were sighted across the whole of the Norfolk and Suffolk land area.

Large species of gull are apex predators in marine ecosystems, feeding on shoaling fish, fisheries discards and smaller seabirds (Votier *et al*., 2008). The black-headed gull is the most common inland gull, with large colonies on the south and east coasts of England. Sociable and noisy, they are found in small flocks and gather in larger numbers when roosting and where food availability is good. Mediterranean gulls can be found nesting in black-headed gull colonies at coastal wetlands. Occasionally, more than a hundred of these birds have been found on some beaches in Norfolk, which makes it highly likely they utilise the East Coast REC Study Area to feed. Herring gulls are large and noisy birds, white in colour with grey backs, and have black wingtips with white "mirrors" and a large red spot on their bills. They have the ability to nest on a variety of sites, including rooftops, allowing the population some sort of stability in terms of numbers. There has, however, been an overall decline in coastal colonies (Kim and Monaghan, 2006; Parkin and Knox, 2010), making it a seabird species of conservation concern. The lesser black-backed gull and great black-backed gull are similar to the herring gull in appearance but are much more common on the east coast. The mew (common) gull has greenish legs and a yellow bill and is abundant on various UK coasts, including the eastern counties. Britain remains an important wintering site for migratory common gulls from Scandinavia and the Baltic states (Parkin and Knox, 2010). Black-legged kittiwakes are small, strictly coastal, summer visitors to the east coast. They are extremely susceptible to changes in food availability (Votier *et al*., 2008) as their surface-feeding habits limit their ability to extend foraging time (Heubeck, 2004).

Terns (Sternidae)

Sea terns are small sea birds, typically silver/grey and white in colour except for the black "cap" on the upper portion of the head. Differences in legs and bills are used to distinguish species. The little tern *Sterna albifrons*, common tern *Sterna hirundo*, sandwich tern *Sterna sandvicensis*, and Arctic tern *Sterna paradisaea* are all migratory species that inhabit nesting sites on the east coast during the summer breeding season (Figure 2.34). Colonies are often large and are found in a range of coastal areas, including coastal lagoons, islands, beaches and also rivers and reservoirs (Parkin and Knox,



Black-headed gull, *Larus ridibundus* © Gardline Environmental

Figure 2.33 Distribution of gull observations made during aerial surveys across the east coast region in 2009 (Cowrie Ltd) and nesting sites in 2009 (JNCC, 2010d). Gull species encountered include black-headed gulls, *Larus ridibundus*, great black-backed gulls, *Larus marinus*, lesser black-backed gulls, *Larus fuscus*, Mediterranean gulls, *Larus melanocephalus*, mew or common gulls, *Larus canus*, herring gulls, *Larus argentatus*, and black-legged kittiwakes, *Rissa tridactyla*.

2010). As small, active flyers, terns tend to carry only single prey items back to their waiting partner or chicks (Perrow *et al.*, 2006). Typical prey are primarily sandeels (Rock *et al.*, 2007), pilchards, sand smelt and garfish (Paiva *et al.*, 2006).

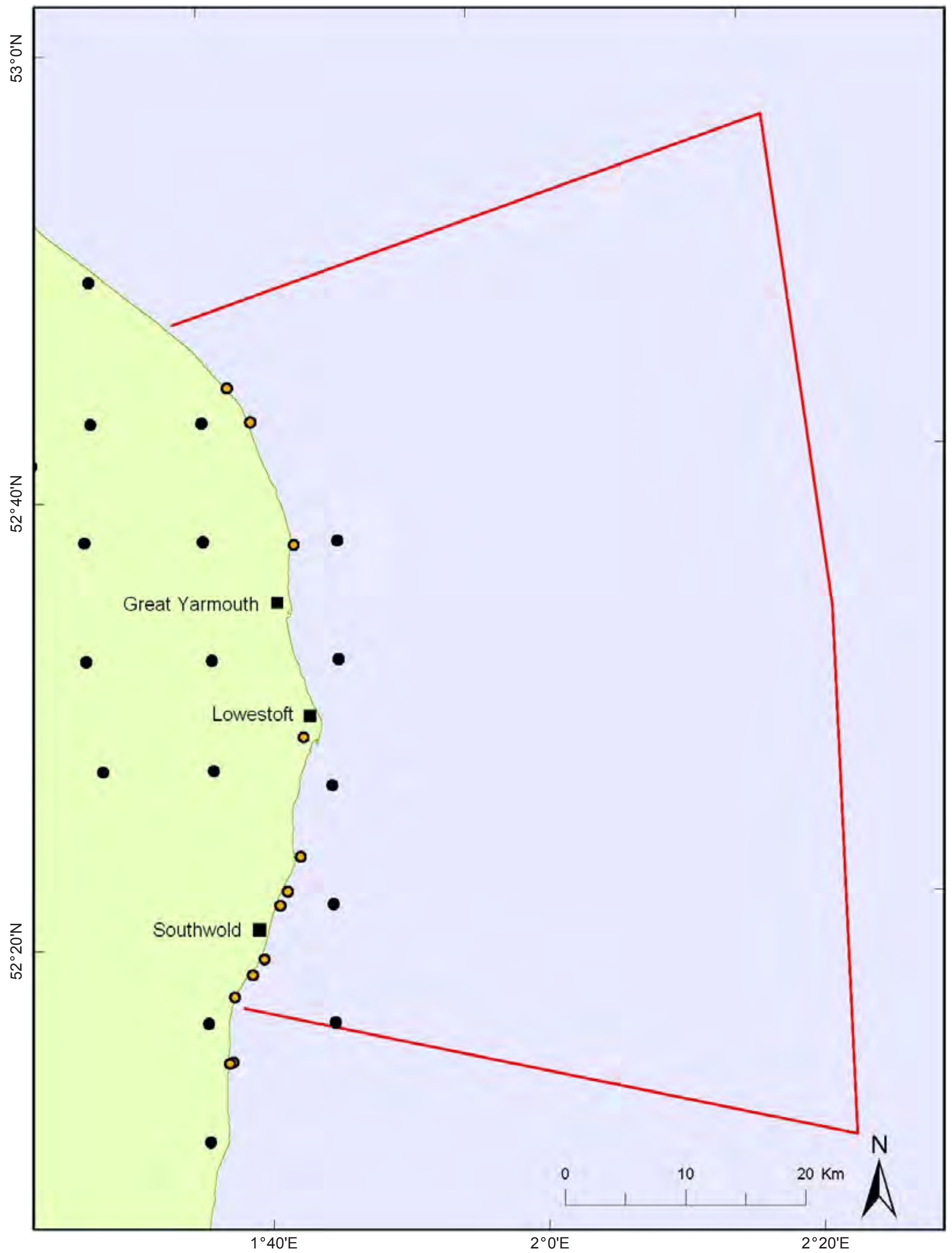
The little tern is the smallest tern species, with a distinctive black-tipped yellow bill, and UK populations have been identified as internationally significant to their conservation (Eaton *et al.*, 2009). It is the most prominent tern species on the east coast, with large colonies at Great Yarmouth North Denes, Minsmere, Suffolk and at some sites in Norfolk. Research has shown great variation in the foraging distances of little terns, but the majority remain within the first 2 km of the coastline during the breeding season (Perrow *et al.***,** 2006).

Common terns are relatively noisy when in groups and are often seen offshore during their autumn migration period. Human disturbance is a major threat to colonies, as are gulls and foxes, the common tern's main predators (Parkin and Knox, 2010). There are known colonies of sandwich terns along the north Norfolk coast and also at Minsmere, Suffolk (JNCC, 2010d).

Arctic terns are oceanic migrants (Parkin and Knox, 2010), occasionally observed inland during migration periods (Scottish Seabird Centre, 2010). They mostly visit the northern parts of the United Kingdom but are known to frequent the east coast, with at least one colony recorded in the area in 2008 (JNCC, 2010d). They have been known to be affected by fish shortages and are particularly vulnerable to predation by land animals (Parkin and Knox, 2010; Scottish Seabird Centre, 2010).

Auks (Alcidae)

Only a few auk species were observed within the East Coast REC Study Area during an aerial survey carried out by Cowrie Ltd in 2009 (WWT Consulting, 2009), but many were spotted to the east and south-east of the study area (Figure 2.35). Thus, Atlantic puffins *Fratercula arctica*, common or murre guillemots *Uria aalge*, razorbills *Alca torda* and little auks *Alle alle* observed in the wider region are likely to utilise the East Coast REC Study Area. There have been many auk observations across the Norfolk and Suffolk areas, particularly on, or



Common tern, *Sterna hirundo* © Gardline Environmental

Figure 2.34 **Distribution of tern observations made during surveys across the east coast region (NBN, 2010). Tern species encountered include little tern, *Sterna albifrons*, common tern, *Sterna hirundo*, sandwich tern, *Sterna sandvicensis,* and Arctic tern, *Sterna paradisaea*. The distribution of tern nesting sites is also shown (JNCC, 2010d).**

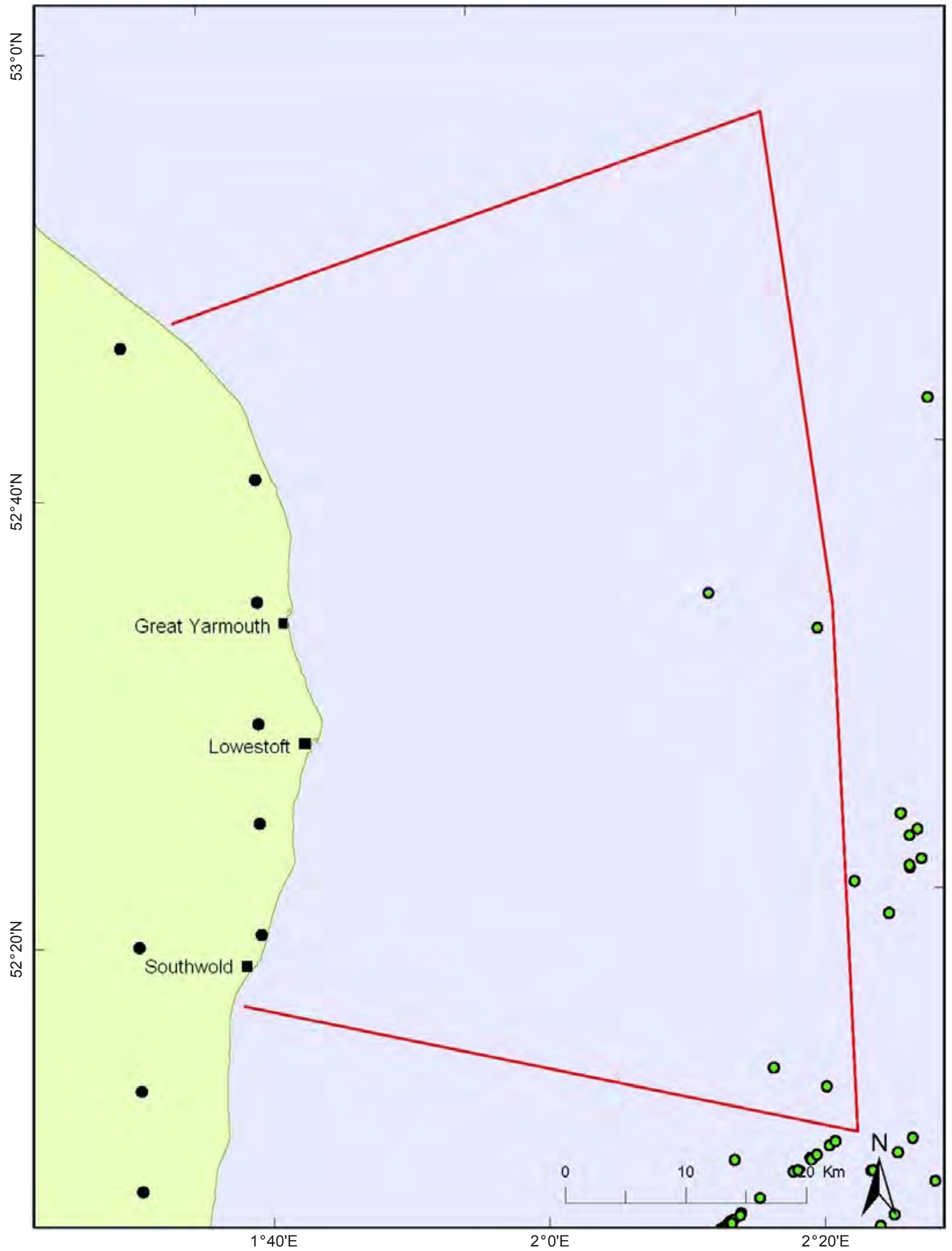
near to, the coastline, but it is not known if there are any nesting sites in the area. With the exception of the little auk, which is a coastal bird, most auk species spend their lives at sea, only coming inland to breed (Scottish Seabird Centre, 2010). Auks are also seen on the east coast following stormy weather at sea as strong gales force them inland (Scottish Seabird Centre, 2010).

The various auk species are dissimilar in appearance despite being in the same family. Common guillemots are chocolate brown with a black head and neck and have a white ring around the eye and a stripe behind the eye (Parkin and Knox, 2010; Scottish Seabird Centre, 2010), razorbills are black in colour with white underneath and have a distinctive white stripe on the black beak. Little auks are the smallest auks, the size of starlings, black on top, white underneath, with a short neck and tail and a black stubby bill. Atlantic puffins are the most distinctive of the auks, black in colour with a white breast and a large vibrantly coloured flattened beak capable of carrying several sandeels back to their chicks. In addition to their prominent bills, the puffin's large pale cheeks, orange legs and red and black eye-markings make them unmistakable and probably the most recognisable seabird in UK waters.

There are more than a million breeding pairs of common guillemots in the United Kingdom (Harris and Wanless, 2004), but they have experienced almost complete breeding failure in the past as a result of low availability of sandeels and changes in plankton communities (Harris *et al*., 2007). Like terns, guillemots carry only single prey items at a time (Thaxter *et al*., 2009). Razorbill populations tend to mirror changes in guillemot populations and vice versa (Merne and Mitchell, 2004). Atlantic puffins and little auks are generally scarce along the east coast, as breeding populations tend to be found further north, particularly in Scotland (Parkin and Knox, 2010).

Northern fulmars (Procellariidae)

Relatively few data-sets relating to the distribution of the northern fulmar *Fulmarus glacialis* are available. However, from aerial survey data, there have been some sightings within the East Coast REC Study Area (Figure 2.36). A few nesting sites were recorded in and



Atlantic puffin, *Fratercula arctica* © USFWS

Figure 2.35 **Distribution of auk observations made during aerial surveys across the east coast region in 2009 (WWT Consulting, 2009). Auk species encountered include Atlantic puffins, *Fratercula arctica*, common or murre guillemots, *Uria aalge*, razorbills, *Alca torda*, and little auks, *Alle alle*. The distribution of land observations is also shown (NBN, 2010).**

adjacent to the East Coast REC Study Area, the majority located along the north Norfolk coast. Fulmars are oceanic birds (Parkin and Knox, 2010) and are most often seen offshore in the east coast area during the summer months. Other members of the Procellariidae family (petrels and shearwaters) – including great shearwaters *Puffinus gravis*, Leach's storm petrels *Oceanodroma leucorhoa*, Manx shearwaters *P. puffinus* and sooty shearwaters *Puffinus griseus* – have been sighted in the East Coast REC Study Area by the Suffolk Ornithologist's Group in 2010.

Great cormorants (Phalocrocoracidae)

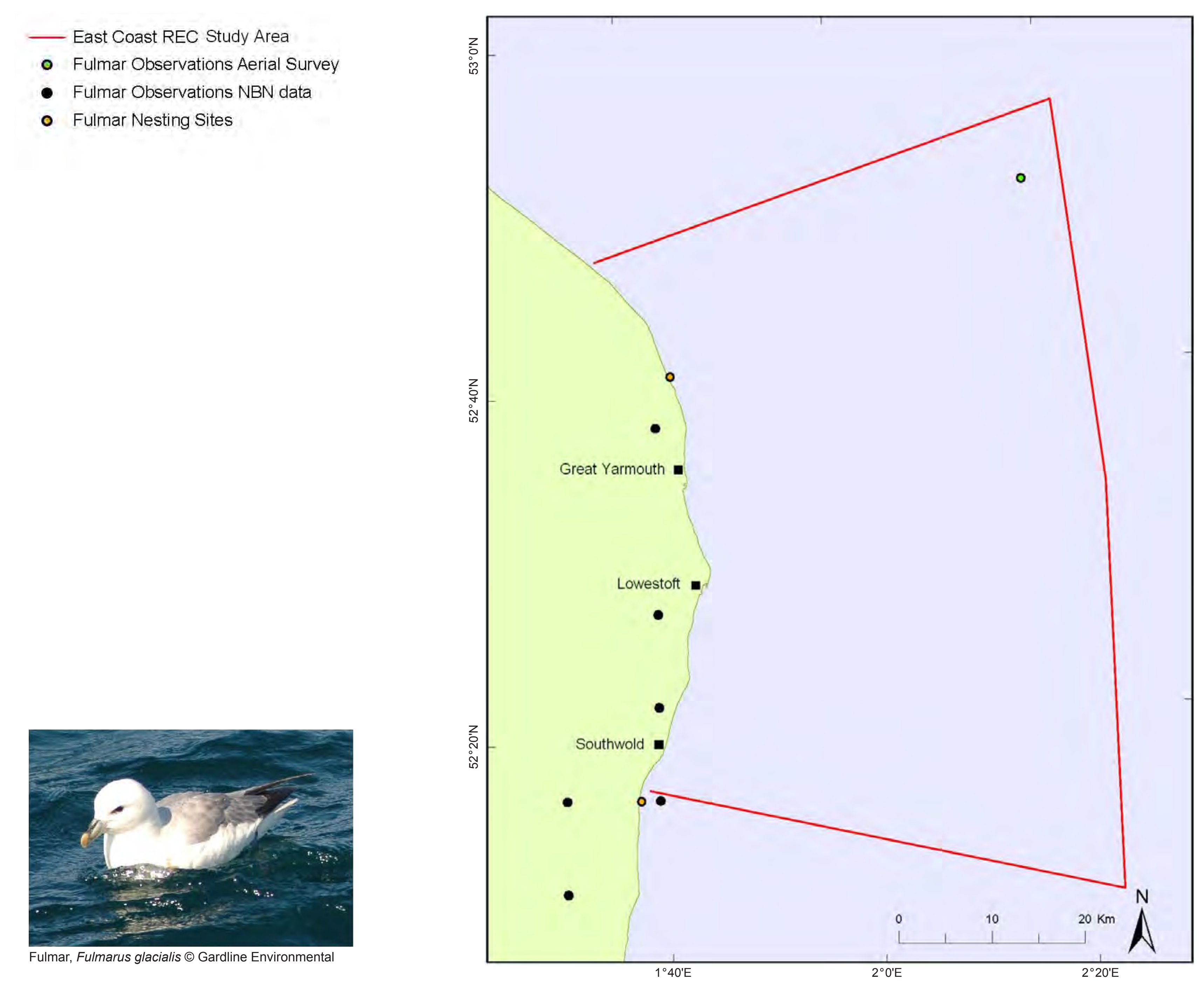
Great cormorants are large, black-coloured birds found on rocky shores, in coastal lagoons and estuaries as well as more recently at inland sites (Parkin and Knox, 2010). There are around 9,000 breeding pairs in the United Kingdom and around 23,000 individuals overwintering here (Kershaw and Cranswick, 2003).They have often come into conflict with fishermen due to their excellent fishing ability and the misperception that they are greedy and sinister birds.

There have been observations of the great cormorant *Phalacrocorax carbo*, and their nesting sites in the east coast region, although only a few fall within the East Coast REC Study Area (see Figure 2.37). Two nesting sites were recorded inland in west Norfolk. One roosting site was recorded in the East Coast REC Study Area in the Wildfowl and Wetlands Trust (WWT) Cormorant Roost Survey in 2003 (Worden *et al*., 2004), although fewer than 10 cormorants were recorded as roosting there. During the same survey, the closest breeding colonies were found near Wells-next-the-Sea in North Norfolk and also in Essex.

The European shag *Phalacrocorax aristotelis* is related to the cormorant but is smaller and slimmer. It has been noted in the east coast region, but few records exist with regards to its distribution in this area.

Divers (Gaviidae and Podicipedidae)

There are recorded sightings for three species of diving birds – the great northern diver *Gavia immer*, the red-throated diver *Gavia stellata* and the great crested grebe *Podiceps cristatus* – in Suffolk and Norfolk, both within and adjacent to the East Coast REC Study Area (Figure 2.38). It



Fulmar, *Fulmarus glacialis* © Gardline Environmental

Figure 2.36 **Distribution of northern fulmar, *Fulmarus glacialis*, observations made during aerial surveys across the east coast region in 2009 (WWT Consulting, 2009) and during other surveys on land (NBN, 2010). The distribution of northern fulmar nesting sites is also shown (JNCC, 2010d).**

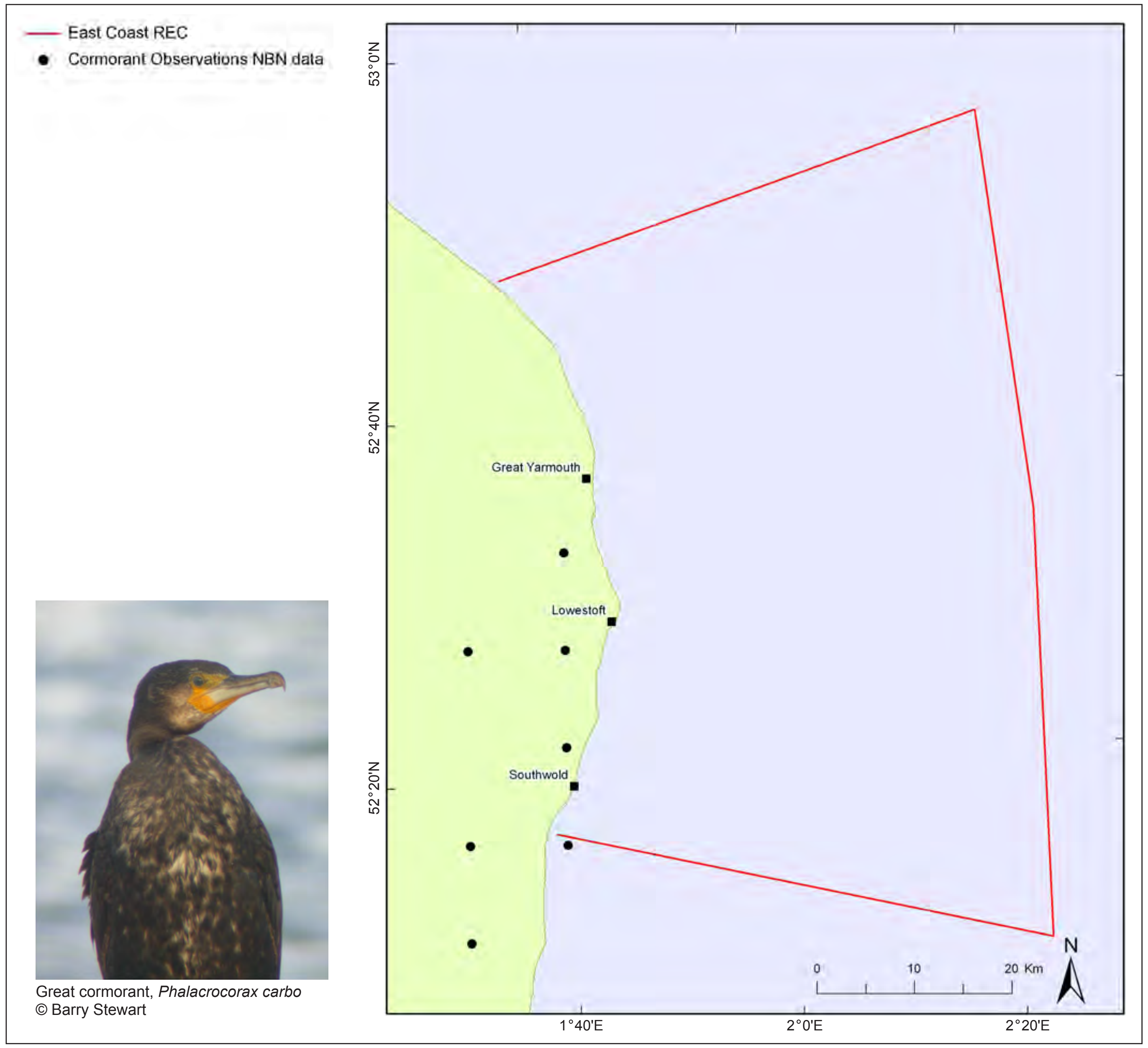


Figure 2.37 **Distribution of great cormorants, *Phalacrocorax carbo*, observations taken from NBN data (NBN, 2010). The distribution of great cormorant nesting sites is also shown (JNCC, 2010d).**

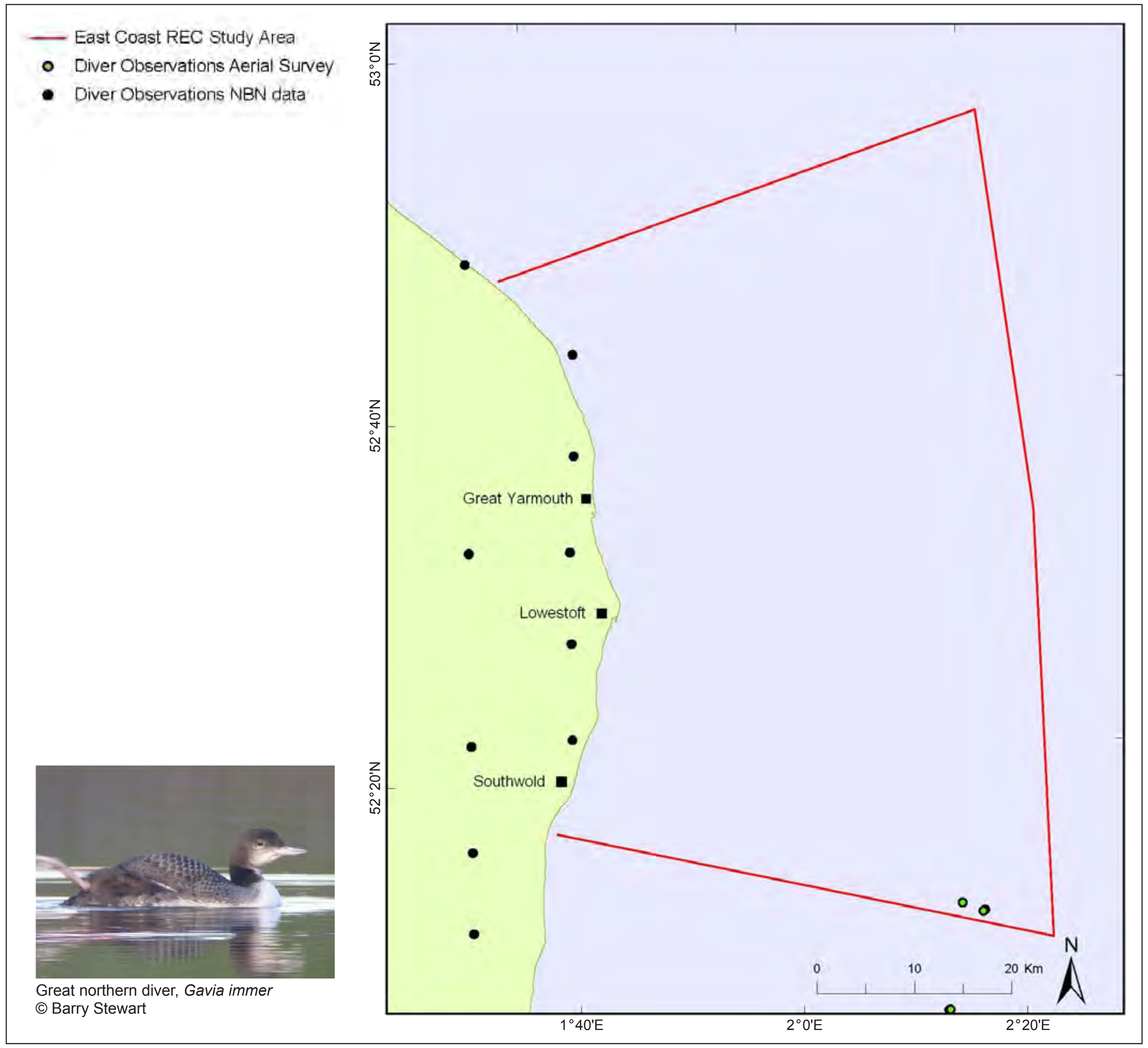


Figure 2.38 **Distribution of diver observations made during aerial surveys across the east coast region in 2009 (WWT Consulting, 2009) and during other surveys on land and around the coast (NBN, 2010). Diver species encountered include the great northern diver, *Gavia immer*, the red-throated diver, *Gavia stellata,* and the great crested grebe, *Podiceps cristatus*.**

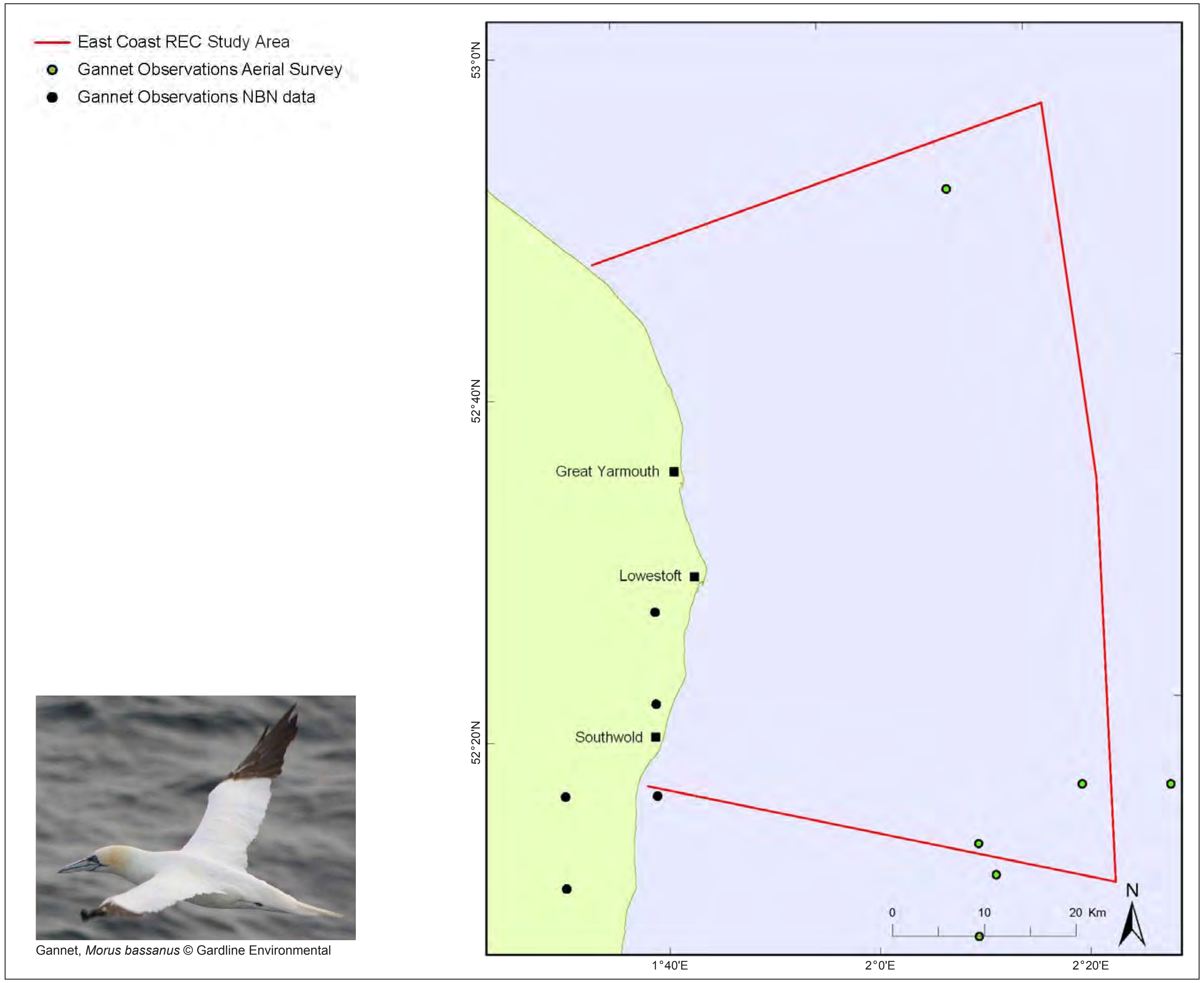
can probably be assumed that offshore sightings of divers were of the great northern diver, as this species feeds further out to sea than other diver species (RSPB, 2010). The great northern diver is the largest of the UK divers and is known to winter in the north Norfolk area, suggesting they utilise the East Coast REC Study Area where they feed on crustaceans and fish. Red-throated divers are often seen in the East Coast REC Study Area, as there are large numbers in the Outer Thames Estuary region (Parkin and Knox, 2010) which leads up to the East Coast REC Study Area. This species are noticeable by the up-tilted bill and red throat during the summer period. *G. immer* and *G. stellata* (both in the Gaviidae family) are amber-listed species (Eaton *et al.*, 2009; RSPB, 2009). Great crested grebes (Podicipedidae family), so-called due to their ornate head plumage, are green-listed species (Eaton *et al.*, 2009; RSPB, 2009) and are found across the whole of the United Kingdom, including the East Coast REC Study Area where they utilise a variety of inland habitats and coastal areas.

Northern gannets (Sulidae)

Northern gannets *M. bassanus* are large white seabirds with black wingtips and a yellow tinge to their heads. An estimated 218,546 pairs breed in the United Kingdom annually, but the limited number of breeding sites in Scotland, Yorkshire and the Welsh Islands places them on the amber list (Parkin and Knox, 2010). Gannets have been observed in the south-east area of the East Coast REC Study Area and just outside it on the east coast of Suffolk (Figure 2.39). Gannets disperse and move south, including off the east coast, following the breeding period (Parkin and Knox, 2010), normally staying in small groups. The main threat to gannet populations is human disturbance (Parkin and Knox, 2010).

Skuas (Stercorarius)

Great skuas, *Catharacta skua*, are large, stout, dark-coloured birds with flashes of white on their wings, visible in flight. They are one of the rarest seabirds in the north Atlantic (Parkin and Knox, 2010). Great skuas are known as the “pirates of the sea” as they regularly harass other birds for food and will readily kill and eat smaller seabirds including puffins and kittiwakes during times of low food availability. They migrate to the United Kingdom after wintering in



Gannet, *Morus bassanus* © Gardline Environmental

Figure 2.39 **Distribution of northern gannet, *Morus bassanus*, observations made during aerial surveys across the east coast region in 2009 (WWT Consulting, 2009) and during other surveys on land and around the coast (NBN, 2010).**

Spain and Africa and have been noted in the east coast area through independent records (eg by the Suffolk Ornithologist's Group in 2010). Several other scarce skua species have been observed in the East Coast REC Study Area including long-tailed and pomarine skuas, which are passive migrants to the United Kingdom, and the Arctic skua, which is generally found in Scotland.

2.9 Areas of conservation interest

2.9.1 Nature conservation

There are a number of different types of conservation and protected areas in the United Kingdom, which have been developed according to both European and local legislations and for a variety of reasons.

In the United Kingdom, the government is advised on conservation issues by the JNCC, led by a joint committee of conservation agencies representing England, Scotland, Wales and Northern Ireland, who oversee conservation designations. The agencies involved are: Natural England, Scottish Natural Heritage, the Countryside Council for Wales, and the Council for Nature Conservation and the Countryside (Northern Ireland). Each of these agencies is responsible for fulfilling the requirements of UK conservation legislation within their respective territories alongside the JNCC. There are three key pieces of UK conservation legislation: the European Habitats Directive 1992, the European Wild Birds Directive 1979 and the Wildlife and Countryside Act 1981. To meet the requirements of UK conservation legislation, each agency has a duty to designate SACs, SPAs and SSSIs where the species and habitats listed as threatened may be found.

The UK is also a contracting party to the Convention on Wetlands of International Importance, called the Ramsar Convention, which came into force in 1975. The mission of this convention is "the conservation and wise use of all wetlands through local, regional and national actions and international co-operation, as a contribution towards achieving sustainable development throughout the world" (www.Ramsar.org). As a result of this agreement, the UK Government is obliged to designate wetlands of international importance as Ramsar sites. There are currently 168 such sites in the United Kingdom, although only 2 of these fall in the region of interest for the East Coast REC.

Other locally and nationally important sites are protected by designations such as Marine Nature Reserves (MNRs), NRRs and No Take Zones (NTZs). At present there are no MNRs or NTZs in the East Coast REC Study Area, and only 5 NRRs (those further than 1 km from the coast have not been considered). The Marine and Coastal Access Act 2009 will create a network of MCZs to protect some of the United Kingdom's most important marine species and habitats (see Appendix A).

The IBAs programme is part of a worldwide initiative by BirdLife International. It is aimed at identifying and protecting a network of sites critical for conservation of the world's birds, and it is sponsored in the United Kingdom by the RSPB. There are currently 287 of these areas in the United Kingdom, 5 of which are in the vicinity of the East Coast REC Study Area (see Figure 2.32).

2.9.2 Protected sites in the East Coast REC Study Area

There are several sites of international and national importance, both coastal and offshore, within the East Coast REC Study Area that cover threatened habitats and species in this area. Due to the differing legislations and reasons for protection, a number of sites are covered by more than one protection designation. The distribution of international designations including SPAs, potential SPAs (pSPAs), SACs and possible SACs (pSACs) is shown in Figure 2.40 and the national NNR and SSSI designations in Figure 2.41. A brief summary of the types that are present in this area may be seen in Table 2.5. Information on these sites can be found on the Natural England website (www.naturalengland.org.uk).

Haisborough, Hammond and Winterton (cSAC)

The status of this area, which covers 184,808 ha, was given candidate SAC (cSAC) status and submitted to the European Commission for approval for designation in August 2010. This cSAC lies off the north-east coast of Norfolk and covers an area of non-vegetated sublittoral headland-associated sandbanks that meet the Annex I habitat description "Sandbanks slightly covered by seawater all the time". The data available for this area suggest that the sandy sediments are very mobile in strong tidal currents. Movement of the banks themselves appears to be slow, with higher levels of movement within the system itself causing megaripples and sandwaves to form on the banks. This causes the fauna on top of the banks to be impoverished, consisting of a few polychaetes and amphipods able to tolerate such dynamic conditions. On the flanks of the banks, towards the trough, sediments are found to be slightly more stable and gravelly. In these more stable regions, the benthic and epibenthic communities are more diverse. Some areas have transport reduced enough to support sessile epifauna such as bryozoans, hydroids and sea anemones. Tube-building polychaetes such as *Pomatoceros* and *Lanice* are also found in these areas, along with bivalve molluscs and crustaceans. There are also moderately dense aggregations of the tube-building polychaete *S. spinulosa*, which provide hard substrate on which rich epifaunal communities may develop (JNCC & Natural England, 2009).

Outer Thames (SPA)

The Outer Thames area covers 393,734 ha. It has been designated as part of the European Wild Birds Directive, as it regularly supports wintering populations of the red-throated diver *G. stellata* in numbers of European importance and an estimated 38–50% of the British population. The SPA runs from Great Yarmouth in Norfolk to Felixstowe in Suffolk, following the Mean Low Water mark or the seaward boundary of existing SPAs, so it will directly abut a number of existing SPAs along the Norfolk and Suffolk coast. It also extends into the area covered by the Outer Thames Regional Environmental Characterisation (Emu Ltd & University of Southampton, 2009).

Minsmere–Walberswick

This area is covered by a number of national, European and international designations including an SSSI (2,327 ha), an IBA (2,190 ha), Ramsar (2,004 ha), an SPA (2,018 ha), and an SAC (1,265 ha). It is situated on the Suffolk coast between Southwold and Sizewell and contains a complex series of noteworthy habitats,

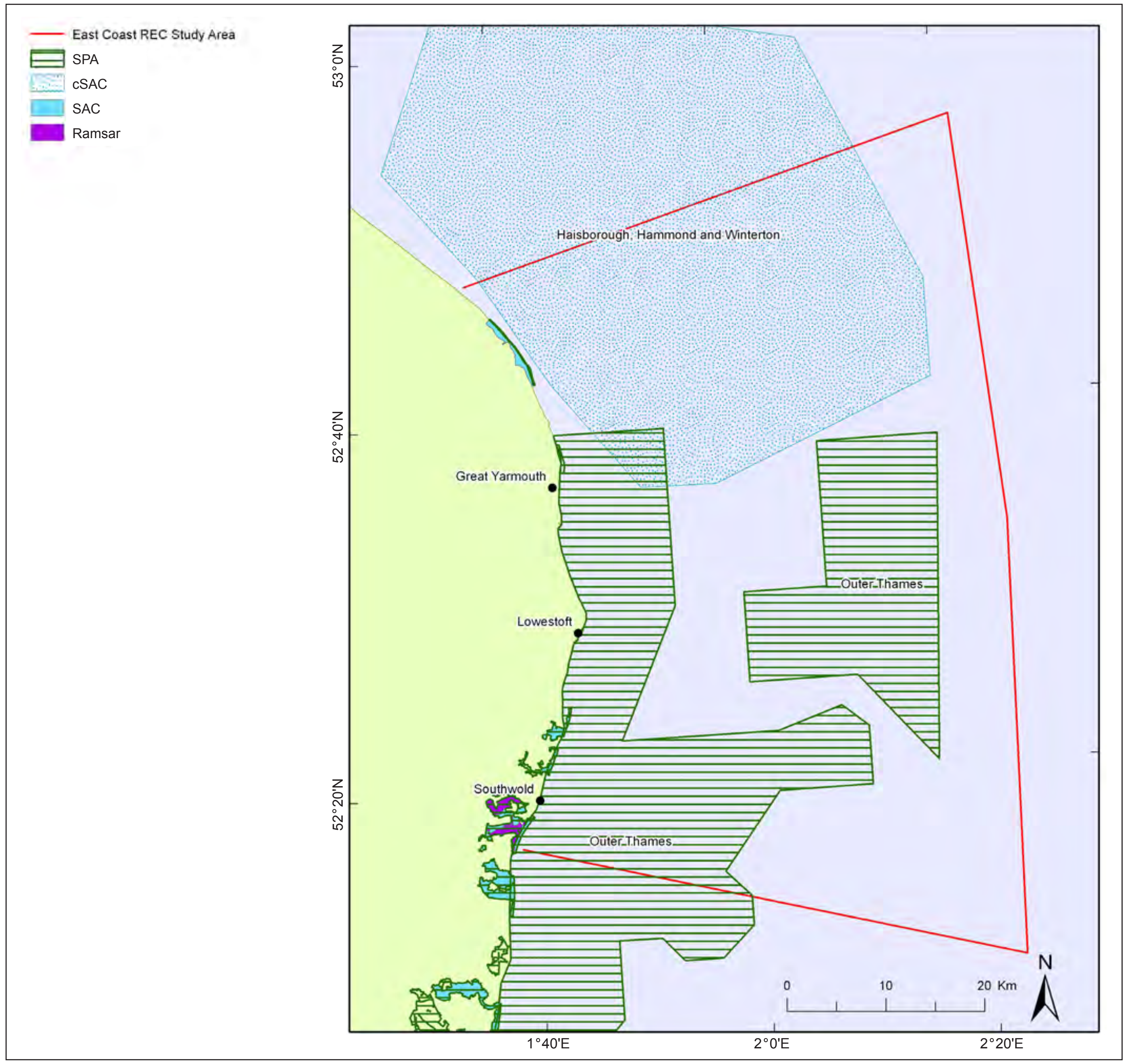


Figure 2.40 Distribution of international designations, including SPAs and SACs, in the East Coast REC Study Area.

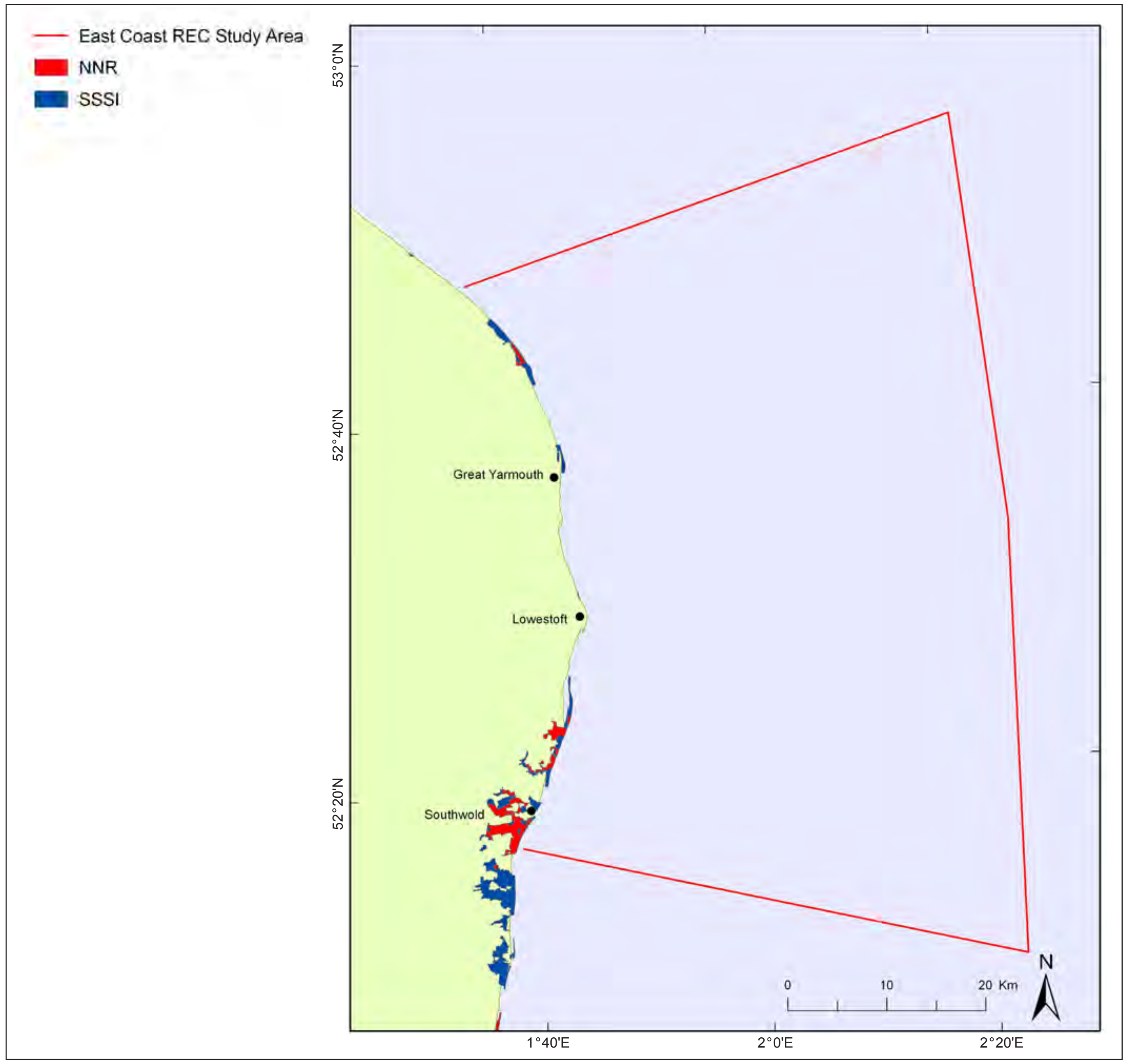


Figure 2.41 Distribution of national NNR and SSSI designations in the East Coast REC Study Area.

Designation	Abbreviation	Legislation	Importance	Focus of protection
Special Areas of Conservation	SAC	European Habitats Directive (92/43/EEC)	European	Habitats and species (as listed under Annex I and Annex II of the Directive)
Possible Special Area of Conservation	pSAC	European Habitats Directive (92/43/EEC)	European	Habitats and species (as listed under Annex I and Annex II of the Directive)
Special Protection Areas	SPA	European Wild Birds Directive (79/409/EEC)	European	Birds and habitats used by birds (bird species specified in Annex I of the Directive)
Potential Special Protection Area	pSPA	European Wild Birds Directive (79/409/EEC)	European	Birds and habitats used by birds (bird species specified in Annex I of the Directive)
Ramsar sites	Ramsar	Convention on Wetlands of International Importance (1971)	International	Wetlands utilised by birds
Sites of Special Scientific Interest	SSSI	Wildlife and Countryside Act (1981)	National	Species, habitats and geological features of national importance
National Nature Reserves	NNRs	Wildlife and Countryside Act (1981)	National	Best UK examples of SSSIs – species, habitats and geological features of national importance

Table 2.5 **Summary of marine and coastal conservation designations in the East Coast REC Study Area: their underlying legislation, level of importance and protection focus.**

including mudflats, shingle beach, brackish lagoons, reedbeds, heathland and grazing marsh. Together, these combine to form an area of exceptional scientific interest. The area is home to a variety of wildfowl and shorebird species associated with reedbeds, as well as plant and tree species of interest and many nationally rare and scarce terrestrial invertebrate species.

Alde-Ore Estuary including Orfordness to Shingle Street

This area is protected by three types of designation: Ramsar (2,416 ha), SPA (2,416 ha), SAC (157 ha & 901 ha) and NNR (909 ha). The estuary is located on the Suffolk coast and encompasses the estuarine complex of the rivers Alde, Butley and Ore, together with Havergate Island and Orfordness. There is a variety of habitats present, including intertidal mudflats, saltmarsh, vegetated shingle, saline lagoons and grazing marsh. The vegetated shingle is the second-largest and best-preserved example of this habitat in the United Kingdom. The land here is also geomorphologically unique within the United Kingdom, as it combines a shingle spit and a cuspate foreland. The diverse wetland habitats provide an area of particular significance for feeding, roosting and nesting birds. The site also supports notable assemblages of seabirds, wildfowl and waders, the composition of which changes depending on the time of year. As well as providing an area for over-wintering birds, it is also important as breeding habitat for several species of seabird, wader and raptor. The saline lagoons provide habitat for specialised invertebrate fauna, notably the rare anemone *Nematostella vectensis* and the amphipod *Gammarus insensibilis*, both of which are protected under the Wildlife and Countryside Act 1981.

Benacre to Easton Bavents

This area on the East Suffolk coast, between Kessingland and Southwold, is covered by five different designations of varying size: SSSI (735 ha), SPA (516 ha), IBA (516 ha), NNR (393 ha) and an SAC (366 ha). The coast is low lying and consists of shingle beach and low cliffs, and at Benacre Broad there are natural brackish lagoons separated from the sea by a shingle bar. On the landward margin, these are fringed by reedbed, and elsewhere in the area there is also ancient woodland, unimproved meadows and grazing saltmarsh. The area supports important breeding populations of birds associated with shingle and reedbed habitats, including raptors and seabird. The reedbeds provide important habitat and breeding sites for important numbers of the bittern *Botaurus stellaris.* The lagoons exhibit a range of salinity depending on the time of year, storms and position within the system, and as a result there is a wide range of associated vegetation, including beds of narrow-leaved eelgrass *Zostera angustifolia* in fully saline or hypersaline conditions, beds of the spiral tasselweed *Ruppia cirrhosa* in brackish water, and dense beds of the common reed *Phragmites australis* in freshwater. As with the lagoons at Orford, this lagoon system also provides habitat for specialised invertebrate fauna, notably anemone, *N. vectensis* and the amphipod *G. insensibilis*.

Great Yarmouth North Denes

On the Norfolk coast between Great Yarmouth and Caister, there is a wide shingle beach behind which is an actively accreting dune system, which is covered by three designations: SPA (149 ha), SSSI (101 ha) and an IBA (146 ha). It is an important breeding area for the little tern *S. albifrons* and is home to a number of rare species of vegetation. There is a band of mobile and semi-fixed dune vegetation characterised by marram *Ammophila arenaria* and red fescue *Festuca rubra.* There is also a band of fixed dune, with more acidic conditions, which is characterised by sand sedge *Carex arenaria* and the lichen *Cornicularia aculeata*. This area also supports the nationally rare grey hair-grass *Corynephorus canescens*.

Winterton–Horsey Dunes

This area of Norfolk is covered by the designations SAC (425 ha), SSSI (425 ha) and NNR (108 ha). It is a narrow cuspate foreland dominated by well-developed dunes and a sandy beach. It has been identified as having a sediment budget surplus and is of considerable importance to sediment transfer offshore. Behind the dune system are shallow pools (humid dune slacks) grading into grazing land and birch woodland. The acid dunes here also support extents of grey hair-grass *C. canescens*. The area is also an important area for both breeding and overwintering birds, notably the little tern *S. albifrons*. The pools provide a breeding area for natterjack toads, and there are also important areas of swamp and mire communities in this region, characterised by the creeping willow *Salix repens* and Yorkshire-fog *Holcus lunatus*.

2.9.3 Historic sites

Wrecks of historic importance located within UK waters are protected under Section 1 of the Protection of Wrecks Act 1973 (PWA). This Act identifies an area surrounding the historic wreck site within which it is a criminal offence to: conduct diving or salvage operations, remove any part of the site or deposit anything such as anchors or fishing gear without an appropriate licence from the Secretary of State. Within the East Coast REC Study Area, there are no wrecks that are protected under the Act.

2.9.4 Military sites

The Protection of Military Remains Act 1986 (PMRA) relates to the marine historic environment with regard to military ship and aircraft remains. The sites of military wrecks are designated as either “protected places” or “controlled sites”. This designation is primarily to protect war graves. However, the losses may not have occurred during a time of war.

Protected places are wreck sites that are designated by name, even if the exact location of the wreck is unknown. This type of designation allows all military aircraft to automatically be covered even if the location of the aircraft cannot be identified. These sites may be visited by divers, but it is a criminal offence to interfere with, disturb or remove anything from these sites. Controlled sites are designated by location and can be applied to any military craft that was lost after 1786. It is a criminal offence to conduct any operations on these sites, including diving, without a licence from the Ministry of Defence.

There are currently 46 protected places and 12 controlled sites designated under the PMRA, although these numbers do not include any aircraft sites. Of these wreck sites, one protected place, HMS *Exmoor*, is situated within the East Coast REC area (Figure 2.42).

HMS *Exmoor*

A total of 104 servicemen (100 ranking and 4 Officers) lost their lives when the HMS *Exmoor* caught fire and sank, south of Great Yarmouth, on 25 February 1941. The cause of this is still unclear. Built by Vickers Armstrong Company at the Walker Yard on the River Tyne in November 1940, the ship was operational by December the same year. A Hunt Class Destroyer, the HMS *Exmoor* had a 1,000-ton displacement, with a total length of 85 m, a beam of 8.8 m and a draft of 5.1 m (Tikus, 2004).

In January 1941 the HMS *Exmoor* joined the 16th Destroyer Flotilla, and a month later the ship and its crew were deployed with HM Corvette *Shearwater* and other escorts for Convoy FN417 from the Thames Estuary to Methil, Fife (Naval-history.net, 2010). This would mean that the convoy would travel through some of the most hostile waters of Europe, as the Germans attempted to squeeze the British dependence on imports and shipping. They did this in a number of ways, but by far their most successful strategy was that of E-Boat [*Schnellboot*] attack operations (Hewitt, 2008).

On 25 February 1941, during such an E-Boat attack off Lowestoft, the vessel sustained damage in the aft section from an explosion. This caused a rupture in the fuel-supply pipe-work which ignited, and the ensuing fire spread midships and forward, capsizing the ship. It is believed to have taken just 10 minutes to sink. HM Corvette *Shearwater* and HM Trawler *Commander Evans* were present to rescue survivors, who were later taken to Great Yarmouth. Although the Germans reported a strike by E-Boat S30, at the time the British reported that the vessel was more likely to have struck a British mine in the East Coast Barrier. HMS *Exmoor* was the first of the Hunt Class to be sunk; by the end of the war there would be 19 in total (Naval-history.net, 2010).

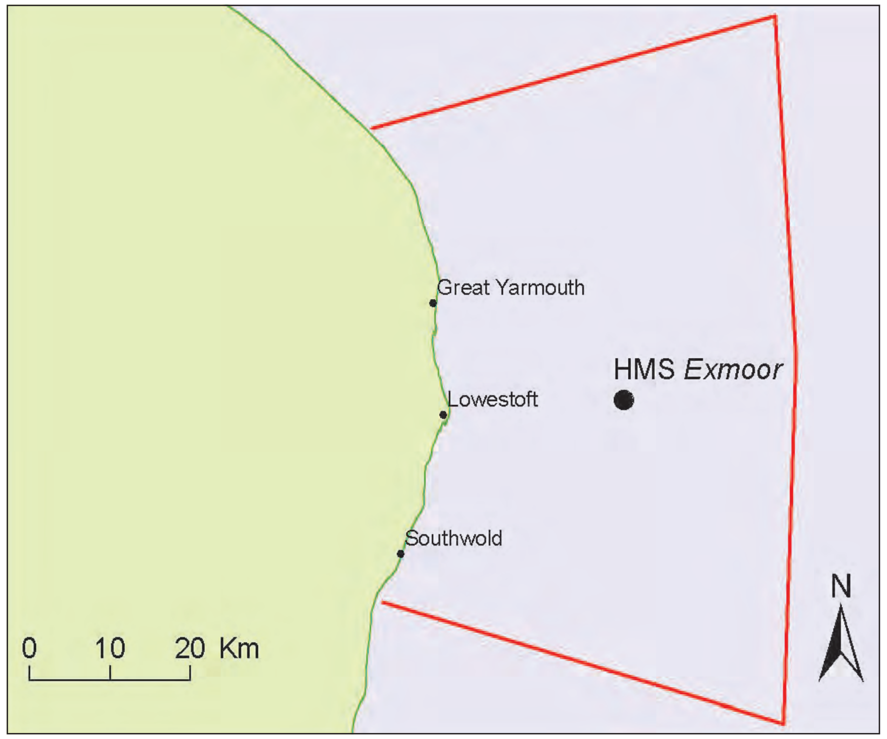


Figure 2.42 Location of HMS *Exmoor*, protected under the Protection of Military Remains Act 1986.

2.10 Fisheries

Fishing in England and Wales is managed under the Common Fisheries Policy (CFP), although by way of derogation, seas out to the 6 mile limit are managed by Sea Fisheries Committees (SFCs). Fisheries management under the CFP is largely achieved through the use of technical measures (eg, gear type, mesh sizes), effort controls and minimum landing sizes. SFCs have the authority to augment the management of stocks within their jurisdiction through the use of additional byelaws that may include technical measures restricting the type and sizes of fishing vessels or gears, establish seasonal restrictions on fishing activities, and set minimum landing sizes. Finfish fisheries are principally managed at the European level through the CFP, with the management unit being the whole of the North Sea. Shellfish fisheries tend to be managed at a national or regional level.

The East Coast REC Study Area falls under the jurisdiction of the Eastern Sea Fisheries Joint Committee, which is responsible for 172 miles of coastline in Lincolnshire, Norfolk and Suffolk. Under the Marine and Coastal Access Act 2009, the Sea Fisheries Committees will be replaced by Inshore Fisheries and Conservation Authorities (IFCAs) and will have an extended marine nature conservation remit.

A variety of fixed and mobile gears are employed to catch a range of target species in the East Coast REC Study Area (Figure 2.43). Longlines are used to target cod, thornback ray, smooth hound, spurdog and, seasonally, sea bass. Gill and trammel nets are set for cod and whiting in the winter, and tangle and trammel nets target sole, plaice, turbot and rays in the spring, with sole being of particular commercial importance (Elson *et al.*, 2010). Beam trawlers may be used to catch brown shrimp, along with a variety of finfish species such as plaice, sole and flounder. Drift netting takes place for herring, and parlour pots are used to catch crabs and lobsters (Walmsley and Pawson, 2007). A summary of the main types of fishing gear used in the East Coast REC Study Area to catch species or groups of species is given in Table 2.6.

Figure 2.43 Types of fishing vessel used in the East Coast REC Study Area. Top left: longliner; top right: beam trawler; bottom left: longshore boats; bottom right: otter trawler. © Crown Copyright 2011.

Category	Subcategory	Species	Fishing gear
Finfish	Roundfish	Cod	Longlines, gill and trammel nets
	Flatfish	Sole, flounder	Trammel and gill nets, beam and otter trawl
	Large pelagic	Sea bass	Longlines, trammel and gill nets, recreational angling
	Small pelagic	Herring	Drift nets
	Elasmobranchs	Thornback ray, spotted ray, blonde ray, spurdog, starry smoothhound	Longlines, tangle and trammel nets
Shellfish	Crustacea	Edible/brown crab, lobster, brown shrimp	Parlour pots, beam trawl

Table 2.6 A summary of the main types of fishing gear used in the East Coast REC Study Area to catch species or groups of species.

The East Coast REC Study Area has eight ports into which fish are regularly landed, namely Winterton-on-Sea, Great Yarmouth, Lowestoft, Southwold, Dunwich, Sizewell, Aldeburgh and Orford. The majority of vessels are <10 m in length, but in Great Yarmouth and Lowestoft larger vessels of >10 m length may also land their catches. In addition to these large ports, many longshore boats operate from beaches throughout the study area. The exposed nature of the coastline, which offers little in the way of shelter from north-easterly winds, and the small size of these longshore boats makes them vulnerable to poor weather conditions and water currents.

Within the East Coast REC Study Area, the distribution of fishing effort tends to be quite localised. Using data from the Marine Management Organisation's (MMO) Vessel Monitoring System (VMS) (for vessels >15 m length) and data from vessel sightings made by the Eastern SFC between 2007 and 2009, Vanstaen and Silva (2010) plotted the relative fishing effort by gear type, vessel size and vessel power. Results showed that fishing activities were mainly observed in the southern and outer parts of the area, with little activity in the northern inshore part of the area, where shallow sandbanks are present. The majority of the effort observed was of vessels engaged in trawling, potting or longlining/angling (Figure 2.44).

2.10.1 Finfish

In terms of weight landed, cod, skates and rays and sole are the most important finfish species in the East Coast REC Study Area (Table 2.7). Unfortunately, due to the way in which commercial landings are recorded it is impossible to provide an estimate of finfish landings for the East Coast REC Study Area alone. Fisheries landings are recorded at the ICES rectangle level, and these rectangles cover an area of 1 decimal degree by half a decimal degree. The East Coast REC Study Area falls within, but does not completely cover, four of these rectangles. Therefore, to illustrate the common finfish species landed from the East Coast REC Study Area, data were extracted for landings into the 8 ports covered by study the area, from the four rectangles covered, between 2005 and 2009. As can be seen, finfish landings are dominated by cod, sole, skates and rays (predominantly thornback ray), herring and spurdog. These findings are also confirmed by the results of the Environmentally Responsible Fisheries (ERF) project, in which the landings of 10 vessels from Lowestoft were recorded for a period of 12 months from August 2008 (Elson *et al.*, 2010). A wide variety of other species are landed, with some, such as bass, commanding a high price during the season.

2.10.2 Roundfish

Cod – *Gadus morhua*

The cod is arguably the most important commercial species for England and Wales fisheries. The species is distributed widely in the waters of the north-east Atlantic, where it is commonly found from the Celtic Sea in the south to Spitsbergen and Iceland in the north and from the shoreline to depths of 800 m (Wheeler, 1969). Cod is a stout-bodied gadoid fish, with a distinctive chin barbel and white lateral line. The general colouration is a greenish to sandy brown back that becomes mottled towards the lower sides, and a white belly. Individuals that live around rocky outcrops may be darker in colour (Figure 2.45).

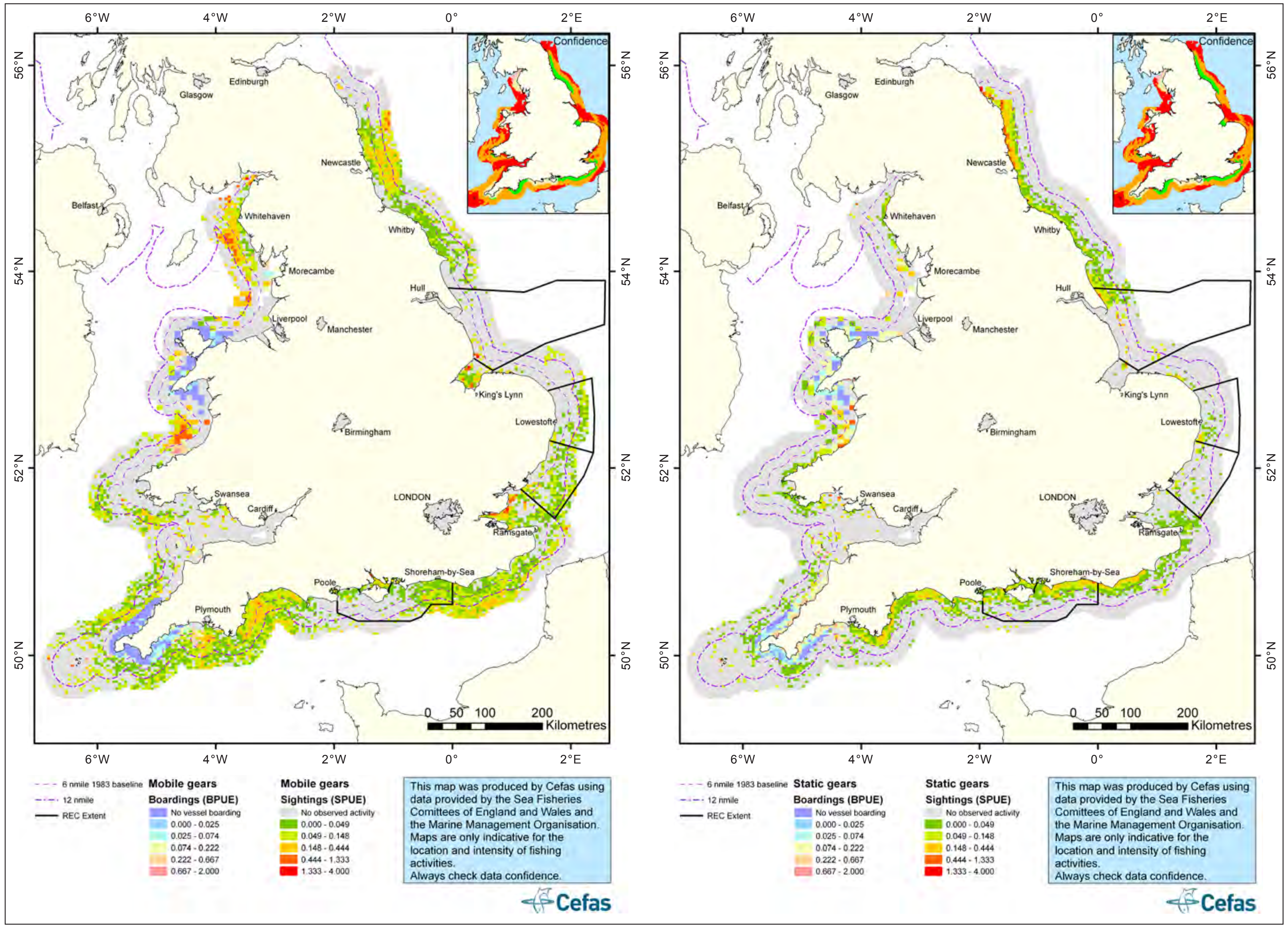
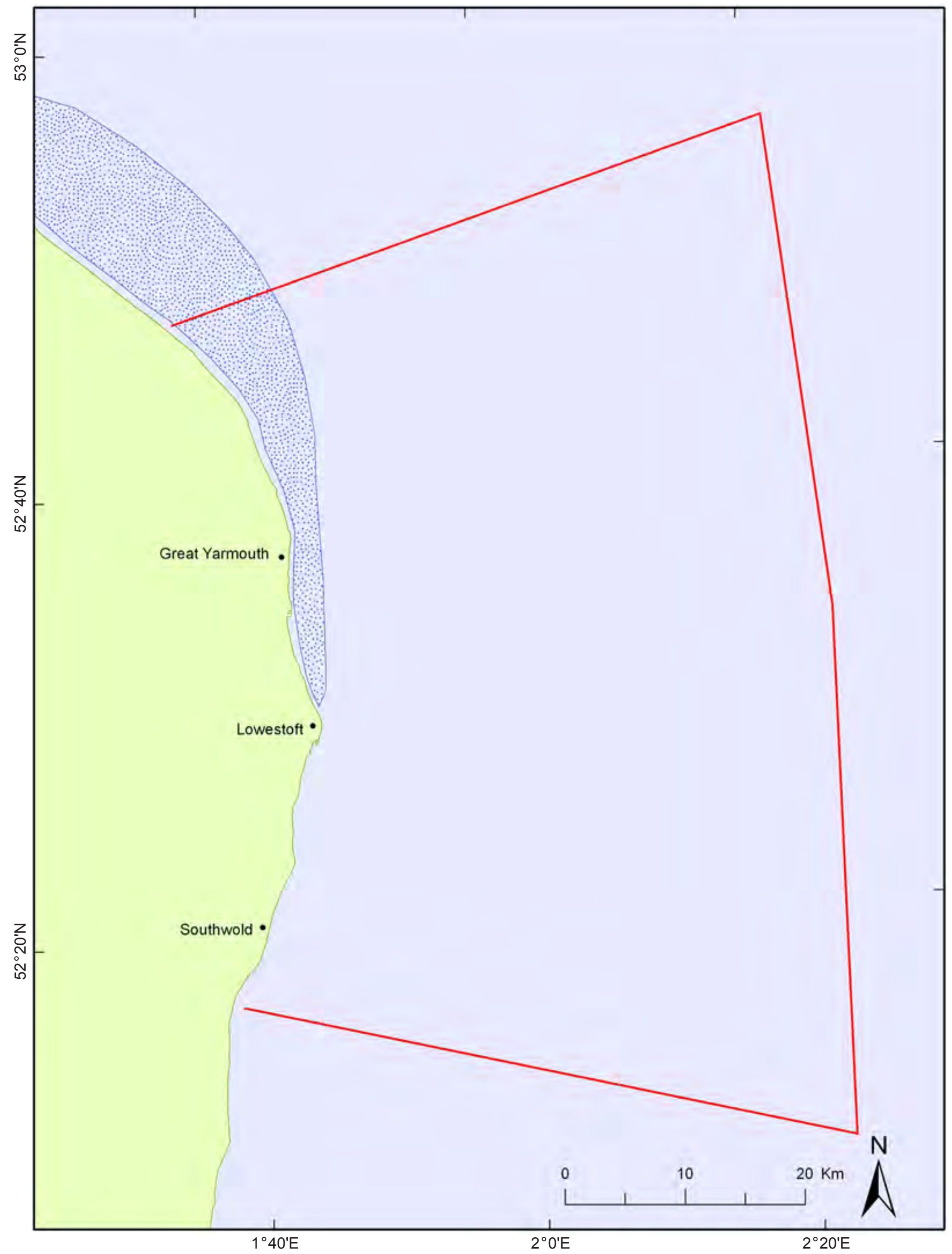


Figure 2.44 **Relative fishing effort distribution for (left panel) all mobile gear (dredging and trawling) activities and (right panel) all static gear (netting, potting, lining and commercial angling) activities (Vanstaen and Silva, 2010). (BPUE = Boardings Per Unit Effort; SPUE = Sightings Per Unit Effort.)**

Species	Landing (tonnes)	Proportion of total landings (%)
Cod	422.3	26.4
Skates and rays	293.0	18.3
Sole	257.5	16.1
Crabs	132.2	9.3
Herring	120.1	7.5
Thornback ray	62.6	3.9
Lobster	46.9	2.9
Spurdog	44.2	2.8
Brown shrimp	40.7	2.5
Flounder	37.8	2.4
Bass	35.5	2.2
Smoothhound	17.6	1.1
All other species	90.4	5.6
Total	1,600.6	100.0

Table 2.7 Nominal landings of finfish and shellfish species from ICES rectangles 34F1, 34F2, 33F1 and 33F2 into the eight ports within the Eastern REC area (Winterton-on-Sea, Great Yarmouth, Lowestoft, Southwold, Dunwich, Sizewell beach, Aldeburgh and Orford) between 2005 and 2009. Source: MMO, Fishing Activity Database.

Cod are fast growing, reaching approximately 40 cm in total length (*TL*) by the end of their first year (Cook *et al.*, 1999). In the North Sea, cod spawn at 3–4 years of age and approximately 55 cm *TL*. Spawning takes place between January and April over large areas of the North Sea (Brander, 1994; Coull *et al.*, 1998; Fox *et al.*, 2008), although spawning does not generally occur in the East Coast REC Study Area. The most important cod nursery areas on the English coast are inshore along the north Norfolk coast, the Wash and the Lincolnshire coast, and off Yorkshire and County Durham (Coull *et al.*, 1998). In the wider North Sea, juveniles can be found in the south-eastern North Sea, and in northern parts of the North Sea (ICES, 2009a)



Cod, *Gadus morhua* © Crown Copyright

Figure 2.45 Cod, *Gadus morhua,* nursery grounds in the East Coast REC Study Area (Coull *et al.*, 1998).

Cod are caught by virtually all the demersal gears in the North Sea, including longlines, beam trawls, otter trawls, seine nets and gill nets. Most of these gears take a mixture of species. In some of them, cod are considered to be a bycatch (eg, in beam trawls targeting flatfish), and in others the fisheries are directed mainly towards cod (eg, some of the fixed-gear fisheries) (ICES, 2010a).

The species is highly important in recreational sea fisheries due to their size, taste, fighting ability and abundance. Cod may be caught both from the shore (beaches, piers, harbours, rocks) or fished from a boat. Cod are caught throughout the year in the North Sea, but are primarily a winter species in the southern North Sea, with the main season extending from October to February (Ford, 2002).

Reported cod landings from the North Sea stock increased at the beginning of the 1960s from just over 100,000 tonnes (t) annually to a peak of around 590,000 t in 1980. Since that time, landings have steadily declined, falling to around 150,000 t by 1990. Over the period 2005–09, reported annual landings of North Sea cod have averaged just over 27,000 t, with a series low of 24,400 t in 2007 (ICES, 2010a). Cod stocks are seriously depleted in the North Sea, with an estimated spawning stock biomass (SSB) of 68,500 t in 2009, compared to the historical high of around 265,000 t in 1971. However, this is an increase on the lowest observed SSB of around 35,000 t in 2006 (ICES, 2010b).

The management measures in place for cod in the North Sea are extremely complex and consist of technical measures (minimum landings size, gear specifications) and effort controls (numbers of days that a vessel may be at sea per month), and relate to the target species or gear type being used (ICES, 2009a).

Whiting – *Merlangius merlangus*

The whiting is a common gadoid species in the North Sea that is distributed from the north coast of the western Mediterranean, the Bay of Biscay, the English Channel, the North Sea and Norwegian coast and Iceland (Wheeler, 1969). It is distinguished by its pointed snout and upper jaw, which is longer than the lower (Figure 2.46).

Figure 2.46 Whiting, *Merlangius merlangus*. © Crown Copyright 2011.

The whiting has a small barbel on the chin and a dark spot at the base of the pectoral fin. In general, whiting are a shallow-water species, most commonly found at depths of 30–100 m.

Whiting are active predators. Juveniles feed on crustaceans such as shrimps and small crabs, while the adult diet comprises a greater proportion of fish, such as sandeels, sprats and poor-cod.

In the North Sea, whiting spawn between February and June (Coull *et al.*, 1998), although the most intense spawning period is in April and May (Wheeler, 1969). Spawning takes place in water of 50–100 m depth, and in the southern North Sea this is in the area between the English east coast and Belgian/Netherlands coasts. Inshore nursery areas are found in the Thames Estuary, south of the East Coast REC Study Area. Whiting are relatively fast growing, reaching about 15 cm *TL* in their first year and around 22 cm *TL* by their second year. Maturity is reached at between 1 and 2 years (ICES, 2009b).

Whiting are an important target species in roundfish fisheries of the North Sea, along with cod. The species has been attracting high market value in the last three years, and the value of whiting quota has increased substantially. In addition, whiting are a bycatch in some *Nephrops* fisheries that use a smaller mesh size, although landings are restricted through bycatch regulations. They are also caught in flatfish fisheries that use a smaller mesh size.

Management of whiting is by Total Allowable Catch (TAC) and technical measures that include the number of days at sea and the minimum mesh size that may be used. In addition, the minimum landing size for whiting in the North Sea is 27 cm *TL* (ICES, 2010a).

In the absence of defined reference points, the state of the stock cannot be evaluated. An analytical assessment estimates SSB in 2009 as having increased from its lowest level since the beginning of the time-series in 1990 but remains below the series average. Recruitment has been very low since 2002, with an indication of a modest improvement in the 2007 and 2008 year classes (ICES, 2010c). In contrast, abundance off the English north-east coast has increased, as documented by the Fisheries Science Partnership. The most recent report (De Oliveira and Elliot, 2010) documents the spatial distribution and abundance of whiting from 2003 to 2008 and shows that the local abundance of whiting has increased, particularly between 2005 and 2008.

In addition to cod and whiting, pout and pollack may also be landed from the East Coast REC Study Area (Walmsley and Pawson, 2007).

2.10.3 Flatfish

Dover sole – *Solea solea*

The Dover sole is one of the most important flatfish species targeted by the UK fleet, especially in the East Coast REC Study Area. In the north-east Atlantic, the distribution of sole extends from the Mediterranean and the coast of North Africa up to southern Norway and the Shetland Islands (Wheeler, 1969). The main populations of sole around the United Kingdom are in the shallow southern North Sea (mainly south of 56°N), the English Channel and the Irish Sea. The northern limit is determined by the winter sea temperature, which needs to be above the lower lethal limit of about 3–4°C for sole (Burt and Millner, 2008). Sole prefer sandy and muddy grounds, feeding mainly at night on small invertebrates such as polychaete worms and small bivalves (de Groot, 1971; Lagardere, 1987; Braber and de Groot, 1973; Le Mao, 1986; Rogers, 1992).

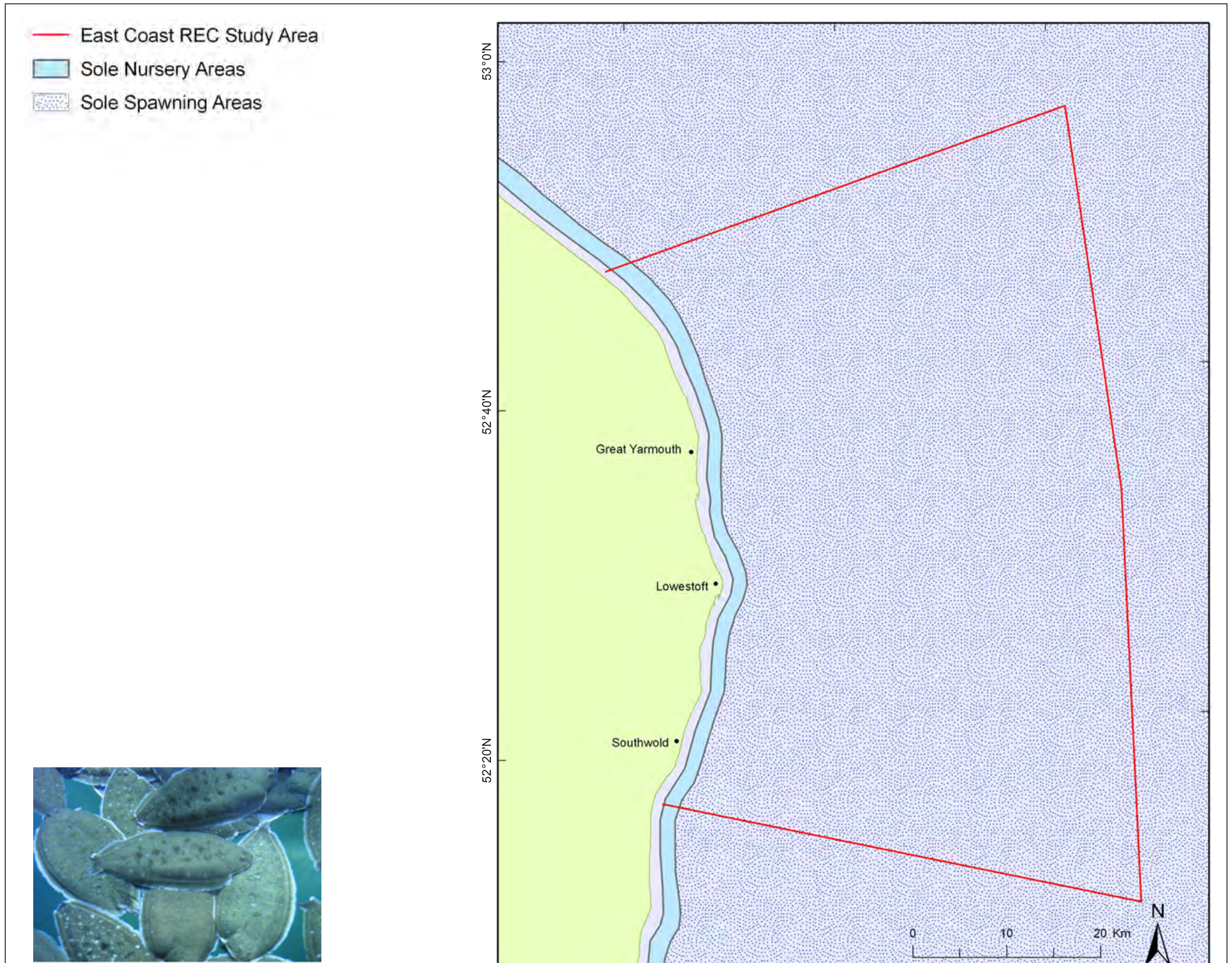
Spawning in the southern North Sea and eastern English Channel begins in March when the water temperature reaches about 7°C, peaks in April and lasts sporadically until late June. Spawning in the North Sea takes place inshore, particularly near the mouths of estuaries and in protected bays, including the Wash and the Thames estuaries in the North Sea, with spawning beginning in March and peaking in April (Figure 2.47) (Coull *et al.*, 1998).

The larvae drift into shallow sandy nursery grounds close to the areas of spawning. These are always areas of high productivity, providing suitable feeding conditions for the juvenile demersal sole. It is thought that the size of suitable nursery areas is one of the factors controlling the population size of sole (Rijnsdorp *et al.*, 1992). Sole are resident in these nursery areas for up to two years before moving farther offshore and becoming more widely distributed. Juveniles are found in shallow waters of the English east coast, where they may be caught as bycatch by shrimp beam trawlers using fine-mesh nets. Females first spawn at around 3 years of age and about 26 cm *TL*.

Results of tagging experiments show that sole tagged in the Greater Thames area (including the East Coast REC Study Area), migrate seasonally (Burt and Millner, 2008). During Quarters 1 and 4 of the year (winter) sole move offshore, before returning inshore during the summer (Quarters 2 and 3). The dominant offshore movement is north and east, along the Essex coast and as far north as the Humber estuary, although approximately 8% of fish moved southwest in the winter.

Sole is mainly taken by beam trawlers in a mixed fishery with plaice in the southern and central part of the North Sea. Technical measures applicable to the mixed flatfish fishery affect both sole and plaice. The minimum mesh size of 80 mm in the beam trawl fishery selects sole at the minimum landing size (27 cm *TL*). However, this mesh size generates high discards of plaice (ICES, 2010a).

Sole in the North Sea is currently under a long-term management plan, which was introduced in 2008, the first phase of which aims to ensure the return of the stocks of plaice and sole to within safe



Dover sole, *Solea solea* © Crown Copyright

Figure 2.47 Dover sole, *Solea solea,* spawning and nursery grounds in the East Coast REC Study Area (Coull *et al.*, 1998).

biological limits. The most recent ICES advice reports that SSB has fluctuated around the precautionary reference points for the last decade, and fishing mortality has shown a declining trend since 1995 (ICES, 2010d).

Plaice – *Pleuronectes platessa*

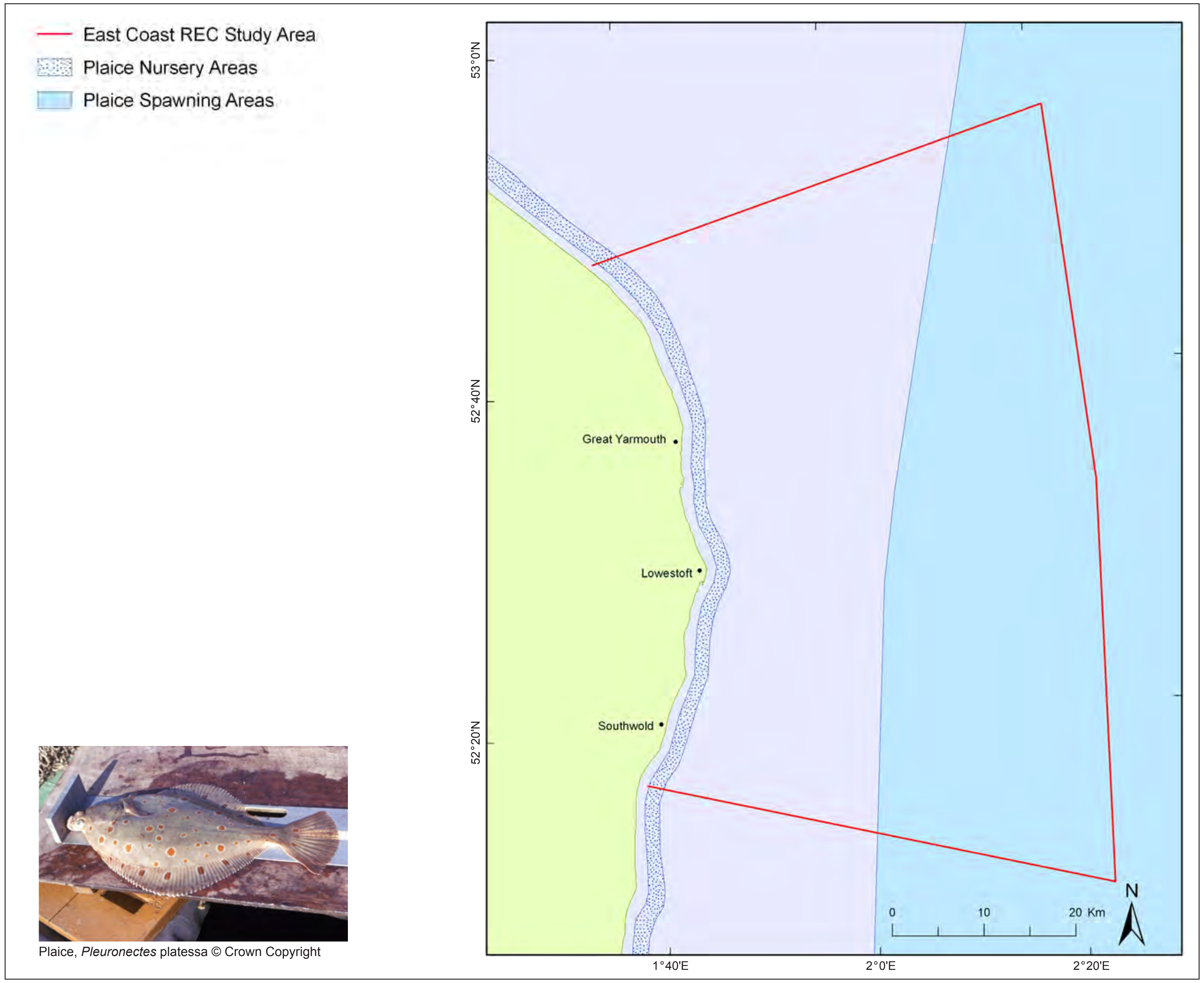
Plaice is an easily recognised flatfish species with distinctive orange spots on the dorsal region and a bright white belly. It is a widespread species, occurring from the western Mediterranean in the south to as far north as Iceland (Wheeler, 1969), and is an extremely valuable commercial flatfish species. The plaice is a long-lived flatfish (up to 30 years of age) that grows quickly in the first few years, reaching approximately 15 cm *TL* in the first year of life and 25 cm *TL* in the second (Bromley, 2000).

Juvenile plaice feed on small polychaete worms and harpacticoid copepods, but as their size increases the diet includes a wide range of small crustaceans, ampipods and crab larvae. Large plaice feed on molluscs and crustaceans (Wheeler, 1969).

Male plaice mature at a smaller size and age (approximately 28–30 cm *TL*, 2–3 years) than females (approximately 33 cm *TL*, 4 years). In the southern North Sea, plaice spawn between December and March (Coull *et al.*, 1998), and in the central North Sea, spawning activity is at its peak in January and February (Bromley, 2000). Juveniles are found on both sides of the southern North Sea, in shallow, coastal areas, moving further offshore as they grow (Figure 2.48).

Plaice is mainly taken by beam trawlers in a mixed fishery with sole in the southern and central part of the North Sea. Total landings in 2009 were estimated by the ICES Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK) as 55,000 t (ICES, 2010a). However, there is also a high degree of plaice discarding in this fishery, particularly of small plaice.

Plaice in the North Sea is currently under a long-term management plan, which was introduced in 2008, the first phase of which aims to



Plaice, *Pleuronectes* platessa © Crown Copyright

Figure 2.48 **Plaice, *Pleuronectes platessa,* spawning and nursery grounds in the East Coast REC Study Area (Coull *et al.*, 1998).**

ensure the return of the stocks of plaice and sole to within safe biological limits. Based on the most recent estimate of SSB (in 2010) and fishing mortality (in 2009), ICES classifies the stock as being well within precautionary limits, with recruitment around the long-term average from 2005 onwards (ICES, 2010e).

Flounder – *Platychthys flesus*

The flounder (Figure 2.49) is a widely distributed flatfish species that is found in the Mediterranean and Black Seas and in the Atlantic northwards to Iceland, the Baltic and the Murman coast (Kennedy, 1969). It is common around the coasts of England and Wales. The flounder is an estuarine species, penetrating creeks and rivers, and can spend short periods of time in fresh water (Wheeler, 1969). They are usually found over mud, sand or sandy mud substrates (Kennedy, 1969).

Growth is fast, with juveniles reaching approximately 8 cm *TL* by the end of the first year and 14 cm, 19 cm and 24 cm at the end of their second, third and fourth years, respectively (Wheeler, 1969). Males reach sexual maturity at approximately 11 cm *TL*, while females mature at around 17–20 cm *TL*. Juvenile flounder feed on small diatoms and copepods and (in brackish water) chironomids, switching to crustaceans, amphipods, young shore crabs and small molluscs as they grow. Adults generally feed on cockles, mussels and polychaete worms (Kennedy, 1969).

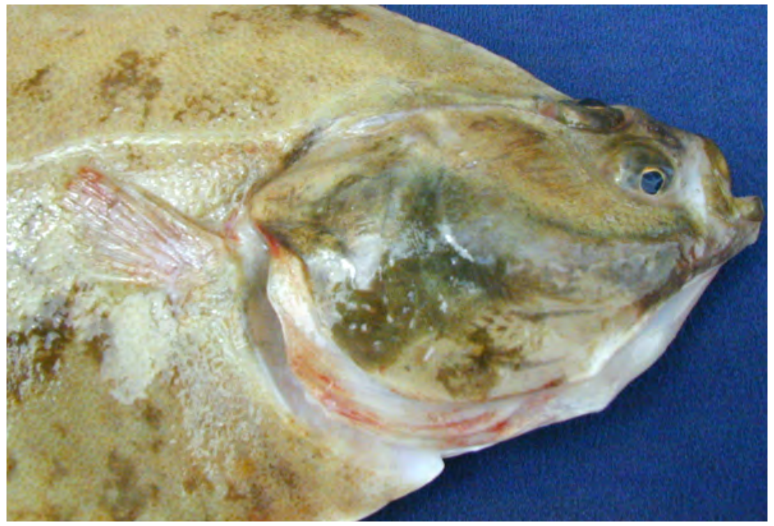


Figure 2.49 Flounder, *Platichthys flesus*. © Crown Copyright 2011.

Spawning takes place between March and May in shallow (30–55 m) water (Wheeler, 1969). Following metamorphosis, the young fish move inshore to the shallow coasts and estuaries. The results of Young Fish Surveys show high catch rates of juvenile flounder in the Wash and the Thames Estuary (Rogers *et al.*, 1998).

The flounder is generally a bycatch species for the UK fleet, primarily being caught by beam trawlers or otter trawlers targeting other flatfish species. There is currently no stock assessment for this species. The species is also a popular angling species around many parts of the country, ranking highly among anglers for their preferred target species (NFSA, 2006), as it can easily be fished from the shore and will take a variety of baits (Thrussel, 2006).

2.10.4 Large pelagic fish

Bass – *Dicentrarchus labrax*

Bass *Dicentrarchus labrax* (Figure 2.50) is a widely distributed species in north-east Atlantic shelf waters, with a range from southern Norway, through the North Sea, the Irish Sea, the Bay of Biscay, the Mediterranean and the Black Sea to north-west Africa. The species is at the northern limits of its range around the British Isles and southern Scandinavia (ICES, 2002). It is an important commercial and recreational species (Pawson, 2008).

Growth of bass is relatively slow, and the species is long-lived (up to 30 years of age). At the end of their third year, juveniles are approximately 25 cm *TL,* and at the end of their fourth year they are approximately 33 cm *TL*. Maturity is attained at around 4–7 years, which is around 35 cm *TL* for males and 42 cm for females *TL* (Pawson and Pickett, 1996). The maximum length in UK waters is approximately 95 cm *TL*.

Bass are opportunistic feeders, preying on a variety of species. Larval bass primarily feed on small zooplankton, such as copepod

Figure 2.50 Bass, *Dicentrarchus labrax*. © Crown Copyright 2011.

nauplii, cladocerans and mysids, while 0-group bass eat small crustaceans such as isopods, amphipods and mysids. The diet of juvenile bass is dominated by larger crustaceans (such as brown shrimp and the shore crab) and small fish such as gobies, herring and sprat. Adults feed on fish and crustaceans when they are feeding inshore and on pelagic fish such as mackerel and pilchards when they are feeding offshore (Kelley, 1987; Pickett and Pawson, 1994).

Bass migrate from their inshore feeding grounds to over-wintering grounds in the western English Channel and the eastern Celtic Sea. Adults show a westward migration as the water cools between October and December (Pawson *et al.*, 1987) and adult females seek out water above ~9°C for final gonad maturation and spawning. Spawning tends to start in the western Channel in March and continues until May, with the spawning fish moving eastwards in the English Channel and into the North Sea as the water warms. The eggs float in the water column, hatching 4–9 days after fertilisation and at approximately 4–4.5 mm long (Pickett and Pawson, 1994). Water currents carry the larvae inshore until the summer, when they actively recruit into estuaries and creeks (Jennings and Pawson, 1992).

During the winter, juvenile bass move into deeper channels or into open water. They return in spring to the larger estuaries and shallow bays on the open coast, where they remain for the next 2–3 years. When they reach 4 or 5 years of age, their movements become more wide-ranging and they eventually adopt the adult feeding/spawning migration patterns (Pawson *et al.*, 1987).

Recent warming of the North Sea has led to bass extending their northerly distribution range, and juveniles have been observed in the Wash and the Humber Estuary. In a review of bass nursery areas, Smith and Brown (2009) reported that there have been reports of juvenile bass in the Rivers Blythe, Deben, Alde and Ore, Stour and Orwell and in Breydon Water, all of which fall in or around the East Coast REC Study Area. However, there are currently no surveys in these areas with which to confirm these sightings.

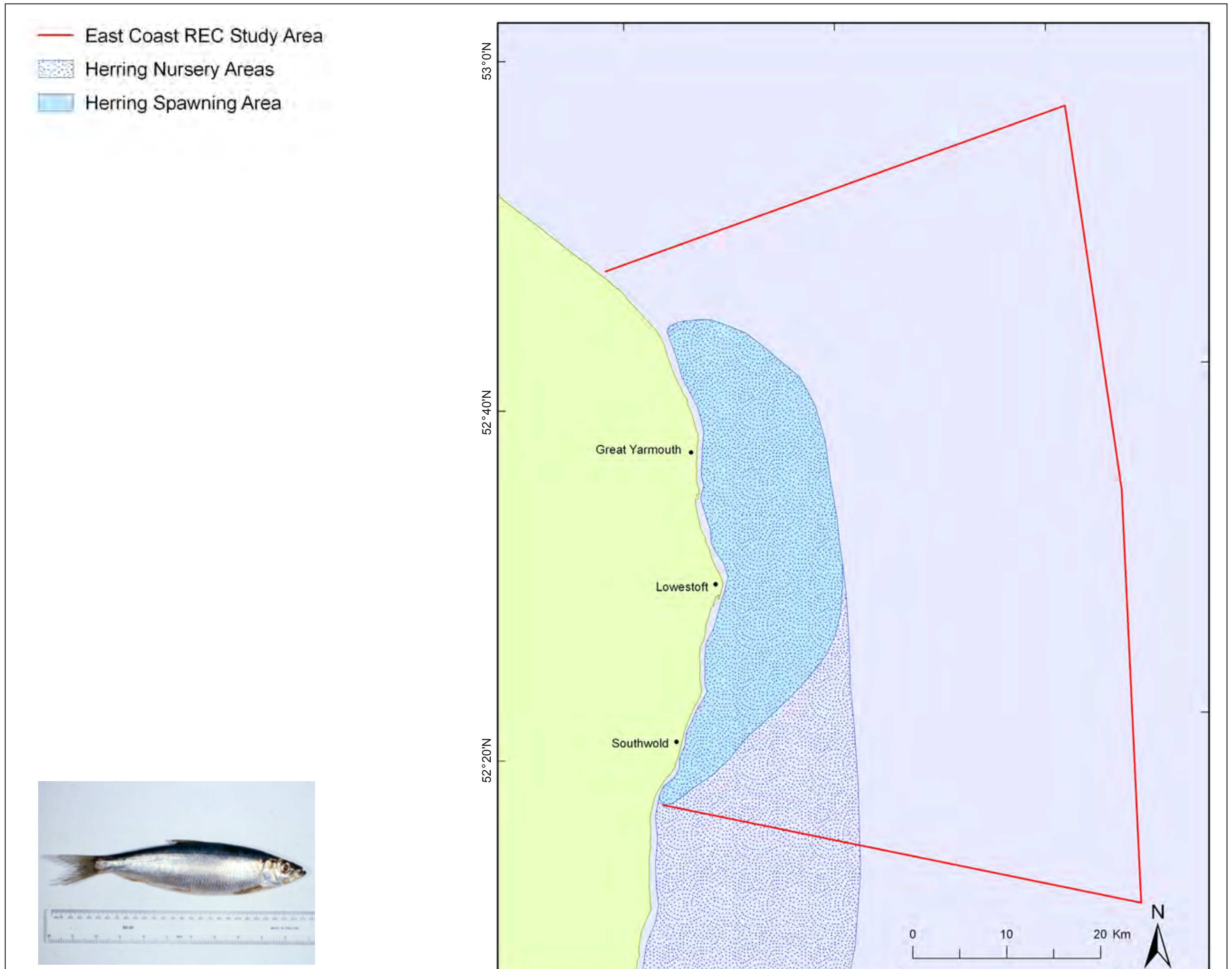
2.10.5 Small pelagic fish

Herring – *Clupea harengus*

Herring is a small, silvery pelagic species that is widely distributed from the Bay of Biscay in the south, through the English Channel, the Irish Sea, and the North Sea, as far north as Iceland (Wheeler, 1969). The diet of Atlantic herring is dominated by planktonic crustaceans. In the North Sea, the diet varies by season but is dominated by copepods (*Calanus* spp., *Temora* spp., and *Pseudocalanus* spp.) and juvenile sandeels (*Ammodytes* spp.), with fish eggs, amphipods, *Sagitta* spp., and *Oikopleura* spp. also being major constituents (Segers *et al.*, 2007).

Three separate spawning stocks exist in the North Sea: Buchan herring, which spawn from July to September off the north of Scotland and the Orkney Isles; Banks herring, which spawn off the eastern coast of England; and Downs herring, which spawn in late autumn to February in the southern North Sea and eastern English Channel (Nichols, 2001) (Figure 2.51). Individuals from these stocks mix in the feeding grounds where they are fished, and as a result North Sea herring is managed as a single unit. Blackwater herring is a distinct, small estuarine stock that spawns in spring on shallow gravel banks off the Blackwater Estuary in Essex, and it is managed as a separate stock.

For all spawning types, gonad maturation starts in April–May, but whereas autumn spawners keep developing the oocytes until they



Herring, *Clupea harengus* © Crown Copyright

Figure 2.51 Herring, ***Clupea harengus***, spawning and nursery grounds in the East Coast REC Study Area (Coull ***et al.***, 1998).

are ready to be spawned in September–October, winter and spring spawners stop development in September, have a resting period through autumn (and winter for spring spawners), followed by further oocyte development just prior to spawning. This longer maturation period results in larger oocytes but lower fecundities (Van Damme *et al.*, 2009). In the East Coast REC Study Area, herring spawn between November and January (Coull *et al.*, 1998).

Herring eggs are attached to gravel substrates on the seabed, and natural variability in the survival of eggs and larvae result in large fluctuations in the abundance of year classes. Spawning and nursery areas are sensitive and vulnerable to anthropogenic influences, such as the development of offshore windfarms and marine aggregate extraction (ICES, 2010f). Herring may abandon and then re-populate spawning grounds, so the lack of spawning in some years does not necessarily mean that the spawning ground is no longer viable.

Herring fisheries have a long history of boom and collapse. From the end of the Second World War until the early 1960s, landings of North Sea herring averaged 650,000 t and peaked at nearly 1,200,000 t in 1965. There was a dramatic collapse in landings to 300,000 t in 1975, which was followed by a moratorium on directed herring fisheries in 1977. Following the closure and reopening of the fishery, SSB increased, and landings steadily rose to over 800,000 t in 1988. Landings have declined again since that time as a result of TAC restrictions, and in 2010 the ICES Herring Assessment Working Group (HAWG) estimated that landings in 2009 were 166,000 t (ICES, 2010f).

Currently, North Sea herring is caught for human consumption and as a bycatch of industrial fisheries. The fishery is seasonal, and in the southern North Sea, most catches are taken in the fourth quarter of the year. According to the management plan agreed between the EU and Norway, adopted in December 1997 and amended in November 2007, efforts should be made to maintain the SSB of North Sea Autumn Spawning herring above 800,000 t. The most recent assessment estimates that, in 2009, SSB was 1,300,000 t (ICES, 2010f).

Sprat – *Sprattus sprattus*

Sprat are small herring-like pelagic fish that are widely distributed in the waters of the north-east Atlantic. The species is distinguished from the herring by a lower jaw that is longer than the upper and a belly that is sharply keeled, with a distinct line of spiny scales from the throat to the vent. In contrast to the herring, the dorsal fin originates behind the base of the pelvic fin (Wheeler, 1969).

Sprat in the North Sea has a prolonged spawning season, ranging from early spring to the late autumn, which is triggered by the water temperature. Sprat is a batch spawner, producing up to 10 batches in one spawning season and 100–400 eggs per gram of body weight (Alheit, 1987). Spawning takes place over large areas of the North Sea, including the offshore edges of the East Coast REC Study Area (Figure 2.52). The eggs are pelagic, floating either at the surface or in mid-water, and hatch after 3–4 days, then the larvae drift inshore. Juveniles are well distributed in the southern North Sea (Coull *et al.*, 1998) and are often found in shoals with first-year herring. Sprat are mature at between ages 1 and 2 years. Young sprat feed on diatoms, as well as on the eggs and young of copepods, while adults feed on planktonic crustaceans.

The majority of the sprat landings are taken in a Danish industrial small-meshed trawl fishery and a Norwegian purse seine fishery. Both landings are used for reduction to fish meal and fish oil. However, in the last decade, the United Kingdom has occasionally landed small amounts of sprat, with some fish coming into Lowestoft. During the mid-2000s, vessels from the Thames region are known to have fished off the East Anglian coast for sprat, though this has declined in the last 2–3 years (ICES, 2010f).

Many predators in the North Sea feed extensively on sprat, including predatory fish, marine mammals and seabirds. Sprat can be very important for breeding seabirds in southern areas of the North Sea. Estimates from 1985 have shown that the total seabird consumption of sprat in the North Sea could be at the same level as the fisheries take (ICES, 2010f).

The fisheries information available on North Sea sprat is inadequate to evaluate stock status, and therefore the state of the stock is unknown. The sprat stock in the North Sea is short-lived, and the catch is dominated by young fish. The stock size is mostly driven by the recruiting year class. Thus, the fishery in a given year is dependent on that year's incoming year class. The sprat fishery is considered opportunistic (and thus influenced by external factors such as abundance and price of other species), and therefore landings probably do not reflect the stock status (ICES, 2010g).

2.10.6 Crustacea

The most important crustacean catches in the area are of brown shrimp, which are caught by beam trawlers using fine-mesh nets (Figure 2.53). The majority of brown shrimp landings are of *Crangon crangon*, but some *Crangon allmanni* may be landed from the southern part of the East Coast REC Study Area.

At the Northern end of the East Coast REC Study Area there are a number of vessels working from the Winterton-on-Sea area that use pots to target crabs and lobsters (Figure 2.53). This corresponds to the south-eastern end of the Norfolk potting grounds, the majority of which are to the north and east of the East Coast REC Study Area. Very little fishing for molluscs takes place in the East Coast REC Study Area.

Brown/edible crab – *Cancer pagurus*

In England and Wales, the edible crab (Figure 2.54) is one of the most important commercially fished shellfish species. It is distributed over a wide geographical range, extending north to Norway and south through to west Africa as well as into the Mediterranean. Although it is found all around the British coast, it is most abundant off the south coast of Devon and Cornwall and off Northumberland, Yorkshire and Norfolk. A major fishery exists off the north Norfolk coast, and the eastern edge of this fishery coincides with the northern extent of the East Coast REC Study Area.

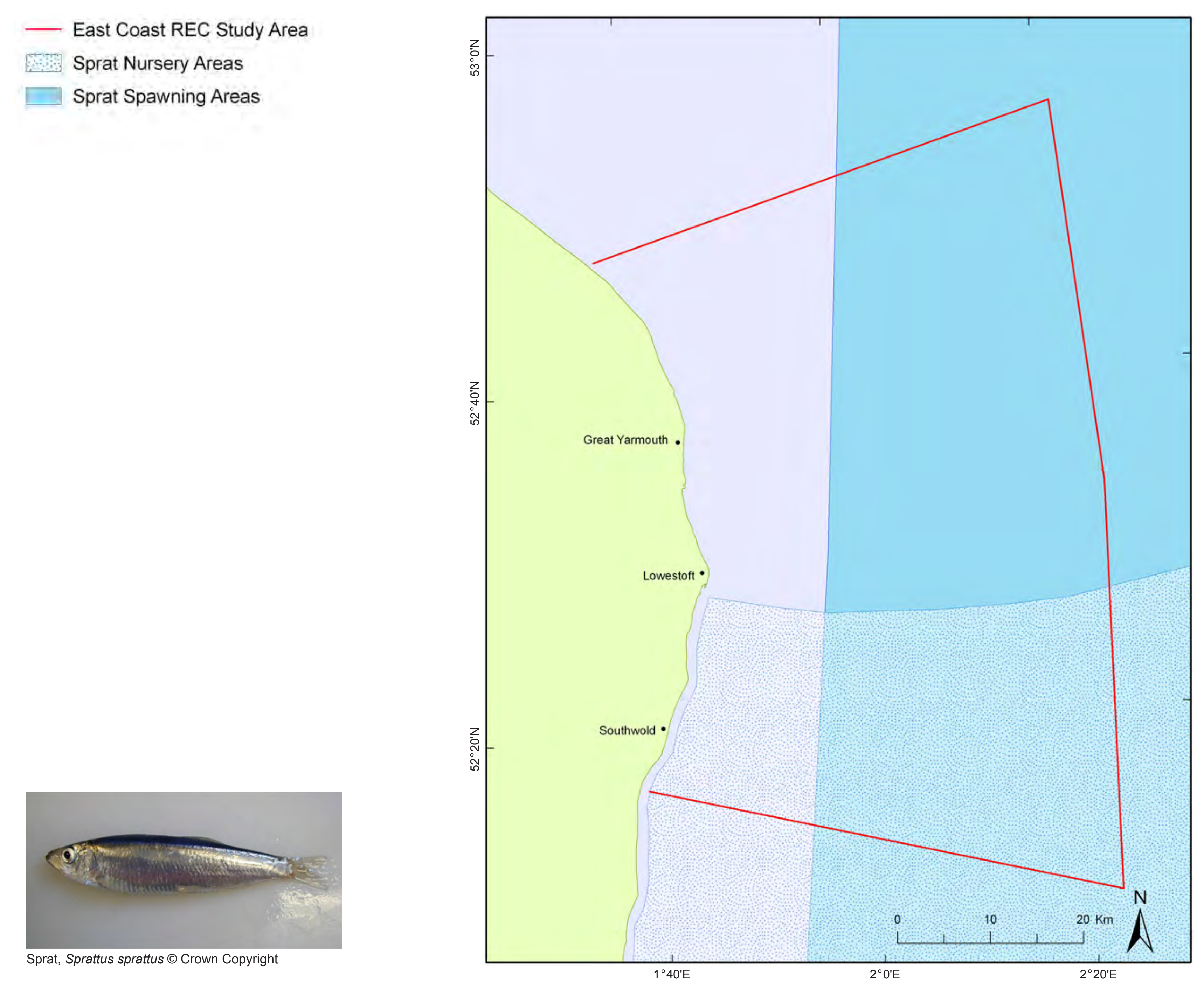


Figure 2.52 Sprat, *Sprattus sprattus*, spawning and nursery grounds in the East Coast REC Study Area (Coull *et al.*, 1998).

Figure 2.53 Types of fishing vessel used in the East Coast REC Study Area to catch crustaceans. Left: beam trawler catching brown shrimps; right: crab potter. © Crown Copyright 2011.

The edible crab is mainly carnivorous, feeding on fish, polychaetes, mussels, cockles and other shellfish, crushing them with its powerful claws.

Generally male crabs are sexually mature at >110 mm carapace width (CW) whilst female crabs mature at a larger size (110–150 mm CW). Fertilisation can only take place when the female is still soft after moulting. Some females migrate to favoured spawning grounds in the autumn. Female migrations can be over very long distances (the record to date is around 500 km) and are northwards in the North Sea and westwards in the Channel, against the long-term tidal residuals. Males, by comparison, are relatively sedentary.

In the North Sea, there are major spawning grounds on offshore grounds off the River Humber. These grounds are usually areas of coarse, sandy gravels. Spawning occurs in early winter, and each female produces between 250,000 and 3,000,000 eggs, depending on her size, which she keeps attached to her abdomen and actively incubates for up to 8 months. Hatching of the eggs occurs later (June–August) in more northern seas than it does in the warmer waters to the south and west, where it can occur as early as February. Crab larvae are planktonic, with a shrimp-like appearance. After a short period, the larvae settle on the seabed and assume the adult shape. Crabs, like other crustaceans, grow in discrete steps by shedding off the old shell followed by a rapid swelling of the new and temporarily soft shell. As such, growth depends on the frequency of moulting, and the resulting increase in size is called moult increment. While crabs are juveniles, moulting takes place frequently and growth is fast. However, with the onset of maturity, moulting is reduced to once a year or even less in the largest crabs.

The main season for crab fishing extends between March to October on the east coast, with a large fishery for female crabs in the autumn. Many of the boats fishing for crabs may also fish for lobsters. At certain times of the year, particularly during the summer, fishermen will concentrate their pots on known lobster grounds.

There are currently no landings quotas for *C. pagurus*, and management in UK waters is primarily by the use of technical measures – in particular, minimum landing size (MLS). EC regulations set this at 130 mm CW in the North Sea (with a derogation to 115 mm in the area under the jurisdiction of the Eastern Sea Fisheries Joint Committee, part of the North Norfolk fishery), but in other sea areas more stringent restrictions may apply. Other conservation measures include a ban on landing soft or egg-carrying crabs or crab parts (claws), the use of escape gaps, and effort control by means of restricting the numbers of traps used by each boat.

Figure 2.54 **Brown crab, *Cancer pagurus*. © Crown Copyright 2011.**

Brown shrimp – *Crangon crangon*

The brown shrimp (Figure 2.55) is a commercially and ecologically important species, supporting large commercial fisheries in Germany, Holland, Belgium and Denmark. Brown shrimps are abundant in coastal waters surrounding much of western Europe, including most of the coastline of England and Wales, and the East Coast REC Study Area (Henderson and Holmes, 1987). The main UK brown shrimp fishery is situated in The Wash embayment and along the adjoining Lincolnshire and Norfolk coastlines. Small artisinal fisheries also exist along the Norfolk and Suffolk coastline, which yield modest landings into Lowestoft.

Shrimps prefer muddy and sandy habitats where they bury themselves when not actively feeding. They are particularly abundant in brackish waters, especially those with strong tidal currents. These nutrient-rich habitats support a wide range of prey species for the shrimp, including polychaete worms, molluscs and small arthropods (Henderson *et al.*, 1990).

“Berried” or egg-carrying female shrimps can be observed over much of the year, but they are most frequently found from January to June. Eggs are incubated for 5–13 weeks, depending upon temperature. The highest quantities of shrimp larvae are found during the summer months, so it is believed that there is a peak hatching period during the spring. Larvae go through five moult stages at a rate of approximately one a week. Gaining mobility, they migrate to tidal inshore brackish water and settle onto the seabed. They continue to grow through a succession of moults to around 35–40 mm (half their maximum length) at around 4–6 months old. They then head offshore, continuing to moult and growing to reach maturity at 40–50 mm. At this size, newly matured shrimps start recruiting to the fishery and form the bulk of the autumn fishery. Maximum size is approximately 80 mm for females and around 55 mm for males.

Information regarding age is sketchy, though it is thought that females attain 3–5 years of age and males 2–4 years. Natural mortality is very high, and the older individuals will be extremely rare.

Figure 2.55 **Brown shrimp, *Crangon crangon*. © Crown Copyright 2011.**

Shrimps have traditionally been fished with push-nets on mud-flats and beaches when the water is not too cold, but they now may be caught throughout the year by beam trawlers operating in slightly deeper water. The main fishing season extends from August to December, peaking in October and November.

Lobster – *Homarus gammarus*

The European lobster (Figure 2.56) is found from the Arctic Circle to Morocco and into the Mediterranean, but its main centre of distribution is around the coast of the British Isles. Lobsters are usually found on rough or rocky ground, from the intertidal zone to depths of 110 m and possibly deeper (Phillips, 2006).

Lobsters are territorial, usually living in a crevice or underneath a rock, where they spend much of their time, coming out to feed mainly at night, when their activity is increased considerably. They feed on fish, marine worms, molluscs, crustaceans and starfish. Around the British Isles, the high unit price ensures that the lobster fisheries are amongst the most valuable shellfish fisheries.

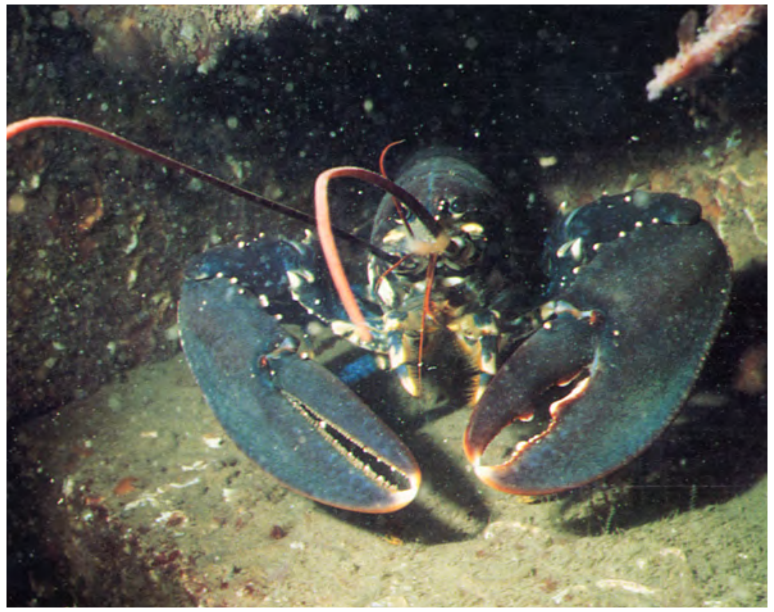


Figure 2.56 Lobster, *Homarus gammarus*. © Crown Copyright 2011.

The European lobster can grow up to 10 kg in weight, although this is unusual. It is estimated that a lobster takes between four and six years to reach the minimum legal landing size in the North Sea area of 87 mm carapace length, which is equivalent to a total length of 249 mm and an approximate weight of 440 g.

Mating takes place between a soft-shelled female and a hard-shelled male. Sperm is retained by the female in a sperm receptacle. Eggs are fertilised as they are extruded, which may be several months later. The eggs attach to the hairs of the pleopods and are constantly aerated and cleaned by the female until they hatch some 10 months later. The majority of females found carrying eggs (ie, berried) have a carapace length above 80 mm. A berried female will carry between 5,000 and 100,000 eggs, depending on its size. The eggs usually hatch in June or July, when the lobster larvae are released into the plankton.

Lobsters are usually caught in the same areas as edible crabs, although they prefer different substrate types. In the southern North Sea, the main lobster fishing areas are the Norfolk coast around Sheringham and Cromer, and some lobster are landed from the East Coast REC Study Area. The main catches are made between May and October, although lobster fishing may take place at all times of the year. Weather conditions and harbour facilities, as well as the availability of lobsters on the grounds, are the major factors determining the length of the fishing season. Many boats fish for lobsters only when catches are good, and for the remainder of the year they will turn to other types of fishing such as trawling, lining or drift-netting or move their pots to crab fishing grounds.

The national minimum permitted landing size for lobsters is 87 mm carapace length, but 90 mm is the MLS in other sea areas around the United Kingdom. In addition to this, local Sea Fisheries Committee Byelaws restrict the landing of egg-carrying lobsters in Northumberland, Norfolk, Suffolk, Essex and Kent and soft lobsters in Northumberland, Norfolk and Suffolk. In addition, restrictive licence schemes that limit the number of pots per vessel or specify the use of escape gaps in traps may also be used to help conserve stocks.

2.10.7 Sharks and rays

In the North Sea, around 10 skate and ray species and 7 demersal shark species are found (ICES, 2010h). Of highest commercial importance are the tope, spurdog and starry smoothhound sharks and thornback ray.

Large pelagic sharks

Tope – *Galeorhinus galeus*

The tope (soupfin or school shark) (Figure 2.57) is a widely distributed species in northwest Europe, with a range from the coasts of Norway and Iceland in the north to north-west Africa and the Mediterranean Sea in the south (Compagno *et al.*, 2005; Ellis *et al.*, 2005) and from shallow waters to depths of about 475 m (Walker, 1999). Tope is a medium-sized shark that is uniformly grey on the dorsal side, to white on the belly, with a pointed, flattened snout and typical shark-like cutting teeth. Maximum size is approximately 1.75 m length for males and 1.95 m for females (Compagno *et al.*, 2005).

Tope feed on a wide range of schooling fish, especially whiting, pout and cod as well as demersal fish, crustaceans and echinoderms (Wheeler, 1969). There are no published age and growth studies for tope in the north-eastern Atlantic, though studies of other tope populations suggest that it is a long-lived species (up to 36 years), based on tag returns and age and growth studies (eg, Moulton *et al.*, 1989; Peres and Vooren, 1991).

The species is highly active and individuals are strong swimmers, able to undertake large migrations of up to 1,600 km (Compagno *et al.*, 2005) (see also the UK Shark Tagging Programme website www.ukshark.co.uk/ and Ireland's Central Fisheries Board Marine Sportfish Tagging Programme website www.cfb.ie/fisheries_research/tagging/tope.htm). Tope form small schools, which are partly segregated by sex and size and may be seasonally highly migratory.

Tope are ovoviviparous, and Wheeler (1969) reports that tope in the United Kingdom bear between 20 and 40 pups in each litter. Litter size increases with maternal length. The young are born in late summer, when the females move into shallow water to pup, before

Figure 2.57 Tope, *Galeorhinus galeus*. © Crown Copyright 2011.

moving off again to offshore feeding grounds. Pups are approximately 40 cm *TL* at birth, and gestation lasts around one year (Wheeler, 1969). The juveniles remain on the nursery grounds for about two years before moving offshore to form schools of immature individuals. In the Mediterranean, males and females mature at lengths of approximately 122–158 cm *TL* and 140–190 cm *TL*, respectively, with first spawning occurring at a length of about 150 cm *TL* for Mediterranean stocks (Capapé *et al.*, 2005).

This is a highly prized recreational species, which is caught on a catch and release basis (NFSA, 2006). The species can be caught from the shore or from a boat, with the Wash, the Greater Thames Estuary and the Essex coast being major fishing areas.

In 2006, the UK government consulted on proposals for managing the exploitation of tope. This was in direct response to proposals for a directed tope fishery off the East Anglian coast. Respondents were asked for their opinions on either doing nothing, on limiting the catching of tope to the use of rod and line only, or the complete prohibition of fishing on this species. In response to the replies received, the Minister concluded that though a commercial fishery for tope did not currently exist, there was a risk that a targeted fishery could be set up quickly and could have a rapid adverse impact on populations, both locally and throughout the North East Atlantic. The Minister decided that, to ensure the sustainable use of tope, fishing by methods other than rod and line would be prohibited. Where tope is a bycatch in commercial fisheries targeting other species, a 45 kg per day tope bycatch limit would apply. Rod and line anglers fishing from boats are not allowed to land their catches (dead or alive) ashore, but they are allowed to practice “catch and release”. Thus, commercial and recreational fishermen share the responsibility for tope conservation. This legislation was implemented as The Tope (Prohibition of Fishing) Order 2008 No 691 in April 2008.

In addition, the Eastern Joint SFC has introduced a byelaw that strengthens the conservation of tope within the district by prohibiting the removal of tope or body parts dissected from tope. All tope caught must be returned to the water immediately.

Thresher shark *Alopias vulpinus* may occasionally be found in the area.

Dogfish and triakid sharks

Spurdog – *Squalus acanthias*

Spurdog (Figure 2.58) has a worldwide distribution in temperate and boreal waters and occurs mainly in depths of 10–200 m. In the North East Atlantic, this species is found from the coast of Northwest Africa to Iceland and the Barents Sea (McEachran and Branstetter, 1984). It is easily identified by the two dorsal fin spines, the first of which is shorter than the dorsal fin itself (Compagno *et al.*, 2005), and by the colouration, which is dark grey on the dorsal surface with distinct white spots on the back and sides.

Worldwide, spurdogs are long-lived, slow growing, have a high age-at-maturity, and are particularly vulnerable to high levels of fishing mortality. Population productivity is low, with low fecundity and a long gestation period. They were once the most abundant shark and most important commercial shark species, but fisheries have declined in many areas of the world. In addition, they form size- and sex-specific shoals and therefore aggregations of large fish (ie, mature females) are easily exploited by target longline and gillnet fisheries (Compagno *et al.*, 2005).

Figure 2.58 Spurdog, *Squalus acanthias.* © Crown Copyright 2011.

In the North Atlantic, this species exhibits a complex migratory pattern. Tagging studies have indicated a winter migration from Scotland to the coast of Norway, returning in summer (Aasen, 1960, 1962). Other tagging studies in the English Channel indicate summer movement into the southern North Sea (Holden, 1965). A tagging study initiated in the Irish and Celtic Seas in 1966 yielded recaptures over 20 years from all round the British Isles and suggests that there is one single north-east Atlantic stock (Vince, 1991).

The ICES Working Group on Elasmobranch Fishes (WGEF) assumes a length-at-50%-maturity of 80 cm *TL* for females and 64 cm *TL* for males (ICES, 2010h). From the literature, other estimates of female length at 50% maturity include 74 cm *TL* (Fahy, 1989), 81 cm *TL* (Jones and Ugland, 2001) and 83 cm *TL* (Gauld, 1979). Pups are born at around 18–33 cm *TL* in the winter, spring or summer. Gestation varies regionally between 18 and 24 months. Ellis and Keable (2008) reported a maximum uterine fecundity of 21 pups, which was greater than previously reported for north-east Atlantic spurdog.

In 2006, the International Union for Conservation of Nature categorised north-east Atlantic spurdog as critically endangered. However, this categorisation has not yet been subject to peer review. WGEF has undertaken preliminary stock assessments for this species and concludes that the North East Atlantic stock of spurdog has been declining rapidly and is around its lowest ever level. Preliminary assessments making use of the long time-series of commercial landings data suggest that this decline has been going on over a long period of time and that the current stock size may only be a fraction of its virgin biomass (<20%) (ICES, 2010h).

In 2007 and 2008, North Sea fisheries were regulated by a bycatch quota whereby spurdog should not have comprised more than 5% by live weight of the catch retained on board. The bycatch quota was removed in 2009, when a maximum landing length (MLL) was introduced to deter targeting of mature females.

Starry smoothhound – *Mustelus asterias*

The starry smoothhound (Figure 2.59) is distributed throughout the northeast Atlantic from Mauritania and the Mediterranean in the south to the North Sea. It is the only European smoothhound with many small white spots on the dorsal surface which is uniformly grey or grey-brown (Compagno *et al.*, 2005). The species' main habitat is over continental shelves on or near gravel and sand at depths up to about 100 m. The species is relatively small, reaching a maximum of approximately 140 cm *TL*.

Little information is available on the biology of *M. asterias* in the North Sea. In the Irish Sea, *M. asterias* feeds almost exclusively on crustaceans, in particular *Liocarcinus* spp. and *Pagurus* spp. (Ellis *et al.*, 1996).

M. asterias are ovoviviparous with females bearing litters of 7–15 pups, with litter size increasing with maternal size. Pups are born inshore in the summer after a gestation period of about one year. Individuals mature at around 2–3 years or 78–85 cm *TL* for males and 85 cm *TL* for females.

With regard to fisheries management, the stock boundary of smoothhound *Mustelus* sp. is not known. In the North Sea, abundance appears to have been increasing in recent years, both in survey catches and in commercial and recreational fisheries, but the stock status is uncertain (Daan *et al.*, 2005). In 2008, ICES provided advice for 2009 and 2010 for these stocks, stating that catches should not increase for smoothhound *Mustelus* spp. (ICES, 2010h).

Figure 2.59 Starry smoothhound, *Mustelus asterias*. © Crown Copyright 2011.

Skates and rays

Thornback ray – *Raja clavata*

The thornback ray (commonly known as roker) (Figure 2.60) is a widely distributed skate species found in coastal and shelf areas from the Bay of Biscay north to the English Channel, the Irish Sea and the North Sea (Wheeler, 1969). The species is the dominant skate species in the southern North Sea and is an important target and bycatch species for inshore fisheries in the Greater Thames Estuary and the East Coast REC Study Area (Ellis *et al.*, 2008). It is easily recognised by the sharp prickles on the dorsal side of the body, which in adults develop into large dermal spines on the back and the tail.

Results of tagging studies conducted between 1959 and 1976 suggested that thornback ray are distributed in local populations, but that there is a regular exchange of individuals between them (Walker and Heessen, 1996). The majority of recaptured individuals were 50–60 km from their original release site, but some individuals had travelled several hundred kilometres. However, results suggested that there is little interaction between the fish in the North Sea and eastern English Channel. Hunter *et al.* (2006) also reported that thornback ray undergo seasonal migrations into deeper water in the autumn and are able to range throughout the southern North Sea. Of 197 individuals tagged with data storage tags and released in the Thames Estuary, 3 were subsequently recaptured in the East Coast REC Study Area.

Using data from research surveys, Ellis *et al.* (2005) showed that the highest abundance of thornback ray in the North Sea is concentrated around the Thames Estuary and East Anglian coast and that they are rare further north than Flamborough Head. Since the 1970s, there has been a decrease in the abundance of thornback ray off the Netherlands coast (Walker *et al.*, 1997). Juveniles tend to be concentrated off the Kent coast, though juveniles may occasionally be caught in the East Coast REC Study Area.

Figure 2.60 Thornback ray, *Raja clavata*. © Crown Copyright 2011.

As with many ray species, the thornback ray is slow growing and relatively long lived. A variety of maximum length estimates are given in the literature (eg, Holden, 1972), but in the North Sea it is given as 85 cm *TL* (Walker and Hislop, 1998). Females mature at approximately 72 cm *TL* and about 10 years of age. The thornback ray is an oviparous species, laying 38–66 eggs per year (Ellis and Shackley, 1995; Chevolot *et al.*, 2007). Whereas some oviparous elasmobranchs are thought to have specific spawning beds (Ellis *et al.*, 2005), it is not known whether there are specific spawning grounds for thornback ray.

Thornback rays feed on amphipods and small *Crangon* spp., while adults eat crustaceans such as *Liocarcinus* spp., *Crangon* spp. *Upogebia*, *Portunus*, *Corystes*, as well as sandeels, herring and sprats (Wheeler, 1969; Ellis *et al.*, 1996; Morato *et al.*, 2003).

The Kent and Essex SFC has issued a byelaw to prevent the landing of juvenile skates, but there is nothing comparable for the Eastern SFC.

In addition to thornback ray, spotted ray *Raja montagui* may be caught in the offshore areas of the East Coast REC Study Area, and blonde ray *Raja brachyura* may be seasonally and locally important.

2.10.8 Recreational activities, including angling

Recreational activities are largely covered in three discrete topics: sailing, diving and angling.

Great Yarmouth is primarily a commercial port with little in the way of recreational facilities. In contrast, Lowestoft is more targeted towards recreational boating, with three marinas (Royal Norfolk & Suffolk Yacht Club, Haven Marina and Lowestoft Cruising club) (Figure 2.61).

Southwold (Figure 2.62) also has riverside moorings for visitors, and nearshore dinghy racing is practiced off Lowestoft and Southwold. North of Great Yarmouth the coast is exposed, with no safe haven until Blakeney and Wells-next-the-Sea, which are beyond the limits of the East Coast REC Study Area.

Great Yarmouth and Lowestoft are also gateways to the inland river system containing the Norfolk Broads National Park (Figure 2.63). Great Yarmouth has open river access via the river Yare, with high tidal flows.

Figure 2.61 Lowestoft Royal Norfolk & Suffolk Yacht Club (taken from the bridge of research vessel *Cefas Endeavour*). © Crown Copyright 2011.

Figure 2.62 Southwold Town. © Crown Copyright 2011.

Figure 2.63 Great Yarmouth Breydon Bridge, and the Bure/Yare junction gateway to the Broads. © Crown Copyright 2011.

Lowestoft access is via a sea lock, which is more restricted in size but has fewer weather or tidal complications. Southwold harbour also experiences strong tidal flows, and a sandbar across the end of the River Blyth limits access. Privately owned sailing and motor vessels use the inshore channels to transit between the coastal ports, or to access the Broads, either for recreation or to use various small shipyard repair facilities – for example, Brooms of Brundall or Goodchild Marine near Burgh Castle (Figure 2.64). The marinas in Lowestoft also attract recreational traffic from North Sea ports and from destinations in Europe.

Recreational diving is mainly undertaken on small rigid inflatable boats, sometimes launched from various slips along the coast. The opportunities are mainly limited to slack-water wreck diving and drift diving, due to the high tidal streams and, especially in the south of the region, poor underwater visibility.

Sea angling activities are beach and small-boat based. Locally owned charter boats also provide wreck fishing opportunities, sailing mainly from Great Yarmouth, Southwold and Lowestoft, as well as Aldeburgh and Ipswich. The main target species of recreational anglers are cod, bass, skates and rays and whiting. Cod may be caught both from the shore (beaches, piers, harbours, rocks) or fished from a boat. They are caught throughout the year in the North Sea but are primarily a winter species in the East Coast REC Study Area, with the main season extending from October to February (Ford, 2002).

School bass may be caught around the south and west coasts for most of the year, with the exception of February, when the weather is coldest. Larger individuals are caught inshore from April until late October or November. Fishing for bass on the East coasts tends to take place between May and October. Bass are caught over a variety of beach types from surf beaches to gravelly beaches. They are also found around pier pilings and stone breakwaters and off rocks and deep gullies (Pickett and Pawson, 1994). Boat angling tends to be more localised than shore fishing, as there is a need for good access to the sea via harbours or slipways. There are no data on the number of recreational anglers that fish in the East Coast REC Study Area, nor estimates of the catches or landings made by these anglers.

Figure 2.64 Traffic approaching Burgh Castle on Breydon Water Estuary near Great Yarmouth. © Crown Copyright 2011.

Marine Aggregate Levy Sustainability Fund MALSF

2.11 Aggregates

Sand and gravels dredged from the seabed (marine aggregates) are an important source of high-quality raw material to the UK construction industry and for use in coastal defence. In England and Wales, marine aggregates account for about 20% of total sand and gravel supply (Highley *et al.*, 2007). Licences for marine aggregate dredging fall into seven regions around the UK coastline, the majority of them concentrated off the East and South coasts of England.

The East Coast region is located within the East Coast REC Study Area (the East Coast region in this aggregates section refers to the region as defined by The Crown Estate in their aggregate statistics, www.thecrownestate.co.uk/dredge_areas_statistics). Licensed extraction first began in 1969, with a maximum annual extraction level, recorded in 1996, of 10 million tonnes. A total of 89 million tonnes of marine sand and gravel was dredged from Crown Estate licence areas in the East Coast region between 1998 and 2007 (The Crown Estate and BMAPA, 2008).

The East Coast region has 14 aggregate production licences, which are held by five operating companies (Figure 2.65). The majority of these are located together in the centre of the East Coast REC Study Area, with 1 located to the south. There are an additional 7 areas where applications have been submitted and 11 prospecting areas in the East Coast region, most of which are located within the main central block, with one exception that spans part of the East Coast REC Study Area boundary to the south of the area.

However, annual aggregate extraction volumes from all East Coast licensed areas have shown a steady decline in recent years to around 7 million tonnes, reflecting a reduction in permitted extraction volumes (Figure 2.66). The area of seabed licensed also decreased between 1998 and 2007, with 146.85 km² of area being surrendered and only 5.23 km² of new area licensed, resulting in a net decrease of 141.62 km².

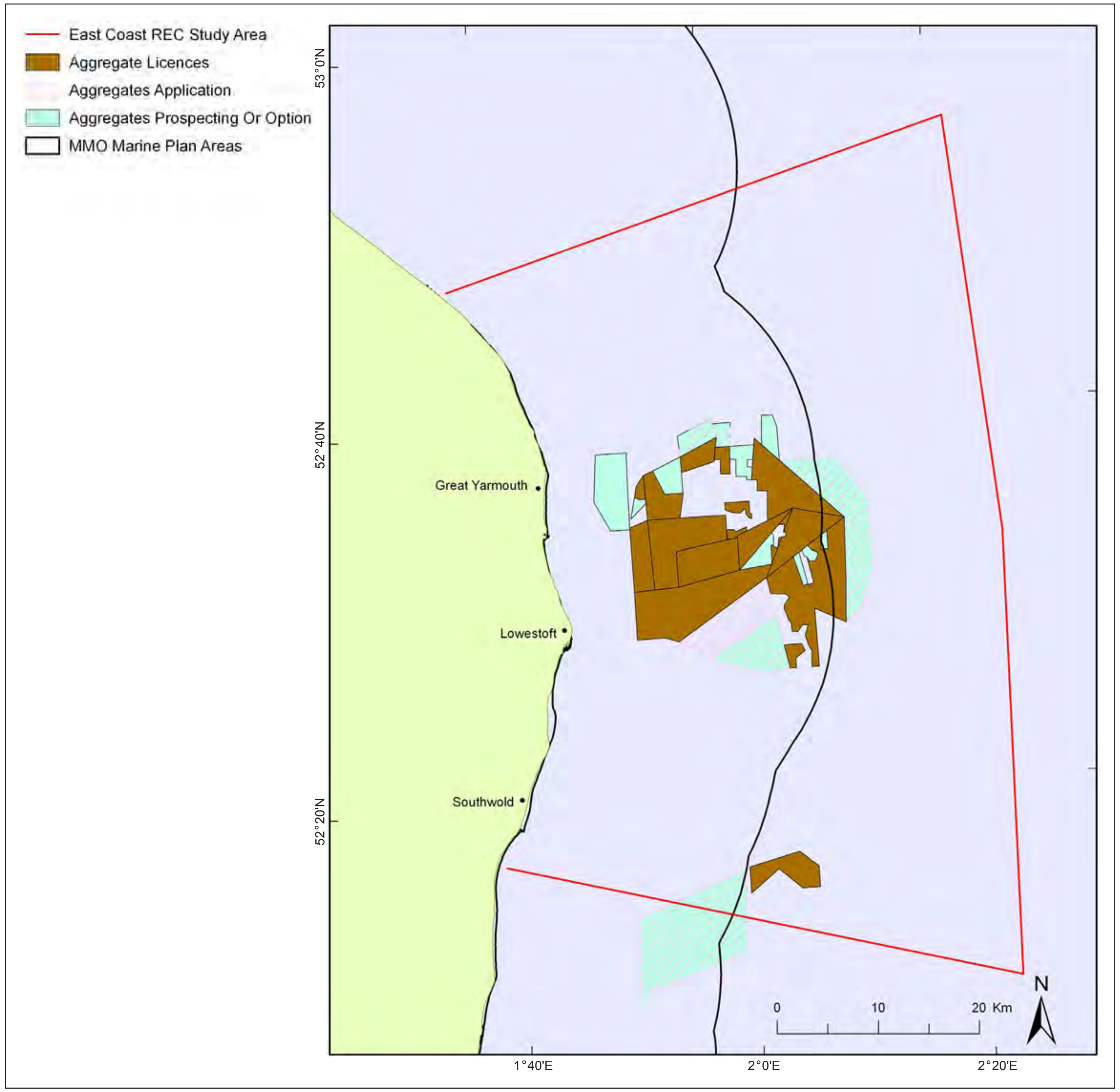


Figure 2.65 **The location of aggregate activity, and current and future licence and extraction areas, within the East Coast REC Study Area and Marine Plan Zones.**

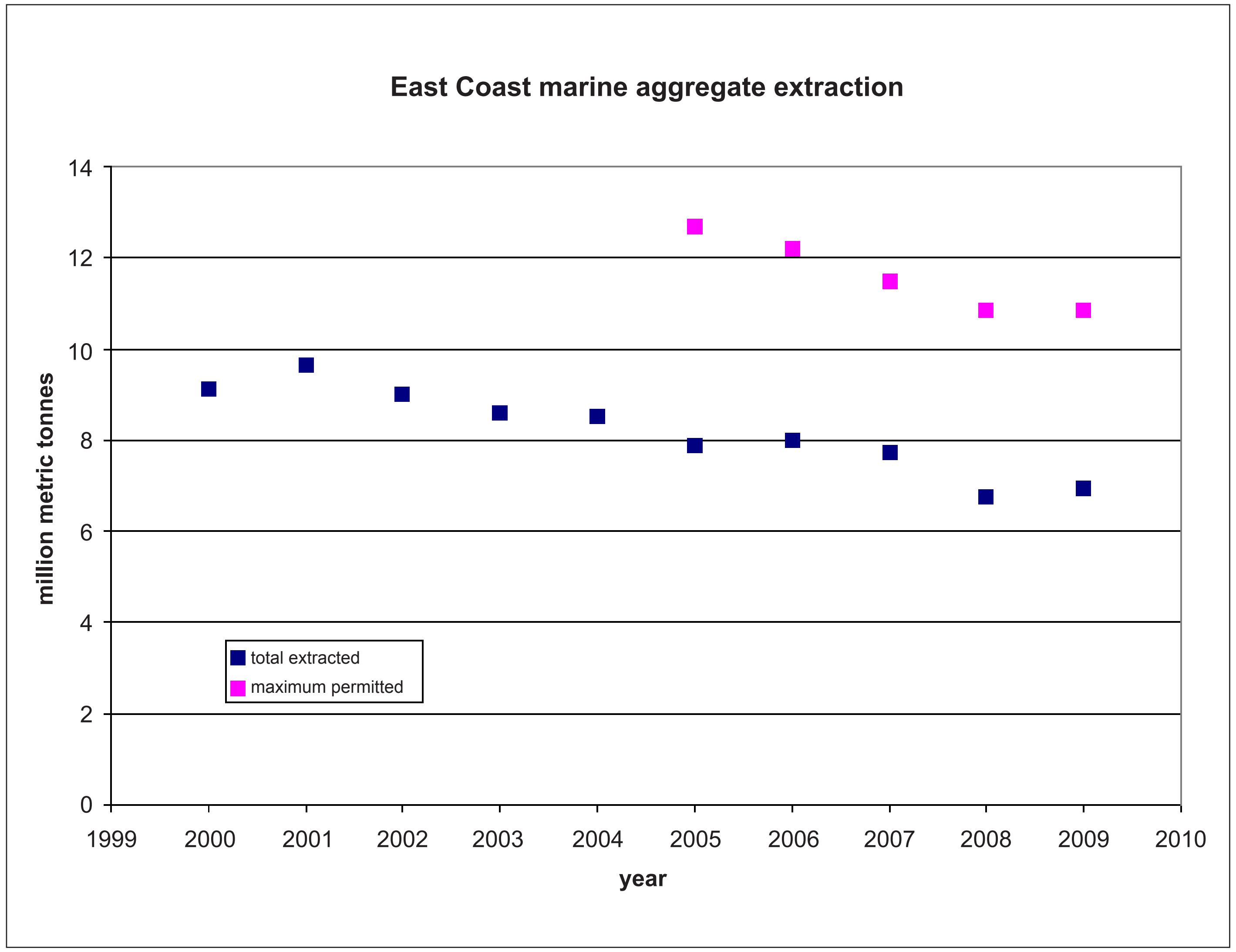


Figure 2.66 Volumes of aggregate extracted in recent years from the Cross Sands/ Great Yarmouth and Southwold licensed areas, together with the annual volumes for permitted removal. Data from The Crown Estate, www.thecrownestate.co.uk/dredge_areas_statistics.

The cumulative dredging footprint – the overall footprint of marine aggregate dredging activity over time – was determined for the East Coast region to show the overall extent of dredging over the 10 yr period between 1998 and 2007 (The Crown Estate and BMAPA, 2008). The total area of seabed dredged was 185.51 km². Given the total amount dredged from the area during that period, this represents 28.8 cm of sediment removed, on average, across the area dredged. The cumulative footprint has implications for the potential environmental impacts of the aggregate dredging industry, and these impacts have been investigated in the East Coast REC Study Area by Cooper *et al.* (2007) and Barrio Froján *et al.* (2008).

In 2009, the East Coast region produced 6.93 million tonnes, which accounted for 34.3% of the total marine aggregate production in England and Wales during that year. The total area licensed for aggregate extraction in the East Coast region in 2009 was 266.52 km², of which 158.17 km² was actively dredged. Dredging took place within 47.26 km² (18.25%) of the licensed area, and 90% of that dredging activity took place from 16.38 km² (The Crown Estate and BMAPA, 2010).

In 2009, the majority of the aggregate dredged for the construction industry from the East Coast region was landed at wharves located along the Thames and Medway rivers (3.01 million tonnes) and wharves in mainland Europe (2.47 million tonnes). Only 0.02 million tonnes was landed at wharves on the East Coast (The Crown Estate and BMAPA, 2010).

The location of these licensed and application dredging areas is dictated largely by the quality and quantity of suitable sand and gravel, whilst legislation, environmental issues, fisheries, conservation and shipping are also a consideration. Marine sand and gravel is a relatively finite resource, and new resources need to be found to ensure aggregate resources are maintained at a regional and national planning level. Prospecting area licences are issued by The Crown Estate to companies, allowing them to undertake geological and geophysical surveys to assess potential aggregate resource areas.

2.12 Disposal sites

In the United Kingdom, dredged material disposal to sea is currently licensed under Part II of the Food and Environment Protection Act 1985 (FEPA). FEPA controls deposits in the sea below MHWS tides in order to protect human health, the marine environment and legitimate uses of the sea. There are over 150 sites designated for the disposal of dredged material around England and Wales. These are located off the coast of the mainland, generally within a few miles of the coast or, in some cases, within estuaries. Eleven disposal sites exist within or partially within the East Coast REC Study Area (see Figure 2.67). These sites have well-defined boundaries, and the type and amount of dredged material deposited each year is monitored.

Types of material

Records exist for four types of material that have been deposited at licensed sites in the East Coast REC Study Area. The types of materials are as listed below:

- *Capital dredgings (CD)*. This is material that is dredged from the seabed, generally for construction or navigational purposes, either in an area or down to a level (relative to

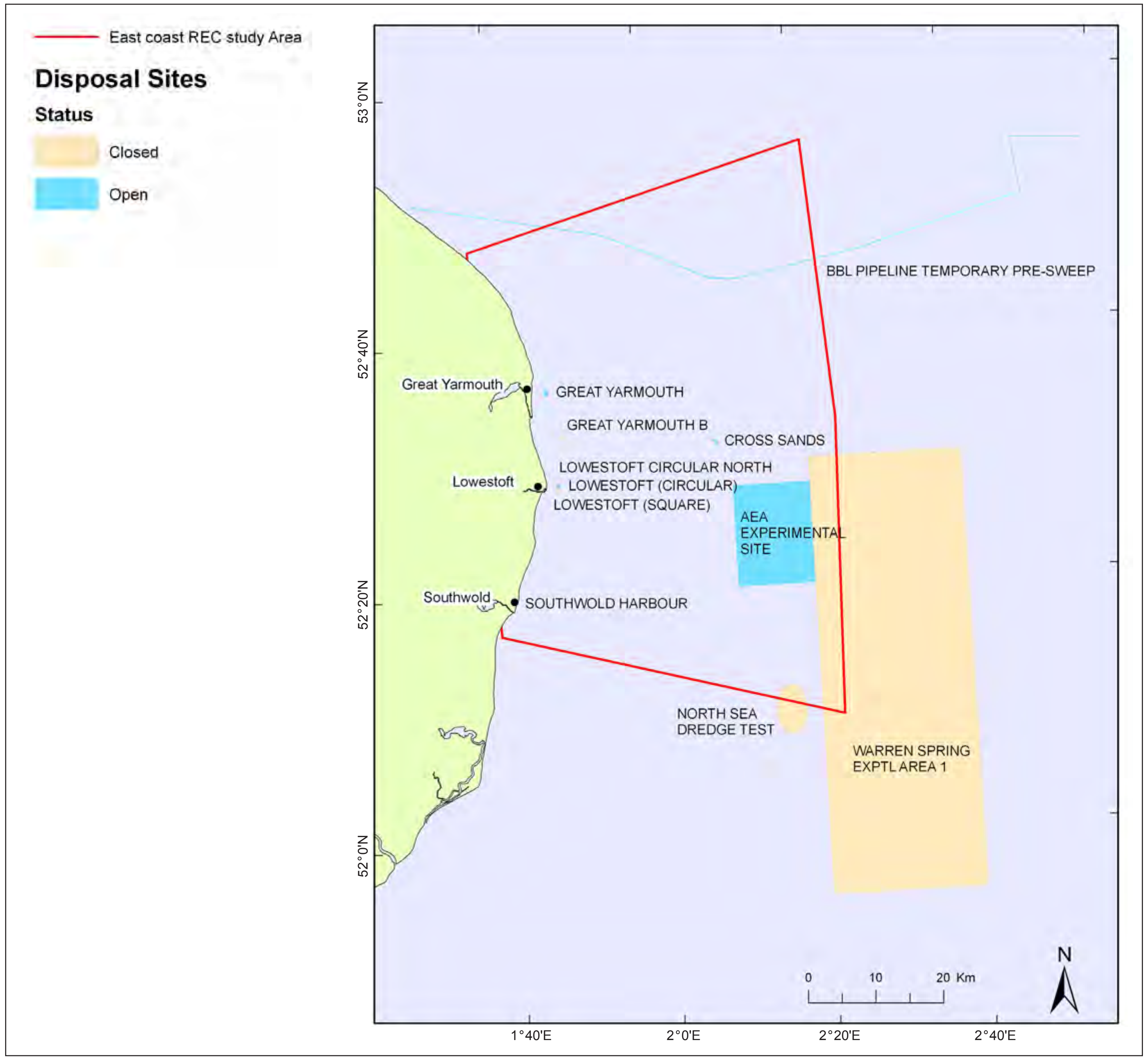


Figure 2.67 Licensed disposal sites in the East Coast REC Study Area region (Cefas data).

ordnance datum) not previously dredged during the preceding 10 years.

- *Maintenance dredgings (MD)*. This is material that is dredged from the seabed, predominantly from areas such as ports, marinas and navigation channels, which has built up through natural siltation processes (ie, mud or sand). It only applies to material from areas that have been dredged within the last 10 years.
- *Re-deposited dredgings (RD)*. This is material that originates from aggregate dredging and is deposited back on to the seabed as it does not meet the necessary quality requirements.

In addition to dredge material, another deposit that has previously taken place in the area is the release of tracers and reagents for experimental purposes.

- *Tracers and reagents (T)*. These are dyes and bacteriophages that are deposited into the marine environment for the purposes of tracking the movement of water currents or discharges.

Licensed disposal sites

There are 11 disposal sites in the East Coast REC Study Area (Figure 2.67) though only 4 are currently open to receive material. Dredged material disposal records for the period 2000–09 shows that the total amount of material received by all disposal sites was just over 2 million tonnes (Table 2.8). The majority of the material disposed was Maintenance dredgings (65%) followed by Capital dredgings (34%) and Re-deposited dredgings (1%). Figure 2.68 shows the annual amounts disposed to each of the four open disposal sites from 2000 to 2009.

The most heavily used disposal site over that 10 yr period was Lowestoft Circular North (TH005) which received 54% of the dredged material deposited in the East Coast REC Study Area. A total of 1.094 million tonnes of Maintenance dredgings was disposed of at this site during this period.

The BBL Pipeline (HU202) received 34%, just under 675,000 tonnes, of the material deposited over that 10 yr period. However, this was capital material that was disposed between 2006 and 2007

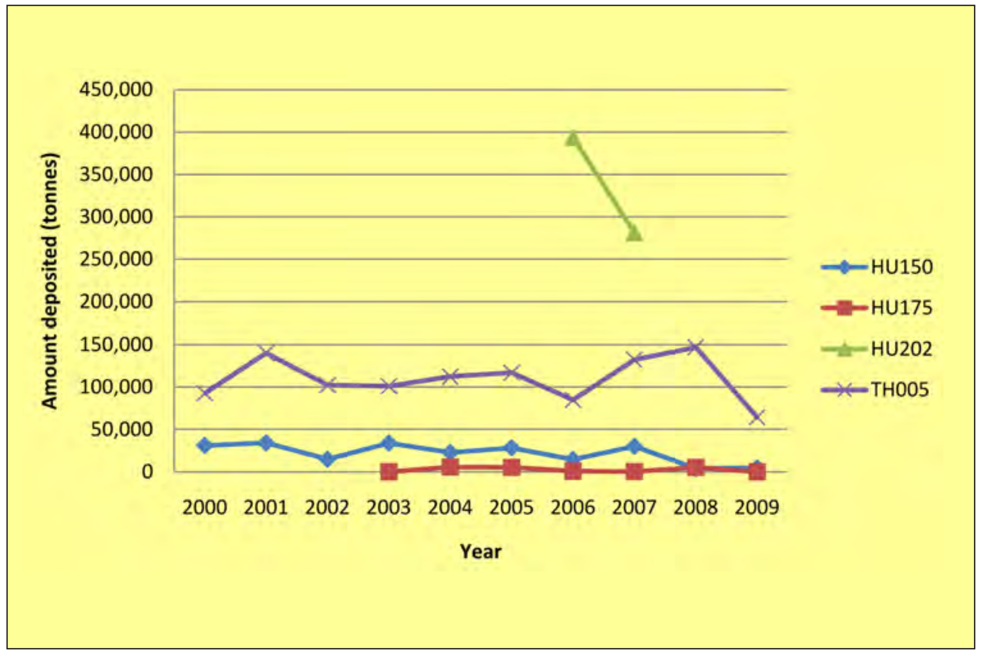


Figure 2.68 **Annual disposal quantities to each open disposal site between 2000 and 2009.**

Disposal site code	Disposal site name	CD	MD	RD	Grand total	% of total EC REC disposed
HU150	GREAT YARMOUTH		218,174		218,174	10.89
HU175	CROSS SANDS			17,004	17,004	0.85
HU202	BBL PIPELINE TEMPORARY PRE-SWEEP	674,892			674,892	33.68
TH005	LOWESTOFT CIRCULAR NORTH		1,093,989		1,093,989	54.59
Grand total		**674,892**	**1,312,163**	**17,004**	**2,004,059**	**100.00**

Note: CD = Capital dredgings, MD = Maintenance dredgings, RD = Re-deposited dredgings; EC REC - East Coast REC Study Area.

Table 2.8 **Type and total amount (wet tonnes) of dredged material disposed to each of the four open disposal sites in the East Coast REC Study Area during the period 2000–09.**

Disposal site code	Disposal site	Year closed	Waste ype			
			CD	MD	RD	T
HU150	GREAT YARMOUTH		X	X		
HU155	GREAT YARMOUTH B	1983	X	X		
HU160	LOWESTOFT (CIRCULAR)	1999		X		
HU175	CROSS SANDS				X	
HU202	BBL PIPELINE TEMPORARY PRE-SWEEP		X			
NS111	NORTH SEA DREDGE TEST	1999			X	
TH005	LOWESTOFT CIRCULAR NORTH		X	X		
TH010	LOWESTOFT (SQUARE)	1990		X		
TH026	AEA EXPERIMENTAL SITE	1998				X
TH075	WARREN SPRING EXPTL AREA 1	1998				X
TH020	SOUTHWOLD	pre-1998	ND	ND	ND	ND

Note: CD = Capital dredgings, MD = Maintenance dredgings, RD = Re-deposited dredgings, T = Tracers, ND = No data.
(Data taken from the marine licensing database owned by the MMO.)

Table 2.9 **Types of dredged materials received during the life of each disposal site in the East Coast REC Study Area, with the year the site was closed (if applicable).**

only, as this site was created specifically for one licence for the disposal of material associated with pipeline works.

The Great Yarmouth disposal site (HU150) received maintenance dredged material only in each of the years from 2000–2009, totalling 218,174 tonnes. This represents 11% of the total material disposed in the East Coast REC Study Area. Cross Sands (HU175) received the least amount of material, 17,004 tonnes of re-deposited dredgings (less than 1%) over the period 2003–09.

The majority of disposal sites that are no longer in operation were closed in the 1990s, with the exception of Great Yarmouth B (HU155) which was closed in 1983 (Table 2.9**).**

The information on disposal sites has been provided by Cefas' Regulatory Assessment Team. The data were sourced from the Marine Consents Management System (MCMS), which is owned by the FEPA licensing body, the MMO.

2.13 Ports and shipping

Ports

There are three main ports located within the East Coast REC Study Area: Great Yarmouth, Lowestoft and Southwold (Figure 2.69). Historically these ports were the centre of the largest herring fishery in the world. However, the decline of the fisheries means that these ports are not as busy as they once were. Great Yarmouth and Lowestoft handle both foreign and domestic goods, and the tonnages are given in Table 2.10.

Great Yarmouth port is the largest of the three ports, and in 2010 the newly constructed Outer Harbour became operational, making it the closest deep-water facility to Northern Europe. The new Outer Harbour is a modern multipurpose facility supplementing the existing river port and has been designed to facilitate a wide range of vessels including the latest generation of offshore support vessels, freight ferries, self-discharges and

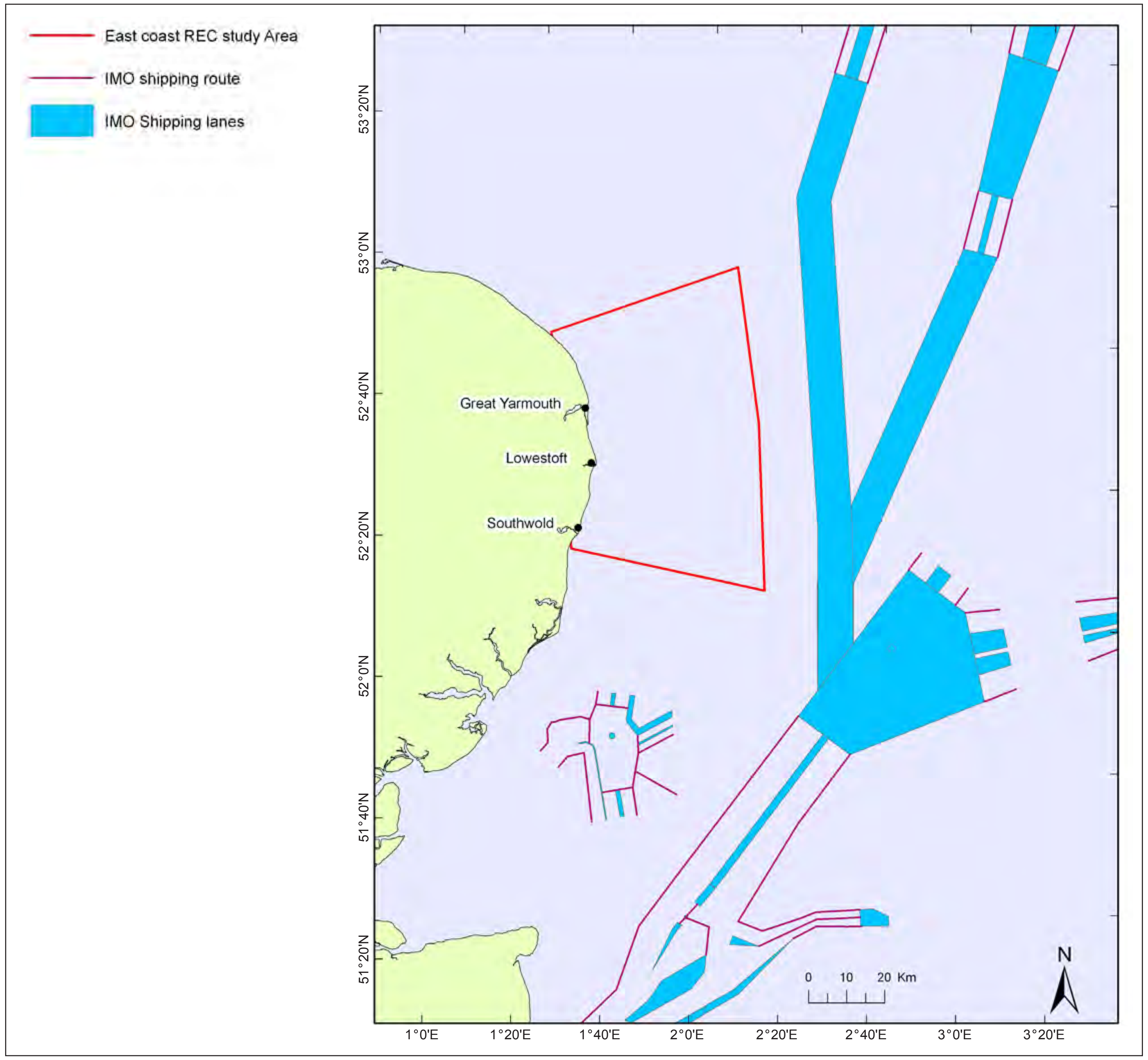


Figure 2.69 The location of the East Coast REC Study Area in relation to main shipping routes and ports. (Shipping routes data from Ian McConnel ShipAIS.)

Port	2006	2007	2008
Great Yarmouth (tonnes × 10^3)	950	900	784
Lowestoft (tonnes × 10^3)	323	237	169
All UK traffic (tonnes × 10^6)	583.31	581.50	562.16

Table 2.10 Foreign and domestic goods handled by Great Yarmouth and Lowestoft ports 2006–08 (Department of Transport, 2009).

trade car carriers. The port is also the United Kingdom's number one offshore support port to the southern North Sea.

Lowestoft port has a wide range of facilities for handling containers, bulk and general cargoes. The port is a major centre for servicing the offshore oil, gas and rapidly expanding renewable-energy industries. Rig structures and modules are fabricated at facilities located in both inner and outer harbours of the port. Extensive ship-repair facilities, including a dry dock and slipways, are also located at the port (Ports and Harbours of the United Kingdom; www.ports.org.uk). Lowestoft is also a designated fishing port with a modern fish market, auction and processing facilities, serving a fleet of inshore and deep-sea vessels. The port is also used by the leisure industry and hosts a 140-berth marina with a wide range of facilities (Ports and Harbours of the United Kingdom, www.ports.org.uk).

Southwold Harbour is the smallest of the three ports in the area. Activities at the port are fishing (on a smaller scale than Lowestoft) and tourism, with berthing facilities, river trips and a small ferry service to Walberswick. Many old fishing sheds have been converted into restaurants, and current plans for Southwold Harbour include redeveloping the fishing quay-side facilities. In October 2010, Southwold Harbour secured £1.22 million of European funds to regenerate the harbour area and boost the local fishing industry.

Shipping

Shipping routes

The East Coast REC Study Area is located 57 km from the main shipping routes, primarily the western end of the Northern Sea Route (Figure 2.69). This is a shipping lane running from the Atlantic Ocean to the Pacific Ocean along the Russian Arctic coast from the Barents Sea, along Siberia, to the Far East.

Ship to ship transfer

Ship to Ship (STS) transfer – the transfer of oil from one ship to another – takes place within the East Coast REC Study Area in an area off Southwold and Lowestoft. In recent years, there has been an increase in STS transfers in UK waters due to new trading patterns in Europe and Russia, particularly the increase in trade through European waters of Russian crude oil and heavy and residual fuel oils. The area off Southwold is presently England's only STS transfer area.

Currently, there is no UK legislation controlling STS operations inside UK territorial waters. To date it has been controlled through voluntary measures and guidelines, and under these arrangements offshore STS transfers are only conducted in an identified area spanning both the United Kingdom's territorial waters and the Exclusive Economic Zone (EEZ) off Southwold. Service providers must notify the Maritime and Coastguard Agency (MCA) at least 72 hours in advance of the commencement of an intended transfer operation.

New regulations – The Merchant Shipping (Ship-to-Ship Transfers) Regulations 2010 – have been proposed in the United Kingdom and are due to come into force in 2011. They aim to control STS transfers in UK waters, ensuring that all transfers within the United Kingdom's 12 nautical-mile territorial sea limit take place within harbour areas where additional resources are available to combat any pollution incidents that may occur. More information on STS transfer can be found on the MCA and the Oil & Gas UK Environmental Legislation websites:

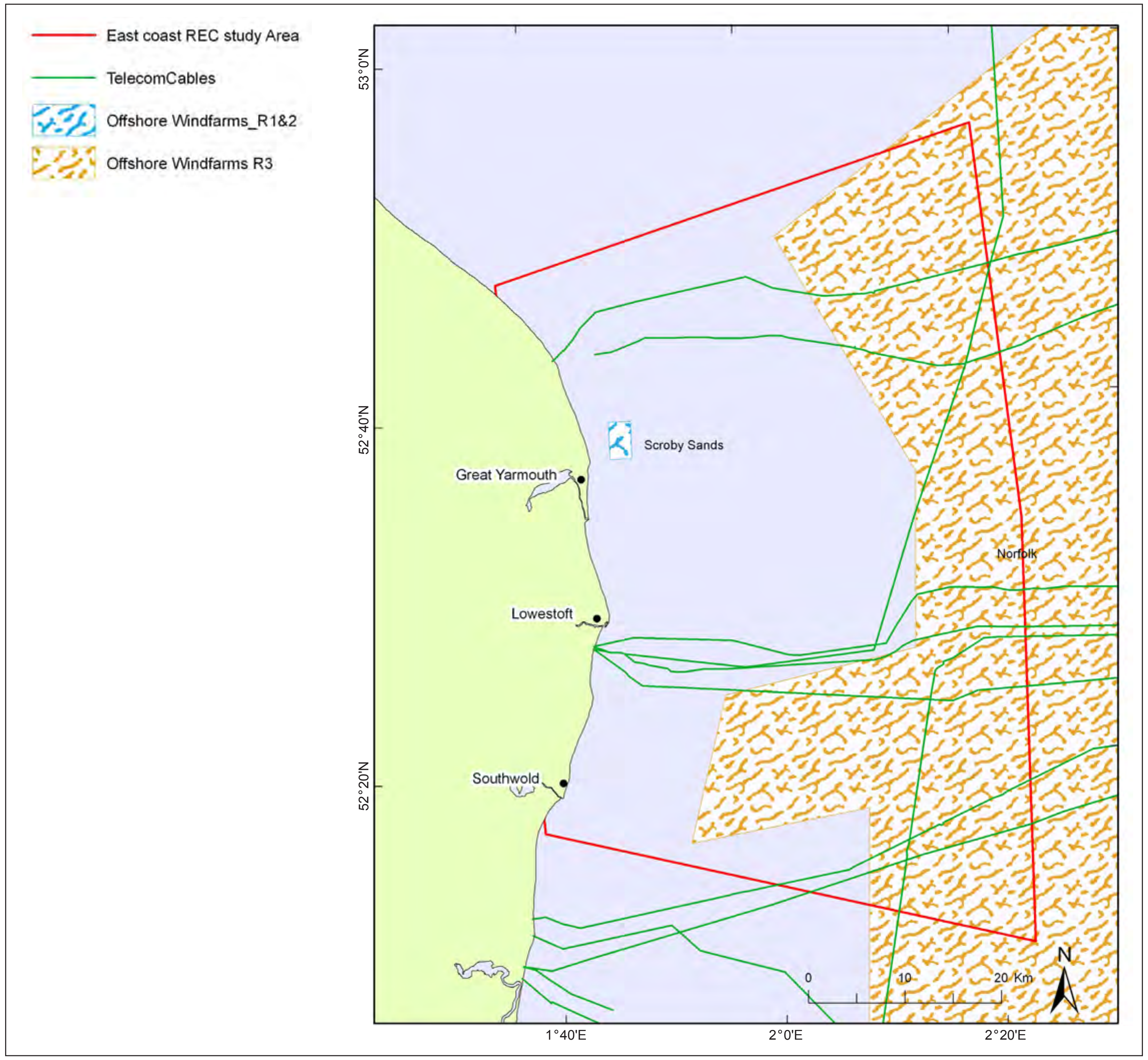


Figure 2.70 The location of the offshore windfarm sites and cables in the East Coast REC Study Area. (Windfarm layer from The Crown Estate, cable data from Kingfisher Information Service – Cable Awareness – at www.kisca.org.uk)

- www.mcga.gov.uk/c4mca/mcga07-home/shipsandcargoes/consultations/mcga-currentconsultations/consultations-sts.htm
- www.ukooaenvironmentallegislation.co.uk/Contents/Topic_Files/Offshore/ship%20to%20ship%20transfers.html

2.14 Offshore windfarms

The United Kingdom has a target to produce 10% of its energy from renewable resources by 2010 and 20% by 2020. In 2000, The Crown Estate opened Round 1 for licensing of UK offshore windfarm development. It was undertaken as a demonstration round for sites of up to 30 turbines, the purpose of which was to provide developers with the opportunity to gain expertise in the technological, environmental and economic aspects associated with offshore windfarms. The sites were largely chosen by the developers, and 12 were granted licences.

The Scroby Sands windfarm was developed under Round 1 and is situated within the East Coast REC Study Area off Great Yarmouth (Figure 2.70). The windfarm has been generating electricity since July 2004. Thirty turbines are located ~2.5 km east of Great Yarmouth, in 6–12 m water depth, positioned on a shore-aligned sandbank. Recent multibeam surveys of the area surrounding the windfarm suggest that significant southeasterly scours are forming behind the turbines, reaching up to 400 m in length, as the mobile sands and gravels react to the changes in the hydrodynamic regime across the sandbank The scour pits (Figure 2.71) have the potential for cumulative impact; however, overall sandbank morphology was found to be unaffected (Cefas, 2004).

The Crown Estate launched its Round 3 leasing programme in June 2008, for the delivery of up to 25 gigawatts (GW) of new offshore windfarm sites by 2020. There are nine development zones around the United Kingdom, one of which, Zone 5 “Norfolk”, overlaps the East Coast REC Study Area (Figure 2.70). These zones were selected following a Strategic Environmental Assessment (SEA) programme, conducted by the Department for Energy & Climate

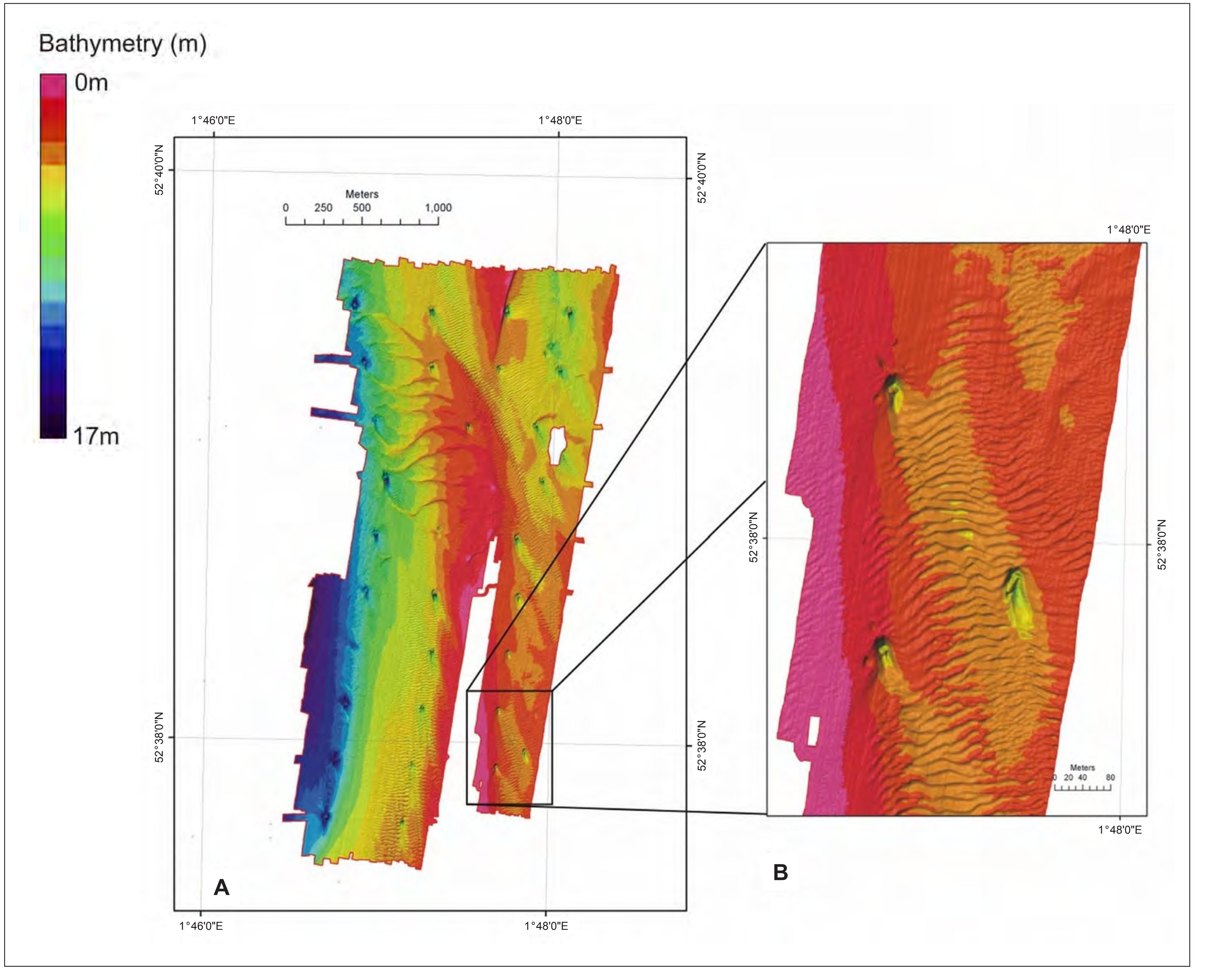


Figure 2.71 **Multibeam bathymetry image from Scroby Sands showing (A) an overview of the Scroby Sands windfarm, with an enlargement (B) of the effects on the seabed geomorphology from three of the turbines.**

Cable	Operator	Type	UK Landfall	Route
ATLANTIC CROSSING 1 (AC1) Seg.B1	Global crossing	Telecom	DOES NOT LAND IN UK	SENNON TO BEVERWIJK
CONCERTO 1N	Inter route	Telecom	Sizewell	ZANDVOORT TO SIZEWELL
HERMES NORTH	GLOBAL TELESYSTEMS	Telecom	Aldeburgh	ALDEBURGH TO ZANDVOORT
NORSEA COMS 1	NORSEA COMS AS	Telecom	Lowestoft	LOWESTOFT TO NORTH SEA
PANGEA SOUTH-UK/NETH	ASN	Telecom	Lowestoft	LOWESTOFT-EGMOND
REMBRANDT 1	KPN TELECOM BV	Telecom	Lowestoft	CASTRICUM TO LOWESTOFT
UK-GERMANY 5	BT	Telecom	Winterton	WINTERTON TO NORDICH
UK-NETHERLANDS 14	C&W	Telecom	Winterton	WINTERTON TO EGMOND
ULYSSES 2	VERIZON BUSINESS	Telecom	Lowestoft	LOWESTOFT TO IJMUIDEN

Table 2.11 **Submarine cables in the East Coast REC Study Area (data taken from Kingfisher Information Service – Cable Awareness – February 2010 at www.kisca.org.uk).**

Change (DECC). The purpose of this SEA programme was to assess the suitability of UK offshore waters for windfarm development. Whilst The Crown Estate will not be involved in the construction or operation of the windfarm sites, they will work with partners to identify suitable windfarm sites within each zone. By being more involved in programme delivery and zonal management, The Crown Estate will play a larger part in the Round 3 development than in earlier rounds. Progress on the Round 3 development can be followed on The Crown Estate website:

- www.thecrownestate.co.uk/our_portfolio/marine/offshore_wind_energy/round3

2.15 Cables

There are a number of submarine cables that traverse the East Coast REC Study Area (Table 2.11), many connecting the United Kingdom to mainland Europe.

One cable running from Winterton-on-Sea connects the United Kingdom to Germany, whilst another connects the United Kingdom to the Netherlands. With the exception of one cable from Lowestoft, which connects to the platforms in the North Sea, all the remaining cables running through the East Coast REC Study Area connect the United Kingdom to the Netherlands. There is also a trans-Atlantic cable that traverses the East Coast REC Study Area, running from the Netherlands around England through the English Channel, but it does not land in the United Kingdom (Figure 2.70).

2.16 Oil and gas

The licensing of oil and gas exploration and production in Great Britain, its territorial sea and on the UK Continental Shelf (UKCS) (including Northern Ireland) is governed by DECC. The licences are made available within licensing rounds by the Secretary of State. Licences are granted by the DECC to enable the exploration and extraction of hydrocarbon reserves. These licences fall into several categories and include the traditional Seaward Production Licence, the Six-Year Frontier Licence (designed to allow companies to evaluate large areas so they can look for a wider range of prospects), and the Promote Licence, which is a variant of the Seaward Production Licence aimed at small and start-up companies to enable them to attract the necessary operating and financial capacity later. Each licence grants rights over a limited area, for a limited period of time, and has specific terms and conditions attached. Similar to marine aggregate extraction, oil and gas is a finite resource only occurring in certain locations; however, before a licence is granted, other considerations are taken into account, including protection of the environment and the interests of other users of the sea.

Although most of the East Coast REC Study Area has been licensed for hydrocarbon exploration over the last 45 years, it lies south of the extensive gas fields of the southern North Sea, and almost all of the area has since been relinquished (Figure 2.72). One of the first gas discoveries in the UK sector of the North Sea – Camelot, in November 1967 – is located to the north-eastern edge of the East Coast REC Study Area.

Currently two licence areas – Block 53/2B and Block 52/5B – and the active gas field “Arthur” intersect the northern boundary of the East Coast REC Study Area (Figure 2.72). A sub-area of Block 53 was surrendered at the end of the previous round, No. 25. There are eleven marine oil wells and one associated pipeline within the East Coast REC Study Area. Only four wells are located within a currently licensed block; however, none has a current licence to operate.

With the advancement in technologies and the changes in economy, there is the potential for old oil and gas wells, where oil was previously inaccessible or not economically viable, to be re-opened and further exploited.

2.17 Future management

The Marine and Coastal Access Act 2009 (the “Act”) received Royal Assent on 12 November 2009 and aims to help the UK government achieve its vision by putting in place better systems for delivering sustainable development of the marine and coastal

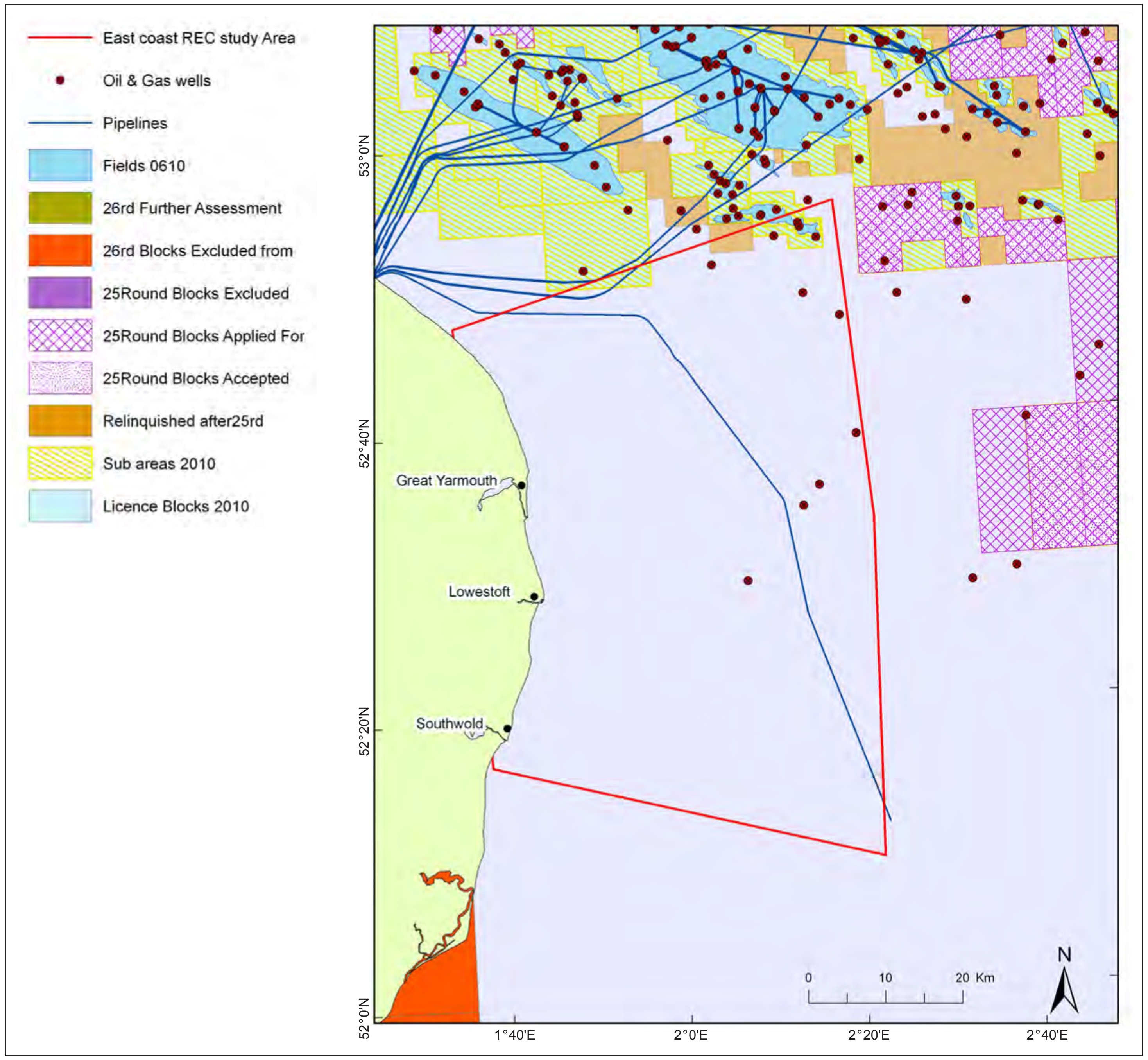


Figure 2.72 The location of oil and gas activity in the East Coast REC Study Area (oil and gas layers from DECC).

environment. The Act intends to do this through a new system of marine planning, streamlining the licensing processes and improving marine conservation and marine fisheries management. These will all be overseen by the new delivery body, the MMO, established in April 2010. The MMO has brought together the delivery of several marine management functions into one organisation incorporating the work of the Marine and Fisheries Agency (MFA) and acquiring several new roles, principally marine-related powers and specific functions previously associated with the DECC and the Department for Transport (DfT).

Marine planning

Part 3 of the Act sets out the framework for a new system of marine planning for UK waters in order to contribute to the achievement of sustainable development of the marine area. The new system of marine planning will have two stages: the production of a national statement of marine policy – The Marine Policy Statement (MPS) – and a series of sub-national Marine Plans to cover smaller Marine Plan areas. The Act divides the UK marine area into marine planning regions, and the MMO has responsibility for preparing marine plans in the English inshore and offshore regions in accordance with the policies and objectives set out in the MPS. The East Inshore and East Offshore areas are the first areas in England to be selected for marine planning. The East Inshore area includes a coastline that stretches from Flamborough Head to Felixstowe. The East Coast REC Study Area lies within the East Offshore and Inshore planning areas (Figure 2.65).

Marine licensing

The Act also introduces a new marine licensing system, the overall objective of which is to effectively regulate sustainable development in the marine environment. It should allow sensible and necessary development to go ahead but in a manner that minimises adverse impacts on the environment, human health and other legitimate uses of the sea. The new marine licensing system is to be established in April 2011, and it aims to introduce a streamlined, transparent and consistent marine licensing system, to make it faster, cheaper and simpler to license marine developments. This includes replacing licences and consents required under the Food and Environment Protection Act 1985, the Coastal Protection Act 1949 and the 2007 Marine Minerals Regulations with a single Marine Licence.

The new licensing and marine planning systems will enable more strategic decisions to be made about what activities are permissible in the marine environment and where they should take place. They should also simplify the system for managing our use of natural resources and controlling activities that impact upon them.

More information on The Marine and Coastal Access Act 2009 can be found on the Defra and MMO websites:

- ww2.defra.gov.uk/environment/marine/mca/
- www.marinemanagement.org.uk/index.htm

3 Survey strategy and methodologies

The ability of acoustic techniques to discriminate seabed features and different sediment types presents the prospect of making accurate and reliable seabed maps that can support marine spatial planning. To maximise the value of such resulting seabed maps, it is necessary to adopt a structured approach to survey design that can be adapted to meet the needs of the investigation and, in particular, is tailored to target features at different spatial scales (Coggan, 2006; Boyd *et al*., 2006; Coggan *et al*., 2009). During the execution of surveys as part of the East Coast REC programme, a nested survey design was therefore adopted, expanding and developing upon existing data-sets for the region (see, eg, James *et al*., 2007, 2010). Previous surveys of the East Coast REC Study Area employed a relatively coarse interpretation of acoustic data to classify seabed sediments (Harrison, 1988; Pantin, 1991). To supplement this, the current programme expanded the coverage of acoustic data-sets and undertook detailed interpretation, supported by existing geological, ecological and archaeological data-sets. The acoustic surveys of the East Coast REC Study Area were also complemented by ground-truthing surveys, to collect additional geological, ecological and archaeological data-sets, both to provide a holistic assessment of the seabed across the East Coast REC Study Area and to characterise important isolated fine-scale features (see Kostylev *et al*., 2001).

Summaries of the approach, methodologies and equipment used during these new surveys are provided below. Further information can be found in the full cruise reports (CEND 18/08 and CEND 09/09) for these surveys, which are provided in Appendix B.

3.1 Survey planning

Prior to the acquisition of new data and samples under this project, a data review was conducted to investigate the amount and quality of existing acoustic, biological, geophysical and archaeological data-sets from the East Coast REC Study Area. This information was used to identify where important gaps in knowledge existed and enabled the development of survey strategies that most effectively addressed them. The existing geophysical base layers provided useful underpinning data-sets to direct the survey strategy. Such data-sets also facilitated the decision-making process regarding individual sample-site selection and the identification on a site-specific basis of the most cost-effective survey and sampling strategies (see Coggan *et al*., 2007). However, the nature of the existing geophysical data in this area was variable in coverage and quality. It was clear that additional geophysical work was needed to characterise the area. Geophysical data enables rapid characterisation of large areas of seafloor, providing information on physical attributes of the seafloor, sub-seabed features and the footprint of any anthropogenic activities. There was a significant volume of existing biological data; however, this had been collected over a number of years and was heavily skewed in its distribution towards areas targeted for aggregate extraction. A significant number of the biological studies were also lacking in broad-scale remote observations and data. Comprehensive information was therefore considered necessary to provide a high-quality assessment of habitats and species of nature conservation importance. Furthermore, although the East Coast REC Study Area was known to have significant archaeological potential, with previous finds ranging from the Palaeolithic to the Second World War, information on the regional context was lacking. Therefore, to produce robust seabed maps of the East Coast REC Study Area, it was judged that the acoustic data needed to be complemented by co-located modern data on the physical nature of the seabed, on the biological communities it supports and as confirmation of the heritage value of the area.

Once an overall understanding of the area had been established, it was decided that a two-stage survey strategy would be most appropriate. Consequently, an initial survey collected a suite of geophysical data-sets that were used, along with existing data, to design a subsequent, separate ground-truthing survey.

The overall design and conduct of the two data-gathering surveys took into account a wide range of factors, including:

- The overall aims of the project.
- The regional scale of the total area to be surveyed.
- Isolated, small-scale features of interest.
- Navigational limitations forced by the seabed topography.
- Equipment specification.
- The resources available.
- Areas of interest identified by geologists/archaeologists/biologists during the survey.

3.2 Geophysical survey

3.2.1 Survey design

Given the overarching factors stated above, a regular grid-line pattern of acoustic survey design, with average spacing between the lines of 2.7 km, was selected. This design was judged to provide sufficient coverage across the entire East Coast REC Study Area to allow a holistic assessment of habitats but also sufficient data resolution to support subsequent model development and testing. The geophysical survey was conducted onboard RV *Cefas Endeavour* during September and October 2008 (CEND 18/08). Twenty N–S corridors (total of 2,322 km) were aligned with the tidal vectors to assist line-keeping during operations. This corridor orientation was also generally aligned with existing BGS N–S geophysical lines, which would be used to assist the final interpretations. Twenty-six E–W lines (total of 993 km) were placed perpendicular to the N–S lines. These lines were also aligned with existing BGS survey lines. Each N–S corridor was composed of two survey lines: a primary line, and a parallel line offset from it by 100 m. Each primary N–S line was run using multibeam echosounder (MBES), acoustic ground-discrimination systems (AGDS), surface-towed boomer (STB), side-scan sonar and magnetometer. The aim was to survey each N–S offset line in the opposite direction from the primary line, as this would provide acoustic coverage from two reverse aspects along each acoustic corridor. The E–W lines comprised a single line run using MBES, STB, side-scan sonar and magnetometer.

Prior to the survey, the gap analysis revealed sites of particular interest where additional data would be sought. Once the main grid lines had been plotted in the project Geographical Information System (GIS), the existing data that had been produced via the review exercise was plotted over them. This established whether or not priority biological, geological and archaeological considerations had been adequately covered in the design. If particular features of interest did not fall within the swath of the line, some manipulation of the line position was undertaken to bring it close to the features. In some cases, particular areas of interest were not adequately surveyed under the proposed grid design. Where this was the case, additional survey lines were assigned to incorporate these features. These additional lines comprised single lines or high-resolution sets of lines, depending on the scale and nature of the features of interest. These additional lines were surveyed using a varying combination of sensors, depending on the particular objective of each survey (Figure 3.1).

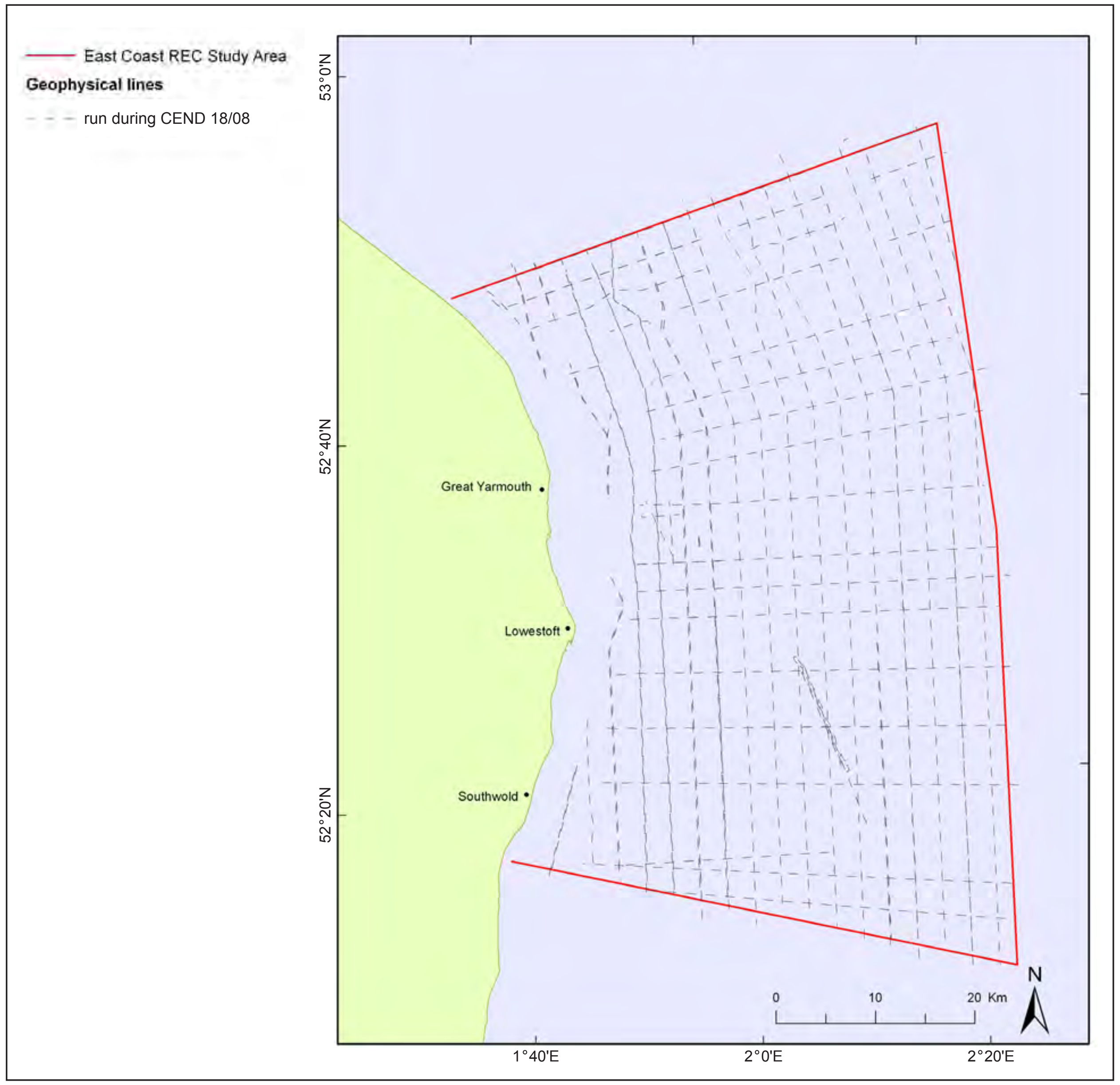


Figure 3.1 Geophysical lines surveyed during CEND 18/08.

3.2.2 Geophysical survey methodology

Multibeam echosounder

Initially, a Kongsberg Simrad™ EM3000D MBES system was used to acquire swath bathymetry data. However, a problem with the processing unit at the start of Leg 2 of the 2008 geophysical cruise resulted in the installation of an EM3002D processing unit. This system was then used for the remainder of the geophysical cruise and for the entirety of the sampling and ground-truthing data acquisition in 2009. Both systems operate at 300 kHz with an angular coverage of 200°.

The MBES heads and sound-velocity meter were mounted on a retractable blade on the RV *Cefas Endeavour*. The blade placed the heads approximately 3.2 m below the vessel hull, thereby reducing the introduction of noise artefacts due to bubble blowdown and wave blanking. The vessel draft, as applied in the Kongsberg SIS™ acquisition software, was measured to millimetre resolution using a Druck PTX 1830™ Depth/Level sensor located in the blade space. Primary navigation and positioning data came from the Fugro Seastar™ Network positioning system. All data acquisition systems deployed during the 2008 survey received the same navigation signal, ensuring consistent positioning across all data types.

The multibeam data were processed using CARIS HIPS™ software, within which the navigation positioning data stream and tidal corrections were applied. Tide gauge data for two primary stations were obtained from the British Oceanographic Data Centre (BODC), giving corrections on a 15 min basis for the entire survey period. Due to the size of the survey area and the complex bathymetry and hydrodynamic regimes surrounding the many sandbanks, 12 additional tide stations were also generated using the TideSOL(© Gardline) software. Following calculation of the Total Propagated Uncertainty (TPU) to IHO Order 1 standard within CARIS, a series of filters were applied to the data (beam rejection, depth and slope filters). A base surface was then computed using the Combined Uncertainty and Bathymetry Estimator (CUBE)

Figure 3.2 **Boomer, side-scan sonar and magnetometer towed sensors (from front to back). © British Geological Survey.**

method, also to IHO Order 1, after which manual cleaning was undertaken and the CUBE surface re-computed. Data were exported as ASCII XYZ and generic sensor format files (.gsf). The ASCII files were taken into IVS-3D Fledermaus Pro™, where high-resolution scene files (.sd) and colour Geotiff's were created. The main multibeam bathymetry grid, consisting of the corridor data acquired in 2008, was gridded at a resolution of 1 × 1 m.

Side-scan sonar

The side-scan sonar data were collected using an Edgetech™ 4200 dual-frequency system and the Edgetech™ Discover software package. The two frequencies acquired were 120 kHz and 410 kHz. Low-frequency (120 kHz) data were acquired at 200 m range; high-frequency (410 kHz) data were acquired at 100 m range. For the high-resolution surveys conducted to underpin archaeological assessment, the data were acquired at 75 m range (both low and high frequency). Data was routed from Edgetech Discover™ software into ISIS™ software, where it was monitored in real-time by shipboard engineers and scientists. All data were stored electronically in .xtf format. The side-scan data were also printed to film in real-time using an Octopus™ High Resolution 120 printer.

Over the greatest proportion of the survey area, the positioning of the towed side-scan sonar sensor (Figure 3.2) was carried out using a Kongsberg HiPAP™ hydroacoustic USBL (Ultra Short Base Line) tracking system, which was fully integrated into the primary GPS. However, where shallow water precluded the use of the USBL system, side-scan sonar positioning was calculated using cable layback. Under both scenarios, the navigation string was applied directly to the data as the fish position.

Surface-towed boomer

An STB was deployed to acquire sub-bottom profiles of the geology at depth. The system incorporated an Applied Acoustics™ CSP-D (2400) high-voltage power supply that fed a high-voltage direct current to a "boomer" plate (transducer) towed astern of the vessel (Figure 3.2). Return signals were received by an EG&G 265™ hydrophone and amplified using a bespoke system incorporating low-pass and anti-aliasing filters with a manually adjustable gain. For the STB, the low cut was set at 458 Hz and the anti-aliasing was set to 4,588 Hz.

The data were recorded using a CODA DA1000™ system, and hard copies of the sub-bottom profiles were also printed using an Octopus™ High Resolution 120 printer. The STB system signal was sampled at 20,000 Hz with 3,000 samples, and was stored as both SEGY (.sgy) and CODA (.cod) formats.

Initially, two bandpass filters were applied to the hardcopy printouts whilst offshore: for the water column filter, a low-cut of 1,500 Hz and a high-cut of 2,000 Hz; for the sub-bottom geological data, a low-cut of 800 Hz and a high-cut of 2,000 Hz. Following assessment of these initial print-outs, the data were replayed and re-printed using a bandpass filter with a low-cut of 1,000 Hz and a high-cut of 2,000 Hz and a seabed filter of 150 Hz. In addition, The Time Varying Gain (TVG) was assessed and modified to maximise the detail at depth within each line, and a trace mix of three traces was applied.

The data were exported from the CODA™ system, and an initial assessment of the navigational quality, data contained within the seismic headers and quality control was conducted in ProMAX™. The data were then imported into Landmark's SeisWorks™ software for interpretation of the sub-surface geological formations. For the archaeological interpretation the data were processed using the CODA™ system.

AGDS: Single-beam acoustic ground discrimination

There are two proprietary AGDS that are commonly used in the fishing and survey industries: RoxAnn™ and *QTC Impact*™, and both were used during the survey (Foster-Smith, 2007). A *QTC*™ system is permanently installed on RV *Cefas Endeavour* and was used in conjunction with an EA600 Kongsberg™ hydrographic sounder operating at 50 kHz. The RoxAnn GroundMaster™ signal processing system was integrated into the same EA600 Kongsberg™ hydrographic sounder used for the QTC™ system. The RoxAnn™ system was installed and calibrated according to the manufacturer's specification and left to run throughout the first survey. Both systems were fed position from a Thales 3022™ DGPS using Fugro Seastar™ differential service. Results from the AGDS systems were used to support outputs from other techniques and are therefore not reported further here.

Magnetometer

A Marine Magnetics Seaspy™ magnetometer (Figure 3.2) system was deployed to survey for magnetic artefacts between 29 and 30 September 2008. Following that, the BGS Marine Magnetics™ Seaspy system was used for the remainder of the survey. Position was applied during post-processing using layback. Data from both systems were logged onto a standard PC using the SeaLINK™ software and were recorded in ASCII format. The data were then processed using GeoMetrics MagPick™ software, to produce XYT files comprising grid co-ordinates (X, Y) and total field strength (T) recorded in nanoTeslas (nT). Each line of data was then processed to remove the regional magnetic field and also any large diurnal variations, which may mask small magnetic anomalies.

3.3 Ground-truthing survey

The ground-truthing survey was conducted onboard RV *Cefas Endeavour* during May and June 2009. The overarching aim of the survey was to validate the data that were collected during the geophysical cruise completed in 2008. This was achieved through the collection of geotechnical samples (ie, vibrocores and Clamshell grabs) and biological samples and data (ie, benthic grabs, camera images, scientific beam trawls and high-resolution side-scan and MBES). Summaries of the approach, methodologies and equipment used during this survey are provided below. Further information can be found in the full cruise report for this survey (CEND 09/09) and is provided in Appendix B.

3.3.1 Geotechnical ground-truthing site selection

Geotechnical ground-truthing sites were selected using data acquired during the 2008 geophysical acoustic survey. The criteria used for their selection were:

- Geological/geomorphological interest.
- Geographical spread across the survey area to enable accurate ground-truthing of a range of sites.
- Potential penetration depths based on sediment type.
- Uniqueness of sub-surface features within the survey area.
- Channels and associated fills.
- Edges of channels.
- Evidence of peat.
- Ravinement surfaces.
- Submerged channels.

Once identified, the sites were ranked according to priority based on:

- Depth of target and possible penetration expected.
- Sediment and bedform distribution (eg, proximity to large sandwaves may prevent coring of the feature if the vibrocore accidentally hits a sandwave crestline).
- Quality of the feature (a number of similar features were chosen, such as formation boundaries near the seabed, and the best example was ranked the highest).
- As a result of this exercise, a total of 39 vibrocore (Figure 3.3) and 19 Clamshell grab sample sites were chosen based on their geological and archaeological value.

3.3.2 Biological ground-truthing site selection

To assist the process of biological site selection, two broadscale maps of the area were produced. One map was based on existing single-beam bathymetry and segmented the region into a set of broad morphological strata. The second map used the acoustic data-sets collected on the geophysical cruise as well as existing BGS particle size data to classify the area into regions based on reflectivity, homogeneity and sediment type. By overlaying the two maps, a set of 56 sites were selected which represented the combined strata. The number of samples within each stratum was weighted based on the spatial extent of each stratum, with larger and less homogenous strata having more samples than smaller and more homogenous strata (for further details of the approach see, eg, Birchenough *et al*., 2010). There were a further 5 sites chosen from inspection of the multibeam echosounder data and side-scan sonar data, which represented sites that appeared to be unusual in terms of fine-scale topography and texture, possibly indicating biogenic activity. These 61 sample sites were ranked as Priority 1 and made up the first tranche (T1) of the biological ground-truthing survey. Further sites were selected partly to reinforce the primary sites with additional samples. However, an emphasis was also placed on areas of backscatter heterogeneity. These additional sample sites made up the second tranche (T2) of the survey. Finally, a third tranche (T3) was devised to include further sampling of the seabed to investigate additional areas or features of interest identified during the survey.

In addition to the sampling activity taking place on the ground-truthing cruise, a number of high-resolution acoustic surveys were undertaken. These were targeted at areas where previous acoustic data suggested that biogenic features may be present, as well as providing wider context for grab and camera samples.

A total of 158 Hamon grab samples were acquired (Figure 3.4), photographic images were collected from 85 camera sites (Figure 3.5) and 128 scientific 2 m beam trawls were processed on board (Figure 3.6). A total of 1,194 km of multibeam data and 698 km of side-scan data were collected (Figure 3.7).

3.3.3 Ground-truthing survey methodology

Summaries of the methodologies and equipment used during this survey are provided below. Further information can be found in the full cruise report for this survey, which is provided as Appendix B.

Positioning

Navigational data were logged using the Tower CEMap™ navigation software, which was linked directly into the ship's primary positioning system, the Fugro Seastar™ Network. All data acquisition systems received timestamps from this navigation signal, ensuring seamless positioning of all data types acquired during the cruise. All steering nodes were defined from the vessel's central reference point (Table 3.1). The co-ordinate system used was WGS84Lat/Lon. The Tower CEMap™ navigation software was used to record fixes for all ground-truthing samples.

Vibrocore

The BGS 6 m vibrocorer (Figure 3.8) is a steel open-frame structure with electro-hydraulic winch retraction, seabed penetration monitoring unit and vibrator motor. The vibrocorer is 7.7 m high, with a 5.5 m span at the extremities of its feet, and weighs 4 tonnes.

The vibrocorer was deployed over the stern of the vessel. On reaching the seabed the vibrator motor was started and the core barrel penetrated the seabed. An echosounder monitored seabed penetration, which was displayed in a time–depth graph on a monitor in the control cabin. Once either 6 m depth was reached, or the penetration curve levelled off with time, the vibrator motor was stopped and the core barrel was retracted. The vibrocorer was recovered on deck and the core barrel removed and carried to the core bench. Navigation data was logged using the Tower CEMap™ software package, which took its data stream from the Fugro Seastar Network positioning system. A manual fix was recorded on the Tower CEMap™ software for each vibrocore station.

At each site, one vibrocore sample was collected in a clear plastic liner, and a second sample was collected in a black liner to preserve the core for later dating using Optically Stimulated Luminescence (OSL). Cores were cut into 1 m length sections onboard and stored appropriately for further assessment. Initial shipboard digital geological core logs were completed using Strater™ software based on examination of core ends, smear slides and the inspection of the cores through the clear liner.

These digital logs were refined once the clear-plastic liner vibrocore samples were split onshore and detail on accessories (eg, shells, wood), lithology (eg, colour, grain size) and lithological

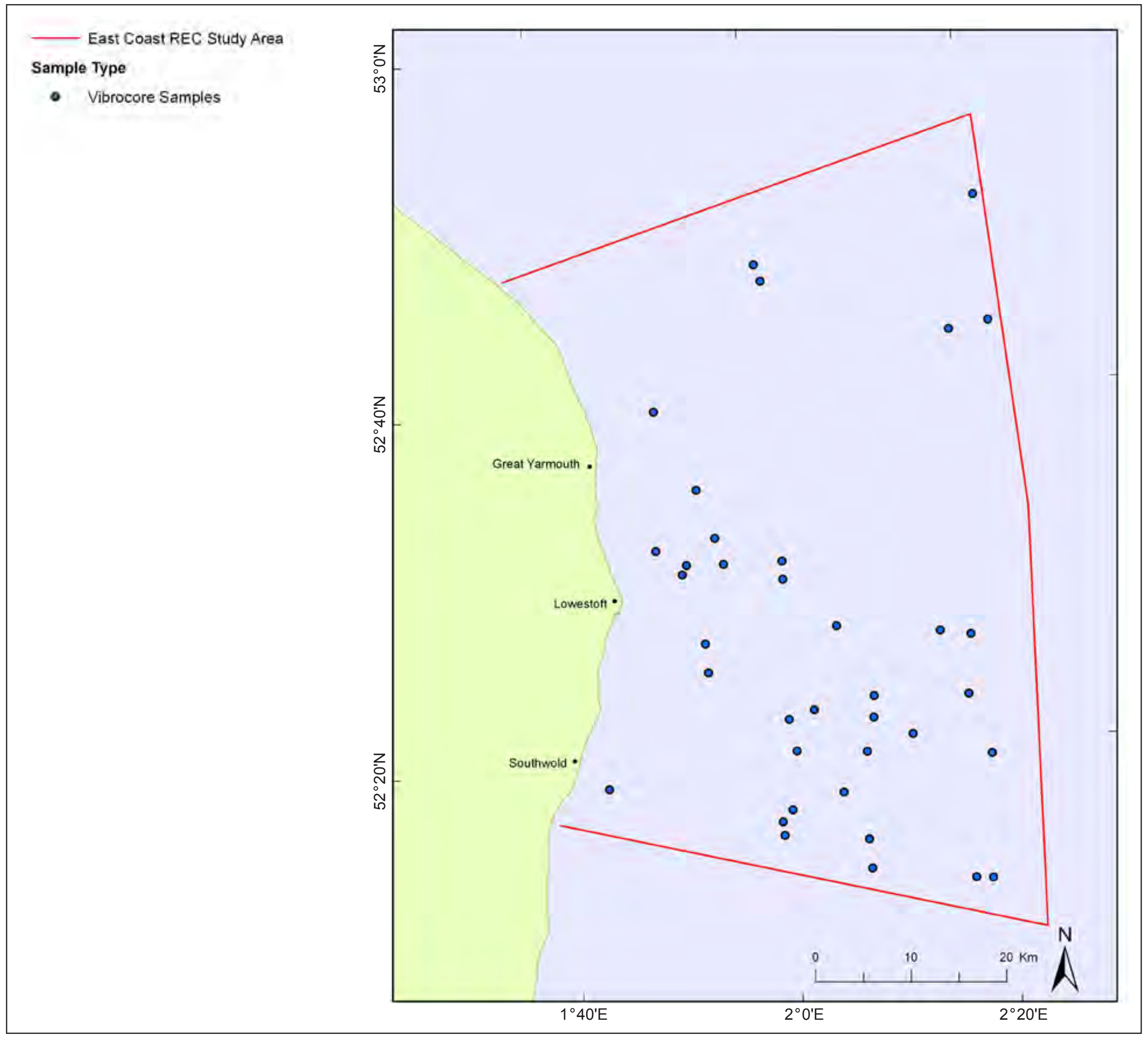


Figure 3.3 Vibrocore sampling sites visited during CEND 09/09.

Equipment	Steering node
6 m Vibrocorer	Stern gantry. Correction applied in real-time by Tower
Clamshell grab	Side gantry. Correction applied in real-time by Tower
Mini-Hamon grab	Side gantry. Correction applied in real-time by Tower
2 m beam trawl	Stern gantry. Cable counter on winch. Correction applied in real-time by Tower
Camera systems	Stern gantry. Cable counter on winch. Correction applied in real-time by Tower
Side-scan sonar	Stern gantry. Cable counter on winch. Automatically updated in ISIS software
Multibeam echosounder	Drop-keel reference point. Correction applied in real-time by acquisition software

Table 3.1 List of equipment utilised during the cruise and the steering node that each item utilised.

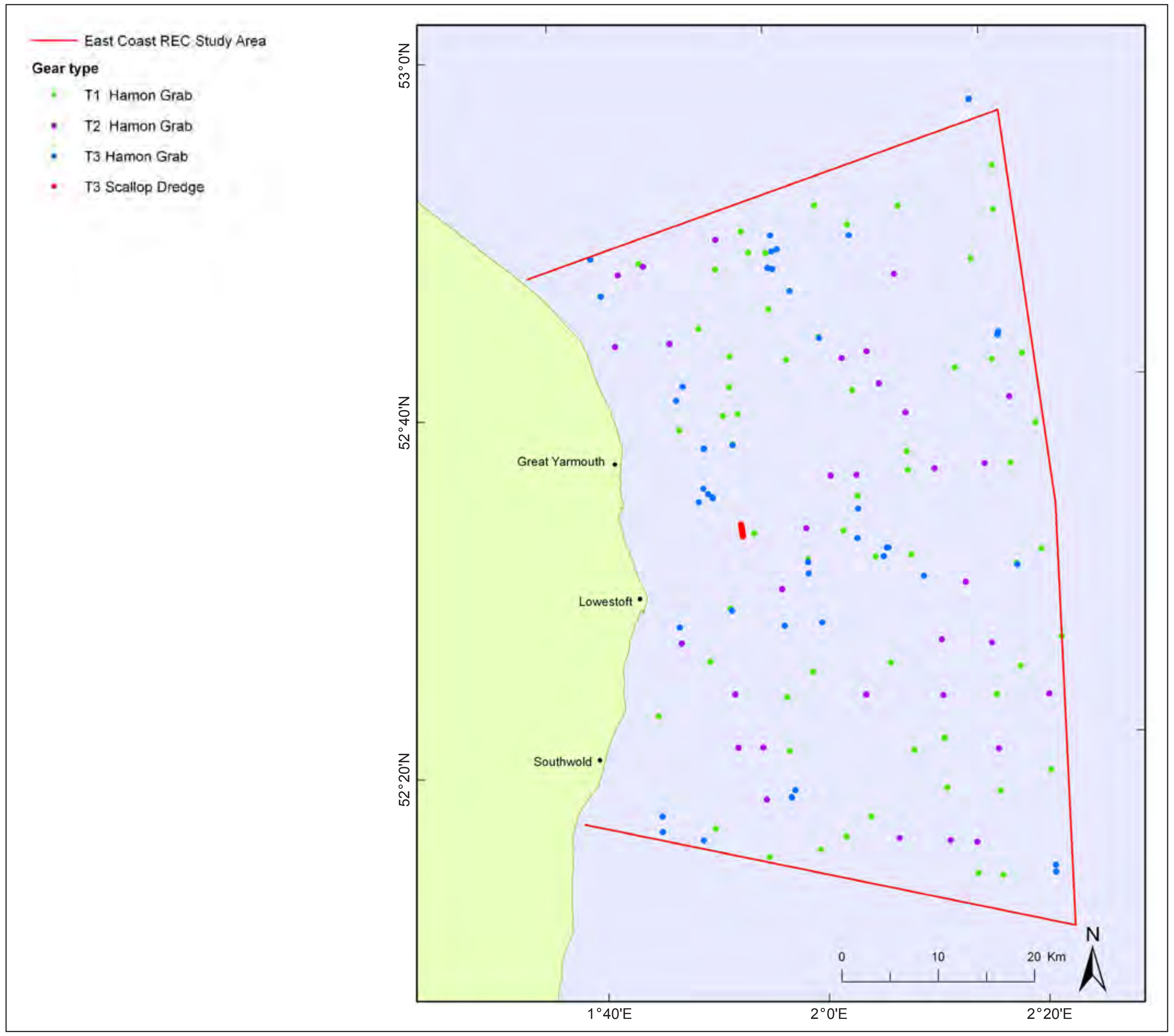


Figure 3.4 Hamon grab and scallop dredge sampling sites visited during CEND 09/09.

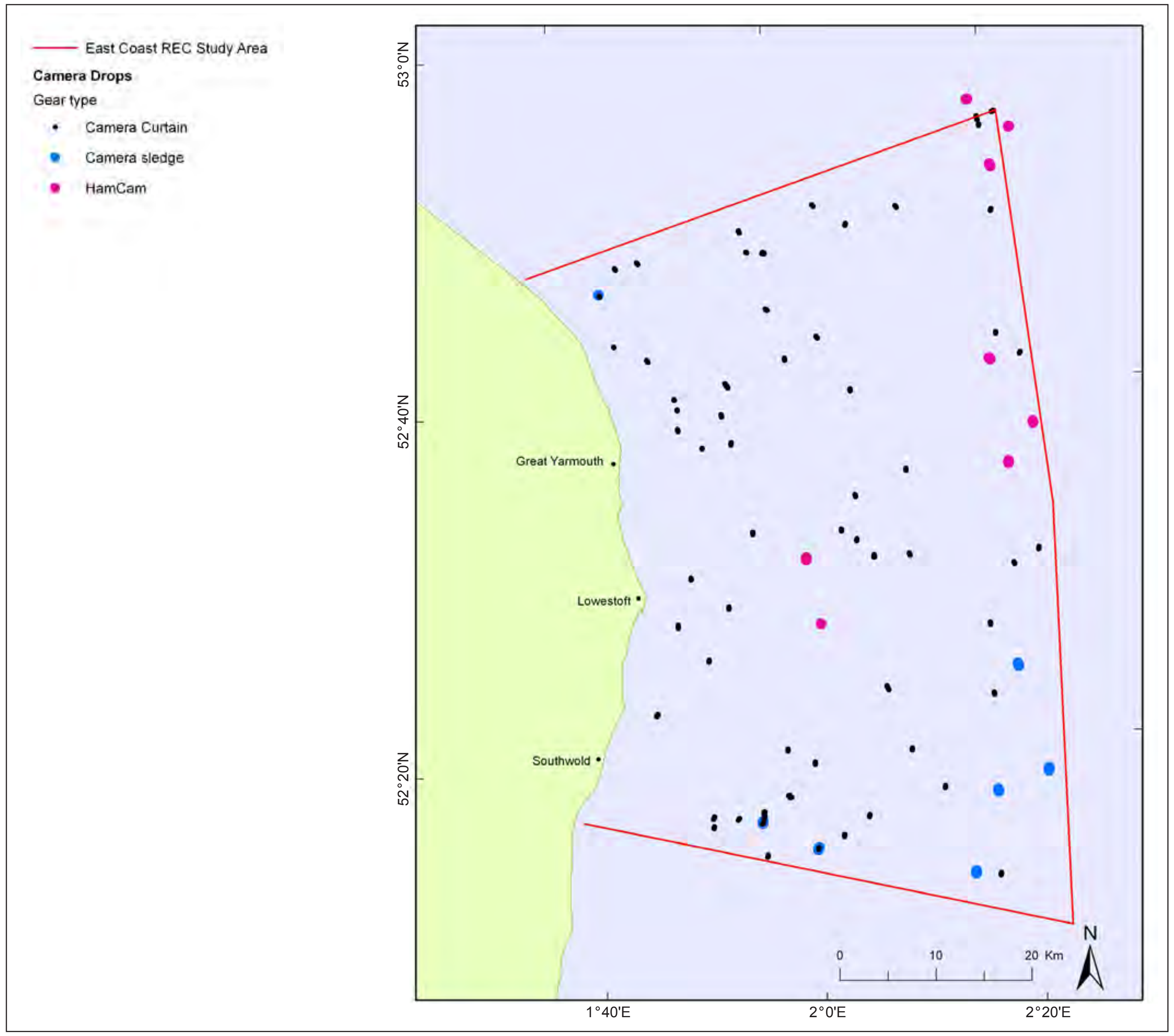


Figure 3.5 Camera stations visited during CEND 09/09.

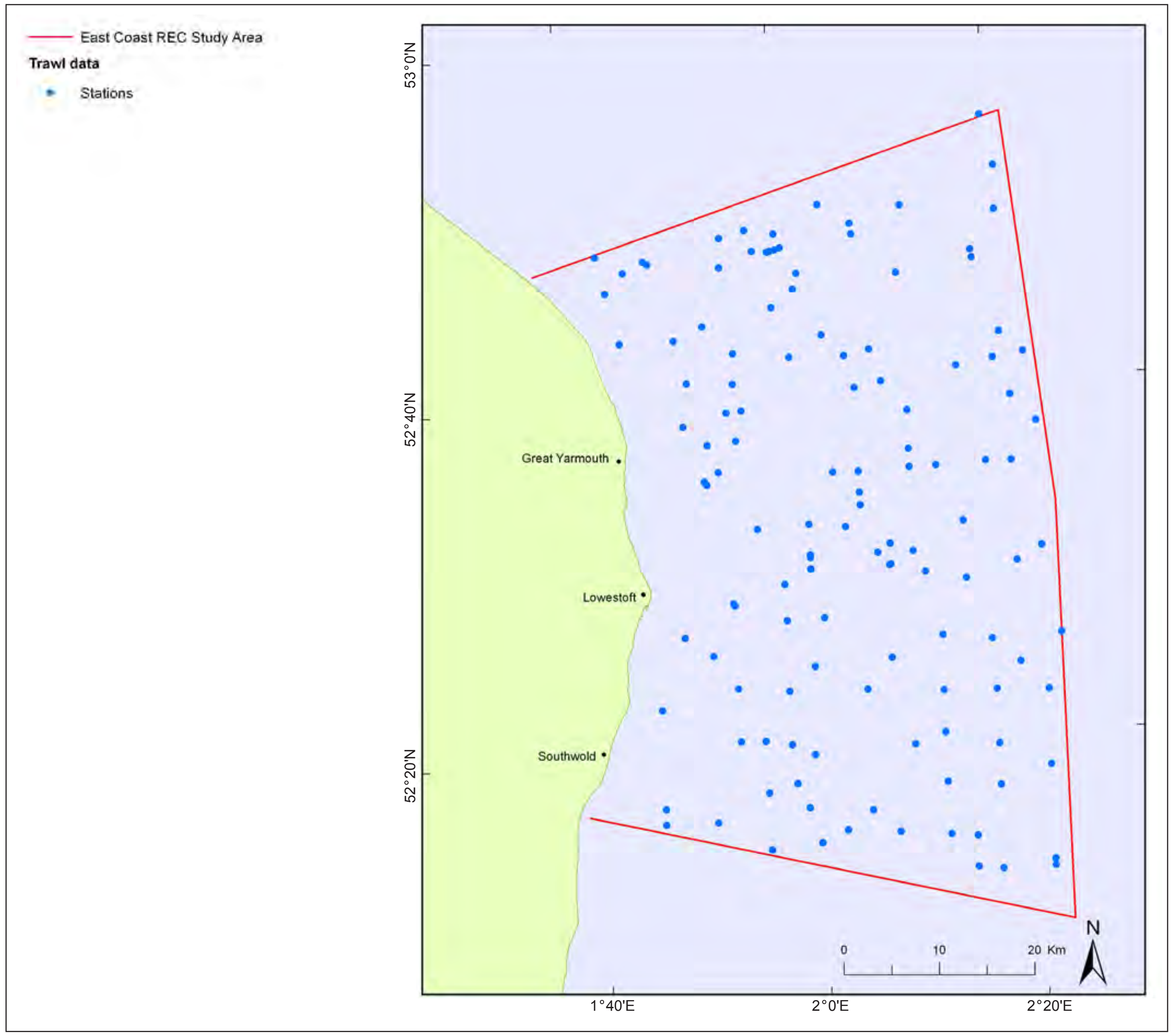


Figure 3.6 Scientific beam trawl stations visited during CEND 09/09.

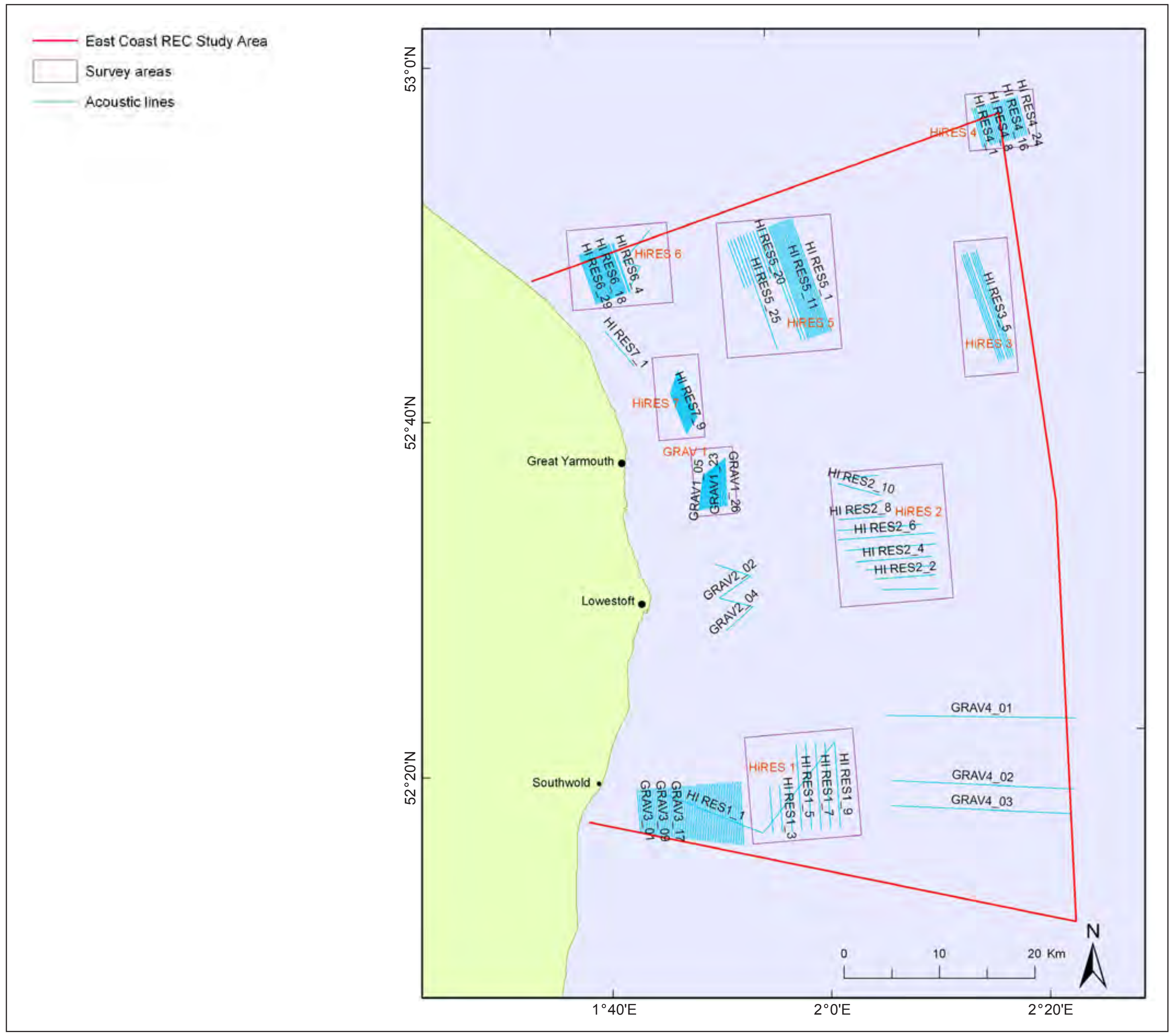


Figure 3.7 High-resolution geophysical surveys conducted during CEND 09/09.

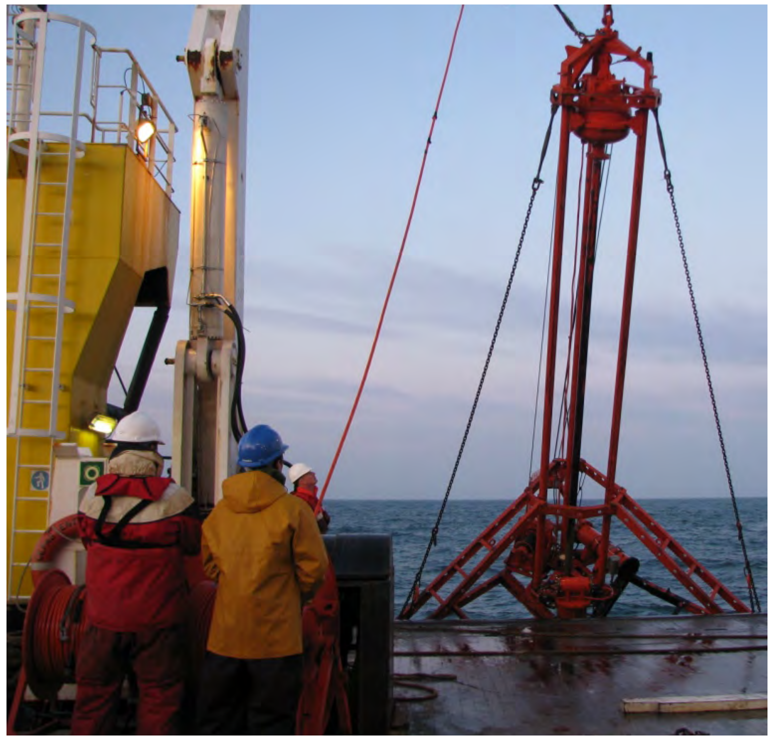


Figure 3.8 **6 m Vibrocorer with a steel open-frame structure and electro-hydraulic winch retraction. © British Geological Survey.**

boundaries within the cores added. The detailed core logs can be found in Appendix C.

Samples for palaeo-environmental assessment and dating were taken from selected vibrocore samples. This is detailed further in Section 5.2.4.

Clamshell grab

The BGS Clamshell grab (Figure 3.9) was used to collect large-volume seabed sediment samples for particle size analysis (PSA), geological descriptions and archaeological investigations. This grab is a hydraulically operated industrial "hopper type" grab with a 340 l capacity. The system uses a combination of high-voltage electricity (415 V) and high-pressure hydraulics (200 bar).

The Clamshell grab was deployed off the starboard side of the vessel. On reaching the seabed, the grab was closed hydraulically. The grab was recovered on deck, where samples were inspected for suitability and were rejected if the grab had not operated correctly (eg, jaws held open by pebbles/rocks allowing fines to be lost on recovery).The sample was emptied into a 2 × 1 m stainless-steel tray, where it was mixed using a shovel, photographed and sub-sampled into two 20 l samples (archaeology and bulk properties), one 10 l sample (PSA) and one approximately 1 l sample (archive). Once the sub-samples had been collected and described, the remainder of the sample was sieved over a 5 mm mesh to look for any archaeological artefacts that may have been present.

A total of 19 Clamshell grab sampling sites were chosen based on their geological value in assessing the seabed sediment distribution, with a total of 21 good samples being collected.

Hamon grab

The Hamon grab is an effective sampler of coarse sediments for the analysis of benthic macrofauna and particle size distribution (PSD) and is the accepted sampling tool for coarse substrates such as those found in the East Coast REC Study Area (Oele, 1978; Boyd, 2002; Eleftheriou and Moore, 2005). The grab consists of a rectangular frame forming a stable support for a sampling bucket attached to a pivoted arm (Figure 3.10). On reaching the seabed, tension in the wire is released, which activates the grab. Tension in the wire during in-hauling then moves the pivoted arm through 90°, driving the bucket through the sediment. The bucket stops against an inclined rubber-covered steel plate, which completely seals it, preventing any washout of sample material. The grab samples an area of 0.1 m^2 and penetrates up to 0.15 m into the seabed (Boyd *et al.,* 2006). The maximum sample volume is 12 l. Samples were collected within a pre-determined 100 m range ring, and a maximum of three attempts to collect an acceptable sample were made at each site before the site was abandoned. Samples of less than 5 l were rejected for use in subsequent quantitative assessments, but these may have been retained for qualitative purposes.

Figure 3.9 **Hydraulically operated industrial "hopper-type" Clamshell grab with a 340 l capacity. © British Geological Survey.**

Figure 3.10 **0.1 m^2 Hamon grab. © Crown Copyright 2011.**

On deck, samples were emptied into a 70 l container and taken to the processing area. Samples were photographed in the container and the total volume of the retained material was measured. A representative 0.5 l sub-sample was collected from each sample for PSA, and the remaining sample was sieved over a 5 mm and a 1 mm square mesh. The retained fauna and residual sediment was collected in a suitable container and preserved in a 10% formaldehyde solution. A full description of the collection and processing of infaunal samples can be found in Cefas SOP No 1380 included in Appendix D. The sample was also reviewed onboard for any archaeological artefacts.

Scientific beam trawling

Epibenthic megafauna samples were collected using a 2 m Jennings-type beam trawl (see Jennings *et al*., 1999). The gear comprises a heavy-duty steel beam, a chain mat to prevent the collection of large boulders, and chafers to limit net damage (Figure 3.11). It has commonly been employed in scientific studies to characterise epifaunal diversity in the North Sea (Jennings *et al*., 1999; Rees *et al*., 1999; Callaway *et al*., 2002; Reiss and Kröncke, 2004; Rees, 2009). A 4 mm knotless mesh liner is used in the cod-end to retain smaller organisms. The 2 m beam trawl is deployed from the vessel's stern, with the amount of warp paid out being roughly three times the water depth. Each tow was approximately 500 m long and was conducted at a speed of 1.5 knots over the ground. The tow was deemed to start when the winch stopped paying out and was ended when the winch started to haul. Using the vessel's dynamic positioning (DP) system, the trawl was towed along a line that crossed the range ring (50 m diameter) that enclosed the stated sample position and also intersected the video-camera tow path.

On retrieval, beam trawl samples were emptied into 70 l containers on deck, photographed and processed according to Cefas SOP No 1385 (see Appendix D) and following the guidelines given in Boyd (2002). In brief, samples were washed over a 5 mm sieve and motile and sessile organisms remaining on the mesh were picked off and, where possible, identified and enumerated. Full species identification and enumeration was completed onboard where possible. Where full species identification was not possible, reference collections were kept for later identification in the laboratory. Sub-sampling of trawl samples was employed when the number of organisms retrieved was so vast it was deemed impractical to count them all. The sub-sampling procedure consisted of dividing the total sample volume into smaller aliquots, processing each aliquot by counting every individual but stopping the count of any super-abundant taxon as soon as 100 individuals were counted. The total abundance of super-abundant taxa was extrapolated from the volume of sample required to contain 100 individuals to the total volume of the sample. The abundance of all other taxa was counted in full.

Seabed imagery

Photographic images were acquired from 85 sites over the East Coast REC Study Area to assist with the identification of benthic habitats. The area under investigation is subject to high tidal currents, which, when combined with mobile sediments, relatively shallow water and wave action, make underwater visibility extremely limited for much of the time. In general, the more-offshore sites proved to have the better visibility, with turbidity increasing further inshore. The slack-water periods also saw an improvement in visibility compared with the higher tidal periods. A number of camera systems were taken onboard the survey vessel to ensure that images could be collected under the widest possible "window of visibility". The video sledge would generally be considered to be the optimum tool for the collection of video and still images under good conditions, but due to the widespread high turbidity, the water curtain camera (WCC) was the most commonly used piece of equipment throughout this survey. Where conditions allowed, the camera sledge was used preferentially at routine camera sites, and it was also used to identify the putative borders of acoustically distinct areas. The WCC was used when useable images could not be collected using the camera sledge. Further options for visualising the seabed included the Video grab (Ham-Cam) and the Sediment Profile Imager (SPI), and each tool had its own advantages under varying conditions. The poor visibility and application of novel camera solutions meant that photographic images were routinely used qualitatively rather than quantitatively for the purposes of subsequent habitat determination. Figure 3.5 shows where each type of camera was deployed over the East Coast REC Study Area.

Figure 3.11 A Jennings 2 m scientific beam trawl with a chain mat and cod-end chafer. © Crown Copyright 2011.

Water curtain camera

The WCC (Figure 3.12) consists of a high-resolution digital video/stills camera (Kongsberg™ OE14-208) mounted vertically in a square steel frame. A 1 m³ freshwater tank with a perspex base is mounted in the frame that sits on four legs approximately 0.3 m off the seabed. The camera looks vertically downwards through the tank, giving a clear image of the seabed. A dual LED (Seatronics SeaLED™) lighting set-up provides "white natural" lighting. Still shots are taken from the surface control unit. Positional data are fed into the video overlay. The vessel's position is logged to a separate data file at set intervals or by manual fix using the Tower

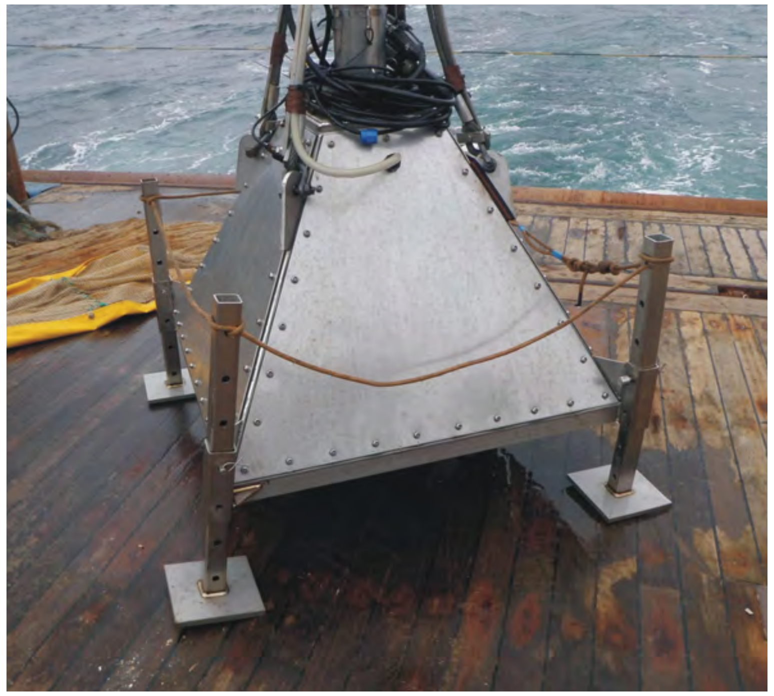


Figure 3.12 Water curtain camera. © Crown Copyright 2011.

CEMap™ system. The internal camera clock is synchronised with the GPS clock on the video overlay, so that the timestamps on still images reflect the timestamps on the video. The WCC was deployed from the stern gantry onto the end of the predetermined camera transect. Video was taken of the seabed as the camera approached it, and once the WCC was on the seabed, a still image was taken. After the image was taken the WCC was lifted clear of the seabed, and the vessel moved 25 m along the pre-determined 250 m transect line using the ship's DP, where another image was taken. In areas where specific features were being targeted, the spacing between photographs was adjusted accordingly.

Camera sledge

The camera sledge design illustrated in Figure 3.13 is typical of towed devices used for subtidal surveys of the epibenthos and for discriminating small-scale features and boundaries. Camera sledge deployments were conducted according to the draft Cefas SOP (Appendix D) and following the Mapping European Seabed Habitats (MESH) guidelines (Coggan *et al*., 2007; White *et al*., 2007). The camera sledge is an alloy frame, 2.5 × 1.5 × 1.5 m, which is configured with an oblique, forward-facing high-resolution Kongsberg™ OE14–208 digital video/stills camera. Four LED (Seatronics™ SeaLED) lights provide even "white natural" lighting over the camera scene. The camera sledge was deployed from the stern gantry, and once the sledge was on the seabed and considered to be towing steadily, a still image was taken and the video tow formally started. The vessel moved along a 250 m line at approximately 0.5 knots under DP, and still images were taken manually every 60 s. Additional still images of particular scenes of interest were also taken manually. At the end of the 250 m tow, a final still image was taken and the tow formally ended before the sledge was recovered onboard. Still images were georeferenced using manual fixes in the Tower CEMap™ system. The camera sledge was deployed at seven sites within the East Coast REC Study Area.

Ham-Cam drop-camera system

The Ham-Cam drop-camera system consists of a miniature Bowtech™ video camera and LED array mounted on the Hamon grab frame so it looks vertically downwards. It has proven useful for the *in situ* evaluation of surface features adjacent to the grab bucket (see, eg, Brown *et al.,* 2002) and was used in conditions of high turbidity when other systems were deemed unsuitable. There is no still-image facility available. The Hamon grab was deployed and fixed in the "fired" position so that it did not fire on contact with the seabed. The grab was lowered and halted when a suitable altitude above the seabed was reached. The vessel moved along the pre-determined 250 m camera transect under DP, with the winchman raising and lowering the grab at the request of the camera operator, who used the live camera feed to obtain optimal images. This system was used at eight sites over the East Coast REC Study Area.

Side-scan sonar

The side-scan sonar data were collected using a Benthos 1624™ dual-frequency system and the TEI ISIS™ software package. The two frequencies acquired were 100 and 400 kHz. Data were displayed using TEI ISIS™ in real-time and were monitored by shipboard engineers and scientists. All data were stored electronically in .xtf format. Quality control and post-processing of data were carried out during and post-acquisition. Side-scan sonar data were reviewed at frequent intervals with respect to quality, resolution and spatial coverage to ensure that the acquisition programme would provide adequate data to meet the objectives of the survey.

Multibeam echosounder

The Simrad™ EM3002 MBES system used the same equipment spread as that employed in the East Coast REC geophysical survey conducted in 2008, and the specification can be found in Section 3.2.2 above. The high-resolution areas surveyed in 2009 during the ground-truthing cruise were gridded at a resolution of 0.5 × 0.5 m.

Due to the size of the survey areas and the resolution required, the data for the high-resolution surveys were split into eight fieldsheets comprising 32 scene files.

Particle size analysis

Subsamples from vibrocores were analysed for their PSD by EMU Ltd. All samples were sieved at 0.50 intervals between 63 µm and 63 mm based on British Standards Methods BS1377:1990. Where samples contained >5% of material finer than 63 µm, then laser diffraction using a Malvern Mastersizer™ Micro was used to measure the percentage sediment at 0.50 intervals between 3.9 µm and 301.7 µm and the fraction finer than 3.9 µm (overlap between sieved and Malvern sizes).

All of the Hamon grab samples, and all but 4 of the Clamshell grab samples, were analysed by Cefas following the method described above. However, where samples contained >5% of material finer than 63 µm, the <63 µm fraction was pre-treated for removal of organics, and analysed by pipette analysis, rather than using a Malvern Mastersizer™ laser sizer.

The results from all the PSA determinations were processed to derive values using methods from Folk (1974) (see Appendix E).

To meet various differing objectives during the project, granulometric analyses have been undertaken on samples from a variety of different grabs and corers. It is important to consider the effect that the sampling methods of each of the grabs and corers used has on the data resulting from PSA. For example, pre-existing BGS samples used to provide historic PSA data were primarily gathered using a Shipek grab, which gathers a maximum of 4 l with a sampling footprint of 0.05 m^2 and a typical penetration of 5 cm. A comparison between the PSA data from the Hamon grab samples and the top 5 cm of the vibrocores suggests a relative reduction of fine material in samples collected using the Hamon grab. Therefore, caution should be taken when comparing PSA data generated using different sampling tools, and it is recommended that each PSA data-set is considered in isolation from others.

Figure 3.13 **Conventional towed camera sledge for collecting still and video images of the seabed. © Crown Copyright 2011.**

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4 Geological characterisation

4.1 Physical regions

In previous REC projects, the survey area was divided into physical regions or zones based on common or distinctive attributes.
The possible elements by which to divide an area into physical regions are:

- Seabed bathymetry.
- Seabed geomorphology.
- Solid geology (Eocene and Pliocene formations imaged) and/or bedrock geology (not imaged).
- Quaternary sediments.
- Seabed character.

Water depths across the East Coast REC Study Area range from ~10 m to ~138 m, with a gradual deepening eastwards towards the Southern Bight. Dividing the area by bathymetric depth is complicated by the existence of significant deeps between shallow sandbank features. Setting a depth limitation for each physical region could result in multiple small regions scattered across the area which share common features such as sediment composition and bedforms with the surrounding area but have significantly different depths. Similarly with the seabed geomorphology, it is observed that all of the feature classes identified exist across the whole survey area, with the exception of the sandbank features.

Division of the area on the basis of geology, be it the sub-surface solid geology, Quaternary geology or the Holocene veneer and seabed sediment deposition, is again complicated by the geographical spread of each formation or sediment class identified. There is an underlying north to north-eastwards dip to the Quaternary sediments, which influences the sub-cropping of the older solid geology underneath. However, the point at which a zonal division could be made is unclear. It could be that a division is made based on the age of the formations, but this would in no way bear any relevance to the biological or physical characterisations, as

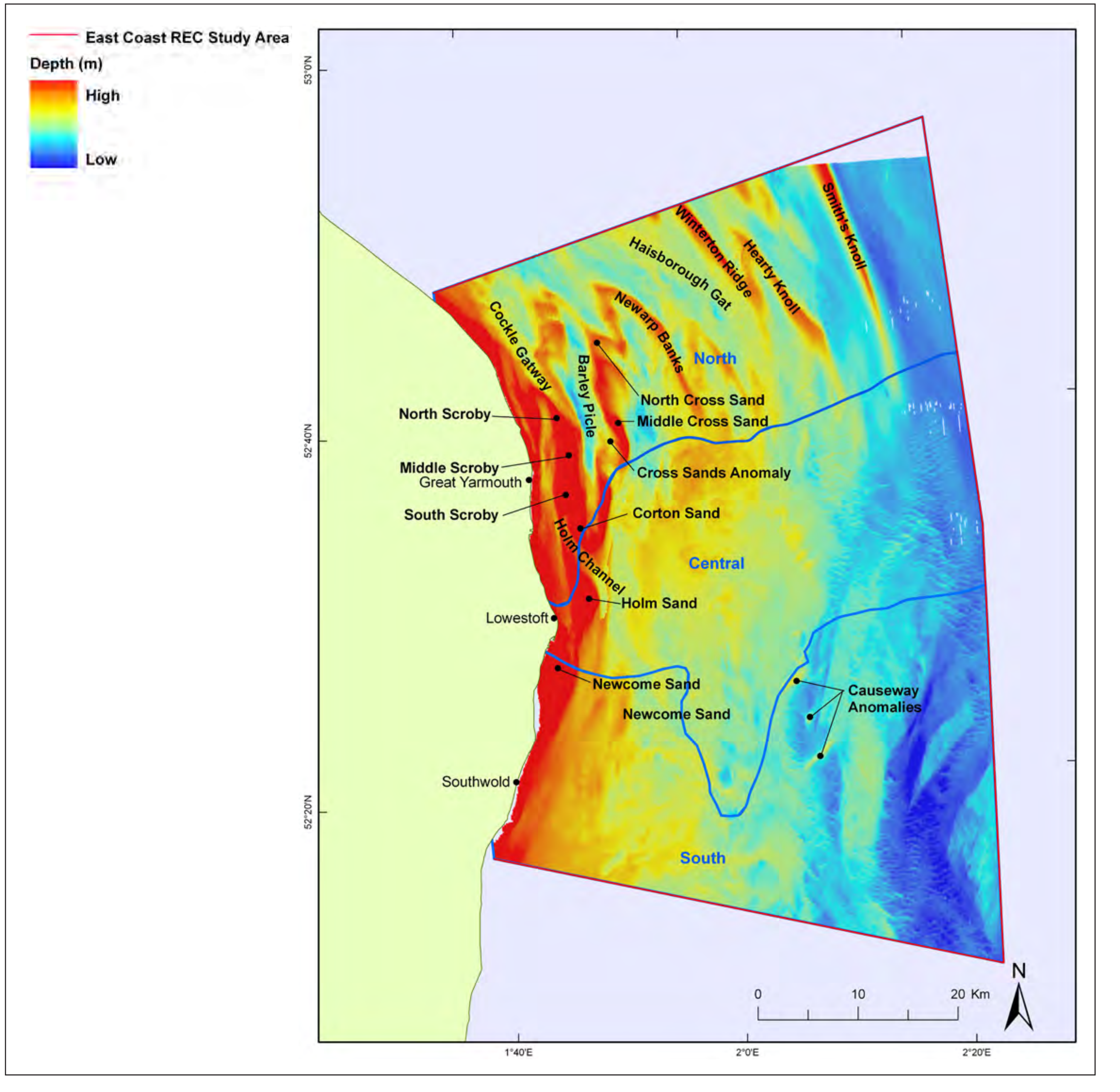


Figure 4.1 Seabed morphology of the East Coast REC Study Area with locations of the physical regions and named localities identified. Digital bathymetry data © British Crown and SeaZone Solutions Ltd. All rights reserved. Data Licence 052008.012.

they appear to be primarily driven by (or driving) the Holocene veneer that covers the entire East Coast REC Study Area.

Therefore, it has been decided to divide the East Coast REC Study Area into three physical regions based on a combination of geomorphology and Holocene seabed sediment distribution (Figure 4.1), as those aspects are most likely to be factors strongly influencing the biotope distribution. Not all of the possible elements by which to divide the region are used in all of the boundary placements – in one instance the physical southerly limit of the sandbank extents is the chosen criterion, whilst in another instance it is the sum of the geomorphology and the gravel-rich sediment distribution that jointly combine to distinguish a region.

Physical Region 1 – North

The northern region (~1,180 km^2) is delineated to the north, east and west by the East Coast REC Study Area boundary. The southern limit is defined by the lateral extent of the sandbank features, as the dominant geomorphology characteristic of this physical region. The region contains a complex distribution of sediment and smaller bedform types, and it shows a gradual deepening of the seafloor from west to east.

Physical Region 2 – Central

The central physical region (~760 km^2) is delineated to the north by the southernmost extent of the sandbanks, to the east and west by the East Coast REC Study Area boundary, and to the south by a boundary based primarily on the distribution of sandy gravel. The region is dominated by a sandy gravel deposit that is ~36.5 km in length and ~14 km at its widest. Over 95% of the active or licensed dredging areas within the East Coast REC Study Area lie within this central region.

Physical Region 3 – South

The southern area (~1,360 km^2) is delineated to the north by the central region and to the east, south and west by the East Coast REC Study Area boundaries. It shows a complex pattern of seabed sediment distribution and geomorphology. The most prominent geomorphological features are two “causeway” anomalies that bridge a topographic low. They are unusual in that their orientation (NE–SW) lies oblique to the general trends in either sandbanks (N–S) or sandwave crestlines (E–W), and their sub-cropping Quaternary formation is Brown Bank, which is generally considered to consist of channel infill in a series of N–S down-cutting features.

4.2 Interpretation methodology

4.2.1 Introduction

The methodology adopted for the geological and geomorphological interpretation of the East Coast REC Study Area was based on the principles and procedures undertaken in both the Eastern English Channel Marine Habitat Map (EECMHM) study (James *et al.*, 2007), and the South Coast Regional Environmental Characterisation (James *et al.*, 2010). Prior to commencing any data interpretation, authors for both the East Coast REC Study Area and the Humber Regional Environmental Characterisation formulated a “common” seabed sediment and geomorphology nomenclature in order to ensure consistency in geological and geomorphological mapping across both regional characterisations.

The interpretation was undertaken in two stages based on the different requirements of those partners engaged in characterising habitats and those assessing the archaeology. With respect to quantifying and understanding the distribution of biological flora and fauna, the nature of the seabed sediments and geomorphology is of prime importance. Therefore, the seabed sediment and seabed geomorphology maps formulated incorporate the upper ~0.5–1 m of sediment.

Archaeological characterisation, as well as encompassing shipwrecks, aircraft and other seabed artefacts, is also targeting the sub-bottom geology. The importance of these deeper Quaternary deposits lies in the fluctuation of sea level across the southern North Sea basin associated with the cyclical transitions from glacial to interglacial to glacial periods, and the associated shoreline movements. In certain periods during the Quaternary, it is known that a significant proportion, if not all, of the East Coast REC Study Area was aerially exposed and was therefore subject to human habitation, with the shoreline shifting by as much as ~65 km (~40 km west and 25 km east of the present coastline). Both Jelgersma (1979) and Lambeck (1995) indicate that, during the Holocene period, the southern Bight – and hence the East Coast REC Study Area – was entirely exposed at certain times, with full marine conditions not occurring until as late as ~5500 BP (Cooper *et al.*, 2008). Understanding the relationships between the sub-bottom geological formations and the associated climatic and sea-level fluctuations was therefore necessary to help refine the archaeological potential.

4.2.2 Additional data

In order to acquire geophysical data that best illustrated the regional character of the survey area, it was decided to adopt a “corridor” survey plan, running a series of N–S and E–W lines at a regular spacing across the area (Figure 3.1). However, this approach had obvious implications for the interpolation between survey lines in order to produce a regional interpretation of the seabed sediment distribution and geomorphology. In order to mitigate the potential impact of data gaps in this characterisation, additional geophysical data-sets were incorporated at the interpretation stage:

- British Geological Survey (BGS) Technical Report WB/88/9C (Harrison, 1988) – 884 km of sub-bottom Boomer profiles with associated seabed sampling and seabed coring data and interpretations.
- Provision of commercial multibeam imagery of the Interconnector Pipeline.
- Provision of digital single-beam bathymetric data across the whole survey area (Figure 2.2) as licensed from SeaZone Solutions Ltd. This enabled visualisation of the seabed morphology to guide the initial survey planning strategy and later geomorphological interpretations.
- Provision of four high-resolution multibeam surveys from the MCA, detailing the position of nearshore sandbanks and the Scroby Sands sandbank area.

- Use of UKHO Admiralty fairsheets and texture sheets to aid interpolation of seabed geomorphology between the REC survey lines.

In order to update the BGS DigSBS250 (Digital Seabed Sediments) map and increase the resolution to 1:100,000 scale, a large number of existing seabed sample data points were assessed for particle size analysis (PSA) and Folk classification, in addition to the samples acquired during the ground-truthing survey of 2009. These historical data-sets were sourced from BGS, Cefas and the DTI SEA2 project, totalling 858 sample sites spread evenly across the survey region. UKHO fairsheets were utilised to enable interpolation between sample locations.

4.2.3 Methodology

The geological framework for the area came from the integration and re-interpretation of sub-surface boomer profiles collected in 2008, and historical BGS profiles (eg, Harrison, 1988). In the far south of the survey area it was possible to interpret geological strata back to the Eocene. However, for most of the area, deep penetration to the underlying bedrock was not possible. The Holocene veneer was frequently masked by the seabed pulse in areas of very thin cover (<5 m), and so some minor re-processing of some profiles was undertaken to enhance the uppermost 10 m of the sub-bottom profiles and aid interpretation. The interpretation of formation boundaries in the uppermost 10 m was then reconciled against the geological interpretation of the vibrocores acquired during the 2009 ground-truthing survey.

The seabed sediment analysis was undertaken using a number of data-sets (multibeam and single-beam bathymetry, side-scan sonar, seabed samples, video and stills imagery, historical geological maps and UKHO texture sheets). Sediment samples obtained during the 2009 ground-truthing survey were sent for PSA. The resulting data were then combined with historical PSA data held by BGS and Cefas (Figure 4.2), and applied to the existing seabed sediment 1:250,000 maps, used in the BGS DigSBS250 compilation, to produce an updated 1:100,000 version based on the modified Folk

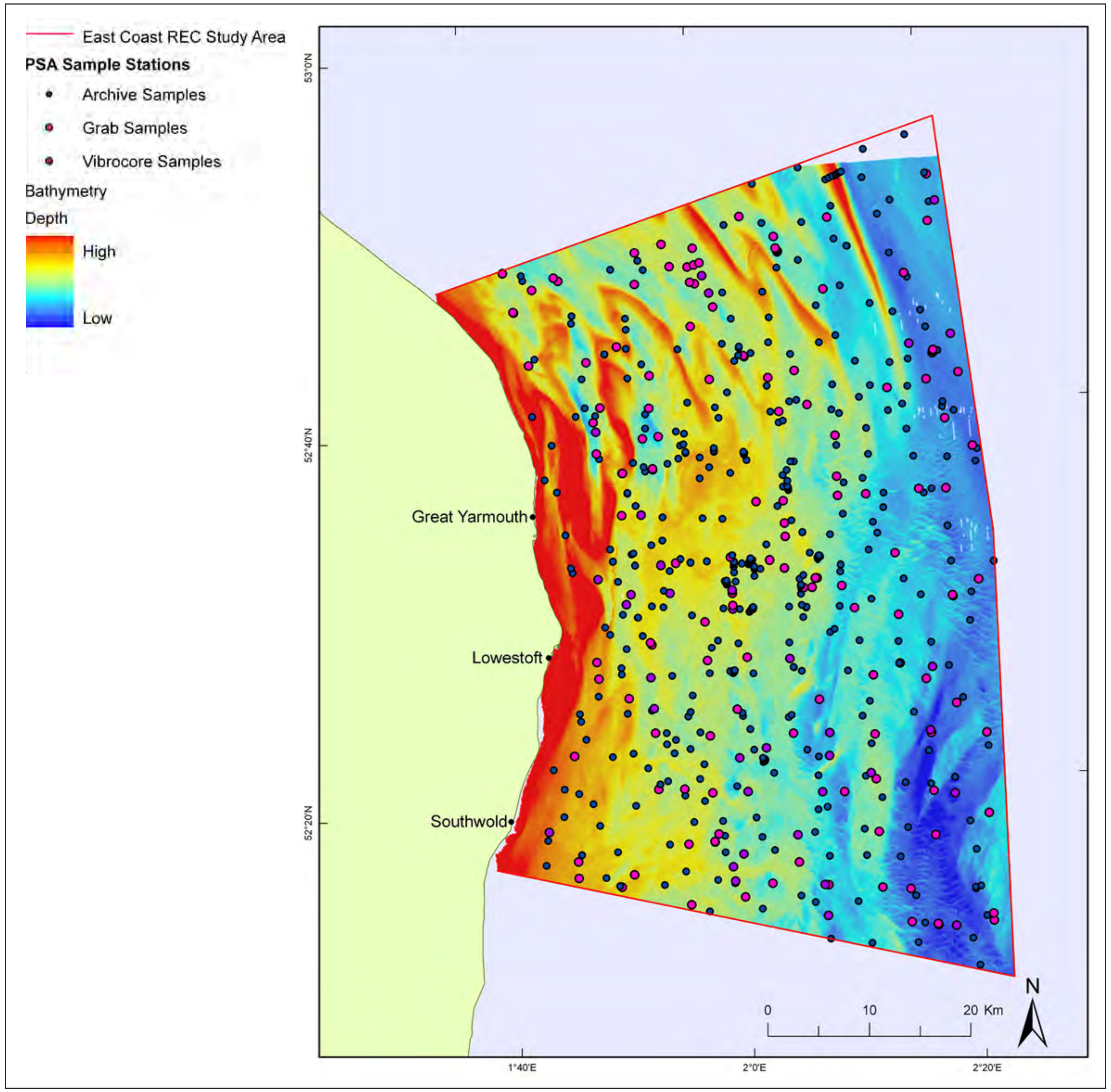


Figure 4.2 **Sample station locations used in the PSA. Digital bathymetry data © British Crown and SeaZone Solutions Ltd. All rights reserved. Data Licence 052008.012.**

classification scheme (Figure 4.3). In addition, the PSA data were used to produce a series of maps detailing % gravel, % sand and % mud (Figure 4.4) and sorting (Figure 4.5). Where areas had limited numbers of samples, or PSA information was not available, multibeam and single-beam bathymetry and UKHO texture sheets were used to help guide the interpretation of sediment boundaries. Sediment classifications were based around the dominant sediment percentage in each sample.

The seabed geomorphology again used a combination of geophysical data-sets (multibeam and single-beam bathymetry, side-scan sonar, UKHO texture sheets and sub-bottom profiles). Multibeam bathymetry and side-scan sonar records were used to map the lateral extent of bedform types along the data acquired during the 2008 and 2009 cruises, as these were the data-sets with the highest resolution. The next highest resolution records were the UKHO texture sheets, and these were overlain onto the initial interpretation and used to extrapolate the interpretation across the whole East Coast REC Study Area (Figure 4.6). Single-beam bathymetry was then used to verify the location and lateral extent of the large bedforms such as sandbanks and large sandwave fields, whilst video imagery and stills were used to ground-truth other areas.

In a number of areas, there were multiple scales of bedform features that could be mapped, such as sandwaves with parasitic megripples, and consolidated Quaternary “rock” scarps at or near the surface that were partially covered by sandwaves. In these instances, the largest or most laterally extensive bedform type was mapped, as this is believed to be the feature that impacts most on the biological aspects of this regional characterisation. The presence of additional smaller-scale bedforms was identified either through linear lines (indicating the presence of scarps at or near the surface) or data contained with an attribute table in the accompanying ArcGIS project (ie, presence and scale of parasitic bedform types).

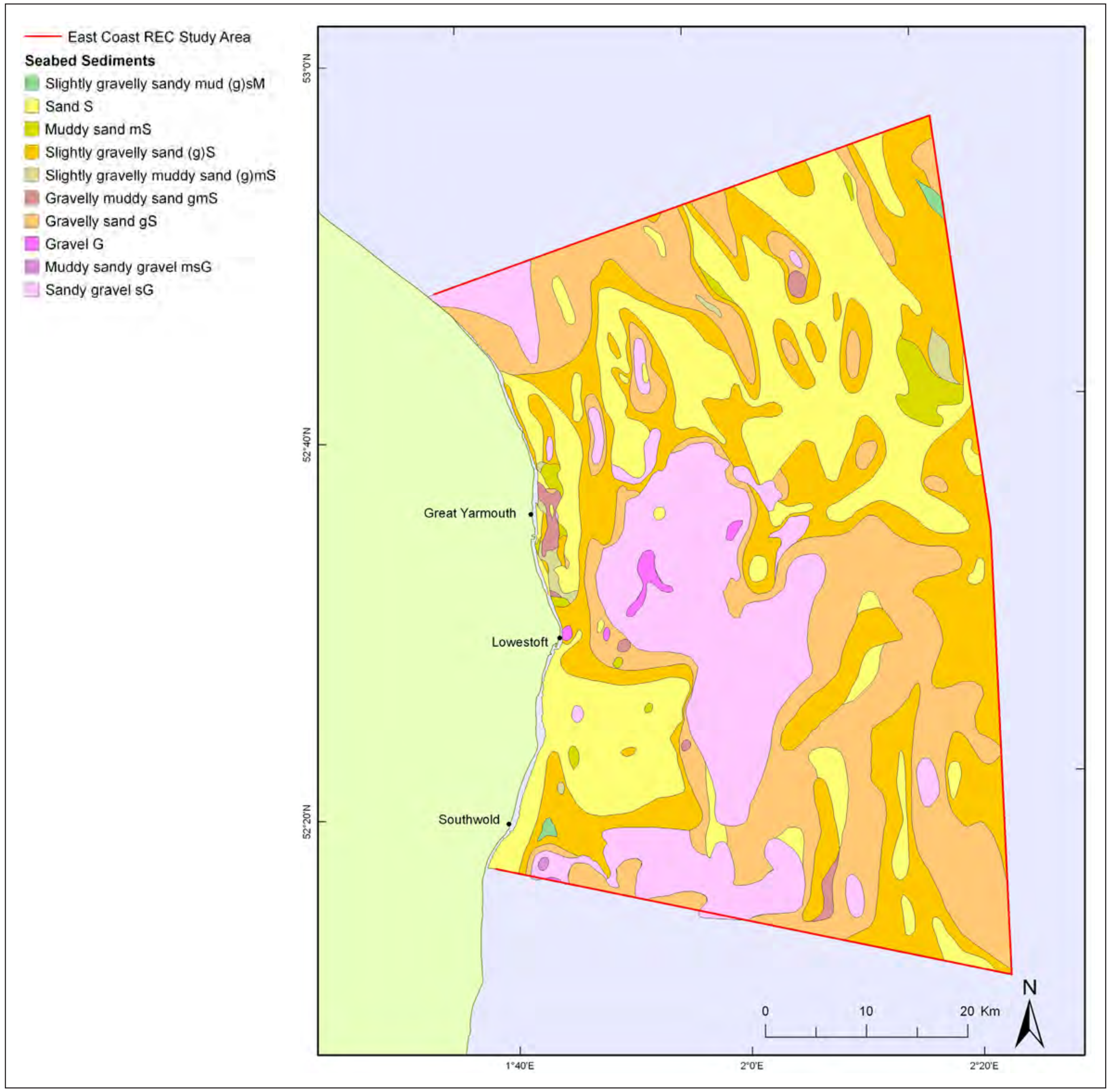


Figure 4.3 **Seabed sediment distribution in the East Coast REC Study Area (after Folk, 1974).**

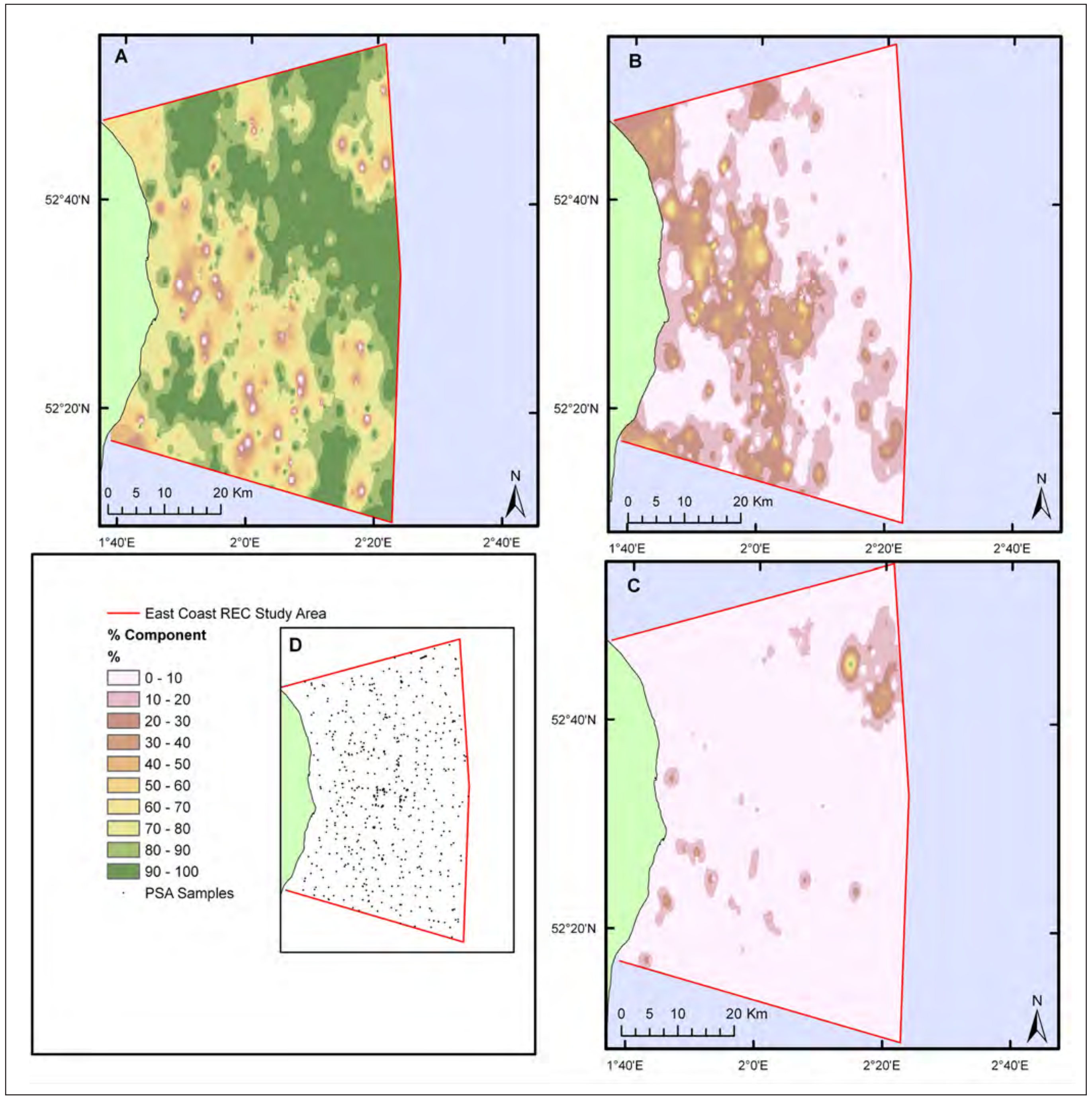


Figure 4.4 Modelled gravel (A), sand (B) and mud (C) distribution (%) in the East Coast REC Study Area. Sample stations used in the modelling are shown in (D).

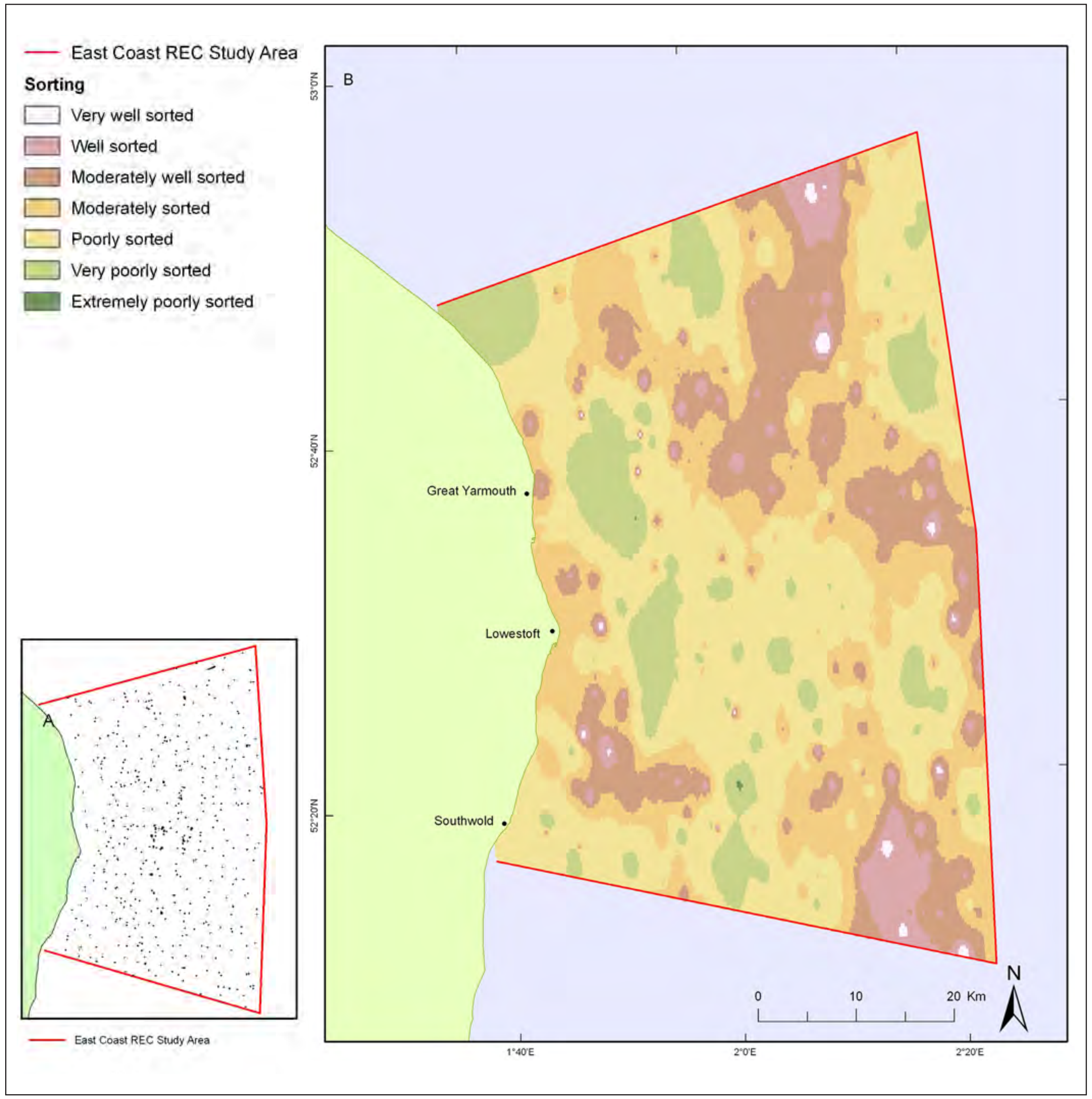


Figure 4.5 Modelled sediment sorting distribution in the East Coast REC Study Area. Sample stations used in the modelling are shown in inset (A).

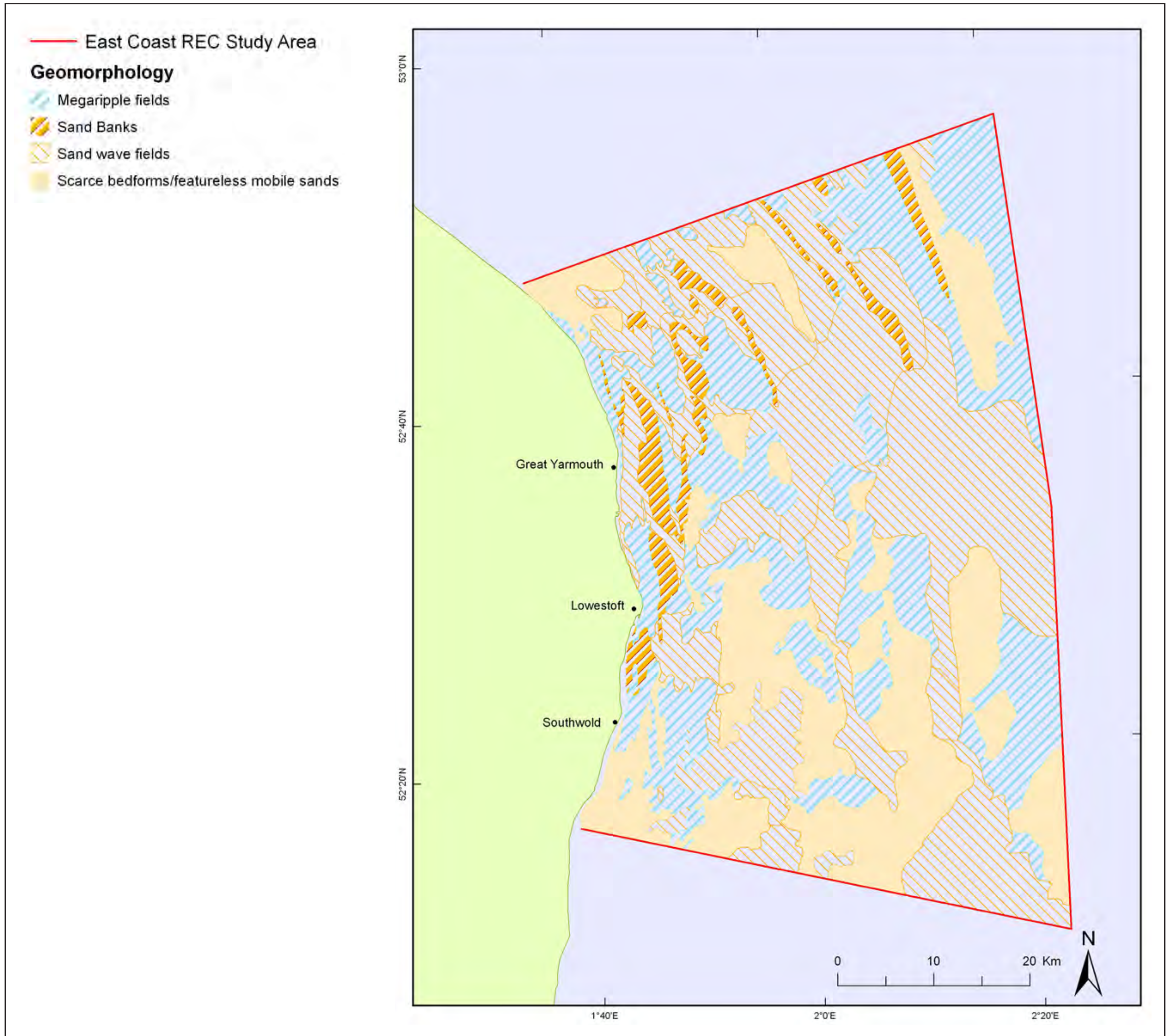


Figure 4.6 Seabed geomorphology in the East Coast REC Study Area.

4.3 Solid geology

Much of the East Coast REC Study Area is underlain by the London–Brabant Massif, an upstanding block of Lower Palaeozoic rocks with the feather edges of Carboniferous and Permo-Triassic basin sediments, marine and evaporite sequences deposited on its northern flank beneath the northeast corner of the East Coast REC Study Area. The massif was not overwhelmed until mid-Cretaceous times, when shallow seas covered the area in chalk. This was followed by thin sands and muds of the Palaeocene before a much thicker Eocene sequence was deposited. However, the first formations that are observed in the sub-bottom profiles are of Eocene age, with the predominant depositional formations being of Pleistocene age. Table 4.1 summarises the imaged geological stratigraphy of the East Coast REC Study Area, with the oldest formations/rocks at the base.

4.3.1 Eocene

London Clay

The London Clay Formation was deposited during the Ypresian Stage of the early Eocene. The Ypresian transgression represented the most widescale marine transgression into the southern North Sea during the Tertiary Period, corresponding to a period of globally warm temperatures. The facies consists of clays and silt clays, with clayey silts observed south of the East Coast REC Study Area, in the Thames Estuary. To the north of the survey area the formation reaches 76 m in thickness, whilst to the south of the survey area it reaches 150 m in thickness in the Thames Estuary.

Numerous cycles of transgressive/regressive fluctuations can be recognised within the facies, and the seismic signature is marked by a number of small (<2 m offset) faults that lie in the middle of the facies, penetrating neither the base nor the top of the formation. It is suggested that these small-scale faults are soft-sediment deformation features induced by compaction. The London Clay Formation is one of the dominant lithologies observed in the central and southernmost reaches of the East Coast REC Study Area, from ~52°17′N south, sub-cropping in the central region, but occurring at

Seismostratigraphic elements and lithogenic division		Formation	Depositional environment	Inferred chronostratigraphy
Californian Glacigenic Group	J	Various formation	Marine	HOLOCENE
	H	Sunderland Ground (SG)	Subglacial to Proglacial: Glaciolacustrine to Glaciomarine	
		Botney cut (BCT)	Subglacial: Glaciolacustrine to Glaciomarine	
	G	Kreftenheye (KR)	Periglacial: Fluvial	UPPER WEICHSELIAN
		Twente (TN)	Periglacial: Aeolian	
		Well Ground (WLG)	Proglacial: Fluvial	
		Dogger Bank (DBK)	Proglacial: Glaciomarine to Glaciolacustrine	
		Bolders Bank (BDK)	Subglacial: Terrestrial	LOWER WEICHSELIAN
	F	Brown Bank (BNB)	Marine to Lacustrine	EEMIAN
		Eem (EE)	Marine	
	E	Tea Kettle Hole (TKH)	Periglacial Aeolian	SAALIAN
		Cleaver Bank (CLV)	Proglacial Glaciomarine	
	D	Egmond Ground (EG)	Marine	HOLSTENIAN
		Sand Hole (SH)	Marine (lagoonal)	
	C	Swarte Bank (SBK)	Subglacial: Glaciolacustrine to Glaciomarine	ELSTERIAN
Dunwich Group	B	Yarmouth Roads (YM)	Non-marine Fluvial to intertidal	LOWER PLEISTOCENE TO MIDDLE PLEISTOCENE
Southern North Sea Deltaic Group	A	Aurora (AA)	Marine	
		Outer Silver Pit (OSP)	Marine	
		Markham's Hole (MKH)	Marine	
		Winterton Shoal (WN)	Marine	LOWER PLEISTOCENE
		Ijmuiden Ground (IJ)	Marine	
		Smith's Knoll (SK)	Marine	
		Weskapelle Ground (WK)	Marine	
		Red Crag (RCG)	Marine	PLIOCENE

Table 4.1 **Synthesis of Pleistocene formations and depositional environments (modified from Cameron *et al.*, 1992).**

or near the seabed in the central and south-west of the survey area from ~52°10′N southwards.

4.3.2 Pliocene

Red Crag

The Red Crag Formation observed offshore consists of glauconitic muddy sand containing molluscs, bryozoans and echinoids (Balson, 1989), with a foraminiferal assemblage similar to that found in the onshore Red Crag of eastern England, which corresponds to marine shelly sands and gravels deposited in a shallow marine subtidal environment from the late Pliocene. The formation lies unconformably on top of Palaeogene formations, namely the London Clay Formation in the survey area, and in the East Coast REC Study Area it is overlain unconformably by the Westkapelle Formation.

The Red Crag Formation is only observed in the East Coast REC Study Area south of ~52°15′N, outcropping in the far south beneath the Holocene veneer. Seismic records collected previously suggest a maximum thickness of 70 m for this formation (Cameron *et al.*, 1989). However, this cannot be verified in the sub-bottom profiles acquired for this regional characterisation due to limited penetration (maximum ~70 mbsl) to maximise detail in the upper Holocene and late Pleistocene stratigraphy.

4.4 Quaternary

Figure 4.7 illustrates the Quaternary formations that outcrop beneath the Holocene veneer.

4.4.1 Pleistocene

The Pleistocene sediments can be broadly divided into eight elements (A–H) based on depositional environments, with two unequal seismostratigraphic divisions based on deltaic (A and B) and non-deltaic (C to H) geometries.

The deltaic formations comprising Elements A and B represent the amalgamation of two delta systems – a small western delta bordering East Anglia and derived from UK sediment influx, and a larger eastern delta that extended from the Low Countries driven by sediment input from the European mainland (Cameron *et al.*, 1987, 1992). The time period encompassed by these elements (lower to mid-Pleistocene) is predominantly marine, moving into fluvial to intertidal in the mid-Pleistocene, with relatively stable climatic conditions. However, the non-deltaic formations comprising Elements C to H (mid-Pleistocene to the start of the Holocene) represent a more chaotic period of variable climatic conditions, transgression and regression, resulting in varied lithologies and seismic signatures. There are two significant periods of down-cutting, corresponding to the Elsterian (300/380–455 ka BP) and Weichselian (12–110 ka BP) glaciations, which form the lower boundaries to Elements C and H respectively (ka: a thousand years).

4.4.2 Element A

The acoustic facies of all formations forming Element A show variability within each formation, corresponding to systematic lithological and depositional variations due to the location within the pro-delta, delta front or delta top environments. However, at any point in the East Coast REC Study Area, the profiles of these formations show a vertical upward transition from the pro-delta to delta top.

Westkapelle Ground

The Westkapelle Ground Formation is the basal and oldest formation of Element A, with an inferred chronostratigraphy that encompasses the late Pliocene and early Pleistocene. This facies has previously been sampled by BGS boreholes, and comprises of silty clays with fine glauconitic bioturbated sands passing upward into predominantly mud-free sands (Cameron *et al.*, 1992). Foraminiferal assemblages support the interpretation that within the East Coast REC Study Area, this facies corresponds to the decreasing water depths and high-energy environment of a pro-delta location, deposited when the proposed East Anglian coastline was ~43 km west of its present-day location.

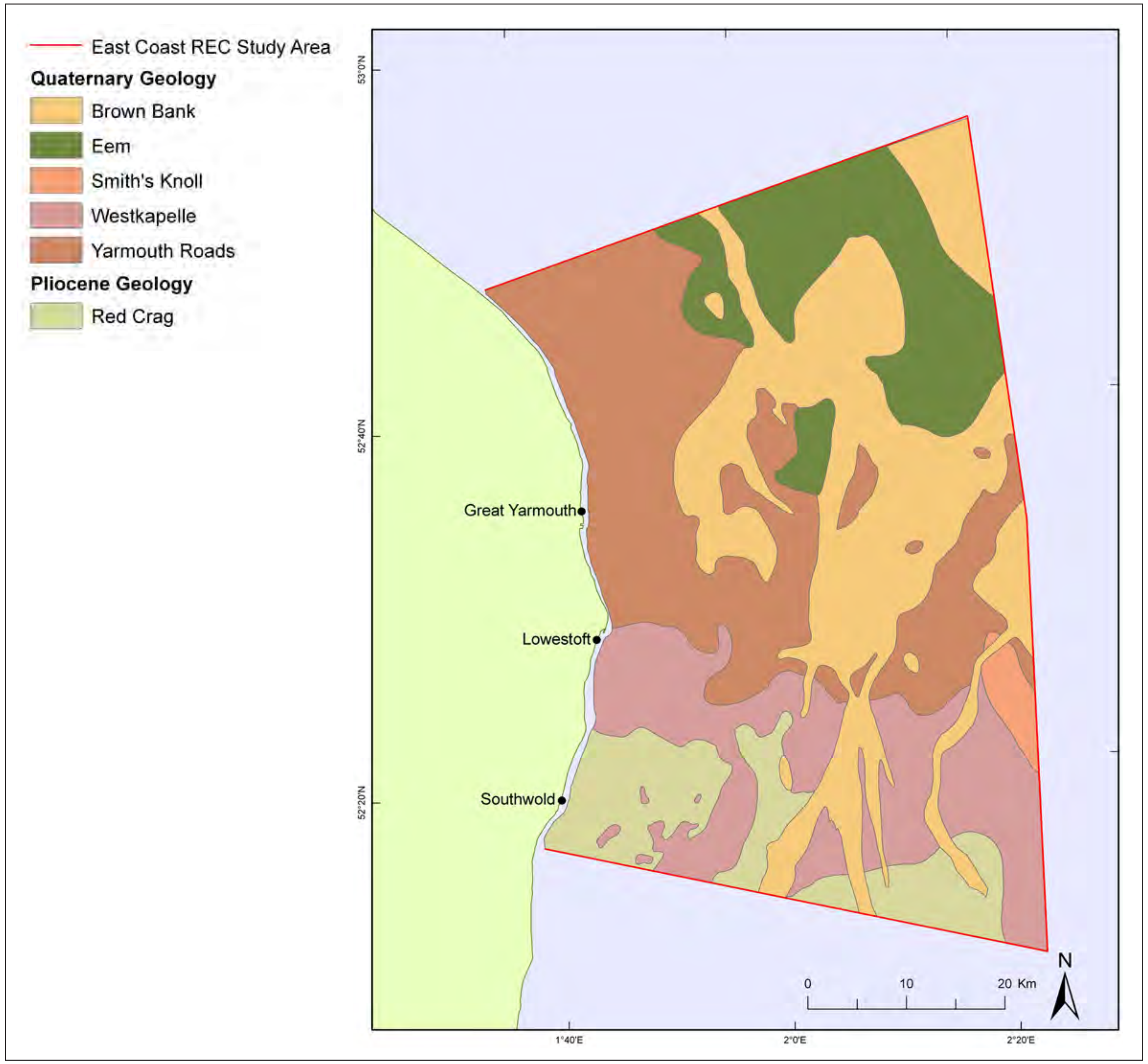


Figure 4.7 Pliocene and Quaternary geology underlying the East Coast REC Study Area.

In seismic sections, the Westkapelle Ground Formation is characterised by nonsigmoidal, parallel continuous reflectors. Within the East Coast REC Study Area, this facies has the same base as, and is equivalent to, the upper part of the Red Crag Formation. It is predominantly located in the central and north of the East Coast REC Study Area, dipping N–NE, where in places it is observed to be up to 40 m thick, with occasional outcropping beneath the Holocene veneer (see Figure 4.7). However, it does also appear in the south of the survey area as outcropping (beneath the Holocene veneer) localised channel infill, overlying and also cutting down into the Red Crag Formation.

Smith's Knoll

The Smith's Knoll Formation is also of marine deltaic origins and is found sub-cropping in a narrow zone east of the delta-front Westkapelle Ground Formation, in the east to north-east of the survey area, north of ~52°22′N. BGS boreholes have characterised the Smith's Knoll facies as consisting of 20–55 m of muddy, fine-grained glauconitic, locally micaceous sand with minor intercalations of silty clay and of pebbly or shelly sand (Cameron *et al.*, 1992), also representing a delta-front depositional environment. Within the East Coast REC Study Area, the seismic signature of this facies shows divergent, inclined reflectors.

The Smith's Knoll Formation is coeval with the Ijmuiden Ground Formation, terminating in a wedge-like geometry over a 5 km-wide zone to the south of the East Coast REC Study Area, and over a 15 km transition zone to the north of the East Coast REC Study Area. It formed contemporaneously with the Smith's Knoll Formation, as sediment influx from the European mainland overwhelmed and partially over-stepped the eastwards-growing delta-front, causing shallowing of the Southern Bight and extension of the Netherlands delta plain westwards.

Winterton Shoal

The Winterton Shoal Formation is again marine deltaic in origin, representing the merging and northwards growth of the eastern and western deltas in the southern North Sea. Within the East Coast REC Study Area, the seismic signature of this facies shows divergent sigmoidal parallel to sub-parallel reflectors. Three BGS boreholes have sampled this facies (just outwith the East Coast REC Study Area) and documented bioturbated calcareous sandy muds with glauconite and granules of partially pyritised monosulphide, with an upper delta-top of shelly sand. The change in mineralogy indicates that the source rocks for this formation are primarily Continental in origin, with the exception of the delta-top sands, as opposed to the predominantly UK-derived sediments of the previous two formations.

During the period of deposition, the probable location of the East Anglian Coast is approximately 16 km east of its present-day location, and therefore this formation is only observed in sub-crop in the far north-east of the East Coast REC Study Area, dipping to the NE.

4.4.3 Element B

Element B comprises solely of the Yarmouth Roads Formation and is characterised by a varied acoustic signature associated with the transition from fully marine conditions to an upward shallowing into fluvial/intertidal conditions.

Yarmouth Roads

The Yarmouth Roads Formation is strongly diachronous, with its stratigraphic base in the East Coast REC Study Area considered to be coeval with the Westkapelle Ground Formation. Towards the western edge of the East Coast REC Study Area, the base of the Yarmouth Roads Formation is delineated by a strong reflector representing the transition from fully marine into intertidal conditions. However, in the more central Southern Bight, outside the survey area, the unbroken subsidence and reduced impact of erosion during deposition has led to a more gradual transition into the Yarmouth Roads Formation and to a less easily identifiable boundary.

Within the East Coast REC Study Area, the seismic signature of this facies is generally chaotic, with sub-horizontal discontinuous reflectors and a maximum thickness of <50 m. BGS boreholes that have penetrated this facies describe partly or wholly decalcified sands, commonly including plant debris, scattered pebbles, wood clasts and peat (Cameron *et al.*, 1992). In places the sands are associated with intertidal sand/mud rhythmites, indicating a complex series of delta-top deposits. The facies is predominantly found north of 52°25′N, with limited evidence of channel infill slightly south of this.

4.4.4 Element C

Element C comprises solely of the Swarte Bank Formation and is characterised by acoustically transparent and slightly chaotic channel infill. It represents the first record of ice penetrating into the southern North Sea basin during the Elsterian glacial period, forming a complex series of anastomising valleys, eroded into the older deposits.

Swarte Bank

The Swarte Bank Formation contains three mapped members, as identified in BGS boreholes. The basal member comprises a chalky Jurassic till, with stiff grey diamictons and lenses of coarse-grained glaciofluvial sands. The middle member is clearly stratified, consisting of stiff grey glaciolacustrine muds with an upward transition into marine clays. The uppermost member is only sporadically identified, consisting of marine interglacial sediments.

The Swarte Bank Formation fills an array of scaphiform valleys that are often anastomising with an irregular thalweg, formed by subglacial meltwater under pressure (Balson and Jeffery, 1991; Praeg, 2003). The majority of these valleys have been mapped to the north of the East Coast REC Study Area, reaching up to 12 km in width and 450 m in depth. However, there is evidence in some of the northernmost sub-bottom profiles from the East Coast REC Study Area that these valleys do extend into the survey area (see Section 4.6.2). This would suggest that the southernmost limit of a major still stand by an ice sheet during the Elsterian was slightly further south than has previously been mapped.

4.4.5 Elements D and E

Elements D and E comprise marine (lagoonal Sand Hole Formation and Egmond Ground Formation), proglacial (Cleaver Bank Formation) and periglacial (Tea Kettle Hole Formation) deposits. These represent formations that were deposited during the interglacial Hostenian Stage after the collapse of the Elsterian ice sheet (Element D), before a move back into glacially dominated sedimentation during the Saalian Stage (Element E). The specific lack of Element E deposits supports the model that glacial ice did not reach the study area during Saalian times, as opposed to the more prevalent glacial conditions experienced in both the Elsterian and Weichselian (Sumbler, 1983; Balson and Jeffery, 1991).

As neither of these elements is found within the East Coast REC Study Area, with only the Egmond Ground of Element D located within close proximity, no further details will be included in this report. Further details may be found in Cameron *et al.* (1992) if required.

4.4.6 Element F

Element F was deposited during the Eemian interglacial period when a transgressive event, followed by a regression, deposited the Eem and Brown Bank Formations. Due to the absence of Elements D and E in the East Coast REC Study Area, the Eem Formation sits unconformably over the older deposits present.

Eem

The Eem Formation is a shallow marine deposit (Harrison, 1988) consisting of shelly sands that become increasingly muddy before passing into intertidal muds westwards outwith the survey area (Cameron *et al.*, 1992). It has only been identified in the northernmost East Coast REC Study Area (north of ~52°33′N), forming isolated discontinuous patches that sit unconformably on the Yarmouth Roads Formation.

Brown Bank

The Eem Formation was succeeded by the marine to lacustrine Brown Bank Formation, deposited in the late Eemian to early Weichselian. The formation records the presence of a brackish-water lagoon that was supplied by sediments from the south-west. East of the survey area, the facies consists of a thin (~5 m thick) silty clay with significant bioturbation and sedimentary lamination. Passing westwards into the survey area, the facies lies predominantly as infill in a series of approximately N–S channels ranging from 2 to 15 km in width and reaching up to 20 m in thickness.

The sediments in the survey area are sandier and lack the bioturbation and lamination observed in the more easterly deposits, cutting down into and resting unconformably on the Red Crag and Westkapelle Formations to the south, and the Yarmouth Roads to the centre and north of the survey area.

4.4.7 Elements G and H

Elements G and H comprise subglacial, proglacial, periglacial and a return to subglacial deposits associated with the Upper Weichselian (Bolders Bank, Dogger Bank, Well Ground, Twente, Kreftenheye, Botney Cut and Sunderland Ground formations). Depositional environments ranged from terrestrial through aeolian and fluvial to glacilacustrine and glacimarine. However, as with Elements D and E, there is no evidence within the East Coast REC Study Area of any of these deposits, although the area would have been subjected to periglacial conditions at the Weichselian glacial maximum. For further detail see Cameron *et al.* (1992).

4.5 Holocene

As the Weichselian glaciers retreated from their maximum extent (see Figure 5.6), the sea level across the southern North Sea began to rise from the maximum glacial low of ~120 m below the present-day sea level, being ~65 m below the present-day sea level at the start of the Holocene period (Jelgersma, 1979), with the southern coastline of the southern North Sea lying to the north of the East Coast REC Study Area. Therefore the survey area was predominantly aerially exposed (with the exception of any lakes/channels/rivers) and subject to the deposition of periglacial aeolian sands at this time.

With the continuing sea-level rise during the Holocene period, the East Coast REC Study Area became covered by a shallow, low-tidal sea, leading to the development of tidal flats. These are termed the Bligh Bank Formation, comprising fine- to medium-grained sands. Possible pockets of intertidal muds and peats belonging to the Elbow Formation may be preserved close to the present coast (Cameron *et al.*, 1992). Once the connection between this sea and the English Channel was established at ~8,300 ka BP (Cameron *et al.*, 1992), the area became subject to strong tides and a large tidal range. Modelling has suggested that this occurred once water depths were ~10–15 m below the present-day sea level (Austin, 1991).

Holocene sediments in the southern North Sea generally form a thin veneer overlying Pleistocene and older deposits. However, in the East Coast REC Study Area, there are areas of significantly thicker deposits due to the formation of sandbank features.

The early Holocene deposits were subject to re-mobilisation and erosion with the introduction of a strong hydrodynamic regime and the full marine transgression. The present-day seabed deposits are predominantly mobile sands and gravels, which maintain a dynamic equilibrium due to the modern hydrodynamic regime. However, modern-day anthropogenic activities, such as coastal engineering projects and the development of offshore windfarms, are known to have had an effect on the sediment deposition within the East Coast REC Study Area (Kenyon and Cooper, 2005) (Figure 2.7).

The sediment source for the modern seabed is predominantly pre-existing glacial deposits that are winnowed and re-mobilised by the currents with minimal terrestrial input. However, there is locally significant input from coastal erosion (Brooks and Spencer, 2010).

4.6 Seabed characterisation

Characterisation of the East Coast REC Study Area seabed in terms of sediment distribution and geomorphology (bedform features) was based on an integration of multiple data-sets (multibeam, side-scan sonar, boomer sub-bottom profiles, UKHO texture sheets, PSA samples, seabed grab sampling, video and stills imagery). Sediment samples from a range of sources were used to improve the resolution of the published BGS DigSBS250 seabed sediments map within the East Coast REC Study Area (see Figure 4.3). A number of other statistical parameters were also calculated using spatial analysis tools within ArcGIS. Using an Inverse Distance gridding method, shaded contour maps with an output cell size of 250 m were produced for percentage gravel, sand and mud, and also sorting (see Figures 4.4 & 4.5). Multibeam bathymetry, side-scan sonar and sub-bottom profiles were used to delineate the lateral extent of bedforms over the corridors and high-resolution areas surveyed during 2008–09. UKHO texture sheets were then utilised to interpolate across the entirety of the survey area, producing a final geomorphological interpretation (see Figure 4.6).

A number of processes have been identified that significantly modified or influenced the nature of the seabed in the East Coast REC Study Area:

- The development of a ravinement surface and associated erosion of older formations following the marine transgression during the early Holocene.
- Establishment of the present-day hydrodynamic regime, with strong tidal currents, a large tidal range and development of a bed-load parting zone controlling the mobilisation direction of suspended sediment.
- The migratory nature of some of the sandbank features, many of which may have a stationary "core" but tips that fluctuate in their position.
- The Holocene response to the channels and cuts that were created during the Quaternary by the series of glacial and interglacial stages.

The seabed geomorphology of the East Coast REC Study Area is complex, with many smaller features appearing as parasitic bedforms on top of larger scale features. The interpretation has therefore been based on the largest scale of bedform visible during the integration of the data-sets, with the accompanying ArcGIS attribute table giving more detailed information on any additional bedforms present within each area. The seabed geomorphological interpretation (see Figure 4.6) is best viewed in association with the seabed sediment distribution (see Figure 4.3) and statistical analysis plots (see Figures 4.4 & 4.5) in order to develop a comprehensive understanding of the seabed character within the East Coast REC Study Area.

Five different geomorphological categories were established:

- Sandbanks.
- Sandwave fields.
- Megaripple fields.
- Scarce bedforms to featureless.
- Linear features.

Sandbanks (open shelf linear/sinuous banks)

Sandbanks are the largest bedform feature observed on the continental shelf of the United Kingdom, and within the East Coast REC Study Area, and are often associated with the marine transgression following the Last Glacial Maximum (LGM) and the subsequent evolution of the Holocene coastline. Dyer and Huntley (1999) proposed that linear offshore sandbanks form initially as banner banks at a retreating coastline and attain an equilibrium state with time, forming linear open shelf sandbanks.

In plan-view morphology, they appear as linear elongated features with wide upstream heads and narrow downstream tails (Caston, 1981), termed "open shelf linear banks" by Kenyon and Cooper (2005). They are generally orientated either parallel or sub-parallel to the dominant tidal flow direction, often with their crestline rotated between 7° and 20° anticlockwise to the peak tidal flow direction (Kenyon *et al.*, 1981; Stride, 1982).

Sandbanks can reach dimensions in the order of 50 km in length, 6 km in width and up to 40 m in height (Stride, 1982). An active sandbank feature will often have associated parasitic sandwaves on its flanks, with an asymmetrical plan view and a lee slope angle approaching 6° and a stoss slope angle of ~2°. They will have sharp crests, unless situated in shallow water depths where wave action will cause flattening. They are generally found in areas where near-surface mean spring peak tidal currents exceed 1 knot (50 cm s^{-1}), being separated from each other by gravel troughs. In contrast, a moribund sandbank will have no associated bedforms, rounded crestlines and lee and stoss slope angles approaching 1° and 0.5°, respectively. They will generally be located in calmer hydrodynamic regions and be separated by sandy or muddy troughs.

However, sandbanks can also form nearshore parabolic banks linked by a low col, forming a zigzag pattern termed "open shelf sinuous banks" (Kenyon and Cooper, 2005). These sinuous forms are often associated with groups of linear banks that are located further offshore, and one hypothesis presented by Caston (1972) is that a single sinuous sandbank – as an inherently unstable feature due to having no prevailing net sediment transport direction (Kenyon and Cooper, 2005) – may split up into multiple linear sandbanks over time. Examples of both open shelf sinuous banks, such as the feature formed by Middle Cross Sand, North Cross Sand and Newarp Banks, and open shelf linear banks, such as Winterton Ridge and Smith's Knoll, are found within the East Coast REC Study Area (see Figure 4.1).

Work by Caston (1972) suggested that the strongest tidal currents run parallel to the longest axis of the sandbank, in opposite directions either side. These flows are deflected upslope, causing net sediment deposition at the convergence along the sandbank crestline. Williams *et al.* (2000) stated that these residual gyres were the result of the interruption of the dominant cyclonic semi-diurnal southern North Sea tidal flow. Modelling of the sandbank systems in the East Coast REC Study Area by Horrillo-Caraballo and Reeve (2008) indicates that the sediment supply is recycled in the bank system between Lowestoft and Winterton, with some moving northwards along the Scroby banks, some southwards along the shoreline and some feeding the offshore linear banks, passing over Cross Sands. The net loss in the system due to sediment passing offshore to the linear banks is supplemented by sediment coming southwards into the region from north of Great Yarmouth and coastal erosion along the Suffolk Coast (Cooper *et al.*, 2008).

Sandwave fields

Sandwaves are defined as generally having wavelengths >30 m with wave heights ranging from 2 to 20 m, with a wavelength to wave-height ratio >15 (Stride, 1982). They are a transverse bedform, with crestlines orientated across the main flow direction. Crestlines can be straight, sinuous, bifurcating or lunate, depending on the hydrodynamic influences and surrounding seabed morphology. They may be symmetrical or asymmetrical depending on the prevailing current conditions, with asymmetry indicating the net sediment transport direction. Migration of sandwaves or even sandwave fields will be in the direction of net sediment transport and can often be seen in the sub-bottom profile by internal cross-bedding.

Sandwaves are prevalent across certain areas in the southern North Sea (van Veen, 1935; McCave, 1971; Terwindt, 1971). They are more usually found in water depths greater than 18 m, as the effects of storm wave activity can destroy any bedforms located in shallower water depths. They can often have smaller parasitic megaripples on their stoss, and sometimes lee, slopes. The crestlines of these smaller bedforms will generally lie at an oblique angle to the parent sandwave (Langhorne, 1973). However, they may also form the parasitic bedform on larger sandbank features, with their crestlines usually aligned at 90° to the sandbank ridge crest on the lower flanks, becoming more parallel to the ridge crest on the upper flanks (Cameron *et al.*, 1992). They are useful bedforms for use in assessing the hydrodynamic regime surrounding a sandbank, with different sides of the sandbank often having asymmetric sandwaves with different facing directions (Caston, 1981).

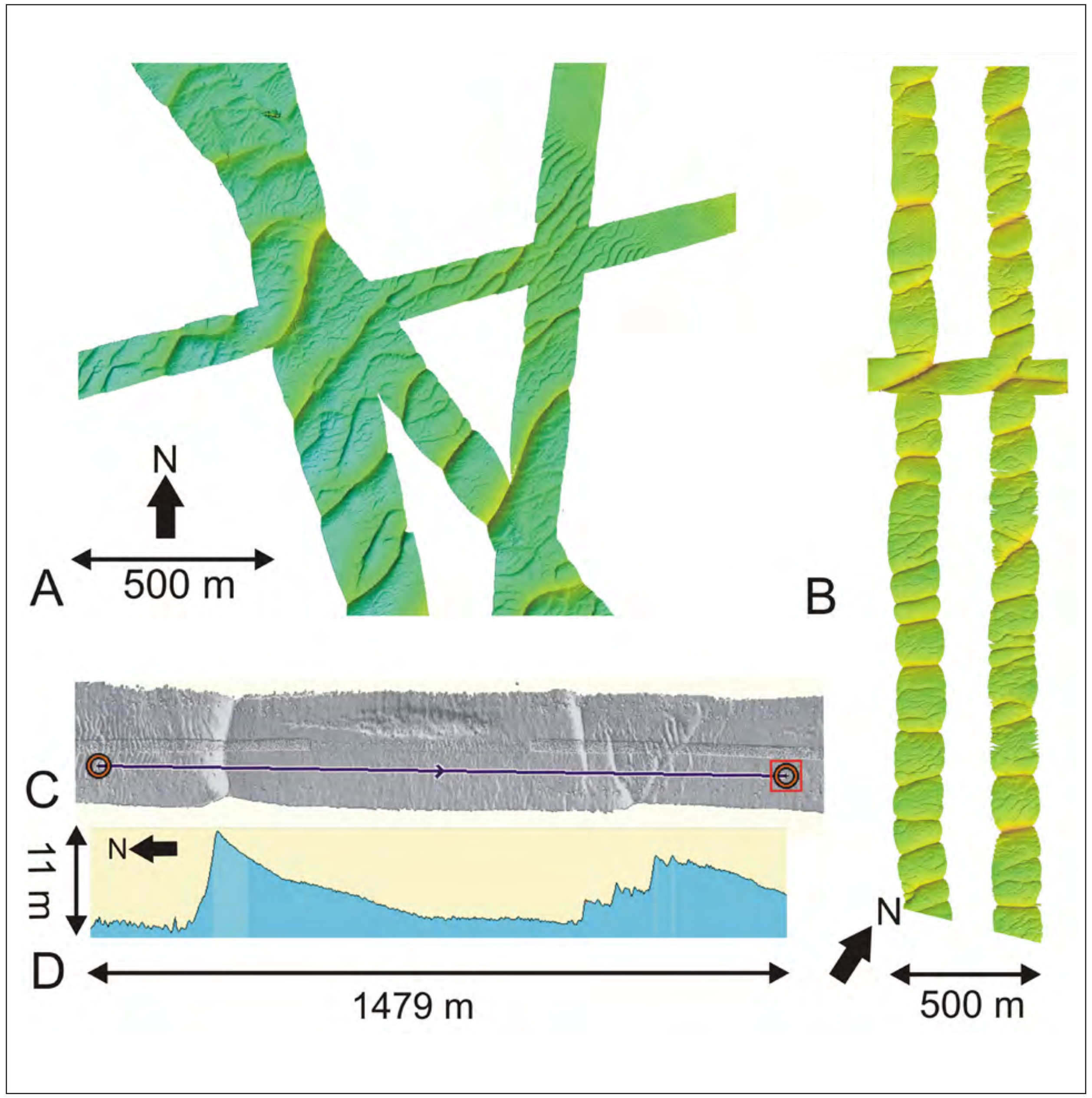


Figure 4.8 Example sandwave imagery from the East Coast REC Study Area. (A&B) High-resolution multibeam bathymetry, (C) backscatter imagery and (D) an OLEX generated profile of (C) showing average wave height and wavelength.

The East Coast REC Study Area is dominated by sandwave fields, being by far the most prevalent and laterally extensive bedform observed (Figure 4.8). In the north and central regions they cover ~65% of the survey area, dropping to ~45% in the southern region. The wavelengths range from 25 to 350 m, with crestline orientations predominantly NE–SW, although some localised patches run more E–W.

Megaripple fields

Megaripples are defined as generally having wavelengths of <30 m and wave heights of <1.5 m, although there are some exceptions to this with examples of wavelengths reaching up to 50 m and wave heights of up to 2–3 m. They are a transverse bedform, with crestlines orientated across the main flow direction. Crestlines can be straight, sinuous, bifurcating or lunate (Figure 4.9), depending

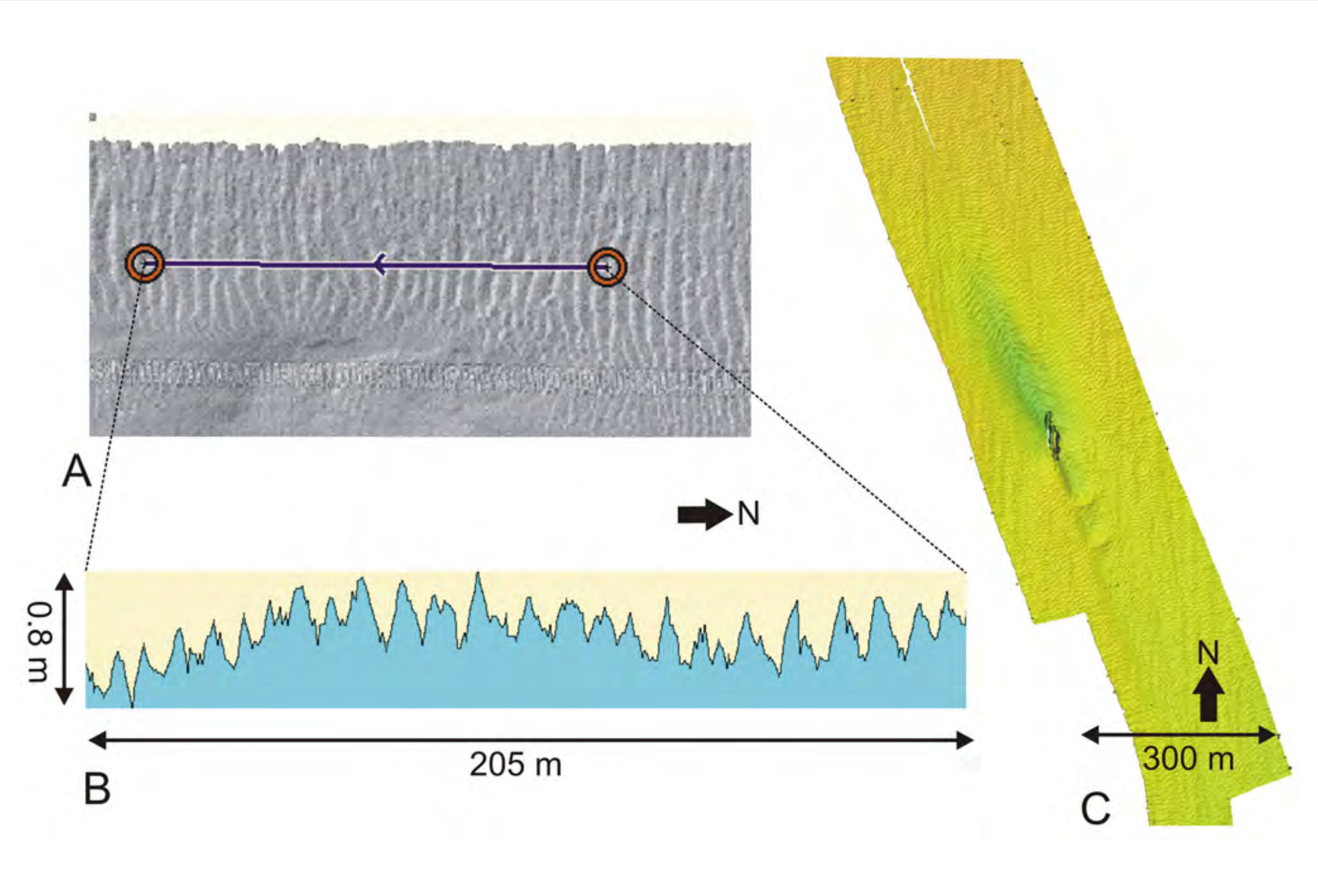


Figure 4.9 Example megaripple imagery from the East Coast REC Study Area. (A) Backscatter imagery, (B) an OLEX-generated profile across the megaripple field in (A) showing average wave heights and wavelengths and (C) high-resolution multibeam bathymetry showing the megaripple field around a wreck.

Figure 4.10 Side-scan sonar image of sand ribbons in the East Coast REC Study Area.

on the hydrodynamic influences and surrounding seabed morphology, and are either in-phase or out of phase. Megaripple fields may also form with branching and interdigitation of different sizes of megaripples. They often appear as parasitic bedforms on the larger sandwave features. Where the megaripples are symmetrical, it implies that the tidal conditions are approximately equal in their ebb and flow forcing. However, an asymmetry with a steep lee slope and a more gradual stoss slope indicates a direction of travel for the megaripple trains, giving an indication as to the primary hydrodynamic direction for sediment movement.

Scarce bedforms to featureless

Areas in the East Coast REC Study Area that have been classified as being “scarce bedforms to featureless” were observed to not be 100% devoid of features. However, the features present are known to be more ephemeral and subject to hydrodynamic influence, consisting of sand/sandy gravel ribbons and streaks (Figure 4.10). Sand ribbons develop where there is a thin veneer of sand (few grains to <1 m in thickness), often overlying a gravel substrate, and strong tidal currents. They are a longitudinal feature, orientated parallel to the tidal flow, with width-to-breadth ratios of >40:1. At near-surface mean spring peak currents of >1.5 knots (77 cm s^{-1}), featureless sand ribbons may be found between isolated sand waves, whereas at ~1.75 knots (90 cm s^{-1}) sinuous megaripples may be found on their surface, and at higher speeds of ~2.5 knots (130 cm s^{-1}) these megaripples will become straight crested sandwaves. Sand streaks are generally more wispy in character, forming as a very thin veneer, usually over a gravel-rich substrate, and do not have sharply defined edges as with sand ribbons. Because of the ephemeral nature of these features, it was decided not to map discrete areas containing sand ribbons and streaks, as that would only capture their position at that one point in time. By identifying the areas currently devoid of the larger, more permanent bedforms, this interpretation indicates those areas in which ephemeral bedforms are currently present or could form in the future.

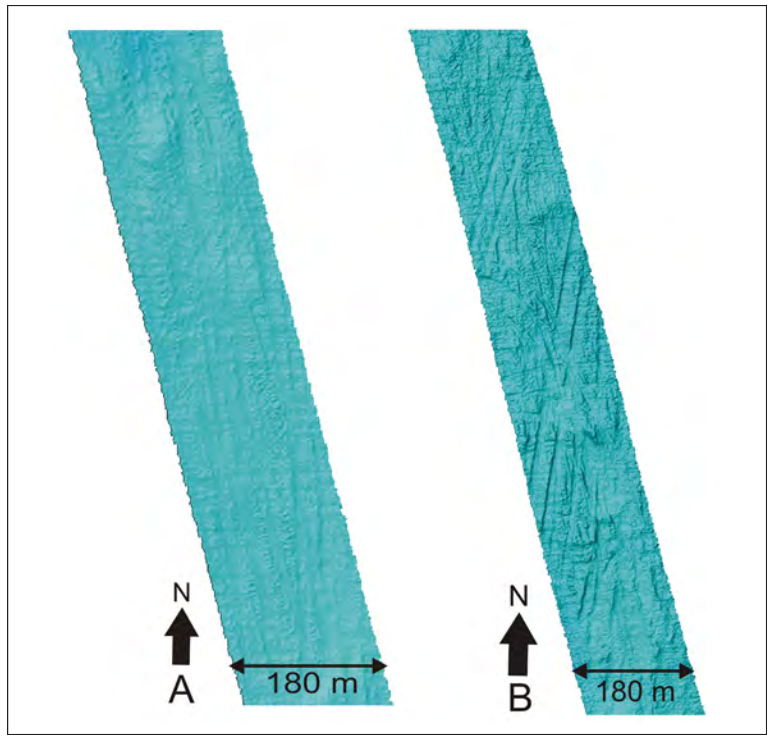


Figure 4.11 High resolution multibeam images of *Sabellaria spinulosa* reef with evidence of trawling activities.

Linear features

In addition to the positive bedform features formed through the deposition and accumulation of mobile sands and gravels, there were a number of more linear and anthropogenic features that were mapped across the East Coast REC Study Area. One significant anthropogenic feature affecting the seabed character was multiple trawling/dredging scars. The impact of these activities was particularly noticeable in areas of *Sabellaria* (Figure 4.11), although there is no evidence to suggest that these areas were singled out for trawling or dredging activity.

A natural feature, observed primarily in the nearshore areas, were scarps formed by near-surface sub-cropping of the more consolidated Quaternary formations, in particular the Yarmouth Roads Formation. In many instances, the outcrops were draped with a thin veneer of Holocene sediments (Figure 4.12) and often appeared in association with major-scale bedforms, namely sandwaves and parasitic megaripple fields. The scale of the bedforms close to and draping these scarps suggests that active deposition and bedform migration is ongoing, particularly when considering the shallow water depths concerned (<30 m) and the significant tidal currents active across the area.

Another feature mapped was the extent of scour around features observed on the seafloor. An example of scour from the wind turbines on Scroby Sands has previously been mentioned (see Figure 2.7). Another example is of the scour associated with wrecks (Figure 4.13).

4.6.1 Summary

A number of different geomorphological features were identified ranging from permanent scarps formed in outcropping Quaternary formations to ephemeral sand streaks and ribbons overlying gravel lag deposits. The largest bedforms observed are a series of approximately coast-aligned sandbanks, with sandwave and megaripple fields also prominent across the whole East Coast REC Study Area. Over 65% of the total area is covered by some scale of bedform, often with multiple bedforms existing in association with each other (see Figure 4.6).

The sediments of the East Coast REC Study Area are dominated by sand, slightly gravelly sand and gravelly sand, covering ~80% of the area (see Figure 4.3). There are isolated pockets of finer grained material such as slightly gravelly mud which is characterised by >90% mud-grade sediment and 1–5% gravel material. A considerable proportion of the central East Coast REC Study Area is dominated by coarser grained, gravelly sediments largely represented by sandy gravel, where 30–80% of the sediment is of gravel size and >90% of the remainder is composed of sand.

Throughout the East Coast REC Study Area the coarsest component of the gravel fraction (>16 mm) tends to be more rounded than the 2–16 mm fraction. The latter is dominantly sub-rounded to sub-angular iron-stained flint. The former, although rich in flint, includes a wider range of lithologies probably reflecting a glacial input and varies from sub-rounded to very well rounded. Lithologies include sandstone, limestone, igneous and metamorphic. Shell fragments, including whole valves, are found up to 40 mm in diameter, but they tend to be found within the finer gravel fractions. The amount of grey flint, although never dominant, increases towards the south of the East Coast REC Study Area.

4.6.2 Physical Region 1 – North

The majority of the northern sector is characterised by sandy deposits ranging from sand (~45% of the total cover) to slightly gravelly sand and gravelly sand (~40% of the total cover combined) (see Figure 4.3). Localised areas of sandy gravel (<10% of the total cover) are also present in western and central areas and are broadly coincident with the bathymetric lows between sandbanks. The most extensive area of coarser sediment in this section is located in the north-western corner of the northern sector where sandy gravel has been identified.

The coastal area of the northern sector extends to just north of Lowestoft at ~52°30′N. This incorporates the Caister Road, Yarmouth Road, Gorleston Road and Corton Road channel areas that run N–S between Caister Shoal, Scroby Sands and the coast. This is a relatively shallow-water coastal region where a mixture of sediment types have been recorded, including sand, slightly gravelly sand, gravelly muddy sand, slightly gravelly muddy sand and gravel. These mixed nearshore sediments have settled in a relative topographic low (10–20 m water depth surrounded by <10 m water depth). It is believed that this localised variability of sediment types and grain sizes over a comparatively short distance (21 km length by 3 km width) is due to the fluvial inputs and palaeodrainage pattern from the Holocene River Yare, which currently enters the North Sea at Gorleston, Great Yarmouth, being constrained by the seabed topography.

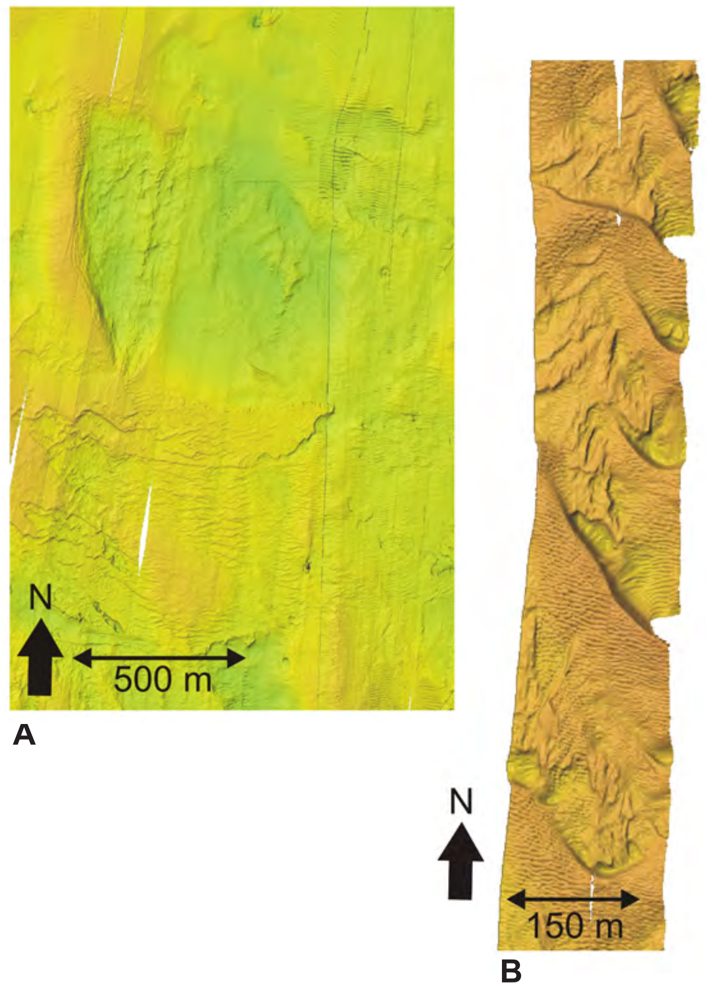


Figure 4.12 High-resolution multibeam imagery of sub-cropping Quaternary formations that have been draped with a thin Holocene veneer of sediment (A) and the interaction between sub-cropping Quaternary formations and the development of bedform features (B).

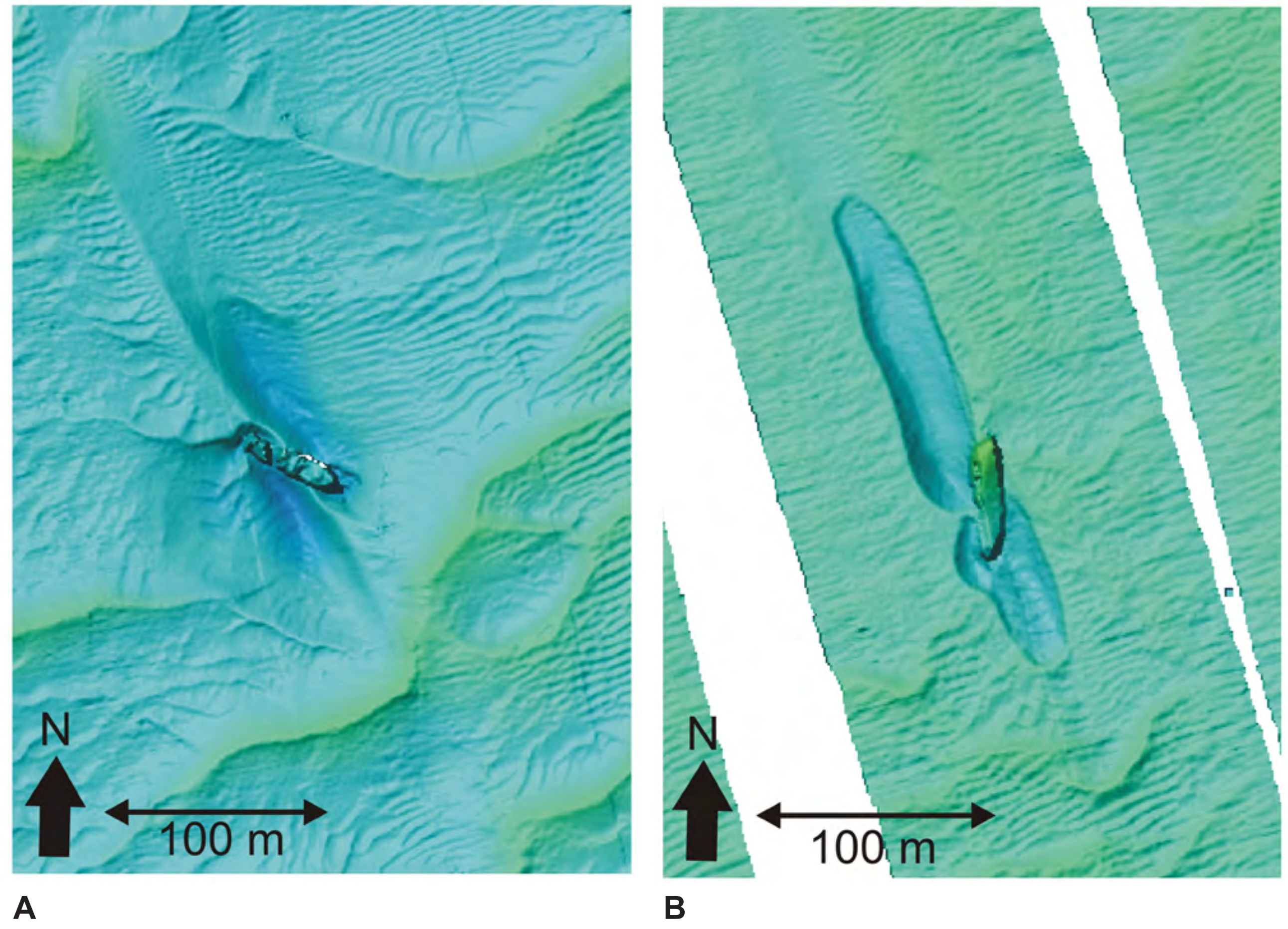


Figure 4.13 High-resolution multibeam imagery of the scour surrounding two shipwrecks, and the impact on the surrounding bedform development.

The gravel component (>2 mm) includes lithics and carbonate with the coarsest fraction lithic dominant. These clasts are overwhelmingly well-rounded flints. The largest recovered clasts are over 40 mm.

Localised patches of mud-dominated sediments exist in the central and eastern parts of the northern sector of the East Coast REC Study Area. These include sandy mud and slightly gravelly mud. These patches are of limited extent and broadly correspond to deeper water, featureless areas of the seabed and the lower flanks of sandbanks.

The degree of sorting measured in the sediment samples varies considerably across the northern sector of the East Coast REC Study Area (see Figure 4.6). There is a trend towards coarser sediments such as sandy gravel and gravelly sand exhibiting poor sorting whilst finer grained sediments and those with muddy components are moderate to well sorted. However, a suite of samples collected by the SEA2 project in 2001 across Smith's Knoll in the north-eastern part of the region show a uniform fining of sediment north-eastwards over the bank (Mean 1.8–2.40). However there is no similar trend in values for sorting or other parameters. The evaluation of sediment grain size across Smith's Knoll is comparable with studies of Haisborough Sand by McCave and Langhorne (1982), who found the sand to become finer grained from south-west to north-east across the bank, with the best sorting on the crest of the bank.

Sandbanks are the dominant bedform type within the East Coast REC Study Area, lying solely within the northern region (see Figure 4.6) and stretching extensively across the whole of the northern survey area from landward to seaward, and down the western edge in the shallow nearshore waters. As a group, these sandbanks form a sub-set of the Norfolk Banks, called the Great Yarmouth Banks (Cooper *et al.*, 2008). Cooper *et al.* (2008) suggest that approximately 5,000 years ago the coastline lay approximately 5 km offshore. Therefore, the Inner Great Yarmouth Banks of Corton Sand, Holm Sand, Scroby Sands and Cross Sands will have had a much shorter period of evolution than the Outer Great Yarmouth Banks of Winterton Ridge, Smith's Knoll and Newarp Banks, which may help account for differences in their present-day morphology (predominantly sinuous as opposed to linear).

The most extensive sandbank complex comprises North Scroby, Middle Scroby and South Scroby, running down into Corton Sand and Holm Sand (see Figure 4.1). At its widest point (Middle Scroby) the sandbank has a width of ~2 km and a combined length of ~50 km from the northern tip of North Scroby to the tail of Holm Sand. In general, the sandbanks have a slope angle of ~2° on their western flanks and 0.5° on their eastern flanks, in comparison to the offshore linear banks of Winterton Ridge and Smith's Knoll that show slopes of ~6° and 1° on their respective western and eastern flanks.

The largest examples of the linear sandbanks are Winterton Ridge and Smith's Knoll, being ~16 and 20 km in length and ~1.3–1.7 km in width at their widest point, respectively. The more nearshore sandbanks of Middle and South Scroby, Holm Sand, Corton Sand and Newcome Sand all have water depths above them of <2 m in places (height above mean high-water springs), whereas over the more seaward linear sandbanks, minimum depths are closer to 5 m.

Most of the sandbanks are between 10 and 20 m in height above the surrounding seafloor (Cooper *et al.*, 2008). Between them, the Inner Great Yarmouth Banks have an approximate volume of 620 × 10^6 m^3, with Smith's Knoll at ~390 × 10^6 m^3 and Winterton Ridge at ~105 × 10^6 m^3. They therefore represent a significant sink for sediments in the East Coast REC Study Area, with predictions by Reeve *et al.* (2001) suggesting that the volume of the Great Yarmouth Banks is growing at ~5 × 10^5 m^3 yr^{-1}.

Sandbanks are known to be semi-mobile, with the core of the sandbank remaining fixed but the head and tail positions migrating. Seismic profiles show that they typically have an asymmetric cross-sectional profile, with internal dipping reflectors that indicate the direction of migration. The majority of studies conducted on sandbank migration in this area (eg, Arthurton *et al.*, 1994) indicate that migration is in a N–S direction, with the recirculation of sediments being in a southerly direction along the inner flank and a northerly direction along the outer flank, and no lateral movement that mirrors shoreline retreat during the marine transgression. However, a UKHO assessment (UKHO, 2010) of the approaches to Lowestoft found that, between 2002 and 2009, Newcome Sand had had significant accretion to its western edge, with the 2 m contour migrating westwards at an average of 50 m yr^{-1} since 2002, whilst the eastern side of Holm Sand had also seen accretion, with a subsequent eastwards migration of depth contours. Historical migration seen in the sub-bottom profiles, with internal dipping surfaces, suggests the direction of travel and so net sediment transport, indicating that this migration has been ongoing since the inception of fully marine conditions ~5.5 ka BP.

All of the sandbanks in the East Coast REC Study Area have a complex relationship with parasitic smaller-scale bedform features such as sandwaves and megaripples. An assessment of the parasitic sandwave orientation on the flanks of Corton Sands and Holm Sands shows a distinct 180° difference in facing direction, with those on the north-easterly flank of Holm Sand facing NW and those on the south-westerly flank of Corton Sands facing SE (Figure 4.14). A bedload parting zone runs through the East Coast REC Study Area from north to south, but this area of sandwaves lies within the zone where net sediment transport is predicted to be in a southerly direction. This asymmetry observed in the facing directions therefore suggests that the sandbanks themselves have a significant impact on the hydrodynamic regime and sediment deposition, with currents and eddies circulating around the sandbank heads and tails. In addition, towards the end of sandbanks, sandwaves with opposing symmetries are often separated by a zone of symmetrical sandwaves, supporting the hypothesis of localised fluctuations in the dominant net sediment transport direction.

In the northern region, where the sandwave fields surround and interact with the sandbank features, the sandwaves appear to be predominantly asymmetrical, with a facing direction to the south or south-east. Their crestlines range from linear to sinuous and bifurcated, dependent on their proximity to the heads or tails of sandwaves and the localised residual eddies that these can initiate. All sandwave fields have associated parasitic megarippling, with crestlines that appear predominantly sinuous in-phase. Areas where megaripples form the dominant bedform feature are generally <50 km^2 in areal extent and appear to be predominantly located either between sandbanks or at the heads or tails of sandbanks, covering approximately 25% of the northern physical region.

Cross Sands Anomaly

One significant feature located within the northern region is the Cross Sands Anomaly. In 2006 a survey was conducted by UKHO (UKHO, 2007), which imaged a geological feature located in the Barley Picle channel, protruding out to the west from the Middle Cross Sands sandbank (Figure 4.15). It has an orientation of E–W, a maximum length of 165 m and a maximum width of 30 m, with an elongated ovoid shape. Its top sits ~33 m below the sea surface, with a depth to the base of the surrounding scour of 46 m from the sea surface.

Historic grab samples taken from its top surface were classified as pebbles, weed and marine growth. Video imagery taken during the ground-truthing cruise in 2009 suggested that the Anomaly was formed from an eroded outcropping consolidated geological formation, possibly the Yarmouth Roads Formation. This would appear to be consistent with other outcropping scarps located

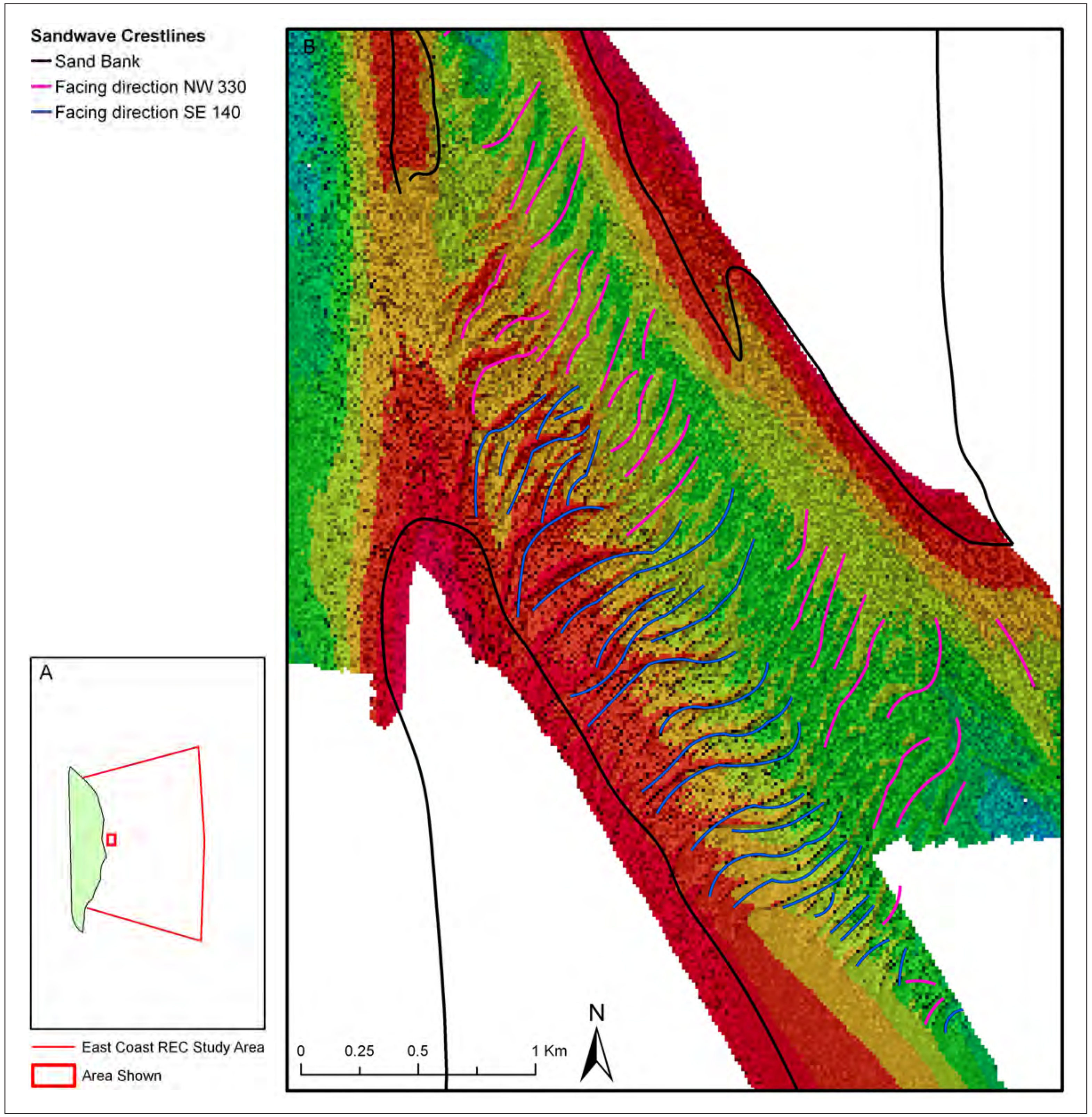


Figure 4.14 Interpretation of the facing direction of sandwaves located at the head of Holm Sand and the tail of Corton Sand, imaged using multibeam bathymetry. Inset (A) shows the location within the East Coast REC Study Area.

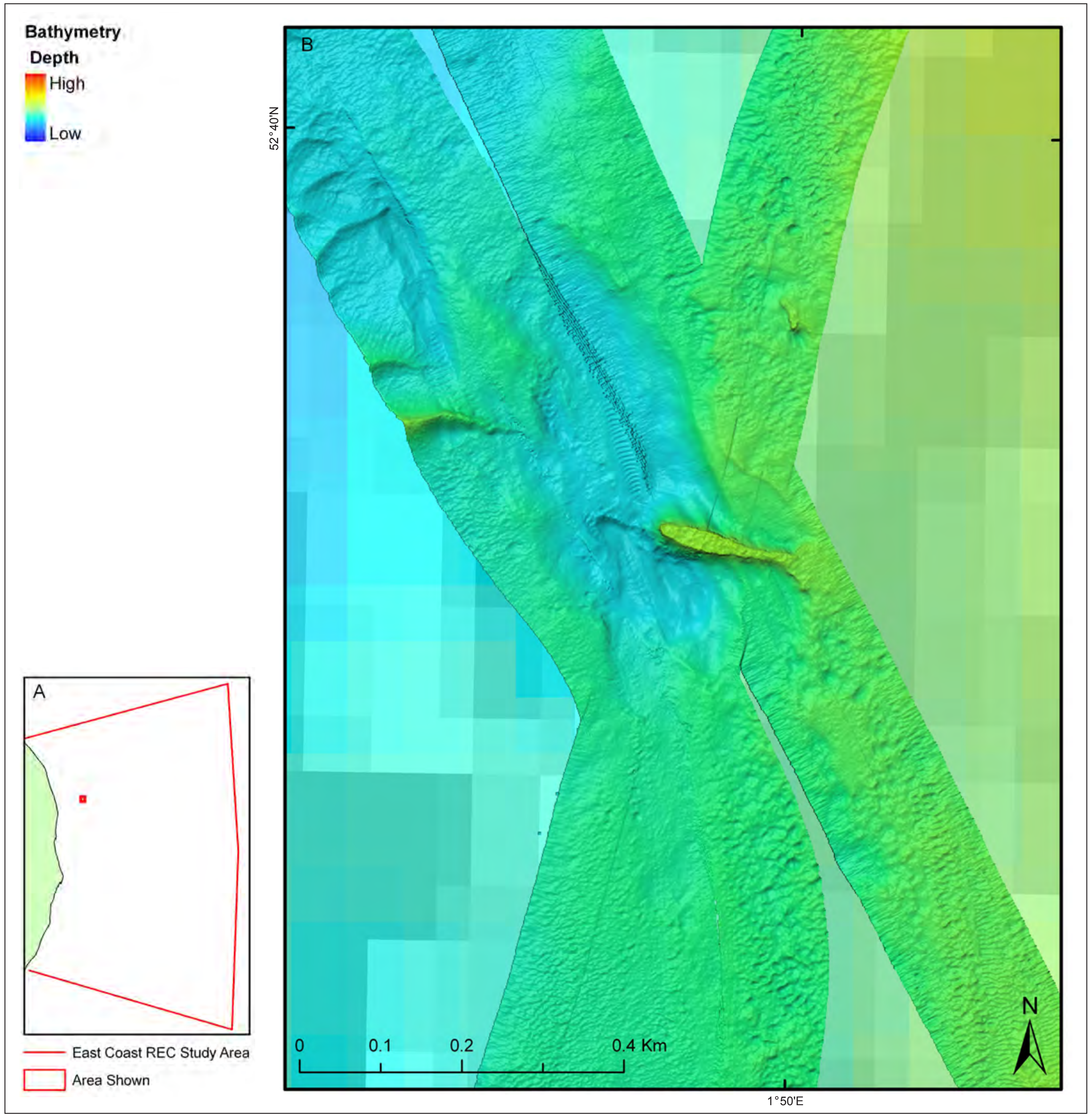


Figure 4.15 High-resolution multibeam bathymetry of the Cross Sands Anomaly, overlain onto the regional single-beam bathymetric data. Inset (A) shows the location within the East Coast REC Study Area. Digital single-beam bathymetry data © British Crown and SeaZone Solutions Ltd. All rights reserved. Data Licence 052008.012.

4.5 km to the southeast at the boundary between Regions 1 and 2, where the Yarmouth Roads is again observed (Figure 4.16).

However, the scarps to the south-east, although showing a degree of rounding, have a more NNW–SSE orientation instead of the defined E–W protrusion exhibited by the Cross Sands Anomaly. In addition, sub-bottom profiles suggest that the Cross Sands Anomaly does not extend to depth, and it could have its base resting in a channel infill package which has been interpreted as possibly being Swarte Bank Formation (Figure 4.17). Therefore an alternative hypothesis is proposed.

Praeg (2003) documents a number of tunnel-valleys carved out during the Weichselian and Elsterian glaciations, with the Elsterian southern ice limit reaching south of the East Coast REC Study Area. Sub-bottom imagery acquired from the north of the survey area during the geophysics cruise in 2008 appears to show these valleys extending into the East Coast REC Study Area (Figure 4.18), formed from the high-pressure meltwater drainage of glacial ice near the edges of continental ice sheets. It is suggested that the Cross Sands Anomaly is a glaciotectonic rafted block that was brought down by the ice sheet and deposited during meltwater drainage. This is supported by the work of Burke *et al.* (2009), who mapped chalk raft emplacement along the North Norfolk Coast, associated with ice movement during glacial times. Until the topographic feature is cored, uncertainty regarding its origin will remain.

The Yarmouth Roads Formation is the first identifiable formation, situated below the Cross Sands Anomaly, supporting the view that there could be a package of Swarte Bank Formation present surrounding the Cross Sands Anomaly. However, the packages above are not identifiable, and they could therefore be assigned to localised patches of either Brown Bank or Eem Formation, if the suggestion above is correct. This in turn indicates that in localised areas, the formations sub-cropping beneath the Holocene sediments could vary on a scale finer than can be recognised in the Quaternary interpretation (see Figure 4.7).

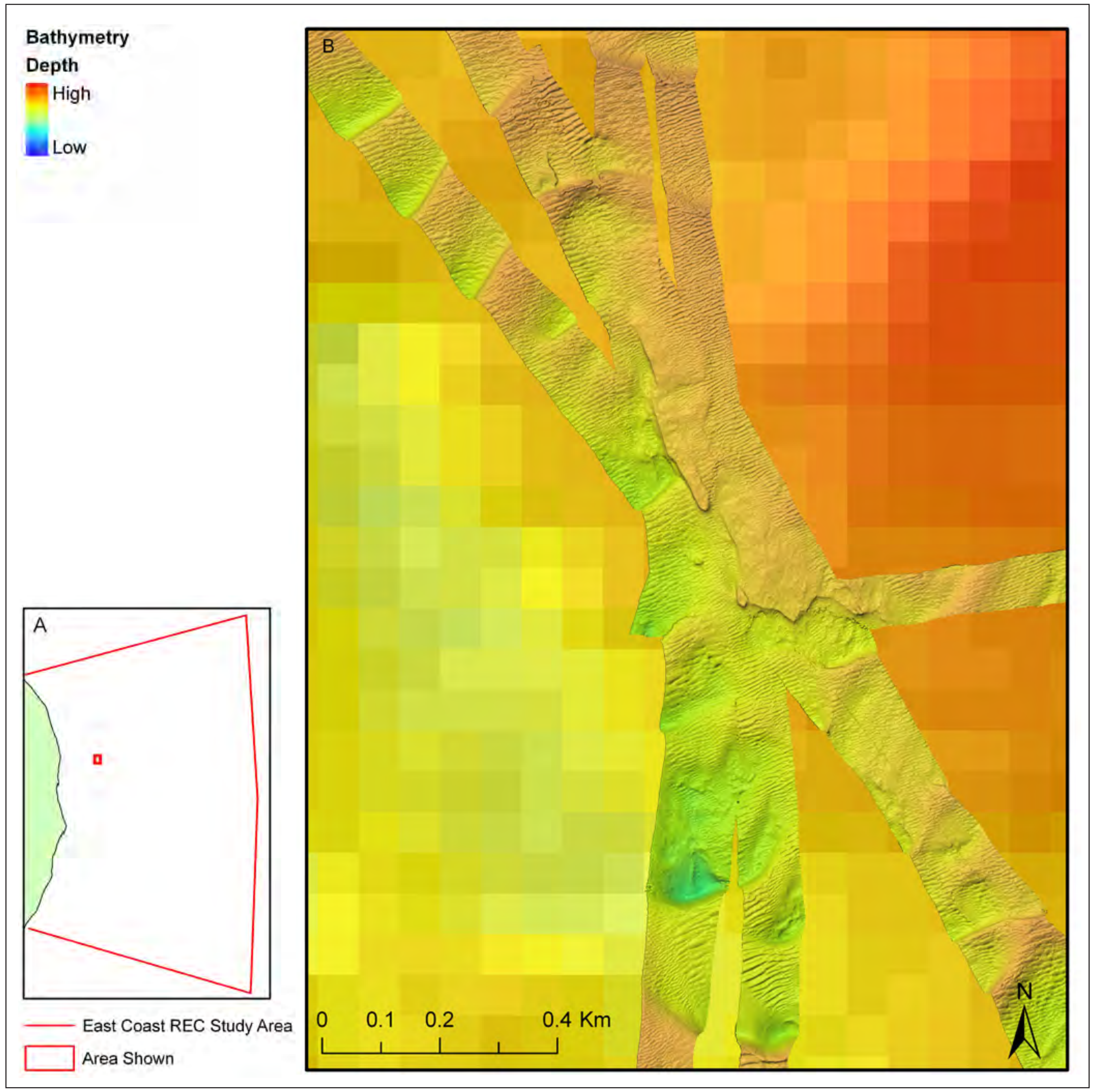


Figure 4.16 High-resolution multibeam bathymetry of sub-cropping Yarmouth Roads scarps, overlain onto the regional single–beam bathymetric data. Inset (A) shows the location within the East Coast REC Study Area. Digital single–beam bathymetry data © British Crown and SeaZone Solutions Ltd. All rights reserved. Data Licence 052008.012.

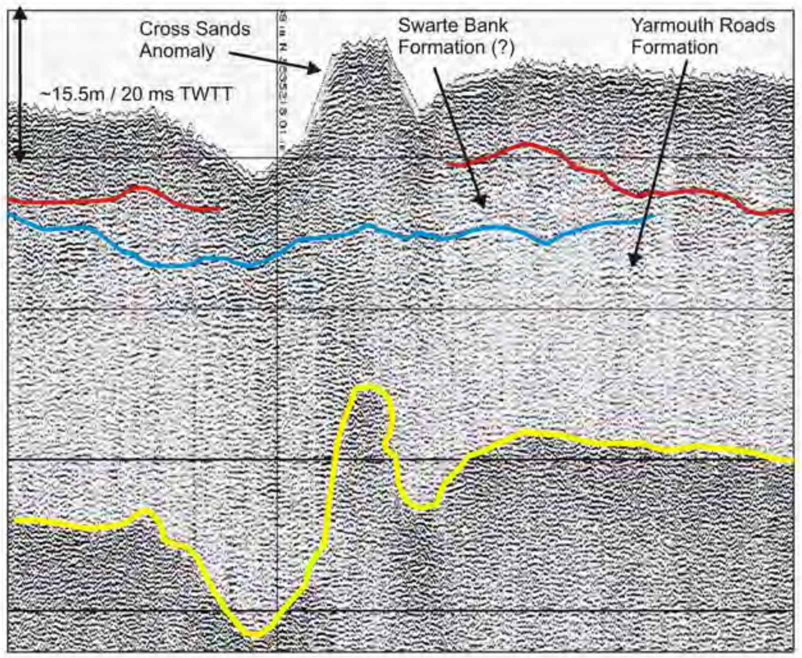


Figure 4.17 **Sub-bottom profile and interpretation of possible Swarte Bank Formation beneath the Cross Sands Anomaly. The yellow reflector identifies the seabed multiple; the blue reflector the top Yarmouth Roads Formation and the red reflectors the top Swarte Bank Formation (?).**

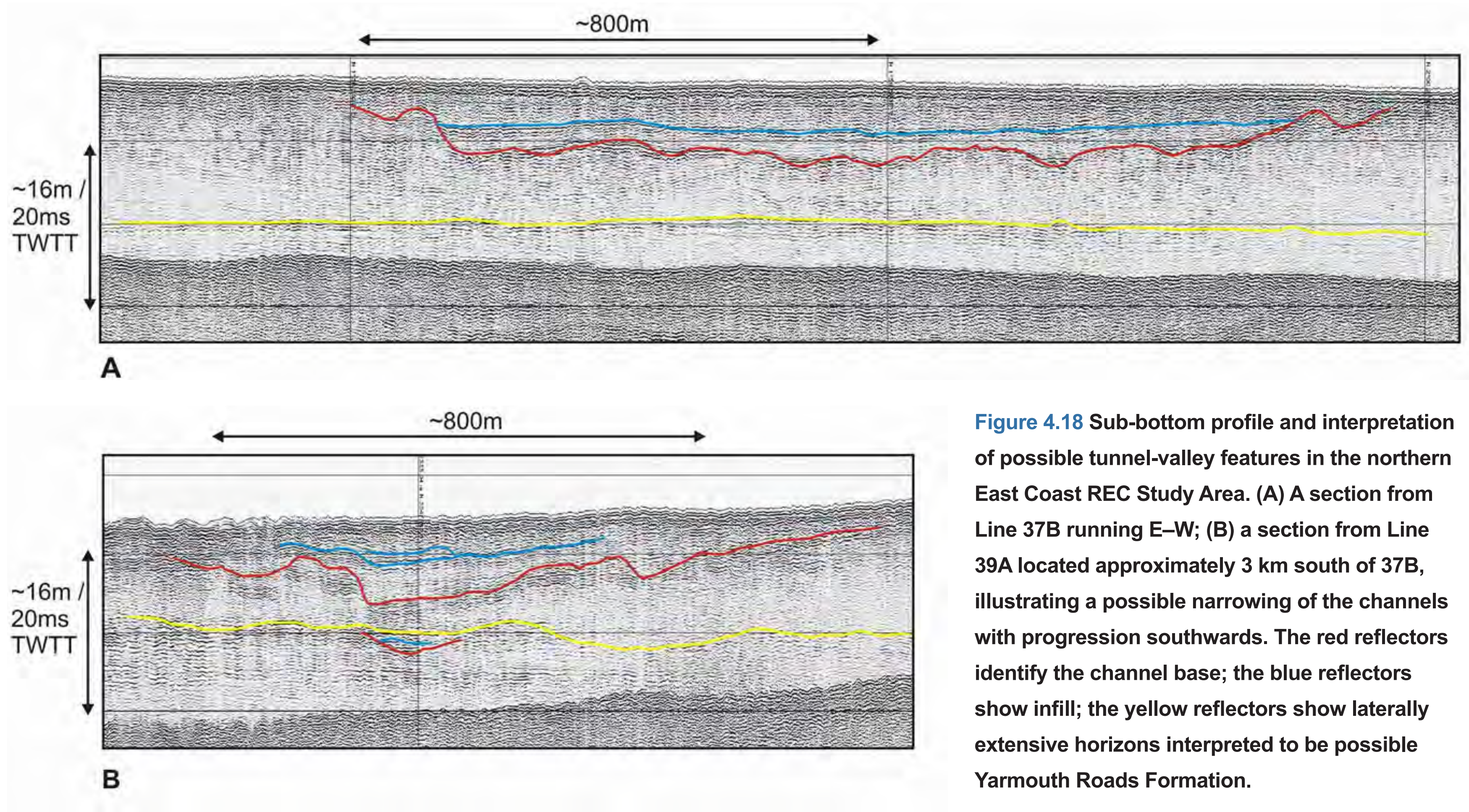


Figure 4.18 **Sub-bottom profile and interpretation of possible tunnel-valley features in the northern East Coast REC Study Area. (A) A section from Line 37B running E–W; (B) a section from Line 39A located approximately 3 km south of 37B, illustrating a possible narrowing of the channels with progression southwards. The red reflectors identify the channel base; the blue reflectors show infill; the yellow reflectors show laterally extensive horizons interpreted to be possible Yarmouth Roads Formation.**

4.6.3 Physical Region 2 – Central

The central sector of the East Coast REC Study Area is dominated by a relatively large area (~350 km^2) of sandy gravel, with a defined southerly orientated “tail”, situated in the central area of this region (see Figure 4.3). Small localised patches of gravel have also been interpreted within this region. The presence of these coarse-grained, very poorly sorted sediments (see Figure 4.5) is likely to be associated with strong currents in this part of the North Sea, leading to winnowing of finer sediments. Stride (1982) noted that with the development of long-term velocity gradients due to the establishment of tidal currents and net sediment transport pathways in the Holocene, the seabed sediments respond by developing lag deposits that coarsen in the direction of net transport. It is therefore suggested that this deposit has evolved due to the focusing of tidal currents by the sandbank complex to the north of this region that has led to the winnowing of the sand fraction and formation of this southerly migrating gravel lag deposit. Due to the presence of some percentage of sand, this gravel deposit does have examples of both sandwave and megaripple fields covering portions of it. As the majority of these overlying bedforms are located adjacent to sand-rich areas, it is believed that they are being fed and maintained by tidal currents moving the finer fractions from these adjacent deposits across the gravel lag.

The sediments in the east of the central sector are composed predominantly of sand-grade sediments with variable gravel components (<1% to 30%). The level of sorting within these sediments again shows a general trend of increased sorting where the sand component is greater. The western central area is dominated by slightly gravelly sand and gravelly sand with small pockets of muddier sediments.

The largest area of finer sediment mapped within the central sector occurs in the north-east corner, where ~30 km^2 of megarippled muddy sand has been identified. This may be associated with local hydrodynamic conditions surrounding Smith’s Knoll – an elongate bathymetric high trending NNW–SSE that terminates to the immediate north of this area of muddy sand.

In the east of the central region the sandwaves are predominantly orientated E–W with irregularly spaced sinuous crestlines that are slightly asymmetric to the south, suggesting that the direction of net sediment transport is southerly. They have associated linear bifurcated megaripples as a parasitic bedform, whose crestlines lie obliquely to the parent sandwave feature. The bifurcation is usually indicative of lower mean-current velocities and current oscillation, suggesting a localised bathymetric influence. Further west in the central region, despite the sandwaves still maintaining a sinuous crestline with the associated megarippling, the wavelength decreases to between 40 and 140 m from 100 to 400 m, due to the decrease in water depth and the changes in localised hydrodynamics due to sandbanks and Quaternary scarps in close proximity.

4.6.4 Physical Region 3 – South

The seabed sediments of the southern region are again comprised largely of a variety of sandy materials with variable-percentage gravel components (see Figure 4.3). Sorting of the sediments is extremely variable and patchy, ranging from well-sorted slightly gravelly sand in the south-eastern corner to poorly sorted sandy gravel patches along the southernmost limit of the East Coast REC Study Area (see Figure 4.5). The sorting does appear to be linked primarily to the seabed sediment type, with sand-dominated sediments being much better sorted than the gravel-dominated ones, as opposed to being controlled by the bathymetry, with well-sorted areas being located in both the deeps and the shallower water depths. Likewise, the areas of both well- and poorly sorted sediments lie in equal part either side of the bedload parting zone.

There is a large expanse of sandy gravel in the eastern and central part of the area, covering ~120 km^2. Samples from this region recorded moderate to poor sorting values, indicative of a variable-grain-size gravel component. Again, there are small isolated areas of slightly gravelly sandy mud, gravelly muddy sand and muddy sand that are located primarily in regions that have ephemeral or no bedform features. These small areas may represent localised variations in sedimentation conditions due to their lying within small topographic lows/being surrounded by small nearshore bank-like features. These positive and negative geomorphological features would afford protection from the prevailing tidal currents, leading to a reduction in the winnowing of existing sediments.

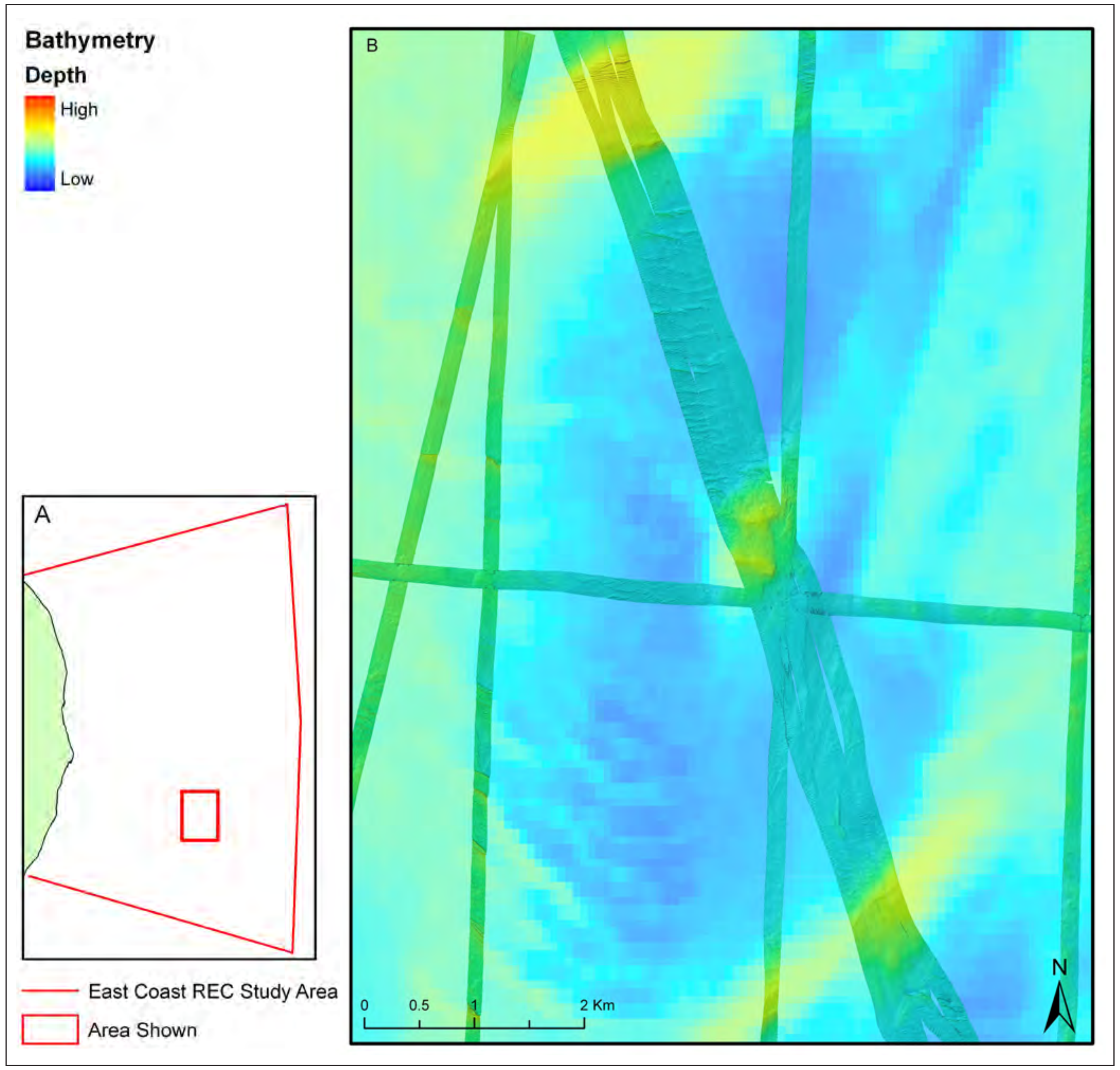


Figure 4.19 **High-resolution multibeam bathymetry of the three Causeway Anomalies, overlain onto the regional single–beam bathymetric data. Inset (A) shows the location within the East Coast REC Study Area. Digital single-beam bathymetry data © British Crown and SeaZone Solutions Ltd. All rights reserved. Data Licence 052008.012.**

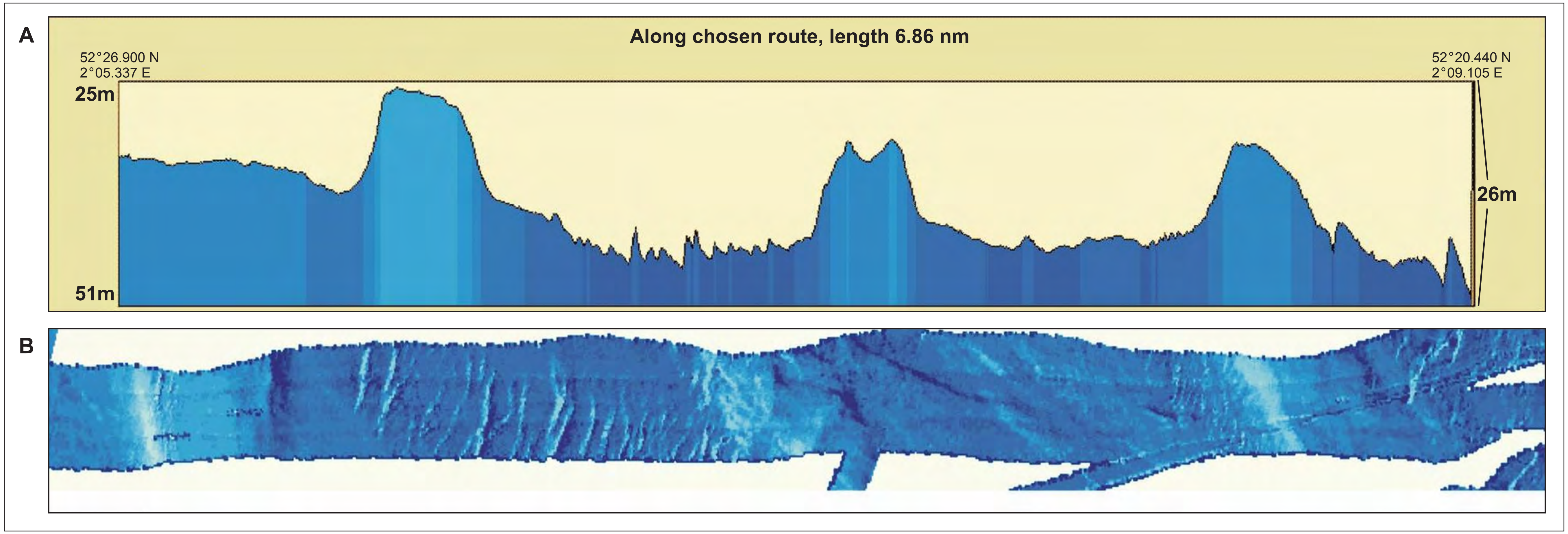


Figure 4.20 (A) OLEX-generated profile across the three topographic highs showing their steep-sided geomorphology and relative height above the surrounding seabed. (B) Plan-view OLEX image of the three topographic highs, showing their steep-sided north-western face, featureless tops and stepped south-eastern slopes with possible bedrock outcropping.

In the easterly southern region the sandwave fields have irregularly spaced crestlines that are predominantly linear with some bifurcation. These appear in association with sinuous bifurcated megarippling on their stoss sides. Further west, there is a mix of irregularly spaced linear in-phase and sinuous bifurcating sandwaves, which are interspersed with regularly spaced sinuous symmetrical sandwaves. Both have associated megarippling. There is no obvious bathymetric control determining why the southern region sandwave fields are more irregular in nature. However, it does correspond to an increase in the gravel percentage of the seabed sediments, which may limit the production and long-term maintenance of sandwave features.

Causeway anomalies

Three topographic highs were identified in the single-channel echosounder data-set, centred around 52°23.5′N, 2°8′E. Two, termed “causeways”, appear to bridge a trough between other more extensive geomorphological highs, with the third being isolated in the trough (Figure 4.19). What is unusual is their NE–SW orientation, which is opposed to the primary N–S sandbank or E–W sandwave orientations, and oblique to the dominant N–S tidal and net sediment transport direction. High-resolution multibeam imagery over these highs shows they share a complex surface morphology. They have a steep NW-facing slope that rises up rapidly to 8–12 m in height above the surrounding seabed before moving onto a south-easterly dipping shallow plateau top. Two of the highs also have a shallow dip in the top plateau (Figure 4.20). The south-easterly lee slopes of each high have a gentler slope angle, gradually falling off to the seafloor. Each south-easterly lee slope also shows some degree of “stepping” downslope, suggesting that a northerly to north-easterly dipping formation may be outcropping at or near the surface, creating small ridges.

The slopes of each high have large sandwaves running across them, orientated approximately E–W, with parasitic linear sinuous/linear parallel megaripples infilling between each sandwave. The plateau of each topographic high is predominantly bedform-free, covered by a plain sediment veneer with possible relict trawl scours.

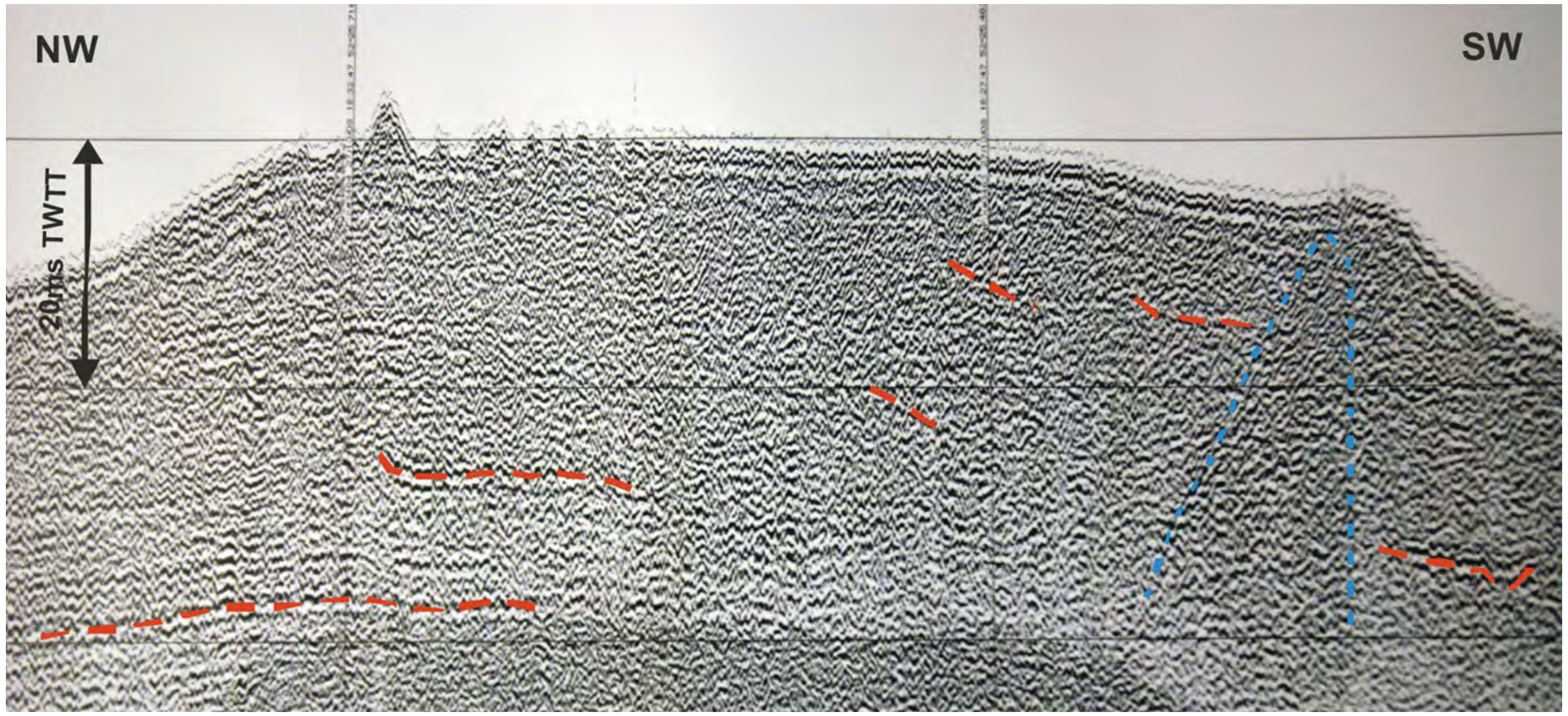


Figure 4.21 **Surface tow boomer profile of the northernmost "causeway" anomaly, showing a few laterally discontinuous internal reflectors (red), an inverted "V" shaped anomaly (blue), and the acoustically chaotic signature of the feature, with little internal structure or obvious core.**

In between each topographic high there are strong ~E–W lineations that appear to be controlling the orientation of initially NW–SE-orientated bifurcated sandwaves that became more E–W in orientation on butting up against the lineations. The backscatter return from the multibeam suggests that the dominant sediment type in this area is a coarse sand/gravel, with finer grained sediments lying in the troughs between gravel-rich bedforms.

However, the sub-bottom profiles indicate there is little internal structure within each of the highs (Figure 4.21), with no evidence of outcropping bedrock, and an acoustic signature that is very similar to the surrounding lows. It is suggested that they may be relict sandbanks, formed during a previous marine inundation of the southern North Sea. To have maintained their size in the current hydrodynamic regime, with the associated deep scouring between each one, suggests that they are dense structures resistant to re-working, although none of the highs show evidence of an internal core around which the structure could be anchored.

They are located in an area underlain by Brown Bank, Westkapelle and Yarmouth Roads formations, and so it is suggested that they could be grounded on a sub-cropping consolidated formation that is beyond the penetration range of the Boomer records due to the interference from the overlying Holocene sand deposits. It is also possible that they have formed around remnants of recessional moraines deposited as the Elsterian ice sheet retreated at the end of its glacial maximum. Their location in deeper water and south of the significant Holocene sandbank features acting as potential sediment sources could have protected them from burial by sediments re-worked during the late Holocene.

4.7 Seabed sediments

Sediments collected from 192 sample stations during the ground-truthing cruise (Hamon grab, Vibrocores and Clamshell grab) were combined with data from 589 historical sample sites within the East Coast REC Study Area to assess the seabed sediments distribution (based on Wentworth and Folk) using PSA to assess % sand, % gravel, % mud and sorting.

Sediment characteristics from sampling

The large number of samples collected during the May 2009 ground-truthing cruise have been analysed for their particle size distribution. These included analyses from 154 Hamon grab samples and 38 tops of vibrocores. Their basic gravel:sand:mud ratios have been used to update BGS's DigSBS250 map that describes the seafloor according to the Folk classification. The revised plot (Figure 4.22) shows several changes to that previously drawn. This includes a substantially greater area of sandy gravel in the centre of the East Coast REC Study Area than previously mapped. This revision fits with the areas of active interest for aggregate extraction.

However, it should be born in mind that these polygons for each Folk class may include a few samples with a different PSA result as the map has to be considered a summary to be viewed at a regional scale. This is demonstrated by detailed repetitive sampling previously carried out by Cefas, where three or four samples were taken annually from 1998 to 2005 from a selection of sites (Figure 4.23).

This shows that in some areas the seabed sediments vary considerably in their grading even over distances of a few tens of metres (Figure 4.24). Site G34 shows a range from gravelly Mud (gM) to sandy Gravel (sG), but all generally show a gravelly nature with similar amounts of sand (Figure 4.25). Other sites show greater consistency – for example, Site G3 (Figure 4.26) – whereas G38 (Figure 4.27) shows a wider variety among the sediments sampled. However, these fine-scale variations occur at a level finer than can be displayed on maps at 1:100,000 scale or at 1:250,000, the scale of DigSBS250 (see Figure 4.22).

Many of the samples assessed for PSA showed a very diverse range of grain sizes, even where a sample was dominated by one particular class. Photographs of some of the assessed samples from Tranche 1 illustrate the divisions into which each sample was divided, and the diversity of sizes within the samples (Figure 4.28).

By splitting and documenting the vibrocores collected, it was possible to relate the seabed sediment cover to the older Holocene and Quaternary deposits beneath (Figure 4.29).

Sediment characteristics from remote sensing

On a broader scale, imagery from both the camera sledge and the water curtain camera (see Section 3.3.3) were used to ground-truth the seabed characteristics and sediment distribution. They revealed a complex seabed character ranging from fine-grained sand-dominated areas, through sand veneers overlying clay-like formations, to a much coarser shell hash-dominated substrate, with occasional glimpses of sub-cropping solid formations being overlain by a thin, patchy, veneer of sand (Figure 4.30).

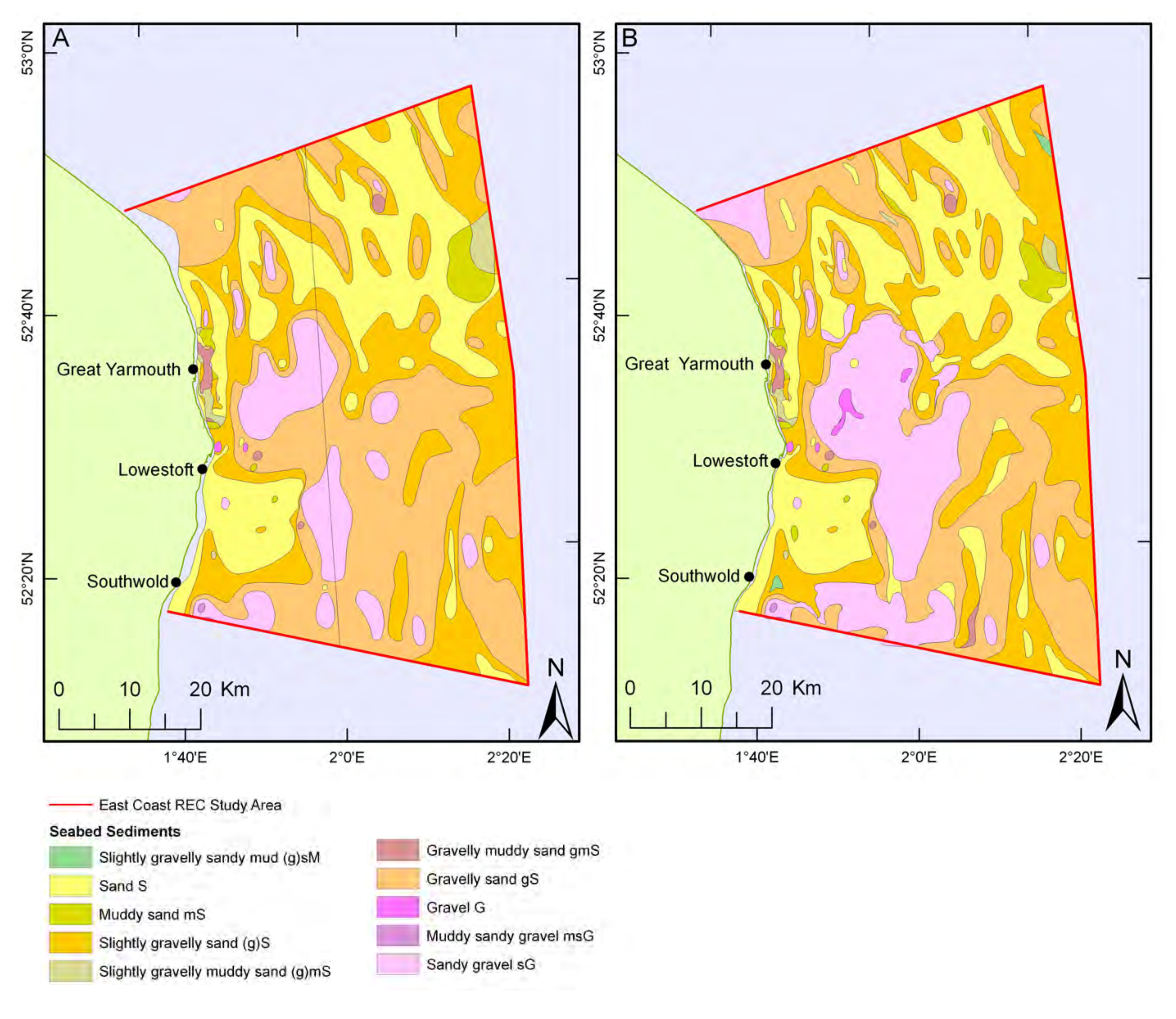


Figure 4.22 Comparison between DigSBS250 (A) and the updated seabed sediments map (B) of the East Coast REC Study Area at 1:100,000 scale.

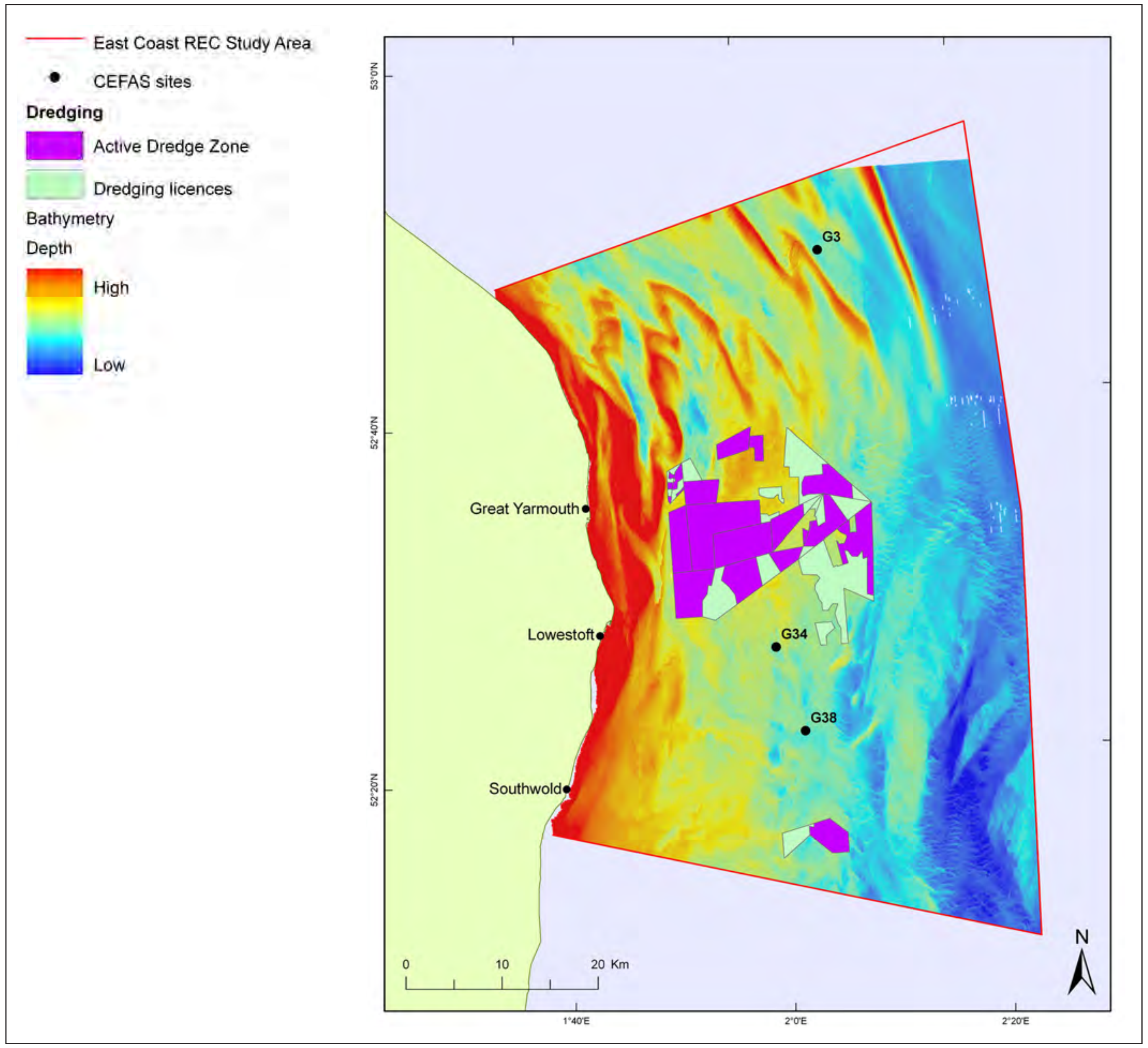


Figure 4.23 **Location of the Cefas long-term sampling sites with respect to aggregate licensed areas (after Barrio Froján *et al.,* 2008). Digital bathymetry data © British Crown and SeaZone Solutions Ltd. All rights reserved. Data Licence 052008.012.**

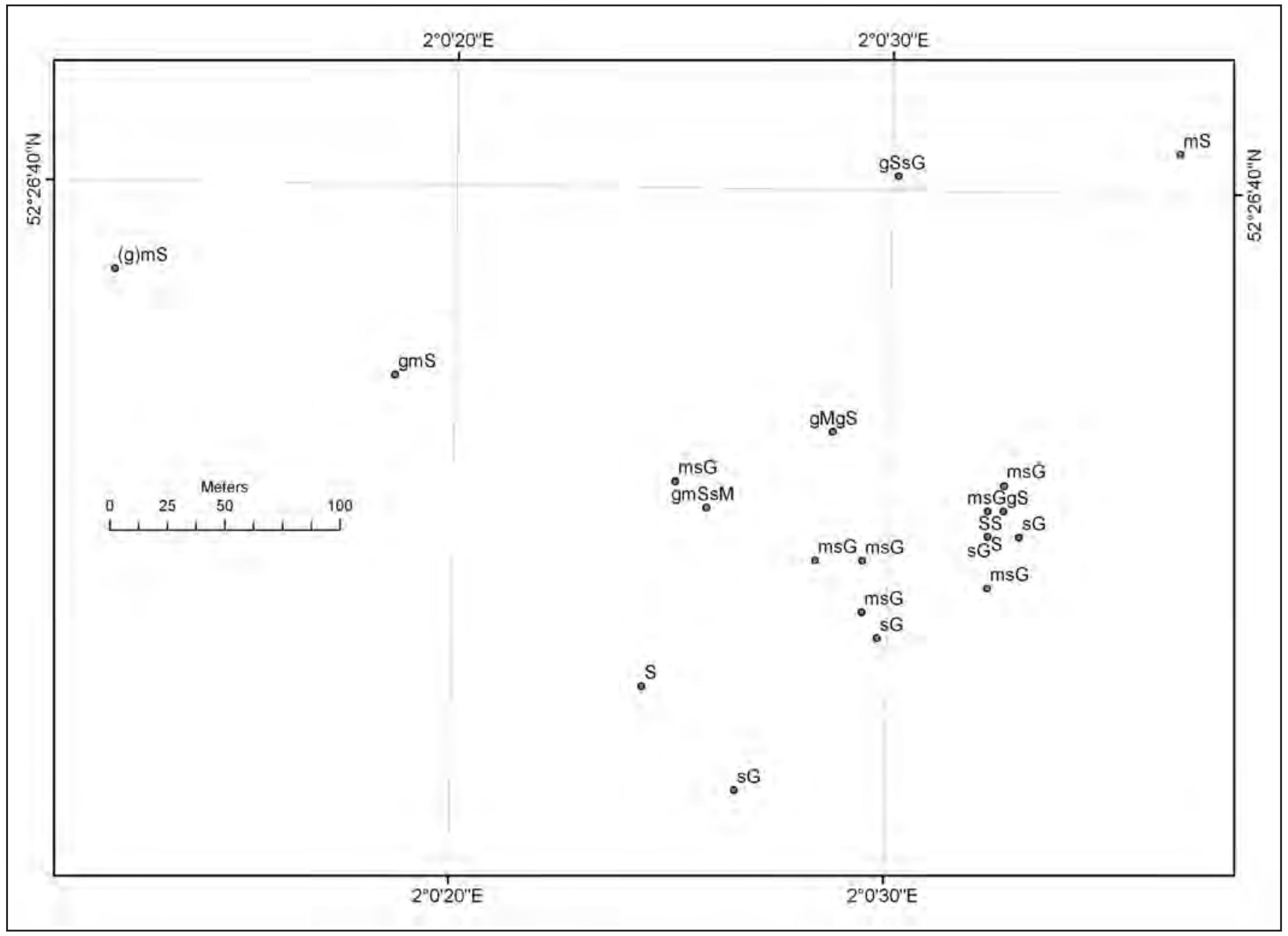


Figure 4.24 **Folk classification for samples taken at Site G34 between 1998 and 2005.**

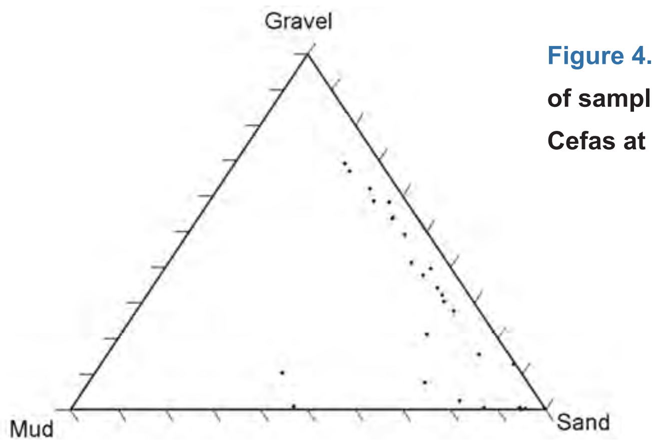


Figure 4.25 Triangular plot of samples collected by Cefas at Site G34.

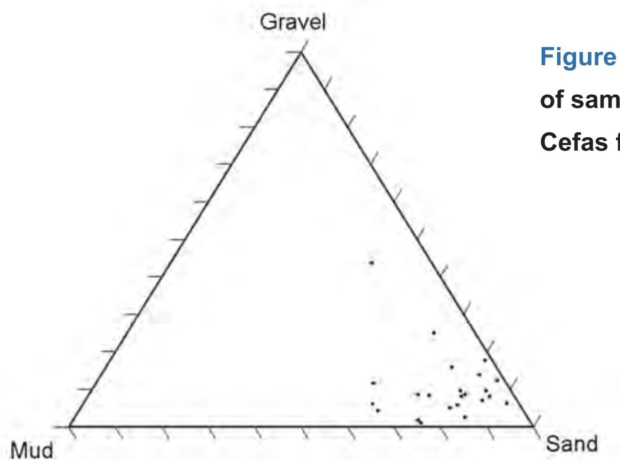


Figure 4.26 Triangular plot of samples collected by Cefas from Site G3.

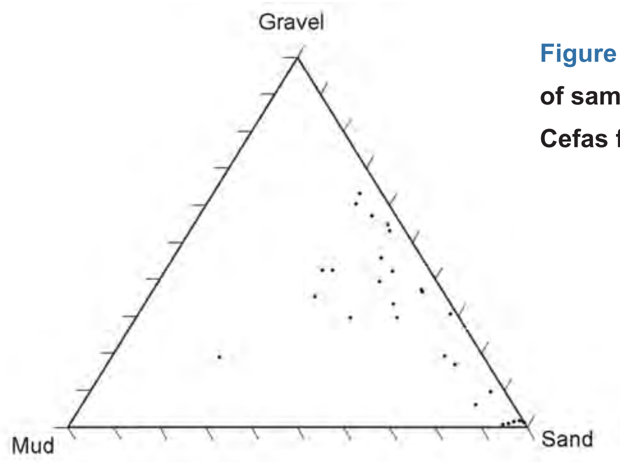


Figure 4.27 Triangular plot of samples collected by Cefas from Site G38.

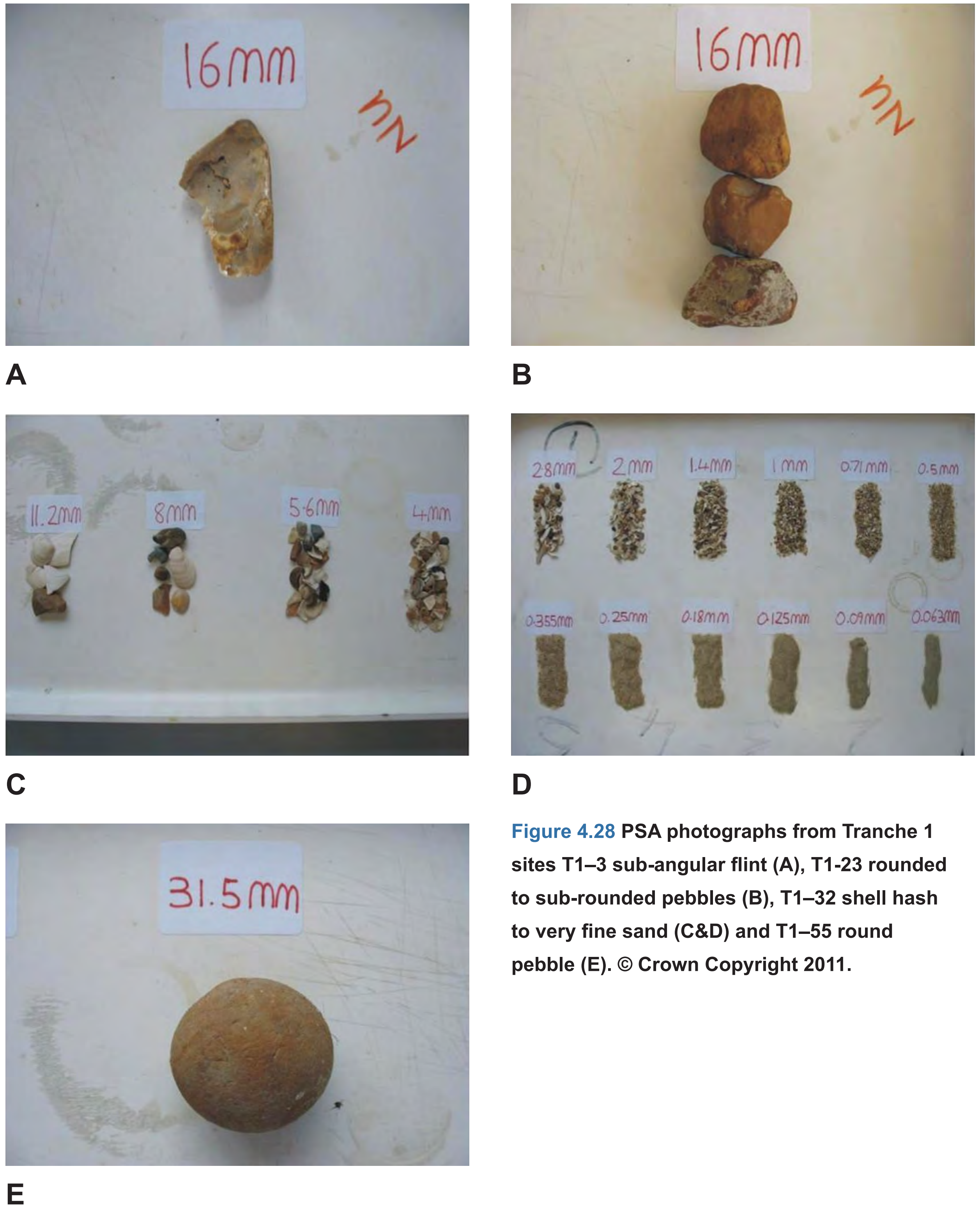
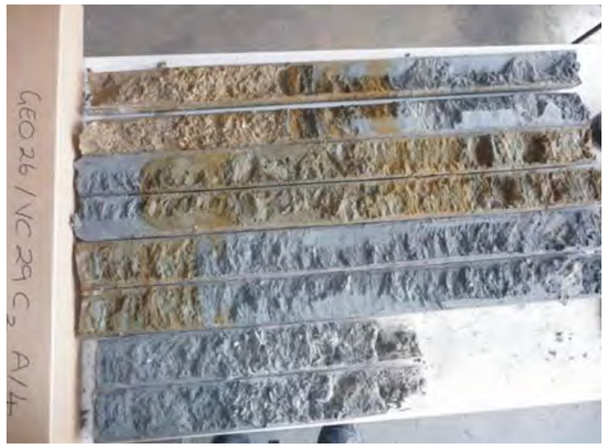
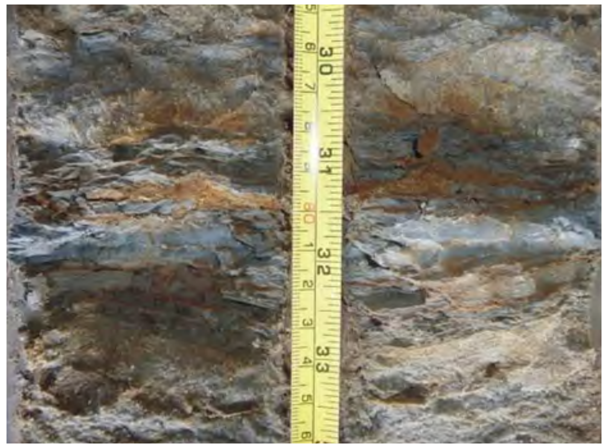


Figure 4.28 PSA photographs from Tranche 1 sites T1–3 sub-angular flint (A), T1-23 rounded to sub-rounded pebbles (B), T1–32 shell hash to very fine sand (C&D) and T1–55 round pebble (E). © Crown Copyright 2011.



A

B



C

D

Figure 4.29 Example imagery from Vibrocore 29 (A) showing the change from a medium-coarse sand with rounded to sub-angular flint pebbles (B), down through a fine-medium sand with interbedded clay layers (C), a fine sandy clayey silt, and on to a densely packed horizontally bedded layer of mollusc shells at the base of the core (D). © Wessex Archaeology and British Geological Survey. (See Appendix C for full geological logs.)

A

B

C

D

E

Figure 4.30 Example camera imagery illustrating the range of substrates observed. (A) Shell hash-dominated substrate, (B) sub-cropping Quaternary formations with a thin sand veneer, (C) sand overlaying clay with indications of ripple bedforms and a coarser shell hash gathering in the troughs, (D) sand-dominated substrate and (E) *Sabellaria spinulosa* reefs. © Crown Copyright 2011.

5 Archaeological characterisation

5.1 Introduction

As detailed in Section 2.3, the marine historic environment comprises all forms of physical evidence of people's activities in the past, including both direct evidence, such as shipwrecks, and indirect evidence, such as palaeo-environmental remains. The archaeological resource in the East Coast REC Study Area comprises elements of prehistoric, maritime and aviation archaeology. Understanding the distribution of archaeological material in this region has the potential to greatly enhance our understanding of how the use of this area has changed over the last million years, as well as indicating where further material may be found and in what context.

This chapter details the prehistoric archaeology of the East Coast REC Study Area in terms of its archaeological potential and the evidence of this potential as identified in the survey data; the evidence and characterisation of maritime archaeology; and the aviation archaeology associated with the area.

A summary of the archaeological characterisation of the East Coast REC Study Area is presented in Table 5.1.

5.2 Interpretation methodology

5.2.1 Introduction

The characterisation of the archaeological resource is primarily based on the geophysical and geotechnical data acquired during the East Coast REC Study Area 2008 geophysical survey and 2009 ground-truthing survey (Figure 5.1). These data were complemented by records held by regional and national inventories and by secondary sources.

Figure 5.1 Geophysical data reviewed for marine archaeology.

The data-sets from the East Coast REC Study Area 2008 geophysical survey that were used for the evaluation of the archaeology in the study area are:

- Side-scan sonar – principally high frequency.
- Magnetometer.
- Multibeam echosounder.
- Sub-bottom profiler (surface-tow boomer) data.

The data-sets from the East Coast REC Study Area 2009 ground-truthing survey that were used for the evaluation of the archaeology in the study area are:

- Side-scan sonar – high frequency only.
- Multibeam echosounder.
- Vibrocores.
- Clamshell samples.
- Hamon grab samples.

In addition to these data-sets, the following were also used in the archaeological characterisation:

- Sub-bottom profiler data acquired during the Seabed Prehistory Round 2 project (Wessex Archaeology, 2008a, 2008b).
- Shuttle Radar Topography Mission (SRTM) topographic data.
- SeaZone Solutions Ltd bathymetry data.

Geochronology			British Archaeological Record		East Coast Regional Environmental Characterisation
Period	**Epoch**	**MIS[a] stage**	**Period**	**Date**	
Quaternary (2.5 Ma to present)	Holocene	N/A	Modern	AD 1800–present	Characterisation is one of a zone of use. Maritime activity of fundamental importance, regionally, nationally and internationally. Continuing development of ports and rapid intensification of maritime activity of all types during nineteenth and twentieth centuries. Region of great importance to the defence of the realm and the liberation of Europe in the Second World War. Lowestoft and Great Yarmouth Harbours utilised by Royal Navy to protect and defend British shipping in the North Sea and eastern English Channel. A large number of known shipwrecks and potential aviation crash sites. High concentration of nationally important shipwreck sites. Very high maritime archaeological potential, both inshore and offshore.
		N/A	Post-medieval	AD 1500–1800	Characterisation is one of a zone of use. Increasingly intense trade in diverse goods, fishing vessels exploiting the full extent of North Sea, with greater international connections. Maritime activity increasingly important regionally, nationally and internationally. Encroaching coastal erosion processes. However, a low number of shipwreck sites from this period known, mainly commercial. High maritime archaeological potential, both inshore and offshore.
		N/A	Medieval	AD 1066–1500	Characterisation is one of a zone of use. Extent of maritime activity uncertain in early medieval period but records and evidence suggests significant maritime activity, especially in early half of the period from ship burials to sea discoveries. Subsequent growth of trade with the continent, predominately fishing, wool transport and naval activity, with the development of important trading and fishing ports extending along the coast. Evidence of vulnerability of shoreline to erosion. Moderate to high maritime archaeological potential, both inshore and offshore.
		N/A	Anglo-Saxon (early medieval outside England)	AD 410–1066	
		N/A	Romano-British	AD 43–410	Characterisation is one of a zone of use. Coastal regions were further out to sea than at present, with the region supporting settlement including some large urban centres, garrisons and forts, villas, farmsteads, temples and road network. Use of harbours and estuarine coasts for entrance to rich farmlands and salterns. Also the movement of between forts along the shore was essential at this time. No shipwreck sites known from this period. Uncertain archaeological potential, although all maritime sites of this period likely to be very important within a wider heritage context.
		N/A	Iron Age	700 BC–AD 43	Characterisation is one of a zone of use. Coastal regions were possibly further out to sea than at present, with harbours and estuaries arguably deeper and wider than modern configuration. The potential for coastal activity including settlement and burial sites, temples, salterns and deposition of metal objects in shallow water is still possible. Potential for wooden coastal structures such as jetties, causeways and fish traps extending across current intertidal zone. Offshore potential limited to material washed out by phases of coastal erosion and settled by deposition processes.
		N/A	Bronze Age	2200–700 BC	Sea level approaching modern position. Submerged forests on former coastal plains. Potential for coastal activity including burial sites and deposition of metal objects in shallow inland water, some with continental influence. Potential for wooden coastal structures such as jetties, causeways and fish traps extending across current intertidal zone. Offshore potential limited to material washed out of harbours and saltmarshes.
		N/A	Neolithic	4000–2200 BC	As above. Potential for submerged land surfaces within estuaries and in lower intertidal zones. Submerged forests indicate sea-level rise. Eroding material from coastal intertidal zone. Offshore potential probably limited to washed-out material in the East Coast REC Study Area.
		N/A	Mesolithic	9500–4000 BC	Period of rapidly rising post-glacial sea level and climatic amelioration. Development of peat, especially in coastal-plain river valleys. Geologically the Holocene is characterised by transgressive deposition of inorganic fine silts and muds sealing organic surfaces and filling palaeovalleys, with gradual coastal retreat. Archaeologically the region is characterised by the occurrence of extensive scatters of worked flint, sometimes accompanied by hearths, faunal assemblages and environmental sequences. High potential for archaeological remains in nearshore locations and extending beyond modern intertidal zone onto shelf, with some potential for recovery in palaeovalleys where net sedimentation rates greater than net erosion rates.
	Pleistocene	MIS 3–1	Upper Palaeolithic	40,000 BP–9500 BC	Prior to Last Glacial Maximum rapidly falling temperatures and sea levels leading to abandonment of Britain and NW European mainland. After LGM rapid rise in sea level from low of approximately 120 mbOD (metres below Ordnance Datum) and in climatic amelioration leading to recolonisation by modern humans. Characterisation of open lowland plain with cliffs, bluffs, downcutting river valleys and extensive sand blows. Occupation and utilisation of caves, rock shelters and, later, open-air hunting sites. High potential for recovery of material.
		MIS 7–3	Middle Palaeolithic	300 ka to 40,000 BP	Period of complex and poorly understood fluctuations in climate and sea level but mostly fairly cold. For large parts of period Britain probably uninhabited. Later part archaeologically characterised by distinctive lithic technology, but population likely to have been low and occupation sporadic. Known findspots in study area (Area 240 especially) indicate potential of significant survival possibly quite high.
		?MIS 25–7[b]	Lower Palaeolithic	?970–300 ka	Complex pattern of glacial and interglacials, fluctuating sea levels and coastal morphology. Southern North Sea dry for long periods when main influence fluviatile rather than marine. River channel infill, floodplain and possible terrace deposits associated with archaeological material, latter mostly derived and reworked at later periods. Channel fills of particular importance for archaeology and associated faunal and micro-faunal assemblages; high potential where any such submerged features occur.

[a] MIS = Marine Isotope Stage. [b] Questions remain regarding the MIS associated with the lower limit of the Lower Palaeolithic.

Table 5.1 Summary characterisation table.

The Seabed Prehistory sub-bottom profiler data were acquired by Wessex Archaeology during 2005 for the Aggregates Levy Sustainability Fund (ALSF) Seabed Prehistory project, administered by English Heritage (EH). These data were interpreted for the East Coast REC project specifically to assess the nearshore area at Pakefield (Wessex Archaeology, 2008b) and an infilled channel feature offshore Great Yarmouth (Wessex Archaeology, 2008a). The extents of these data are illustrated in Figure 5.1.

Shuttle Radar Topography Mission (SRTM) topographic data, with a digital elevation model (DEM) of 90 × 90 m resolution, was obtained for the coastal region of the study area (CGIAR-CSI, 2009). These data were used together with the regional bathymetry data to reconstruct the land surface in the East Coast REC Study Area at different stages in the past. The methods used to create the merged DEMs are discussed in more detail below.

The principal desk-based sources used during the archaeological characterisation are as follows:

- Records of wrecks and obstructions held by the UKHO and collated by SeaZone Solutions Ltd.
- Records of Named Losses, other wrecks, maritime obstructions and terrestrial sites of all periods held by the National Monuments Record (NMR).
- Records of terrestrial sites from both the Suffolk and the Norfolk Historic Environment Records (HERs).
- Various secondary sources relating to the palaeo-environment and to the Palaeolithic and Mesolithic archaeology of Northern Europe with specific reference to the ALSF Seascapes Project (Southwold to Clacton) (Oxford Archaeology, 2007) and the Seabed Prehistory projects (Wessex Archaeology, 2008a, 2008b, 2009a, 2009b, 2010a, 2010b).
- Various secondary sources relating to historic shipping patterns, as well as those sources relating to known and potential wreck sites and causalities, with specific reference to ALSF England's Shipping (Wessex Archaeology, 2003) and ALSF Navigational Hazards (Merritt *et al.*, 2007).
- ALSF Air Crash Sites at Sea (Wessex Archaeology, 2008c) and various secondary sources relating to historic aviation patterns.
- A range of previous archaeological assessments carried out by Wessex Archaeology within the East Coast REC Study Area relating to prehistory, known and potential wrecks and casualties.
- The annual reports of the British Marine Aggregate Producers Association (BMAPA) Protocol implementation service for the reporting of potential finds of archaeological interest (Wessex Archaeology, 2006, 2007, 2008d, 2009c, 2010c).

5.2.2 Maritime and aviation archaeology

Coda GeoSurvey software was used to process the side-scan sonar data. The software allowed the data to be replayed with various gain settings in order to optimise the quality of the images. The data were initially visually scanned to give an understanding of the geological nature of the area and were then interpreted for any objects of possible anthropogenic origin. The position and dimensions of any such objects were recorded into a gazetteer and an image of each anomaly acquired.

For the side-scan sonar assessment, the high-frequency data from the 2008 geophysical cruise (100 m range) and the 2009 ground-truthing cruise (200 m range) were reviewed. In addition, the low-frequency (200 m range) data acquired during the 2008 geophysics survey were checked for known charted wrecks situated beyond the 100 m range of the high-frequency data.

The magnetic data were processed to give XYT files comprising grid co-ordinates (X, Y) and total field strength (T) recorded in nanoTeslas (nT) using GeoMetrics MagPick software. Each line of data was then processed to remove the regional magnetic field and also any large diurnal variations, which may have masked small magnetic anomalies. The data were then gridded to produce a contour map, plotted with the magnetic field strength values represented by graded colour bands to show changes in the magnetic field strength. The magnetic anomalies were then assessed and the position and magnitude of all anomalies with an amplitude of 5 nT or more were recorded into a gazetteer.

The multibeam echosounder data were reviewed for seabed anomalies, in particular wrecks and their surrounding areas. The seabed topography surrounding the wreck, particularly any seabed scour associated with the wreck site, was detailed into a gazetteer.

The East Coast REC Study Area 2008 geophysical survey sub-bottom profiler data were also used for the detection of maritime or aviation sites. Any small reflectors that appear to be buried material, such as a wreck site covered by sediment, were recorded into a gazetteer and an image of each anomaly acquired. It should be noted that anomalies of this type are rare, as the sensors must pass directly over such an object in order to produce an anomaly.

The positions of the side-scan sonar, multibeam echosounder, sub-bottom profiler and magnetometer anomalies were uploaded to the project GIS and grouped together as sites. This grouping process addresses situations where the same feature as seen in more than one data-set or line of data or where several anomalies occur in close proximity and are thought to be related. A final combined gazetteer was produced detailing each anomaly (Appendix F).

The physical regions (Figure 4.1), the seabed sediments map (Figure 4.3) and the geomorphology map (Figure 4.6) were used to characterise the seabed environment surrounding the wrecks and to allow assessments of the visibility and survivability of the wrecks to be made.

5.2.3 Prehistory

The East Coast REC Study Area 2008 sub-bottom profiler data were interpreted using Coda GeoSurvey software using a seismic velocity of 1,600 ms^{-1}. This is a standard method for use in shallow, unconsolidated sediments (Sherriff and Geldart, 1983). The data were assessed and interpreted with the aim of identifying prehistoric features of interest, namely indicators of former land surfaces. All such features were marked on the data in the processing software, an image was taken and the points exported to the project GIS. Features occurring together were grouped as a site. Each feature was given a unique identifying number.

The multibeam echosounder data acquired during the East Coast REC Study Area 2008 geophysical survey were assessed in conjunction with the sub-bottom profiler data to identify any geomorphological characteristics associated with these features. Any discernible patterns of the features identified, which occur on a broad scale within the East Coast REC Study Area, were also identified. A gazetteer was produced detailing each feature of archaeological interest (Appendix F).

To investigate the topography and bathymetry of the study area and adjoining coast as a whole, SRTM data, with a DEM of 90 m resolution, was obtained from the Consultative Group for International Agriculture Research Consortium for Spatial Information (CGIAR-CSI; http://srtm.csi.cgiar.org).

There are obvious limitations to using modern seabed bathymetry to reconstruct the palaeo-geography of the continental shelf. The sediments would have undergone extensive modification (ie, erosion or burial) since the seabed was sub-aerially exposed. However, evidence of past land surfaces is fragmentary, and contiguous shelf-scale Palaeolithic land surfaces have yet to be reconstructed. As such it is necessary to use present-day bathymetry to provide an approximation of the palaeo-geography (Bailey *et al.*, 2010).

The data were edited using the IVS Fledermaus software suite so the required section of the east coast of Britain could be selected. The SRTM and SeaZone Solutions Ltd bathymetric data-sets were converted into a single digital terrain map and reduced to Ordnance Datum (OD).

There are several large sandbanks at the northern limit of the East Coast REC Study Area (Section 4.6.2). These are most likely to be the result of modern deposition and would significantly skew attempts to analyse the prehistoric landscape. As such, the data points for these large sandbanks were removed from the data-set. A false seabed grid was created in these areas using ArcGIS based on the surrounding seabed depths. This “false” grid was then re-modelled with the bathymetry and SRTM data.

A colour map was then developed using a similar scheme to UKHO charts (yellow: >10 m; green: 0 to 10 m; blue: –5 to 0 m; light blue: –10 to –5 m; white: <–10 m, eg, Figure 5.5). By using the chart colour map but reducing the values (e.g yellow:>–10m; green –20 to –10m; blue: –25 to –20m; light blue: –30 to –25m; white:<–30m), it became possible to emphasise features at increasing depth. This also provided a rough estimate of changes in coastal morphology at levels ranging from 5 m to 80 m below mean sea level, based on existing sea-level model curves (Funnell, 1995; Jelgersma, 1979; Shennan and Horton, 2002). This information was used to assess land surfaces at different stages in the past in terms of their potential for human habitation.

The vibrocores acquired during the East Coast REC Study Area 2009 ground-truthing survey were assessed and the results integrated with the geophysical data in the prehistoric characterisation. The clear plastic vibrocore samples were split and descriptions logged. The vibrocore descriptions provide details of the depth to each sediment horizon and the character of the sediment. Sedimentary characteristics were recorded including texture, colour, stoniness and depositional structure (cf. Hodgson, 1976). Five vibrocores were selected for further palaeo-environmental analysis and dating. The selections were made on the basis of the sediment identified from the archaeological recording of the vibrocores and analysis of the geophysical data. These methods are discussed in further detail below.

5.2.4 Palaeo-environmental assessment, analysis and dating

The five selected vibrocores for palaeo-environmental assessment analysis and dating were as follows: VC7, VC18, VC26, VC27 and VC29 (Figure 5.2). Environmental samples were taken from relevant deposits to provide chronological and environmental information relating to their formation.

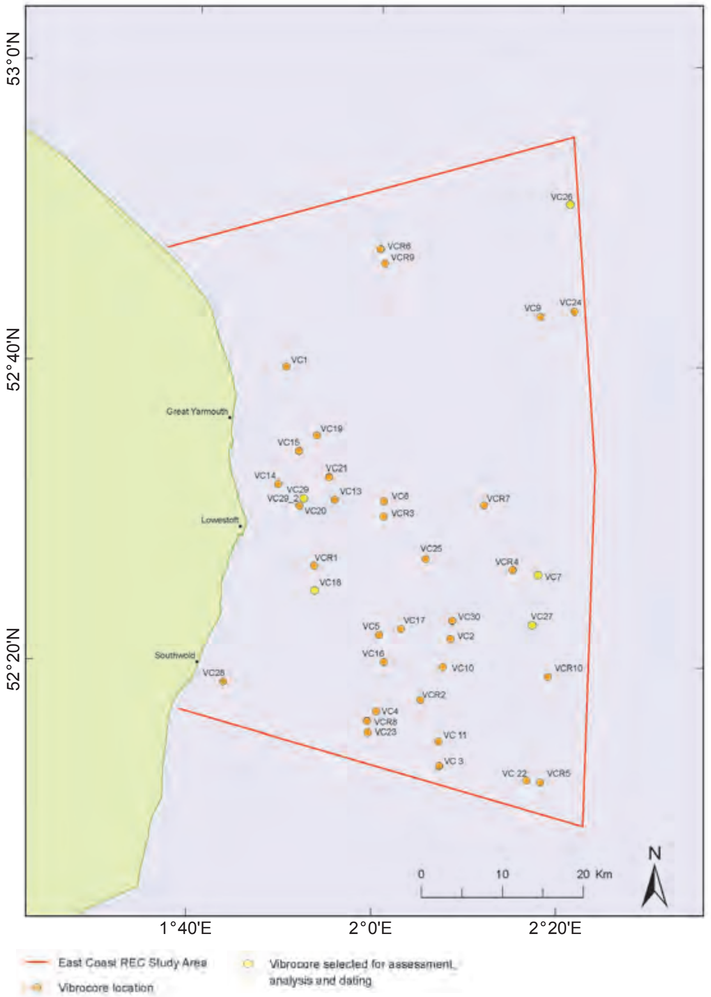


Figure 5.2 Vibrocore locations, highlighting those selected for palaeo-environmental assessment, analysis and dating.

The palaeo-environmental assessments included:

- Microfaunal assessment: foraminifera and ostracods.
- Microfloral assessment: pollen and diatoms.
- Macrofaunal assessment: molluscs and insects.
- Macrofloral assessment: plant material, wood and charcoal.

Based on the results of the assessment, further samples were then selected for analysis. The methodologies described below incorporate both assessment and analysis. Unless stated, analysis was carried out by Wessex Archaeology.

For the microfaunal assessment, a total of 24 samples were assessed from the five vibrocores. Roughly 25 g of sediment was obtained for each sample. The sediment was then disaggregated in a weak solution of hydrogen peroxide and water before being wet sieved through a 63 µm mesh. The sample was then dried and sieved through increasingly fine meshes of 500 µm, 250 µm and 125 µm. A Vickers TM binocular microscope using transmitted and incident light was used to pick out microfossils under 10–60× magnification. Where possible, a minimum sample size of 100 specimens per sample was obtained, with specimens kept in card slides. Identification and environmental interpretation of ostracods follows Athersuch *et al*. (1989) and Meisch (2000) and that of foraminifera, Murray (1979, 1991).

The pollen assessment and analysis was carried out by Dr Rob Scaife, University of Southampton. A total of 36 samples were assessed from 5 vibrocores. Sample intervals varied; details are provided on relevant figures in Section 5.3. Samples of 3 ml volume were processed using standard techniques for the extraction of the sub-fossil pollen and spores (Moore and Webb 1978; Moore *et al.* 1991). Micromesh sieving (10 µm) was also used to aid with removal of the clay fraction in the mineral sediments. The sub-fossil pollen and spores were identified and counted using an Olympus TM microscope fitted with Leitz optics. Pollen sums of 100 pollen grains per level were counted for each level where possible. Additionally, all extant fern spores and miscellaneous pre-Quaternary palynomorphs were also counted for each of the samples analysed. The pollen diagrams were plotted using Tilia and Tilia*Graph. Taxonomy, in general, follows that of Moore and Webb (1978), modified according to Bennett *et al.* (1994) for pollen types and Stace (1997) for plant descriptions.

Diatom assessment and analysis were carried out on 12 samples by Dr Nigel Cameron, University College London. Standard techniques were followed during diatom preparation, counting and analysis (Battarbee *et al.*, 2001). Diatom floras and taxonomic publications were consulted to assist with diatom identification; these include Hendey (1964), Van Der Werff & Huls (1957–1974), Hartley *et al.* (1996) and Krammer and Lange-Bertalot (1986–1991). Diatom species' salinity preferences were discussed using the classification data in Denys (1992), Vos and de Wolf (1988, 1993) and the halobian groups of Hustedt (1953, 1957). Diatom data were plotted using the "C2" program (Juggins, 2003).

For the macrofaunal and macrofloral assessments, samples of between 150 and 250 ml of sediment were taken from six points within each of the five vibrocores. The samples were then processed by wet-sieving using a 0.25 mm mesh size. The sieved material was then visually inspected using a stereo-binocular microscope at 10× and up to 40× magnification. Where molluscs were present, preliminary identifications and quantifications of dominant taxa were conducted. Habitat preferences for dominant taxa were determined based upon those described by Kerney (1999) and Barrett and Yonge (1958). All of the samples were also examined for plant remains during the mollusc assessment. Only samples where plant remains were observed during the visual inspection were examined in greater detail.

Five vibrocores, acquired in black liners to ensure the sediments were not exposed to light, were selected for Optically Stimulated Luminescence (OSL) dating. This method is used to date sediments where exposure to light prior to burial was limited, and it measures the luminescence emitted from the most light-sensitive electron traps in particular minerals, especially quartz and feldspar, following exposure to light (Lowe and Walker, 1997). OSL dating of 17 samples for the East Coast REC Study Area was carried out by Dr Richard Bailey at the Centre for the Environment, University of Oxford.

Four samples were radiocarbon dated from the upper units of VC18. This was carried out at the Scottish Universities Environmental Research Centre (SUERC) accelerator mass spectrometer (AMS) facility. Each sample was pre-treated, chemically and/or physically, to remove any unwanted material (such as silt and clay) before analysis using AMS.

5.2.5 Artefact sampling

During the 2009 ground-truthing survey, the Clamshell grab samples and Hamon grab samples were assessed onboard the RV *Cefas Endeavour* for artefacts. Any potential artefacts were retained and later analysed. In addition to offshore inspection of the samples, a 20 l bulk sample was retained for processing post-survey. Each sample was wet sieved through a nest of sieves, including a 10 mm and a 4 mm sieve. The <4-mm residue was quickly scanned and discarded. The >4 mm and >10 mm residues were sorted wet and finds were kept for subsequent analysis.

A sedimentary description of each sample was made including colour, sediment type and inclusions. These descriptions were combined with notes made onboard about the sample (including Clamshell sample size and inclusions) in order to provide a detailed description of the whole sample.

5.3 Characterisation of prehistoric archaeology

The southern North Sea has a complex Quaternary history of repeated significant changes in relative sea level, primarily glacio-eustatic. In general, the East Coast REC Study Area would have been submerged during interglacials and sub-aerial during cold periods. In terms of potential inhabitation by hominins, dryland areas now submerged would have existed at the cessation and onset of interglacials during periods of falling and rising sea levels, as well as under full cold-stage conditions (almost certainly glacial at times; periglacial at others, with permafrost conditions in existence).

For the archaeological potential of the area to be understood, this pattern of climatic deterioration and amelioration and consequent rise and fall in sea level and exposure and flooding of the continental shelf needs to be set against the known pattern of hominin presence in the surrounding drylands. The pattern is not one of mechanistic and inevitable expansion and retraction as the habitable extents of Europe shifted with the glacial margins (as demonstrated by the recent discovery of hominin tools potentially more than 800,000 years old, north of 45ºN in regions previously thought uninhabitable (Parfitt *et al.*, 2010) but, rather, the result of a series of choices, the implications of which can only be approached by considering the seabed not as a separate entity but as an extension of the terrestrial landscape.

Unlike in the permanently terrestrial regions that remained free of glacial ice, where wholesale post-depositional movement of prehistoric sediments and soils and the artefacts they contain can mostly be shown to be relatively limited in extent and to have been caused by reasonably well-understood processes, taphonomic factors affecting the preservation and recovery of material in the marine zone are very much more difficult to establish, map and evaluate. In addition, the offshore archaeological data are sparse, generally encountered serendipitously and, like the sediments that contain them, difficult to date with any accuracy. The recovery of Palaeolithic stone artefacts and Pleistocene faunal remains from the southern North Sea is predominantly associated with the fishing industry and, more recently, the dredging industry. While individual very local sequences can be investigated in some detail (Wessex Archaeology, 2008a, 2009a, 2009b), discussion of prehistoric seabed archaeology over larger areas (such as the southern North Sea) tends to be very general (eg, Coles, 1998), although recent work on Doggerland has investigated sequences to a high resolution on a regional scale (Fitch *et al*., 2005).

The aim of this characterisation of the prehistory of the East Coast REC Study Area is to attempt to identify areas of the seabed that have the potential for the presence of archaeological material. Key to this is an understanding of the erosional and depositional regimes that accompanied cycles of transgression and regression. It is self-evident that any *in situ* archaeological material surviving in the marine environment can only do so if it is present within a sediment unit and not lying on the seabed surface, exposed to dynamic forces. To make sense of any surviving distributions and sedimentary associations, it is necessary to reach an appreciation of where, how and why material might have been deposited in the first place alongside its subsequent taphonomic history. This requires an understanding of the East Coast REC Study Area at various times during the Pleistocene (and early Holocene), as well as an appreciation of the remnants of these deposits that exist, now submerged under the southern North Sea.

5.3.1 Palaeo-geographic assessment

This assessment of the geophysical and geotechnical data acquired during the course of the East Coast REC project, in conjunction with the known geology, aims to identify features with archaeological potential, namely indicators of past land surfaces (Table 5.2).

Stone artefacts have long been found in sediments associated with river channels, either in sand and gravel layers or associated fine-grained sediments and peats (eg, Wymer, 1999). The presence and survival of these artefacts are closely linked to the environmental processes that caused the associated deposits to be formed.

Peats are indicative of the remains of previous land surfaces, in which prehistoric objects and structures can be found. The preserved vegetation, together with other organic remains such as insects and the microscopic remains of pollen, enable archaeologists to build up a detailed picture of the environment that was once present. The waterlogged and anaerobic conditions under which peat is formed result in the peat having a high preservation potential for both non-degradable and degradable (ie, wood) artefacts, with the potential for *in situ* preservation. Remnants of fine-grained sediment units such as silts, clays and sand can cover artefacts and also prove to be important.

A total of 143 features were identified in the East Coast REC Study Area (see Table 5.3 and Figure 5.3). Detailed descriptions of these features are provided in Appendix F. The characterisation of these features, integrated with the geotechnical data (including the palaeo-environmental assessment, analysis and dating) are presented as part of the prehistoric archaeology characterisation of the East Coast REC Study Area.

Feature type	Description
Channel	Channel cuts and associated infill deposits. May indicate extensions of present-day terrestrial system or now unconnected channels. May include both fluvial and estuarine environments. Can be described as filled, underfilled and unfilled. Archaeological potential for *in situ* and secondary context artefacts. Infill deposits may also be of palaeo-environmental interest.
Gravel terrace Bank	Features associated with the edge of channel features, or within channel features. Archaeological potential for *in situ* and secondary context artefacts.
Cut and fill	As channel features. Cut and fill is used as a descriptor when the feature of interest cannot be traced over distance. Generally used for isolated features. Can be described as simple (one phase of fill) or complex (multiple phases of infill).
Depression Fine-grained unit	Small isolated infilled feature which may include remnant features formed by erosion or be associated with intertidal deposits. Potential for *in situ* and secondary context artefacts. Infill deposits may also be of palaeo-environmental interest.
Peat Organic matter	Indicator of former terrestrial land surface. Potential for *in situ* and secondary context artefacts. Deposits are of palaeo-environmental interest. Generally associated with other features such as channels or cut and fill features.
Gas blanking	Gas blanking masks the seismic reflectors and is caused by the presence of shallow gas. Shallow gas may indicate the presence of organic matter/peat at a particular layer caused by microbial activity. Shallow gas can also be sourced from depth migrating to the surface along migration pathways. Discrimination is made during the assessment and only shallow gas thought to be associated with the presence of organic matter is recorded. Generally associated with channel infills, cut and fill features and erosion surfaces.
Strong reflector	May indicate either hard ground layer or layer containing organic matter.
Erosion surfaces	These tend to be broad-scale features associated with erosion during transgression and regression. May include ravinement surfaces (transgressive erosion surface resulting from nearshore marine and shoreline erosion associated with a sea-level rise).

Table 5.2 Features of potential prehistoric archaeological interest.

Feature	Total
Complex cut and fill	23
Simple cut and fill	77
Bank	15
Depression	15
Gas blanking	1
Erosion surface	5
Fine-grained unit	5
Strong reflector	1
Seabed anomaly	1
Total	143

Table 5.3 **Summary of identified features of potential prehistoric archaeological interest.**

5.3.2 Seabed topography and landforms

Archaeological characterisation of the marine zone can only be of coarse resolution and will rely heavily on terrestrial analogues which may not be directly comparable to post-depositional environments. In terms of the creation of landforms, however, while the landscape beneath the southern North Sea may have been subject to rather different sequences and rates of modification to the permanent terrestrial region, many of the processes involved will have been analogous and will have produced landforms and drainage patterns that are familiar from the surrounding currently terrestrial regions. As such, there is no reason why the drowned lands beneath the southern North Sea should not have presented very similar geographies and ecologies to their dry-land counterparts at various times during the Pleistocene, which could have provided suitable habitat ranges for a familiar suite of land animals, including hominins.

Our knowledge of this succession of landscapes is severely hampered, not only by our inability to observe it directly, but also because the cycles of inundation and emergence have resulted in landscape features and patterns of deposition and movement different to those of the terrestrial zone. In consequence we are, as yet, unable to map it in either sufficient detail or sufficient extent to be able to assess its overall character today, let alone at any period in the past. However, the available geological, geotechnical, bathymetric and seismic data are sufficient to be able to identify some key topographical features, drainage systems and sedimentary sequences, which enable us to put some of the main building blocks in place. By combining such information with terrestrial analogues for particular types of feature (such as river terraces and former shores) and for hominin habitat preferences, we can begin to develop models of landscape, land use and inhabitation that can assist in characterising the archaeological potential of the study area.

Any such attempt must, however, be grounded in an appreciation of the main physical influences on seabed topography as it can be recorded today, and on the creation and destruction of landscape features that can be seen to have more-or-less direct terrestrial correlates. A summary of these influences is given below.

Bedrock formations and uplift

Structurally the region lies predominantly within the London–Brabant Massif, consisting of underlying Cretaceous bedrock (Speeton Clay, Chalk) overlain by Tertiary sediments (Cameron *et al.*, 1992). Locally, the area lies within the East Anglian Crag basin, “a structural depression resulting from downwarping of the crust due to the weight of Neogene sediment in the North Sea basin” (Parfitt *et al.*, 2010), on the western edge of the North Sea basin. Tectonic effects vary across the region and with time, but two main styles can be identified: an Early and early-Middle Pleistocene folding involving both differential subsidence and uplift; and a late-Middle Pleistocene uplift increasing inland (Rose, 2008).

Throughout the Pleistocene, the eastern side of the southern North Sea was sinking, and the western side rising (Bridgland and D’Olier, 1995). In addition, eustatic rise resulting from the thermal expansion of the sea and periodic melting of ice sheets affected, and continues to affect, relative sea levels. Forebulge effect may have influenced topography in ways that are difficult to estimate, as may hydro-isostasy (Johnston, 1995). Such factors complicate the pattern of landforms at different periods on both regional and local scales.

Fluviatile histories

Given that areas that now lie beneath the sea were once dry land, any attempt to understand their development during the Pleistocene needs to take into account the processes of sedimentation and erosion that would have operated on them when they were sub-aerial. In terms of the East Coast Study Area, these processes would have been periglacial, glacial and fluviatile.

Attempts to determine the surviving topography and sediment regimes in the area need to address the effects of rivers. On the western side of the southern North Sea these are dominated in pre-Elsterian periods by the various ancestral courses of the Thames and the extinct Ancaster and Bytham Rivers and their offshore extensions draining into shallow marine basins (Figure 5.4). On the eastern side, no submerged valley systems have been recognised, in an area of continuous subsidence and progressive sediment accumulation. Instead, Middle and Upper Pleistocene sediments of the Rhine and Meuse form the Krefterheye Formation, a delta-like spread of material westward of the Dutch coast (van Gijssel and van der Valk, 2005).

Terraces of the extinct rivers have only been partially identified. No high-level terraces of the Ancaster River have been discovered, due to extensive glacial erosion in what is now the North Sea and the eradication of the river by the Happisburgh Glaciation of MIS 16 at approximately 630 ka (Rose, 2008). Six aggradations have been identified for the Bytham River, dating from MIS 20 (Beestonian; highest) to MIS 12 (Elsterian; lowest), at which point the Bytham River was obliterated by Elsterian glaciers. Both the Ancaster and Bytham Rivers flowed eastwards into what is now the North Sea, carrying coarse-grained material that formed the Wroxham Crag Formation; during a more temperate climate, fine-grained sediments were deposited on low-energy floodplains to form the Cromer Forest-bed Formation.

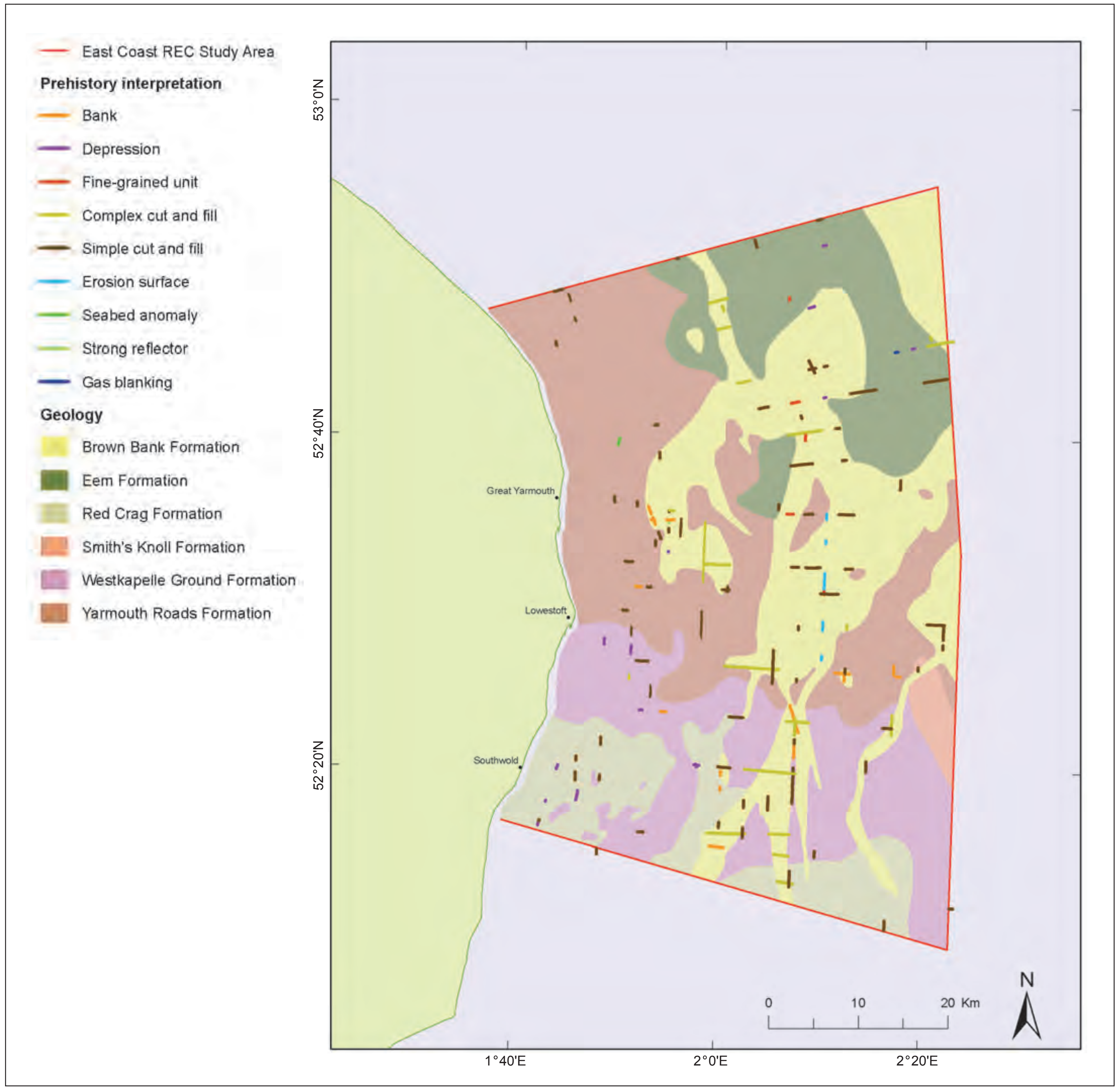


Figure 5.3 Geophysical features of potential prehistoric archaeological interest.

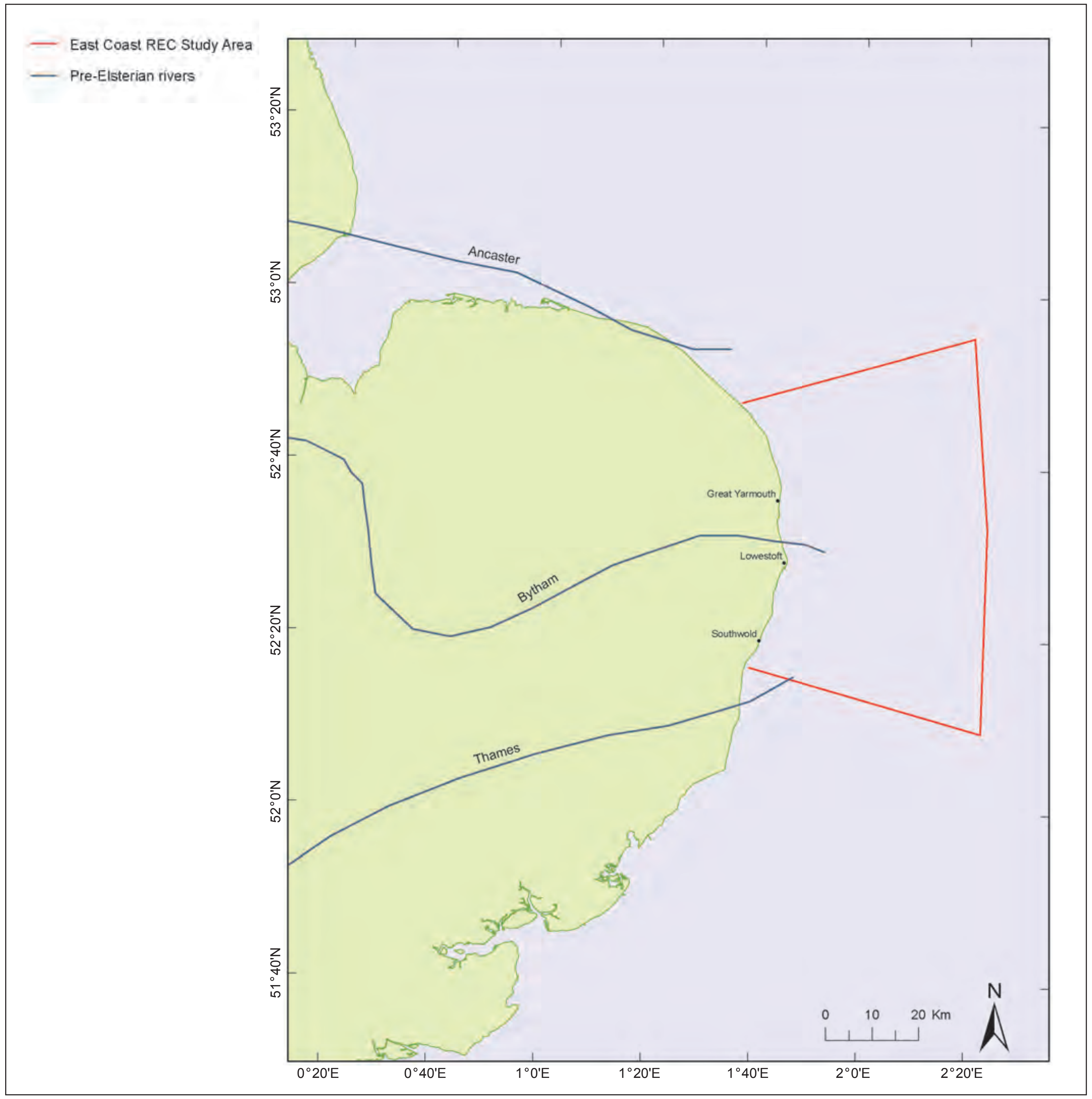


Figure 5.4 Pre-Elsterian river courses during the Early Middle Pleistocene (0.7 Ma) (after Lee *et al*., 2006).

In the continental European rivers, similar sequences of terraces survive, often in much more extensive systems. In the valley of the Meuse, six separate terraces are recorded in the Southern Limburg, all of which can be correlated with interglacials of the Cromerian Complex (van Gijssel and van der Valk, 2005).

The modern drainage of East Anglia – the systems of the Bure, Wensum, Yare and Waveney – post-dates the Elsterian glaciation (MIS 12) (Figure 5.5). According to Wymer (1997), the Bure (and its tributary, the Ant) perpetuate outwash streams that have “cut down into Early Pleistocene Crags and are devoid of terrace deposits”. In general, the rivers are flanked by varying numbers of poorly preserved gravel terraces, laid down successively during periods of high sea-level stand and left in a typical “staircase” flight by the subsequent downcutting of the rivers when sea levels fell and failed subsequently to attain previous heights, and through the process of uplift. Remnant low-level terrace deposits survive along much of the course of the Wensum upstream of Norwich, and commercial quarrying of these has produced faunal remains of Middle and Late Pleistocene date. Downstream, beyond the confluence with the Yare, the river has low terraces on both sides, from which Palaeolithic artefacts have been recovered, sometimes in large numbers (eg, at Whitlingham). Upstream of its confluence, the gravels of the Yare terraces also contain significant deposits of hand axes, at, for instance, Keswick (to the south of Norwich). In the valley of the Waveney, four remnant terrace deposits have been recognised at various levels upstream of Beccles, although there are no well-preserved terrace flights. With the exception of the site at Hoxne, Palaeolithic material is uncommon.

Throughout much of the Pleistocene, these rivers will have extended beyond the modern coastline onto the continental shelf to form drainage systems considerably larger than their modern descendants. Submerged relict river systems have been identified off the coasts, primarily in the form of sediments filling former fluvial channels (Bridgland and D’Olier, 1995). Offshore extensions of the pre-Elsterian river systems have not been traced with any accuracy due to removal or masking of contemporary sediments by later glacial and erosional processes, but continuations of the rivers can be assumed, although to what extent is uncertain. At Happisburgh, surveys suggest that beyond 400 m from the current shore, Middle Pleistocene deposits will have been removed during the Elsterian glaciation or by subsequent marine erosion (Wessex Archaeology, 2008a). At Pakefield, Norwich Crag Formation deposits immediately offshore are interpreted as the lower part of the Bytham River sequence (Wessex Archaeology, 2008b). More generally, the Thames and Rhine systems first flowed together through a single valley in the southern North Sea in the early Middle Pleistocene. It is within the deposits associated with these drainage systems that the earliest Palaeolithic material is likely to exist.

What happens to terraces and other deposits of the post-Elsterian river systems in the marine zone is unclear. Direct physical links between onshore and offshore deposits have not been demonstrated, although some are assumed. Studies of the Yare valley suggest that it extends eastwards of the present coastline for some 12 km before beginning to meander to the south (Bellamy, 1998). Gravels possibly belonging to this formation fill the valley, with pockets of more recent clay and peat deposits, as, for instance, in aggregate extraction licence Area 254 (Wessex Archaeology, 2002, 2008a). The possible links between the terrestrial and offshore remnants of the Yare Valley Formation are discussed in more detail in Section 5.3.5.

Late Weichselian and Early Holocene deposits are represented onshore by the complex of alluvium, peat and Fen silt at the confluence of the Rivers Bure and Yare at Great Yarmouth, the peats overlying the Yare Valley Formation and identified as the Breydon Formation, and the fill of the buried valley system underlying the existing marshland. The lowest of these peat layers is recorded to have formed around 7580 ± 90 BP (600–6240 calibrated years BC [cal. BC]) at a depth of approximately 19 mbOD (metres below Ordnance Datum) (Arthurton *et al.,* 1994). Offshore, Breydon Formation deposits are preserved 6 km off Great Yarmouth (Arthurton *et al*., 1994) and in aggregate extraction Areas 254 and 240 (Bellamy, 1998).

Shoreline configuration

Shoreline positions have fluctuated markedly with rises and falls in sea level. The configuration of the coastline at different periods will have had considerable influence on the nature and rate of sedimentation and erosion and also on the wider coastal landscape, its ecology, soils and habitat mosaic.

The main bodies of evidence are the series of marine and fluvial deposits that survive in East Anglia, the Netherlands and beneath the waters of the southern North Sea. Sediments in the southern North Sea belonging to the Yarmouth Roads Formation demonstrate that, at the beginning of the Cromerian, the area was “a vast wetland complex of delta-top sediments extending in the UK sector to a shoreline in the vicinity of 55°N” (Cameron *et al.*, 1992). Yarmouth Roads Formation deposits are thought to correlate with terrestrial deposits such as the Cromer Forest-bed Formation, Kesgrave Group and Bytham Sands and Gravels (Moorlock *et al*., 2000).

A late Cromerian (MIS 13) marine transgression has been recorded in the Netherlands, resulting in shorelines in a similar position to the modern coast and the deposition of parts of the Cromer Forest-bed Formation in East Anglia. The southern limit of this sea was the Weald–Artois ridge, which was finally breached by waters from an ice-dammed lake at some point during the Elsterian Glaciation.

The breaching of the Weald–Artois ridge did not automatically result in the separation of Britain from the rest of Europe. Molluscan evidence from the lower Thames indicates a confluent Thames/Rhine flowing through the North Sea basin in MIS 11 (the Holsteinian interglacial). Climatic amelioration following the retreat of the ice sheet brought rising sea levels, with maximum levels slightly inland of the present coast, although a connection between the North Sea and the Atlantic Ocean through the English Channel still probably did not exist.

The Saalian glaciation does not seem to have extended as far south as the Elsterian (Figure 5.6), leaving the southern North Sea

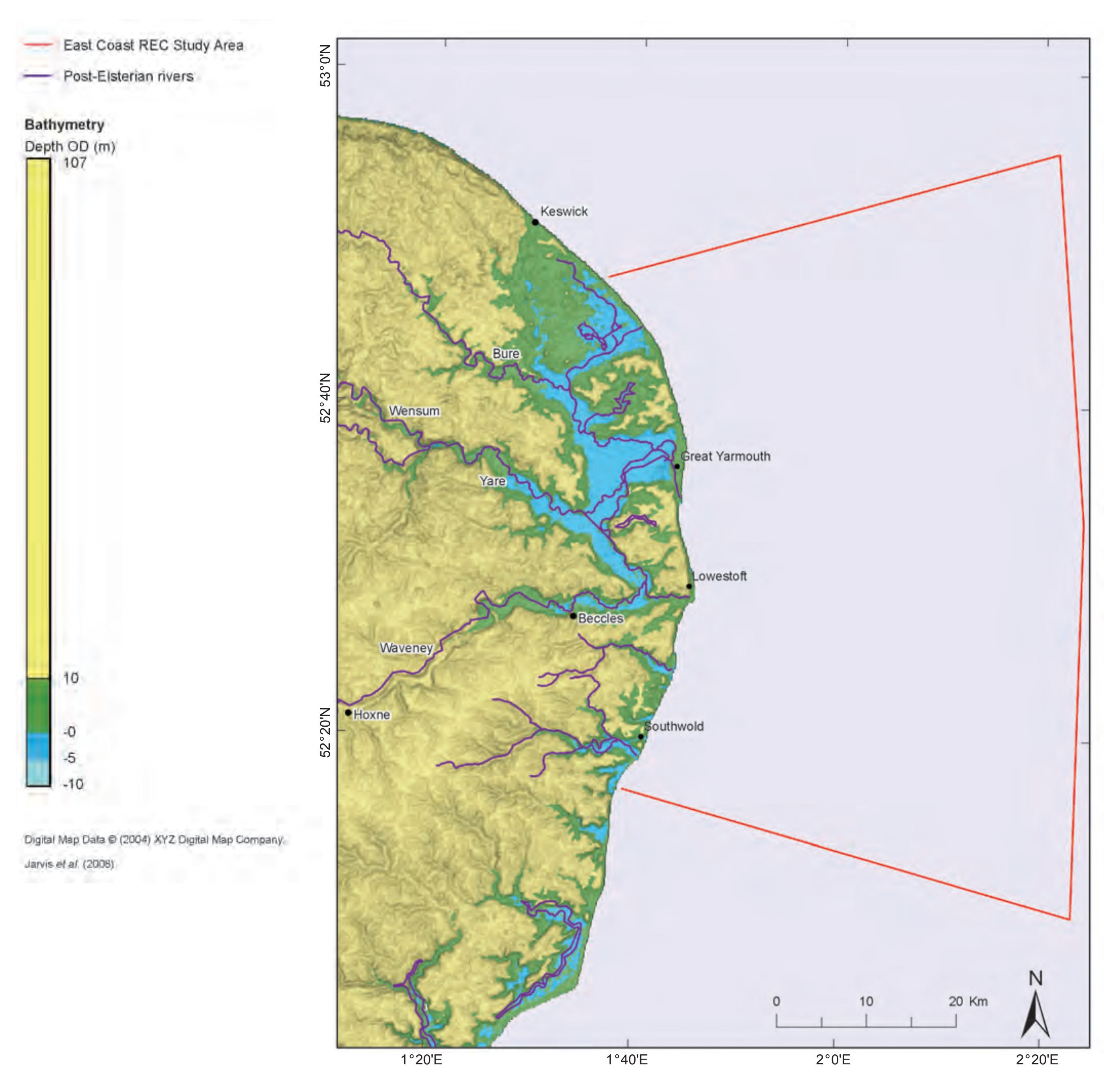


Figure 5.5 **Post-Elsterian river courses.**

Figure 5.6 **Glacial limits (after Emu Ltd & University of Southampton 2009) and key archaeological sites referenced in the text.**

"a partially flooded, periglacial area" (Cameron *et al.*, 1992), with sea levels at first rising in the succeeding Eemian interglacial, then falling into the Weichselian. By the start of MIS 5d, the southern North Sea was dry, with a shallow brackish lagoon north of 52°N fed from the west by a number of N–E-flowing channels representing extensions of the eastern English rivers. As conditions worsened through the Weichselian, the coastline retreated northwards leaving a periglacial plain south of the ice which, at its maximum, reached as far south as the Wash.

Latest Pleistocene and Holocene sedimentation

During the last glacial period, sea levels fell to exceptionally low values leaving what is now eastern England and the Netherlands subject to intense cold and dry conditions and uninhabited by any human populations. What happened to the lower reaches of rivers flowing into the southern North Sea region is very difficult to determine, but the principal mechanisms of erosion were not fluvial in origin but periglacial. The northern icesheet did not extend into the region, but periglacial conditions and the gradual thawing of permafrost promoted sheet movements by solifluction and created localised landforms on varying scales.

Once the glaciers began to retreat, sea levels in the southern North Sea began to rise from the glacial maximum low of 120 mbOD, but the East Coast REC Study Area would still have been an extensive dryland plain of periglacial aeolian sands, on which rivers began to deposit fluviatile sand in the early Holocene.

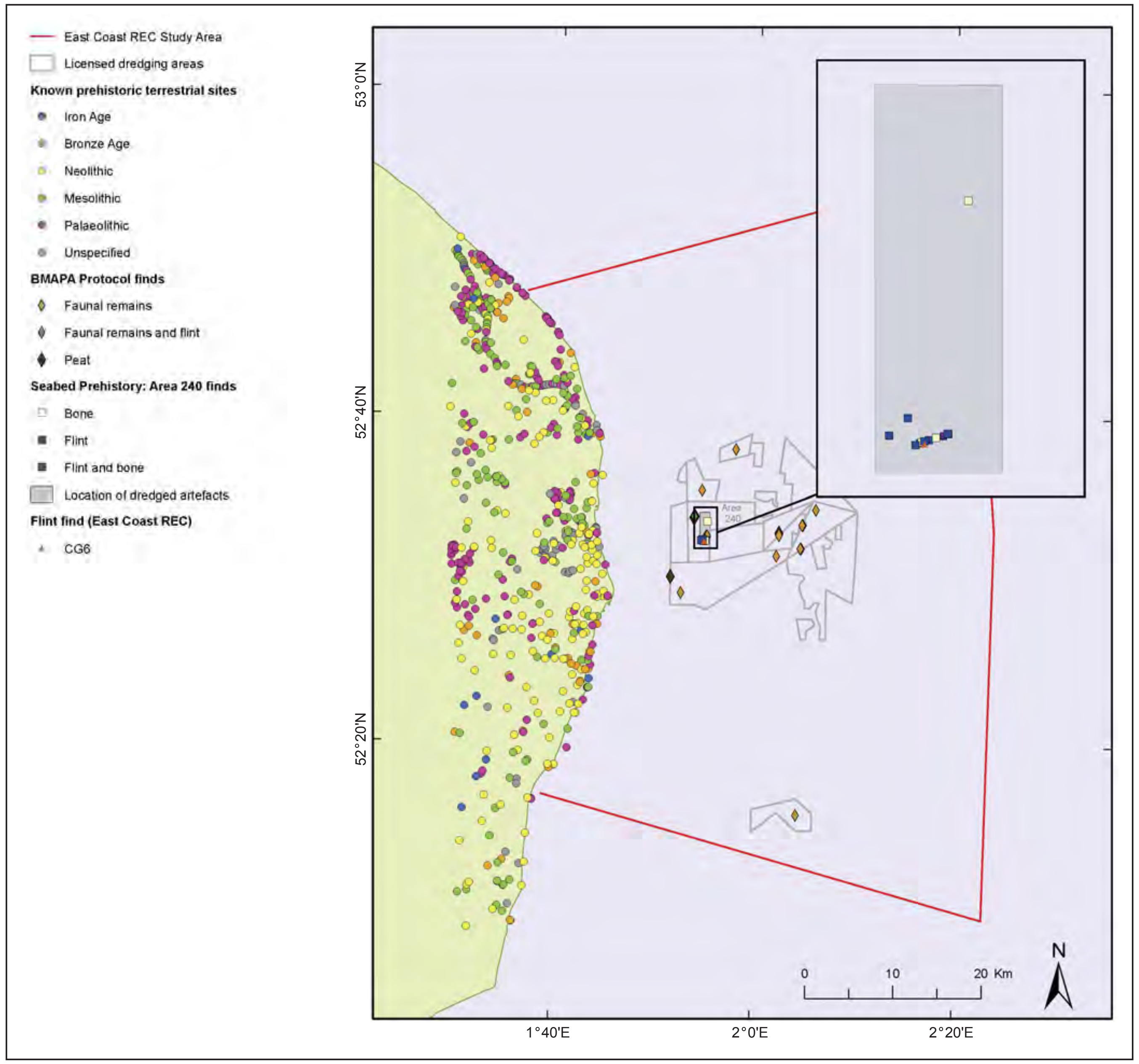


Figure 5.7 Known Prehistoric terrestrial sites, offshore prehistoric finds reported through the BMAPA Protocol and Seabed Prehistory project: Area 240.

5.3.3 Chronology and climatic variation

Archaeology: chronology and typology

Even in the terrestrial environment, the majority of archaeological assemblages are palimpsests which can conflate the remains of activities of very short duration (ie, near contemporaneous events) with extremely lengthy ones covering as much as several millennia, which would originally have been separated temporally (if not spatially) by periods of hiatus. Figure 5.7 illustrates terrestrial sites and findspots within the 10 km coastal strip of the East Coast REC Study Area. Stratified sites allow for the extrapolation of such chronologies, but unstratified material is much more difficult to interpret. Material recovered from contexts that now lie beneath the sea is generally only recovered in circumstances that make it the maritime equivalent of unstratified terrestrial material: even if *in situ* up to the point of its recovery, the circumstances through which the material is encountered (eg, trawling, dredging, grab sampling, aggregate extraction) generally strips it of stratigraphic integrity.

The best terrestrial analogues for understanding such material are the unstratified scatters of prehistoric lithics that occur in the plough zone or incorporated into colluvial and alluvial deposits, including in the intertidal zone, and the many thousands of finds of individual flint objects, such as Neolithic axes and Palaeolithic bifaces (eg, Gardiner, 1988; Schofield, 1991; Allen and Gardiner, 2000). Whilst such material is without direct chronological or stratigraphic context, it can, nevertheless, yield much information concerning large-scale use of landscape, enabling broad definition of, for instance, settlement and procurement activities, raw material acquisition and use, and many technical aspects of tool production. Crucially, the types, range and technological attributes of worked lithics, particularly flint, follow a clear chronological sequence that, with relatively minor local variations, holds good for much of north-west Europe, from the earliest of Palaeolithic finds (approximately 850 ka) to at least the later Bronze Age (approximately 1000 BC). While it is not proposed to discuss the typology and chronology of stone tools here, suffice it to say that even individual tools and many types of unretouched pieces and core materials can, without any other cultural association, be dated at least to period.

Most archaeological finds from the marine zone of the East Coast REC Study Area will be of Palaeolithic or earlier Mesolithic date. Recovery of material of later periods (from after approximately 8000 BP) will be increasingly confined to intertidal and nearshore locations as they post-date the principal episode(s) of Holocene transgression and the establishment of fully marine conditions in the East Coast REC Study Area between approximately 7000 BP and approximately 5000 BP. In practical terms, the effect of post-depositional factors may mean that very little material will be in primary context, and it will retain the similarly limited spatial and temporal integrity as terrestrial plough-zone assemblages, thus restricting the level of interpretation that can be attempted. However, the material has the potential to provide insights into patterns of past land use and demography (Hosfield *et al*., 2009).

Numerous mammal remains have been reported from a relatively restricted area in the southern North Sea between the Brown Bank area and the Norfolk coast, which have yielded Early and Middle Pleistocene mammal fossils (van Kolfschoten and Laban, 1995; Glimmerveen *et al*., 2004; Mol *et al*., 2006; de Wilde, 2006). Isolated finds of artefacts such as flints, bone spearheads and reworked or carved fossil mammal bones are also documented (Godwin and Godwin, 1933; Long *et al*., 1986; Coles, 1998; Flemming, 2002), and a number of finds and faunal remains have been, and continue to be, reported from aggregate extraction areas via the marine aggregate extraction industry protocol for reporting finds of archaeological interest (BMAPA and English Heritage, 2005). To date, approximately 30 reports have been made concerning prehistory as part of the protocol within the aggregate extraction areas offshore East Anglia (Figure 5.3), including reports of worked flint (Figure 5.8), faunal remains, eg, a mammoth tusk (Figure 5.9) and peat. Additionally, further evidence of flint and faunal remains were identified in aggregate extraction Area 240 (Wessex Archaeology, 2010a), and flint was recovered during the East Coast REC Study Area ground-truthing survey (CG6). These finds are discussed further in Section 5.3.5.

The Lower Palaeolithic saw the use of a very restricted range of lithic tools, among which the biface or hand axe was dominant. There is no consensus over the chronological significance or even sequence of changes in biface forms (eg, White, 1998; Ashton and White, 2003). The result of this is that it is very difficult to accurately date individual events or findspots belonging to the 350,000-yr period during which earlier forms of hominin arrived in and left the area that is now the East Coast REC Study Area.

Neanderthal skeletal remains are very scarce in Britain, but the presence, again, of distinctive types of flint artefact of so-called Mousterian affinity that are well associated with Neanderthal remains in the northern French river valleys indicate that they must have been present in some numbers on both sides of the Channel, even if sporadically. The Weichselian (approximately 110 ka to 13,000 BP) witnessed a series of climatic fluctuations that are very difficult to correlate with hominin activity: there does seem to be a very marked paucity of convincing evidence from perhaps close to the onset of the previous glacial period (MIS 6) down to around 40,000 BP (Middle Palaeolithic) even, perhaps surprisingly, during the Eemian interglacial (MIS 5e; approximately 130 ka to 110 ka) when climatic conditions were closely similar to those of the present day. In northern France, however, Neanderthal remains have been found in deposits dating to MIS 5e, suggesting that the apparent absence was only a relatively local phenomenon, and that evidence

Figure 5.8 Flint find reported through the BMAPA Protocol (© Wessex Archaeology and BMAPA).

Figure 5.9 Mammoth tusk reported through the BMAPA Protocol (© Tarmac and BMAPA).

of occupation in this period remains to be discovered. In 2001, a portion of frontal bone belonging to a *Homo neanderthalensis* was discovered in sediments extracted from the North Sea (Hublin *et al*., 2009).

Homo sapiens sapiens was present in north-west Europe from MIS 3 (late Weichselian; Upper Palaeolithic) with radiocarbon dates back to at least 38,000 BP, and a potential period (and range) of overlap with *H. neanderthalensis* of around 10,000 years. Throughout these periods, changes in lithic technology are distinct, providing strong chronological indicators. Associated bone- and antler-working technologies, along with faunal assemblages, are also diagnostic and provide clear indications of the resource base.

Material that is diagnostically late Upper Palaeolithic and earlier Mesolithic post-dates the Last Glacial Maximum and reflects the recolonisation of the Netherlands and southern Britain by anatomically modern humans from approximately 13,000 BP onwards (see, eg, Housley *et al*., 1997; Jacobi, 2004; Roebroeks and van Gijn, 2005) after a period of perhaps 10,000 years of glaciation during which it was uninhabited.

This basic sequence highlights the fact that any potential archaeological resource will not represent a uniform toolkit belonging to a single period, used by one species of Hominidae for a single task or range of tasks, which was only ever interrupted by climatic deterioration. While it is true that it is difficult to match particular data with specific climatic events in the more remote periods of prehistory, key known points from terrestrial archaeological sites and contextually secure assemblages allow us to suggest models of behaviour in the East Coast REC Study Area at different periods. These models inform the chronological sequence presented later.

Fauna and flora

The recovery of evidence demonstrating the presence, absence and sequence of particular species is one of the main ways in which terrestrial sites are tied to periods with particular climatic conditions. For example, glacial stages tend to be typified by reindeer, woolly mammoth, bison and cave lion, while interglacial conditions are indicated by straight-tusked elephant, spotted hyena, aurochs and wild boar. In addition to simple facts of presence/absence and combination, evolutionary changes in anatomy have been tied to particular climatic stages, especially with small mammals. Voles, for instance, exhibit rapid changes in tooth morphology, which act as indicators of particular chronological points.

In the marine zone in general and the East Coast REC Study Area in particular, it is seldom the case that faunal remains are recovered in ways that allow their contextual associations to be understood (eg, Glimmerveen *et al*., 2004). As a result, these remains are of little help in relating deposits to climatic events.

Much more helpful in the marine zone are insects, molluscs and micro-fauna. These latter (ostracods, diatoms and foraminifera) are especially helpful since they reflect local environmental conditions very closely and allow habitat type and sequences of change to be identified with some accuracy. Preserved pollen can contribute similarly.

Correlation with geochronology

Table 5.1 provides a correlation between the main Pleistocene stages, archaeological periods, seabed characterisation and archaeological potential.

5.3.4 Terrestrial analogues for hominin habitat preferences

Key to any prehistoric regime of land-use and resource exploitation is the availability and reliability of food, fresh water and shelter. Modern humans of the Upper Palaeolithic and Mesolithic were highly efficient hunters and foragers, and, though there is limited surviving evidence for foraging in the earlier periods, it seems most unlikely that advantage was not taken of fruits and nuts, and even edible roots, to supplement what has long been assumed have been a largely meat diet.

Raw material procurement and activities

It is likely that a wide range of raw materials were exploited by the early populations of north-west Europe. Few of these survive in any number, with the exception of lithics. A limited range of stone tools were made in large numbers throughout the Lower Palaeolithic, mostly of flint, although other sorts of stone were employed where available. The availability of good sources of flint and other workable stone was therefore a factor of considerable importance in influencing the location of hominin activity. Lower Palaeolithic objects were large and consequently required the acquisition of nodules that were not only of suitable size, but were also of good quality, and would not disintegrate while being worked due to flaws, foreign inclusions and thermal fractures.

Generally, the best-quality flint comes from seams within the chalk. Such flint may have been available in outcrops, most obviously in river and coastal cliffs or in periglacial footslope deposits. Other material from, for instance, river and marine gravels may have yielded nodules of suitable type, particularly on raised beaches.

The makers of Palaeolithic biface assemblages were both very skilled and well aware of the distribution of sources of good-quality stone. Procurement of this essential raw material was not haphazard; known sources were the subject of knowledge that was handed down through generations and were deliberately and repeatedly exploited over many thousands of years. It is therefore the case that sources of suitable, good-quality flint and other stone would have been visited repeatedly and that these locations will therefore have the potential to produce large quantities of Palaeolithic implements and associated manufacturing waste products.

Hunting and scavenging

Evidence from terrestrial sites indicates that early hominins were both hunters and scavengers. Given this, locations that were favoured for inhabitation are likely to have been ones that allowed ready access to animals. Such locations include those where herd animals could be viewed undisturbed at close range and could be ambushed; waterside locations where animals congregated to drink or which were crossing points for migrating herds; and ecotonal positions where a range of species would be likely to be present. Both hominins and other predatory animals are likely to have made use of such locations.

5.3.5 Seabed landscape as habitat

Recovered archaeological material from the seabed is not just a collection of disparate, if intrinsically interesting, objects. Its importance lies in the fact that it indicates the presence of past populations inhabiting a lost landscape, albeit one heavily transformed by subsequent taphonomic processes.

In this section, a series of chronological scenarios is presented. No account is taken of the subsequent history of the seabed, as the intention is to indicate the *potential* of the resource and highlight any locations that may be of particular interest should suitable deposits survive. Where deposits do survive with associated features of interest, as identified in the geophysics data, these are discussed. The predicted extent of sub-aerial exposure, potentially important topographical features and major river courses at appropriate sea-level height are provided where known. Figure 5.6 illustrates the key sites discussed.

Evidence for Pre-Elsterian/Anglian inhabitation

Previous assessments have tended to discount any material older than MIS 13 as pre-dating the earliest human inhabitation of north-west Europe. Over the last decade, however, a series of discoveries along the East Anglian coast has demonstrated that this assumption is no longer appropriate and that hominins were present in these latitudes perhaps as much as 970,000 years ago. These finds of pre-Elsterian material are likely to have important implications for the potential for finding material of this age in the marine zone and are consequently described in some detail.

Happisburgh Site 3: approximately 970 ka (MIS 25/sea level at ±0 mOD) or approximately 850 ka (MIS 21/sea level at 2 mbOD)

A series of channel sediments and associated overbank alluvium belonging to the ancestral River Thames has been mapped along approximately 1 km of coastline at Happisburgh, Norfolk. Excavations close to the northern channel edge revealed flint artefacts within gravel layers belonging to the newly named early Pleistocene Hill House Formation of the Cromer Forest-bed. This comprises approximately 4 m thick gravels, sands and interbedded sands and silts and is most likely to have accumulated in the upper part of the estuary of a large river system, with gravel and sand channel fills and sand and silt mudflats.

A lithic assemblage consisting of cores, flakes and flake tools is not typical of a primary knapping scatter, but seems to represent selected elements removed for use. There are no suggestions of hand-axe technology. The lithics were recovered from several different gravel bodies, suggesting revisiting and a repeated hominin presence (Parfitt *et al*., 2010).

Pollen indicates a succession in which mixed deciduous woodland with alder and willow in damper areas, saltmarsh, damp grassland or fen and open water is replaced by heathland with some nearby coniferous woodland, the heath eventually being replaced by a mixed deciduous/coniferous wood. Insect remains indicate summer temperatures of 16 to 18°C and winter temperatures of –3 to 0°C (Parfitt *et al*., 2010).

This landscape supported a large mammalian fauna consisting of southern mammoth, bovids, deer, elk, equids and hyena, in addition to hominins and a range of small mammals, amphibians and fish.

Pakefield: approximately 750 ka (MIS 19/sea level at ±0 mOD) or 680 ka (MIS 17/sea level at 10 mbOD)

The Cromer Forest-bed Formation yielded struck flint from Pakefield on the former floodplain of the lower course of the pre-Elsterian Bytham River (Parfitt *et al.*, 2005). The material from Pakefield came from river sediments associated with a diverse range of plant and animal fossils, indicating warmer summers (18–23°C), milder winters (between –6 and +4°C) and a strongly seasonal precipitation regime, denoting a warm, seasonally dry Mediterranean climate.

Insect and plant remains suggest extensive reedy vegetation and marshy ground adjacent to the lower reaches of a large meandering river. Deciduous woodland (oak) and open grassland were nearby, supporting browsing and grazing mammals and their predators and scavengers.

The water-worn cortex of some of the lithics suggests material collected locally from lag gravels at the base of the river channel, or from earlier river terraces off the floodplain. Material has been recovered from a number of layers at different depths, suggesting repeated use of the site.

Happisburgh Site 1: approximately 500 ka (MIS 13/sea level at ±0 m)

Organic muds within the floodplain of one of the pre-Elsterian rivers draining eastern England exposed on the beach at Happisburgh in north-east Norfolk contain lithic artefacts including a hand axe (Field, 2010). The date of the organic deposits are a matter of ongoing debate, with arguments in favour of an MIS 17 or earlier age advanced alongside rival arguments for a date in MIS 13 (or late MIS 15). Vertebrate, coleopteran and amino acid racemization (AAR) evidence seem to favour the latter, although the evidence is not conclusive in either case.

The excavated artefact assemblage includes waste flakes, retouched tools, cores and possible indications of hand-axe manufacture. Environmental evidence points to occupation of a temperate, moist, open environment, with slow-moving freshwater fringed by damp grassland and woodland, and still water/marshy conditions. Summer temperatures were in the range of 12 to 15°C; winter temperatures in the range of –11 to –3°C.

A hominin presence at these latitudes in the Cromerian is of very great significance for characterising the potential of seabed deposits to contain contemporary anthropogenic material. The difficulty now lies in identifying seabed deposits that are the equivalents of the relevant parts of the Cromer Forest-bed Formation and in locating any surviving channel fills of the pre-Elsterian river systems.

The Yarmouth Roads Formation (approximately 2.3 Ma to 480 ka), comprising sands with pebbles, abundant plant debris and peat clasts, which was deposited as part of a complex delta-top sequence forming part of the Ur–Frisia delta plain (Cameron *et al*., 1992), is partially equivalent to the Cromer Forest-bed Formation.

Yarmouth Roads Formation deposits of Cromerian Complex age (790 ka to 480 ka) are encountered to the north (Cameron *et al*,. 1992) of the East Coast REC Study Area, while pollen analysis of a core in the Dutch Sector indicates deposition at a similar latitude during the Cromerian III interglacial, around 720 ka to 690 ka (Zagwijn, 1983).

Deposition of the Yarmouth Roads Formation occurred until the end of the Cromerian Complex with a basin-wide marine transgression progressing south to the 52° latitude. It was during this transgression phase that the Cromer Forest-bed Formation was deposited. There may be remnants offshore of these sediments, although it has been suggested that the uppermost parts of the Yarmouth Roads Formation have probably been eroded (Cameron *et al*., 1992). The potential for archaeology in the offshore region is considered greatest where later Yarmouth Roads Formation deposits are associated with features (river valleys, shorelines etc.) cut into earlier Pleistocene or pre-Pleistocene formations. The Yarmouth Roads Formation is observed extensively throughout the East Coast REC Study Area and is observed subcropping the recent seabed sediments in the west of the area (Figure 5.10). Six features of possible archaeological interest were identified in the geophysical data (**7000–7005**).

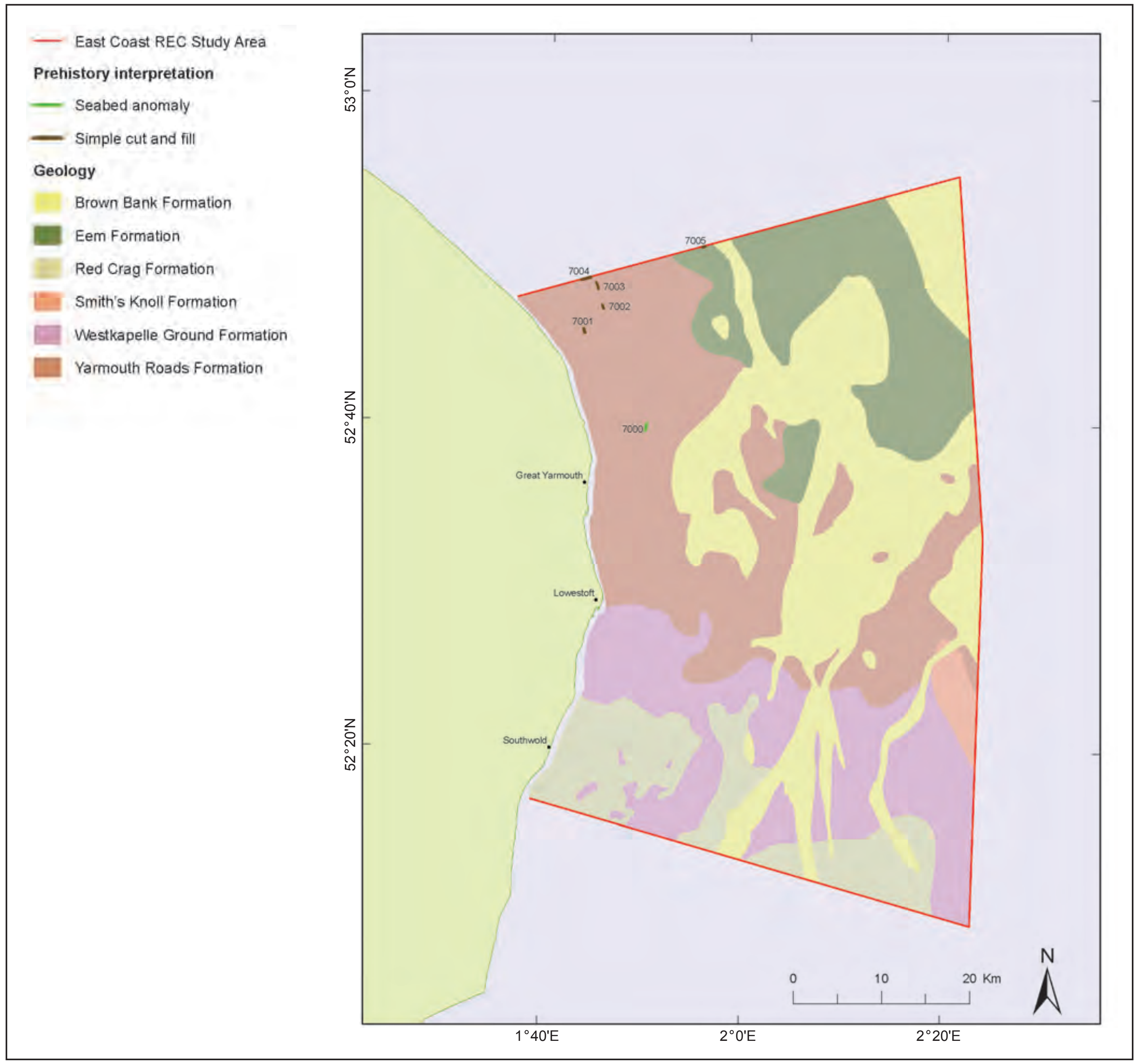


Figure 5.10 **Location of geophysical features associated with the pre-Elsterian period.**

The Cross Sands anomaly (**7000**) is situated approximately 6.5 km from the coast to the north of Great Yarmouth. The feature is approximately 165 m long, 30 m wide and 13 m high. The true nature of the feature is unknown. One theory is that the feature is a chalk raft deposited during the Elsterian Glaciation. Chalk rafts can be seen on the north Norfolk coast (Burke *et al*., 2009) and are defined as dislocated slabs of bedrock and/or unconsolidated sedimentary strata that have been transported from their original positions by glacial action. On the north-east coast of Norfolk the chalk rafts are exposed within the Middle Pleistocene glaciogenic sediments that are exposed in the cliffs capped by periglacial sand and gravel. Although a chalk raft, in itself, is not of particular archaeological interest, the presence of this feature offshore may indicate preservation of underlying sediments that could be of archaeological interest.

During the Early Holocene (approximately 10,000 years ago), the coastline was approximately 5.5 km east of its present-day shoreline and formed the boundary between the terrestrial upland area and the North Sea plain (Arthurton *et al*., 1994). It is possible that the chalk raft formed part of the cliff line at one point and has subsequently been eroded away leaving the feature exposed. As such, the feature may preserve Early Pleistocene sediments in a similar way that the cliffs, until recently, have preserved the sediments containing artefacts and faunal remains at sites such as Happisburgh and Pakefield.

An isolated simple cut and fill feature (**7001**) is situated approximately 3.5 km from the present-day coastline. The feature is interpreted as a cut into the underlying Westkapelle Ground Formation and infilled with up to 4 m of fine-grained sediment, possibly Yarmouth Roads Formation. If this infill does indeed comprise Yarmouth Roads Formation, there may be some potential for Lower Palaeolithic artefacts or palaeo-environmental material. However, it is possible that the infill is in fact younger and may be associated with offshore extensions from present-day rivers.

Further simple cut and fill features (**7002**–**7005**) are interpreted with strong, undulating basal reflectors and infilled by probable coarse-grained sediments. Distinct incised basal cuts are observed (**7004** and **7005**) and it is possible that these cuts were caused by glacial action rather than fluvial action. The nature and age of fill of these features is unknown and difficult to determine. If these features are glacially formed then it is possible that the fill represents remnants of the Swarte Bank Formation (Cameron *et al*., 1992), which infills a fan-like array of valleys cut into Pleistocene and earlier strata. The valleys are generally considered to have been formed by subglacial meltwater under pressure and are filled with till deposits overlain by glaciofluvial sand or glaciolacustrine muds, and overlain sporadically by marine interglacial sediments. Swarte Bank Formation is considered to be of late Elsterian to locally earliest Holsteinian age. If the infill is composed of Swarte Bank Formation, then the fill is unlikely to contain any artefacts. However, if the cut is fluvial in nature and the fill pre-Elsterian, then there is potential for Lower Palaeolithic artefacts.

While unequivocal evidence of hominin activity in the terrestrial zone in MIS 13 is limited, there is a considerable amount of material from the terraces of the Bytham River, suggesting a more widespread hominin presence by this time. At Warren Hill and (particularly) High Lodge (Wymer, 1997), for instance, large assemblages of hand axes and other tools in MIS 12 deposits are likely to have been manufactured, used and discarded in MIS 13. At High Lodge, the raw material was exclusively local East Anglian flint, mostly from the chalk, with only a little from gravel sources, indicating that the material need not have been transported very far.

The Elsterian/ Anglian period: approximately 480,000 BP to approximately 423,000 BP (MIS 12/sea levels as low as 130 mbOD)

This period represents a glaciation and subsequent return to interglacial conditions. The Elsterian ice sheet is the most extensive known to have covered Britain, extending as far south as the Thames Valley in the London area and as far as the north Cornish coast in the west of England; the Scandinavian ice sheet reached the Netherlands and the southern part of the North Sea basin. Throughout much of this period, Britain and much of the Netherlands and the intervening lands would have been uninhabited. The southern North Sea will have been dry (sea levels estimated as low as 130 mbOD), with extensive remodelling of the landscape and old river systems destroyed or buried. The Thames and its tributaries were diverted southwards, and a large ice-dammed lake developed – directly to the south of the ice-front – into which the Thames and other major European rivers flowed (Gibbard, 1988, 2001). Onshore deposits around Great Yarmouth from this period are till deposits belonging to the Corton and Lowestoft Till Formations (Arthurton *et al*., 1994). No Elsterian till deposits are known to be preserved offshore, as they are thought to have been eroded by the subsequent sea-level rise during the Holsteinian interglacial. However, if the Cross Sands anomaly (**7000**) is proved to be a chalk raft, then this would be associated with Elsterian till deposits. This indicates that there is potential for Elsterian deposits offshore.

Onshore, deposits ascribed to the Yare Valley Formation may be associated with the Late Elsterian Period. The Yare Valley Formation occupies the floor of a buried valley system underlying the marshland and river valleys of the present day. It is generally observed overlying Crag deposits or London Clay to the west. Immediately offshore Newtown, sands and gravels interpreted as this formation are observed overlain by the Late Weichselian Breydon Formation.

There is speculation as to the maximum age of the deposits of the Yare Valley Formation deposits. The formation postdates the Elsterian succession (Lowestoft and Corton tills), but it is possible that it includes the glaciofluvial deposits of Late Elsterian age (Arthurton *et al.,* 1994). Coxon (1979) argued either Elsterian or Saalian age, and Cox *et al.* (1989) postulated a possible late Holsteinian age for these sediments. The upper deposits of this formation are ascribed to the Weichselian (Coxon, 1979; Cox *et al.,* 1989), with at least some deposits thought to be of Late Weichselian/ early Holocene age, deposited by rivers flowing within the now-buried valley system and draining central parts of East Anglia to the contemporary southern North Sea basin (Arthurton *et al*., 1994).

The Palaeo-Yare is thought to extend into the North Sea, possibly connecting to the series of channels infilled by the Weichselian Brown Bank Formation (Figure 5.10); gravel deposits identified by Bellamy (1998) within aggregate extraction Area 254 were tentatively identified as analogous to the terrestrial Yare Valley Formation. OSL datings of these sediments suggested deposition during the Saalian and Eemian periods (Wessex Archaeology, 2008a) and are discussed further below.

The Holsteinian/ Hoxnian interglacial: approximately 423,000 BP to approximately 380,000 BP (MIS 11/sea level at approximately 10 mbOD)

Sea level in the southern North Sea rose quite rapidly during this period, and Britain is likely to have become a peninsula. Evidence of human activity in this period is not common, but, at Beeches Pit in Suffolk, evidence of flint knapping and fire occur adjacent to an abandoned channel of the Bytham River, dated to approximately 400 ka (Gowlett, 2006).

At Hoxne, there is a complex sequence of laminated lacustrine deposits that were deposited as a lake was formed in a kettle hole produced in the glacial till, deposited as the Elsterian ice sheet

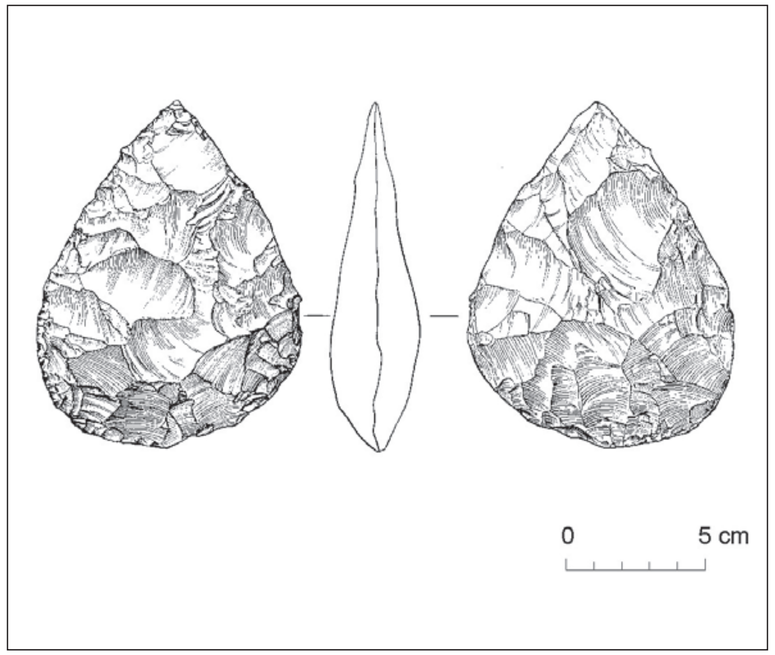


Figure 5.11 **Cordate hand axe from Hoxne (Wymer, 1999).**

retreated. Large numbers of hand axes in near-mint condition (Figure 5.11) indicated more or less *in situ* deposits, associated with mammalian teeth and bones with indications of deliberate cut-marks.

Our understanding of hominid movements and settlement in the Holsteinian interglacial is fragmentary, but we might suggest that the coastal plain was used for occasional forays into the intertidal marshes and the lower portions of river valleys for fishing and fowling, with some sea fishing. It would seem that the potential for recovery of MIS 11 assemblages in the marine zone is greatest in nearshore areas, where remnant river terraces or valleys may be buried. Channel-fill sediments of possible Holsteinian age have been observed on the modern shore at Caister-on-Sea (Arthurton *et al.*, 1994).

The Egmond Ground Formation is observed in the north-east of the East Coast REC Study Area, underlying the Eem and Brown Bank Formations. The Egmond Ground Formation was deposited during the latter stages of the Holsteinian interglacial as the re-establishment of a shallow sea prevailed caused by rising sea levels and continued tectonic subsidence following the decay of the Elsterian ice sheet. The formation comprises fine-grained, sparsely shelly marine sands with clay interbeds. There may be the potential for artefacts to be covered by the transgression sediments, and where Egmond Ground Formation forms the infill to channel deposits there is the possibility of derived artefacts.

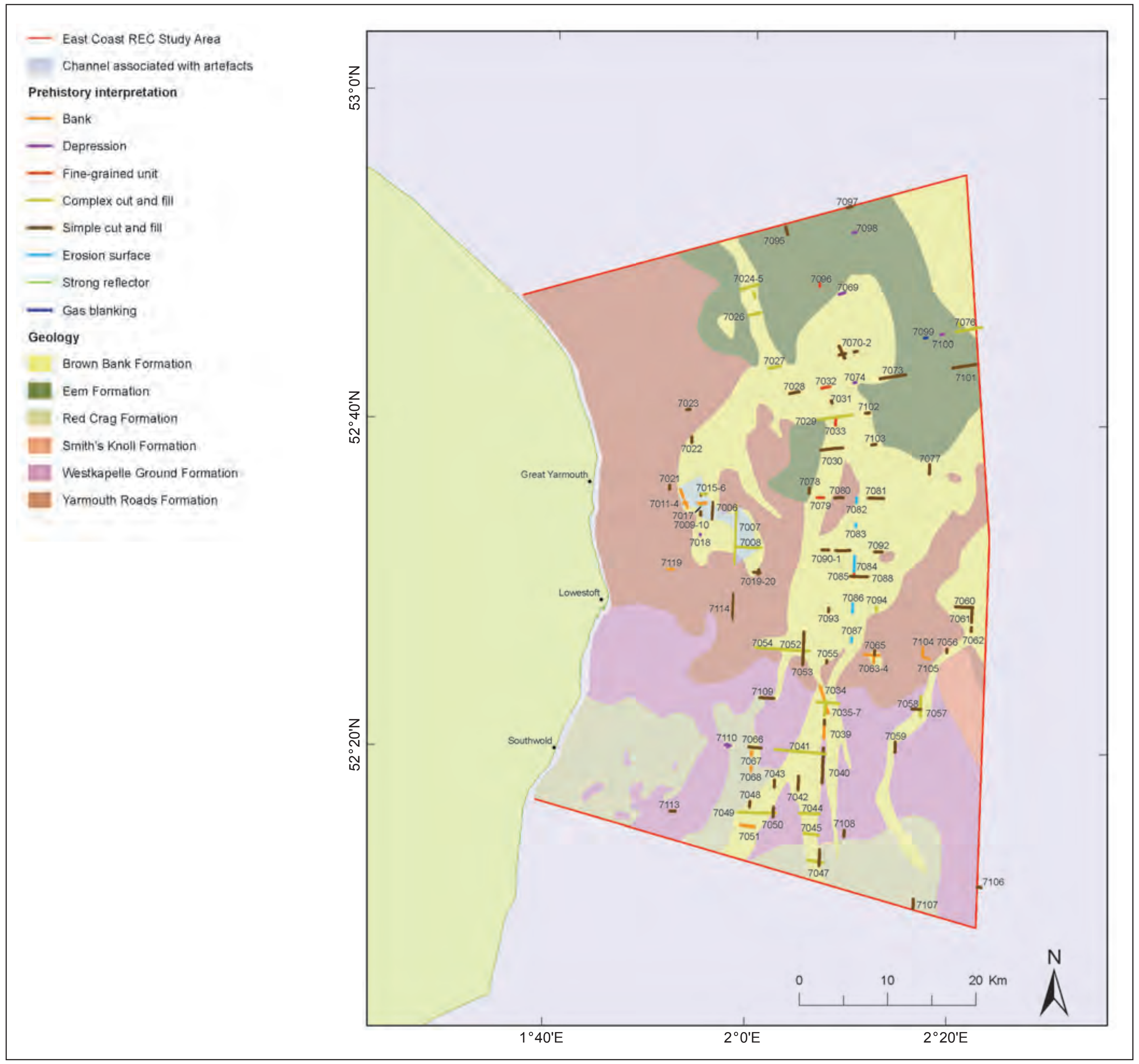


Figure 5.12 **Location of geophysical features associated with the post-Elsterian/ pre-Holocene periods.**

Distinct deep cut features (**7095** and **7101**, Figure 5.12) infilled with a series of strong sub-parallel reflectors were interpreted as Egmond Ground Formation. However, VC24 indicates that the upper 4.3 m of this fill comprises organic silts and clays overlying fine- to medium-grained sands, more indicative of the younger Weichselian Brown Bank Formation.

The Saalian/Wolstonian: approximately 380,000 BP to approximately 130,000 BP (MIS 10–6/sea level as low as 120 mbOD)

This period saw alternating periods of warm and cold, with fluctuating sea levels and climatic conditions. In warm phases – the MIS 9 (Purfleet) and MIS 7 (Aveley) interglacials – hominins were certainly active in northern Europe, including southern Britain, and many Palaeolithic sites and finds occur. Dating evidence is, however, sparse, and it is very difficult to differentiate material belonging to different phases.

Cold phases were comparable in impact to those of the Elsterian glaciation, with river diversion and landscape remodelling on a large scale. The maximum southern extent of the ice remains uncertain, but indications are that, in the North Sea, the limits extended eastwards from the Wash before turning north (Figure 5.6), with much of the central southern North Sea an ice-dammed glacial lake surrounded by tundra and open steppe. A major glacial phase centred around 150 ka (MIS 6), during which the Netherlands were under ice as far south as the Rhine and Britain was unoccupied. This lack of hominin presence seems to have continued into the following period.

In north-west Europe, the Middle Palaeolithic is associated with the appearance and use of a specific flint technology known as the Mousterian, which includes distinctive flat-butted hand axes (*bout coupé*) and flakes and cores employing a technique known as Levallois. This technological complex is generally synonymous with Neanderthals and persisted in use from around 200 ka to perhaps 40 ka. Neanderthal bones are rare (some teeth and jaw fragments from Pontnewydd Cave in Denbighshire, of MIS 7 date). However, flint implements of Mousterian type are frequent on both sides of the southern North Sea, suggesting a more widespread human presence than might otherwise be inferred. What does seem to be clear, puzzling as it is, is that humans were absent from Britain during the last interglacial, the Eemian, so some Mousterian material may be earlier, belonging to MIS 7, but the majority is more likely to be later (Weichselian).

In the Netherlands, Middle Palaeolithic artefacts have been recovered from the Belvédère gravel pit near Maastricht, in fine-grained Meuse deposits of MIS 7 date. These MIS 7 dates on either side of the North Sea highlight the possibility that both the English and the Dutch data provide analogues for material that may survive in present maritime locations.

Sediments of this age have been identified in aggregate extraction Area 254 (Wessex Archaeology, 2008a) and were interpreted as a bank deposited within a wider channel structure composed of Saalian sands and gravels overlain by possible Eemian/Weichselian finer grained fluvial and estuarine sediments. VC29_2 (Figure 5.13) is situated to the south-west of Area 254, situated on a 3 m-high bank structure (**7119**), and was targeted to establish if there was any relationship between these features and those observed in aggregate extraction Area 254. The British Geological Survey has mapped the area as Yarmouth Roads Formation (Cameron *et al.*, 1992), fluvial and intertidal sediments dating to the Cromerian Complex (MIS 17 to MIS 13), approximately 790 to 480 ka.

The sediments within VC29_2 comprised a basal shelly sand from 33.51 to 33.59 mbOD; dark-grey interbedded sandy clayey silt from 33.34 to 33.51 mbOD; and grey sand interbedded with finer silt and clay laminae and evidence of oxidisation between 30.47 and 33.34 mbOD. The uppermost sediment from 30.09 to 30.47 mbOD comprised modern seabed sediment of light yellowish brown sand, including occasional molluscs.

No date was retrieved for the basal shelly sand, but a sample from this layer 33.55 mbOD contained a small assemblage of foraminifera and ostracods indicative of probably cold estuarine/shallow marine conditions.

Above this, the sediments have been dated to between 222 ± 28.7 ka (at 32.50 mbOD) and 188 ± 19.7 ka at 31.50 mbOD. A notable reversal at the base of the sequence (206.5 ± 29.5 ka at 33.40 mbOD) is thought to be contemporary with these other dates, given the error bars quoted. These dates correlate with the MIS 7/6 boundary at 191 ka (Lisiecki and Raymo, 2005) and may thus equate with the Lower Thames, Aveley interglacial/Tottenhill interstadial transition and Middle Palaeolithic archaeological period.

The uppermost date of 57 ± 5.6 ka at 30.88 mbOD has at present been rejected as an age for deposition of the sediment on the grounds that it is possible that the sediment at this depth was exposed to sunlight during the Weichselian, MIS 3, subsequent to its original deposition during the Saalian MIS 7/6 period. The oxidisation noted within the sediments is a result of a fall in the level of the water table, suggesting that they have been elevated above sea level subsequent to their deposition.

Palynologically, the profile does not show full interglacial (MIS 7) characteristics, but an early (Boreal) interglacial stage or interstadial character – that is, dominated by pine (*Pinus*) prior to expansion of deciduous thermophiles.

At the base of the sequence, a high abundance of molluscan remains was recovered in the sample at 33.40 to 33.49 mbOD, dominated by shells of *Scrobicularia/Tellina* type and cockle (*Cerastoderma edule*) indicative of muddy, estuarine and intertidal conditions. The basal sample also contained a seed (*Ranunculus* type), charcoal, some fossilised wood and meagaspores which are likely to have been reworked within these sediments. The charcoal is an indication of possible hominin habitation within the area (ie, use of wood for fuel) or may have been formed naturally by, for example, forest fire.

The vibrocore contained some singular reworked valves of shallow marine ostracods including species of *Cytheropteron*, *Semicytherura* and *Palmoconcha.* Decent foraminiferal assemblages were recovered and were dominated by species of *Elphidium* and *Elphidiella*. *Elphidiella hannai* was the predominant species. These low-diversity *Elphidiella*-dominated assemblages

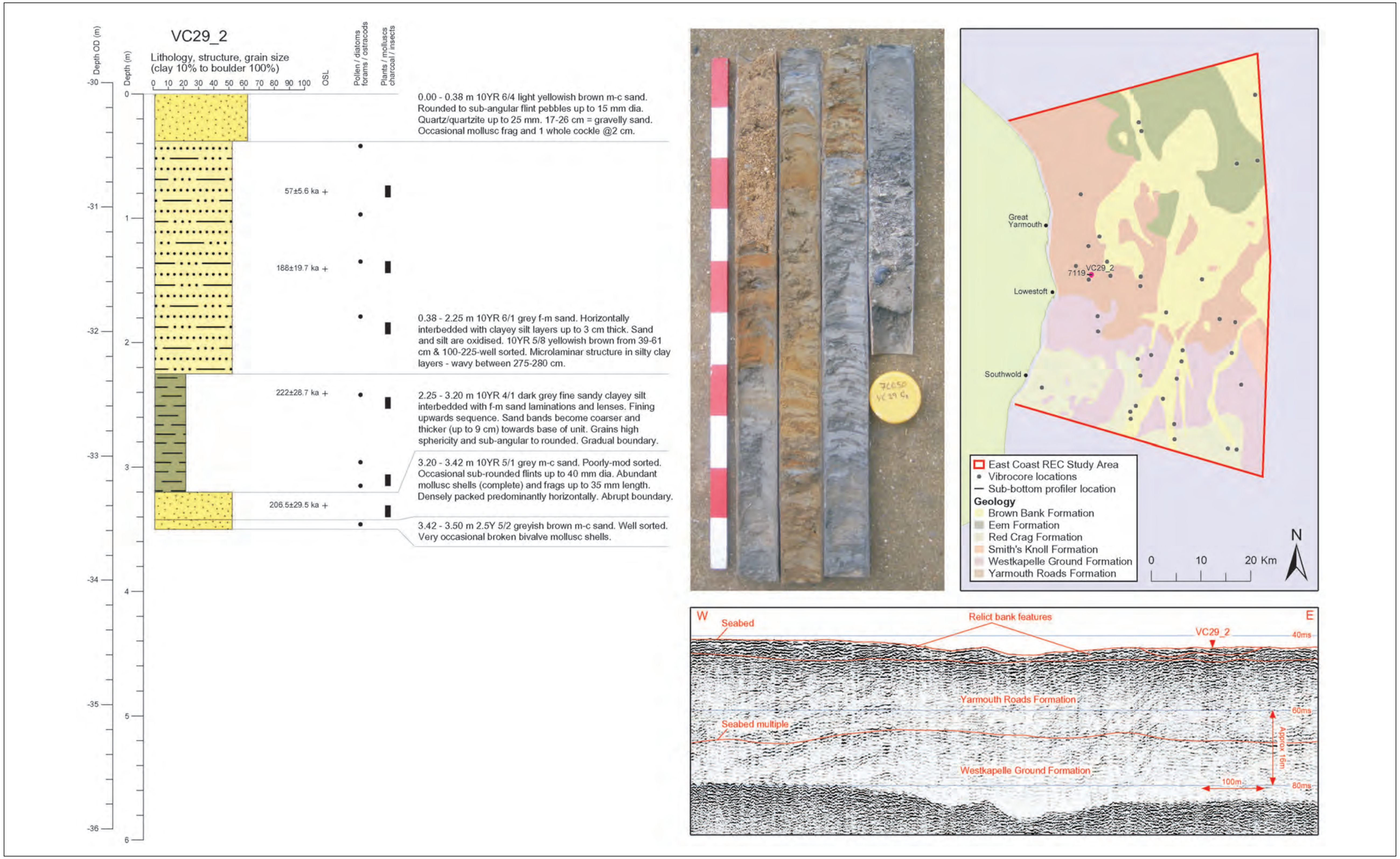


Figure 5.13 VC29_2. © Wessex Archaeology.

are often indicative of pre-Elsterian cold, estuarine/shallow marine conditions (Funnell, 1989), although clearly the OSL dating suggests a post-Elsterian date for these sediments.

Three samples were successfully OSL dated (309.5 ± 29.1 ka, 226.0 ± 26.5 ka, 175.7 ± 22.6 ka) within sediments from aggregate extraction Area 254, approximately 10 km to the north, indicative of a Saalian (MIS 8, 7 or 6) date (Wessex Archaeology, 2008a). One deeper OSL sample within this sediment unit returned a date of 577.2 ± 65.4 ka and is thought to be representative of sediments relating to the underlying Yarmouth Roads Formation. The sediments were, however, largely barren of environmental remains and thought possibly to be fluvial in origin.

The overall environment indicated by the samples within VC29_2 is of a cold estuarine environment, probably deposited during the Saalian. During deposition of these sediments, relative sea level must have been less than 25 to 30 mbOD.

Although there is limited evidence of sediments of this age offshore, the data from the vibrocore samples indicate that these sediments may be more extensive in the East Coast REC Study Area, particularly associated with the sediments targeted for marine aggregate extraction.

Given the potential MIS 7/6 date for these sediments, and possible environment conducive to hominin use (estuarine), then there is a possibility for archaeological material to be associated with these sediments.

The Eemian / Ipswichian: approximately 130,000 BP to approximately 110,000 BP (MIS 5e/sea level at 5 maOD)

A very rapid climatic amelioration followed the end of the last glacial phase of the Saalian, with sea level rising to more than 5 m above OD on the English coasts, and “at most a few metres higher than it is now” in the Netherlands, although “marine Eemian deposits … lie at depths of 8 m and more below NAP … [indicating] the overall subsidence of the southern part of the North Sea Basin over the past 100,000 years or so” (van Gijssel and van der Valk, 2005).

Surprisingly, this warm phase (the Eemian; MIS 5e) has not produced any certain evidence of occupation in Britain, although the riverbank butchery site at Caours, Abbeville, France, where the remains of rhinoceros, elephant and aurochs lie within deposits laid down around 125,000 years ago, indicates that this may be a very local phenomenon (if not simply an absence of evidence). If, however, hominins were absent from Britain, then there is little likelihood of material being present in deposits on the seabed.

Although of limited potential in terms of evidence of hominins, there is some interest from a palaeo-environmental point of view. The Eem Formation (113 to 110 ka) consists of shelly sands passing westwards into muddy sands and muds of a more intertidal aspect (Cameron *et al*., 1992). The Eem Formation is succeeded, gradually in some places but sharply in others, by Brown Bank Formation, which comprises late Eemian to early Weichselian brackish-water silty clays.

Evidence of potential remnant Eemian land surfaces were observed in the upper sediments of a relict bank feature (Figure 5.14) located in the eastern portion of the East Coast REC Study Area (**7104** and **7105**). The base of the bank is observed at 16 m sub-seabed and marks the top of the Westkapelle Ground Formation; the top of the probable Yarmouth Roads Formation is at around 12 m sub-seabed. This is overlain by a series of coarse sediments, which is cut and infilled by a series of finer grained sediments in the upper 6 m of the feature.

The sedimentary sequence within vibrocore VC7, associated with the bank, was characterised by sands interspersed with horizontally bedded silt layers. The upper part of these sands and silt layers was oxidised, probably due to a post-depositional lowering of sea level and of the water table.

The samples at the base of the sequence (at 42.37 and 41.71 mbOD) contained shallow marine foraminifera including numerous reworked specimens of the cold water estuarine and shallow marine foraminifera *E. hannai*. Pollen from this part of the sequence contained woodland species such as oak (*Quercus*), elm (*Ulmus*), hornbeam (*Carpinus*), ash (*Fraxinus*) and maple (*Acer*), indicative of an interglacial woodland. This is in contrast to the other Boreal type pine (*Pinus*)- and birch (*Betula*)-dominated assemblages of the other cores. The presence of hornbeam and maple is possibly indicative of the last interglacial period of the Eemian (MIS 5e).

At 41.25 and 40.85 mbOD, palaeo-environmental remains were rare but included occasional reworked marine foraminifera present at 40.85 mbOD. The pollen assemblage at these levels was similar to that below, including species indicative of an interglacial woodland. Wetland and saltmarsh plants were also represented within the pollen samples, including bur reed and/or reedmace (*Typha angustifolia/Sparganium*), royal fern (*Osmunda regalis*), goosefoots, oraches or glassworts (Chenopodiaceae) and sea plantain (*Plantago maritima*), indicating that salt marsh or brackish-water conditions existed in the local region.

The sands from 42.47 to 40.66 mbOD were deposited in a shallow marine environment, with the laminae of silt indicative of episodes of possible tidally influenced and/or sheltered/restricted conditions rather than fully open marine conditions. The pollen assemblage includes thermophiles, which are indicative of an interglacial type flora in contrast to the pine (*Pinus*)-dominated pollen assemblages recovered from the other cores.

Around 30 km north-west of this location in aggregate extraction Area 254, organic freshwater and brackish silts were OSL dated to 116.7 ± 11.2 ka, suggesting an Eemian, MIS 5e, date (Wessex Archaeology, 2008a). The environmental remains including a seed of the brittle water-nymph (*Najas minor*) and the pollen sequence observed is similar to East Anglian Eemian sites where pine (*Pinus*) and birch (*Betula*) woodland is succeeded by oak (*Quercus*) before

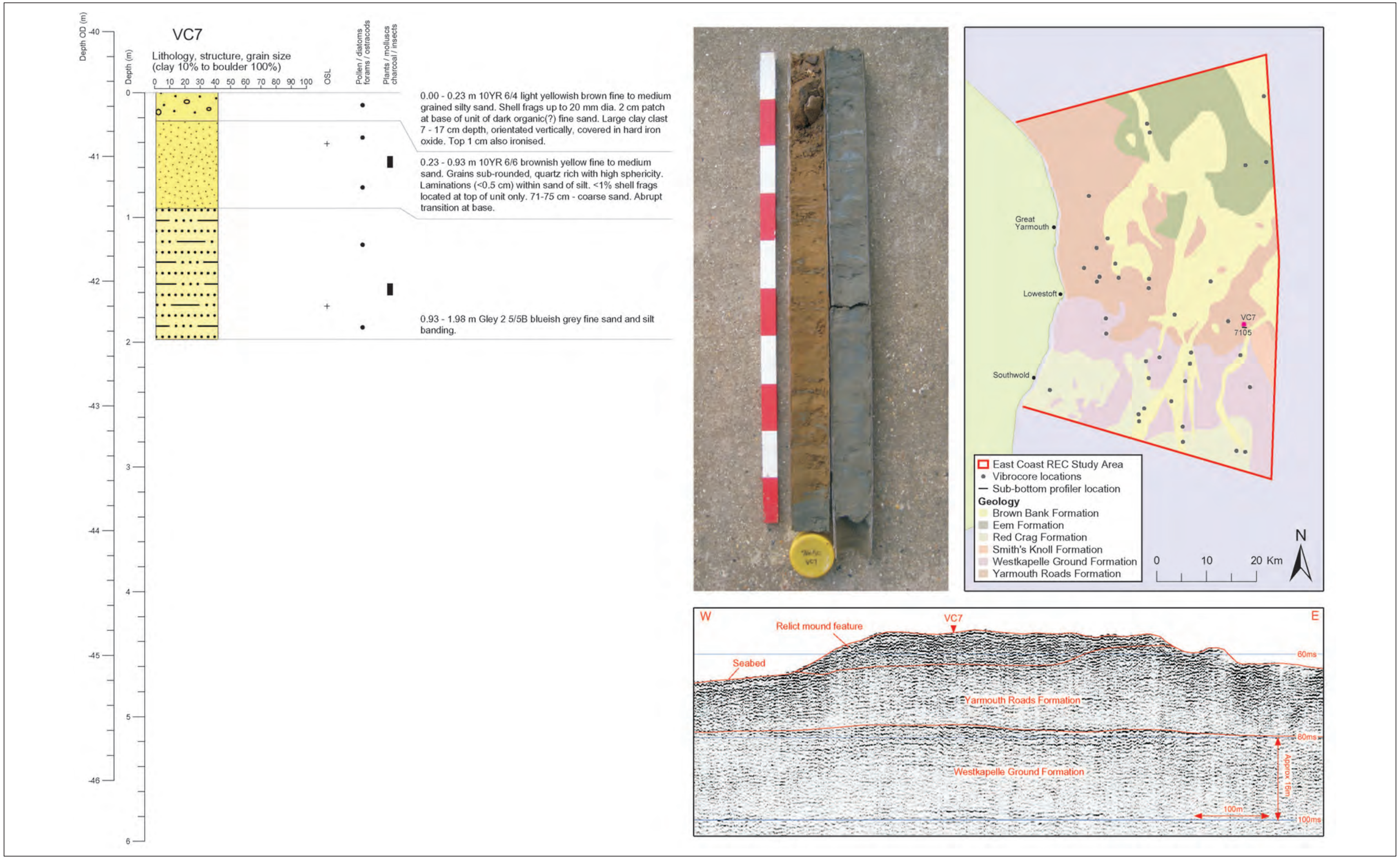


Figure 5.14 VC7. © Wessex Archaeology.

the occurrence of hazel (*Corylus*) supportive of an Eemian or earlier date for these sediments (Godwin, 1975).

The upper part of the core (40.40 to 40.46 mbOD) contained modern seabed sediment comprising shelly sand with one notably large ovoid (100 mm diameter) mudstone cobble. Samples of pollen, diatoms, foraminifera and ostracods were taken from the centre of the oxidised mudstone inclusion, but none of these remains were recovered from the samples. Many of the grab samples recovered from the East Coast REC Study Area also contained oxidised clay and mudstone inclusions, often occurring in sheets. It is noted that the ovoid inclusion sampled in this core is “onion weathered”, forming small sheets of oxidised mudstone. Furthermore, within this core, the horizontally bedded silt laminae have oxidised. This gives two possible scenarios for the formation of oxidised sheets of clay and mudstone occurring within the sediments: that they are (possibly Tertiary) oxidised and weathered lumps of bedrock or more recent waterlain clays and silts oxidised *in situ,* due to post-depositional water-table movements, which were subsequently reworked.

The evidence of potential Eemian environments indicates that remnant land surfaces are potentially widespread throughout the area and, although modified, have not necessarily been completely removed by subsequent transgressions and regressions.

The Weichselian/Devensian: approximately 110,000 BP to 13,000 BP (MIS 5d–2/sea level as low as 120 mbOD)

At around 120 ka, the sea level was falling from its highest level over the last 700,000 years (approximately 5 maOD). The sea-level curve for the Weichselian reflects considerable climatic variability with long periods of relative cold and, overall, a general trend towards ever colder conditions, culminating in the last ice age. Comparatively few archaeological sites have been found that can confidently be dated to the earlier part of the Weichselian in Britain, and Wymer (1999) suggests that, overall, the population was very sparse throughout this period (the Windermere interstadial).

Although interspersed with relatively short warmer phases, the general trend in temperature, climatic conditions and sea level was downwards. The Netherlands remained free from ice throughout, but was likely to have alternated between subarctic open landscape and pine and birch forest in MIS 5, with polar desert and tundra in MIS 4–2. Intermittent occupation is likely in the Netherlands from at least 50,000 BP (three bifacial leaf points of Mauern type and one unifacial Jerzmanovice point indicating either Neanderthals, anatomically modern humans or both (Rensink and Stapert, 2005). Although interspersed with relatively short warmer phases, the general trend in temperature, climatic conditions and sea level was downwards. Intermittent occupation is likely and it is probable that anatomically modern humans were active in southern Britain sporadically (two possible examples around 38,000 BC at Kent’s Cavern, Devon and around 35,000 BC at Beedings, West Sussex) before intense cold all across northern Europe forced human populations to retreat to a few refugia before the LGM (Housley *et al*., 1997).

Offshore, sediments from the early Weichselian (MIS 5d–a; 110 ka to 75 ka) are represented by the later sediments of the Brown Bank Formation, deposited during marine regression at the onset of the last glaciation. In the eastern area of the East Coast REC Study Area, the deposits were deposited in outer estuarine or lagoonal environments. To the west, the Brown Bank Formation comprises more fluviatile current-bedded silt and finely laminated clays filling late Eemian/Early Weichselian channels, up to 20 m deep (Cameron *et al*., 1992). Onshore, the Brown Bank Formation may be equivalent, at least in part, to the sands and gravels of the Yare Valley Formation (Arthurton *et al.,* 1994).

It is possible that Lower Palaeolithic artefacts may have been protected by the deposition of Brown Bank Formation, or that Middle Palaeolithic finds may be associated with the margins of channels infilled with these sediments. Within the East Coast REC Study Area, there are four distinct, large-scale, channel features associated with the Brown Bank Formation, and these flow into an outer estuarine/lagoonal environment (Figure 5.12). The palaeo-geographic assessment identified 107 features (**7006–7103** and **7106–7114**) of potential archaeological interest associated with these deposits (Figure 5.12 and Table 5.4). These include cut and fill features associated with channels or the margins of large-scale channels infilled with Brown Bank Formation. Features of interest within the Brown Bank Formation, such as infilled depressions and fine-grained units, and features situated outside the known limits of the formation, but which are interpreted as small remnant features probably associated with these Brown Bank deposits of this age. Although there is a general paucity of finds in Britain for this period, it is possible that the infilling of any channel cut during this period continued to flow and fill long into the late Weichselian. As such, there may be potential for Middle Palaeolithic finds associated with these features.

Feature	Total
Complex cut and fill	22
Simple cut and fill	54
Bank	11
Depression	8
Gas blanking	1
Erosion surface	5
Fine-grained unit	5
Strong reflector	1
Total	107

Table 5.4 Identified features of potential prehistoric archaeological interest associated with the Weichselian period (Brown Bank Formation).

Of the four channels in the area, the westernmost channel is of particular significance due to a recent find of archaeological material. Between December 2007 and February 2008 lithic artefacts, including hand axes, flakes, cores, and faunal remains, were discovered in stockpiles of gravel at the SBV Flushing Wharf, near Antwerp, Belgium. The artefacts were recovered from a discrete locale within Area 240, a marine aggregate licence area situated approximately 11 km off Great Yarmouth. Further evidence of flints and faunal remains were recovered from the same area (Wessex Archaeology, 2010a).

A flint artefact was recovered and identified during onboard processing of a clamshell sample at station CG6 (Figure 5.7) as part of the East Coast REC Study Area ground-truthing survey. The sediment sample from which the flint was recovered was described as clean gravelly sand with occasional flint and quartz cobbles. This flint was recovered from within the area from which the flint artefacts and faunal remains were dredged.

The artefact is a broken secondary flake (Figure 5.15). The surviving dimensions of the piece are approximately 60 × 43 × 9 mm, although a transverse break means that the piece was originally considerably longer. Although formal retouch is absent, both lateral margins have been used. The right margin has light edge damage towards the distal end; the proximal two thirds, however, show evidence of more robust use. The left margin is almost entirely cortical, but one short section comes to a cortex-free point, which appears to have been used as a piercing tool. The butt is facetted, and the platform edge has been prepared.

Flake debitage is difficult to date, but these traits are suggestive of a potentially Late Glacial date. However, such a flake could also result from hand-axe preparation, and thus may be older. One facet on the dorsal surface has a light patina; otherwise the piece is unpatinated and in very good condition, showing no signs of rolling, staining or damage congruent with its having been redeposited or having undergone any disturbance subsequent to its original loss/discard.

The artefacts and faunal remains were all recovered from an area associated with the infilling of a shallow channel feature and its associated floodplain deposits. The channel associated with this discovery has been previously identified (Wessex Archaeology, 2008a, 2009b) and is also observed within the latest geophysics data (**7006**–**7023**). The northern edge of the channel is observed as gently shoaling, rather than being a steep cut as observed to the south and west of the feature. The sediment infilling this buried channel varies in composition and is indicative of a changing flow regime with periods of both high-energy and low-energy sediment deposition (Figure 5.16). The channel infill sediments comprise outer estuarine/shallow marine sands and gravels overlain by glaciofluvial gravel, which is in turn overlain by estuarine alluvium of clayey sand deposits (Wessex Archaeology, 2010b). There is also some evidence of oxidation, which may be a result of weathering and exposure to oxygen and the formation of a gley-type soil (Wessex Archaeology, 2009b), and evidence of the presence of organic matter. The floodplain of this channel is extensive and comprises sands and gravels, probably deposited in an outer estuarine environment (Wessex Archaeology, 2010b).

The age of the deposits and associated fill are difficult to date. It is thought that the channel was cut post-Elsterian, and the infill and floodplain deposits could be MIS 6/7 date, as suggested by VC29_2. Equally, the fill could potentially be younger and associated with the Brown Bank Formation documented in this area. At this stage, the age of the artefacts is unknown. Given the number of artefacts and faunal remains associated with the floodplains of this channel and that the channel sediments may be associated with the Brown Bank Formation, it is considered possible that artefacts may be associated with further deposits of the Brown Bank Formation within the East Coast REC Study Area. In particular, artefacts may be associated with the margins and channels infilled with these sediments. Irrespective of whether or not the hand axes are associated with the Brown Bank Formation in this area, there is still potential for Palaeolithic material to be associated with these channels.

Features associated with the northernmost of the Brown Bank Formation channels (**7024**–**7030**) indicate a series of complex cut and fills, with the upper sediments comprising sandy clays deposited in a shallow marine restricted environment. Sediments deposited on the eastern limit of the channel comprise shallow marine deposits indicating deposition during changes in sea level, during periods of regression or transgression. Further features within the proximity to

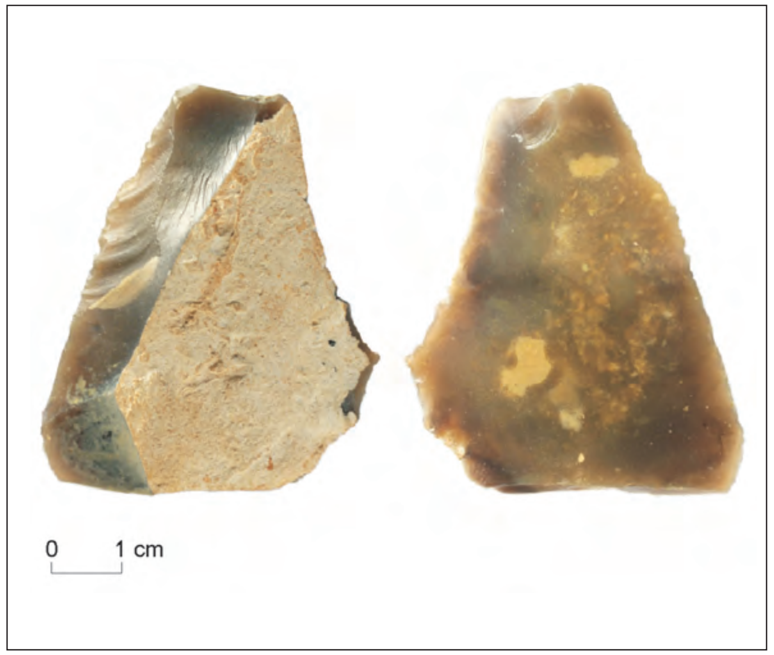
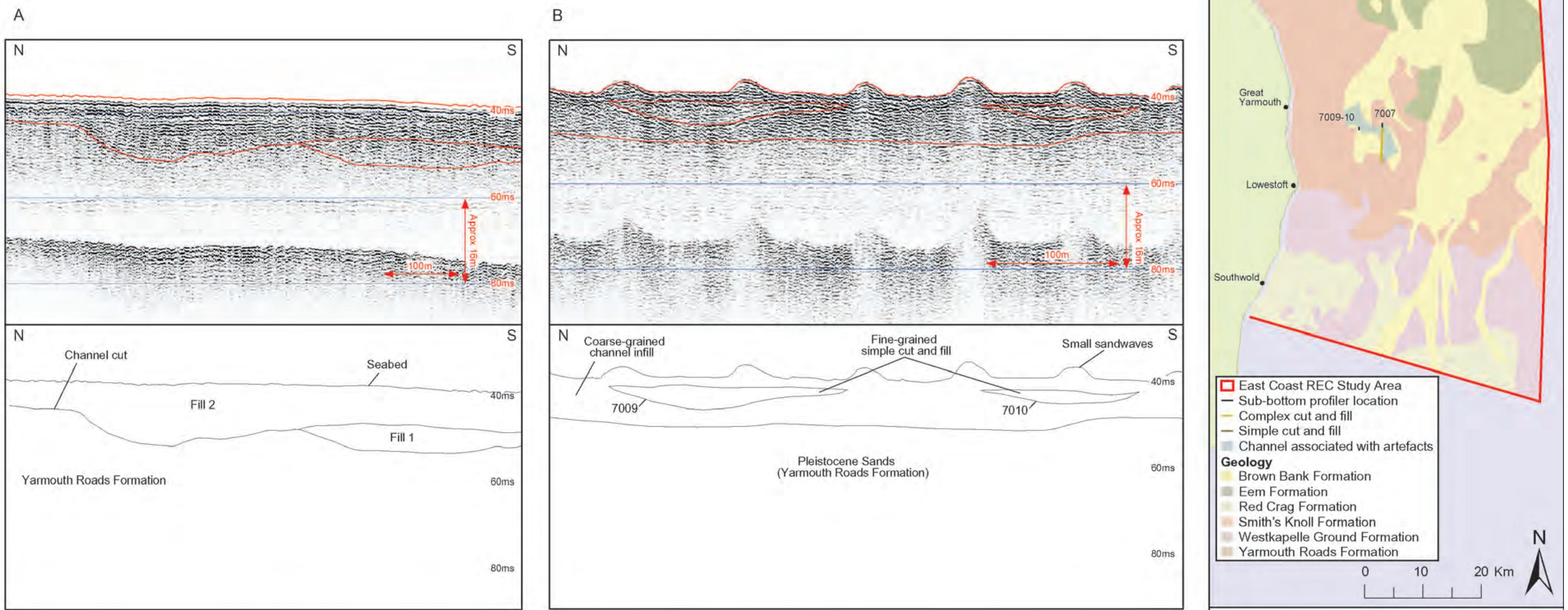


Figure 5.15 Worked flint recovered from Clamshell grab (CG6) in the East Coast REC Study Area. © Wessex Archaeology.

this channel include a small simple cut and fill feature (**7031**) within the channel deposits (a fine-grained unit cutting into Brown Bank Formation), and two remnants of fine-grained units (**7032** and **7033**), probably associated with the channel feature.

The southernmost channel comprises a main channel with tributaries (Figure 5.12). Features (**7034–7054**) associated with this channel include complex cut and fill features, simple cut and fill features and bank features. The complex cut and fill features exhibit undulating basal reflectors cutting into the underlying sands of the Westkapelle Ground Formation with numerous phases of infilling. The infill sediments vary between coarse-grained sediments, indicating higher energy deposition, and finer grained infill sediments, possibly indicating lower energy deposition. The simple cut and fill features exhibit similar characteristics, but with only one phase of fill observed. Evidence of shallow gas blanking is also observed within the infill features, indicating high organic-matter content. Bank features, also interpreted as Brown Bank Formation, are observed associated with this channel. These are probably composed of gravel and form the

Sub-bottom profiler features associated with the Post-Elsterian / Pre-Holocene period: Cut and fill



7007 - Complex cut and fill - Undulating shallow cut. Basal marker is occasionally strong but can be indistinct in places observed to a maximum depth of 10.8 m sub-seabed. Several phases of fill are observed throughout indicating both coarse-grained fills and fine-grained fills. Generally, Fill 1 comprises strong chaotic reflections up to 5 m thick. Fill 2 comprises a more transparent unit indicating fine-grained sediment up to 5.5 m thick.

7009 - Simple cut and fill - Small cut and fill feature within a unit of strong reflectors (coarse-grained channel infill). Fill up to 4.8 m thick probably infilled with a finer-grained infill overlain by sandwaves up to 4 m high.

7010 - Simple cut and fill - Small cut and fill feature within a unit of strong reflectors (coarse-grained channel infill). Fill up to 2.3 m thick probably infilled with a finer grained infill overlain by sandwaves up to 3.8 m high.

Cut and fill features consist of a cut into the underlying geology that has later been infilled by sediments. These features may contain one phase of fill (simple cut and fill feature) or several phases of cuts and fills (complex cut and fill) providing evidence of multiple phases of erosion and deposition.

Figure 5.16 **Sub-bottom profiler features associated with the post-Elsterian/pre-Holocene period: cut and fill.**

upper sediments of infilled cut features. The banks are interpreted as relict features that may have been modified by present-day sea currents, rather than a recent feature deposited under present-day hydrological conditions. Depending on the age of the banks and its depositional nature, there may be some archaeological potential. There may also be archaeological potential associated with the edges of any underlying cut features. Both the upper fill of the cut and fill features and the bank features generally comprise recent sediments, overlying sandy silt and sandy clay deposited in a restricted shallow marine or lagoonal environment. It is possible that the deeper fills may have been deposited in a more estuarine or fluvial environment.

Features associated with the easternmost channel (**7056**–**7059**) are all interpreted as cut and fill features with an infill of Brown Bank Formation. VC27 is situated on the southern edge of one of these features (Figure 5.17) and indicates shallow marine restricted deposition, similar to the upper fill of the other features associated with these Brown Bank Formation channels.

The sedimentary sequence recovered within vibrocore VC27 comprised a basal sand (60.23 mbOD to 60.78 mbOD), overlain by a 5.23 m-thick laminar horizontally bedded greyish-brown silty clay between 55.10 and 60.23 mbOD. This basal sand contained marine and predominantly estuarine molluscs (*Scrobicularia*/*Tellina* type) and a small assemblage of shallow marine/outer estuarine foraminifera, including *Ammonia batavus.* The sample at 60.50 to 60.59 mbOD contained a sedge seed (*Carex* sp.), partially fossilised wood and charcoal. These elements are likely reworked into the sediments from nearby/upstream terrestrial environments, with the charcoal as noted above being a possible indication of human habitation of the area. A nearby environment of grass sedge fen was also noted from the pollen recovered from the sediments in this layer (at 60.40 mbOD). A pine (*Pinus*)-dominated pollen spectrum recorded is an indication of cold glacial conditions.

Overlying this unit, the laminar silty clays between 55.10 to 60.23 mbOD contained a similar pine (*Pinus*)-dominated pollen assemblage. The abundance of pollen within the sediments was generally sparse, although reasonable quantities were recorded from 58.10 and 59.10 mbOD. Of interest are the occurrences of fir (*Abies*) and spruce (*Picea*), which are indicative of interstadial conditions. As with the occurrences of oak (*Quercus*), elm (*Ulmus*) and hazel (*Corylus*), it is likely that these pollen grains are reworked from older interglacial sediments. This pollen assemblage was apparent throughout the sampled sediments, although pollen was notably sparse in the upper sediments.

The samples at the top of the sequence were generally devoid of environmental remains although some outer estuarine and shallow marine (*Scrobicularia/Tellina*) type molluscs were recorded in the uppermost sample (55.01 to 55.09 mbOD). The OSL dating of sediment at 55.10 mbOD returned a date of 30,400 ± 6,900 BP. This date is equivalent to the Weichselian period, MIS 3, and the Upper Palaeolithic archaeological period and is younger than the Brown Bank Formation documented in the area, possibly indicative of a longer period or later period of infilling of the channels.

Siddal *et al.* (2003) suggest that global sea level was approximately 80 mbOD at approximately 30,000 BP. However, the shallow marine environmental remains recovered from the sediments in VC27 suggest that the sea level was, relatively, at least 50 mbOD or less when these sediments were deposited. The possibility that the area was cut off as a saline lagoon, during a relative fall in sea level, is noted. The laminar nature of the sediments is possibly due to seasonal control of sedimentation – that is, varves within a shallow saline, lagoonal and ice marginal environment. A strong terrigeneous organic input, noted in some varved sediments, was not seen within these samples. It is possible that the laminae in this case reflect differing seasonal variations in runoff and types and amounts of sediment settling from the water column.

Features (**7069**–**7094**) are associated with the outer estuarine/ lagoonal deposits of the Brown Bank Formation. These features include depressions infilled with fine-grained sediments and fine-grained units which are interpreted as fills of Brown Bank Formation, or a finer grained fill within the Brown Bank Formation. There are three complex cut and fill features, the largest of which comprises a distinct cut with four phases of fill (Figure 5.18).

The remaining features are simple cut and fill features that mark the edges of the Brown Bank Formation cutting into underlying sediments or mark isolated channels at the base of the Brown Bank Formation.

Erosion features are observed (**7082**–**7087**). The nature of these erosion surfaces is unknown, and, as such, the archaeological potential of these features is unknown. However, in aggregate extraction Area 401/402, to the west of these features, a series of N–S-orientated features were identified and interpreted as deposits possibly representing beach bar progression (Wessex Archaeology, 2008e). It is possible that the erosion features are associated with beach progression that has subsequently been eroded, leaving a series of erosion surfaces. If these features are associated with beach progression deposits, then there is limited potential for archaeological material.

VC26 is situated in the north-east of the East Coast REC Study Area (Figure 5.19) and targets a series of outer estuarine/lagoonal sediments to establish the similarities between these sediments and those identified infilling the channels (VC27).

The sedimentary sequence recovered within vibrocore VC26 comprised a dark-grey organic silty clay (48.52 to 49.59 mbOD) coarsening upwards into fine sandy clay (46.19 to 48.52 mbOD).

OSL dating of this vibrocore produced markedly similar dates; 53.4 ± 5.4 ka at 49.00 mbOD; 51.6 ± 5.8 ka at 48.40 mbOD; 49.9 ± 4.5 ka at 47.40 mbOD and 51.3 ± 4.8 ka at 46.40 mbOD. There is a notable reversal in the upper two dates, although the error margins suggest that all of these dates are broadly contemporaneous. The period encompassed by these dates is the Weichselian period, MIS 3, Upper Palaeolithic archaeological period.

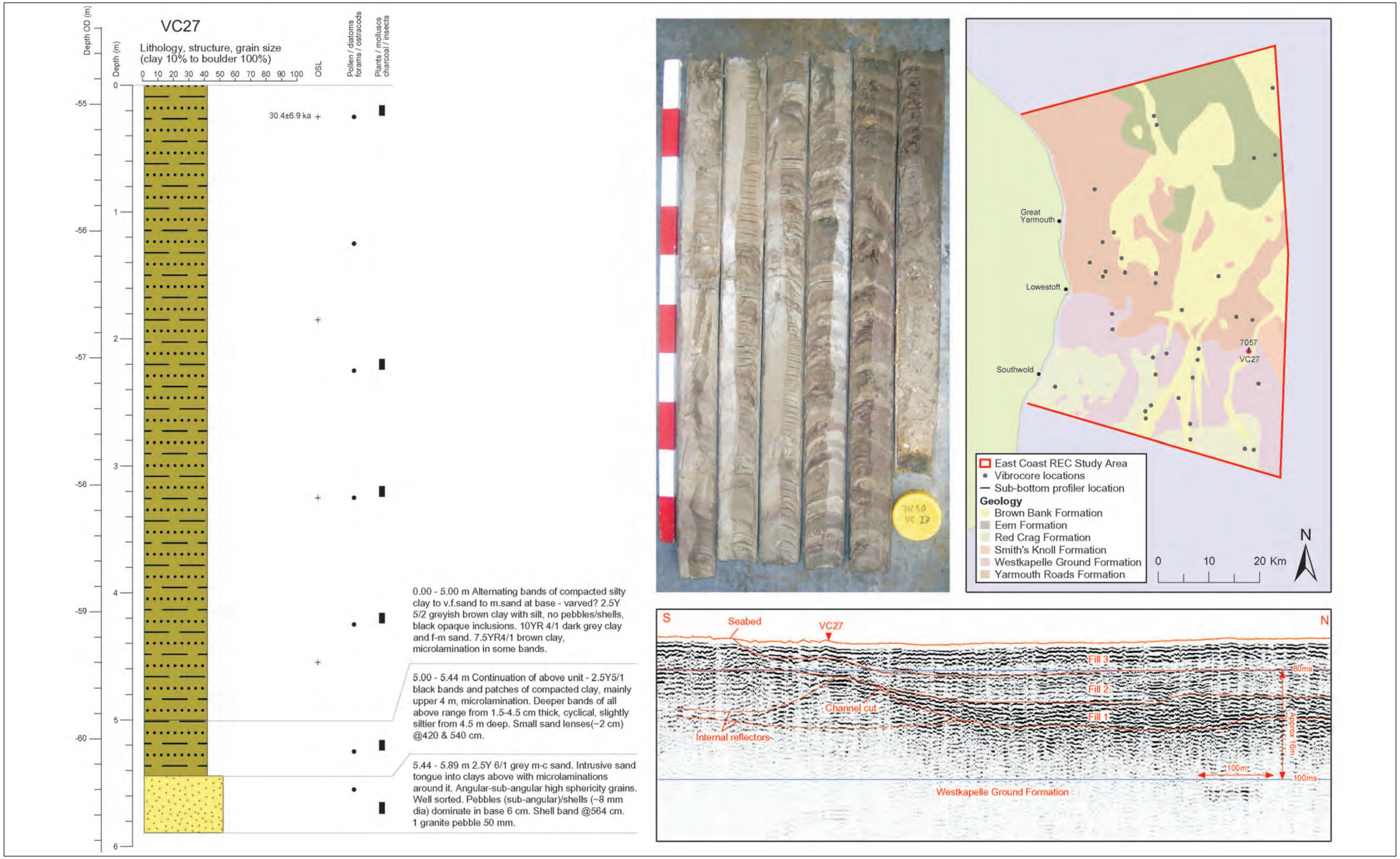
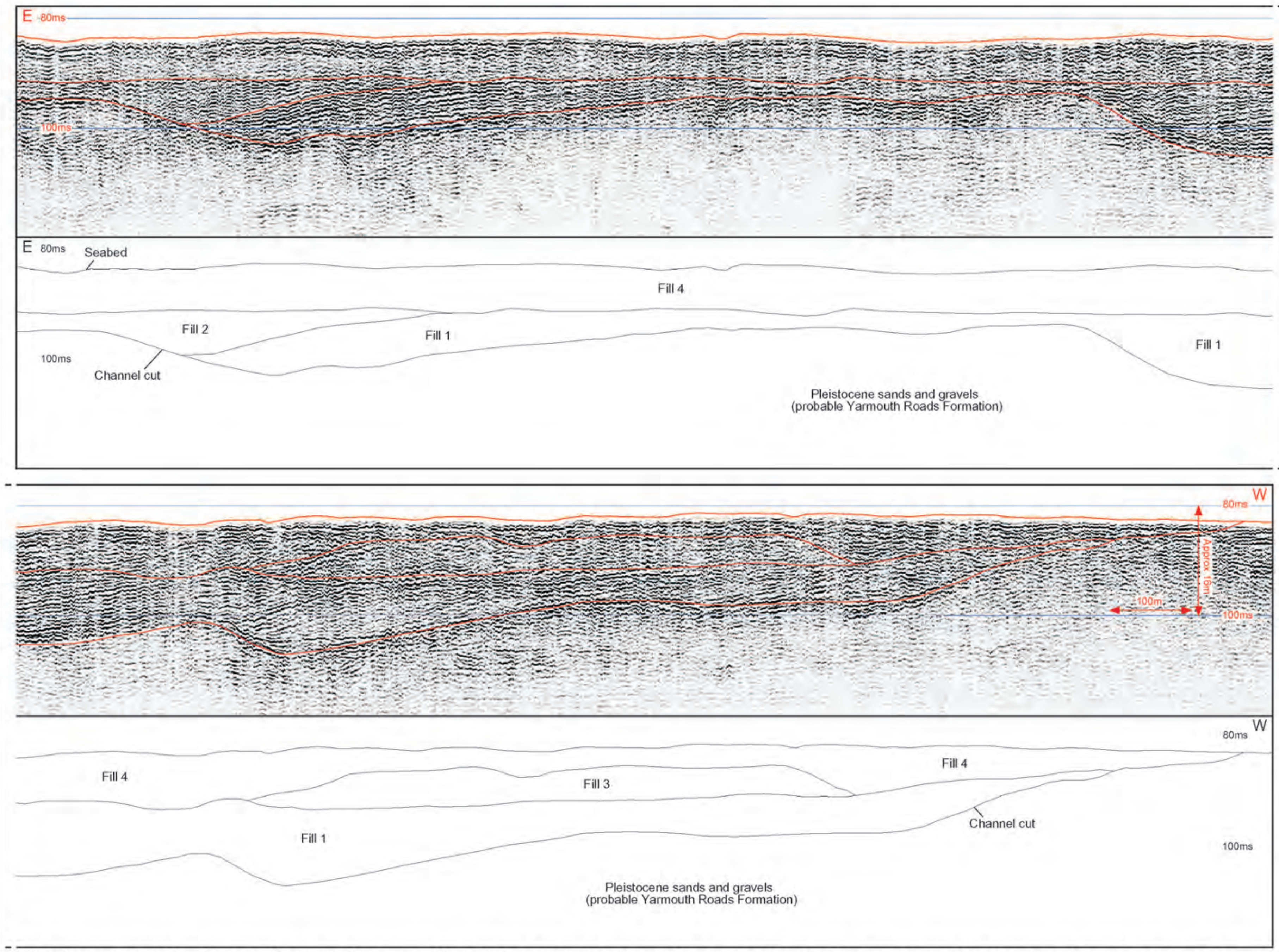
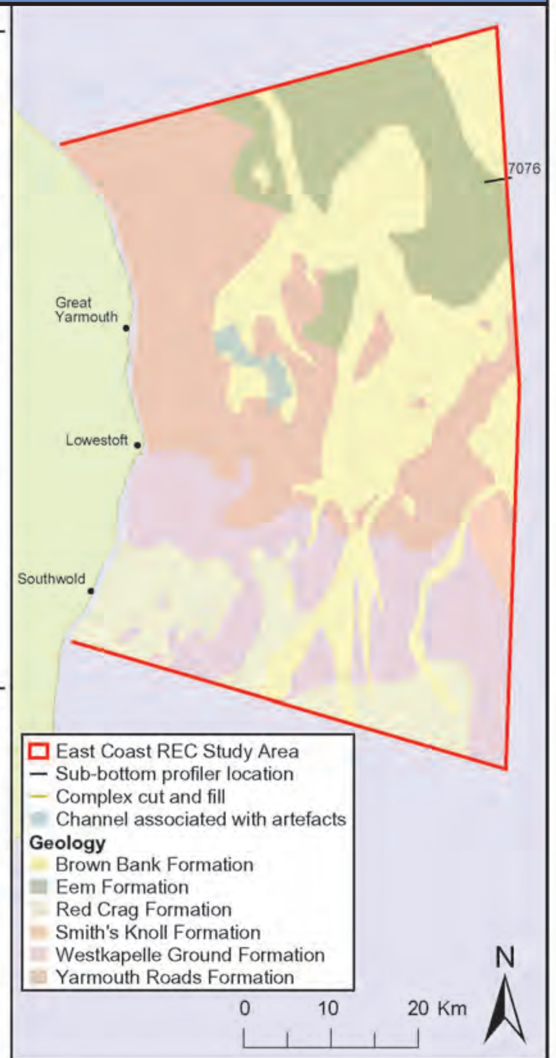


Figure 5.17 VC27. © Wessex Archaeology.

Sub-bottom profiler feature associated with the Post-Elsterian / Pre-Holocene period: Complex cut and fill





Cut and fill features consist of a cut into the underlying geology that has later been infilled by sediments. These features may contain one phase of fill (simple cut and fill feature) or several phases of cuts and fills (complex cut and fill) providing evidence of multiple phases of erosion and deposition.

7076 - Complex cut and fill - Complex cut feature with four phases of fill (Fill 1 - Fill 4). Base of cut is marked by a strong reflector. The base undulates with two deeper cuts observed at the eastern and western end of the feature. The base of the cut has a maximum depth of 18.9m sub-seabed. Fill 1 comprises very strong parallel easterly dipping reflectors. At the eastern end of the feature Fill 1 is onlapped by Fill 2 comprising 6.7 m faint sub-parallel reflectors. Fill 3 forms a bank like structure (subsequently eroded and infilled with Fill 4) towards to western end of the feature. Fill 3 comprises up to 5.2 m transparent reflectors. Fill 4 comprises strong chaotic reflectors throughout the length of the feature.

Figure 5.18 Sub-bottom profiler features associated with the post-Elsterian/pre-Holocene period: complex cut and fill.

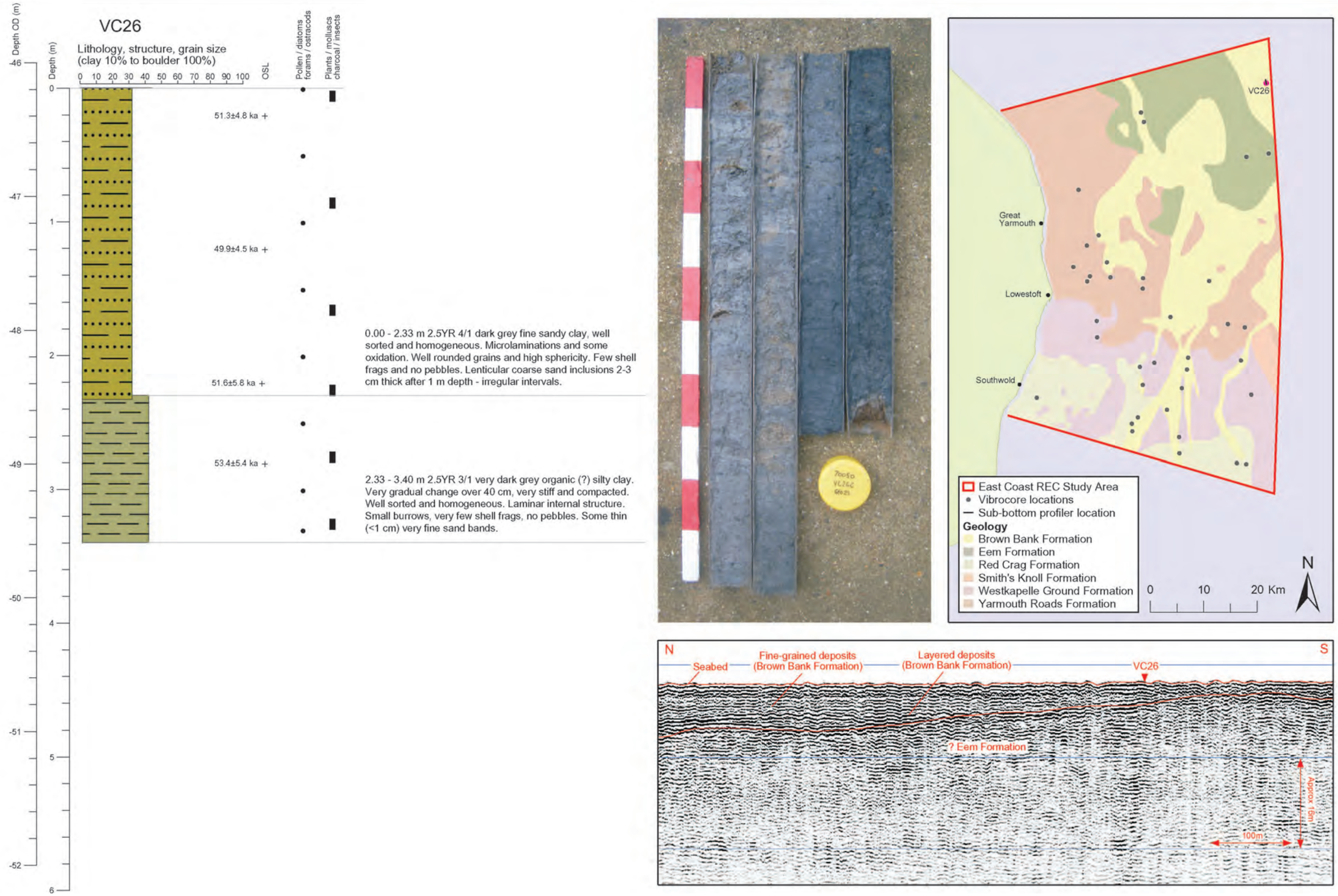


Figure 5.19 VC26. © Wessex Archaeology.

Siddal *et al.* (2003) have suggested, using data from the Red Sea, that global sea level was around 64 mbOD at approximately 50 ka. For the same period, Harmon *et al.* (1983), based on data from Bermuda, suggest relative sea levels to be around 15 mbOD. The faunal remains within this core suggest a shallow marine/outer estuarine depositional environment for these sediments (elevated between 46.19 and 49.59 mbOD) which indicates that the sea level was either at, or less than, 40 to 45 mbOD in this area at this period.

The arboreal pollen recovered from the sediments is typical of a Weichselian interstadial period comprising pine (*Pinus*) and birch (*Betula*), with pine (*Pinus*) increasing in abundance up the profile. The pine pollen may be dominant within these marine sediments due to its ability to travel long distances. Some thermophilic arboreal pollen including oak (*Quercus*), elm (*Ulmus*), hazel (*Corylus*), fir (*Abies*) and spruce (*Picea*) are considered to have probably been reworked within these sediments. Given the possibility of over-representation of arboreal pollen, it is possible that the plant communities were in fact dominated by herbs commensurate with a Weichselian interstadial flora dominated by grasses and sedges. Other environments were represented by plant species including dwarf shrub/ericaceous (*Erica*, *Calluna*, *Empetrum*, *Betula* cf. *nana*, *Salix* spp.), disturbed ground (*Artemisia*, *Plantago major* type, *Spergula*, Chenopodiaceae), halophytic (*Armeria* type, Chenopodiaceae) and marsh (Cyperaceae, *T. angustifolia* type, *Sphagnum*, *Pediastrum*).

The samples contained few plant macrofossils; however, a sedge seed (*Carex* sp.) and a few fungal sclerotia recovered in the sample at 48.91 to 48.99 mbOD is an indication of proximal coastal and terrestrial environments. Charcoal (recovered at 48.91 to 48.99 mbOD and 47.01 to 47.09 mbOD) is an indication of possible hominin activity in the area. A *Charophyte oogonium* and a megaspore (*Lycopodiophyta* – a group including mosses and liverworts) were also recovered from the sample at 47.01 to 47.09 mbOD, and although both were probably reworked into these shallow marine sediments, they are indications of alluvial and terrestrial environments, respectively.

The ostracod faunas recovered from the sediments, although generally small, included some estuarine and brackish forms (*Cyprideis torosa*, *Elofsonia baltica* and *Leptocythere lacertosa*) and numerically predominant shallow marine forms (*Semicytherura sella*, *Leptocythere pellucida* and *Leptocythere castanea*). The species were represented usually by one or two adult carapaces. Foraminifera within the sediments were generally indicative of shallow marine, inner shelf environments (Miliolids, *A. batavus*) with some more nearshore elements probably having been washed in, including the saltmarsh taxa *Jadammina macrescens*. Low abundances of relatively small foraminifera were recovered, which raises the possibility that many of the specimens are reworked. At 47.7 mbOD a good assemblage dominated by *A. batavus,* known to colonise estuary mouths and shallow marine, inner shelf environments, was recovered.

The molluscan fauna from this core was dominated by *Scrobicularia*/ *Tellina* type and the mussel (*Mytilus edulis*). There were also a number of shells of limpets (*Patella*/ *Diodora* spp), flat periwinkles (*Littorina littoralis*), periwinkle (*Littorina* spp.), whelk (*Buccinum* spp.) and *Hydrobia* cf. *ulvae*. The faunal remains within the samples are typical of shallow marine and outer estuarine environments.

VC26 is the most northeasterly vibrocore, and the sedimentary, environmental and dating evidence is interpreted as indicative of a shallow marine and outer estuarine environment in the area during MIS 3, approximately 50 ka. The southern part of the Brown Bank Formation, marked by S–N-delineated channel features, of which VC27 is in the easternmost (Figure 5.12), contained predominantly finer grained and laminated sediments, which may have formed part of a restricted lagoonal environment. The upper part of this sedimentary sequence has also returned a singular date equivalent to MIS 3 (approximately 30 ka). It is possible that this environment was quite widespread, as vibrocores (notably VC3, VC4 and VC23) within the channel feature to the south-west of VC27 (Figure 5.12) also contained fine-grained and laminar sediments, similar to those recorded within VC27.

There are a number of features (**7095–7100** and **7106–7114**) that are situated outside the areas defined as Brown Bank Formation. These features comprise simple cut and fill features, fine-grained units, depressions and gas blanking, indicating the presence of high organic content. It is possible that these features represent isolated remnants of the Brown Bank Formation or similar Pleistocene sediments cutting into pre-Pleistocene sediments. Depending on the timing of the cut and fill of these features, there may be the possibility for the presence of archaeological material.

The Brown Bank Formation is extensive throughout the East Coast REC Study Area. However, the identification of specific features associated with this formation, namely evidence of channel features and other remnant land surfaces, highlights areas where there is a greater potential for the occurrence and preservation of archaeological material.

There are no documented sediments present off the East Anglian coast attributed to the periglacial landscape present at, and after, the height of the Weichselian glaciation. The late Pleistocene courses of the major rivers draining eastern England and the north-western margins of mainland Europe are far from certain, but it seems likely that the Thames/Rhine system flowed south-westwards into the Channel River, rather than northwards into the North Sea basin, from the glacial maximum onwards (Coles, 1998).

Following the glacial maximum, the East Coast REC Study Area will have been terrestrial and will have experienced ameliorating conditions. Nevertheless, there is no evidence of any human or animal population. Surrounding areas experienced polar-like conditions and faunas.

Late Weichselian/Weichselian to Early Holocene: approximately 13,000 BP to 10,000 BP (MIS 2–1/sea level as low as 50 mbOD)

Britain had been recolonised by 13,000 BP**,** by which time cave and rock shelter sites such as Gough's Cave, Badger's Hole and Sun Hole on Mendip, Kent's Cavern, Devon and Robin Hood's cave, Derbyshire, were being occupied on at least a seasonal basis. It appears, therefore, that some human groups were arriving even before the onset of interstadial warming. This is reflected in the animal bone assemblages from these sites, which indicate the hunting of predominantly reindeer along with elk, Saiga antelope and giant deer. As the climate warmed, the specifically cold-climate mammals retreated north, along with the open steppe vegetation that they habitually grazed, with horse, aurochs, red deer and possibly roe deer becoming more common. Low scrub of juniper and willow, followed by pine and birch forest, began to develop. In the Netherlands, a very few Magdalenian sites are known from the south of the country, with much more prolific (and a little later) evidence of human occupation during the Hamburgian in the north. This latter tradition is currently best dated to around 11,500 cal. BC (Rensink and Stapert, 2005).

According to existing models of sea-level change, the East Coast REC Study Area would have remained as dry land following the retreat of the Weichselian ice (there is evidence of a standstill in sea level in the period 12,000–9000 BP (12,000–8250 BC) at approximately 45 mbOD; Figure 5.20). The Late Glacial antler point trawled from Leman and Ower Banks has been dated to 11,740 ± 150 BP (11,346–11,941 cal. BC) (Housley, 1991), broadly contemporary with the dated Hamburgian occupation of the Netherlands.

The bathymetry indicates that at 45 mbOD, the coastline would have been approximately 40 km to the east of the present-day coastline, with a channel observed directly off the coast. Although this image is based on present-day bathymetry, and as such includes more recent erosion and depositional sediments, it highlights the extensive lowland plain that would have been present around 12,000–9000 BP. At the beginning of the period, vegetation will have been sparse, but, as temperatures rose, both flora and fauna will have become more diverse. Eventually, the area of the East Coast REC Study Area is likely to have presented a generally very favourable habitat – albeit still, at first, a cold one, prone to dust and sand blows – for Upper Palaeolithic herd animals and humans alike: a combination of light woodland, open grassland, fresh water and vantage points for hunting. As the climate warmed, so vegetation would have changed, producing a mosaic of habitat zones with increasing maritime influence. Almost anywhere within the marine zone where buried sediments survive has the potential to produce Upper Palaeolithic material. In particular, land forms indicative of bluff positions overlooking former river channels, and palaeochannels containing peat deposits indicative of stabilisation horizons or lag deposits of large clast-size gravels, have high potential for the preservation of such material.

Holocene: approximately 10,000 BP onwards (sea level at approximately 30 mbOD and rising)

Around 11,000 BP there was a rapid return to subarctic conditions: parts of north-west Europe were once again deserted by humans, and much of southern England was a dry, cold desert. Within a thousand years, however, sharp rises in temperature were accompanied by equally rapid rise in sea level until, sometime during the eighth millennium BC, Britain became an island.

Broadly speaking, the gradually shrinking lands around the East Coast REC Study Area will have been occupied by seasonally mobile human groups exploiting a diverse range of resources and leaving behind many thousands of assemblages of artefacts testifying to an organised and diverse lifestyle ranging all across the landscape. River valley sides and lakesides, bluff locations overlooking rivers with locally available flint sources, and locations close to springlines will have been particularly favoured. Mesolithic implements (predominantly bone and antler points, mostly from the Maasvlakte beach of Europoort) attest to the human occupation of the drowned Dutch coastal lands over some two millennia (Verhart, 2005).

The rising sea levels that separated Britain from the continental mainland resulted in the drowning of some valleys and gradual infill of others with fine sediment. This evidence indicates the clear potential for recovery of Mesolithic artefactual material and Holocene land surfaces in and around the rapidly infilled palaeovalleys of the shelf area and wherever land surfaces are preserved in the intertidal zone and immediately offshore.

Onshore, the confluence of the Rivers Bure and Yare at Great Yarmouth has resulted in a large complex of alluvium, peat and fen silts adjacent to the coast. Peat of freshwater and brackish origins is a major component in the valleys of the River Yare and overlies the older Yare Valley Formation gravels (Arthurton *et al.,* 1994). These post-glacial peats are identified as the Breydon Formation, a fill of the buried valley system underlying present-day marshland. The Breydon Formation is dominated by silt and clay, and associated with the formation are three peat layers: the basal, middle and upper peat. Of these peat layers, the basal peat is the layer of interest with regard to the offshore area, as the middle and upper peat were deposited onshore after the inundation of the East Coast REC Study Area (Boomer and Godwin, 1993; Arthurton *et al.,* 1994). The basal peat is recorded to have formed approximately 7580 ± 90 BP at a depth of around 19 mbOD and is up to 2 m thick (Arthurton *et al.,* 1994). Calibration of this date, using OxCal version 4.1.7 (Bronk Ramsey 2001, 2009, 2010) and the IntCal09 atmospheric calibration curve (Reimer *et al.,* 2009), indicates an age of 6600 to 6240 cal. BC (8550 to 8190 cal. BP). Remnants of the Breydon Formation are located in the outer reaches of the Palaeo-Yare and are interpreted in geophysics data (**7115**–**7128**, Figure 5.21).

Around 10 km to the east of the present-day coast, the regional bathymetry of the area indicates a broad, shallow meandering channel (Figures 5.21 and 5.22).

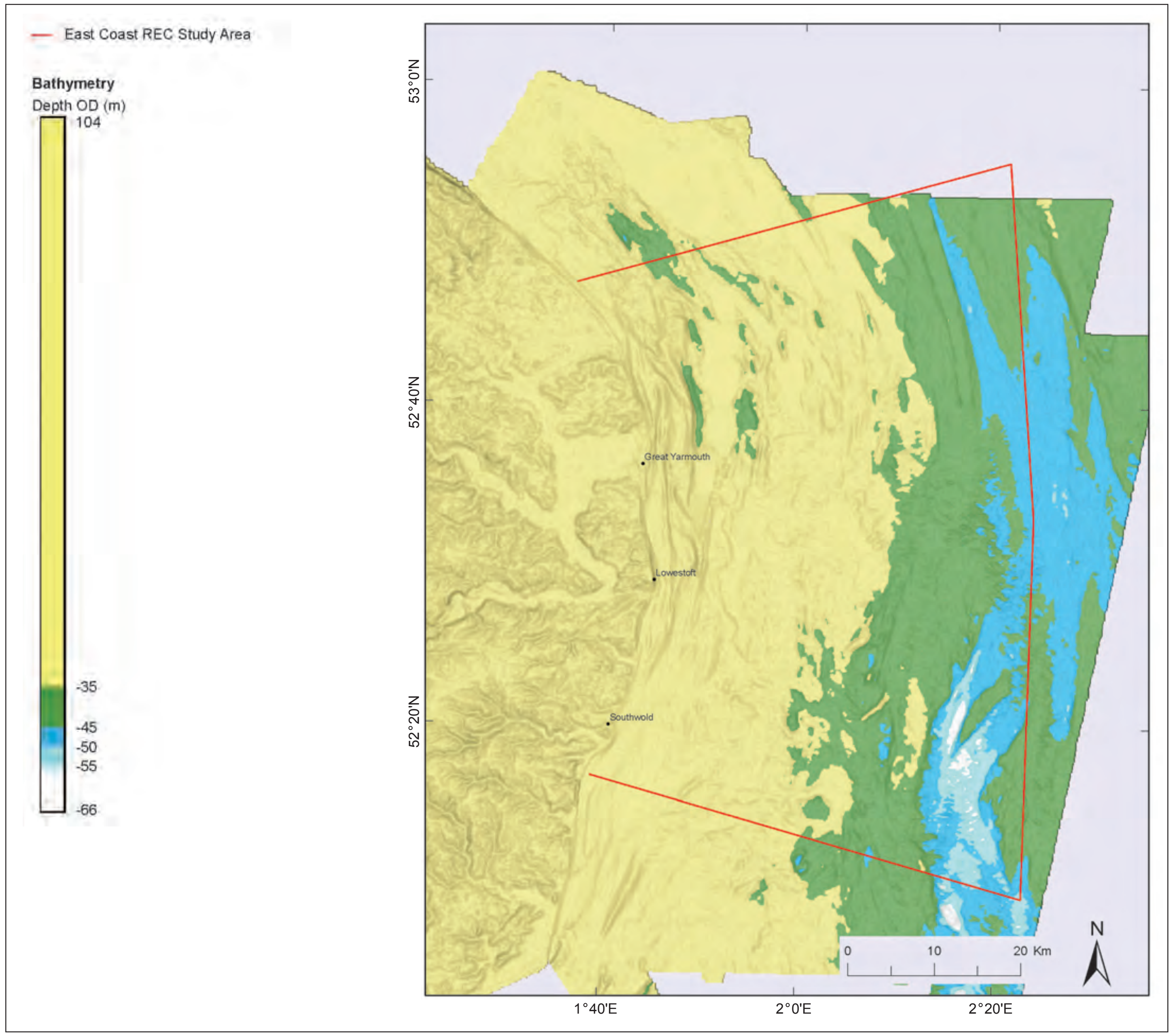


Figure 5.20 East Coast REC Study Area modelled with sea level at 45 mbOD, illustrating a stillstand in sea level between 12,000 and 9000 BP (Jarvis *et al.*, 2008). Digital bathymetry data © British Crown and SeaZone Solutions Ltd. All rights reserved. Data Licence 052008.012.

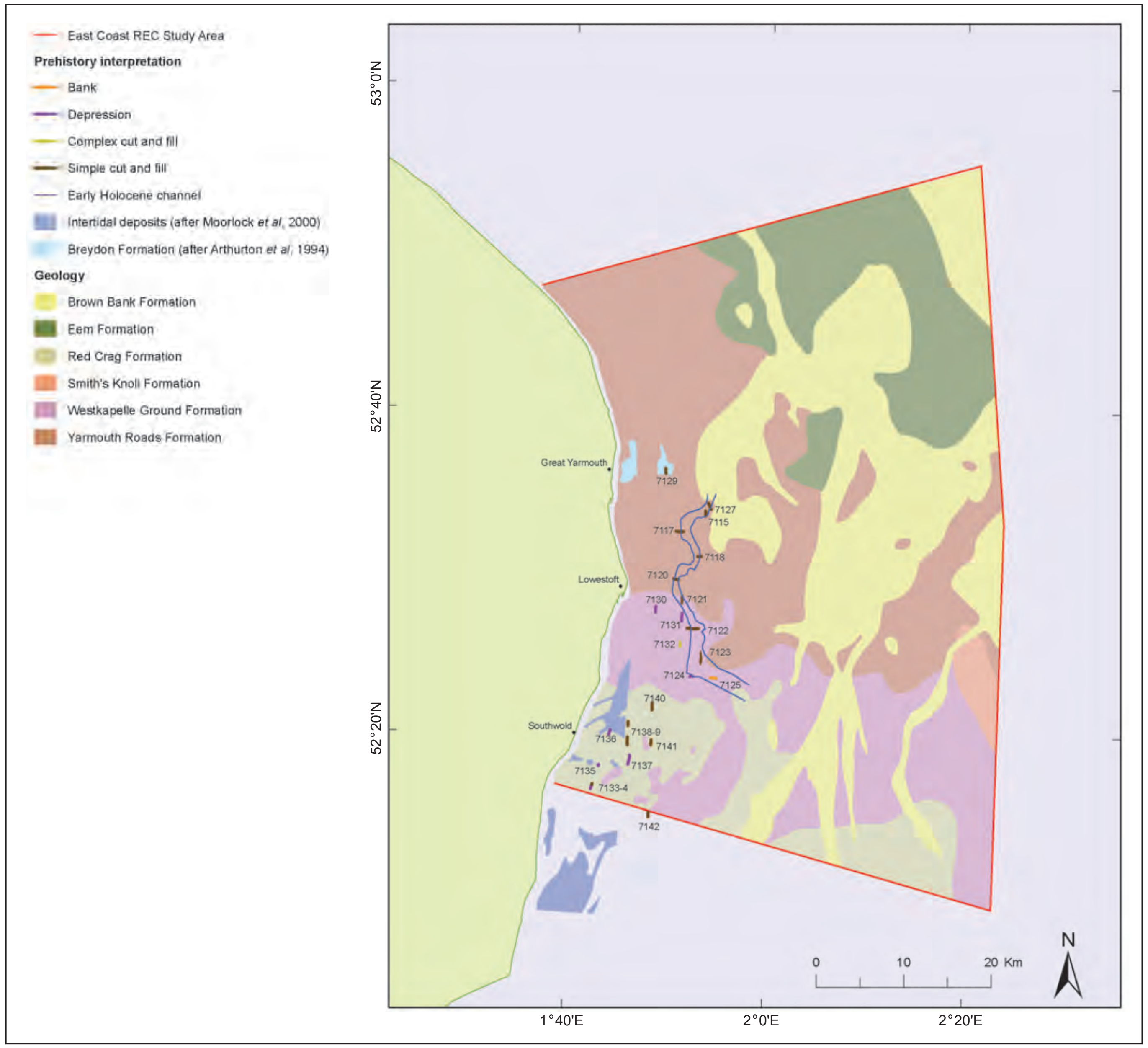


Figure 5.21 Location of geophysical features associated with the Holocene period.

Based on the modern-day bathymetry, the morphology of the shallow channel appears to widen to the south, indicating its likely flow direction, with the width of the channel varying from approximately 350 m in the north to in excess of 2.5 km to the south. Deposits associated with the infilling of this channel (**7115–7128**) are observed, with the base of this channel observed sub-seabed at a maximum of 6.8 m. Many of the features indicate an infill of fine-grained sediments with high peat or organic-matter content.

In the upper reaches of this channel, independent radiocarbon dating of the peat layer dates the peat between 10,710 and 10,280 cal. BC (10,470 ± 35 BC, SUERC-11978) and 7530 to 7350 cal. BC (8370 ± 25 BP, SUERC-11975) at depths of 30.80 mbOD and 30.05 mbOD, respectively (Hazell, in prep.).

A peat sample (Cemex_0296) from an area coinciding with the central portion of the channel (Figure 5.22) was reported through the BMAPA/EH Protocol (Wessex Archaeology, 2010c) from a 1.4 km track on the western limits of aggregate extraction Area 251.

The peat sample contained relatively high numbers of seeds, as well as substantial numbers of wood fragments. The assemblage indicates deposition in an ox-bow lake or similar cut-off chute. The presence of opercula of *Bithynia*, a species associated with flowing channels, suggests that some of the material may be derived from overbank flooding. The assemblage suggests the peat was formed on boggy ground, adjacent to a flowing river or stream, with only slight evidence for larger bodies of standing water. This evidence comes mainly in the form of seeds of white water-lily (*Nymphaea alba*) which is more common in pools, ponds and standing water in ox-bows, but can be found in the still water of slow-flowing rivers.

The high presence of wood fragments may have been derived from shrubs adjacent to the peat, although the presence of sedge (*Carex sp.*), bogbean (*Menyanthes trifoliata*), common reed (*Phragmites australis*) and greater spearwort (*Ranunculus lingua*) points to some marshland and possibly wet grassland elements.

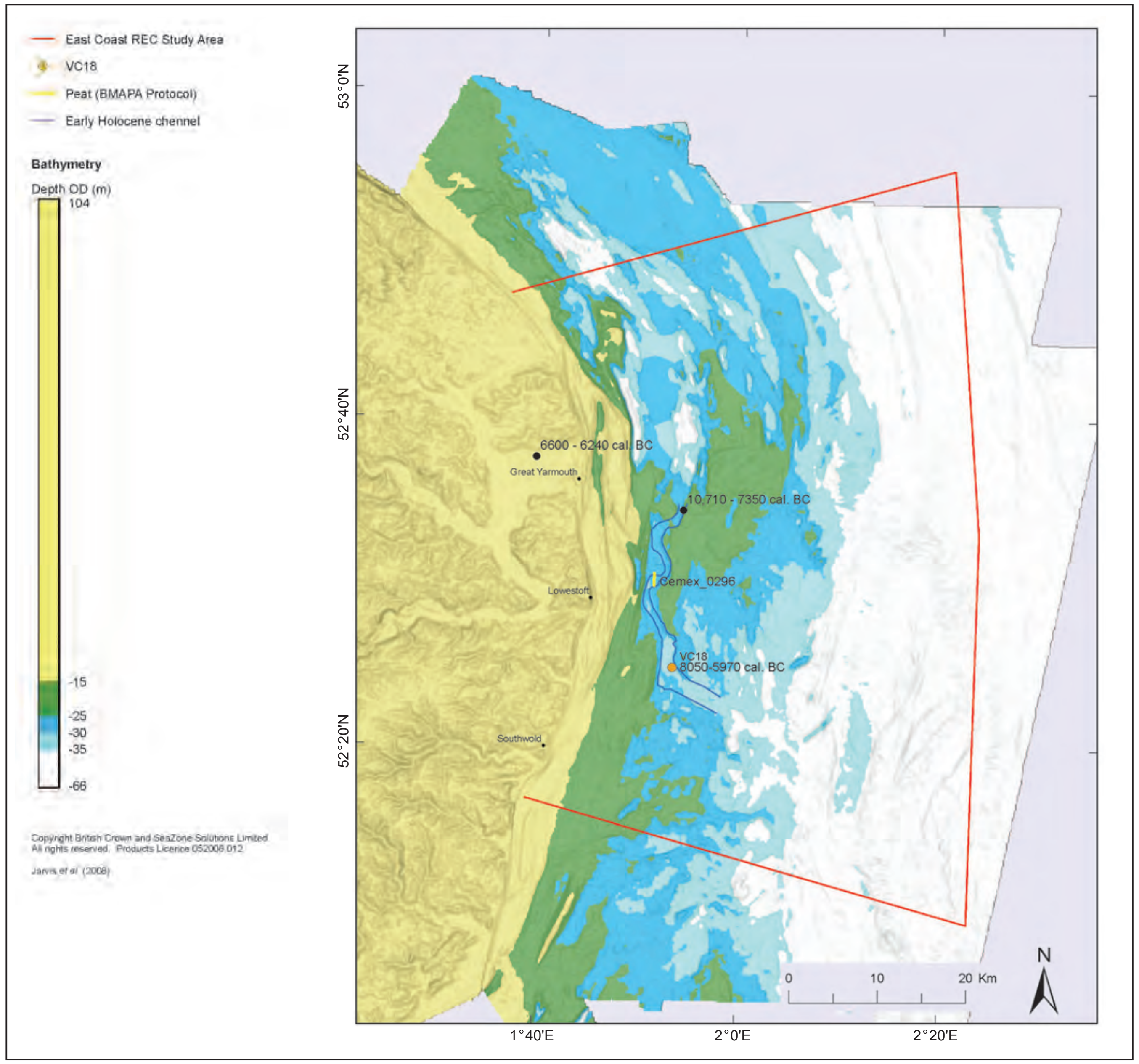


Figure 5.22 East Coast REC Study Area modelled with sea level at 25 mbOD, illustrating the extent of an Early Holocene channel feature. Digital bathymetry data © British Crown and SeaZone Solutions Ltd. All rights reserved. Data Licence 052008.012.

The presence of birch (*Betula pubescens*), aspen (*Populus tremula*), and possibly also willow (*Salix)* (only small tree/shrub species), indicates probable open shrub woodland within close proximity to where the peat formed. It might be noted that marsh fern is also recorded today in Britain in wet downy birch woodland (Rodwell, 1991; plant community W4).

Towards the southern limits of the channel, the sediments in VC18 (Figure 5.23) indicate gravelly sands (36.52 to 37.62 mbOD) overlain by sand (36.07 to 36.52 mbOD) and silty clays (35.39 to 36.07 mbOD).

At the base of the sequence a mollusc shell (*Scrobicularia*/*Tellina* type) at 37.55 mbOD was submitted for radiocarbon dating but

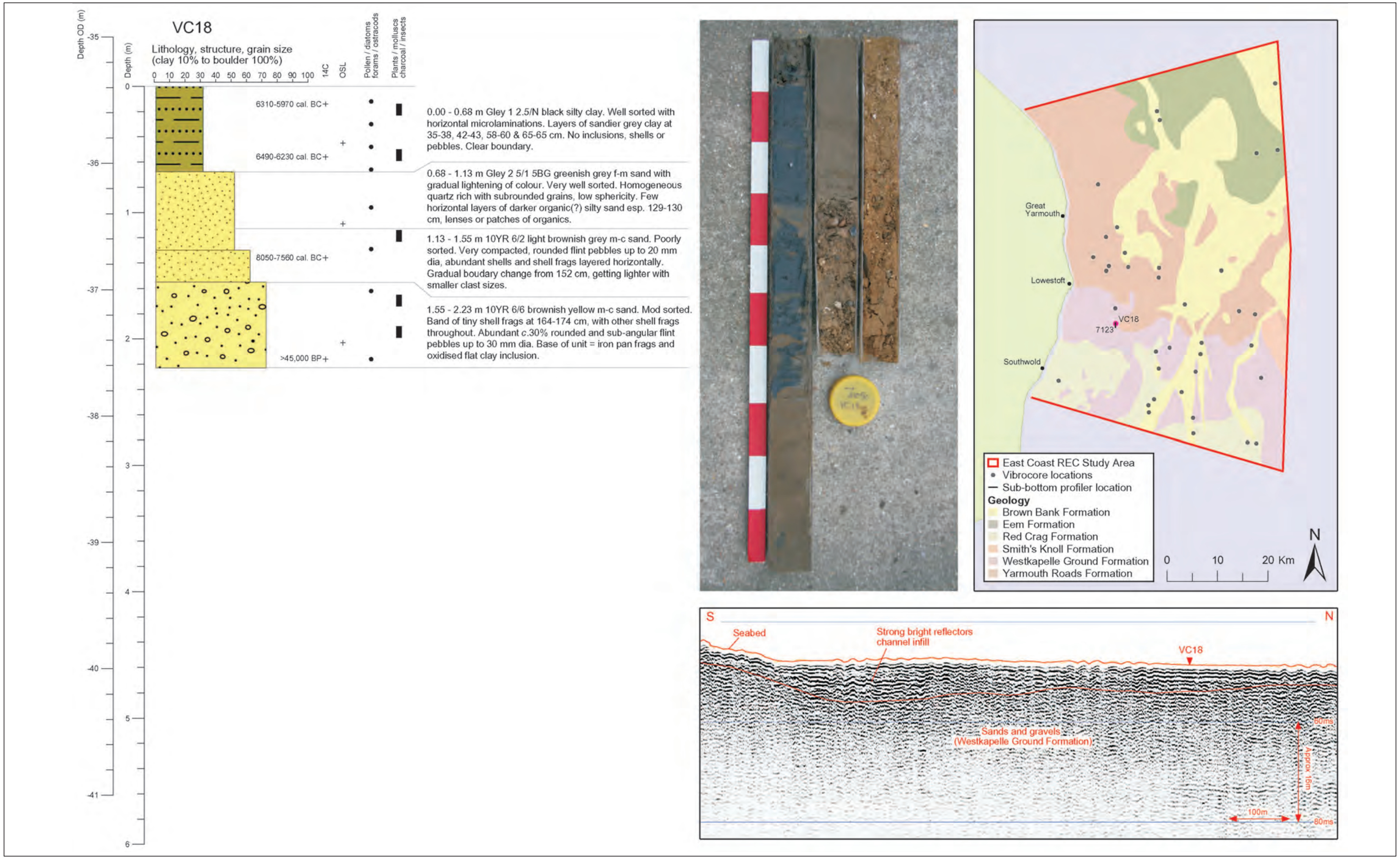


Figure 5.23 **VC18. © Wessex Archaeology.**

failed, returning a determination in excess of >45,000 BP (beyond the limits of radiocarbon dating). The samples taken at these lower levels contained few environmental remains. However, the sample at 37.55 mbOD contained a small assemblage of shallow marine/inner shelf type foraminifera (*A. batavus, E. hannai* and Miliolids). Occasional poorly preserved marine diatoms and marine molluscs retrieved from the sample at 37.29 to 37.38 mbOD (*C. edule*, *Patella/Diodora*, *Venerupidae*, and *M. edulis*), indicated a shallow marine environment with the possibility that the sediment was formed in a beach environment.

A mollusc (Veneridae) from the upper part of the sandy gravels at 36.75 mbOD returned a date of 8050–7560 cal. BC (10,000–9510 cal. BP). This date is equivalent to the early Mesolithic period (approximately 9500 to 7900 cal. BC). Shennan and Horton (2002) have calculated relative sea level to around 30 mbOD for this period. The marine molluscs (*C. edule*, *Patella/Diodora*, *Venerupidae*, *Ostrea edulis, Littorina, Callistoma/Gibbula* and *M. edulis*) recovered from the sediment from 37.04 to 37.13 and from 36.53 to 36.62 mbOD and foraminifera dominated by the *A. batavus* and shallow marine/ estuarine ostracods (from the sample at 36.68 mbOD) are together indicative of inner shelf and outer estuarine environments. This sample at 36.68 mbOD also contained a small assemblage of marine diatoms including *Paralia sulcata, Cymatosira belgica, Podosira stelligera* and *Actinoptychus undulatus.*

Tree pollen from these levels and above included species representative of the early Holocene Flandrian Chronozone 1, including a dominance of pine (*Pinus*) with additional thermophilous trees including oak (*Quercus*), elm (*Ulmus*), alder (*Alnus*) and hazel (*Corylus*). It is thought that the pine pollen is over-represented within the sequence and that oak, elm and hazel were probably dominant. Pollen of more local origin included reworked elements from a nearby freshwater sedge/fen, including bur reed/reed mace (*T. angustifolia/ Sparangium*), royal fern (*O. regalis*), algal *Pediastrum* and pondweed (*Potamogeton*).

More coastal and saltmarsh elements present within the sampled sediments included seeds of goosefoots and oraches (Chenopodiaceae), seathrift or lavender (*Armeria*) and spurrey (*Spergula*). A seed of sea arrowgrass (*Triglochin* sp.) was also recovered from the sample at 36.53 to 36.60 mbOD.

The sample at 36.35 mbOD within finer grained sediments contained a foraminiferal assemblage indicative of outer estuarine and shallow marine conditions including *A. batavus*. Occasional ostracods, including *Leptocythere psammophila* are also indicative of outer estuarine environments.

The upper part of the sequence is characterised by outer estuarine environmental remains, including foraminiferal species of the genera *Ammonia* and *Elphidium*, with a significant amount of the outer estuarine/shallow marine taxa *A. batavus* in the uppermost sample at 35.51 mbOD. Diatoms were also present in moderate numbers from these uppermost samples, indicating a subtidal sedimentary environment of moderate depth. The radiocarbon dating of sediment from the upper part of the sequence returned dates of 6490–6230 cal. BC (8440–8180 cal. BP) at 35.95 mbOD and of 6310–5970 cal. BC (8260–7920 cal. BP) at 33.53 mbOD. Shennan and Horton (2002) suggest that at these dates relative sea level was at approximately 25 mbOD, which correlates well with an outer estuarine type of environment at this location (Figure 5.22), correlating with the later Mesolithic archaeological period (approximately 7900 to 4000 cal. BC). Interestingly, some charcoal was also recovered at the top of the sequence in the sample at 35.89 to 35.98 mbOD. Although reworked into these sediments, it is a possible indication, as noted above, of hominin habitation.

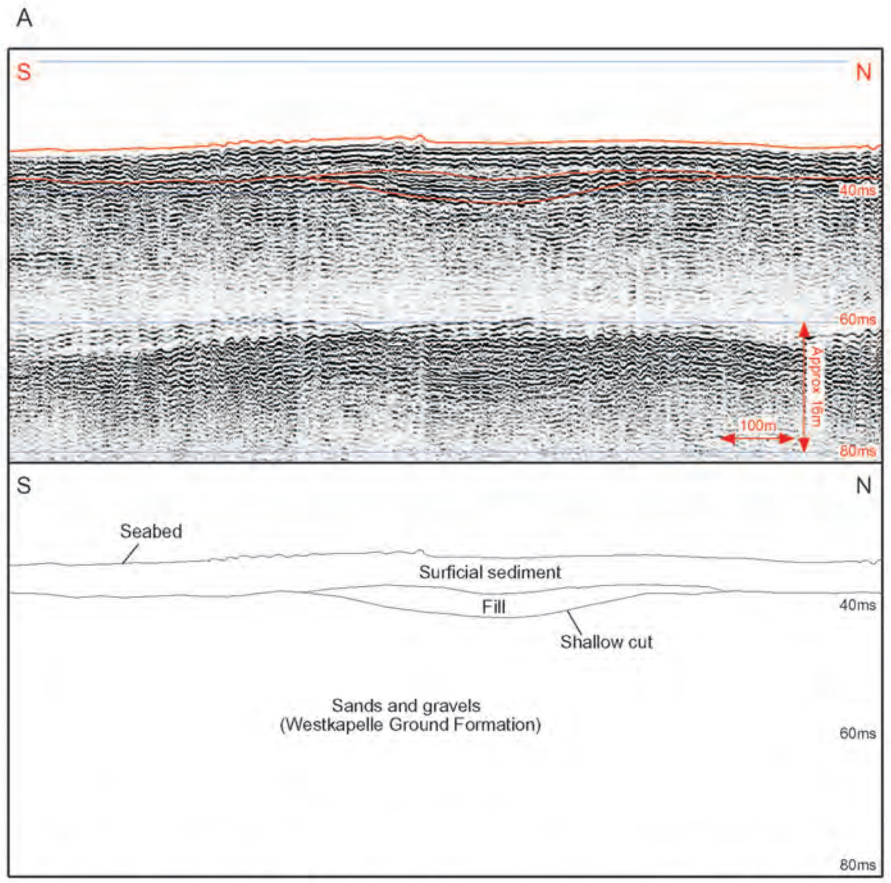
This latter phase of Holocene shallow marine and outer estuarine sedimentation within the channel feature, recorded in vibrocore VC18 and dated to between 8050–7560 cal. BC (at 36.75 mbOD) and 6310–5970 cal. BC (at 33.53 mbOD), marks a transgressive system of sea-level rise. Peat, indicative of marsh development recorded by Hazell (in prep.) further upstream within the same channel system, has been dated to between 10,710 and 10,280 cal. BC (30.80 mbOD) and 7530 to 7350 cal. BC (30.05 mbOD). Onshore, a basal peat within the Palaeo-Yare channel, the lowest part of the so-called Breydon Formation recorded by Boomer and Godwin (1993) and Arthurton *et al.* (1994), elevated at 19 mbOD and dated to 6600–6240 cal. BC, is also indicative of marsh formation at a similar period within the same channel system.

Further features (**7130** and **7132**) are situated to the west of the channel and comprise shallow depressions or cut features infilled with up to 4.3 m of probable fine-grained sediments, overlain by large sandwaves (up to 6.5 m high). These are possible remnants of intertidal sediments or are associated with the former channels of the River Waveney.

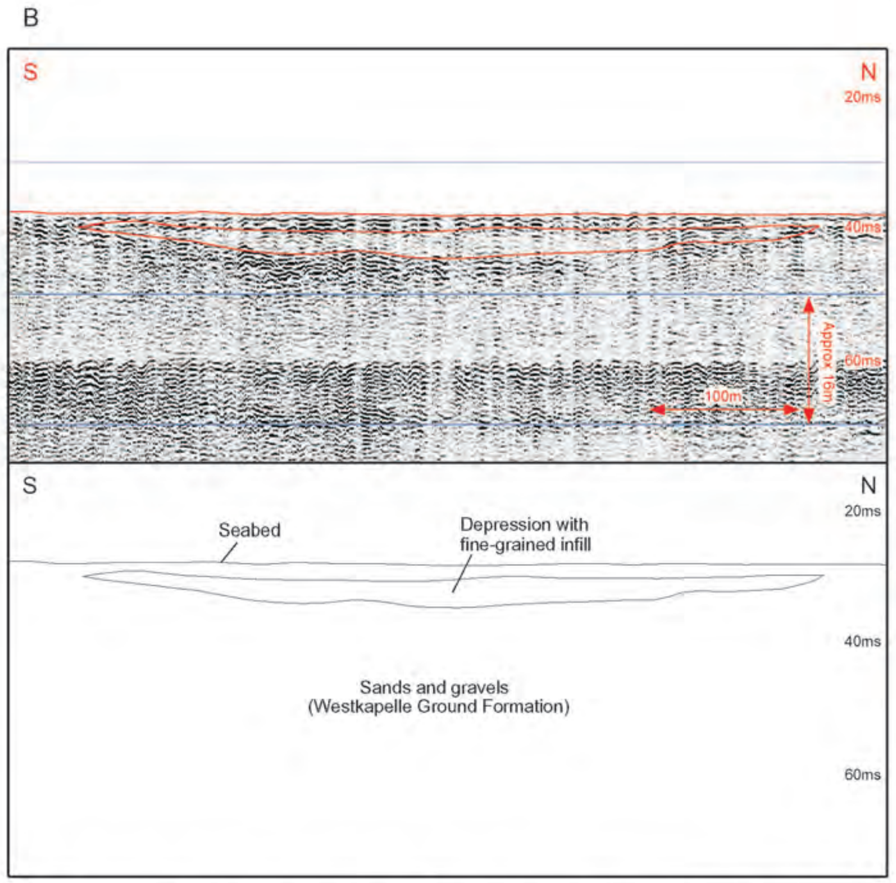
In the south-western corner of the East Coast REC Study Area, a number of small, isolated, shallow features are observed (**7133–7142**, Figure 5.21). Six simple cut and fill features and five infilled depressions (Figure 5.24) are observed and all are interpreted as the remnants of early Holocene tidal flat deposits, comparable to those documented by Moorlock *et al.* (2000). The infill of these features is interpreted as predominantly fine grained. Reedswamp and fen vegetation would have developed in the outer regions of former river valleys forming wide floodplains. These sediments would have become more intertidal and marine as increased inundation occurred. Although these deposits were probably more widespread overlying Pleistocene and older sand and gravel sediments, remnants of it are discontinuous, probably due to erosion during the last transgression (Moorlock *et al*., 2000). VC28, situated in this area, indicates up to 1.73 m shallow marine deposits comprising sand with silty clay inclusions overlain by sand, which in turn is overlain by sand and fine silty organics. The top of the sand unit exhibits evidence of oxidation, indicating a possible lowering of sea level post-deposition and prior to deposition of the upper unit. Towards the base of the core, the silty clay inclusions include possible organics that have not been fully degraded, indicating a possible young depositional sequence.

The presence of these Early Holocene land surfaces offshore indicates that complete removal of these sediments and features

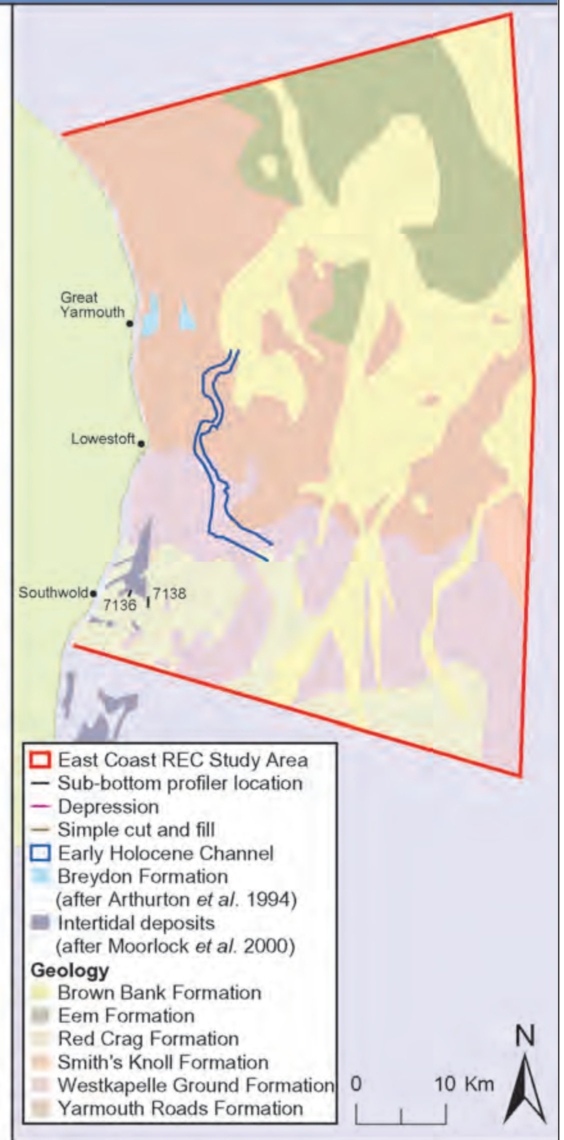
Sub-bottom profiler features associated with the Early Holocene period: Simple cut and fill and depression



7138 - Simple cut and fill - Base of shallow cut observed up to 6.1 m sub-seabed. Base of cut marked by strong reflector. Infill comprises up to 2.5 m of strong parallel reflectors possibly indicating fill containing organic matter, overlain by up to 3.5 m sediment (possibly recent sediment).



7136 - Depression - Small shallow depression. Base of feature is observed up to 4.8 m sub-seabed. Fill comprises weak reflectors indicating probable fine-grained fill. Fill is up to 2.9 m thick overlain by up to 1.9 m surficial sediment.



Cut and fill features consist of a cut into the underlying geology that has later been infilled by sediments. These features may contain one phase of fill (simple cut and fill feature) or several phases of cuts and fills (complex cut and fill) providing evidence of multiple phases of erosion and deposition.

Depression features are small, shallow, isolated infilled features which may include remnant features formed by erosion or be associated with inter-tidal deposits.

Figure 5.24 **Sub-bottom profiler feature associated with the Holocene period: simple cut and fill and depression.**

Physical region	Area covered by the side-scan sonar (km²)				
	2008 Geophysical survey			2009 Ground-truthing survey	Total
	High frequency (100 m range)	Low frequency (200 m range)	High frequency (75 m range)	Low frequency (200 m range)	
1	116.8	233.7	0.5	151.0	502
2	109.4	218.8	0.0	4.3	332.5
3	119.9	239.9	0.0	66.7	426.5
Total	346.1	692.4	0.5	222	1261

Table 5.5 East Coast REC Study Area side-scan sonar data coverage by physical region.

Physical region	Area covered by the multibeam echosounder (km²)		
	2008 geophysical survey	2009 ground-truthing survey	Total
1	115.7	105.4	221.1
2	109.1	30.3	139.4
3	130.7	7.8	138.5
Total	355.5	143.5	499

Table 5.6 East Coast REC Study Area multibeam echosounder data coverage by physical region.

did not occur during the last transgression. Mesolithic communities may have exploited these intertidal areas until its full inundation, and, as such, there is considerable potential in these areas for the presence of archaeological material.

5.3.6 Later prehistoric

For the Neolithic period onwards, the potential for recovery of archaeological material anywhere other than on the coastal margins is low. Sea level continued to rise, and tree stumps representing former forests growing on the Mesolithic and Neolithic coastal plain are well-known, especially in Denmark, where submerged Mesolithic and Neolithic material in shallow coastal waters highlights the potential for widespread preservation elsewhere (Fischer, 2004).

5.4 Maritime archaeology

5.4.1 Introduction

The aim of this characterisation is to assess the evidence for maritime archaeological sites within the East Coast REC Study Area. Maritime sites broadly fall into two categories. First, there are the remains of vessels that have been lost in tidal waters as a result of stranding, foundering, collision, enemy action and other causes. Second, there are those sites that consist of material related to the use of vessels but not of the vessel itself – for example, material lost overboard or deliberately jettisoned, including lost fishing gear and abandoned anchors.

The characterisation is principally based on the interpretation of side-scan sonar, swath bathymetry (multibeam echosounder data) and magnetometer data and is restricted to the coverage of these data-sets from the 2008 geophysics survey and the 2009 ground-truthing survey. However, additional data-sets, including records of wrecks and obstructions collated by the UKHO and NMR, and information concerning seabed features and sediments, have been utilised to inform and enhance the results of the geophysical survey and also to provide comparative material.

Principally, the high-frequency side-scan sonar data were reviewed from the 2008 geophysical survey (range of 100 m, corridor of 200 m). Additionally, the low-frequency data (range of 200 m, corridor of 400 m) were reviewed where external sources (UKHO and NMR) indicated that there was a wreck within the coverage. The side-scan sonar data from the 2009 survey (200 m range, 400 m corridor) were also reviewed as part of the characterisation. A total of 1,261 km² side-scan sonar data were reviewed. Table 5.5 shows a breakdown of the total side-scan sonar data coverage by physical region (as defined in Section 4.1).

A total of 499 km² swath bathymetry data were reviewed. Table 5.6 shows a breakdown of the total swath bathymetry data coverage by physical region. The total seabed coverage (of at least one data type) was 807 km².

The existing UKHO records were primarily used to correlate the identified wrecks with those previously known and to allow an assessment of the number of previously unidentified wrecks within the East Coast REC Study Area. These records were supplemented by the NMR record. No attempt has been made to correlate the NMR records with the UKHO records, as previous studies have demonstrated that there are numerous discrepancies between the two databases which cannot be easily resolved by conducting a simple proximity analysis; some known wrecks in the UKHO and NMR databases were found to be located at positions up to 700 m apart (Merritt *et al.*, 2007).

The UKHO record lists all wrecks and obstructions that are a potential navigational hazard, regardless of their age, and therefore these include modern wrecks of little archaeological interest (Figure 5.25). Discrimination of the archaeological importance of these wrecks has been made as part of this characterisation, based both on the geophysics data and data from secondary sources.

The UKHO records (wrecks and obstructions) that were observed and not observed in the geophysics data are presented in Figure 5.26. A total of 54 wrecks were identified that correlated with UKHO records; 73 records were unidentified in the geophysics data, and 3 wrecks were observed in the geophysics data that are previously unrecorded (by both the UKHO and the NMR).

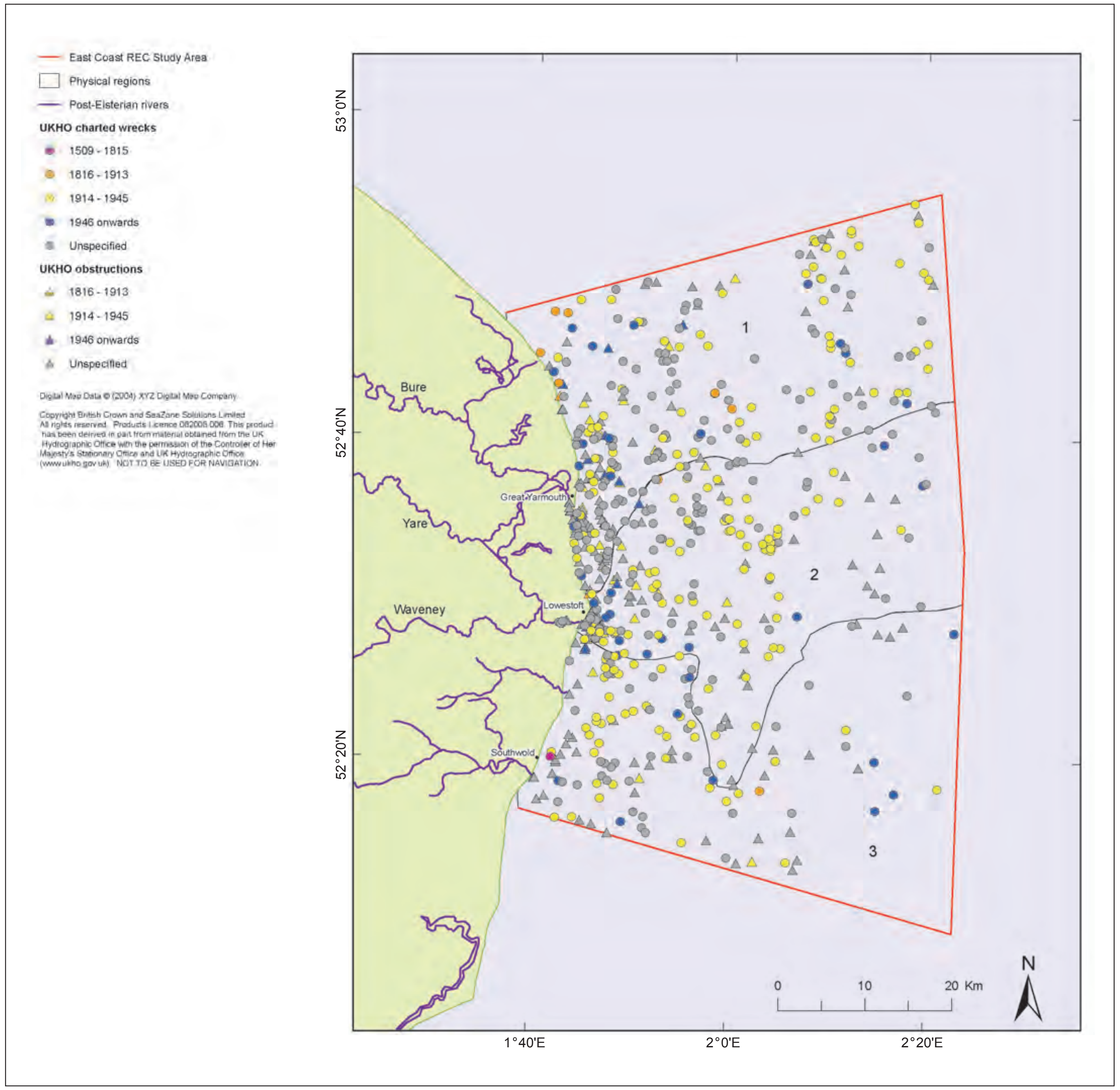


Figure 5.25 Charted wrecks and obstructions in the East Coast REC Study Area.

Figure 5.26 Known wrecks and obstructions covered by the data.

To indicate the relation between the sites and their wider national context, a notional value for importance (low, medium, high) has been ascribed, based on expert judgement, taking into account: the build/construction of the vessel; what it was used for and the wider events in which it was involved; the circumstances of its loss; the degree to which it has survived; and the extent to which it has already been investigated. Whilst rarity is important, particularly in respect of pre-1850 wrecks, which are traditionally viewed as being very scarce, wrecks can also be important because they are "typical" – that is, because they are a well-preserved example of a common type. Where the wrecking dates are known, the wrecks are classified as follows:

- **Pre-1508** AD: The earliest category within the time line covers the period from the earliest Prehistoric evidence for human maritime activity to the end of the medieval period, approximately 1508. So little is known of watercraft or vessels from this period, and archaeological evidence of them is so rare, that all examples of craft are likely to be of importance.
- **1509–1815**: This period encompasses the Tudor and Stuart periods, the English Civil War, the Anglo–Dutch Wars and later the American Independence and French Revolutionary wars. Wrecks and vessel remains from this date range are also quite rare and so can be expected to be of importance.
- **1816–1913**: This period witnessed great changes in the way in which vessels were built and used, corresponding with the introduction of metal to shipbuilding and steam to propulsion technology. Examples of watercraft from this period are more numerous, and, as such, it is those that specifically contribute to an understanding of these changes that can be considered of greater importance.
- **1914–1945**: This period encompasses the First World War (WWI), the inter-war years and the Second World War (WWII). This date range contains Britain's highest volume of recorded boat and ships losses. The importance of certain wrecks relates to technological changes and to local and global activities during this period.
- **Post-1946**: this period extends from 1946 through the post-war years to the present day. Vessels from this date range would have to present a rather strong case if they are to be considered of archaeological importance.

An important factor in the characterisation of the marine source concerns the survivability and visibility of the wreck site. The impacts of both the environment (seabed sediment type and water depth, etc.) and the result of marine and seabed activities, such as dredging and trawling, have an impact on the preservation of sites.

From an environmental point of view, the survival of wreck sites depends largely on whether they come to lie on or within the seabed sediments. Structures that lie exposed within the seawater are at risk of being deteriorated by wood-boring or saprotophic organisms, whereas those that are engulfed or covered by sediments experience a much slower rate of deterioration due to the absence of dissolved oxygen (Gregory, 2006).

The sediment types that contain a higher proportion of finer grained sediments and a lower proportion of coarser grains offer the best preservation for archaeological material on the seabed, partly due to the fact that such sediments tend to have lower bearing capabilities and thus engulf archaeological material more readily (Gregory, 2006). Finer grained sediments are also quite mobile and will more easily cover archaeological material, although the obvious drawback of this is that such sediments may be more easily transported away from a site, leaving it exposed (Gregory, 2006).

The East Coast REC Study Area is dominated by areas of sands and gravels, ranging from fine-grained muddy sands to small areas of gravel. The large proportion of fine-grained sediments in the area suggests that it has a high potential for the preservation of wreck material. Furthermore, a high percentage of the seabed encompasses bedforms that may preserve wreck sites (sandbanks, sandwaves and megaripples). However, the prevalence of mobile sediments may also expose wreck sites. Figure 5.27 illustrates the position of wrecks covered by the geophysics data within the geomorphological typologies found within the East Coast REC Study Area. Figures 5.28–5.38 illustrate typical characteristics of wrecks preserved within the different geomorphological types.

The visibility of the maritime archaeological resource predominantly relies on the ability for individual sites to be identified in geophysical, hydrographical and diving surveys. The visibility of such sites thus depends on the survival of individual wreck sites and their related material on the seabed, the degree to which they are buried beneath sediment and their construction material.

The following sections provide brief descriptions of the wrecks observed in the geophysics data and, where appropriate, are attributed an archaeological importance rating. Those wrecks with limited detail as to their identification are classed as of uncertain importance. Full details of all features identified in the geophysics data are detailed in Appendix F.

5.4.2 Physical Region 1 – North

Physical Region 1 is the northernmost region and covers 1,158 km² and is delineated to the north, east and west by the East Coast REC Study Area boundary. The southern limit is defined by the lateral extent of the sandbank features, as the dominant geomorphology characteristic of this physical region. The area also comprises areas of sandwaves, megaripple fields and featureless seabed, and a variety of seabed sediment types. Approximately 295.3 km² (26%) of the seabed was covered by geophysics data. Additionally, 28.4 km² seabed that lies outside the East Coast REC Study Area boundary was covered by data. All data have been assessed, both within and outside the area boundary.

Within Physical Region 1, a total of 22 wrecks were identified, 2 of which were previously unrecorded by the UKHO. A total of 29 wrecks recorded by the UKHO were not observed in the geophysics data (Table 5.7).

Sandbanks

Due to the shallow water depths in the areas of the sandbanks, the geophysics coverage over this feature type was limited. Only one wreck recorded by the UKHO was not observed in the data.

The unobserved wreck (**7712**, UKHO 11083) is listed with limited information. It was originally found during a survey in 1970 but was not observed during a survey in 1994. This possibly indicates burial of the wreck within the sandbank.

Sandwave fields

Sandwave fields dominate the western and central sections of Physical Region 1. A total of 10 wrecks were observed situated in areas of sandwave fields. All are observed upstanding from the seabed, and 8 are either partially buried or sit within a sandwave. With the exception of 2 wrecks, all show evidence of scour at the wreck site, indicating strong hydrodynamic forces within the area.

Anomaly **7201** is observed as a large, upstanding wreck (65 × 21 × 11.7 m) orientated N–S. Some structure is visible, but the wreck appears to be broken into at least two sections. The wreck is situated in a large scour at a depth of around 2.9 m below the average seabed depth. Sediment build up in the east indicates that at least some of the wreck may be partially buried, and the northern extent of the wreck is covered by a sandwave.

This anomaly correlates with the recorded wreck UKHO 11219. A previous survey indicated the wreck was longer (74 × 20 × 11.5 m) than observed in the East Coast REC Study Area data, indicating possible further burial of the site since 1994 when it was last surveyed. This wreck is not identified by the UKHO.

Anomaly **7203** is a wreck orientated NW–SE. The wreck is 54.5 m long and 15.3 m wide, with a height of 10.9 m. Although the structure is upstanding, it is situated in a scour and, as such, the height above the average seabed is only 4.7 m. The wreck appears to be intact. No apparently related debris was observed, but sandwaves and smaller ripples in the area may be covering such remains.

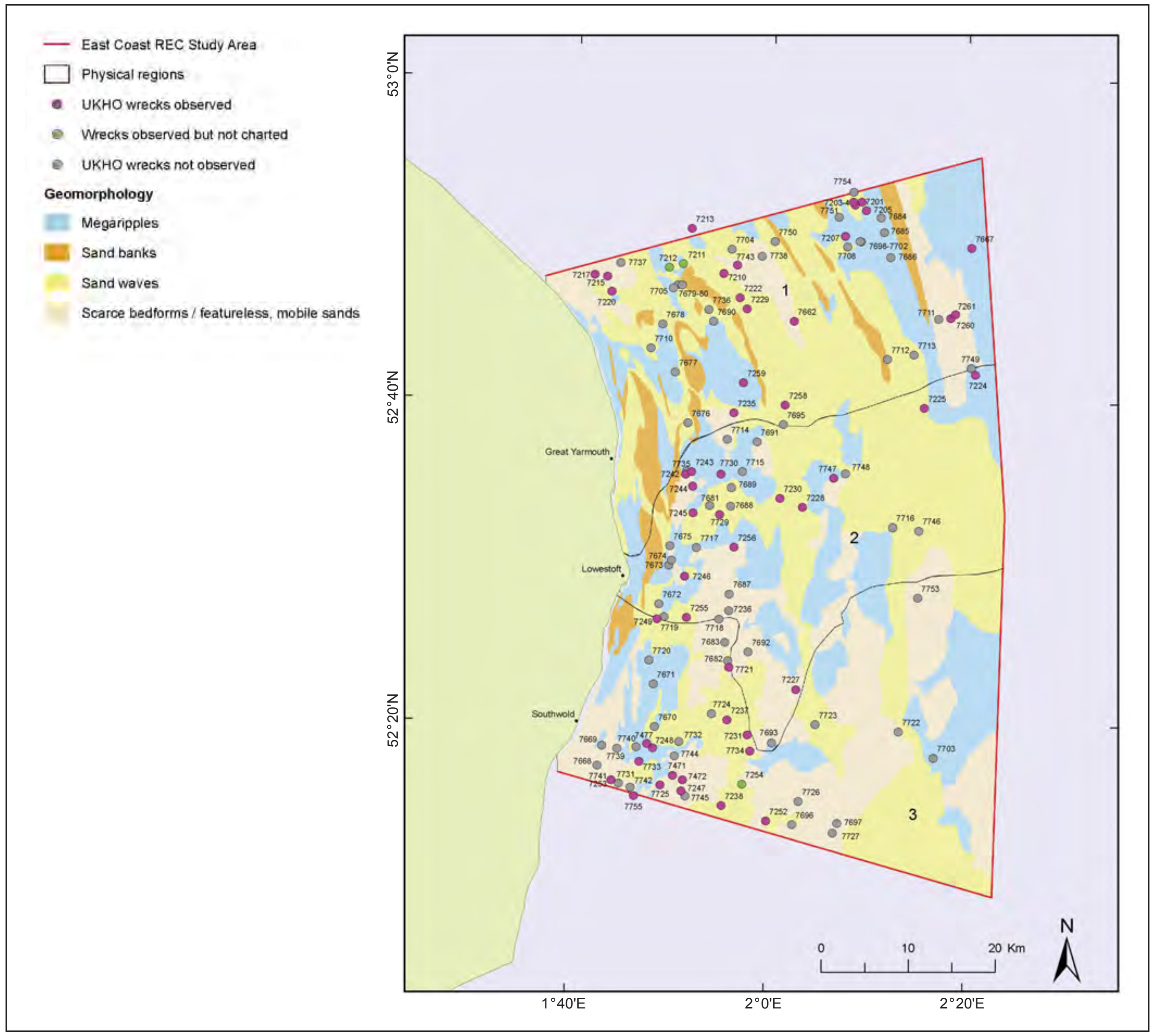


Figure 5.27 Wrecks in the East Coast REC Study Area in the context of the geomorphological region.

This is the possible charted wreck site of the British vessel SS *Blacktoft* (UKHO 11133) that sank when it was torpedoed by a German E-boat on 22 February 1945 with a cargo of pitch on route to Caen, northern France, from Goole. A previous survey in 1994 listed dimensions of 100 × 17 × 10 m, indicating that some of the vessel, probably the northern section, has since been covered by sediment. As a convoy vessel, it would be of special interest to some groups; the remains are therefore of medium archaeological importance.

Anomaly **7204** is observed on the multibeam echosounder data only, and the western edge of the wreck is not visible as the wreck is on the limits of the data. The anomaly is N–S orientated and has minimum dimensions of 72.9 × 21 × 7.9 m. The wreck is upstanding and partially buried by a 2 m-high sandwave to the west. There is no associated debris with the wreck and no obvious seabed scour.

Physical Region 1	Sandbank	Sandwaves	Megaripple fields	Featureless seabed/ mobile sands	Total
Observed wrecks	0	10	5	7	22
Not observed wrecks	1	12	13	3	29

Table 5.7 **Number of wrecks within Physical Region 1.**

This anomaly correlates with UKHO 11131, which is possibly the wreck of the British SS *Goodwood*, a merchant steamship. This wreck was also torpedoed and sunk by a German E-Boat on 22 February 1945, whilst on passage from Blyth to London. In a previous survey in 1990, the dimensions of the wreck were 60 × 13 × 8.5 m. The difference in the length between this and the East Coast REC Study Area is possibly due to seabed sediment movement and the further exposure of the wreck. A diving survey revealed the wreck to be inverted and intact, with a debris field close to the wreck. As with the wreck of the SS *Blacktoft*, the archaeological importance of this wreck is medium.

Situated to the north of Cross Sands, anomaly **7210** is the remains of a wreck aligned E–W, with dimensions 54.8 × 24 × 7.5 m. Some slight scour/depression up to 1.1 m deep is observed to the north and south of the wreck. The wreck appears to be broken up, with some debris observed approximately 3 m north of the wreck, and is partially buried by a sandwave. A magnetometer anomaly of 13 nT is observed in the area, indicating some ferrous material.

This anomaly correlates with the position of UKHO 10849, an intact, upright wreck. The dimensions are similar to those in the East Coast REC Study Area data-set, but the latest data-set indicates that the wreck is broken up rather than intact.

Anomaly **7213** is situated approximately 800 m to the north of the East Coast REC Study Area but was covered by multibeam echosounder data. The anomaly was observed with dimensions of 23 × 12.7 × 3.2 m, aligned NW–SE, with mostly homogenous height and regular shape. Small sandwaves are observed in the vicinity, and it is probable that the wreck is partially buried. Some slight scour with depth of 2.2 m is observed to the north of the wreck.

The anomaly is located at the UKHO charted wreck of the 1,085-ton Finnish vessel the SS *Roine* (UKHO 10569) sunk on 20 March 1953 after a collision in fog with SS *Briardene*. The ship was built by Palmers Shipbuilding and Iron Company, in Newcastle in 1881; it had a length of 70.7 m, a beam of 9.8 m and a draught of 4.9 m. The cargo at the time of sinking was phosphate (Tikus, 2004). This wreck is considered of medium importance. The wreck was last surveyed in 1993 with dimensions 45 × 8 × 3 m and was described as broken-up and partially buried. The reduction in the size of the site in the latest data-set indicates further burial of the site.

Anomaly **7220** (50.6 × 15 × 8.7 m) is orientated approximately N–S, situated in a large scour with actual height above average seabed 6.8 m. The wreck appears largely intact but with some indication of possible collapse or breaking up (Figure 5.28). There is no obvious debris associated with the wreck site.

This anomaly correlates with UKHO 10547, the remains of the 500-ton merchant vessel *Marsworth* built in 1947 in Bristol. It had a cargo of bagged cement and was on voyage for Stornoway from London when it collided with the French ship SS *Larrivet* in dense fog on 26 November 1953 and later sank (Tikus, 2004). Although an attractive-looking vessel during its working life, this vessel is of low archaeological importance. During a survey in 1994, the UKHO lists the dimensions of the wreck as 40 m long, with a height of 6.7 m and a scour depth of 1.5 m. The East Coast REC Study Area indicates that the wreck may have been further exposed since 1994, accounting for the increase in observed length of the wreck. Although of low archaeological importance, the wreck (Figure 5.28) shows typical characteristics of an upstanding wreck, with seabed scour, observed within Physical Region 1.

Anomaly **7222** was observed on the multibeam echosounder data only (no coverage of side-scan sonar or magnetometer data) and has dimensions of 142.5 × 23.2 × 9.8 m, orientated NW–SE. The anomaly is situated in 1.1 m-deep scour and the height above the average seabed is 8.6 m. Some sediment build-up is observed to the north. The wreck appears relatively intact but with some possible collapse.

The UKHO charts this position as the wreck of the MV *Trevethoe* (UKHO 10546), a large British vessel of 5,257 tons that sank on 12 March 1941. Built in Glasgow by A. Stephen and Sons, the vessels dimensions are 131.8 × 17.1 m, with a draught of 7.5 m. The size of the anomaly certainly represents a similar scale to the vessel. The ship sank, with a large cargo of wheat, after being torpedoed by a German E-Boat. A survey undertaken in 1983 recorded the wreck as upright and intact, but a diver survey in 2008 recorded that the stern of the vessel was largely intact and listing 45 degrees, with midships mainly broken and bow intact and upright. The broken midships is apparent on the East Coast REC Study Area multibeam data. Due to its involvement as a Second World War cargo vessel and the loss of life, the remains are of medium archaeological significance.

Anomaly **7229** has dimensions 57.2 × 4.6 × 4.2 m and is orientated approximately N–S. The wreck sits within a scour, and the maximum height of the wreck is 0.7 m lower than the average seabed depth. The wreck is partially buried, and there is some associated debris to the south of the wreck. The side-scan sonar indicates that the wreck is “C”-shaped, indicating that the wreck is broken up.

This anomaly is situated approximately 42 m north-west of UKHO 10544. However, based on the size, description and seabed characterisation, they are considered to be the same wreck. UKHO 10544 is recorded as the remains of the British FN26 convoy merchant vessel, the 1,048 ton SS *Rye*, built in 1924 by W. Beardmore and Company with a length of 73 m, a beam of 10.3 m and a draught of 4.5 m. On 7 March 1941, a German E-Boat torpedoed the vessel while it was on passage for Goole from London carrying ballast. Sadly all crew were lost, with many of the bodies recovered off south Happisburgh Sands buoy (Tikus, 2004). This wreck is of medium archaeological significance. The wreck has been dived numerous times, and in 2000 it was recorded that the wreck was upright and in two pieces, with the midships and stern in one piece lying alongside the bow section. The superstructure was intact, and a small gun is mounted on top of the stern steering house. In 2008 it was reported that two small boilers lie within the debris field, with some shell cases on the seabed and behind the stern.

A previously unrecorded wreck was identified (**7211**) within sandwaves in Physical Region 1. The wreck is aligned E–W, with dimensions of 26.2 × 8 × 3.7 m, and is situated in scour approximately 0.5 m deep. The wreck is 3.2 m above general seabed depth, and it is well-defined to the west and possibly partially buried to the north-west. Some structure is observed on the side-scan sonar image (Figure 5.29). A magnetometer response of 689 nT indicates significant ferrous content. Although there is no observed debris associated with the wreck, the proximity of sandwaves and mobile sediments means that debris may be buried in the area.

Anomaly **7258** is a wreck site with dimensions 50 × 16 × 8 m, although these are minimum dimensions as the wreck extends beyond the limits of the data. The wreck is situated partially within a large sandwave and has an associated large scour to the east, partially covered by the multibeam echosounder data, measuring at least 227 m long and 81 m wide. A magnetometer response of 3,464 nT indicates the presence of a large metal wreck. This correlated with UKHO 11062, the charted resting place for the British tanker SS *Stanmount*. Built in 1914, by W. Gray and Co. Ltd, the SS *Stanmount* was 111 m in length, with a beam of 15 m and a draught of 7.3 m. The vessel sank after it struck a mine on Christmas Eve 1941 while on passage from London to Grimsby with creosote as cargo and is regarded as of medium archaeological importance.

A total of 12 wrecks that were recorded by the UKHO were not observed in the East Coast REC Study Area data-set. Of these wrecks, 8 are classified by the UKHO as “dead” (**7754**, **7676**, **7678**, **7695**, **7704**, **7708**, **7710** and **7713**), indicating that although the sinking of the vessels have been reported at these positions or that they were identified on geophysics data in the past, they have since not been seen. This could be due to past inaccurate positioning/reporting or because the wrecks have now become buried and are no longer identifiable. Given the number and size of the sandwaves in these areas, it is certainly possible that some of these wrecks may be buried.

The remaining 4 records (**7736**, **7679**, **7680** and **7750**) are classified by the UKHO as “live” – that is, they have been observed on previous surveys and reported to the UKHO. Although not directly identified by the side-scan sonar or multibeam echosounder data, 3 of these wrecks have corresponding magnetometer records indicating that the wrecks are buried or situated beyond the limits of the side-scan sonar and multibeam coverage.

Within the vicinity of **7736** (UKHO 10540) there are three magnetometer anomalies (between 20 nT and 41 nT), indicating some ferrous material. However, no evidence of debris or a wreck was observed on the side-scan sonar or multibeam echosounder data. Within the area, there are a number of large sandwaves and megaripples. The UKHO lists the remains of the British SS *Norseman,* which sank following collision in fog with SS *Burnside* en route from London in 1925. Throughout the survey history there is evidence that the remains of this wreck have been periodically covered and exposed. In 1999 it was observed as an area of broken and partially buried wreckage, 40 × 20 m, with no height. The East Coast REC Study Area data indicate that the wreckage has now been reburied.

The wreck TS *Montferland* (**7679**, UKHO 10549) is the remains of a large turbine steamer with dimensions recorded as 145 m in length, 18 m in beam and a draught of 8 m. With an assorted cargo that included sugar, meat, steel and wool, the vessel was attacked by a German aircraft, foundered and sank on 27 June 1941, while on passage from MacKay, Queensland, Australia, for London; all the crew survived (Tikus, 2004). This position was beyond the limits of the multibeam echosounder data and towards the limits of the low-frequency side-scan sonar data-set, and the wreck was not observed. Two magnetometer responses of 15 nT and 49 nT were recorded. In 1995 the UKHO record indicates a wreck with dimensions 160 × 40 × 3 m situated between two sandwaves.

An unknown wreck, but of possible schooner type (**7680**, UKHO 10545), was surveyed in 1999, as upright and intact, with ribs (suggesting timber structure) protruding from the sandwave. It is situated beyond the multibeam echosounder data and towards the limit of the low-frequency side-scan sonar data; it was not observed.

A further unobserved wreck (**7750**, UKHO 11117) is described by the UKHO as a “live” foul ground, possibly the British Tanker *Voreda* sunk in February 1940, bombed and set on fire by German aircraft while on passage to London. The vessel went ashore on Winterton Shoal and later sank. The wreck was last located in 1992 and considered to be within a sandwave. There was no evidence of this wreck on the latest geophysical data.

Megaripple fields

Areas of megaripple fields are observed in the western and eastern sections of Physical Region 1. A total of 5 wrecks were identified, 4 of which are upstanding wrecks situated in scour. The remaining wreck exhibited no height or scour. Four of the wrecks were previously charted; 1 was a previously uncharted wreck.

Anomaly **7205** (Figure 5.30) is situated in the west of the region between Winterton Ridge and Smith's Knoll. The anomaly has dimensions of 58.3 × 24.1 × 10.6 m and is orientated N–S. The highest point of the wreck is 5.6 m above the average seabed to the south, with a gradual slope to the north to approximately 0.8 m. The wreck is situated in a large scour approximately 235 m long, 29 m wide and up to 5 m deep. No apparent associated debris was observed.

This anomaly is situated at the position of UKHO 11130, the wreck of the SS *Horseferry*. The basic dimensions of the vessel were 66 m in length, with a 9.8 m beam and a 4 m draft, when it was built in 1930 by J. Crown and Sons Ltd, in Sunderland. It was torpedoed and sunk by a German E-Boat on passage to London from the River Tyne on 11 March 1942.

The UKHO records the wreck as 62 × 14 × 10 m, orientated N–S, similar to that observed in the geophysics data. A diving survey indicated that the wreck was inverted and intact, with debris field around wreck. The East Coast REC Study Area multibeam echosounder data shows no structure, as would be expected from an inverted vessel, and the vessel remains intact. This vessel is of medium archaeological importance.

Anomaly **7207** was observed on the multibeam echosounder data only (no side-scan sonar or magnetometer data acquired for this area) and was interpreted as a wreck site (Figure 5.31). The anomaly has dimensions of 77 × 17.8 × 12.2 m and is orientated approximately N–S with a height of 5.6 m above average seabed. The height of the wreck is mostly continuous to the south but decreases by 5 m to the north. The wreck is predominantly upstanding, and at the northern end of the wreck there could be separate debris as there appears to be a small break in structure.

This anomaly is situated at the site UKHO 11119, the wreck site of the SS *Aruba*. The vessel was originally a large cargo carrier of 1,159 tons, built in 1916 by Wilton's Engineering and Slipway Company in Rotterdam. The dimensions of the vessel were 70.2 m in length, a beam of 10.4 m and a draught of 3.9 m. It sailed under many other names until in 1929 it was named the SS *Aruba* by the Hook Steam Ship Company in Goole. On 19 November 1941, as part of convoy FS50 on route to Cowes from Blyth, the ship was torpedoed and sunk close to Winterton Ridge and Hearty Knoll by a German E-Boat of the 2nd MTB Flotilla (Tikus, 2004). It had one loss of crew, who was believed to have been blown overboard by the explosion (Larn and Larn, 1997). The remains of this vessel may be of interest to heritage groups, divers and other members of the public with an interest in World War II, so it is of medium archaeological importance.

The UKHO records the wreck as 59 × 15 × 5 m, orientated N–S, appearing whole and within a deep scour. East Coast REC Study Area data indicate that the wreck may be broken into two main sections. There is a possibility of associated debris buried within megaripples in the area.

The wreck site formations of **7205** and **7207** are typical of the upright wrecks in the area, which exhibit scouring around the wreck, indicating the strong hydrodynamic forces in the area.

Anomaly **7259** is situated off Great Yarmouth approximately 4 km from Cross Sands. The wreck is 48 × 19 × 4.2 m, aligned NW–SE. The wreck has a continuous height along its length but with two high points to south-east, which could suggest that the wreck is slightly broken up. There is sediment build-up to the south, partially burying the wreck. The wreck is situated in scour approximately 100 m wide with a maximum depth of 3.8 m. Debris is observed just over 17 m to the south-east of the wreck. A magnetometer response of 951 nT is observed in the vicinity and is probably associated with the wreck. The anomaly is situated at the location of UKHO 10523, an unknown wreck.

Anomaly **7667** was observed in the side-scan sonar data-set as an amorphous feature 31.5 m in length and 20 m wide, with no discernible height. It is recorded by the UKHO (UKHO 11242) as probable debris covering 15 × 10 m with height of 2.8 m.

Anomaly **7212** (Figure 5.32) is a previously uncharted wreck with dimensions 62.5 × 12.5 × 10.8 m, with some structure apparent. The wreck is orientated NE–SW and situated within a large sandwave approximately 3 m high, and, as such, full extent is difficult to discern. The height of the wreck is approximately 5.5 m above general seabed, and two high points are observed situated at each end of the wreck. Possible scour/depression is observed approximately 5.3 m deep, 27 m wide to the west and up to 60 m wide to the east. The wreck has an associated magnetic response of 1,212 nT. There is no apparent debris associated with the wreck, but this may be buried by sandwave and megaripples in the area.

Similar to anomalies **7205** and **7207**, anomaly **7212** is an upstanding wreck with associated seabed scour, typical of wreck sites in Physical Region 1.

A total of 13 wrecks that were recorded by the UKHO were not observed in the East Coast REC Study Area data-set. Of these wrecks, 8 (**7684**, **7698–7702**, **7705** and **7749**) are classified by the UKHO as "dead" with unreliable positioning, indicating that although the sinkings of the vessels have been reported at these positions they have not been located, due to inaccurate positioning/reporting. The remaining 5 records (**7677**, **7685**, **7686**, **7690** and **7751**) are classed as "live" wrecks and have been located within recent years through either diving or geophysical surveys and reported to the UKHO.

UKHO 10527 (**7677**) is charted by the UKHO as a wreck site with no clear identity with dimensions 80 × 14 × 5 m, intact and keeled over to one side. The wreck was not visible in the geophysical data-set as the position is on the edge of the 200 m range of the low-frequency side-scan sonar data. Two magnetometer responses in the vicinity (9 nT and 168 nT) may be associated with this wreck, indicating that the wreck lies just beyond the limits of the geophysics data.

The charted site UKHO 11243 (**7685**) is probable debris from an unknown vessel (13 × 6 × 1 m). It was not observed in the geophysics data as it was beyond the limits of the multibeam echosounder data and towards the limits of the low-frequency side-scan sonar data.

UKHO 11241 (**7686**) was not observed on the geophysics data and may be fully buried. It was identified in 1994 as the hull of an unknown vessel, 30 × 7 × 1.2 m, almost totally buried. This highlights the impact of mobile sediments on the visibility of wreck sites.

UKHO 10537 (**7690**) is situated beyond the limits of the multibeam echosounder data and towards the limits of the low-frequency side-scan sonar data and as such was not observed. The UKHO records the wreck as a steamer with a triple-expansion steam engine, with dimensions of the site 60 × 10 × 2 m, and is described as broken wreckage that is well buried.

UKHO 11127 (**7751**) is recorded by the UKHO as the wreck site of an unknown wreck. It was last observed in 1994, described as an intact wreck in deep scour with dimensions 60 × 15 × 4.1 m. In the East Coast REC Study Area multibeam echosounder data, this area of the seabed is covered by megaripples, and there is no evidence of the wreck.

Scarce bedforms/ featureless seabed

This geomorphological type covers the least area within Physical Region 1 and is confined to the central and eastern areas. Seven wrecks were identified in the area, and all are charted by the UKHO.

Anomaly **7215** (Figure 5.33) is situated in the north-west of Physical Region 1 and has the characteristics of a wreck site with dimensions of 52 × 13.1 × 5.4 m and is orientated NW–SE. There is some sediment build-up to the north-west, and the south-eastern end appears to be partially buried. There is also a large scour observed to the south-west approximately 1.7 m deep and over 100 m wide. The site has an associated magnetometer response of 824 nT. The structure of the wreck is undefined, and there is some possible related debris around the wreck. This anomaly is situated 30 m west of the charted UKHO position of the SS *Seagull* (UKHO 10550), though is considered to be the same wreck.
The SS *Seagull* was an elegant 322-ton two-masted steam paddle schooner built in 1848 in Belfast by Coates and Young, Lagan Foundry. The original dimensions of the ship were 51.8 m in length, 7 m in beam with a draught of 3.6 m. The vessel was struck by SS *Swan*, on 6 February 1868, with a cargo of cotton bound for Rotterdam from Hull. The vessel's charted position is to the east of Cockel Gateway, on a sandwave. The UKHO record this wreck with a length of 40 m and a height of 8.6 m from a survey in 1983. A more recent diving survey in 1994 found the remains of paddle wheels, and a ship's bell was recovered. The wreck has metal hull plates with only the decking visible, and the wreck has collapsed. The wreck is situated in an area of featureless seabed but in a dynamic area with possible mobile sediments, which may account for the differences in observed length and height between 1984 and 2008.

The remains of this vessel would be of high archaeological importance due to the period in which it was built and the manner of its construction. Paddle steamers are rare within the NMR. (For more information, see Section 8.3).

Anomaly **7217** is a well-defined wreck observed on the multibeam echosounder data only (no coverage of side-scan sonar or magnetometer data in the area). The wreck is upstanding and appears intact, with dimensions of 51 × 16 × 7 m, orientated approximately E–W. There is evidence of some sediment build up, although the wreck does not appear to be buried.

This anomaly is situated 10 m south of UKHO 10660. The wreck is the *Xanthe*, a steam screw barque that was built by Messrs. Martin, Samuelson and Company, at Hull, in April 1862, with a length of 62 m, a beam of 8.5 m and a draught of 4.9 m. Much of the vessel's early career was spent in the French and Mediterranean trades, but it also undertook commercial work in Australia and New Zealand. The circumstances of the loss surround a collision with an unknown vessel on 11 December 1869. The UKHO list the wreck as 55 × 10 × 7 m, similar to that observed on the East Coast REC Study Area data, indicating little change in the wreck site since 1983. Diver surveys indicate that the wreck is upright and the hull intact, although the superstructure is collapsed into the hull. Although many barques of this type and size are well recorded, this vessel is an early variation of a possibly three-masted screw barque and is therefore of high archaeological importance. (For more information, see Section 8.3.)

Anomaly **7235** is a wreck with dimensions 19.9 × 7.9 × 2.3 m. The wreck is orientated NW–SE, with scour to the west. Some minimal debris is observed around the wreck. A magnetometer response of 39 nT is associated with the wreck. The anomaly is situated approximately 150 m north of UKHO 10510. The UKHO records inaccuracies in the position of the wreck. Anomaly **7235** may be UKHO 10510 or a previously uncharted wreck. There was no evidence of a wreck in the position listed by the UKHO.

If this is the wreck of UKHO 10510, it is the position of a steel trawler of 224 tons, the *Glenprosen*, built for J. S. Boyle, Glasgow, in Aberdeen in 1907 by Alexander Hall and Company (1811–1958). The firm is best remembered for its development of the Aberdeen or clipper bow in 1839 and Japan's first warship, the *Jho Sho Maru*. The firm would later construct many trawlers such as the *Glenprosen*, as well as coasters, tugs and dredgers (Aberdeen City Council, 2010). The dimensions of the vessel as built were 36.5 m in length, 6.4 m at the beam and with a draught of 3.8 m. Fitted with a triple-expansion engine with one boiler and a single screw, it was requisitioned in August 1914 by the Admiralty and converted to a minesweeper. The vessel struck a mine on active service a mile east of Cross Sand on 3 November 1916. As this vessel was built by such a distinguished shipbuilding company, it is therefore of special interest and of medium archaeological importance.

Anomaly **7260** is situated to the very south of Smith's Knoll and is a wreck with dimensions of 49 × 19.5 × 6.3 m, orientated NW–SE. The wreck has associated seabed scour 49 m in length to the north-west and has a height above the average seabed of 5.3 m.

There is no apparent debris associated with the wreck. This is positioned at the location of UKHO 11025, an intact unknown wreck previously observed with dimensions 45 × 15 × 7 m, similar to the latest observation.

Anomaly **7261** is a wreck with dimension 45.3 × 3.5 × 1.2 m orientated E–W. It is observed on the multibeam echosounder data as a thin feature, which is possibly an artefact of the data, but is situated 30 m south of a dead wreck recorded by the UKHO (11097). The UKHO lists this wreck as the possible *Loch Lomond,* a 42-ton British smack vessel sunk by gunfire from a German submarine in 1916. This wreck has low archaeological importance.

Anomaly **7662** is a wreck with dimensions 64.9 × 13 × 5.9 m, orientated N–S. The wreck is upstanding, with some structure visible. There is no obvious debris or associated seabed scour. The position of this anomaly correlates with UKHO 11222, an unknown intact and upright wreck with similar dimensions to those recorded in the latest geophysics data.

Anomaly **7743** is observed towards the limit of the 200 m side-scan sonar range as a seafloor disturbance 31.3 × 3.8 m with no height, orientated N–S. The anomaly is situated approximately 20 m north of listed wreck UKHO 10851. This is listed as a light vessel. Observed during a dive in 2002, it was recorded as approximately 40 m long with wooden decks. A light tower lies on the seabed adjacent to the wreck, upright but tilted to one side. This wreck has low archaeological importance.

Three wrecks listed by the UKHO were not observed in the data. Two are classified as “dead” (**7711** and **7738**) and with approximate positional data. The remaining wreck is classified as “live”. This is UKHO 10551 (**7737**), an unidentified wreck with dimensions 20 × 15 × 3.2 m. This wreck is situated beyond the limits of the multibeam echosounder data and was towards the limits of the low-frequency side-scan sonar data.

Physical Region 2	Sandbank	Sandwaves	Megaripple fields	Featureless seabed/ mobile sands	Total
Observed wrecks	0	6	4	5	15
Not observed wrecks	0	7	5	8	20

Table 5.8 **Number of wrecks within Physical Region 2.**

5.4.3 Physical Region 2 – Central

Physical Region 2, the central region, covers 998.5 km² and is delineated to the north by the southernmost extent of the sandbanks, to the east and west by the East Coast REC Study Area boundary, and to the south by a boundary based primarily on the distribution of sandy gravel. Approximately 214.8 km² (22%) of the seabed was covered by geophysics data. The area comprises a variety of geomorphological feature types and seabed sediments. No geophysics data were acquired in areas of sandbanks. Additionally, 1.6 km² of seabed was covered by data which lies outside the East Coast REC Study Area boundary. All data have been assessed, both within and outside the area boundary.

Within Physical Region 2, a total of 15 wrecks were identified, all of which were previously recorded by the UKHO (and NMR). A total of 20 wrecks recorded by the UKHO were not observed in the geophysics data (Table 5.8).

Sandwave fields

Sandwave fields are the dominant geomorphological feature type in Physical Region 2 and are prevalent in the central and eastern areas. A total of 6 wrecks were identified, situated in areas of sandwave fields.

Anomaly **7225** is a small wreck with dimensions 27.9 × 22.3 × 4.8 m, orientated E–W. Some structure is visible, and the wreck is sat in a large seabed scour 97 m long, a minimum of 47 m width and 7.2 m deep. There is no obvious debris associated with the wreck. Some possible sediment build-up was observed to the south of the wreck. This correlated with wreck UKHO 11175, the fishing vessel *Boy Karl*, which sank in November 1983. This wreck is of low archaeological importance.

Anomaly **7228** (Figure 5.34) is a wreck with dimensions 42.5 × 12 × 10.2 m. The wreck is orientated E–W and is partially buried by a sandwave. Although 10.2 m high, the wreck height above seabed is only 4.4 m as it is situated in a scour up to 5.5 m deep, with scour mostly observed to the east. No obvious structure is observed, and the wreck appears mostly buried within sandwaves. There is no apparent associated debris. The wreck has a large magnetometer response of 2,373 nT.

This wreck is recorded by the UKHO as that of the British 2,848-ton SS *Cormead* (UKHO 11031). Built in 1939 by the Burntisland Ship Building Company and powered by a three-cylinder triple-expansion engine, it had a length of 96 m, a beam of 44 m and a draught of 6 m. While on passage for London from the River Tyne, the ship struck a mine on Boxing Day 1941 and sank, but all crew and gunners were saved. The UKHO records this wreck as 86 × 16 × 6.3 m, orientated E–W, and it appeared to be decayed with little structure remaining. In 1971 a diving survey observed the wreck to be lying N–NE to S–SW virtually as sunk with no sign of sinking damage, except for masts and light superstructure dragged down by fishermen’s nets and tides. The reduction in the size of the wreck observed in the East Coast REC Study Area data is probably due to increased build up of sediments around the wreck site. Due to its contribution in the Second World War, this vessel is of medium archaeological importance.

Anomaly **7230** is an area of debris (23.5 × 5 m), with no discernible height, associated with UKHO 11037. The anomaly may represent the broken-up vessel, in at least two pieces, with an associated magnetometer response of 78 nT. UKHO 11037 is the wreck of the SS *Crichtoun*, a 1,097-ton steamship built at Leith by John Cran and Somerville Ltd. As part of an FS convoy from Leith to London, it was attacked by a German E-Boat of the 6th MTB flotilla on 19 March 1945. Sadly, of the 25 crew on board, only 3 survived the attack (Tikus, 2004). The remains of this vessel are of medium archaeological importance.

Anomaly **7246** is a sub-circular anomaly with dimensions 27 × 14 × 1.7 m, orientated E–W. The wreck appears partially broken up and buried. As such, the dimension could be larger than observed. This anomaly is situated at the location of UKHO 10430, an unknown wreck. In 1983 it was recorded as having dimensions of 62.3 × 7.5 × 9.9 m and being upright. The East Coast REC study indicates that the wreck has since been almost completely buried.

Anomaly **7255** was not observed fully on the side-scan sonar data as it is directly under the towfish. It is observed with dimensions 22.2 × 22.8 × 5.8 m and a magnetometer response of 40 nT. This anomaly is situated at the location of UKHO 10411, which is the possible wreck of the Dutch merchant coaster *Mudo*, built in 1930 by G. Muller, Foxhol. The vessel sunk due to a collision on 4 May 1949. The remains of this vessel are of low archaeological importance.

Anomaly **7729** is a large wreck with dimensions 95 × 25 × 5 m, orientated NW–SE. The wreck appears buried to the north and the west, and little structure can be observed. Positioned in aggregate extraction Area 240, this is the possible charted wreck site of the 3,091-ton SS *Tregantle* (UKHO 10452). Built in 1903 in South Shields, by J. Readhean and Sons, the vessel was 98 m in length and 14 m at the beam, with a draught of 7.3 m. On passage between Galveston in Texas and Hull with a 4,900-ton cargo of wheat, it was sunk by a torpedo fired from the German submarine UB-16 on 22 April 1916. A survey in 1982 suggested the vessel was upright but partially buried, with bow and superstructure prominent.

A total of 7 UKHO wreck locations were not observed in the geophysics data. Of these, 5 were classified as dead (**7681**, **7688**, **7689**, **7716** and **7746**) and 4 of these are listed as having unreliable positioning. Two wrecks that were unidentified are classified as “live” by the UKHO and have been identified during previous geophysical surveys.

UKHO 10814 (**7672**) is situated 5 km east of Pakefield, to the south of the approaches to Lowestoft, and is the recorded remains of a small British fishing vessel that took on water and then sank in November 1992. This modern wreck site, of low archaeological importance, is situated on the edge of the 200 m range low-frequency side-scan sonar data and was not observed.

UKHO 10473 (**7719**) was beyond the limits of the multibeam data and was not observed on the side-scan sonar data. This is possibly the site of the *UC-2***,** a Type SM UC 1 minelayer submarine of the German Imperial Navy that was previously unknown to the Royal Navy until it was accidentally rammed by the coaster SS *Cottingham* on 2 July 1915. This event exposed the secret German strategy of using mine-laying U-Boats off the east coast and channel. A Royal Navy diver was sent in to investigate and discovered a 3-ft opening in the hull of the *UC-2*. The German minelayer had been on transit to Lowestoft from Zeebrugge as part of a 15-vessel operation to disrupt the British cargo-carrying network (Messimer, 2002). This wreck is significant in that it was one of the first operational mine-laying submarines in the world. Of the 15 built for the First World War, 4 are found off the English coast. If observed, this vessel would be of high archaeological importance.

Megaripple fields

Megaripple fields are mainly observed in the western and central parts of Physical Region 2. Four wrecks were observed on the geophysics data, and all were previously charted by the UKHO.

Anomaly **7224** is observed as a mound feature with three prominent sections. The anomaly has dimensions of 36.4 × 14.9 × 1.5 m and is orientated E–W with no associated scour or debris. This position correlates with UKHO 11075, which is an unknown intact and partially buried wreck site with dimensions 32 × 12 × 2.5 m, indicating little change to the wreck site compared to the latest data-set.

Anomaly **7245** is situated within the aggregate extraction Area 319. The wreck is aligned NW–SE and has dimensions of 80.9 × 29.7 × 9.6 m. The wreck is upstanding, but the eastern end may be partially buried. This anomaly correlates with the position of UKHO 10454. There are no details of this wreck other than its charted position in the UKHO.

Anomaly **7730** (Figure 5.35) is a wreck with dimension 93 × 17 × 2 m, orientated approximately N–S. The multibeam echosounder data indicates partial burial with no obvious scour. The side-scan sonar data indicate a very broken-up wreck with limited height. An associated magnetometer anomaly of 6,722 nT indicates a large metal wreck. The wreck is listed by the UKHO (10480) as 98.9 × 11.6 × 6.3 m, with a minimum depth of 24 m. In 1991 a survey listed that the wreck was upright with a silted-up stern and bow and with the bridge smashed and a jumble of girders. In 1982 the wreck was partially covered by a sand ridge. The latest data indicate a build-up of sediment covering the wreck site.

The majority of the wrecks observed in the geophysics data are upstanding wrecks and are relatively intact. Anomaly **7730** (Figure 5.35) provides an example of a broken-up wreck with minimal height above the seabed. This also shows partial burial of the wreck, which is typical in areas of megaripple fields within the East Coast REC Study Area.

Anomaly **7747** is indicative of a broken-up wreck, with site dimensions of 54 × 18 × 3 m. Two distinct sections are observed: the northern section measures 27 × 8 × 1.5 m, and the southern section measures 35 × 9 × 3 m. This is either two broken sections of wreck or a broken-up wreck that is partially buried. This is charted by the UKHO (11046) as an intact wreck of 56 × 14 × 4.2 m, last observed in 1994. There appears to have been little change to the wreck site since then.

A total of 5 UKHO listed wrecks were not observed on the geophysics data. Two were classified as "dead" (**7675** and **7715**) and have not been observed in previous surveys. The remaining 3 are classed as "live".

UKHO 10433 (**7673**) is described as a "foul" by the UKHO and was previously surveyed in 2005, with an area of debris recorded with dimensions 40 × 18 × 1.5 m. This was not observed on the geophysics data, and the multibeam echosounder indicates an area of megaripples but no evidence of debris. It is possible that any evidence of this site has since been buried.

UKHO 10443 (**7717**) is the wreck of the HMS *Speeton*, a trawler of 205 ton that was sunk by a mine on 31 December 1915 on Admiralty service. The wreck is 18 × 3.4 × 4.8 m, orientated NE–SW. The position of the wreck is situated 20 m outside the geophysics data coverage, and no evidence of the wreck was observed.

UKHO 11047 (**7748**) was not seen in the geophysical data-set. The SS *Atle*, a Swedish vessel, was mined and sunk in November 1914. It was last observed in 1994 (60 × 10 × 5 m, orientated N–S), situated in the lee of a large sandwave. There is no direct evidence of the wreck on the geophysics data, and it is possible that the wreck is now completely buried. Two magnetometer anomalies in the area (19 and 13 nT) may be associated with this buried wreck.

Scarce bedforms/ featureless seabed

This geomorphological type covers the least area within Physical Region 2. However, 5 wrecks were observed in the area, and all are charted by the UKHO.

Anomaly **7227** (Figure 5.36) is a wreck site with dimensions of 92.5 × 42.8 × 14.6 m. The wreck is orientated NW–SE, situated in scour up to 8 m deep, with the height of the wreck 6.6 m above general seabed. Actual width of the wreck is 27 m, with associated debris observed surrounding the wreck. Some structure was observed with some evidence of partial burial in the central section. The wreck has a large magnetometer response of 4,548 nT.

UKHO 10992 lists this wreck site as the Dutch vessel the SS *Stad Alkmaar*, built in Rotterdam by Wilton Feyenoord. With a length of 135 m, a beam of 18 m and a draught of 7.8 m, this vessel was 5,750 tons. While on convoy, FS273, from Cuba to London with a cargo of sugar on 7 September 1940, the vessel sank (the same year it was built). It was torpedoed by the German E-boat, *S33*. The number of casualties is unclear; however, 14 of her crew were documented as being rescued and safely landed at Lowestoft (Larn and Larn, 1997). This vessel would be viewed of medium archaeological importance due to its contribution during the First World War. Previous surveys recorded the wreck as intact and upright, 130 × 20 × 12 m, situated in a scour up to 7 m deep. The difference in the recorded length and the East Coast REC Study Area data may be due to either sediment build up or, more likely, to a side-scan sonar shadow obscuring true length in the latest data-set.

Anomaly **7242** is a wreck with dimensions 18.8 × 6.5 × 2.4 m, with no obvious debris. There is some evident scouring to the north-west with depth of 0.8 m, making actual wreck height 1.6 m above average seabed, with the highest point of the wreck centrally. The wreck is considerably buried. UKHO 10478 is an unknown wreck recorded in 2004 with dimensions 15 × 15 × 1.4 m. By 2006 the wreck was not observed and was assumed to be fully buried. The East Coast REC Study Area data indicates that it has since been partially uncovered.

Anomaly **7243** is a wreck with dimensions of 78.5 × 36.8 × 3.5 m, aligned NE–SW. The wreck is situated within a seabed scour to the south-west, making the actual height 3 m above the average seabed. Some sediment build up is observed in the north-west, indicating partial burial. Possible associated debris is observed to the west (15.2 × 9.5 m). The UKHO described this unknown vessel (UKHO 10483) as large (75 × 25 × 2 m), partially buried and possibly split into two sections, from a survey undertaken in 2006.

Situated to the north of aggregate extraction Area 319 and to the south of Middle Cross Sands approximately 9 km from Great Yarmouth, anomaly **7244** is an unknown wreck in a charted position in the UKHO (10466). The remains of the wreck are aligned N–S, with dimensions 30.3 × 11.2 × 5.5 m. The wreck is situated in 1 m deep scour to the west, which makes the actual wreck height 4.7 m above the average seabed. There is possibly a spread of debris to the north-west and south, while to the north the wreck looks to be broken away. The highest point is centrally located, with partial burial of the northern extent.

Positioned within aggregate extraction Area 251, anomaly **7256** is a wreck site with dimensions 46.1 × 22.9 × 1.3 m, orientated E–W, and appears mostly buried. The UKHO records this wreck as UKHO 10668, an unknown wreck last observed in 1982 measuring 36.3 × 10.6 m with no discernible height. The latest data indicate a slight uncovering of the wreck since 1982.

The UKHO lists 8 wrecks that were not identified on the geophysics data: 5 were classified as "dead" (**7687**, **7691**, **7692**, **7693** and **7735**) and are likely to be completely buried or not present due to unreliable positional data. The other 3 records (**7236**, **7674** and **7714**) are classified as "live").

UKHO 10413 (**7236**) is the charted position of the British Merchant Vessel the *Sea Rhine*. The vessel was a small cargo vessel lost when the cargo of steel coils shifted in rough seas on 11 February 1976. A tug, registered from Liverpool, named the *Crosby*, went alongside and rescued all hands but one, after their emergency call to the Yarmouth Coastguard. The remaining crew member steered the vessel, until it took a dangerous list. He was recovered by the Gorleston Lifeboat (Larn and Larn, 1997). The vessel was built to 44 m in length, a beam of 7.3 m and a draught of 2.6 m, and it now lies in 31 m of water. An acoustic survey undertaken in 1982 noted the vessel to be intact and upright with the mast standing; however, it was only observed in the latest survey as slight scour (edge of multibeam echosounder coverage).

UKHO 10756 (**7674**) is listed as a "foul" of unknown identity and has not been observed since a survey in 1991. Although not observed on the geophysical data, the charted position is in the vicinity of a cluster of four magnetometer responses (between 17 and 24 nT), the closest located 100 m to the north-east.

UKHO 10501 (**7714**) is a wreck site considered to be "live" by the UKHO, but with no further information as to the vessel's identity. It was last surveyed in 1982 with an acoustic sensor as having an upright and intact bow. The charted position is situated beyond the limits of the multibeam echosounder data and was not observed on the side-scan sonar data.

5.4.4 Physical Region 3 – South

Physical Region 3 is the southernmost region and covers 1,172 km² and is delineated to the north by the central region, and to the east, south and west by the East Coast REC Study Area boundary. Approximately 260 km² (22%) of the seabed was covered by geophysics data. The area comprises a variety of geomorphological feature types and seabed sediments. However, no geophysics data were acquired in areas of sandbanks. Additionally, 6.8 km² of seabed was covered by data which lie outside the East Coast REC Study Area boundary. All data have been assessed, both within and outside the area boundary.

Within Physical Region 3 a total of 15 wrecks were identified, 14 of which were previously recorded by the UKHO (and NMR) and 1 previously uncharted. A further charted wreck was identified outside the East Coast REC Study Area but within the data coverage. A total of 25 wrecks recorded by the UKHO were not observed in the geophysics data (Table 5.9).

Physical Region 3	Sandbank	Sandwaves	Megaripple fields	Featureless seabed/ mobile sands	Total
Observed wrecks	0	6	2	7	15
Not observed wrecks	0	5	4	16	25

Table 5.9 **Number of wrecks within Physical Region 3.**

Sandwave fields

Sandwave fields are observed throughout Physical Region 3 and are dominant in the south-east corner of the East Coast REC Study Area. Seven wrecks were identified in areas of sandwave fields within this region, and all have been previously charted by the UKHO. All the observed wrecks have some sort of sediment build-up or partial burial of the wreck, as would be expected in an area of sandwaves.

Anomaly **7231** is a relatively small anomaly (7.2 × 4.4 × 0.7 m) that corresponds with the location of UKHO 10674. The anomaly is orientated N–S, protruding from an E–W-aligned sandwave. No structure or associated debris is apparent. The UKHO lists this as an unknown wreck with dimensions 35.5 × 5.6 × 4.1 m, as recorded in 1980. The wreck was not observed in 2007, being fully buried by the sandwave. The East Coast REC Study Area data indicate that sediment movement has exposed at least part of the wreck.

Anomaly **7237** is situated 23 m north-west of UKHO 10673 but is considered to be the same wreck. The wreck has dimensions of 36.4 × 17.1 × 2.5 m and is orientated NW–SE. There is no apparent structure or associated debris, and the wreck is almost completely buried. The UKHO lists this wreck as an unknown wreck of a trawler measuring 36.2 × 9.4 × 2.6 m and lying on its side when last observed in 1982. The increase in the width measurement of the site possibly indicates subsequent sediment build-up to the north and south of the wreck.

Anomaly **7238** (Figure 5.37) is a wreck aligned NW–SW with dimensions 50 × 13 × 6.2 m and a magnetometer response of 1,653 nT. The highest point of the wreck is towards the south; it decreases centrally then rises again to a lesser extent towards the north, which could suggest collapse. Some debris is observed to the south-west of the wreck. The western side of the wreck is partially buried. This anomaly corresponds to UKHO 10335, the possible wreck of the *Gypsy*, a yacht that sank in May 1941. It is listed by the UKHO as 35 × 10 × 5.0 m with a minimum water depth of 26.6 m and probably broken up. The difference in the length of the wreck between previous survey and that observed on the East Coast REC Study Area is probably due to sediment movement and exposure. The vessel is of low archaeological importance. However, the wreck shows typical characteristics of the wrecks observed within Physical Region 3.

Anomaly **7249** is a wreck with dimensions 27.4 × 7.5 × 2 m, orientated NW–SE. No structure is observed, and the wreck appears partially buried with significant sediment build-up, particularly to the east. Some minor scour is observed to the north. The wreck is situated 10 m west of UKHO 10390, and this is possibly the site of the British Hopper Barge *CD 14*, which sank in April 1973. A survey in 1982 recorded an intact vessel with a mast near the stern with dimensions 26.8 × 3.6 × 3.8 m. The differences in dimensions between 1982 and the latest data are probably due to increased sediment build-up around the wreck. This vessel is of low archaeological importance.

Anomaly **7252** is a wreck with dimensions 69.5 × 11.6 × 9.3 m, orientated N–S with a magnetometer response of 49 nT. The wreck is well defined and upright, but sediment build-up is observed to the north and south. Numerous sandwaves also impact the wreck site. Seabed scour is observed to the south-west and is up to 2.8 m deep. As such the height of the wreck above the average seabed is 6.5 m. This wreck correlates with UKHO 10962, the wreck of the SS *Lapwing* wrecked on 11 November 1917. The vessel was dived in 2005 and was identified as the SS *Lapwing*. Interestingly, prior to this diving evidence a wreck located 3 km to the east within an area of scarce bedforms/featureless seabed (UKHO 10954, **7696**) was thought to be the SS *Lapwing*. The location of this wreck was within the coverage of the geophysics data but was not observed (see below).

Anomaly **7734** has dimensions 74 × 15 × 5.5 m, orientated N–S. There is no associated scour, and the wreck is partially buried to the west. The wreck appears to be broken-up or collapsed. The UKHO charts this position as the wreck of the 1,546-ton British SS *Kenneth Hawksfield* (UKHO 10348) that sunk on 21 June 1941. With a cargo of coal, on passage to Dover from Blyth, the vessel struck a mine, and one man lost his life. The wreck was previously observed in 1995 with similar dimensions and appeared to be badly broken up with debris. This wreck is of medium archaeological importance.

A total of 5 UKHO listed wrecks were not identified in the geophysics data. Of these, 4 (**7670**, **7723**, **7724** and **7732**) were classified as “dead” and not observed, either due to poor positional information or because they are buried beneath sandwaves. One wreck not identified is classified by the UKHO as “live”. UKHO 10389 (**7682**) is an unknown wreck that was last surveyed in 1982 and recorded as upright, intact, with aft superstructure, but well buried. The position of the wreck is situated approximately 25 m outside the limits of the data; no evidence of this wreck or any debris was observed on the geophysics data.

Megaripple fields

Megaripple fields are generally situated in the west and east of Physical Region 3, although there is a small patch in the central region. A total of 2 wrecks were identified in megaripple fields, both observed as upstanding.

Anomaly **7248** (Figure 5.38) is an upstanding wreck aligned NE–SW with dimensions 63.3 × 14.5 × 6.4 m and an associated magnetometer response of 337 nT. Some slight scour to the north at 1.4 m depth is observed. This wreck correlates with UKHO 10349, the wreck of the British SS *Southford*, a 963-ton cargo vessel built in 1883 in Newcastle-upon-Tyne, by Campbell MacKintosh and Bowstead, with dimensions of 66 m in length, 9.5 m beam and a draught of 4 m. The vessel sank in dramatic circumstances with the loss of four lives on 25 of February 1916. While on course for Boulogne from the River Tyne, a violent explosion ripped apart a section of the midships, with the ship sinking quickly. All hands made it to a lifeboat on the portside; however, the boat was destroyed by the ship’s propeller, leaving the crew stranded. This vessel is of medium archaeological significance. The UKHO records the wreck as 75 × 10 × 2.2 m. The wreck was recorded as intact, lying upside down with little damage to the hull. The difference between the height recorded by the UKHO and the latest geophysics indicates sediment movement partially burying the wreck site and strong hydrodynamic forces in the area, indicated by the development of scour around the wreck.

Anomaly **7477** is a linear anomaly measuring 39.0 × 7.8 × 3 m, orientated approximately N–S. No structure is apparent on the side-scan sonar data. The position of the anomaly correlates with UKHO 10818, an unknown wreck measuring 30 × 6 × 3.8 m. The difference in the dimensions is significant, with the latest data indicating a larger wreck site than previously recorded.

The UKHO recorded 4 wrecks in this area that were not identified on the geophysics data. Of these, 1 is classified as “dead” (**7671**), and 3 are classed as live wrecks. **7703** (UKHO 11277) is the possible wreck site of the British steel sloop *Django***,** which sank in 1996 after taking on water in good weather, and has been charted with an approximate position by the UKHO; there has been no previous geophysics survey. However, it was not seen in the geophysical data-set. This could be due to the false position of the wreck, or the wreck could be buried; sandwaves and megaripples are observed in the area.

A further wreck not identified in the geophysics data is the possible wreck of the SS *Tidal* (**7720**, UKHO10388), a British vessel that was recorded to have foundered on 12 January 1922; it was surveyed in 1982 and recorded as upright. The recorded position is situated less than 5 m outside the limits of the geophysics data, but there was no evidence of either the wreck or associated debris in the geophysics data-set.

Finally, **7740** (UKHO 10707) is the possible wreck of the British HMS *Donside*, a trawler that struck a mine off Lowestoft on 7 January 1917. The wreck was previously observed in 1993, and the wreck site comprises an area of wreckage measuring 25 × 25 × 1.6 m. This site was not observed in the East Coast REC Study Area geophysics data, but may have been partially obscured in the data as the side-scan sonar towfish was towed directly over the top of the wreck.

Scarce bedforms/ featureless seabed.

Areas without bedforms (sandwaves, megaripples and sandbanks) are present throughout Physical Region 3. A total of 8 wrecks were identified in these areas, and a further wreck was identified outside of the East Coast REC Study Area but covered by the data. One wreck was previously unrecorded by the UKHO.

Anomaly **7247** is a relatively small wreck measuring 13.3 × 8.5 × 1.6 m. The wreck appears relatively intact and is of a regular shape. This position correlates with UKHO 10337, the wreck of a small barge, previously recorded as 23 × 6 × 2 m. A diving survey in 1998 observed that it was standing upright on the seabed and was starting to lose plates off the side of the vessel. This wreck is of low archaeological importance.

Anomaly **7253**, with dimensions 48 × 24 × 2.4 m, is a small wreck with some structure. This wreck is situated within 20 m of UKHO 10342, the wreck of the large Danish vessel SS *Farmatyr* lost to a mine in September 1916 with a cargo of coal, en route from South Shields to Rouen. This wreck is of medium archaeological importance.

Anomaly **7471** has dimensions of 85.5 × 11 × 4.0 m, with no discernible height, and is observed as a distorted dark reflector on the side-scan sonar data. The anomaly corresponds to the location of UKHO 10343, a wreck of unknown identity. The wreck was surveyed in 1993 with dimensions of 75 × 12 × 6.5 m, intact, with evidence of masts and superstructure.

Anomaly **7472** is small, with dimensions of 9.7 × 8.4 m, with no discernible height. The anomaly is circular in appearance and is diffuse in nature. This correlated with the location of UKHO 10856, an unknown wreck. It was originally examined in 1994 and had dimensions of 21 × 4 × 1.7 m; however, it was not observed in 1998. This possibly indicates continuing burial and exposure at this site. This highlights the effects of mobile sands even in areas where there are generally no bedforms.

Anomaly **7721** is a wreck with dimensions 61 × 26.8 m, with no discernible height, orientated N–S, and is observed on the side-scan sonar as an amorphous feature. It is situated at the location of UKHO 10387, an unknown wreck last surveyed in 1982 measuring 86.5 × 12 × 12 m and described then as partially buried. The discrepancy between the survey in 1982 and the recent survey may be due to further burial of the wreck.

Anomaly **7725** is a relatively small wreck measuring 38.0 × 15.0 × 5.5 m, orientated NE–SW. The wreck appears broken up, with two distinct strong reflectors possibly indicating pieces of wreck or debris. The wreck, which is situated on a sandwave, is charted as UKHO 10339, a small barge with a 50 ton crane that capsized and sank in September 1975 while on tow by the merchant tug *Moorcock*. Previous surveys indicate that there has been little change to the wreck site. This wreck has low archaeological importance.

Anomaly **7733** is observed as a small, intact upright wreck (35.7 × 7.1 × 2.3 m), orientated E–W. The wreck is partially obscured in the data as it was directly under the side-scan sonar towfish and is also partially buried by a sandwave, but some top structure was observed. This is the site of UKHO 10346, the HMS *Jessie Nutten*, a British trawler sunk on 4 September 1916. This wreck is of medium archaeological importance.

Anomaly **7755** is situated outside the East Coast REC Study Area but was observed in the multibeam echosounder data. The anomaly has dimensions of 20 × 9 × 1.5 m and is observed as a small mound orientated N–S. The anomaly is situated 12 m to the east of charted site UKHO 10338. This is the wreck site of the British SS *Mascotte*, sunk in September 1916 when it struck a mine laid by *UC-6*. The size of the vessel was originally 76.1 × 9.4 × 5 m, and previous surveys indicate a site of 40 × 8 × 2.7 m. The size observed in the East Coast REC Study Area data is further reduced, indicating that the site may have been covered by mobile sands.

Anomaly **7254** (Figure 5.39) is a previously uncharted wreck with dimensions of 30.7 × 21.6 × 3.7 m. The wreck is orientated NW–SE, with no apparent debris. Some possible scour to the east is observed with a depth of 1.1 m, making actual wreck height 2.6 m above average seabed. There is a high point to the south-east, with some sediment build-up to the north-east which may be partially burying the wreck. There is an associated slight, broad magnetometer response of 1.7 nT, indicating a possible wooden wreck with little ferrous material. The wreck is situated in an area of featureless seabed, but partial burial of the wreck and seabed scouring indicate some mobile sediments.

Within these areas, 16 wrecks were recorded by the UKHO that were not identified in the geophysics data. Of these, 8 are classified as “dead” (**7668**, **7697**, **7718**, **7722**, **7726**, **7741**, **7742** and **7753**) and have not been identified by the UKHO in recent surveys. Of the 8 classified as “live”, two are listed with unreliable positioning.

Two records (**7669**, UKHO 10705, and **7739**, UKHO 10706) of unknown wrecks are listed as having unreliable positions, and although they are situated within the coverage of side-scan sonar data, they were not observed.

The unknown wreck site **7683** (UKHO 10394) was surveyed in 1982 with dimensions 46.9 × 9.4 × 5.0 m, orientated N–S. This wreck is situated 15 m beyond the limits of the geophysics data, and no evidence of the wreck or any associated debris was observed within the data.

Wreck site **7696** (UKHO 10954) was listed by the UKHO as last surveyed by divers in 2006, who described the wreck as buried with parts showing. This was originally listed as the SS *Lapwing*; however, recent evidence now suggests that the remains of the SS *Lapwing* lie 3 km to the west within a sandwave field (**7252**, UKHO 10962, as described above). The buried vessel at the location of UKHO 10954 was not observed in the geophysics data, indicating that any remains are now fully buried.

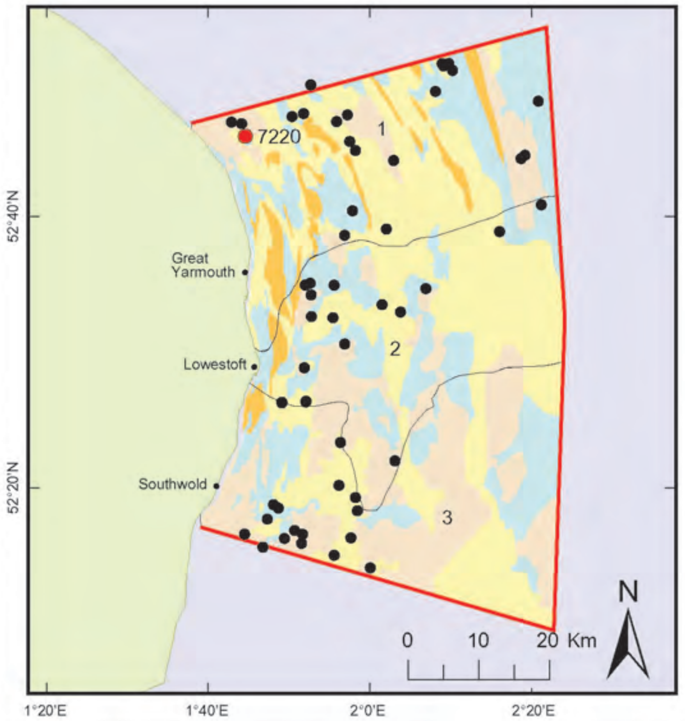
The unidentified wreck site **7727** (UKHO 10958) is described by the UKHO as an area of partially buried debris. A small sandwave was observed in the latest geophysics data but no direct evidence of any debris, indicating full burial of the site.

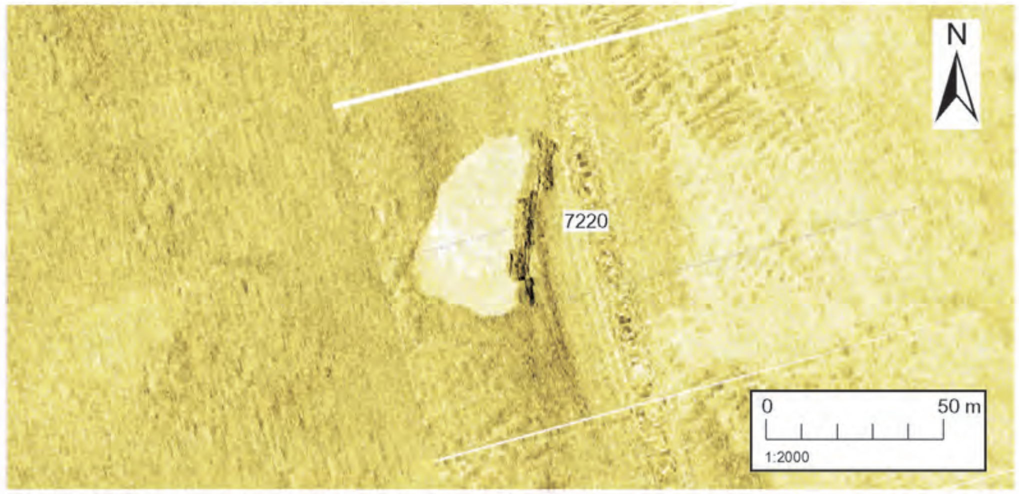
Unidentified wreck site **7744** (UKHO 10855) is described as an area of buried debris with height of 0.2 m; this was not observed in the latest geophysics data. Finally, **7745** (UKHO 10857) is described by the UKHO as a small (20 × 5 × 1.5 m) area of debris comprising iron bars, assumed to be the ballast of a wooden vessel. This was not observed in the latest geophysics data.

WA ID 7220 M/V *Marsworth* UKHO 10547

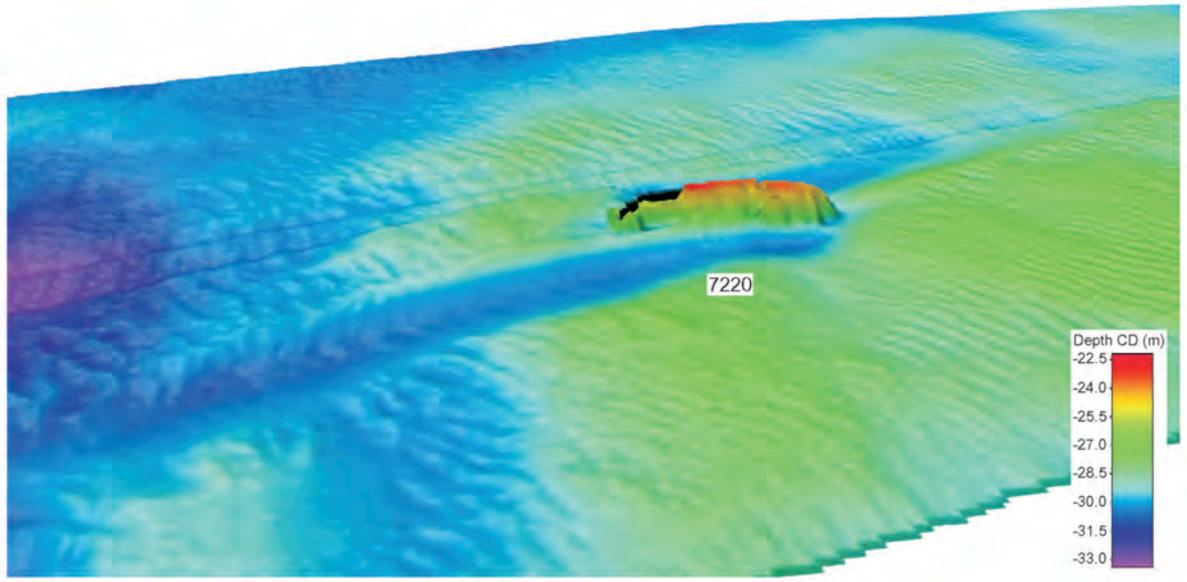
Location		414084 E, 5848385 N (UTM31N) 52 46.71 N, 01 43.58 E (WGS84)	**Region**	1
Archaeological Importance		Low		
Geophysical survey dimensions and notes		Dimension: 50.6 x 15.0 x 8.7 m. The wreck is orientated approximately north-south, situated in a large scour with actual height above average seabed 6.8 m. The wreck appears largely intact but with some indication of possible collapse. Some possible structure visible. No obvious debris associated with the wreck site.		
Build	**Type**	Motor vessel		
	Construction	Unknown		
	Dimensions	Unknown		
	Shipyard	Unknown		
Loss	**Cause**	Collision with French SS *Larrivet* in dense fog and later sank		
Extent of Survival		The wreck is recorded by the UKHO as having a minimum depth of 22.1 m and a general depth of 30 m. During a survey in 1994 the dimensions of the wreck were 40 m long and a height of 6.7 m with scour depth of 1.5 m. The ECREC data indicates that the wreck may have been futher exposed since 1994, accounting for the increase in observed length of the wreck.		
BGS Sediment Characterisation		Sandwave field; sandy gravel		

East Coast REC Study Area
Physical regions
Identified wreck locations
Geomorphology
Megaripples
Sand banks
Sand waves
Scarce bedforms / featureless, mobile sands





Mosaiced sidescan sonar image shows upstanding wreck.



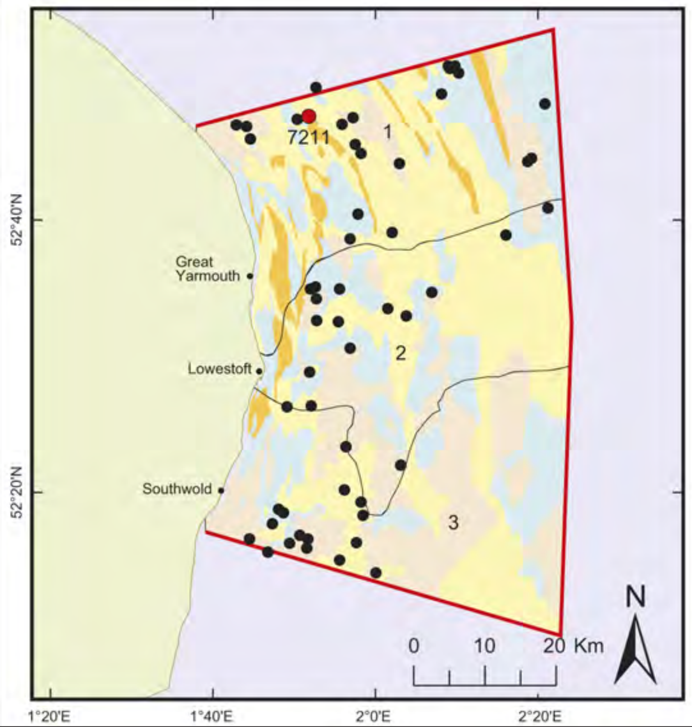
Multibeam echosounder image (looking west) shows upstanding wreck and seabed scour.

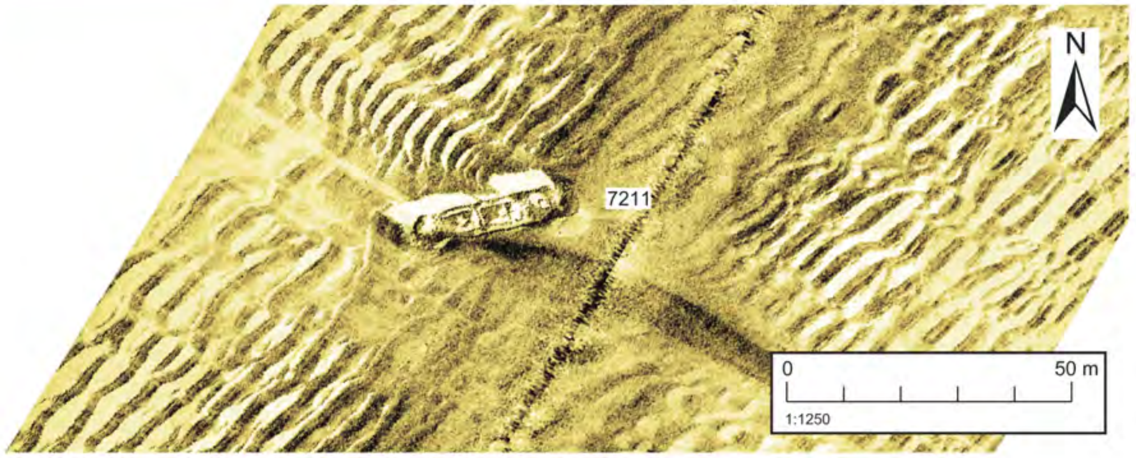
No magnetometer data acquired for this area.

Figure 5.28 WA ID 7720 – M/V *Marsworth*, UKHO 10547.

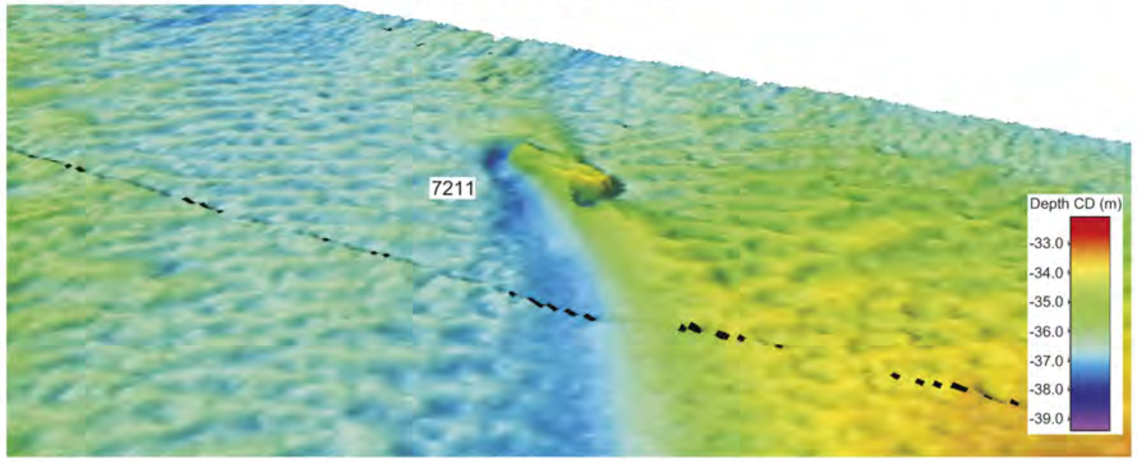
WA ID 7211	Uncharted wreck			
Location		422284 E, 5851572 N (UTM31N) 52 48.50 N, 01 50.82 E (WGS84)	Region	1
Archaeological Importance		Uncertain		
Geophysical survey dimensions and notes		Dimensions: 26.2 x 8.0 x 3.7 m. Wreck aligned east-west. Wreck is situated in scour, approximately 0.5 m deep with wreck 3.2 m above general seabed depth. Wreck is well-defined to west and possibly partially buried to northwest. No observed debris associated with the wreck. Magnetometer response of 689 nT.		
Build	Type	Unknown		
	Construction	Unknown		
	Dimensions	Unknown		
	Shipyard	Unknown		
Loss	Cause	Unknown		
Extent of Survival		Wreck largely intact with partial burial observed. Situated within an area of sandwaves and megaripples so there is a possibility of buried debris surrounding the wreck.		
BGS Sediment Characterisation		Sandwave field; sandy gravel		

East Coast REC Study Area
Physical regions
Identified wreck locations
Geomorphology
Megaripples
Sand banks
Sand waves
Scarce bedforms / featureless, mobile sands

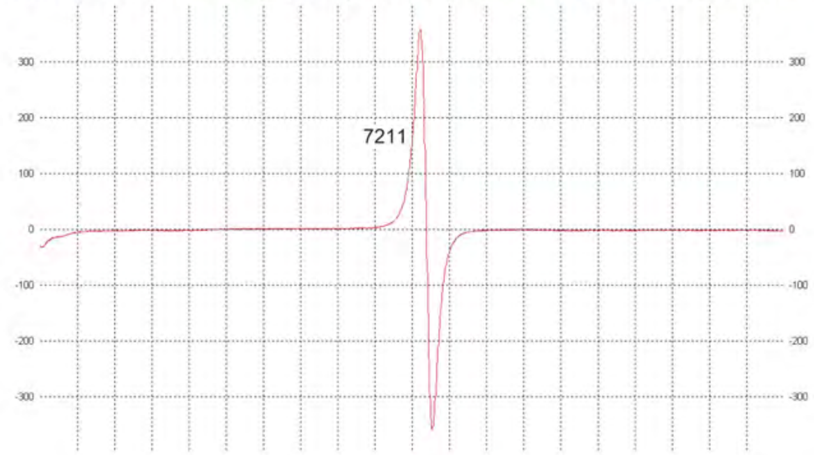




Mosaiced sidescan sonar image shows upstanding intact wreck, with scour.



Multibeam echosounder image (looking northwest) shows intact wreck and seabed scour.



Magnetic profile shows an anomaly of 689 nT.

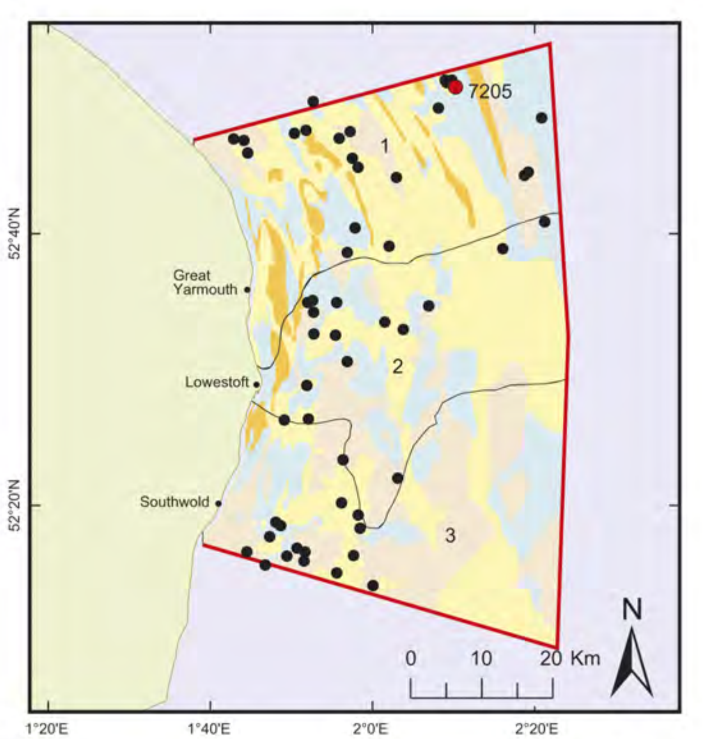
Figure 5.29 **WA ID 7211 – Uncharted wreck.**

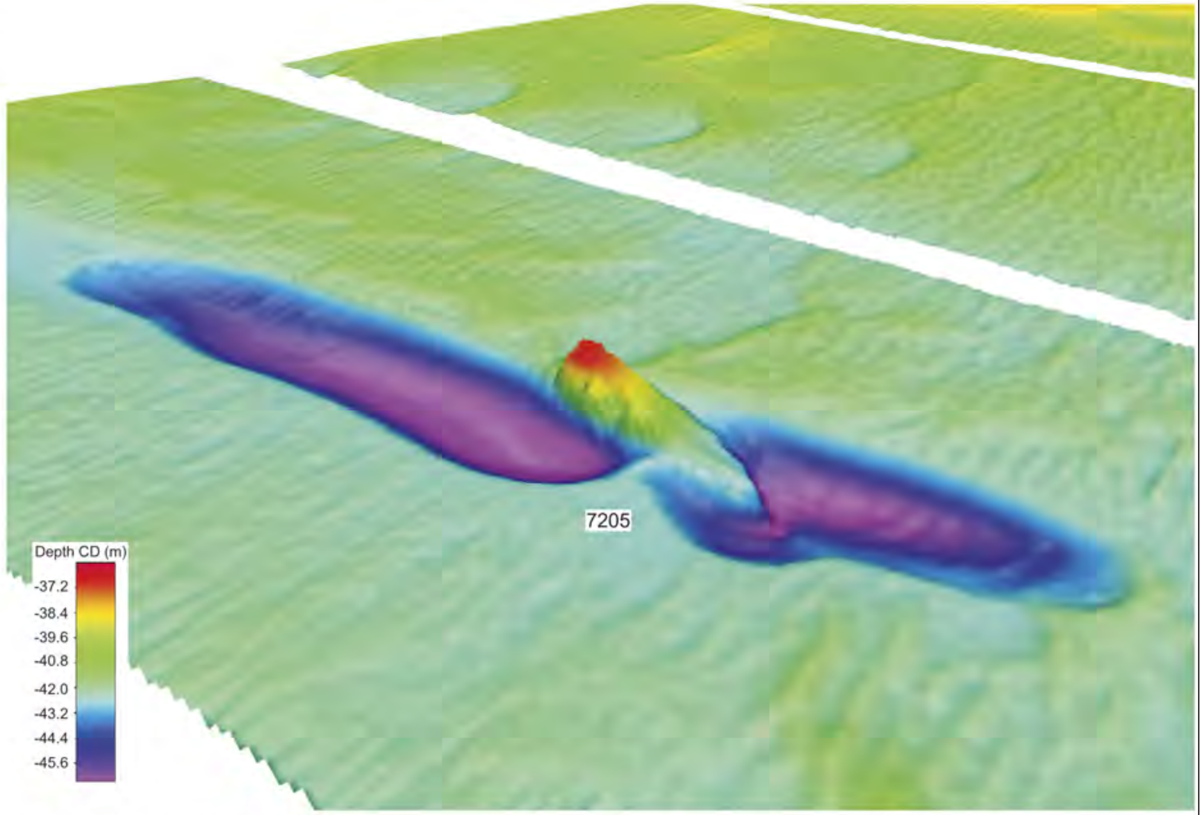
Marine Aggregate Levy Sustainability Fund MALSF

WA ID 7205 - SS *Horseferry* UKHO 11130

Location		443330 E, 5857658 N (UTM31N) 52 51.94 N, 02 09.49 E (WGS84) — Region: 1
Archaeological Importance		Medium
Geophysical survey dimensions and notes		Dimensions: 58.3 x 24.1 x 10.6 m. Wreck orientated north-south and is a regular oval shaped wreck. Highest point of 5.6 m above the average seabed to south with gradual slope to north to approximately 0.8 m. Situated in large associated scour approximately 235 m long, 29 m wide and up to 5 m deep. No apparent associated debris.
Build	Type	Merchant steamship
	Construction	Steel
	Dimensions	66.1 x 9.8 x 4.1 m
	Shipyard	J Crown & Sons Ltd, Sunderland
Loss	Cause	Torpedoed and sunk by German E-Boat while on passage from the Tyne to London
Extent of Survival		UKHO records the wreck as 62 x 14 x 10 m, orientated north-south. Diving survey indicated that the wreck was inverted and intact, with debris field around wreck. The ECREC multibeam echosounder data shows no structure, as would be expected from an inverted vessel and the vessel remains intact.
BGS Sediment Characterisation		Megaripple field; gravelly sand

East Coast REC Study Area
Physical regions
Identified wreck locations
Geomorphology
Megaripples
Sand banks
Sand waves
Scarce bedforms / featureless, mobile sands





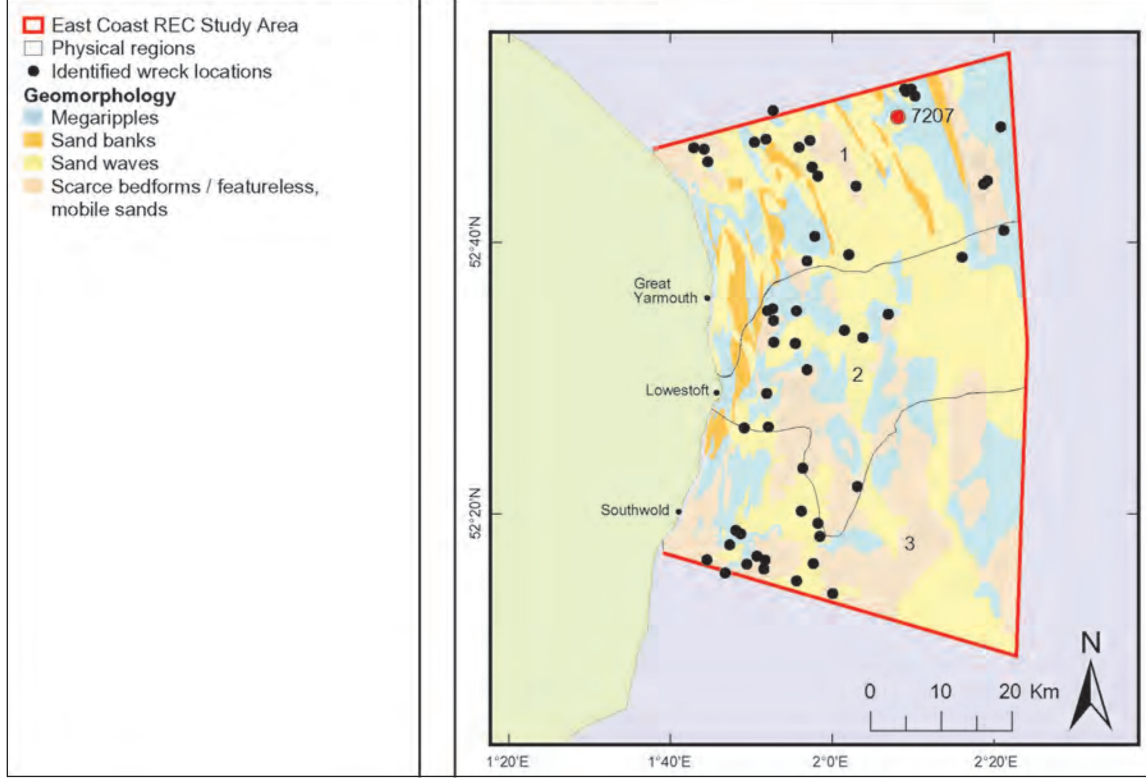
Multibeam echosounder image (looking northeast) shows intact, upright wreck and seabed scour.

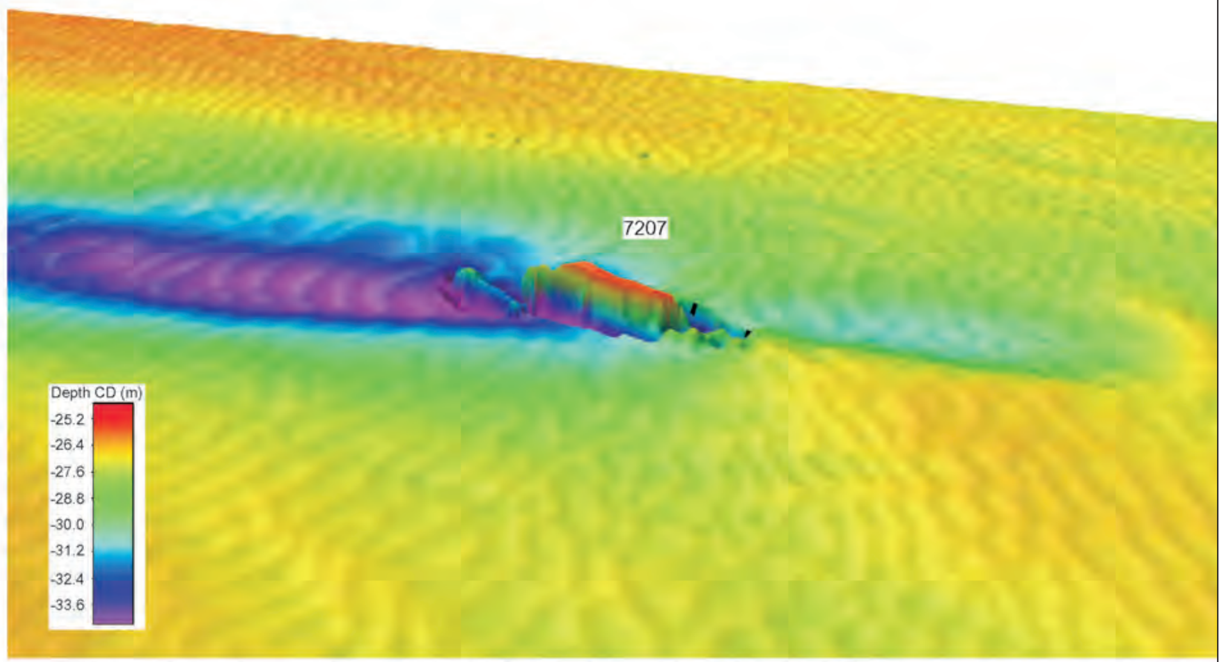
No sidescan sonar or magnetometer data acquired for this area.

Figure 5.30 **WA ID 7205 – SS *Horseferry*, UKHO 11130.**

WA ID 7207 - SS *Aruba* UKHO 11119

Location		440922 E, 5854706 N (UTM31N) 52 50.33 N, 02 07.38 E (WGS84) — **Region** 1
Archaeological Importance		Medium
Geophysical survey dimensions and notes		Dimensions: 77.0 x 17.8 x 12.2 m. The wreck is orientated approximately north-south with a height of 5.6 m above average seabed. Height mostly continuous to south but decreases by around 5 m to north. Upstanding structure, northern end could be separate debris as appears to be a small break in structure. Only observed on multibeam echosounder data (no sidescan sonar or magnetometer data acquired for this area).
Build	**Type**	Steamer (collier)
	Construction	Steel
	Dimensions	70 x 10.3 x 4.0 m
	Shipyard	Wilton Maschinefabriek & Schepswerf N.V, Rotterdam
Loss	**Cause**	Torpedoed by German E-Boat
Extent of Survival		UKHO records the wreck as 59 x 15 x 6 m, orientated north-south, appearing whole within a deep scour. The ECREC multibeam echosounder data shows two sections to the wreck.
BGS Sediment Characterisation		Megaripple field; sand





Multibeam echosounder image (looking northeast) shows broken, upright wreck and seabed scour.

No sidescan sonar or magnetometer data acquired for this area.

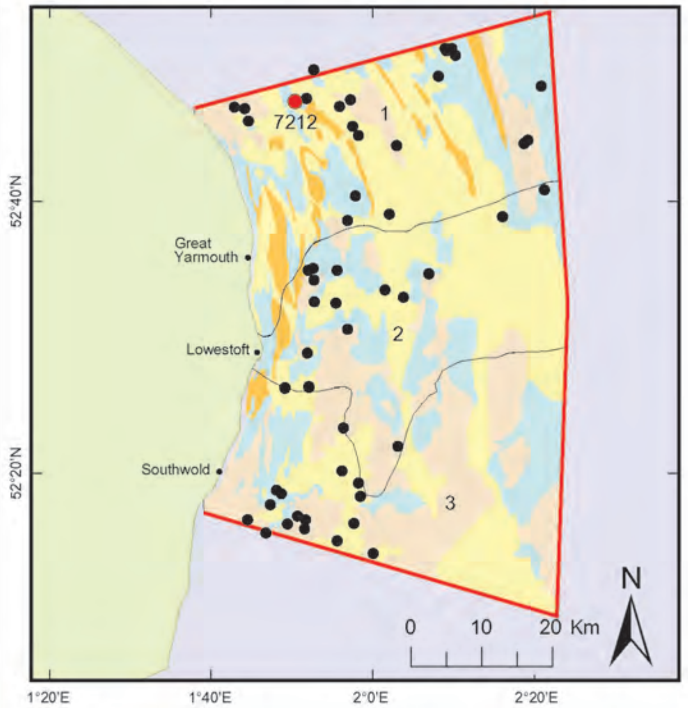
Figure 5.31 **WA ID 7207 – SS *Aruba*, UKHO 11119.**

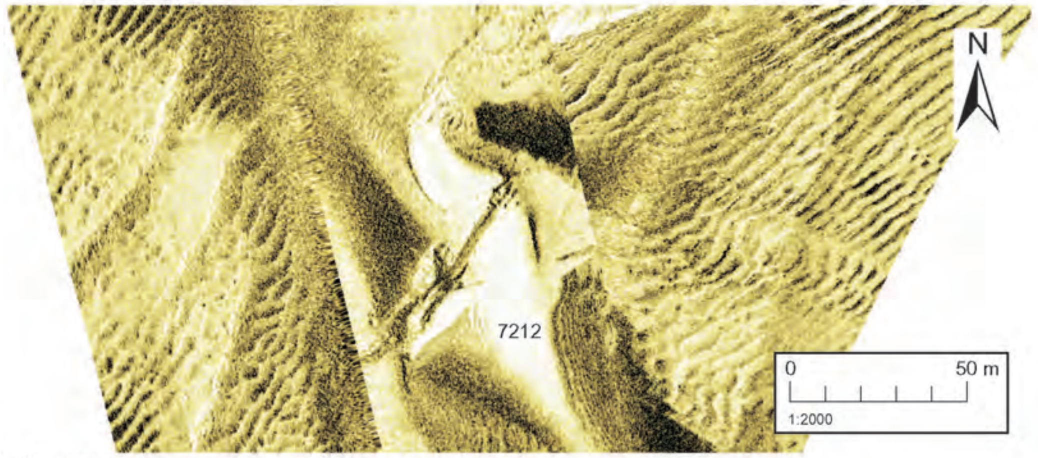
Marine Aggregate Levy Sustainability Fund MALSF

WA ID 7212 Uncharted wreck

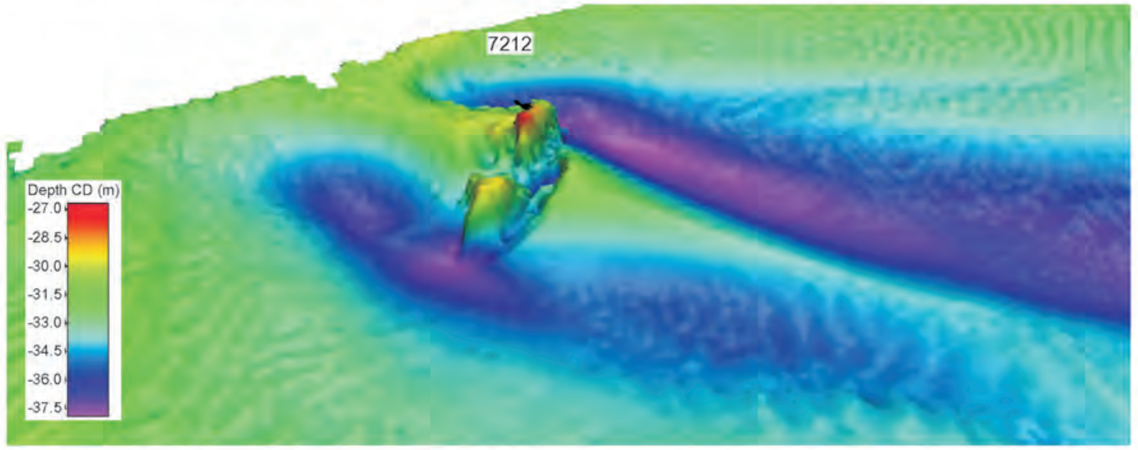
Location		420658 E, 5851148 N (UTM31N) 52 48.26 N, 01 49.38 E (WGS84)	Region	1
Archaeological Importance		Uncertain		
Geophysical survey dimensions and notes		Dimensions: 62.5 x 12.5 x 10.8 m. Wreck orientated northeast-southwest and situated within a large sandwave approximately 3 m high and as such full extent is difficult to discern. Height of wreck approximately 5.5 m above general seabed. Two high points situated at each end of wreck. Some structure observed. Magnetic response 1212 nT. No apparent debris associated with the wreck. Possible scour/depression approximately 5.3 m deep, from 27 m wide to west and up to 60 m wide to east.		
Build	Type	Unknown		
	Construction	Unknown		
	Dimensions	Unknown		
	Shipyard	Unknown		
Loss	Cause	Unknown		
Extent of Survival		Wreck is partially buried within sandwave and appears relatively intact. Its burial may be the reason why this wreck has not previously been observed. Associated debris not observed but may be buried by sandwave and megaripples in the area.		
BGS Sediment Characterisation		Megaripple field; gravelly sand		

East Coast REC Study Area
Physical regions
Identified wreck locations
Geomorphology
Megaripples
Sand banks
Sand waves
Scarce bedforms / featureless, mobile sands

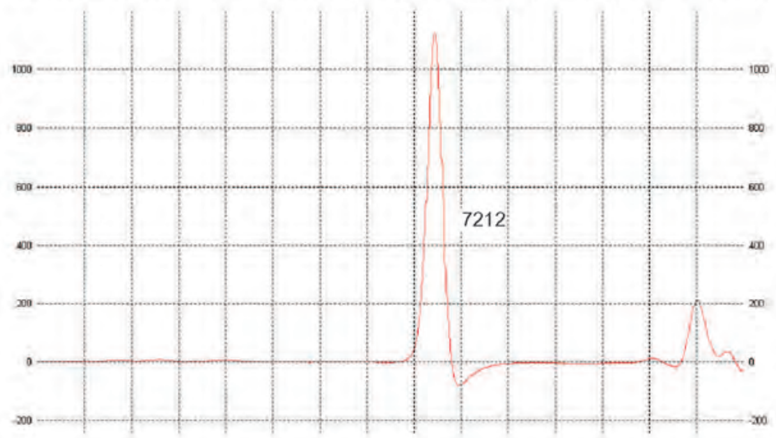




Mosaiced sidescan sonar image shows upstanding wreck.



Multibeam echosounder image (looking northeast) shows upstanding wreck and seabed scour.

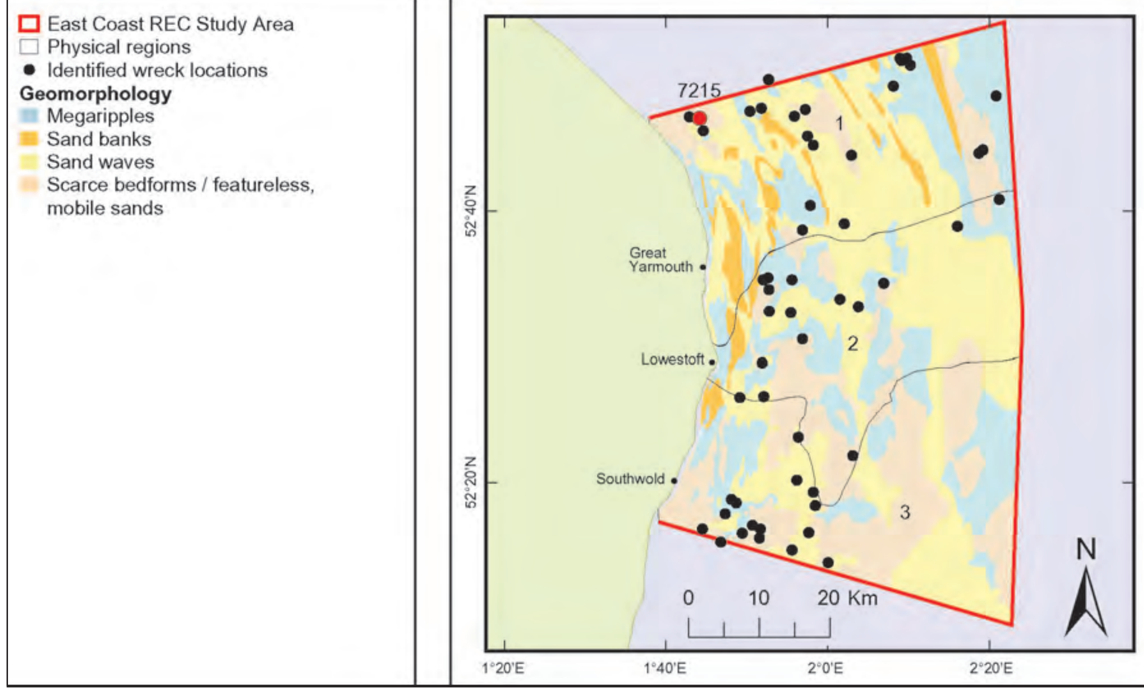


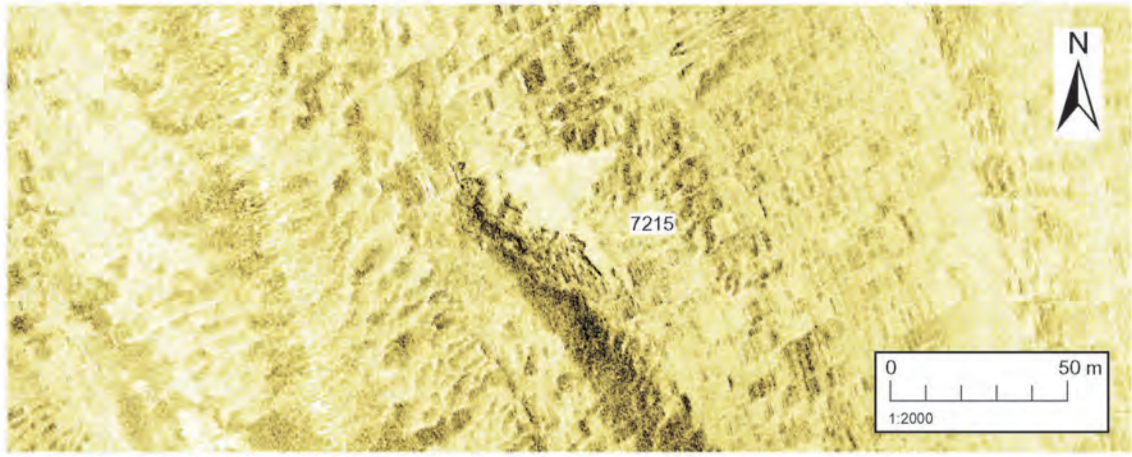
Magnetic profile shows an anomaly of 1212 nT.

Figure 5.32 WA ID 7212 – Uncharted wreck.

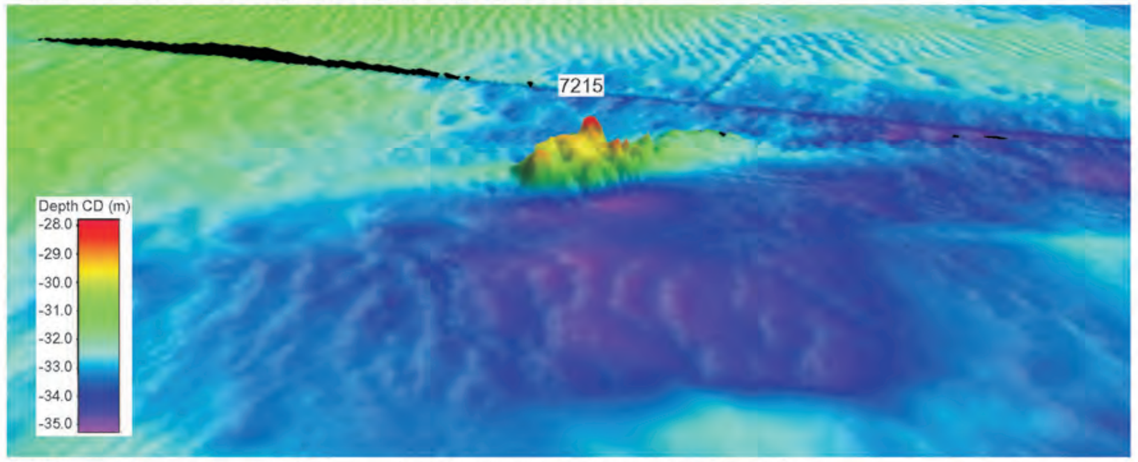
WA ID 7215 - SS *Seagull* UKHO 10550

Location		413548E, 5850143 N (UTM31N) 52 47.65 N, 01 43.07 E (WGS84)	**Region**	1
Archaeological Importance		High		
Geophysical survey dimensions and notes		Dimensions: 52.0 x 13.1 x 5.4 m. Wreck orientated northwest-southeast. There is some sediment build up to northwest and the southeastern end appears to be partially buried. Large depression to southwest approximately 1.7 m deep and over 100 m wide. Magnetometer response of 824 nT. Structure undefined, some possible related debris. Situated 30 m west of the charted UKHO position.		
Build	**Type**	Two-masted steam paddle schooner		
	Construction	Wooden hull with iron fittings		
	Dimensions	52.1 x 7 m		
	Shipyard	Coates and Young, Belfast		
Loss	**Cause**	Collision with SS *Swan* bound for Rotterdam from Hull		
Extent of Survival		The UKHO record this wreck with a length of 40 m and a height of 8.6 m from a survey in 1983. A more recent diving survey in 1994 found the remains of paddle wheels and a ships bell was recovered. The wreck has metal hill plates with only the decking visible. The wreck has collapsed. The ECREC data indicates that the wreck is 30 m west of the UKHO listed position, but it is considered to be the same wreck. The wreck is situated in an area of featureless seabed but in a dynamic area with possible mobile sands, which may account for the difference in observed length and height between 1984 and 2008.		
BGS Sediment Characterisation		Scarce bedforms/ featureless seabed; sandy gravel		

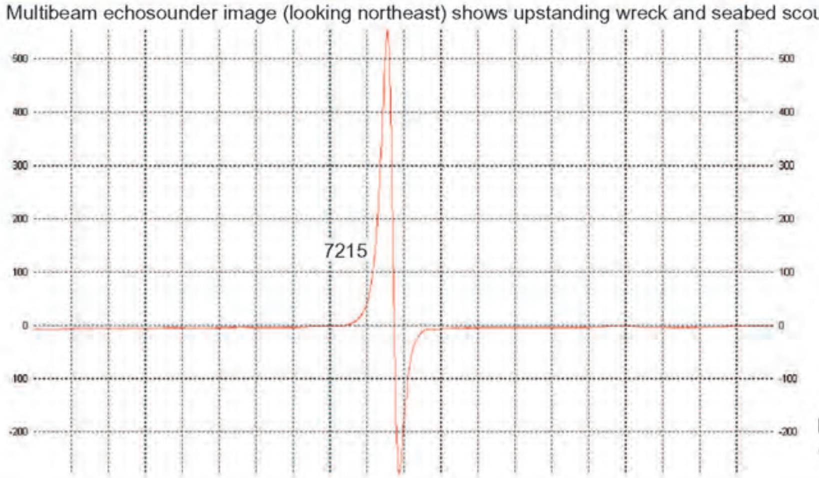




Mosaiced sidescan sonar image shows upstanding wreck.



Multibeam echosounder image (looking northeast) shows upstanding wreck and seabed scour.



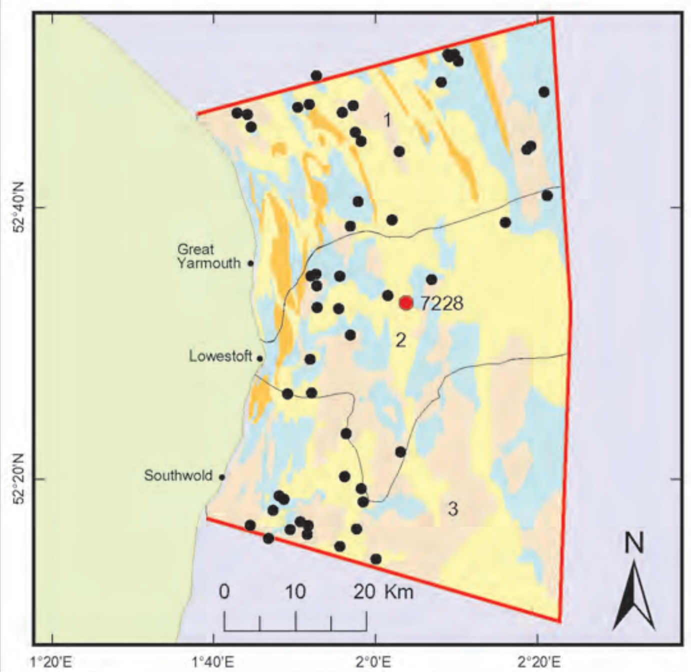
Magnetic profile shows an anomaly of 824 nT.

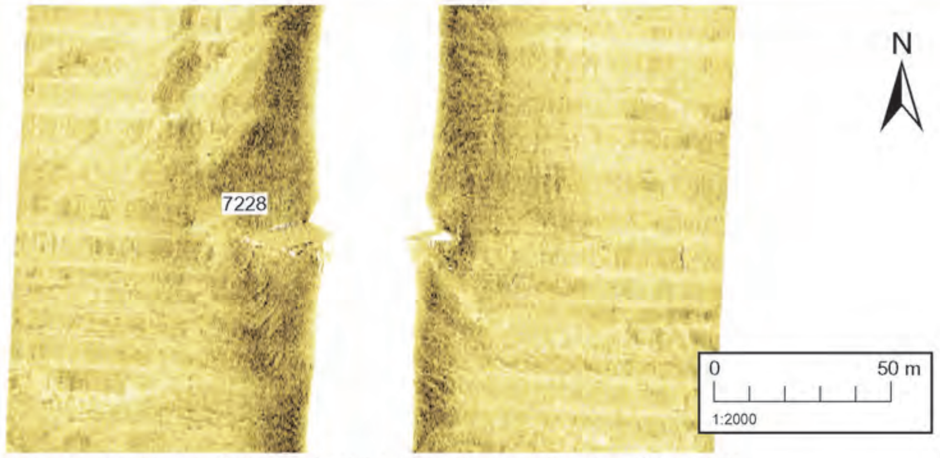
Figure 5.33 **WA ID 7215 – SS *Seagull*, UKHO 10550.**

WA ID 7228 - SS *Cornmead* UKHO 11031

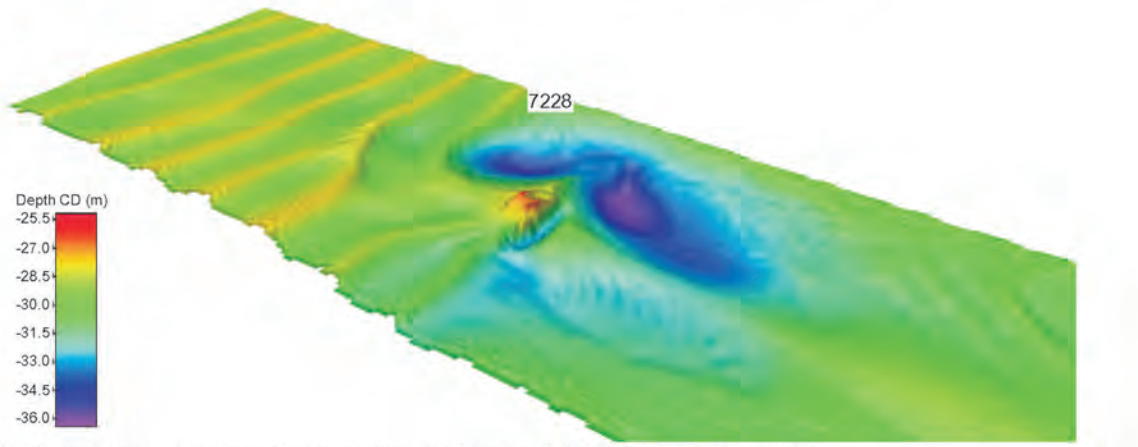
Location		435972 E, 5823539 N (UTM31N) 52 33.49 N, 02 03.33 E (WGS84)	**Region** 2
Archaeological Importance		Medium	
Geophysical survey dimensions and notes		Dimensions: 42.5 x 12.0 x 10.2 m. The wreck is orientated east-west and is partially buried by a sandwave. Although 10.2 m high, the wreck height above seabed is only 4.4 m as wreck is situated in a scour up to 5.5 m deep, with scour mostly to east. No obvious structure, appears to be some sediment build-up to north. No apparent associated debris. Large magnetometer response of 2373 nT.	
Build	**Type**	Steam ship	
	Construction	Unknown	
	Dimensions	Unknown	
	Shipyard	Unknown	
Loss	**Cause**	Mined on passage from London to the Tyne	
Extent of Survival		The UKHO records this wreck as 86 x 16 x 6.3 m, orientated east-west and appeared to be decayed with little structure remaining. In 1971 a diving survey observed the wreck to be lying north-northeast to south-southwest virtually as sunk except masts and light superstructure dragged down by fishermans nets and tides with no sign of sinking damage. The reduction in the size of the wreck observed in the ECREC data is probably due to increased build up of sediments around the wreck site.	
BGS Sediment Characterisation		Sandwave field; slightly gravely sand	

East Coast REC Study Area
Physical regions
Identified wreck locations
Geomorphology
Megaripples
Sand banks
Sand waves
Scarce bedforms / featureless, mobile sands

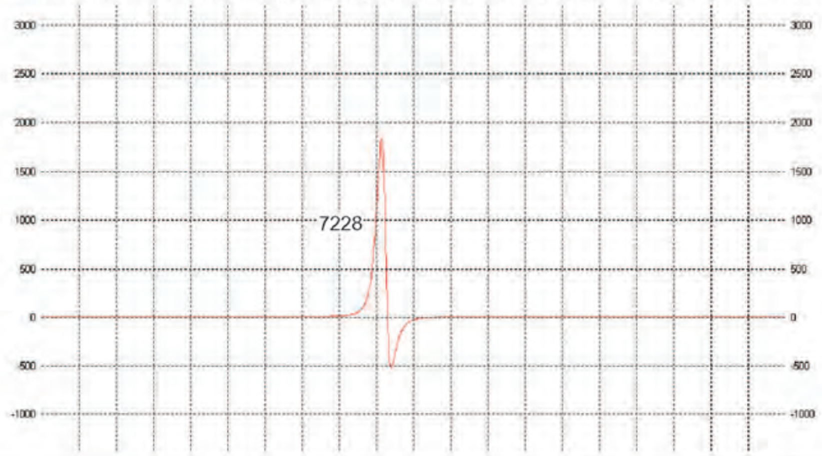




Mosaiced sidescan sonar image shows partially buried wreck (water column intentionally not removed).



Multibeam echosounder image (looking southwest) shows partially buried wreck and seabed scour.

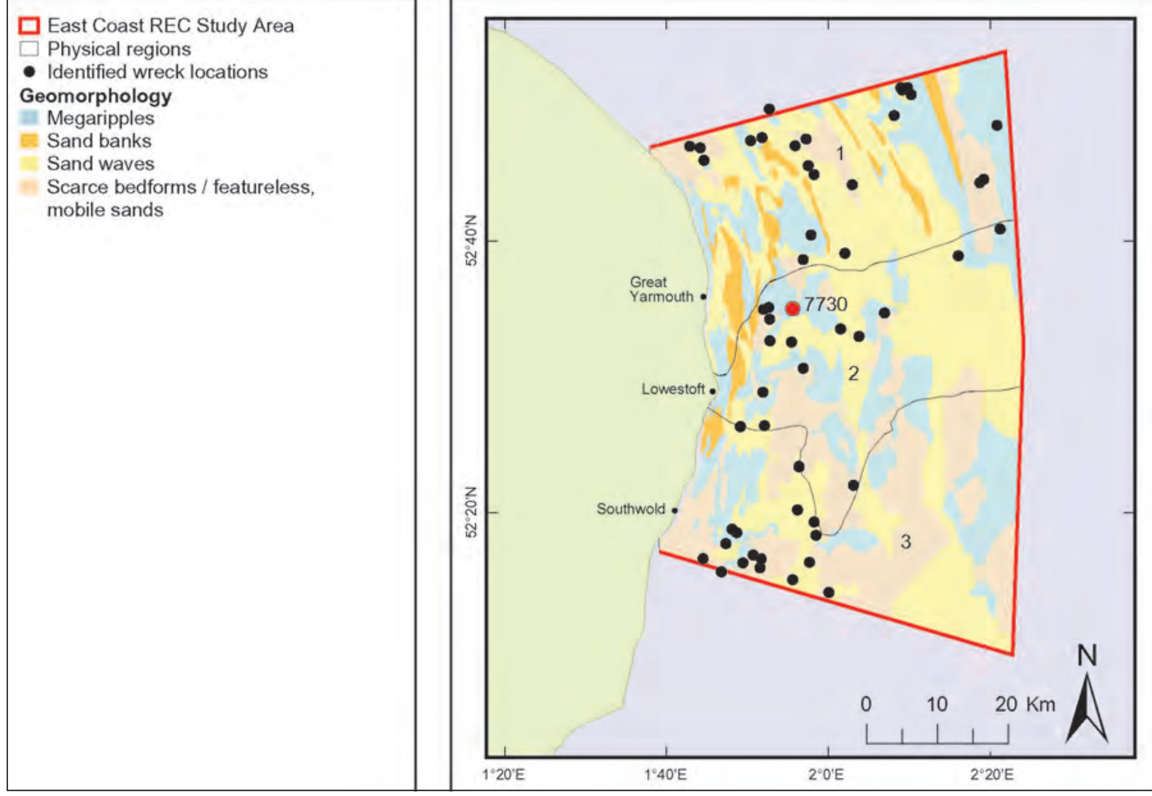


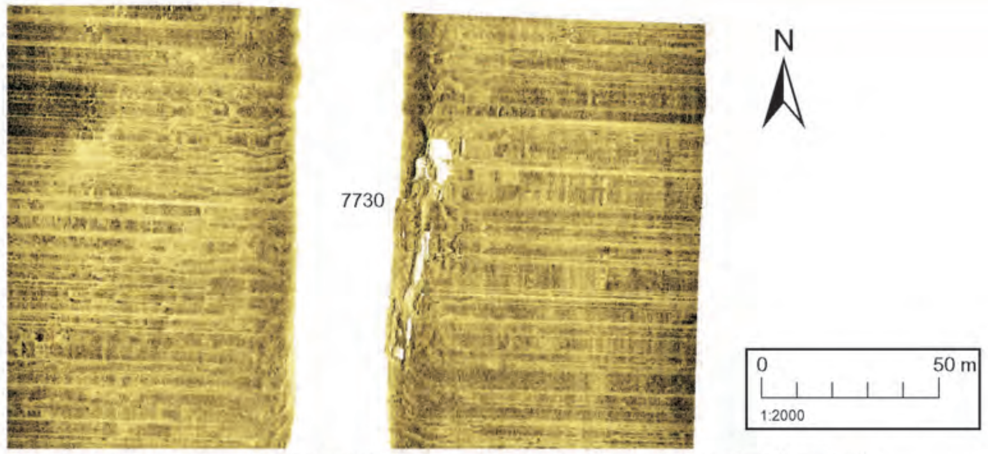
Magnetic profile shows an anomaly of 2373 nT.

Figure 5.34 **WA ID 7228 – SS *Cornmead*, UKHO 11031.**

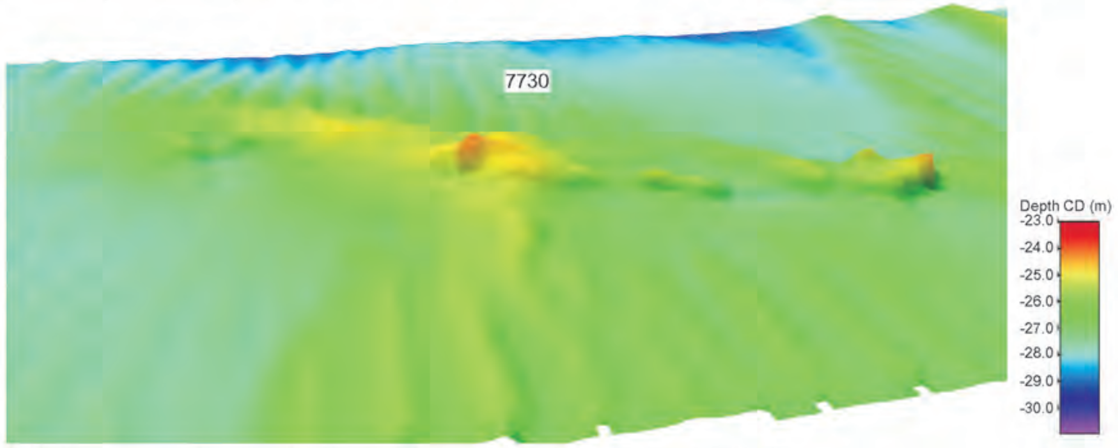
WA ID 7730 - Unknown wreck UKHO 10480

Location		426600 N, 5827326 N (UTM31N) 52 35.46 N, 01 54.99 E (WGS84)	Region	2
Archaeological Importance		Uncertain		
Geophysical survey dimensions and notes		Dimensions: 93 x 17 x 2 m. Mound orientated approximately north-south. The multibeam echosounder data indicates partial burial with no obvious scour. Sidescan sonar data indicates very broken up wreck with limited height. Associated high magnetometer anomaly of 6722 nT.		
Build	Type	Unknown		
	Construction	Unknown		
	Dimensions	Unknown		
	Shipyard	Unknown		
Loss	Cause	Unknown		
Extent of Survival		Listed by the UKHO as 98.9 x 11.6 x 6.3 m with minimum depth of 24 m. In 1991 a survey listed that the wreck was upright with a silted up stern and bow with the bridge smashed and a jumble of girders. In 1982 the wreck was partially covered by a sand ridge.		
BGS Sediment Characterisation		Meggaripple field; slightly gravelly sand		

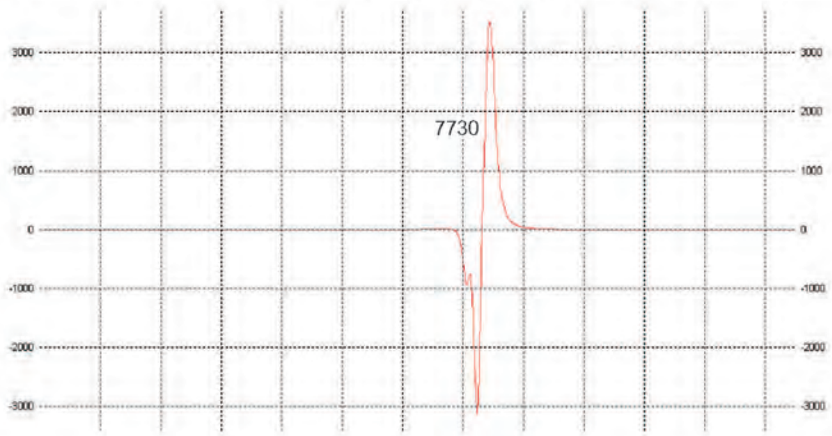




Mosaiced sidescan sonar image shows broken up wreck (water column intentionally not removed)



Multibeam echosounder image (looking west) shows partially buried wreck and seabed scour.

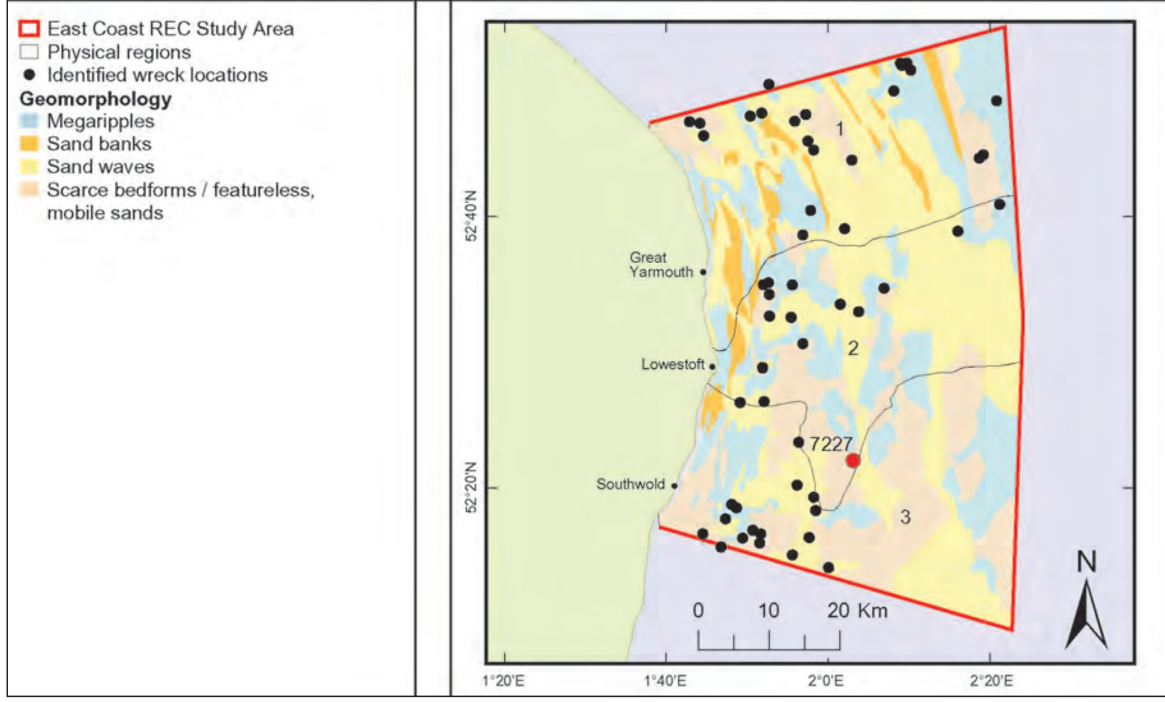


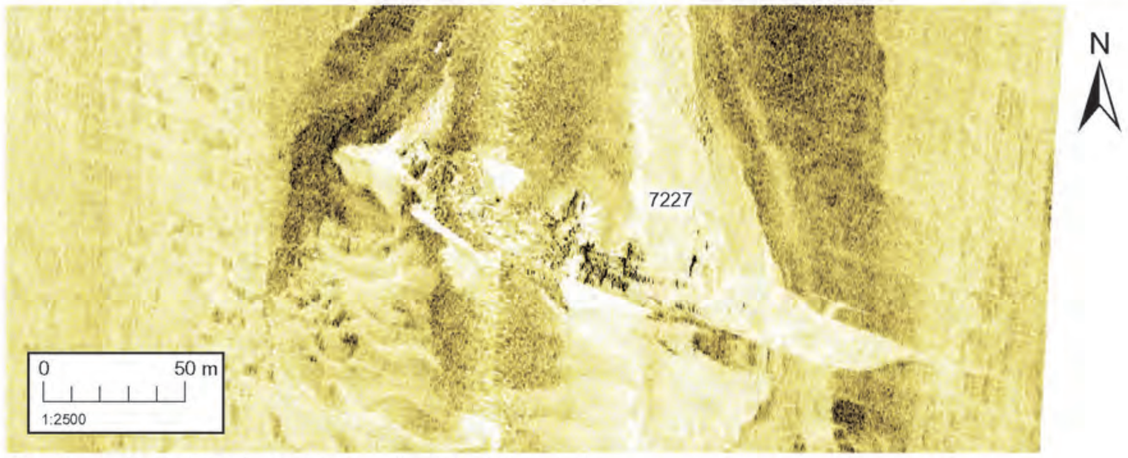
Magnetic profile shows an anomaly of 6722 nT.

Figure 5.35 WA ID 7730 – Unknown wreck, UKHO 10480.

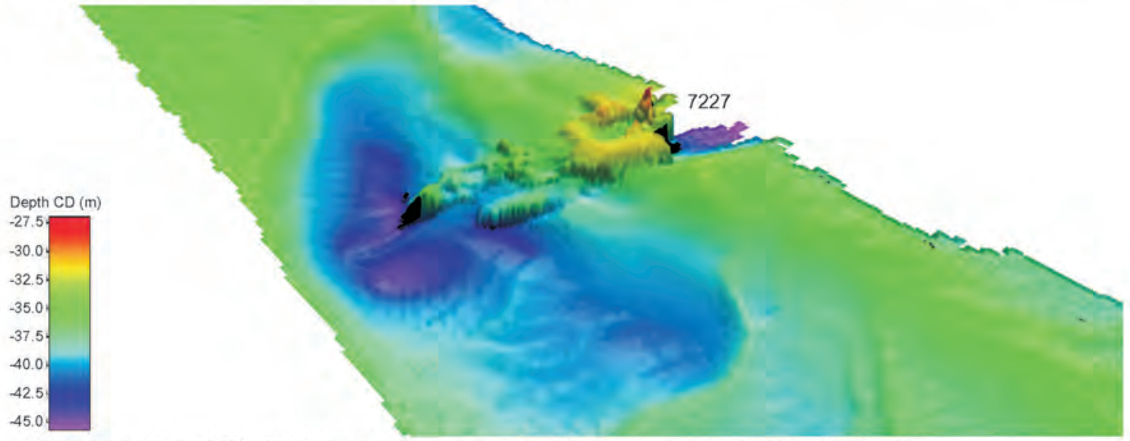
WA ID 7227 - SS *Stad Alkmaar* UKHO 10992

Location		435190 E, 5802594 N (UTM31N) 52 22.19 N, 02 02.88 E (WGS84)	**Region** 2
Archaeological Importance		Medium	
Geophysical survey dimensions and notes		Dimensions: 92.5 x 42.8 x 14.6 m (wreck site). Wreck orientated northwest-southeast situated in scour up to 8 m deep. Height of wreck 6.6 m above general seabed. Actual width of wreck is 27 m, with associated debris observed surrounding the wreck. Some structure observed with some evidence of partial burial in the central section. Large magnetometer response of 4548 nT.	
Build	**Type**	Steam ship (cargo)	
	Construction	Unknown	
	Dimensions	134 x 18 x 7 m	
	Shipyard	Wilton Feijenoord N. V, Rotterdam	
Loss	**Cause**	Torpedoed & sunk by German E-boat, whilst en-route from Santa Cruz to London	
Extent of Survival		UKHO records a wreck of 130 x 20 x 12 m situated in a scour up to 7 m deep. Minimum depth of 19.8 m water depth. The wreck is intact and upright. The difference in the recorded length and the ECREC data may be due to either sediment build up, or more likely due to sidescan sonar shadow obscuring true length.	
BGS Sediment Characterisation		Scarce bedform/ featureless seabed; sandy gravel	

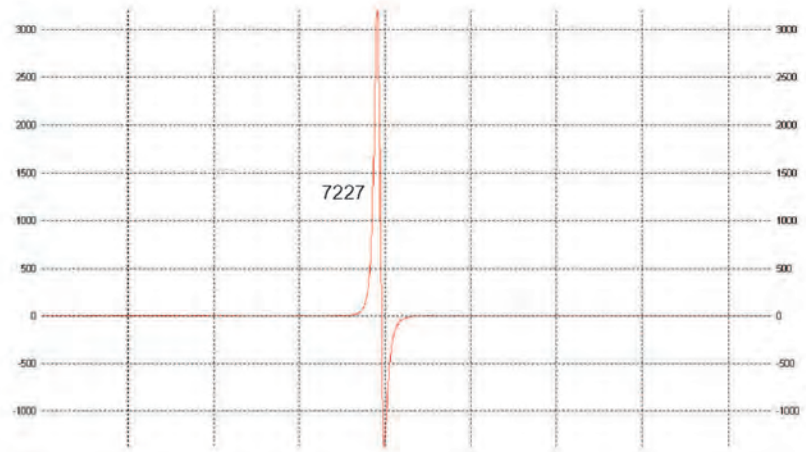




Mosaiced sidescan sonar image shows upstanding, broken wreck.



Multibeam echosounder image (looking northeast) shows upstanding, broken wreck and seabed scour.



Magnetic profile shows an anomaly of 4548 nT.

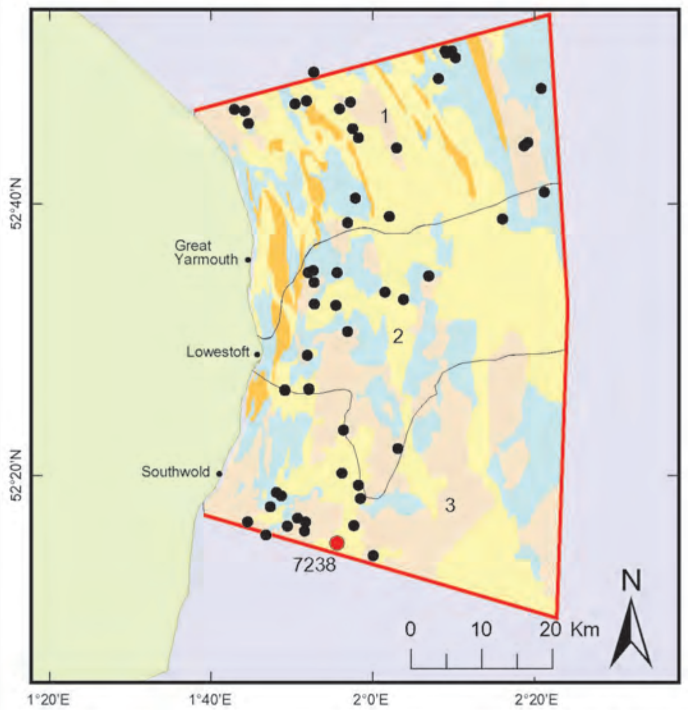
Figure 5.36 WA ID 7227 – SS *Stad Alkmaar*, UKHO 10992.

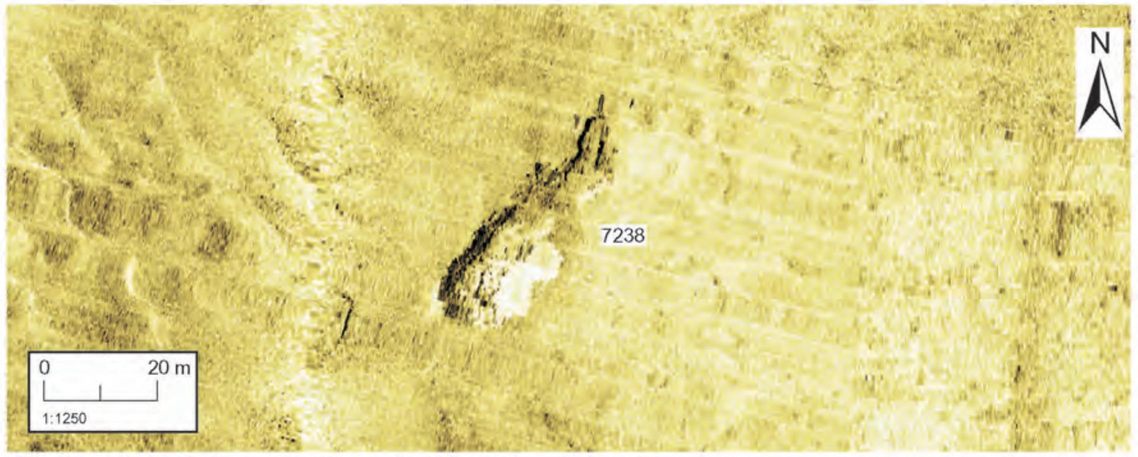
Marine Aggregate Levy Sustainability Fund MALSF

WA ID 7238 - *Gypsy* UKHO 10335

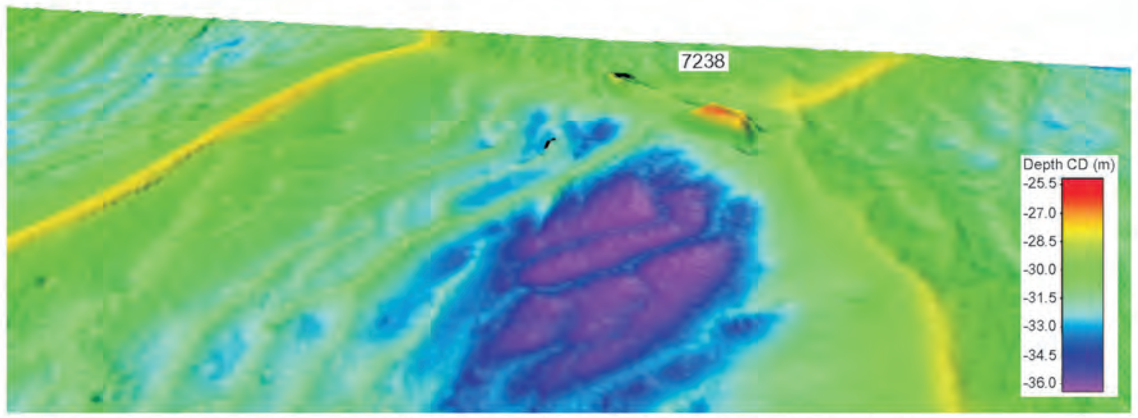
Location		426612 E, 5789267 N (UTM31N) 52 14.93 N, 01 55.50 E (WGS84)	**Region**	3
Archaeological Importance		Low		
Geophysical survey dimensions and notes		Dimensions: 50.0 x 13.0 x 6.2 m. The wreck is orientated northwest-southwest. Highest point of wreck towards south, decreases centrally then rises again to a lesser extent towards north, which could suggest collapse. Some apparent debris to southwest. Sandwaves to south around 4.9 m above average seabed depth, and sediment build-up to southeast around 4.3 m. Magnetometer response of 1653 nT.		
Build	**Type**	Yacht		
	Construction	Unknown		
	Dimensions	Unknown		
	Shipyard	Unknown		
Loss	**Cause**	Unknown		
Extent of Survival		This wreck is listed by the UKHO as 35 x 10 x 5.0 m with a minimum water depth of 26.6 m and probably broken up. The difference in the length of the wreck between previous survey and that observed on the ECREC area is probably due to sediment movement and exposure.		
BGS Sediment Characterisation		Sandwave field; gravely sand		

East Coast REC Study Area
Physical regions
Identified wreck locations
Geomorphology
Megaripples
Sand banks
Sand waves
Scarce bedforms / featureless, mobile sands

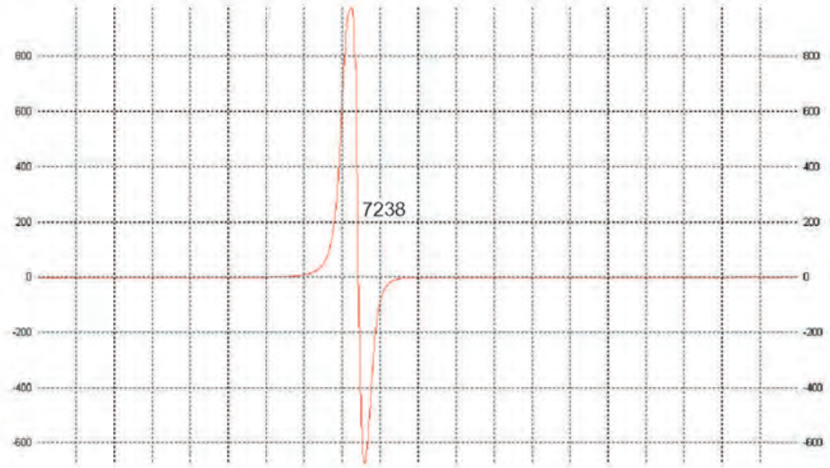




Mosaiced sidescan sonar image shows upstanding wreck.



Multibeam echosounder image (looking east) shows upstanding wreck, seabed scour and sandwaves.

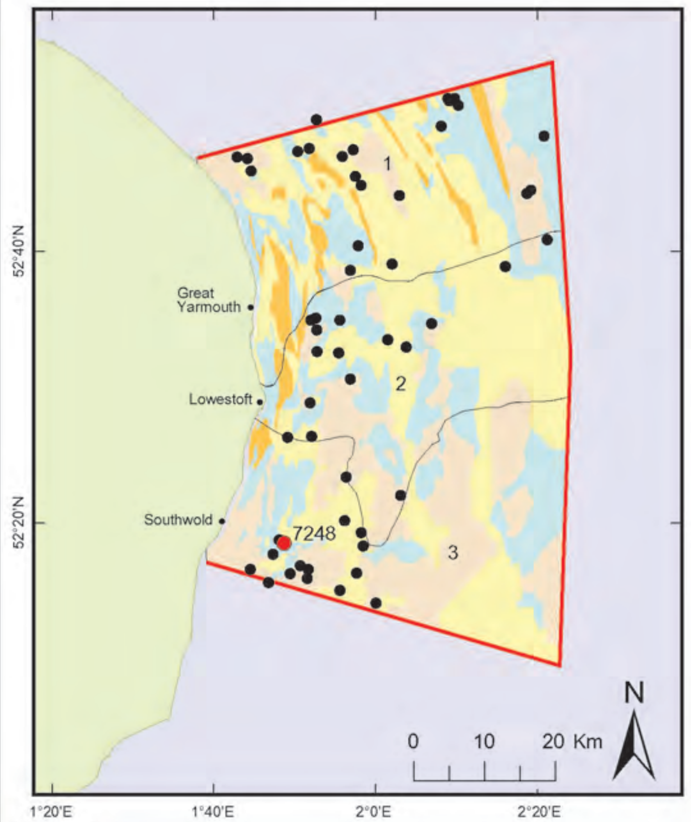


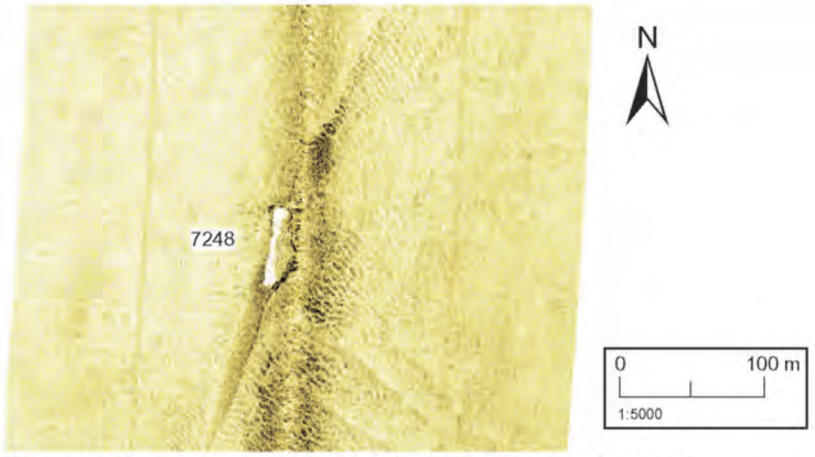
Magnetic profile shows an anomaly of 1653nT.

Figure 5.37 WA ID 7238 – *Gypsy*, UKHO 10335.

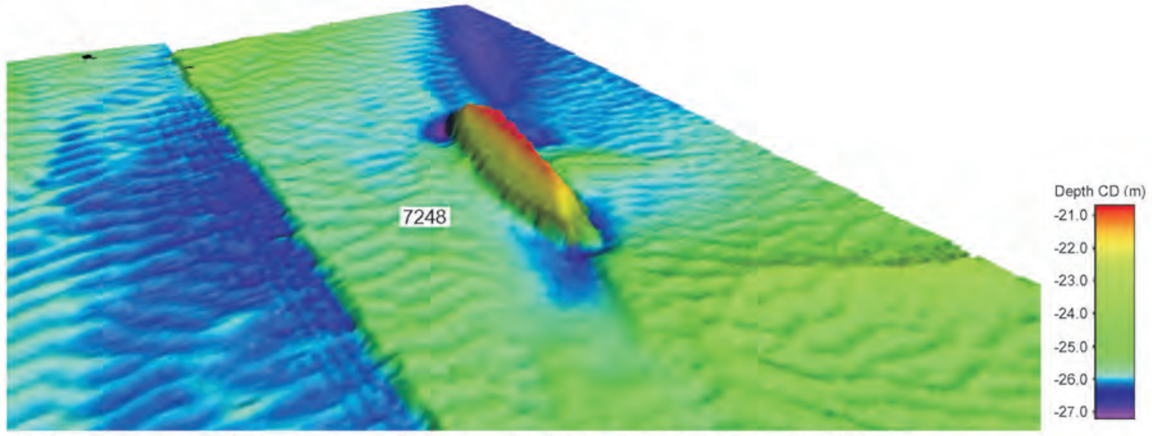
WA ID 7248 - SS *Southford* UKHO 10349

Location		418726 E, 5795914 N (UTM31N) 52 18.45 N, 01 48.47 E (WGS84)	**Region**	3
Archaeological Importance		Medium		
Geophysical survey dimensions and notes		Dimensions: 63.3 x 14.5 x 6.4 m. Upstanding wreck aligned northeast-southwest. Some slight scour to north at 1.4 m depth. No obvious debris and seabed rippled in vicinity. Magnetometer response of 337 nT.		
Build	**Type**	Steam ship (cargo)		
	Construction	Iron		
	Dimensions	65.9 x 9.5 x 4.1 m		
	Shipyard	Campbell, Macintosh & Brownstead, Newcastle upon Tyne		
Loss	**Cause**	Struck a mine on course for Boulogne from the River Tyne		
Extent of Survival		The UKHO records the wreck as 75 x 10 x 2.2 m with a minimum water depth of 20.5 m. The wreck was recoded as lying intact, lying upside down with little damage to the hull.		
BGS Sediment Characterisation		Megaripple fields; sandy gravel		

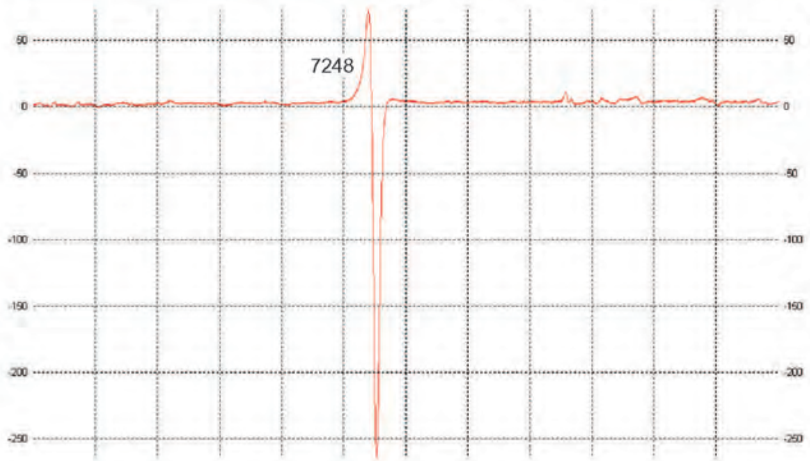




Mosaiced sidescan sonar image shows upstanding wreck and seabed scour.



Multibeam echosounder image (looking east) shows upstanding wreck, seabed scour and megaripples.



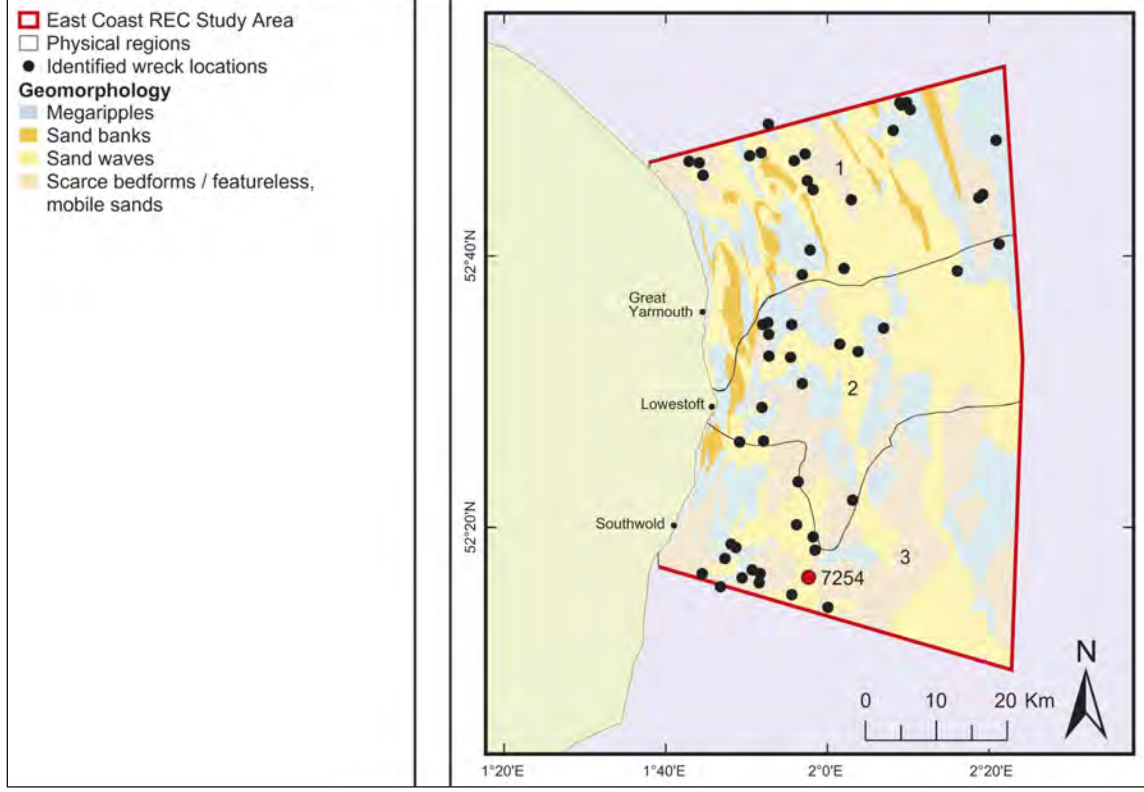
Magnetic profile shows an anomaly of 337 nT.

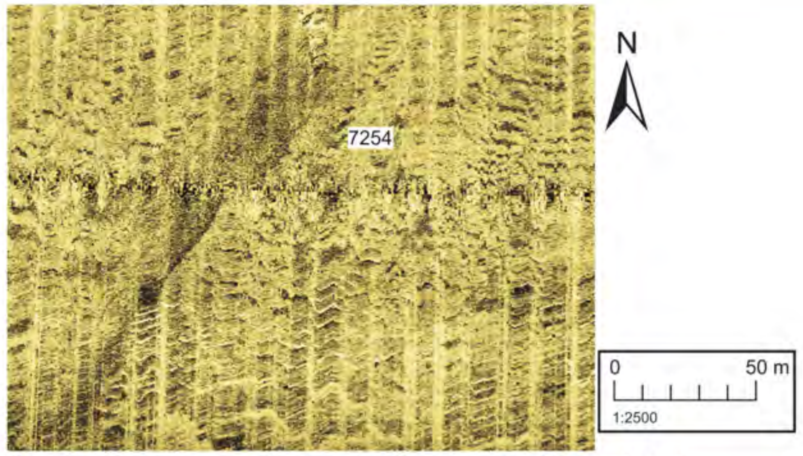
Figure 5.38 **WA ID 7248 – *SS Southford*, UKHO 10349.**

Marine Aggregate Levy Sustainability Fund MALSF

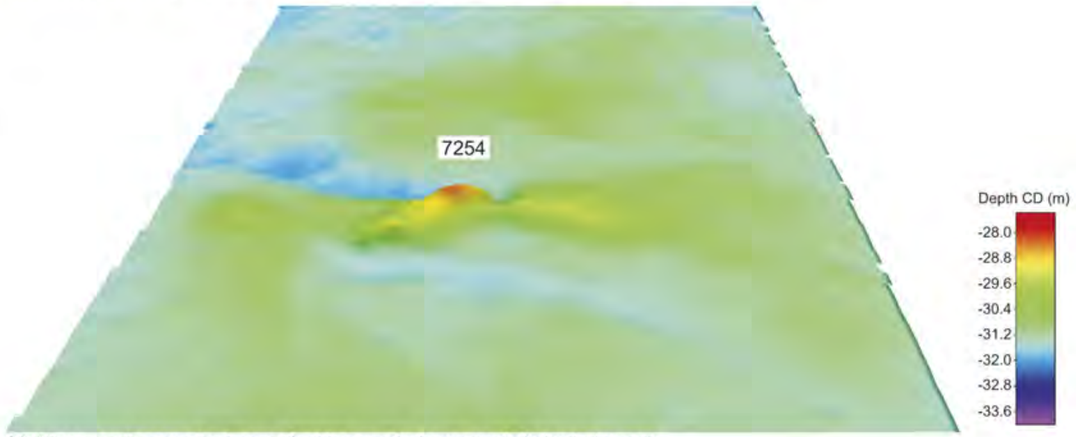
WA ID 7254 - *Uncharted wreck*

Location		428969 E, 5791721 N (UTM31N) 52 16.28 N, 01 57.54 E (WGS84)	Region: 3
Archaeological Importance		Uncertain	
Geophysical survey dimensions and notes		Dimensions: 30.7 x 21.6 x 3.7 m. Wreck orientated northwest-southeast with no apparent debris. Some possible scour to east with depth of 1.1 m, making actual wreck height 2.6 m above average seabed. High point to southeast with some sediment build-up to northeast which may be partially burying wreck. Slight broad magnetometer response of 1.7 nT indicating possible wooden wreck with little ferrous material.	
Build	Type	Unknown	
	Construction	Unknown	
	Dimensions	Unknown	
	Shipyard	Unknown	
Loss	Cause	Unknown	
Extent of Survival		Wreck situated in area of featureless seabed but partial burial of the wreck and seabed scouring indicates some mobile sediments.	
BGS Sediment Characterisation		Scarce bedform/ featureless seabed; sandy gravel	

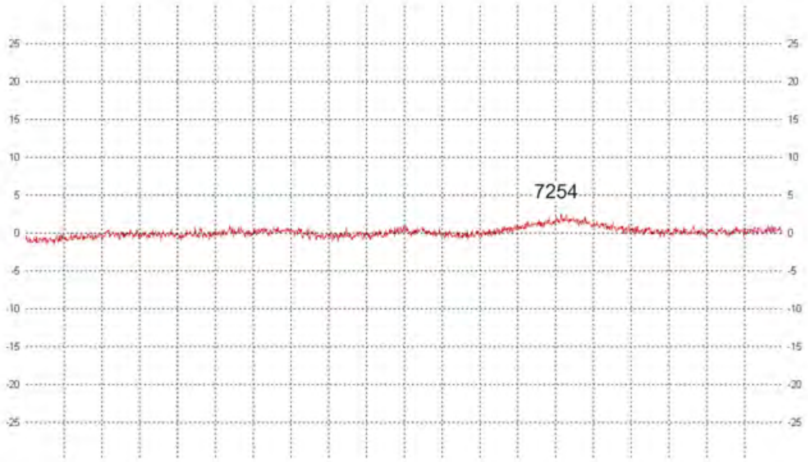




Mosaiced sidescan sonar image shows upstanding wreck with seabed scour.



Multibeam echosounder image (looking east) shows partially buried wreck.



Magnetic profile shows a small broad anomaly of 1.7 nT.

Figure 5.39 **WA ID 7254 – Uncharted wreck.**

5.4.5 Other geophysical anomalies

In addition to the wrecks identified within the East Coast REC Study Area, the assessment of the geophysical data identified 407 further anomalies of possible anthropogenic origin (Table 5.10, Figure 5.40).

As it is often difficult to assess the anthropogenic or archaeological potential of an anomaly, these descriptions are not, on their own, definitive. A single small but prominent anomaly may be part of a much more extensive feature that is largely buried. Similarly, a scatter of minor anomalies may define the edges of a buried but intact feature, or it may be all that remains as a result of past impacts on a once larger site – for example, from dredging and fishing. It is possible that these anomalies may be associated with vessel or aircraft wreck sites or debris. Aircraft wreck sites are discussed in detail in Section 5.5.

Some of these anomalies may prove to be natural or of modern origin and would require further investigation, either by a more detailed geophysical survey or by diver or remotely operated vehicle (ROV) inspection, in order to accurately assess their archaeological potential.

Bright reflectors are identified on the side-scan sonar data and are anomalies of low reflectivity. Bright reflectors indicate areas where little or no acoustic energy is returned to the side-scan sonar towfish and can be characteristic of shadows behind upstanding

Feature	Physical Region 1	Physical Region 2	Physical Region 3	Total
Bright reflectors	5	1	3	9
Dark reflectors	9	3	12	24
Debris	13	6	8	27
Magnetometer	116	96	103	315
Mound	11	6	1	18
Seafloor disturbance	8	3	3	14
Total	162	115	130	407

Table 5.10 **Geophysical anomalies in the East Coast REC Study Area.**

Figure 5.40 **Distribution of geophysical anomalies in the East Coast REC Study Area.**

features, certain sediment types, or material that absorbs the acoustic energy such as waterlogged wood. Only those that are thought to be of anthropogenic nature are of potential archaeological interest.

The bright reflectors in the geophysical data were identified in a variety of geomorphological regions (featureless seabed, sandwave fields and megaripple fields) and were generally associated with areas of sandy gravel, sand and gravelly sand. Examples of bright reflectors are illustrated in Figure 5.41.

A total of 27 dark reflectors were identified on the side-scan sonar data and are observed as areas of high reflectivity. These areas may be objects with or without height and can be observed as amorphous features or well defined. There is no correlation between the dark reflector anomalies and the geomorphological type or seabed sediment classification. Examples of dark reflectors are illustrated in 5.41.

Debris are objects on the seabed, generally exhibiting height or with evidence of structure that are potentially anthropogenic. A total of 27 debris features were observed in the geophysical data, situated within a variety of geomorphological types and seabed sediments. Examples of debris are illustrated in Figure 5.42.

Two debris features (**7202** and **7208**) have corresponding UKHO records. Feature **7202** is observed on the geophysics data as an upstanding (1.3 m high) circular feature measuring 9 × 8 m. The corresponding UKHO record (UKHO 11245) is listed as an obstruction and interpreted as notable debris measuring 17 × 9 × 3 m orientated approximately N–S, possibly associated with nearby wreck UKHO 11133 (**7203**) which is situated approximately 260 m to the south-east. It could also be associated with UKHO 11131 (**7204**), situated around 200 m to the north of the debris. However, it is also possible that this represents an isolated piece of debris.

Feature **7208** was observed on the data as a NW–SE-orientated feature measuring 3.7 × 3.1 × 0.4 m. This is situated in a large depression (20 × 9 m) approximately 20 m to the south-west of UKHO 10852. UKHO 10852 is recorded as probable debris measuring 3 × 2 × 1 m. Given the similar dimensions and the close proximity, it is considered that **7208** and UKHO 10852 describe the same feature.

Although the majority of debris observed indicates isolated features, there are also debris fields situated close to identified wrecks with which they may be associated (**7253**, **7388** and **7623**).

Feature **7660** (Physical Region 1) is a large feature (44.1 × 12.9 × 4.3 m) orientated N–S, situated within an area of sandwaves. Although there is no visible structure, it is possible that this is a feature of anthropogenic origin, either debris or a possible wreck (based on its size alone). It is considered unlikely that the feature is geological, however, as the sandwave crests are generally aligned E–W, unlike the feature's alignment of N–S.

A total of 18 mounds were identified in the geophysics data. A mound can be described as a mounded feature with height that is not considered a natural feature. Mounds may form over wrecks or other debris, either on the seafloor or partially buried, but they do not show any structure indicating their contents.

Two identified mounds have corresponding UKHO records. Feature **7221** is situated in Physical Region 1 in an area of scarce bedforms/featureless seabed and was observed on the edge of the multibeam data measuring 8 × 4 × 0.7 m, with no apparent scour or debris. The feature is orientated E–W and appears quite mound-like, which suggests that it may be at least partially buried if it is a feature of anthropologenic origin. The mound is situated approximately 10 m south of UKHO 10850, which is described as a small item of debris or possible well-head (2 × 2 × 2.5 m). The mound possibly represents the burial of this feature.

Feature **7275** is a rounded mound (39 × 18 × 1 m) situated in Physical Region 1 in an area of megaripples. The feature lies approximately 10 m north of UKHO 11244 which is recorded as debris covering an area of 5 × 5 × 1.9 m. Nothing was observed in the geophysical data at the UKHO position, and it is possible that the mound represents the burial of this area of debris. The remainder of the mounds are isolated features with no correlation with any recorded features.

Within the East Coast REC Study Area, 14 features described as seafloor disturbances were recorded. A seafloor disturbance is an area of seabed that appears disturbed, potentially by a buried or partially buried wreck or debris of archaeological interest. These types of features may be groups of what is apparently debris or may be more ephemeral and consist solely of a patch of bright and dark reflectors distinct from the surrounding seabed. Examples of seabed disturbances are illustrated in Figure 5.42.

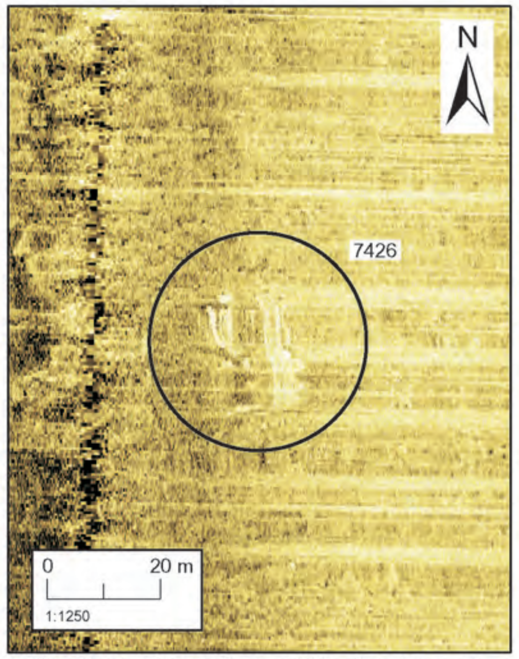
There is no correlation between the seafloor disturbances and the geomorphological type or seabed-sediment classification.

A total of 315 discrete magnetic contacts (greater than 5 nT) were observed, which could represent buried metallic debris or structures such as wrecks. The majority of the magnetic responses are relatively small (between 5 and 10 nT), with only 38 between 20 and 100 nT and 19 with a response greater than 100 nT. The majority of the magnetic anomalies were observed in areas of seabed cover (sandbanks, sandwaves and megaripples), indicating the likelihood of buried material in these areas. However, 80 magnetic anomalies are situated in areas of generally scarce bedforms/featureless seabed, indicating that even where there is little sediment there is potential for buried material to be present.

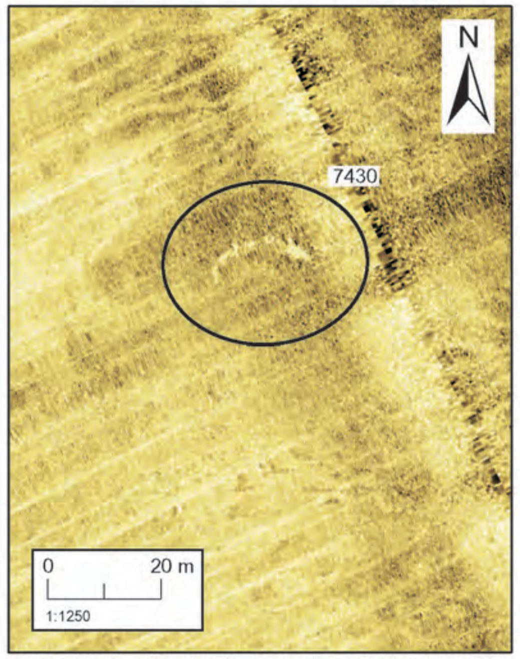
5.4.6 Archaeological characterisation

A total of 462 anomalies were identified in the East Coast REC Study Area as being of anthropogenic origin. Of these, 54 were identified as wrecks, 51 were previously recorded by the UKHO (and NMR) and 3 were previously unrecorded and can be added to the knowledge on the maritime archaeological resource of the area.

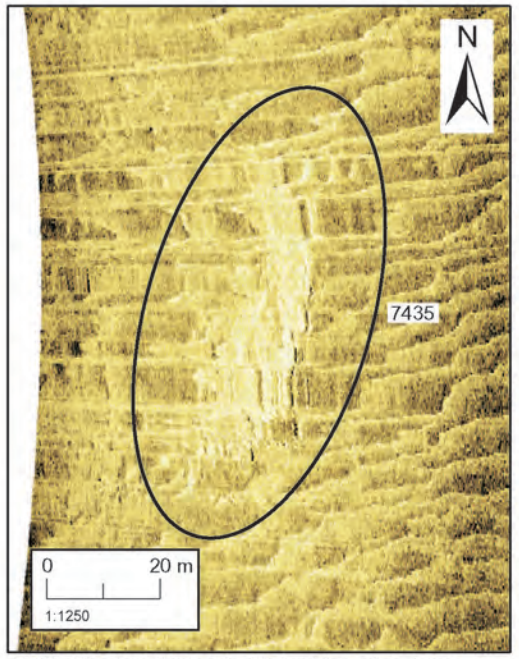
Sidescan sonar anomaly types - bright reflectors and dark reflectors



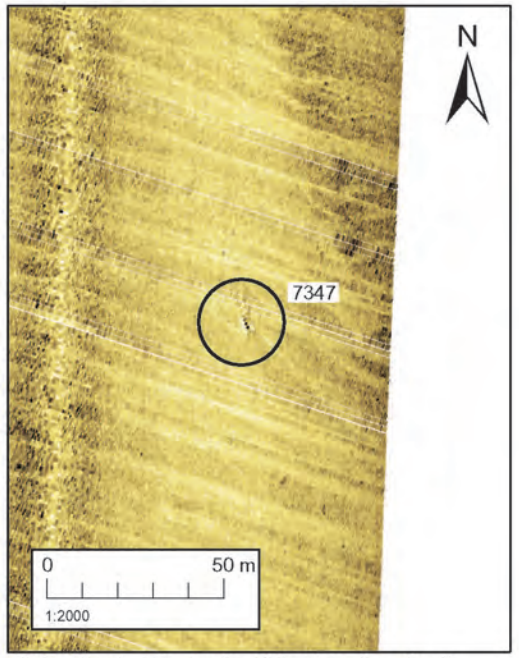
7426 - Physical Region 2 - 14 x 10.9 x 0 m. Series of linear bright reflectors.



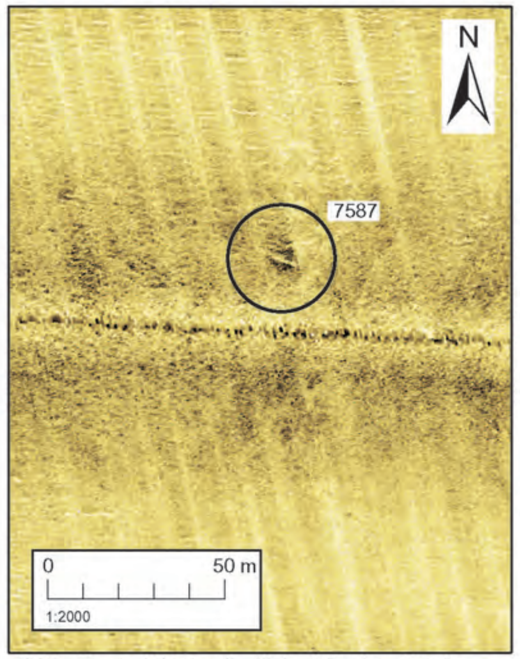
7430 - Physical Region 1 - 17.4 x 2 x 0 m. Semi-circular bright reflector.



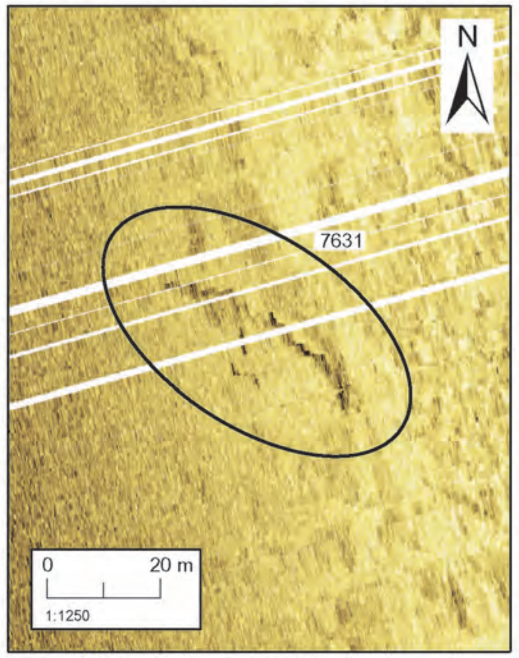
7435 - Physical Region 1 - 20.1 x 12.5 x 0 m. Large bright reflector.



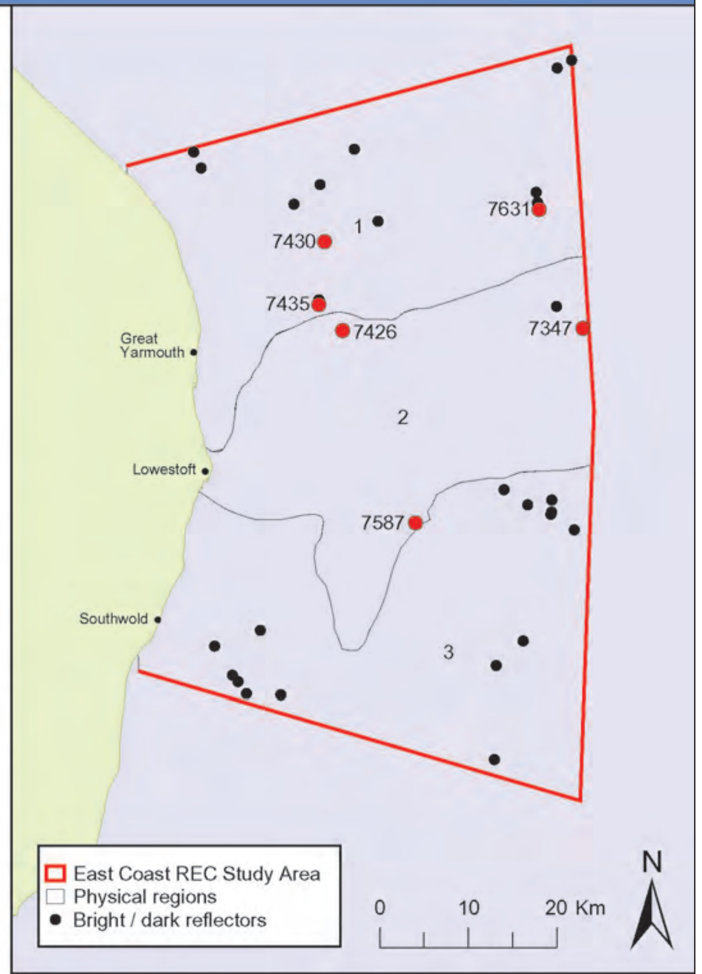
7347 - Physical Region 2 - 10.8 x 6.1 x 0 m. Small, isolated dark reflector.



7587 - Physical Region 2 - 12.1 x 8.7 x 0 m. Small, isolated dark reflector.



7631 - Physical Region 1 - 29.1 x 3 x 0 m. Long, thin dark reflector.



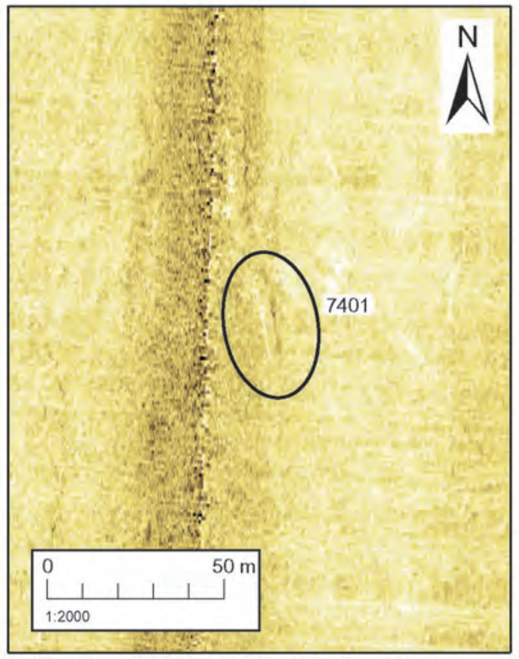
Bright reflectors are areas of low reflectivity. They may be hard edged or diffuse. Shadows are an extreme example where no acoustic energy is returned to the sidescan sonar towfish. Only bright reflectors that are not shadows are of interest.

Dark reflectors are areas of high reflectivity. They may be objects with or without height and may have hard edges or be diffuse.

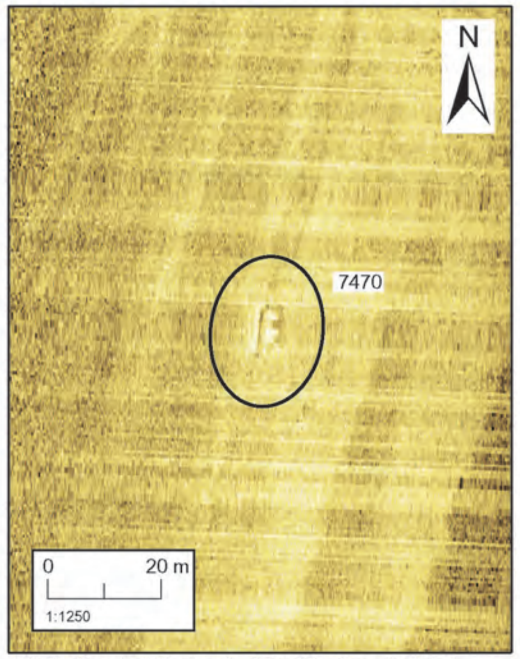
Sidescan Anomaly Type	Physical Region 1	Physical Region 2	Physical Region 3	Total
Bright Reflector	5	1	3	**9**
Dark Reflector	9	3	12	**24**

Figure 5.41 Side-scan sonar anomaly types – bright reflectors and dark reflectors.

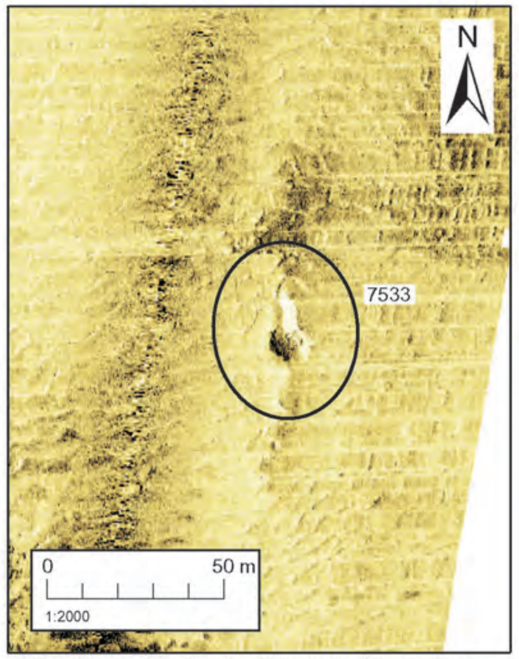
Sidescan sonar anomaly types - Seafloor disturbance and debris



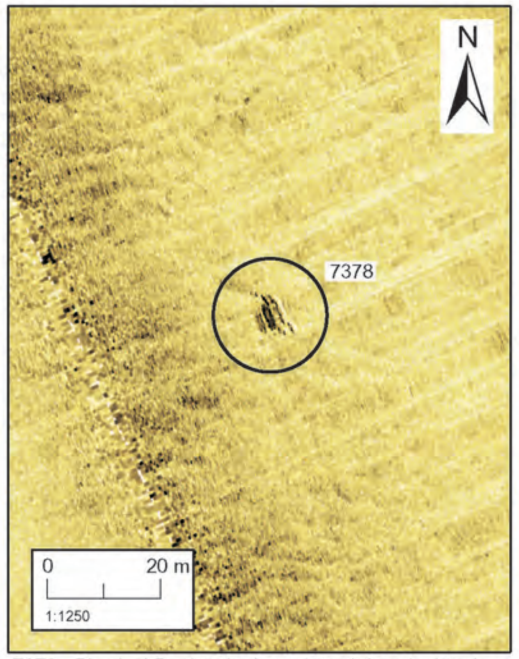
7401 - Physical Region 2 - 13 x 2.6 x 0 m. Linear seafloor disturbance.



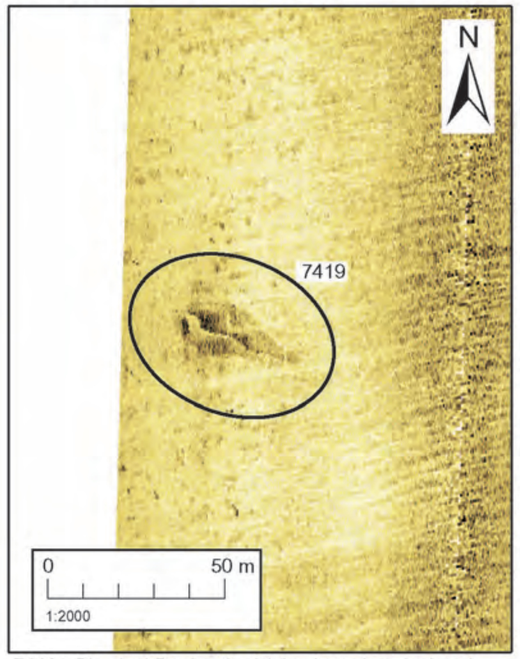
7470 - Physical Region 3 - 30 x 20 x 0 m. Isolated seafloor disturbance, possible debris.



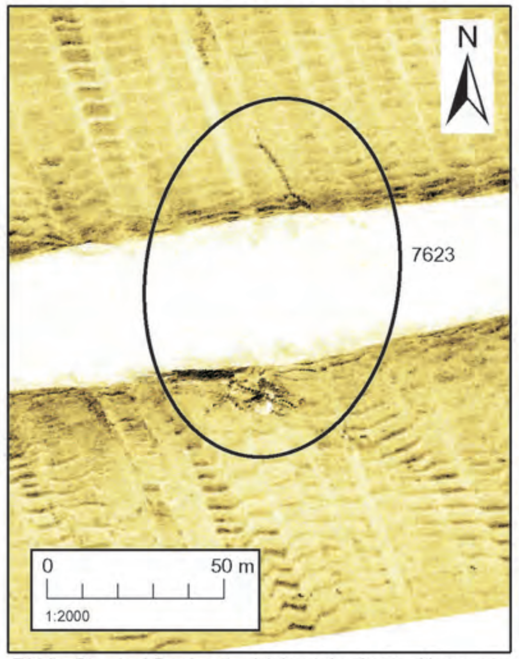
7533 - Physical Region 1 - 12.4 x 5.7 x 0 m. Seafloor disturbance, with dark and bright reflectors.



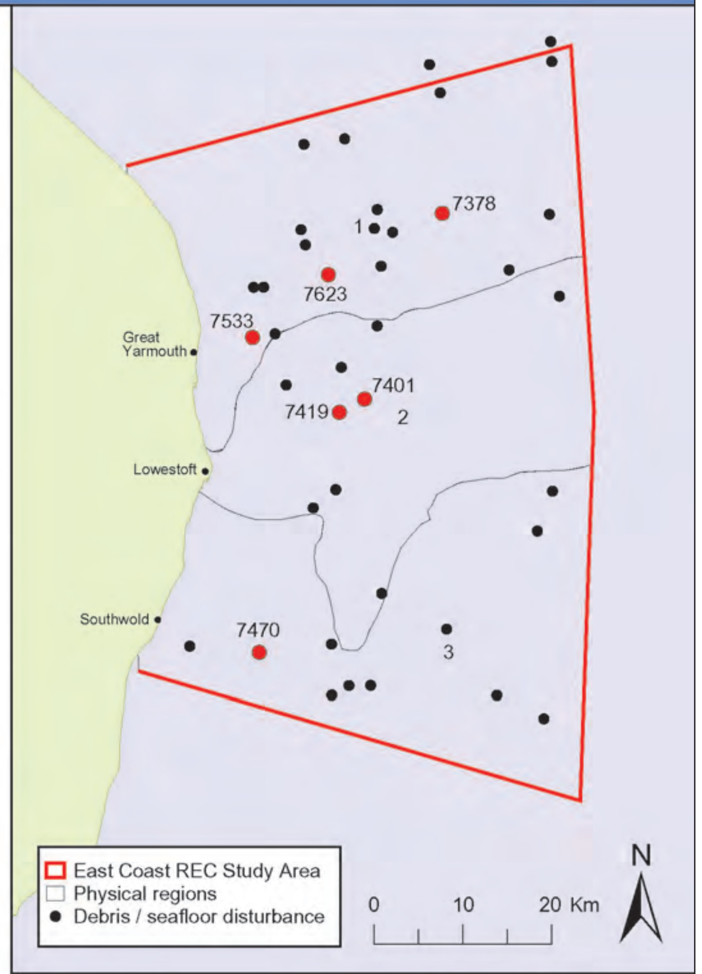
7378 - Physical Region 1 - 6.5 x 4.7 x 0.3 m. Isolated debris.



7419 - Physical Region 2 - 34.8 x 0.7 x 0 m. Isolated debris.



7623 - Physical Region 1 - 34.8 x 1.9 x 0.7 m. Numerous items of associated debris (water column intentionally not removed).



A seafloor disturbance is an area of seabed that appears disturbed, potentially by a buried or partially-buried wreck or debris of archaeological interest. These types of features may be groups of what is apparently debris or may be more ephemeral and consist solely of a patch of bright and dark reflectors distinct from the surrounding seabed.

Debris are objects on the seabed, generally with height or with evidence of structure, that are potentially of anthropogenic origin. They may occur singly or in groups.

Sidescan Anomaly Type	Physical Region 1	Physical Region 2	Physical Region 3	Total
Seafloor disturbance	8	3	3	**14**
Debris	13	6	8	**27**

Figure 5.42 **Side-scan sonar anomaly types – seafloor disturbance and debris.**

Wreck class	Wrecks observed in data		Total resource number (UKHO)	
	Number	%	Number	%
1509–1815	0	0	1	0.1
1816–1913	2	3.7	11	1.6
1914–1945	19	35.2	218	32.0
1946 onwards	6	11.1	53	7.8
Unspecified	27	50	398	58.4
Total	54	100	681	100

Table 5.11 Analysis of wrecks classified by date.

The number of wrecks identified account for 11.7% of the total number of geophysical anomalies. However, if you discount isolated magnetic anomalies and only focus on features identified on the seabed, this accounts for 36.7%.

The observed wrecks can be analysed by date, as shown in Table 5.11.

The coastline of the East Coast REC Study Area contains ports that have been important since the medieval period, and loss records suggest that large numbers of vessels sank within the eighteenth and early nineteenth centuries. However, no wrecks of this age were observed in the geophysics data. This is unsurprising given how few of the documented wreck records (UKHO and NMR) of this age are listed (Table 5.11).

From those vessels observed within the geophysics data, only 2 are attributed to the period 1816 to 1913. Again this is unsurprising when you compare the number of wrecks identified in the geophysics data to the number of wrecks recorded in the area by the UKHO (Table 5.11). In the entire East Coast REC Study Area, only 1.7% of all recorded wrecks pre-date 1914. Given the known large-scale shipping operations during the period 1816 to 1913, the number of recorded wrecks is poorly represented as an archaeological cultural resource.

The survey has been generally successful in characterising late-nineteenth-century and twentieth-century maritime activity within the East Coast REC Study Area, finding evidence of both warships and their victims, typically merchant ships and fishing smacks.

Of the wrecks identified by the geophysics, those with known wrecking dates are dominated by those vessels wrecked during the two world wars of the twentieth century, with 35.2% being lost between 1914 and 1945. This figure is consistent with that of the identified wreck total for the entire East Coast REC Study Area for this period. This high percentage was predominately due to enemy interference rather than to other shipping hazards and certainly represents the degree and variation of wartime activity as a whole within the southern North Sea. For instance, there is one vessel, HMS *Exmoor*, in the East Coast REC Study Area that is designated under the Protection of Military Remains Act 1986 (Section 2.9). This, however, was not covered by the geophysical data.

A density analysis of the wreck distribution (Figure 5.43) illustrates some of the interesting patterns emerging. From vessel losses in the First World War, there are a high proportion of sites situated in close proximity to Great Yarmouth and Lowestoft. Such a high density in this area is to be expected given the strategic importance of the two harbours and the shelter they provided in the area. It also sheds light on the strategies and technologies of the time.

There was one charted site in particular surveyed that would be of great archaeological interest, although the survey data suggests it is unlikely that the vessel is actually positioned where the UKHO has recorded its resting place. This vessel is the *UC-2*, a German mine-laying submarine that sank in July 1915 after a coincidental collision with a British coaster. This submarine and others like it are the main reason for First World War surveyed losses in the East Coast REC Study Area. Also, it appears that they positioned mines in and around the shipping channels, causing merchant shipping casualties to the south of Lowestoft and Great Yarmouth.

In comparison, the Second World War surveyed losses represent a different threat to cargo vessels within the East Coast REC Study Area. The torpedoes fired by German MTBs – "*Schnellboote*", known to the British as E-Boats – are the reason for the loss of 12 large cargo vessels surveyed (7 of which were observed in the geophysics); 9 of these are situated in Physical Region 1, and the remaining 3 were sunk in Physical Region 2. Generally the wrecks are found across the full extent of the East Coast REC Study Area, suggesting the range and capability of the German E-Boats, which attacked big vulnerable vessels on the periphery of large convoys.

Both these survey patterns represent the recorded wreck positions for the UKHO as a whole (Figure 5.44).

Other circumstances for wrecking during this period were attributable to collisions, especially in foggy conditions. This was also true of vessels lost in the post-war period of 1946 to present. A further loss mechanism that appears frequently in historic loss records is stranding when a vessel is lost as a result of going aground – for example, on a sandbank or the shore. This is not represented in the survey results, because none of the survey corridors included locations in which strandings are likely to have occurred, such as the sandbanks in Physical Regions 1 and 2.

The geomorphological character and sediment type are significant in the East Coast REC Study Area with regards to the survivability

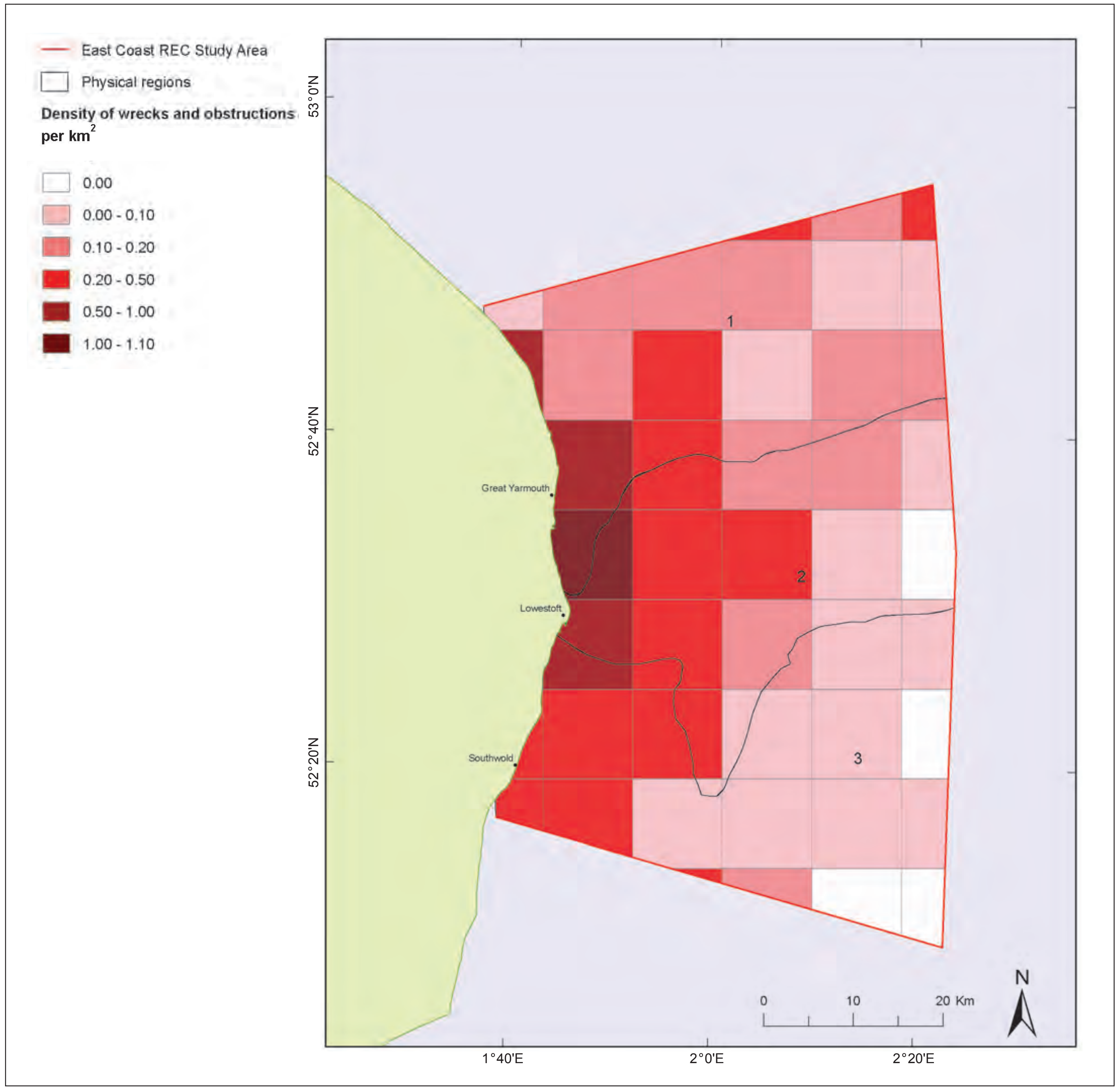


Figure 5.43 Density of UKHO charted wrecks and obstructions per km² within the South Coast REC Study Area, illustrated in 10 km cells.

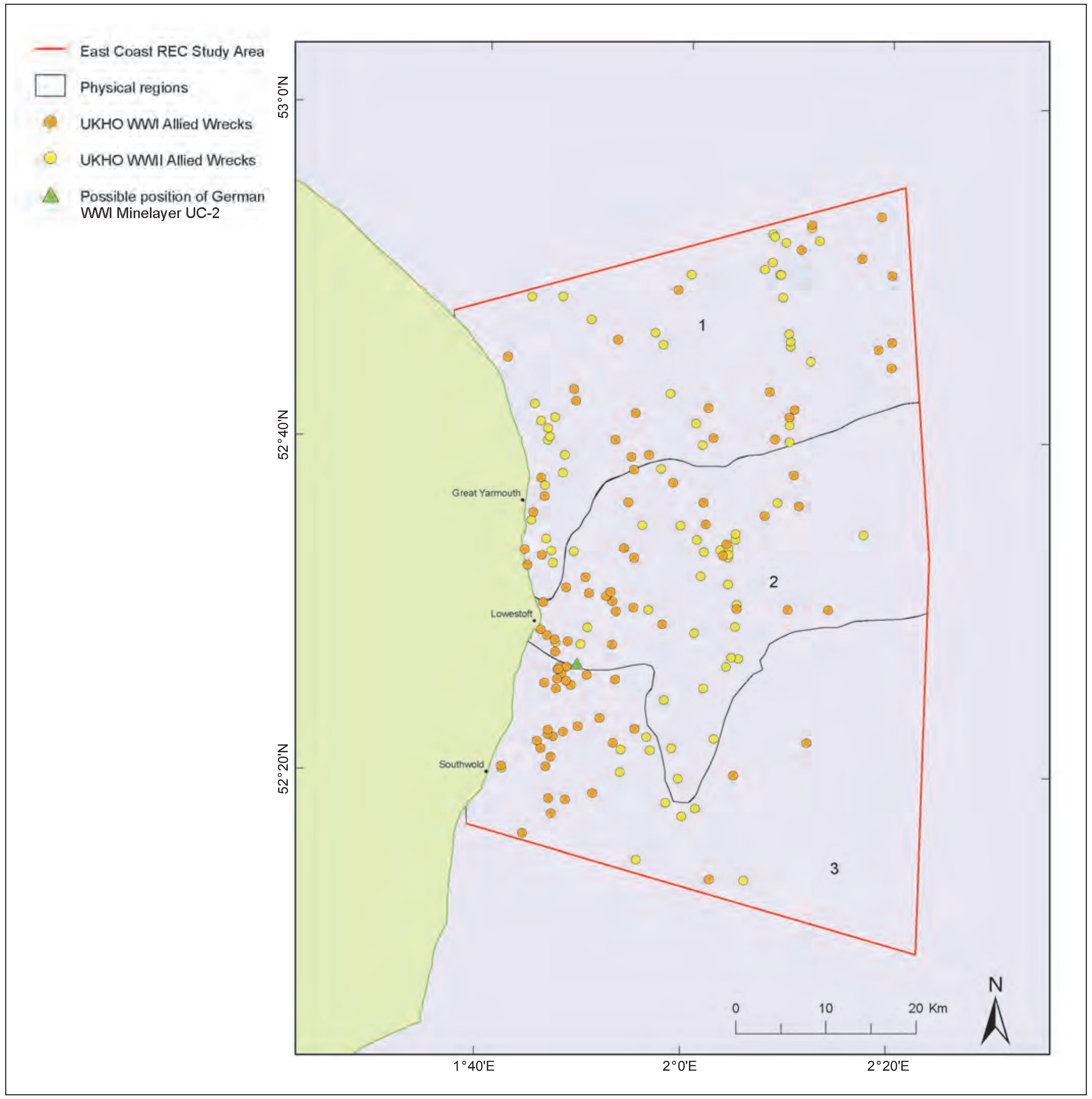


Figure 5.44 UKHO charted First and Second World War Allied wrecks sites.

and visibility of wreck sites. Many of the wrecks observed in the geophysical data were partially buried by sediment, and this occurred in areas of sandwaves and megaripples where you would expect, but it also occurred in areas where there were scarce bedforms and featureless seabed. A sandwave practically obscures the previously unobserved wreck (**7212**) and is possibly the reason that the wreck has remained undetected until now. However, these bedforms also reduce the possibility of identifying wreck sites that have been covered by mobile sediments. This is typified by the number of wrecks recorded by the UKHO in previous surveys which were not observed in the East Coast REC Study Area data, and by the number of wrecks recorded by the UKHO as "dead". Also, the burial of material such as wrecks or associated debris is highlighted by the high number of isolated magnetometer anomalies identified in the area.

5.5 Aviation archaeology

5.5.1 Introduction

The remains of aircraft at sea are usually attributed to that of crash sites. This is due to a number of factors including the act of warfare (combat or training), operation malfunction, running out of fuel, poor weather conditions, ditching or pilot error, which is usually attributed to fatigue or inexperience (English Heritage, 2002).

Within a national context, the numbers of lost aircraft within the East Coast REC Study Area are above the national average, but are relatively low compared to those recorded within the South Coast REC Study Area (James *et al*., 2010). Due to the increased extent of aircraft military activity during the Second World War, aircraft crash sites predominantly date between 1939 and 1945. The south and east coasts of England at this time were the focus of such activity.

Aircraft crash sites are, therefore, historically significant in many ways. They can include structural features of a rare or experimental type; they may have played important roles in air battles and military campaigns; and they may be associated with distinguished individuals (English Heritage, 2002). Such wreckages are also sensitive, as they may contain human remains or associated material of a fragile (explosive) and personal nature. Some aircraft can also be made up of a number of alloys and metals, some corrosive or hazardous. The dials on many RAF aircraft instruments were painted with radium-based paints, for instance.

Military aircraft sites are automatically protected by UK Government legislation under the Protection of Military Remains Act 1986. Any interested parties in such wreck sites can visit them, but are under strict instruction not to disturb or enter any of the compartments. Any further disturbance or works requires a licence from the Royal Air Force Personnel Management Agency (PMA), and guidance has been provided by English Heritage (2002).

Surface impacts at sea can disfigure the structure and cause large-scale spreading and dispersal of deposits, making the process of discovering a coherent wreck site difficult. The nature of such impacts (controlled ditching or crashing) is crucial to the aircraft's likelihood of preservation, as a ditched aircraft can float for many hours or days before sinking (Wessex Archaeology, 2008c). The additional impacts of marine conditions and environments upon aviation archaeological remains are still poorly understood in comparison to shipwreck sites, be they timber or metal. This is certainly due to the combining elements of the alloys used (such as duralumin), with the variable corrosive potential of such material (MacLeod, 2006).

Although it should be possible to identify aircraft during geophysical surveys, the lack of coherent wreck sites can make them difficult to discover, especially with mobile sediments burying the site and the effects of seabed disturbance (eg, trawling and dredging). Unless the aircraft is intact and fully exposed, it can be difficult to identify on side-scan sonar and multibeam echosounder records. Also, due to the materials used in their construction, there is often little or no magnetometer response from an aircraft wreck site.

A recent study (Wessex Archaeology, 2008c) concluded that there was a large discrepancy between the number of aircraft losses that are known to have occurred and the number of aircraft crash sites that have actually been located.

5.5.2 Background

As a process of engineering and human endeavour, the mechanised propulsion of fixed-wing aircraft has to be one of the fastest developments in human history. Although many of the early attempts at flight had been undertaken using gliders in the nineteenth century, between 1900 and 1914, fixed-wing aircraft, although fragile, had progressed enough to become tasked with patrolling and reconnaissance missions on England's East Coast within the context of a global conflict (English Heritage, 2002). Seaplanes, such as the Felixstowe F.2A using the "Spider Web" patrol system over the North Sea, would also become an essential element in anti-submarine and anti-airship warfare (Jefford, 2005). The national archives record 712 aeroplanes used for the anti-submarine campaign, and possibly the greatest achievement of the Royal Naval Air Service (RNAS) was the provision of air escorts for shipping convoys in the First World War (Jefford, 2005).

The structure of aircraft at this time did not always lend itself to the unpredictable nature of the environment in which they could be deposited as archaeological finds. The Sopwith Camel (state of the art for its time) had a fabric-covered fuselage, wings and tail, with an aluminium cowling and plywood-covered panels around the cockpit. Therefore, the likelihood of discovering such significant archaeological remains from the First World War within the marine East Coast REC Study Area is extremely low.

Due to the various operational successes (even on such a small scale) the scope and effectiveness of aircraft in war was a development worth pursuing. A rapid progress in the field of aviation during the inter-war years saw commercial and civil airliners becoming safer and relatively cheap to build and, therefore, more accessible. The United States led the way in design, with production companies such as Douglas Aircraft

Corporation and Boeing. During the 1920s and 1930s in Britain, various cross-channel services began to travel to a number of European and worldwide destinations (Wessex Archaeology, 2008c).

By the Second World War further advances in aviation technology enabled the military to utilise airpower, and it became increasingly important at a strategic and tactical level for defence and attack. The English Channel and the North Sea formed a frontier between the Allies and Axis Europe during this period, becoming a significant focus for this high volume of aviation activity (Wessex Archaeology, 2008c). Hostile aircraft activity was particularly concentrated off the east and south coasts of the UK.

An example of this can be illustrated by the total of 84 airfields utilised by the Royal Air Force Bomber Command in England during the Second World War. They were predominantly situated centrally and toward the east coast of England. To the west and south-west of the East Coast REC Study Area, there were 18 RAF Bomber Command Stations, including Lakenheath and Mildenhall in Suffolk. This meant that the most direct flight routes to German targets were over the East Coast REC Study Area.

In more general terms, the Monuments Protection Programme (MPP) noted that Second World War losses tended to be situated along the southern and eastern margins of England, with 1,000 losses noted in Suffolk alone, more than double those of the land-locked county of Warwickshire (English Heritage, 2002). Specifically, 217 RAF losses were recorded for Norfolk coastal regions and 73 RAF losses for Suffolk's coastal regions (Wessex Archaeology, 2008c).

Between the end of the war and the early 1990s, military aviation in the United Kingdom was dominated by activities related to the Cold War, with a large number of United States Air Force (USAF) planes stationed on airfields in East Anglia and considerable operational flying missions over the North Sea (Wessex Archaeology, 2008c).

Physical region	Number of aircraft casualties (NMR)	Number of aircraft wrecks (UKHO)
1	17 (includes 1 unknown and 4 on land or intertidal)	0
2	24	0
3	9 (1 inland or in intertidal)	1
Total	50	1

Table 5.12 **Aircraft casualties and known aircraft wrecks in the East Coast REC Study Area.**

5.5.3 Casualties (recorded losses)

There are a total of 50 NMR records for aircraft casualties within the East Coast REC Study Area (Table 5.12 and Figure 5.45). Predominantly, NMR records of aircraft casualties at sea are based on locations where an aircraft was reported to have crashed, and they tend not to be accurate positions of a wreck site. The records can cluster a number of aircraft losses centred on a single position. For instance, a position located at the northern extent of Physical Region 2 has been assigned 15 crash sites of various Second World War military aircraft.

Such position imprecision is understandable, due to the many complex parameters that are required for accurate coordinates of specific crash sites at sea; many are based upon a last-recorded radio message. Conversely, the three NMR records within the East Coast REC Study Area on land have far more precise positions. Two of these were excavated by the Norfolk and Suffolk Aviation Museum and were identified as an Avro Lincoln Mark II and an unknown aircraft.

With regards to the general distribution of the aircraft crash sites at sea, the NMR records are certainly more of a consistent guide to the nature and spread of aviation archaeology within the East Coast REC Study Area in comparison with the UKHO records of known aircraft wrecks. The records also illustrate the potential for the remains of aircraft that only exist as remnants within the RAF Reserve Collection, such as the Short Stirling bomber.

All of the 50 NMR recorded losses were built for the military campaigns of the Second World War, with only one occurrence of a casualty after the war – that of an Avro Lincoln Mark II in 1947 (MonID: 1368105). Generally, there is a trend towards incidents involving both Allied and Axis bombers throughout the East Coast REC Study Area. However, it is important to note that there were aircraft that could perform various functions, depending on the operation. The British de Havilland Mosquito, also known as the "wooden wonder" as it was made predominantly of plywood, is an example of such versatility (Bishop, 2001). Although classified within the NMR as a Fighter, it performed a number of roles, which included low-altitude bombing, aerial reconnaissance, and day-and-night fighter, even though it was originally conceived as a fast bomber.

The breakdown of the NMR for the East Coast Study Area is as follows: 33 British and German aircraft with bombing capabilities (including British fighter bombers such as the Hawker Typhoon), 13 fighters (including two RAF de Havilland Mosquito), a British de Havilland Mosquito recorded as a reconnaissance aircraft, a German reconnaissance aircraft, a German seaplane and an unknown aircraft. The majority of all losses (41 in total) took place between the beginning of 1940 and the end of 1943. Seven were lost between 1944 and 1947. In addition, a Wellington MKI, L4257, was lost in 1939.

Geographically the distribution of recorded losses indicates greater casualties further from the coast, 36 in total, leaving 14 near coastal, intertidal and on land (8 British, 5 German and 1 unknown). Physical Region 1 has more recorded losses, numbering 8, although encapsulating far more of the East Coast REC Study Area. Offshore distribution illustrates Physical Region 2, with 23 casualties, with the most activity containing high numbers of bombers and heavy bombers from the RAF, 2 RAF fighters and 6 Luftwaffe losses.

The high number of RAF bomber losses could be due to a number of reasons, especially with the East Coast REC Study Area on the direct flight path of bombers, and possibly represents the ditching of returning aircraft from raids made upon the Continent. The cause of such losses may be due to a lack of fuel (after consuming too much attempting to make an accurate sighting of the target). An example of this was the RAF Lancaster DV243 (MonID: 1318379) of the 207 Squadron based at Spilsby airfield, Lincolnshire, that ditched off Great Yarmouth in October 1943 when it ran out of fuel on return from a raid on Frankfurt (Lost Bombers, 2010). Or the Vickers Wellington Bomber Z1489 (MonID: 1354226) lost 10 miles off the Norfolk coast after heavy anti-aircraft damage received over a target in Wilhelmshaven; all the Polish crew were rescued (Lost Bombers, 2010). Another example that further illustrates the dangers faced was the instance of the British coastal battery shooting down the RAF Stirling MKI BF390 British bomber in 1942 (MonID: 1342820) in a case of mistaken identity (Lost Bombers, 2010).

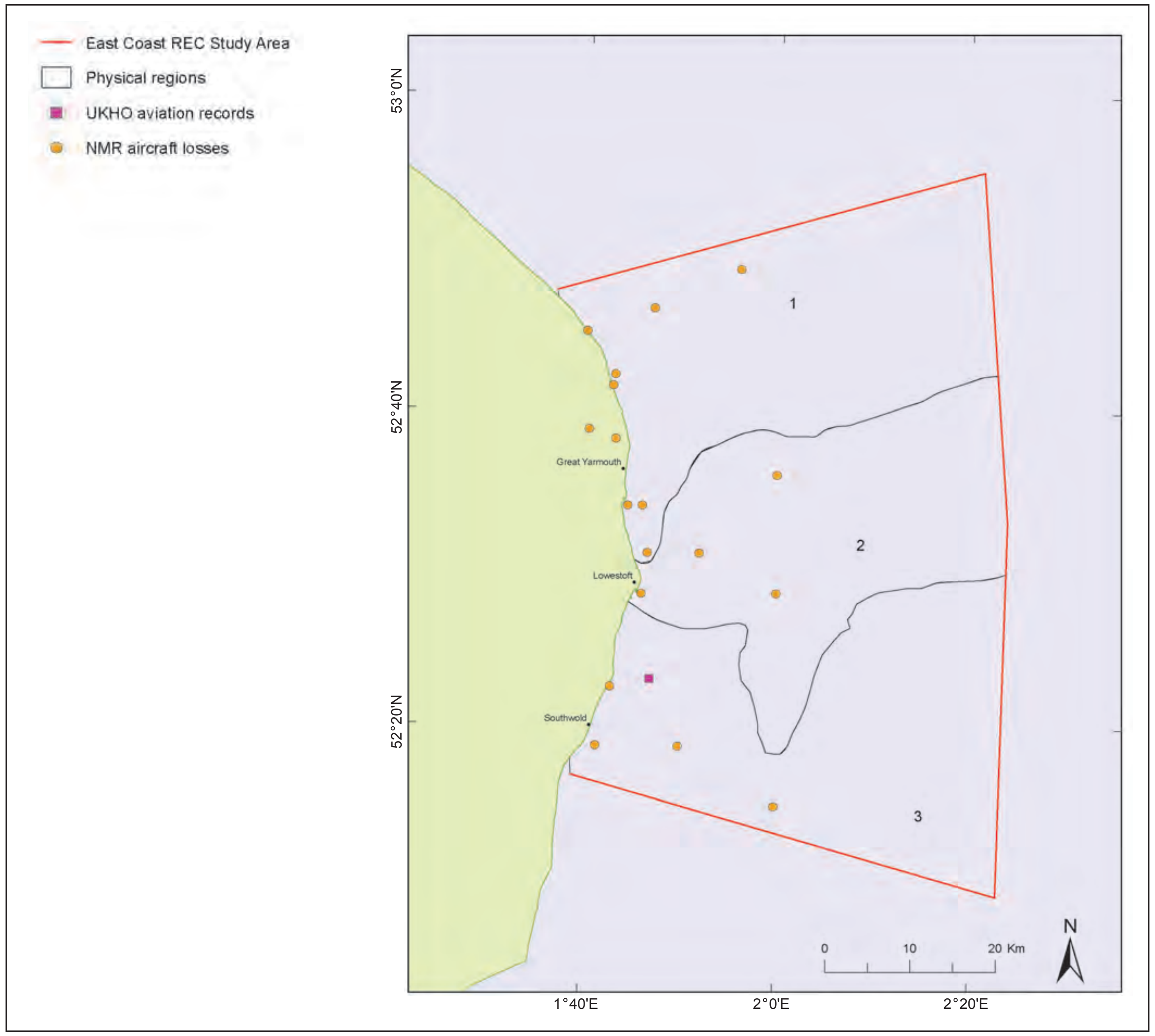


Figure 5.45 Known and potential aircraft crash sites.

5.5.4 Aircraft wrecks

Only one UKHO record within the East Coast REC Study Area is known to relate to aircraft loss. UKHO 10382 is situated in Physical Region 3 and was not covered by the geophysical survey.

UKHO 10382 is a Royal Air Force Buccaneer believed to have crashed on 27 July 1975, 4 km offshore south of Kessingland Beach (Figure 5.45). Built to fulfil a 1952 Royal Navy requirement for a carrier-based strike/attack/reconnaissance aircraft, it was to become a much-loved and admired aircraft by all those employed to pilot it. It was built in two variants, the S1 and S2; the S2 would serve for both the Royal Navy and the Royal Air Force. The aircraft was fitted with a hydraulic wing-fold mechanism and a nose that could be folded parallel to the fuselage to accommodate the aircraft in the minimum of deck space. It had two Rolls-Royce Spey Mk101 axial bypass turbojet engines with a tandem seated crew. It was a large aircraft, 20 m in length, with small wings that allowed it to fly at greater speeds at low levels (Holmes, 2005). This meant that the airframe had to be extremely strong and durable to handle the pressure of low-altitude air strikes. Being constructed around three large frame spiders, it had a “Coke bottle”-like appearance (Exelby, 2004).

Local fishermen located wreckage within the vicinity of the crash site in 1976; however, the wreckage was not located during a sonar search carried out in 1982. It is possible the aircraft could be broken up or damaged from trawling; also, given that the site is situated in an area of megaripples, it is possible that some of the wreckage may now be buried.

Although no aircraft wrecks were positively identified in the geophysics data, it is possible that some of the geophysical anomalies identified (Figure 5.40) may be related to aircraft, rather than vessel, wreck sites.

Marine Aggregate Levy Sustainability Fund MALSF

5.5.5 BMAPA finds

Since 2005, 11 reports associated with aircraft have been made through the BMAPA protocol for reporting finds of archaeological interest (BMAPA and English Heritage, 2005), from the licensed dredging areas within the East Coast REC Study Area. They predominately comprise a large quantity of aluminium wreckage from Second World War aircraft. Although the accuracy of the positions for the material is generally approximate, the finds illustrate the potential for finding aircraft remains within the area.

In particular, aggregate extraction Area 430 illustrates this potential for the region. Finds include a pedal from either a P-51 Mustang or a B-25 Mitchell Bomber from the USAF, discovered in 2005, and a human bone, from the right upper arm, thought to be that of a German airman, possibly associated with a Heinkel He 111 or Junkers Ju 88 that may have gone down during the Battle of Britain around August 1940 (Wessex Archaeology, 2007).

5.6 Characterisation summary

5.6.1 Prehistoric archaeology

One of the key issues in characterising the submerged prehistory is that, in archaeological terms, it involves working “blind”. The precise location and extent of prehistoric archaeological material offshore is currently unknown. However, finds such as those recovered during dredging and fishing activities, and surveys such as this one, can provide insights to past patterns of land use and demography. Taking this limited number of finds into account, the aim of the characterisation was to identify areas of the seabed which have the potential for the presence of such archaeological material.

The characterisation involved the integration of archaeological knowledge and theory with geological, geophysical and palaeo-environmental interpretations. This approach focused on identifying offshore the types of landscape features where archaeological material is found on land. It is not possible to provide definitive maps of the landscape at various times in the past as there is not enough evidence to do so based on the modern bathymetry. However, it is certainly possible to highlight areas of the seabed where the potential of archaeological material remaining is higher than that of the seabed as a whole.

The results of the characterisation have illustrated the presence, and further potential, of deposits associated with the key periods of occupation, from the earliest known sites, such as Pakefield and Happisburgh, through the Palaeolithic to the Mesolithic as evidenced by the saltmarsh channel infilled just prior to the last inundation of the area around 6000 BC.

5.6.2 Maritime archaeology

The results of the geophysical survey have enhanced and added to existing data-sets, such as those of the UKHO and the NMR, and the characterisation has produced a more reliable guide to the density of archaeological material on the seabed. The characterisation has enhanced our understanding of the maritime heritage resource and provides a reliable guide of the quantity, preservation and age of wrecks that lie in the East Coast REC Study Area. From these results a broader theme of maritime activity can be inferred, providing further insights into the regional and national variations of shipping and some of the subsequent wreck sites.

The characterisation of the maritime archaeological sites observed in the geophysics data imply a broad comparison with that of the entire UKHO charted wreck record within the East Coast REC Study Area. This illustrates that the survey provided a representative sample of shipping losses as a whole. This is especially true of ships that sank in the period between 1914 and 1946. However, vessels wrecked prior to 1914 are underrepresented by the characterisation, similar to the entire UKHO record for the East Coast REC Study Area. Knowledge of vessels built earlier than the nineteenth century would be of great archaeological value, and it is possible that there are the remains of such vessels yet to be recorded.

Another interesting result from the survey was the distribution and density of wreck sites across the East Coast REC Study Area, which illustrates, for instance, within the twentieth-century wreck sites, the changing usage of the maritime environment and general patterns in the position of wreck sites. This was apparent in the geophysical data, with the remains of First World War vessels discovered closer to the coast, and Second World War vessels distributed more evenly throughout the East Coast REC Study Area. Such evidence provides wider indications of the changing nature of warfare and the scale of dependence that the people of the United Kingdom had on maritime trade.

The geomorphological character and sediment type are significant in the East Coast REC Study Area with regards to the survivability and visibility of wreck sites. Although the majority of the wrecks observed were upstanding, many showed evidence of partial burial, particularly in areas of sandwave fields and of megaripples. Comparing the wreck sites observed in the East Coast REC Study Area data with descriptions of previous surveys indicates repeated burial and exposure of the wreck sites over time.

5.6.3 Aviation archaeology

Since there are very few records concerning aircraft crash sites within the East Coast REC Study Area, a reliable understanding of the accurate distribution is unknown. The quantity of aircraft wrecks is very probably underestimated, especially considering the large scale of operations that passed over the area throughout the Second World War. Due to the fragile structure of aircraft and relatively small size, it is difficult to consistently detect sites using current geophysical technologies. It is conceivable that many more sites will be found through intrusive means, either by fishing trawlers or dredging.

It is possible however, that future developments in geophysical technology will enable the detection of aircraft wreck sites, in mobile seabed environments, before they deteriorate through corrosion.

6 Ecological characterisation

6.1 Introduction

The purpose of this chapter is to apply a biogeographical approach to the characterisation of biological marine resources within the East Coast REC Study Area. This particular work is designed to assist in the filling of existing gaps in baseline ecological data as identified in the pre-survey data review (Appendix G) and to enhance the understanding of key ecological patterns and processes to support the marine resource management process.

Four objectives were addressed in the ecological characterisation of the East Coast REC Study Area:

- Conduct analysis of the benthic infaunal and epifaunal organisms collected to ascertain the presence and variability of distinct faunal assemblages.
- Identify correlations between biological and physical parameters that can be used to augment understanding of the distribution of the distinct faunal assemblages.
- Identify ecologically important areas within the East Coast REC Study Area.
- Explore the biological dependencies that may influence the temporal and spatial dynamics of the wider ecosystem represented within the East Coast REC Study Area.

The data gathered and patterns of distribution described will provide essential information needed to inform future scientific studies, as well as assist in the development of educational material, and support other spatially explicit monitoring and management decisions.

6.2 Interpretation methodology

6.2.1 Descriptive statistics

A suite of assemblage metrics was produced for each faunal sample, including the number of organisms (abundance, N), number of species (S) and biomass (ash-free dry weight [AFDW] in grams). In addition, species diversity (Hill's N1) and evenness (Hill's N2/N1) indices were calculated (Hill, 1973), as well as the taxonomic distinctness index (Δ*), which is a measure of the relatedness of species identified within a sample (Warwick and Clarke, 2001). Colonial taxa were excluded from the calculation of indices that required abundance information.

6.2.2 Identification of distinct macrofaunal assemblages

Multivariate analyses were conducted using the PRIMER v6 software package (Clarke and Gorley, 2006). Taxon abundance-by-sample data matrices were transformed to reduce the influence of the most abundant taxa. Bray–Curtis similarity was calculated between every pair of samples, and these values were used to plot dendrograms (based on group average clustering) or multidimensional scaling plots to visualise the relationship between samples. The SIMPROF routine was applied to identify statistically distinct groups of samples. The faunal composition of statistically distinct assemblages was examined by applying the SIMPER routine.

6.2.3 Assemblage–environment interactions

In PRIMER, a RELATE routine was carried out to investigate the degree of concordance between patterns within the faunal assemblage and patterns in the associated environmental data. Any significant relationships between data-sets were investigated further using the BIO-ENV routine, which identified the environmental variables – either in isolation or in combination – that were most highly correlated with patterns observed in the faunal assemblage. A summary of the environmental parameters used in this analysis is given in Table 6.1.

6.3 Grab data results

Hamon grabs sample infaunal taxa, predominantly invertebrates, that live in or on the surface of seabed sediments. Infauna are generally considered to have limited motility and it is therefore reasonable to sample them using a grab as they are not fast enough to avoid it. Larger or more motile taxa living on the seabed surface are termed epifaunal (along with sessile encrusting organisms). Epifaunal taxa, which are under-represented in grab samples, are more effectively sampled with a beam trawl. For the purpose of this study, all taxa found in the Hamon grab samples are considered as infaunal, with no species that could be considered as epifaunal excluded from analyses.

6.3.1 The infaunal assemblage

A total of 158 grab samples were collected from the East Coast REC Study Area, yielding 30,796 countable organisms, representing 391 taxa (individuals belonging to colonial taxa were not enumerated). Most organisms belonged to the Annelida, accounting for 66% of the total abundance (Figure 6.1). These were followed by the Mollusca (12%), Miscellanea (10% – including hydroid and byozoan colonies, Sipuncula and Porifera), Crustacea (7%) and Echinodermata (5%).

The distribution of biomass amongst the major phyla was slightly different (Figure 6.1), with Annelida being the most represented (43%), followed by Miscellania (30%), Echinodermata (11%), Crustacea (8%) and Mollusca (8%). Similarly, most species collected belonged to the Annelida (43%), followed by the Crustacea (26%), Miscellania (16%), Mollusca (12%) and Echinodermata (3%).

By far the most numerous macrofaunal species encountered in the East Coast REC Study Area was the Ross worm (*Sabellaria spinulosa*), with a total of 12,408 individuals recorded (Figure 6.2). Other abundant taxa included the T-headed worm (*Scalibregma inflatum*), adult blue mussels (*Mytilus edulis*), juvenile mussels (Mytilidae), the white furrow shell (*Abra alba*) and sea anemones (Actiniaria).

Variable	Source	Data type	Details
Sediment fractions	REC	Numerical	% of sample (by weight) retained in a series of different sized sieves (Wentworth scale) from the Hamon grab sediment sub-samples.
Mean particle size	REC	Numerical	Mean (arithmetic average) particle size (phi) recorded from Hamon grab sediment sub-samples.
Sorting	REC	Numerical	Sorting (standard deviation) of the grain sizes (phi) recorded from Hamon grab sediment sub-samples.
Skewness	REC	Numerical	Skewness (asymmetry) of the sediment composition (phi) recorded from Hamon grab sub-samples.
Kurtosis	REC	Numerical	Kutosis (peakedness) of the sediment composition (phi) recorded from Hamon grab sediment sub-samples.
% Mud	REC	Numerical	% of sample (by weight) recorded from the Hamon grab sediment sub-samples.
% Sand	REC	Numerical	% of sample (by weight) recorded from the Hamon grab sediment sub-samples. NB: there was a very strong inverse correlation between % Sand and % Gravel, therefore % Gravel has been excluded from analyses.
Water depth	REC	Numerical	Water depth at which the sample was collected.
Latitude	REC	Numerical	Recorded position of sample, latitude
Longitude	REC	Numerical	Recorded position of sample, longitude
Near-bed temperature	Envision	Modelled numerical	Near-bed temperature averaged by month, resolution 1/9 degrees calculated using the Atlantic Margin Model (www.myocean.eu.org).
Tidal current strength	DECC tidal resource atlas	Modelled numerical	Strength of spring tide (kW/m) per horizontal metre of wave crest calculated using the energy period calculation. DECC Renewable energy atlas: www.offshore-sea.org.uk/site/scripts/documents_info.php?documentID=25
Slope	REC	Modelled numerical	Slope (degrees) calculated using Spatial Analyst in ArcGIS V9.3 from single beam echosounder bathymetric data on a 25 x 250 m grid.

Table 6.1 List of environmental variables used to investigate the relationship between biological communities and their physical environment in the East Coast REC Study Area.

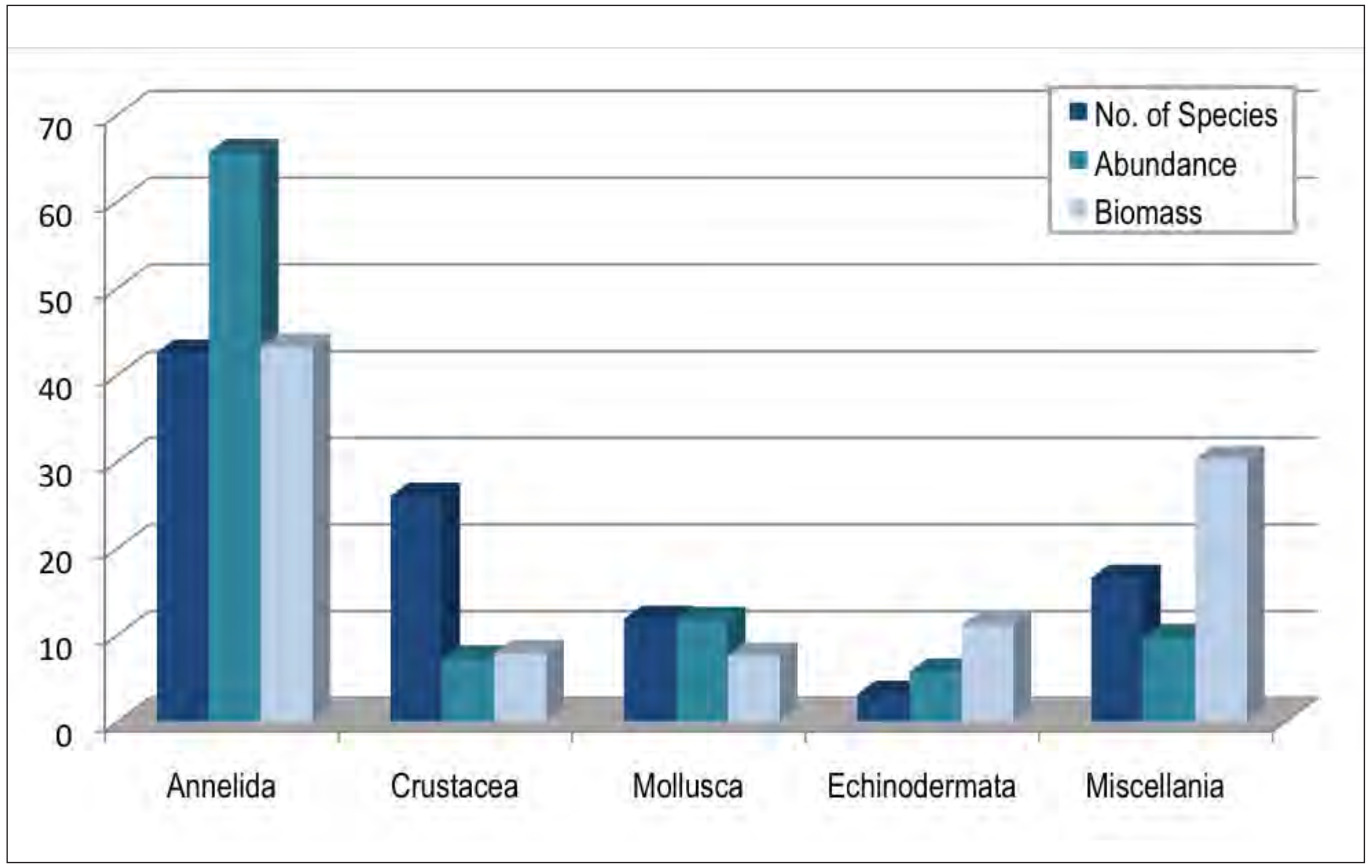


Figure 6.1 Relative contribution of major phyla to the abundance, number of species and biomass (g AFDW) recorded from 0.1 m^{-2} Hamon grab samples taken across the East Coast REC Study Area (values given as a %).

The variability in abundance per sample values across the survey area was relatively high, with minimum numbers of organisms per grab being in single figures and a maximum of 4,675 individuals being recorded in a single sample. Clusters of samples with much higher abundance values (see Figure 6.3) corresponded with the areas of increased numbers of species (Figure 6.4) as well as with areas of increased biomass (Figure 6.5).

The variability in the number of species recorded per sample was low, with the majority of the grab samples harbouring fewer than 17 species. There were, however, a number of samples in which species number was much higher (Figure 6.4). Given the concordance between samples containing high faunal abundance and high numbers of species, together with the fact

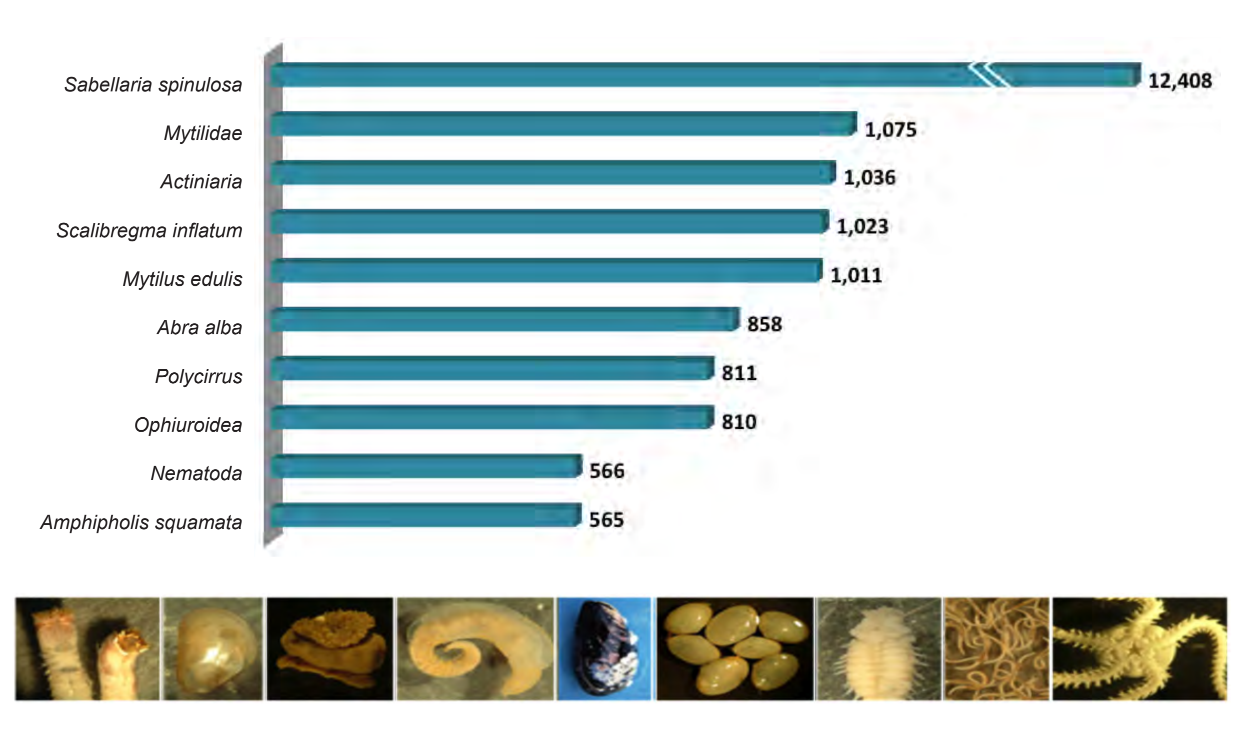


Figure 6.2 The ten most abundant infaunal taxa recorded in 158 Hamon grab samples taken across the East Coast REC Study Area. Photographs running left to right represent the taxa from top to bottom along the x-axis (vertical). © seasurvey.co.uk.

that *S. spinulosa* was mostly responsible for instances of high faunal abundance, it is likely that these samples correspond to areas of *S. spinulosa* reef, which is known to support an increased density and diversity of other invertebrates relative to its surroundings (George & Warwick, 1985).

Variability in biomass per sample was also generally low, with most samples yielding less than 4 g AFDW. A small number of samples yielded up to four times this amount of biomass (Figure 6.5); *S. spinulosa* reef was likely to have been present at these locations.

Species diversity, as measured by Hill's N1 index, was highly variable across the East Coast REC Study Area (Figure 6.6). Species evenness (Hills N2/N1), on the other hand, was relatively stable (Figure 6.7), indicating that in the majority of samples, no single species was overwhelmingly numerically dominant. In other words, most species were represented by similar numbers of members. Species evenness tended to be relatively low in samples where species diversity was relatively high (and vice versa), suggesting that high diversity was recorded in areas where gregarious (ie, numerically dominant) species were present that promoted the settlement of other taxa (eg, *S. spinulosa*, *M. edulis*), thus increasing diversity but lowering the evenness index of the assemblage.

The taxonomic distinctness index (Δ*) describes the relatedness of species within a sample. Taxonomic distinctness was relatively high (>70) over the whole of the East Coast REC Study Area (Figure 6.8), indicating that samples contained representatives from distantly related taxa.

6.3.2 Infaunal assemblage composition

Multivariate analyses have been performed on the infaunal data-set to assist in the identification of statistically distinct assemblages or communities within the East Coast REC Study Area. The taxon abundance-by-sample matrix was square-root transformed before the calculation of Bray–Curtis similarity between all samples. Simultaneous CLUSTER and SIMPROF routines were applied to identify statistically distinct groups of samples. For ease of interpretation, some of the smaller statistically distinct groups have been merged with other groups (merged groups depicted by red dashed lines in Figure 6.9)

Fourteen distinct groups were identified within the infaunal data-set, each of which was considered to represent a distinct infaunal assemblage. The corresponding multidimensional scaling (MDS) ordination plot (Figure 6.10) shows that there is considerable overlap between some of the 14 groups, indicating that some assemblages have a number of species in common. This is confirmed by the results from a SIMPER routine, which identifies the species contributing to the similarity within each of the 14 distinct assemblages. In many instances, the separation of groups was down to the differences in relative proportions of the most characteristic species that were shared between them. For example, Groups E, G, H and I (plotted towards the left in the MDS plot – Figure 6.10) all contained differing proportions of *S. spinulosa* and associated species. Groups A, B, C, P and U (towards the right in Figure 6.10) were more species-poor but share different proportions of their characterising species.

Some of the distinct assemblages were represented by many more samples than others. Similarly, some assemblages were dispersed widely throughout the East Coast REC Study Area, while others were more spatially discreet (Figure 6.11). It was not always the case that the less represented assemblages were more spatially restricted (eg, Group P). A detailed biological characterisation of each of the groups identified in this analysis, together with a description of the physical environment in which they occur, is presented in Chapter 7.

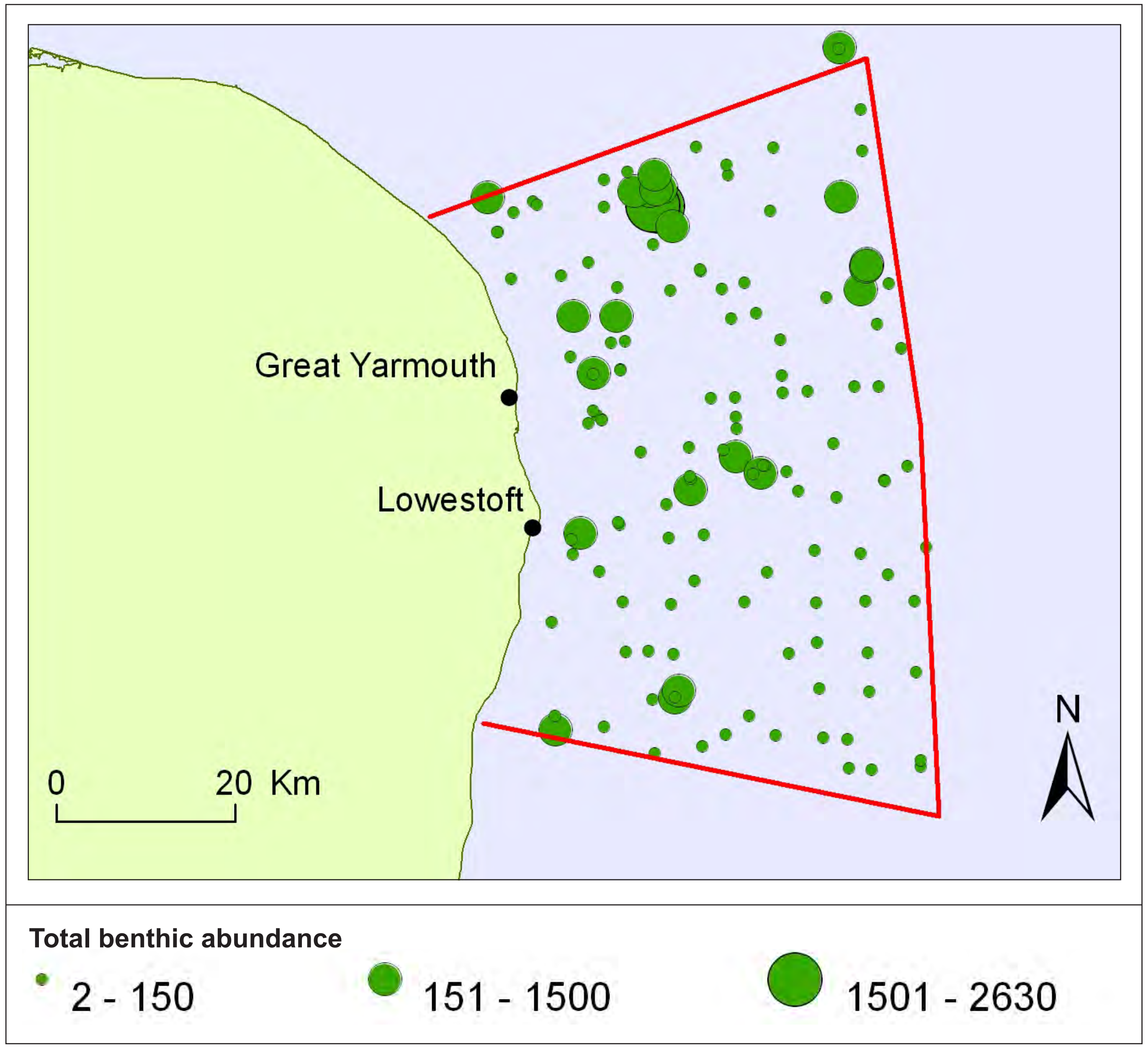


Figure 6.3 **Distribution of infaunal abundance recorded per 0.1 m^{-2} Hamon grab sample.**

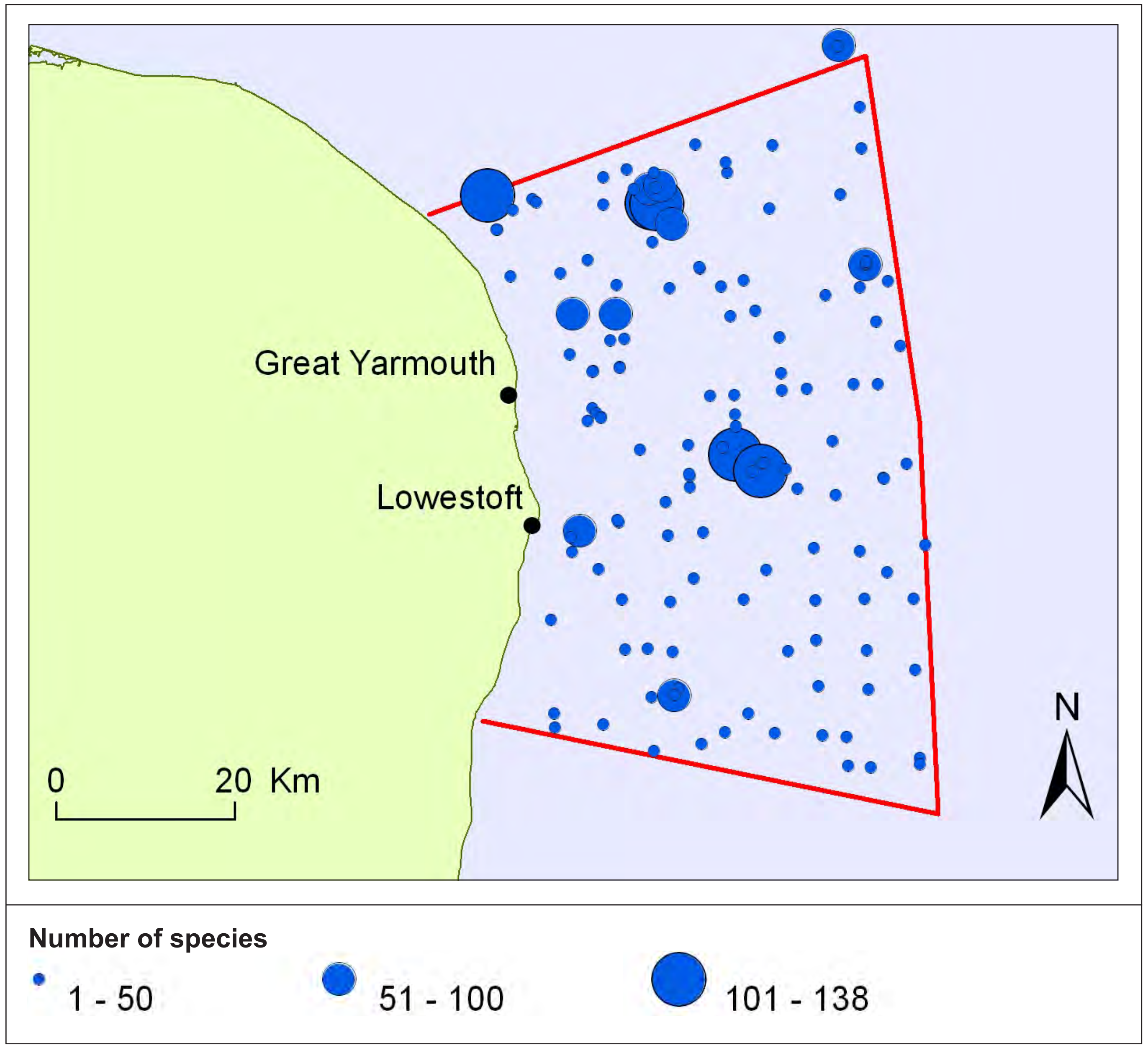


Figure 6.4 **Distribution of the number of infaunal species recorded per 0.1 m^{-2} Hamon grab sample.**

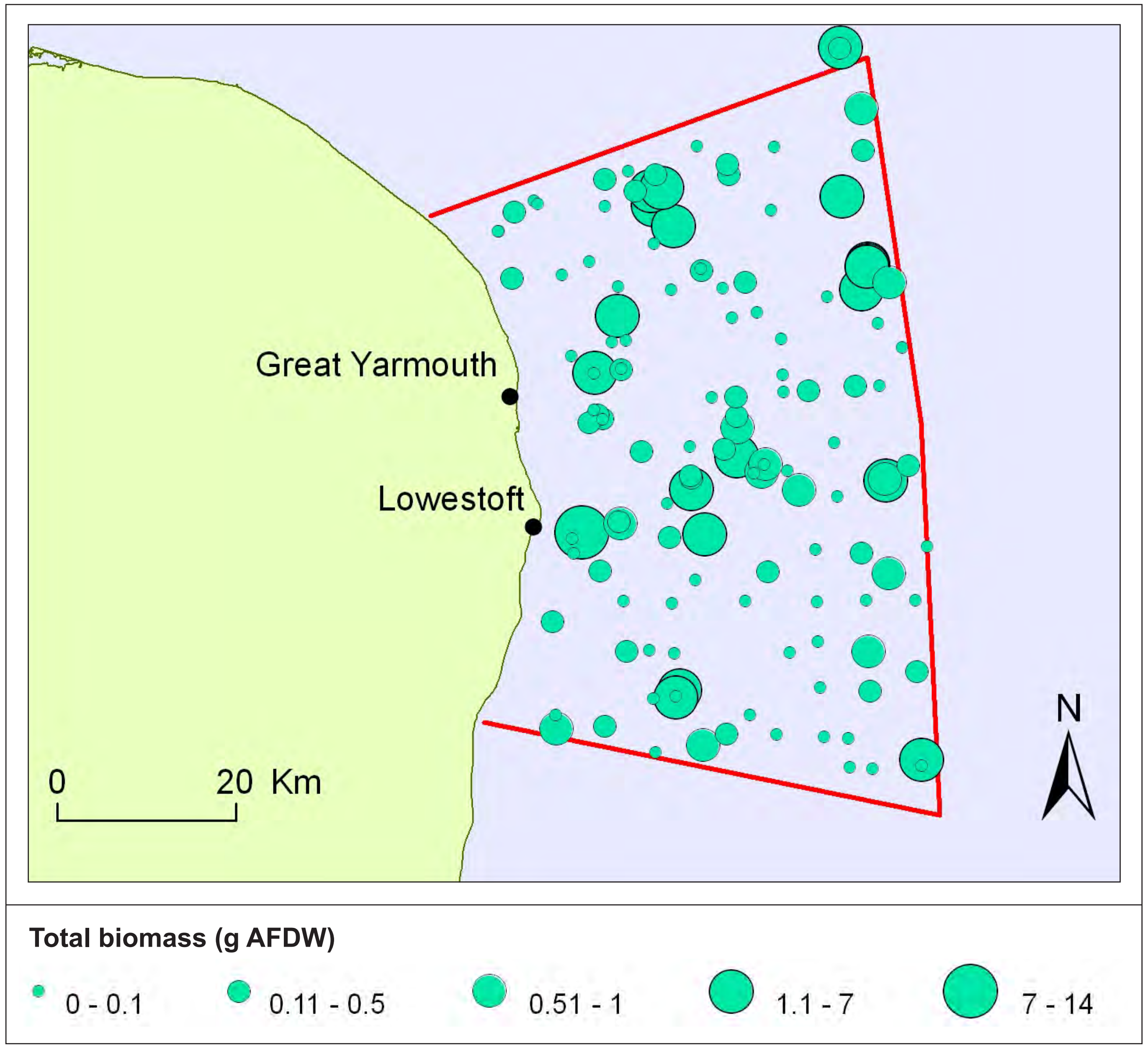


Figure 6.5 Distribution of biomass (g AFDW) recorded per 0.1 m⁻² Hamon grab sample.

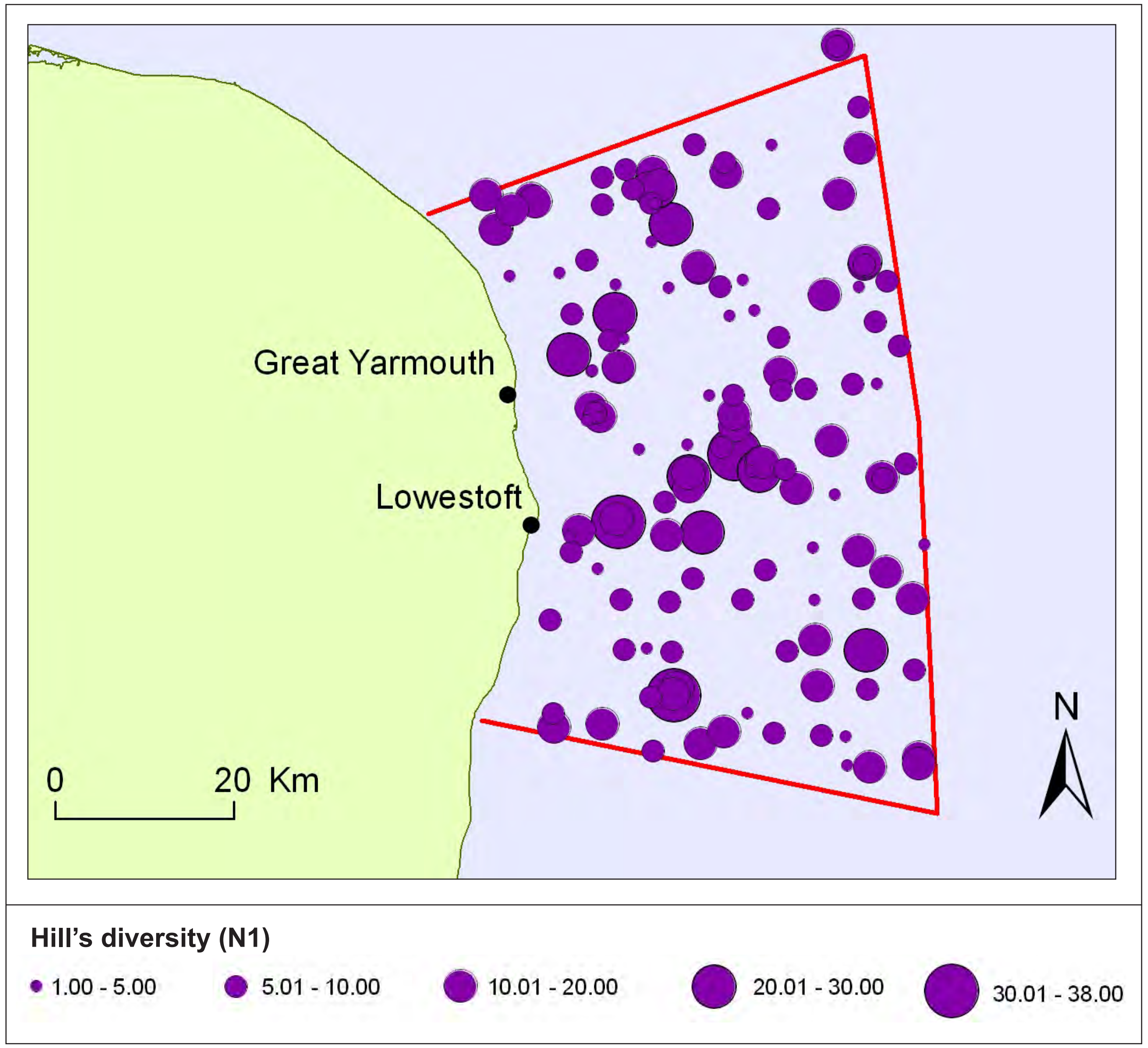


Figure 6.6 Distribution of species diversity (Hill's N1) per 0.1 m^{-2} Hamon grab sample.

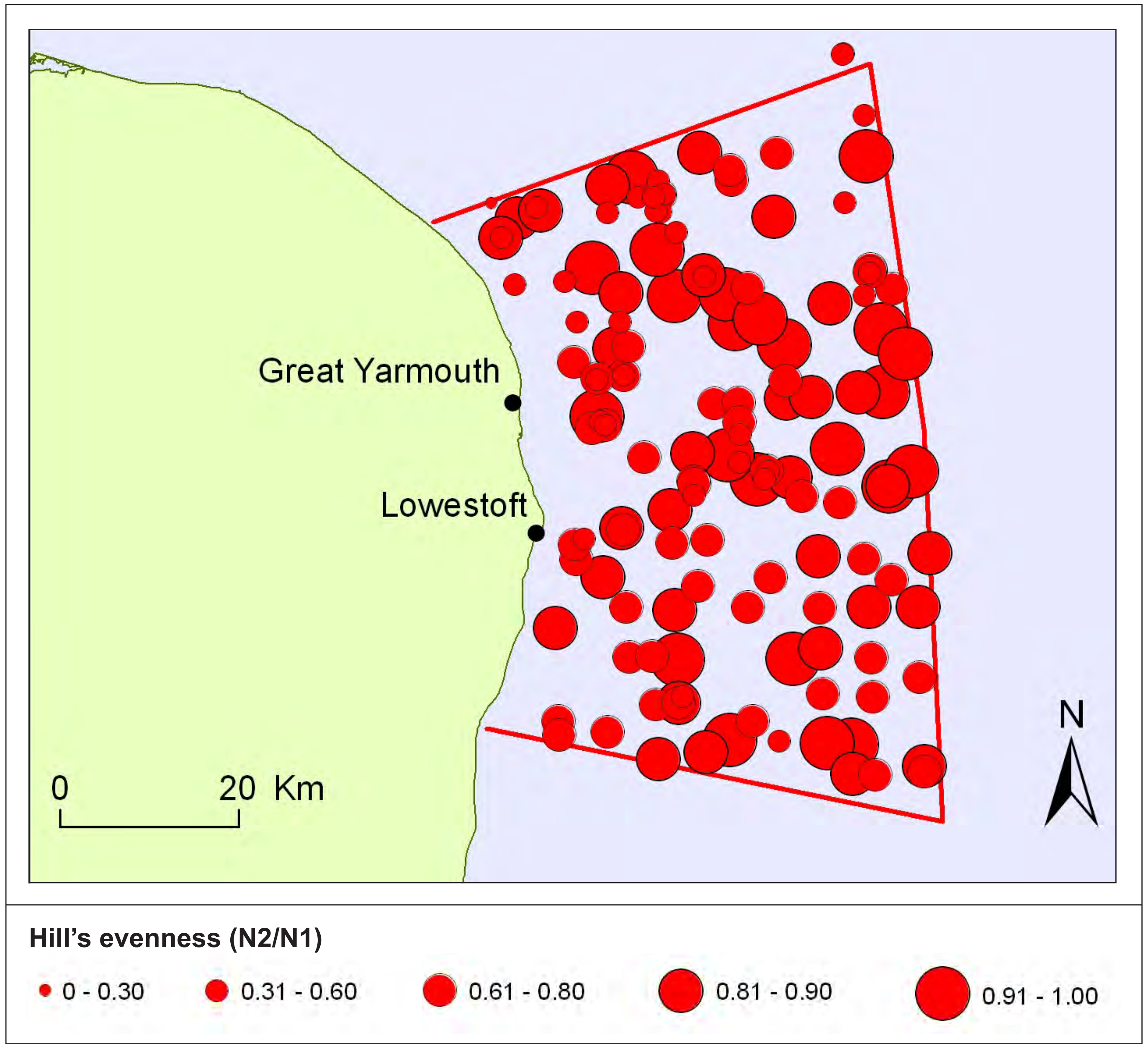


Figure 6.7 Distribution of species evenness (Hill's N2/N1) calculated per 0.1 m^{-2} Hamon grab sample.

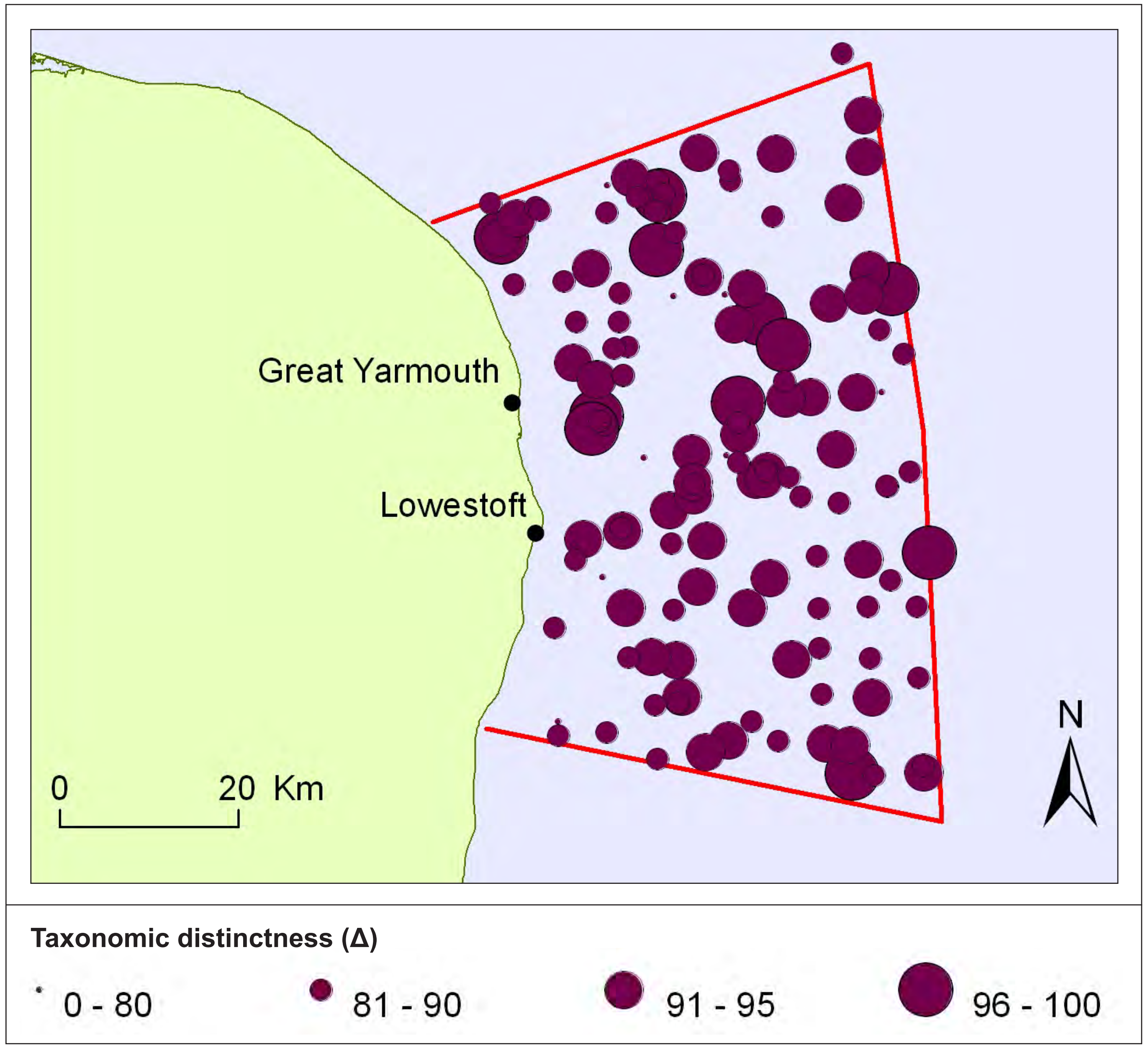


Figure 6.8 Distribution of taxonomic distinctness (Δ*) calculated per 0.1 m^{-2} Hamon grab sample.

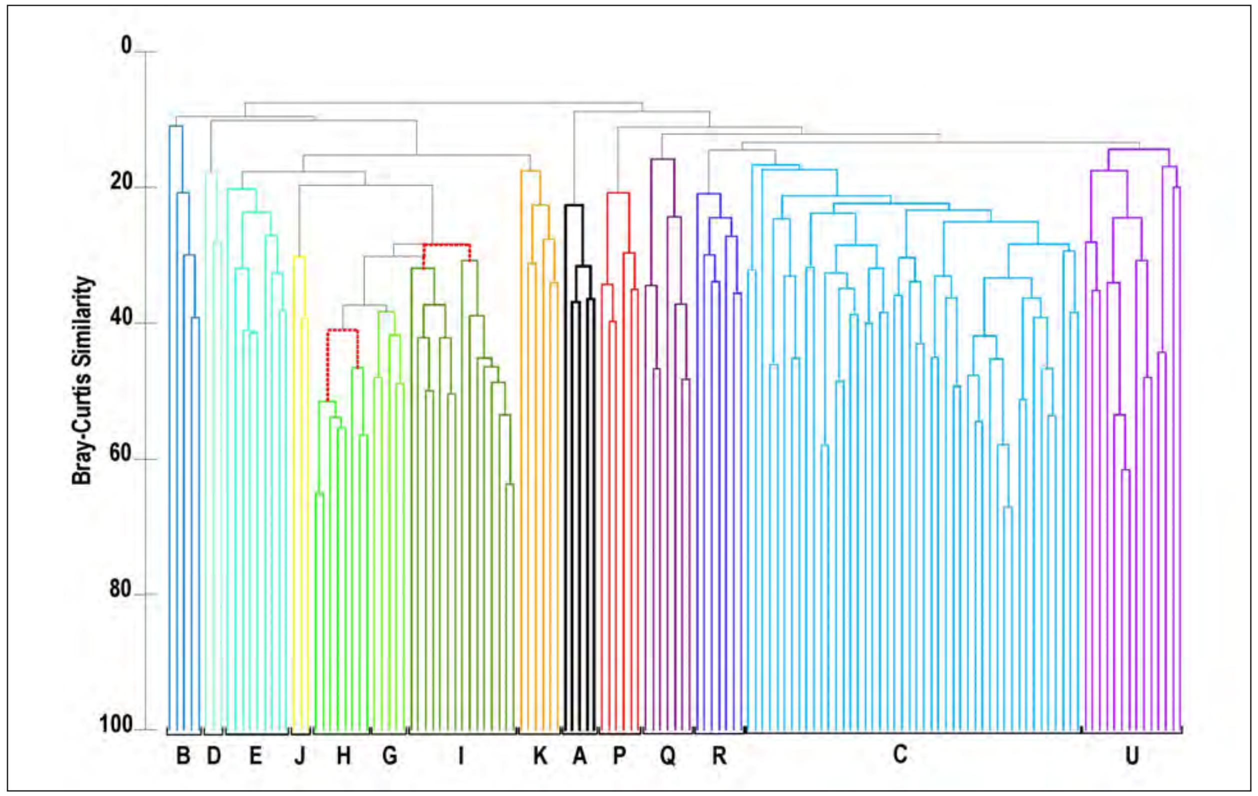


Figure 6.9 Dendrogram based on group-averaged Bray–Curtis similarity values between samples. Statistically distinct groups of samples (α = 0.05) are joined by coloured lines. Groups H and I are each composed of two statistically distinct groups (separated by red dashed lines) to provide broader classes more suitable for a regional characterisation.

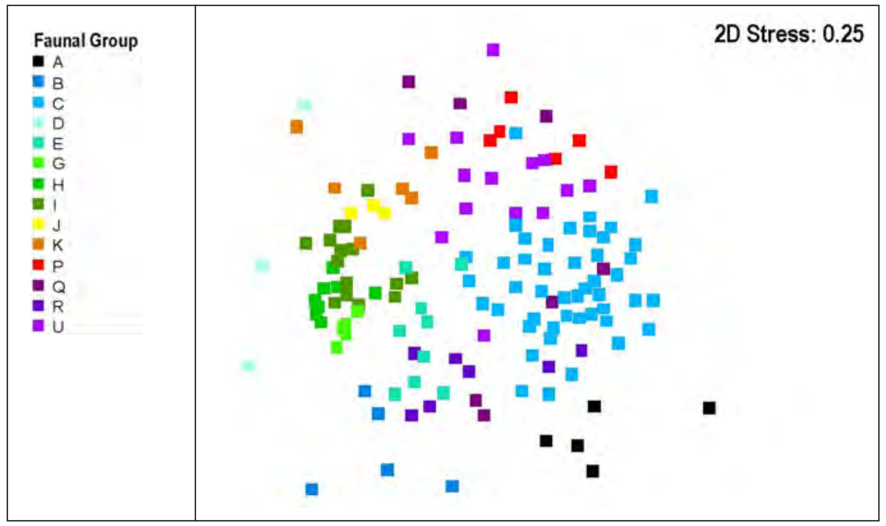


Figure 6.10 A multidimensional scaling ordination plot based on Bray–Curtis similarity between samples. Sample points have been colour-coded according to the distinct assemblages identified in Figure 6.9.

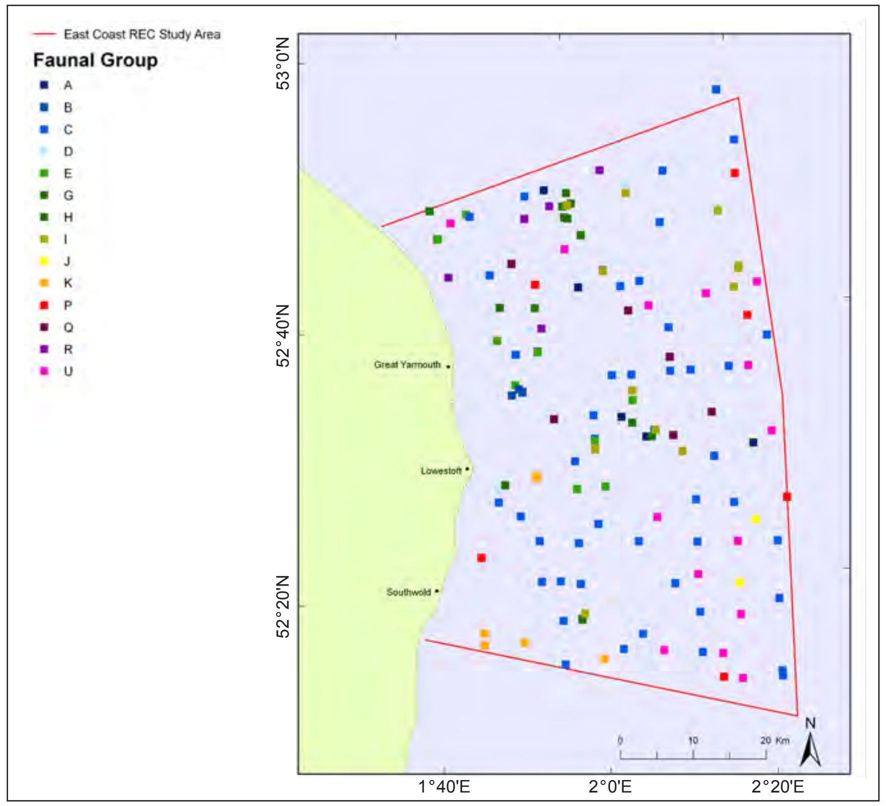


Figure 6.11 Spatial distribution of the 14 distinct infaunal assemblages identified through multivariate analysis of grab sample data.

6.3.3 Assemblage–environment interactions

Understanding the ways in which environmental conditions influence marine fauna and assemblage composition is of key importance to the effective management of marine resources, since such knowledge can assist in the prediction of the distribution of assemblages and even individual species of interest. Comparisons between patterns in the infaunal assemblage and patterns in the physical environment of the East Coast REC Study Area have been made using a range of environmental variables obtained for each of the Hamon grab sampling sites. The different environmental variables used are listed in Table 6.1, together with a brief description and their source. The univariate descriptors of the sediment composition (eg, sorting coefficient, skewness of distribution, mean particle size, etc.) were calculated according to methods set out in Folk and Ward (1957). Some variables were found to correlate highly with one another, in which case one (or more) variable was removed from the analysis and the remaining covariate was considered as a proxy for those removed.

The relationship between the infaunal assemblage and the environment was investigated using the RELATE routine in PRIMER. Tests were carried out to look for correlations between the observed patterns in faunal similarity and any patterns in similarity between samples based on their physical characteristics. Physical variables were differentiated into two groups: (1) sediment particle size-related and (2) non-sediment-related. Comparisons were conducted using either all physical variables together or with just one of the two differentiated data-sets (ie, excluding sediment-related variables or non-sediment-related variables). RELATE test results from all comparisons are presented in Table 6.2.

When all samples were used for the comparisons, the correlation between similarity within the infaunal samples and similarity within the physical samples was weak (ρ = 0.187, 0.1% significance). A slightly stronger relationship exists between the infaunal similarity and that of the sediment size fractions alone (ρ = 0.234, 0.1% significance), suggesting that differences in particle size

RELATE test	Sample statistic (ρ)	Significance level (%)
Using all 158 samples		
All environmental variables	0.187	0.1
Raw particle size data	**0.234**	**0.1**
All environmental variables excluding raw particle size data	0.095	0.1
Using all samples averaged by Group		
All environmental variables	0.515	0.2
Raw particle size data	**0.722**	**0.1**
All environmental variables excluding raw particle size data	0.394	2.8

Table 6.2 **RELATE test results from comparisons between the similarity of the infaunal assemblage and the similarity in environmental variables. Note: Variables averaged by Group: see Section 6.3.2.**

No. of variables	Correlation (ρs)	Variables (sediment fraction)
1	0.751	0.5 mm (coarse sand)
	0.674	0.71 mm (coarse sand)
	0.621	0.355 mm (medium sand)
3	0.797	1.4 mm (very coarse sand), 0.71 mm (coarse sand), 0.5 mm (coarse sand)
	0.796	2.8 mm (very fine gravel), 0.71 mm (coarse sand), 0.5 mm (coarse sand)
	0.793	2 mm (very fine gravel), 0.71 mm (coarse sand), 0.5 mm (coarse sand)
5	0.811	2 mm (very fine gravel), 1.4 mm (very coarse sand), 0.71 mm (coarse sand), 0.5 mm (coarse sand), 0.063 mm (very fine sand)
	0.811	2.8 mm (very fine gravel), 1.4 mm (very coarse sand), 0.71 mm (coarse sand), 0.5 mm (coarse sand), 0.063 mm (very fine sand)
	0.810	1.4 mm (very coarse sand), 1 mm (very coarse sand), 0.71 mm (coarse sand), 0.5 mm (coarse sand), 0.063 mm (very fine sand)

Table 6.3 **Summary of results from the BIO-ENV routine carried out between the infaunal benthic assemblage (averaged by Group) and sediment fraction data (% retained).**

No. of variables	Correlation (ρs)	Variables (sediment fraction)
1	0.300	Near Bottom Temperature
	0.299	% Sand
	0.287	Longitude
3	0.575	Latitude, Near-bed Temperature, % Sand
	0.571	Near-bed Temperature, Sorting, Skewness
	0.556	Latitude, Near-bed Temperature, Sorting
5	0.575	Latitude, Longitude, Near-bed Temperature, Sorting
	0.573	Latitude, Longitude, Near-bed Temperature, Skewness
	0.573	Longitude, Near-bed Temperature, Sorting, Skewness

Table 6.4 **Summary of results from the BIO-ENV routine carried out between the infaunal benthic assemblage (averaged by Group) and all environmental data except sediment fraction data.**

composition between samples are a slightly better predictor of infaunal assemblage composition than differences in all physical variables considered together. The differences in non-sediment-related physical variables between samples were the least reliable at predicting any differences in infaunal assemblage composition ($\rho = 0.095$, 0.1% significance).

When faunal and physical variables were averaged by Group (as described in Section 6.3.2 and illustrated in Figure 6.9) and a RELATE routine applied to the averaged data-sets, the correlation between faunal and environmental similarity matrices was much stronger (Table 6.2). Again, differences in sediment-related physical variables between Groups were a much better predictor of differences in infaunal assemblage composition between Groups ($\rho = 0.722$, at 0.1% significance) than all physical variables analysed together or excluding sediment-related variables.

The BIO-ENV routine was employed to investigate which of the physical variables, individually or in combination, had the strongest influence on the patterns observed in the infaunal assemblage (Table 6.3). Sediment fractions on their own showed a strong correlation with the benthic assemblage structure (the highest being the 0.5 mm coarse sand fraction, with a ρs value of 0.751). However, a five-variable combination of very fine gravel (2 mm), very coarse sand (1.4 mm), coarse sands (0.71 and 0.5 mm) and very fine sand (0.063 mm) achieved the highest correlation value of all combinations of physical variables ($\rho s = 0.811$).

The strongest correlation of all physical variables examined together was obtained from a three-variable combination of Latitude, Near-bed Temperature and % Sand ($\rho s = 0.575$: Table 6.4). BIO-ENV tests are correlative rather than causal but can offer very strong clues as to the environmental factors that are influencing the distribution of biological assemblages. These test results indicate that the composition of the substrate has a strong influence on the infauna able to inhabit it. The composition of the sand component of the substrate seems to be of particular importance. Near-bed temperature may also be influencing the distribution of benthic assemblages in this area. This is perhaps unsurprising since many benthic species have well-known temperature tolerances. The positional attribute (latitude) has also been shown to influence the distribution of benthic fauna in the North Sea (Heip *et al*., 1992). However, it may be acting as a proxy for other, unmeasured, but geographically important variables, possibly including other derivatives of temperature such as winter minimum temperature, which is known to be the limiting factor in the distribution of the American slipper limpet, *Crepidula fornicata* (Thieltges *et al*., 2004).

In Chapter 7 of this report, attempts are made to model and map the extent of the distinct infaunal assemblages identified in this section using a combined analysis of faunal and physical variables, akin to the biotope concept first advocated by Ernst Haeckel (1876). The biotope concept has evolved over time to become a management tool that describes broad biological assemblages in combination with environmental conditions under which they occur, namely sediment type, energy (water currents) and their biological zonation (Connor *et al*., 2004).

6.4 Trawl data results

The target organisms of the 2 m beam trawl are those that are too large, infrequent or motile to be adequately sampled using a Hamon grab. Organisms obtained by trawling are considered to represent the resident epibenthic community of an area, as this sampling method catches mostly organisms living on – or in close association with – the surface of the seabed. It is inevitable that some infaunal and pelagic organisms are caught by this sampling method, but for the purposes of the present investigation, the data-set obtained from the 2 m beam trawls is referred to as the “epifaunal assemblage”. Unambiguously pelagic organisms, such as Cnidaria (jelly fish) and Ctenophora (sea gooseberries), have been excluded from these analyses.

A total of 127 beam trawls were collected, with all but 11 of them being at the same target stations as the Hamon grabs (Figure 6.12). Spatial coverage of samples across the East Coast REC Study Area was fairly even, with large gaps only apparent in areas where it was too shallow for the vessel to operate safely (north of the centre and towards the northeast of the East Coast REC Study Area).

6.4.1 The epifaunal assemblage

In total, 130 different taxa were collected, of which 20 were colonial. Chordata (fish) were the most speciose taxon captured, followed by the Crustacea, Mollusca, Echinodermata, Annelida, Cnidaria (anemones) and Miscellania (Figure 6.13). Taxa included under Miscellania are the Bryozoa, Porifera, Platyhelminthes and Sipuncula.

In terms of abundance, Echinodermata (predominantly Ophiuroidea, or brittlestars) were the most abundant taxon, contributing 77.5% of all organisms sampled. These were followed by the Crustacea (18.7%), Mollusca (2.2%), Chordata (1.1%) and the rest of the phyla, which cumulatively contributed less than 1% to the total abundance of organisms caught (Figure 6.13). Colonial taxa were only counted as present in analyses of abundance.

The ten most abundant taxa collected during the epifaunal survey are listed in Figure 6.14. By far the most abundant species was the brittlestar *Ophiura albida*, with over 100,000 individuals collected. The two next most abundant species were also brittlestars (*Ophiothrix fragilis* and *Ophiura ophiura*), but these were present in numbers less than one third of those observed for *O. albida*. Crustacean and other echinoderm species comprised the rest of the ten most abundant taxa collected.

The most frequently encountered species was the common hermit crab *Pagurus bernhardus*, found at 123 out of 127 stations sampled, closely followed by the starfish *Asterias rubens*. The frequency of the top ten most often encountered taxa is presented in Figure 6.15. The spatial distribution of the number of taxa and faunal abundance is illustrated in Figure 6.16.

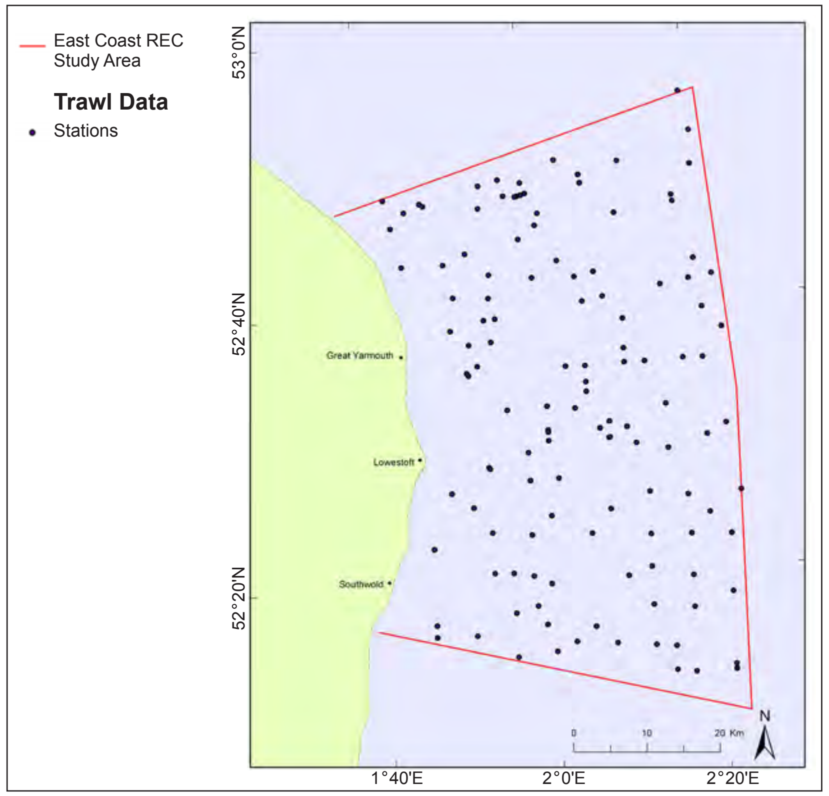


Figure 6.12 Map illustrating the location of all 2 m beam trawl deployments.

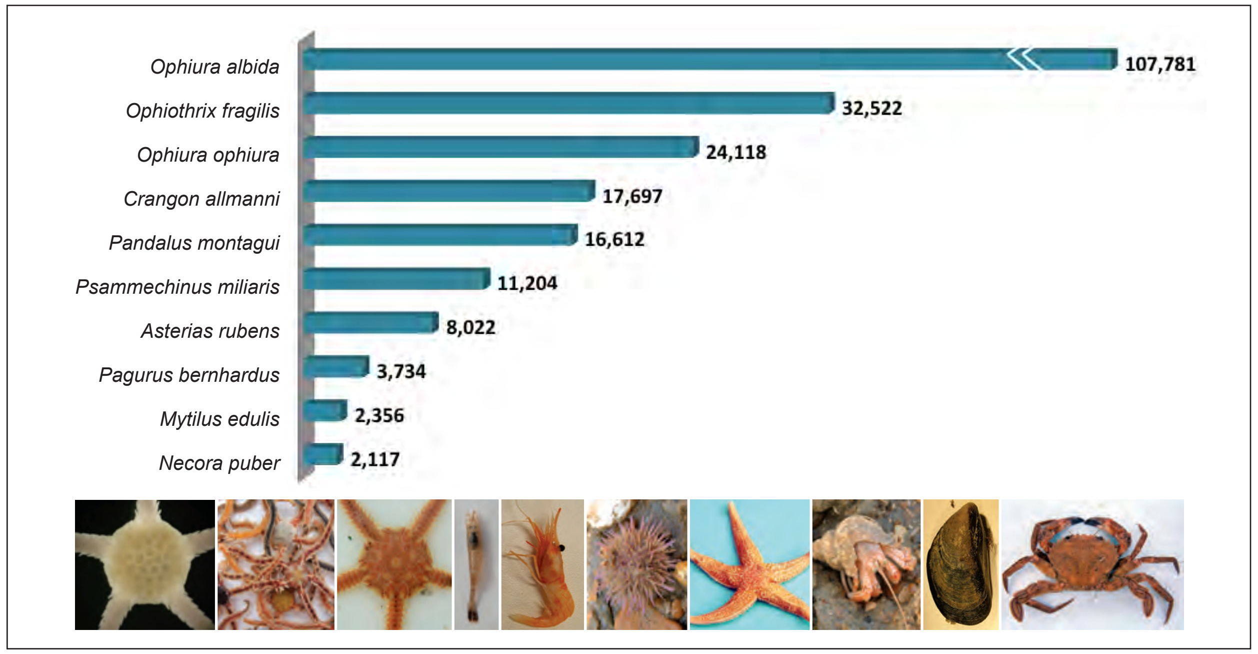


Figure 6.14 The ten most abundant epifaunal taxa recorded in 127 beam trawl samples taken across the East Coast REC Study Area. Photographs running left to right represent the taxa from top to bottom along the x-axis (vertical). © seasurvey.co.uk.

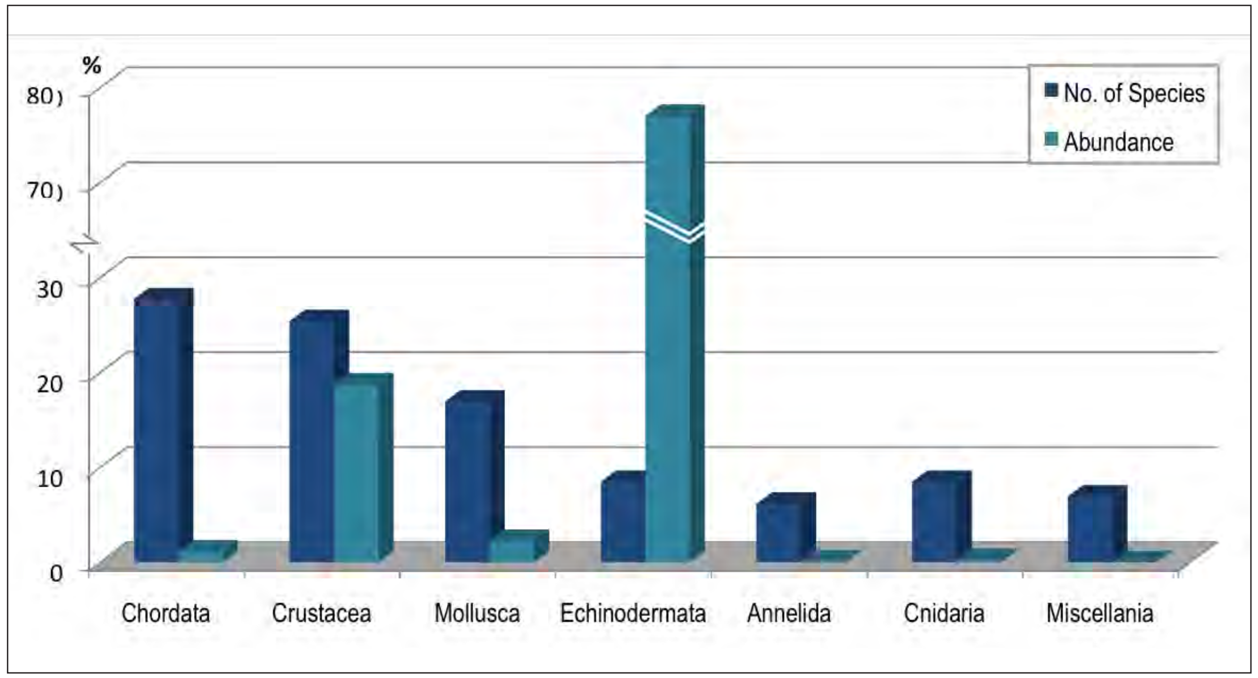


Figure 6.13 Number and relative contribution of taxa within each major phylum captured using a 2 m beam trawl.

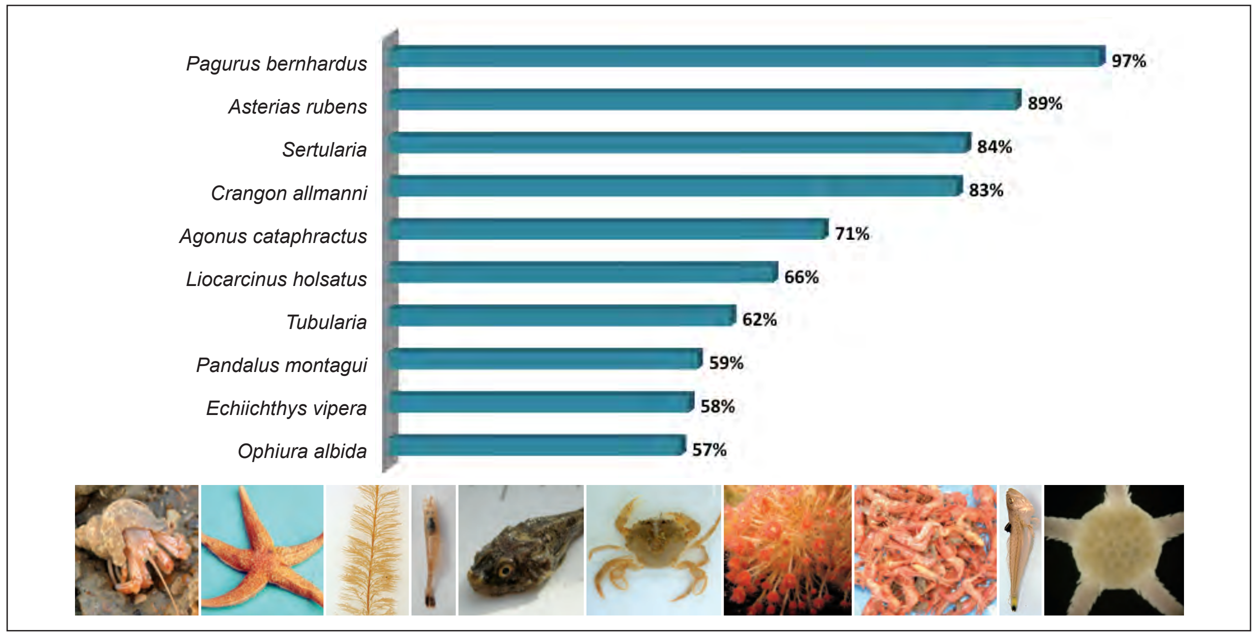


Figure 6.15 The ten most frequent epifaunal taxa recorded in 127 beam trawl samples taken across the East Coast REC Study Area. Photographs running left to right represent the taxa from top to bottom along the x-axis (vertical). © seasurvey.co.uk.

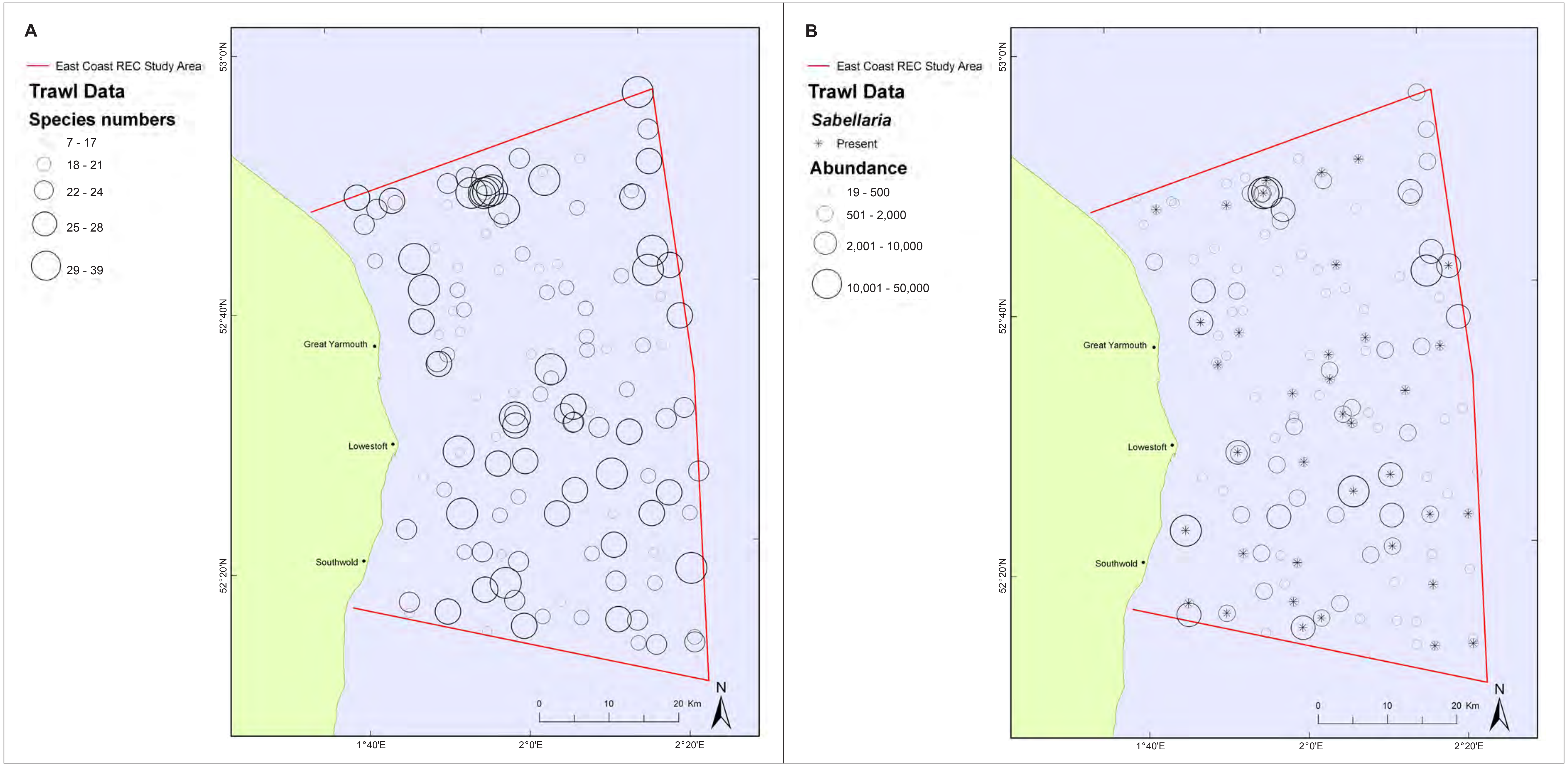


Figure 6.16 Representation of the number of species (A) and number of organisms (B) at each sampling station.

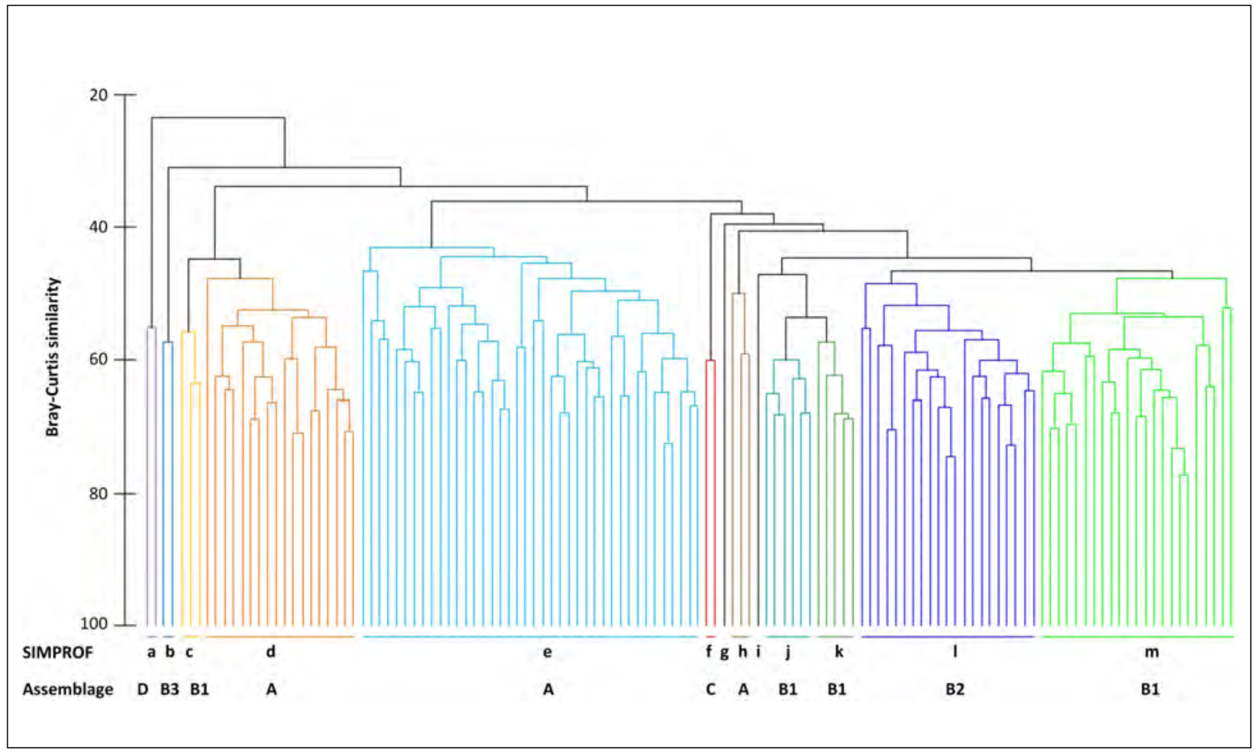


Figure 6.17 Dendrogram illustrating the relative group average similarity between all samples and the occurrence of statistically distinct clusters of samples (connected by coloured lines) as defined by SIMPROF. For rationale behind assignation of statistically distinct groups into assemblages see Table 6.5.

The spatial distribution of the number of taxa and their overall abundance is illustrated in Figure 6.16. High numbers of taxa were recorded across most of the East Coast REC Study Area, interspersed with samples yielding low taxon numbers – except for the centre of the northern half of the area (Figure 6.16A). Here, trawls consistently delivered relatively low numbers of taxa, but no lower than those recorded elsewhere. Abundance values were also very variable. At most stations, epifaunal abundance was relatively low (up to 500 individuals per trawl: Figure 6.16B), but occasionally larger numbers were obtained. No discernible pattern or causative factor can readily be observed in the occurrence of high numbers of organisms. The presence of live *S. spinulosa* reef does not appear to have any influence on the abundance values recorded, as *S. spinulosa* was found equally in trawls with low and high numbers of organisms.

6.4.2 Epifaunal assemblage composition

Multivariate analyses were carried out on the epibenthic data. Using the PRIMER analytical package (Clarke and Gorley, 2006) the taxon abundance-by-sample matrix was fourth-root transformed. Bray–Curtis similarity was computed between every pair of samples, followed by the application of simultaneous CLUSTER and SIMPROF routines to obtain statistically distinct ($\alpha = 0.01$) groups of samples based on similarity (Figure 6.17).

A SIMPER routine was performed to identify the species contributing to the similarity within each statistically distinct group. The SIMPER output was exported into Excel and rearranged using pivot tables to visualise the relative contribution of species to each statistically distinct group (Table 6.5). Columns were re-ordered following visual inspection of the resulting table to maximise shared characteristics between groups and assign assemblage composition.

The routines revealed 13 statistically distinct groups of samples, 2 of which were represented by a single trawl sample; the remaining 11 (each represented by 2 or more samples) could be grouped further based on shared characterising species. As a result, four major assemblages have been identified (A to D), one of which (B) contains several sub-assemblages (B1, B2 and B3) in which the characterising species were broadly the same, but differed in relative abundance. Each of these assemblages is described below.

Assemblage A

Assemblage A was found mostly towards the north-western half of the REC area (Figure 6.18), and incorporated three statistically distinct groups. It was characterised by the presence of brown shrimp *C. allmanni*, common hermit crab *P. bernhardus*, common starfish *A. rubens* and pink shrimp *Pandalus montagui*, amongst other less abundant species (notably, sessile colonial organisms such as *Tubularia*, horn wrack *Flustra foliacea* and Actiniaria). Another distinctive characteristic relative to all other assemblages in the area was a conspicuous lack of any Ophiuroidea (brittlestars), a taxon represented in most other assemblages in the area. (See Figure 6.19 for photographs of representative samples of this assemblage.)

Assemblages B1, B2 and B3

Assemblages B1, B2 and B3 were the most extensive, covering most of the south and eastern edge of the East Coast REC Study Area (Figure 6.18). The unifying factor in all three groups was the presence of relatively large numbers of brittlestars *O. albida* together with brown shrimp *C. allmanni*, common hermit crab *P. bernhardus*, and common starfish *A. rubens*. Other conspicuous species not present in every sample but contributing to the similarity within the assemblage were brittlestars *O. ophiura*, Dover sole *Solea solea*, common whelk *Buccinum undatum*, green sea urchin *Psammechinus miliaris*, hydroid *Sertularia* spp. and pogge fish *A. cataphractus*. The relative contribution of the main characterising species as well as differences in the variety of the less abundant characterising species was the basis for the differentiation between sub-assemblages 1, 2 and 3. B3 contained the highest numbers of brittlestars *O. albida* and *O. ophiura* of all three sub-assemblages, yet it contained no common starfish *A. rubens* (Figure 6.19). B2 had higher numbers of *O. albida* than of *O. ophiura* and moderate

ASSEMBLAGE	A	A	A	B1	B1	B1	B1	B2	B3	C	D	Grand total
SIMPROF group	d	e	h	c	j	m	k	l	b	f	a	
Ophiura albida				5.25	2.61	1.85	2.72	5.36	11.2			28.99
Crangon allmani	1.52	1.44	1.47	3.84	2.79	3.2	3.09	3.77	3.54			24.66
Pagurus bernhardus	1.87	1.83	2.47	2.72	2.52	2.55	2.29	2.22	1.82	2.62		22.91
Asterias rubens	3.15	1.29	2.66	5.36	2.65	1.95	1.83	1.58			2.24	22.71
Ophiura ophiura								2.49	10.16			12.65
Ophiothrix fragilis											11.13	11.13
Psammechinus miliaris					2.65	1.37	6.7					10.72
Liocarcinus holsatus			1.73				1.64	1.55		1.56	1.65	8.13
Agonus cataphractus	1.08				1.48	0.92	1.6	1.2		1.75		8.03
Pandalus montagui	4.06	1.31		2								7.37
Necora puber	2.31			3.52								5.83
Sertularia	0.94	0.9		1	1	0.74		0.86				5.44
Liocarcinus depurator	1.18			2.36						1.64		5.18
Buccinum undatum				1.33	1.1		2.33					4.76
ACTINIARIA	1.47		1.45		1.55							4.47
Solea solea			1		1.16				1.7			3.86
Echiichthys vipera		1.11				1.25				1.37		3.73
Sepiola atlantica		1.04			1.37						1.19	3.6
Tubularia	0.72	0.75		1		0.74						3.21
Cancer pagurus	1.41			1.7								3.11
Pomatoschistus				1.63	1.24							2.87
Macropodia			1		1.84							2.84
Spisula elliptica						1.67		1.06				2.73

Table 6.5 **Snapshot of a table listing species abundance values (fourth-root transformed) of the most abundant species contributing towards the similarity within each statistically distinct group of samples (as indicated by SIMPROF). Warm to cold colour range reflects relative abundance.**

numbers of *A. rubens* (Figure 6.19), whereas B1 occasionally contained large aggregations of the green sea urchin *P. miliaris*, similar numbers of *A. rubens* and *O. albida* and, notably, no *O. ophiura* (Figure 6.19).

Assemblage C

Assemblage C was identified from two samples belonging to the same statistically distinct group. It is characterised by having relatively few, highly motile species, each displaying low abundance values. Most abundant of these species were common hermit crab *P. bernhardus*, pogge fish *A. cataphractus*, the small sandeel *Ammodytes tobianus*, blue-leg swimming crab *Liocarcinus depurator* and solenette *Buglossidium luteum* (Figure 6.19).

Assemblage D

As with the previous assemblage, Assemblage D was identified from just two samples belonging to the same statistically distinct group. It was also relatively species-poor compared with other assemblages, but its most distinguishing feature was a very high abundance of common brittlestar *O. fragilis* (a species found in no other assemblage) and moderate numbers of common starfish *A. rubens*, northern horsemussel *Modiolus modiolus*, black serpent-star *Ophiocomina nigra* and swimming crab *Liocarcinus holsatus* (Figure 6.19).

Because each trawl sample was collected over a relatively large area (~500 m of seabed), there was a chance that any one sample could represent more than one benthic biotope. In addition, trawl samples did not have physical variables directly associated with them, so direct comparisons between fauna and environment could not be conducted to ascertain potential correlations between the two. For these reasons, results from the multivariate analysis of epifaunal data were not included in the modelling of the distribution of benthic biotopes (Chapter 7).

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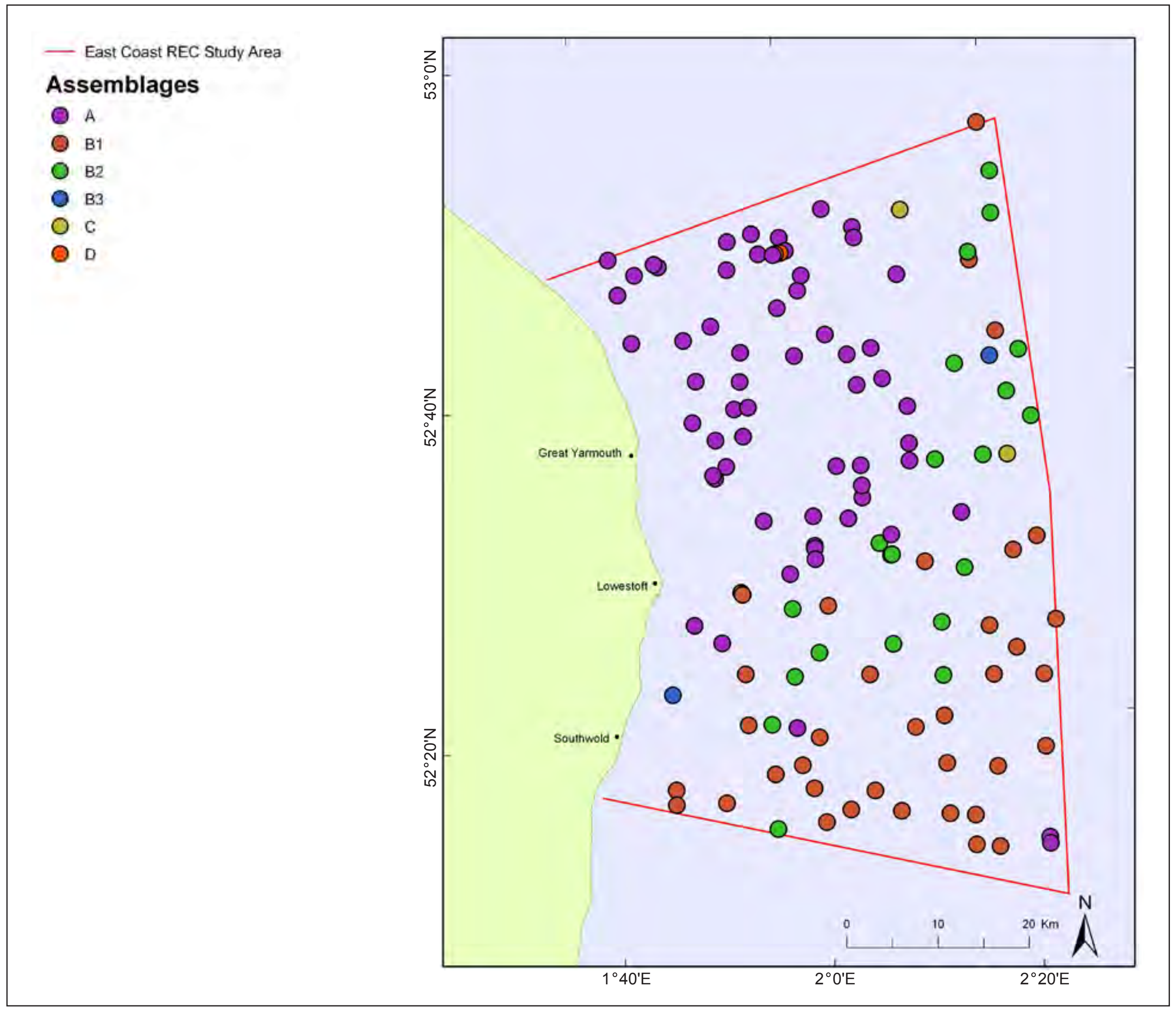


Figure 6.18 **Spatial distribution of samples falling within each epibenthic assemblage.**

Figure 6.19 **Photographs of epibenthic samples representing each of the assigned assemblages.**

6.5 Video data results

The quality of the video and stills was variable and generally poor due mostly to the high turbidity of the environment and the strong tidal currents. Thus, it was not possible to achieve a consistent level of description of the habitat and conspicuous species. However, an overview of the results from the analysis of the images is given.

A total of 89 video segments were analysed, of which 7 were duplicates (because two different video gear types were used) and 5 were from video transects that were split into a number of different habitats. The sediment types observed ranged from pebbly sand to muddy sand with gravelly muddy sands predominating (Figure 6.20). The sediment types were distributed more or less evenly throughout the survey area, with no obvious spatial trends.

Abundance scores were given to conspicuous species (*O. albida*, *S. spinulosa* and *Lanice conchilega*) or to life form classes: epifauna (attached to the substratum), infauna (mostly as observed through burrows and casts in the sediment) and motile fauna (mostly decapods and starfish). No fauna were observed in 31% of the samples, and in a further 49% only sparse epifauna or *Sabellaria* tubes were recorded (with a total abundance score of less than 7, with no individual species or life form scoring more than 3). Only 14 samples (16%) could be considered rich, with

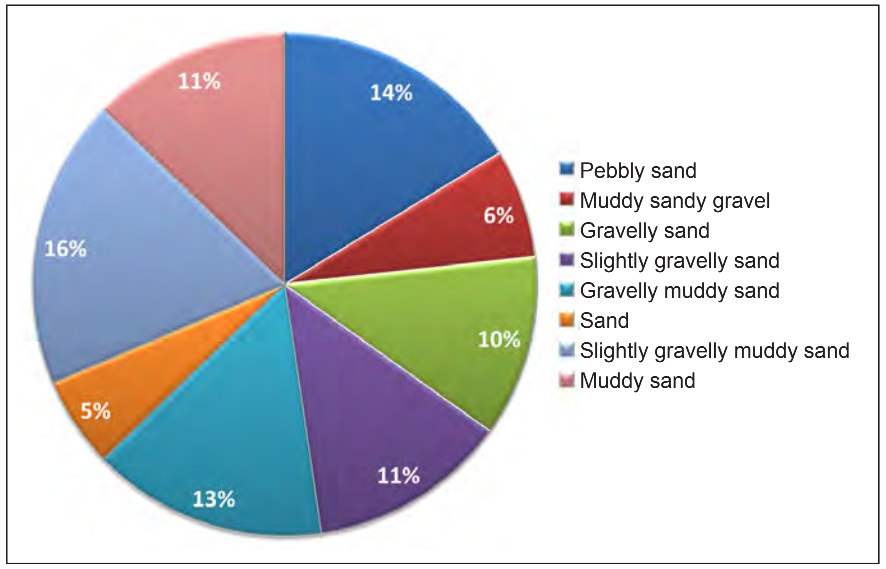


Figure 6.20 Distribution of the Folk sediment classes amongst the video samples.

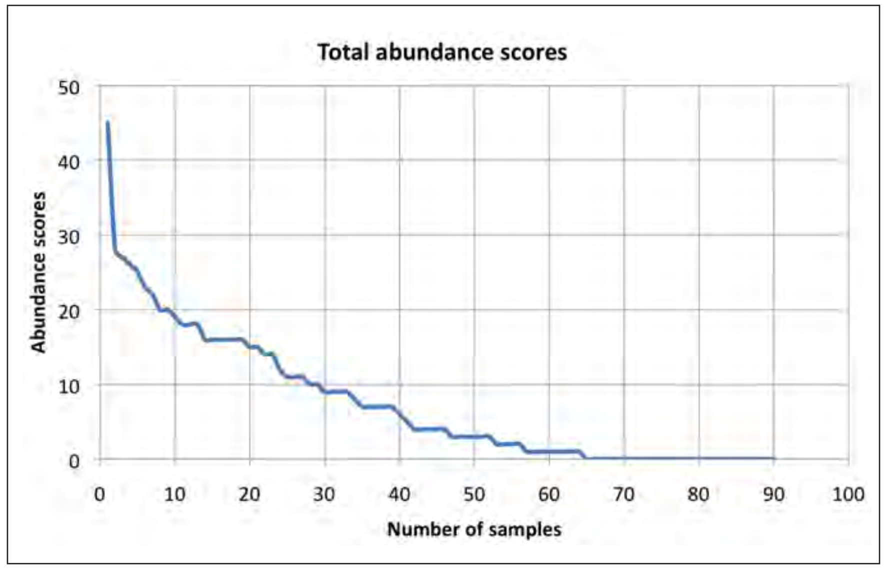


Figure 6.21 Video samples arranged by decreasing total abundance scores.

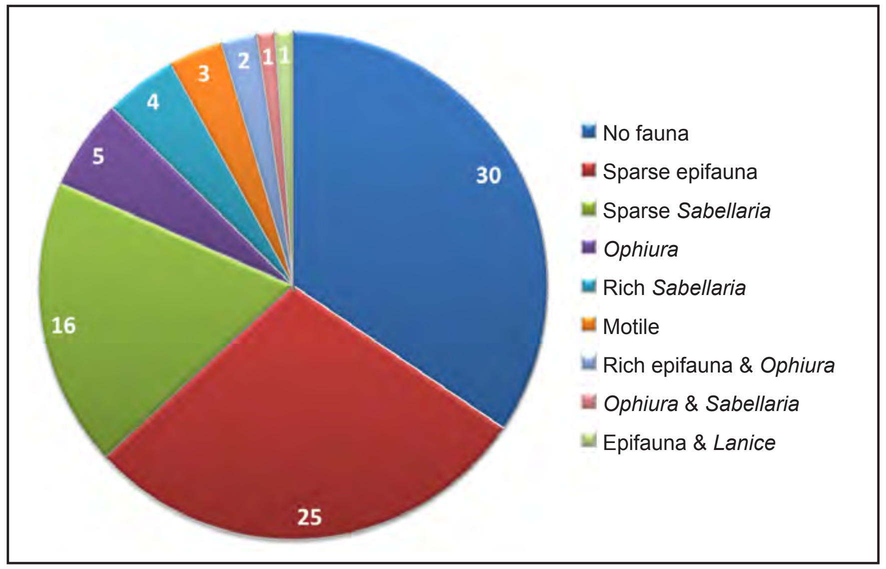


Figure 6.22 Distribution of the video samples categorised by their predominant fauna.

abundance scores greater than 18 (Figure 6.21). These were mostly characterised by epifauna and *S. spinulosa* and/or *O. albida* (Figure 6.22).

The relationship between the Folk sediment classes and the presence/absence of observed fauna (ie, any sign of fauna versus complete absence of signs) has been investigated by calculating a contingency table [observed – expected] (Table 6.6) and arranging the Folk classes from greatest negative departures (left) of barren samples to positive departures (right) from expected (and vice versa for samples with fauna). The darker blue and pink cells show departures that are statistically significant. The numbers in Table 6.6 are the actual numbers of samples observed in each category. This indicates that pebbly sand and muddy gravelly sands generally support more biological richness than slightly gravelly sand, although this pattern is only significant in the pebbly sand and gravelly muddy sand categories. The presence of seabed features (sandwaves and ripples) was also recorded, but a similar analysis using contingency tables indicated no clear association between barren samples and the presence of seabed features.

	peb S	gmS	msG	mS	S	(g)S	gS	(g)mS
Fauna absent	0	1	1	4	3	5	5	8
Fauna present	14	12	5	7	2	6	5	8

Table 6.6 Numbers of video samples without signs of fauna (top row) or with fauna in the Folk sediment classes arranged in order of the departure from their expected frequencies: blue cells where less than expected, pink where more than expected. Only the pebbly sand and gravelly muddy sand classes showed significant departure of observed from expected. KEY: pebS (pebbly sand), gmS (gravelly muddy sand), msG (muddy sandy gravel), mS (muddy sand), S (sand), (g)S (slightly gravelly sand), gS (gravelly sand), (g)mS (slightly gravelly muddy sand).

It was decided that the video data would play a subordinate role to the more quantitative data from the analysis of the grab samples when classifying the biota because of (a) the poor quality of the video and, therefore, the data extracted from them, and (b) the more numerous grab samples. It was considered that the data extracted would not support multivariate statistical analysis because of the uncertainty of the observations from the images and the low level of taxonomic detail. Nevertheless, the video records probably accurately reflected the generally barren appearance of most of the sediment in the survey area.

6.6 Rare and alien species

A key objective of nature conservation is the protection of biodiversity. To reduce the likelihood of species extinction, an assessment of rare and scarce species is required. Special management practices may be required to ensure the persistence of such species. In the United Kingdom, criteria for the assessment of rarity of marine benthic species have been developed by the JNCC (Sanderson, 1996). Species that have been recorded in 8 or fewer of the 1,546 squares (10 km^2) of the Ordinance Survey national grid are considered nationally rare, and those recorded in 9–55 squares are nationally scarce. Threatened and/or declining species and habitats are also listed in the Oslo and Paris (OSPAR) Commission Convention, which includes a small number of benthic and epibenthic marine species, including fish (OSPAR, 2008).

Another important objective in nature conservation is the monitoring and control of introduced non-native species (JNCC, 2010c). Thousands of marine organisms, as adults or larvae, are transported to new biogeographic regions through the transport and discharge of ship ballast water, as fouling organisms on ships' hulls and through aquaculture practices. Whilst most transported species will not survive the environmental conditions at the new destination, many species have been able to colonise and thrive in previously unoccupied areas around the world. Introduced species that have established self-maintaining populations in the United Kingdom are referred to as "alien" species, and some have the potential to impact the state of native populations and communities. The term "cryptogenic" is applied to those non-native species that have not established self-sustaining populations or where their origin is unclear. This classification prevents introduced species from being incorrectly recorded as new or rare species. The success of new recruits of introduced species may be impacted by environmental changes, such as rising sea temperature, so the success or expansion range of recent introductions could be used as an indicator of climate change.

A number of rare, scarce, threatened and alien species were identified in both the grab and trawl samples taken across the East Coast REC Study Area; these are summarised in Table 6.7.

Species	Phylum	Description	Status	Grab samples			Trawl samples		
				Records	Abundance	Samples	Records	Abundance	Samples
Crepidula fornicata	Mollusca	American slipper limpet	Alien in UK	3	6	T1–60, T3–25, T3–34	15	174	T1–01, T1–57, T3–33, T1–18, T3–19, T3–35, T3–26, T3–24, T3–48, T3–34, T3–42, T3–36, T1–60, T2–34, T3–25
Elminius modestus	Crustacea	Acorn barnacle	Alien in UK	1	1	T1–15	0	0	0
Gadus morhua	Chordata	Atlantic cod	OSPAR listed	0	0	0	4	15	T3–05, T3–40, T3–55, T3–58
Monocorophium sextonae	Crustacea	Amphipod	Alien in UK	2	13	T1–42, T1–60	0	0	0
Monticellina dorsobranchialis	Polychaeta		Not found in UK	1	1	T3–03	0	0	0
Obelia bidentata	Cnidaria	Erect colonial hydroid	Nationally rare	5	Present	T3–03, T3–13, T3–16, T3–52, T3–53	0	0	0
Photis pollex	Crustacea	Amphipod	Cryptogenic	2	2	T1–24, T1–51	0	0	0
Raja clavata	Chordata	Thornback ray	OSPAR listed	0	0	0	10	11	T1–11, T1–12, T1–15, T1–47, T1–50, T2–17, T2–22, T3–14, T3–42, T3–41
Raja montagui	Chordata	Spotted ray	OSPAR listed	0	0	0	3	3	T1–23, T1–26, T3–40
Rissoides desmaresti	Crustacean	Mantis shrimp	Nationally scarce	0	0	0	5	22	T1–31, T1–57, T1–59, T3–19, T3–36

Table 6.7 **Summary of the status and records of OSPAR listed, rare and alien species (Sanderson, 1996; OSPAR, 2008) within the East Coast REC Study Area. Abundance figures refer to the total number of individuals found across the survey area.**

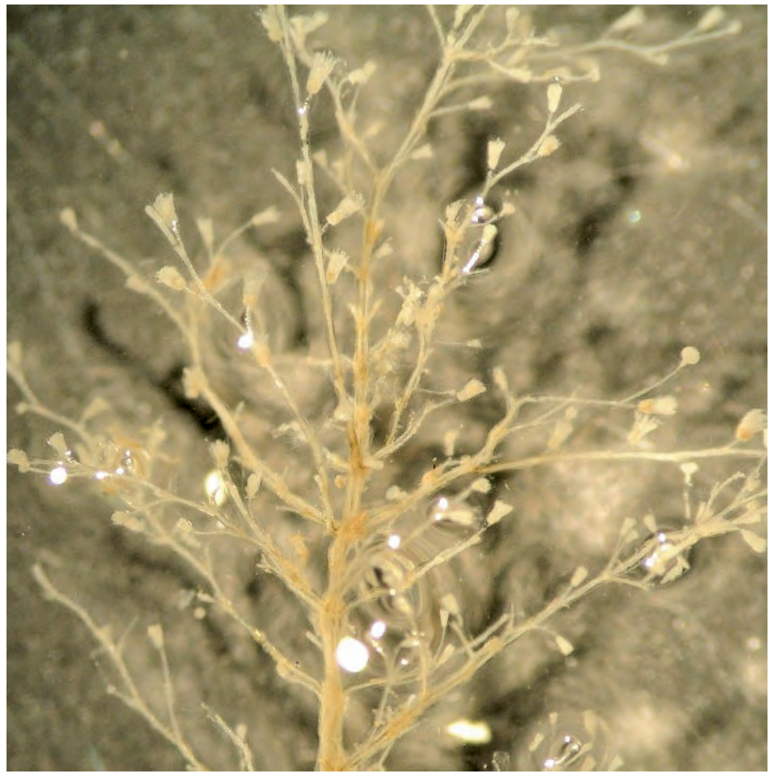


Figure 6.23 Stock picture of *Obelia bidentata*, a nationally rare species recorded in the East Coast REC Study Area. © seasurvey.co.uk.

Figure 6.24 Specimens of *Rissoides desmaresti* found in the East Coast REC Hamon grab samples.

6.6.1 Nationally rare species

There was one nationally rare species found in the East Coast REC Study Area, the erect colonial hydroid *Obelia bidentata* (Figure 6.23), which was recorded in five samples. *O. bidentata* has been recorded on non-living hard substrates, both man-made and natural. It has been found previously from north Norfolk out to nearly 100 m offshore (Cornelius, 1995), so it is not surprising it has been found in the East Coast REC Study Area.

6.6.2 Nationally scarce species

The only nationally scarce species found during the East Coast REC survey was the mantis shrimp *Rissoides desmaresti* (Figure 6.24). This species creates a simple burrow system in sandy, gravelly mud sediments. It can be found from the lower shore down to 50 m deep. It has a limited distribution and has previously been recorded from the south coast and Wales.

6.6.3 Threatened species

In 2004 OSPAR adopted a priority set of species “under threat or in decline” (OSPAR, 2004). This list contains over 40 UK species of invertebrates, fish, reptiles, mammals and birds. The species from this list that were identified during the East Coast REC survey were the thornback ray *Raja clavata*, the spotted homelyn ray *Raja montagui* and the Atlantic cod *Gadus morhua* (Figure 6.25).

6.6.4 Non-native species

Three established alien species were found during the benthic sampling in the East Coast REC Study Area, although none was widespread or found in large numbers. The most abundant was the American slipper limpet *C. fornicata* (Figure 6.26), which was found in 15 of the trawl and 3 of the grab samples, with a total of 180 individuals collected. The Australasian barnacle *Elminius modestus* (Figure 6.26) and the amphipod *Monocorophium sextonae* were less evident, only being found in 2 and 1 grab samples, respectively. The cryptogenic amphipod species *Photis pollex* was also found to be present in the East Coast REC Study Area, in 2 of the grab samples.

Figure 6.25 Stock pictures of threatened species encountered in the East Coast REC Study Area (from left to right: *Raja clavata*, *Raja montagui* and *Gadus morhua*). © seasurvey.co.uk.

Figure 6.26 Stock pictures of non-native species encountered in the East Coast REC Study Area (left: *Elminius modestus*; right: *Crepidula fornicata*). © seasurvey.co.uk.

The slipper limpet *C. fornicata* is a well-known alien on British shores. The highest abundance of *C. fornicata* is found on the south coast where the species has had a detrimental impact on oyster fisheries (Davidson, 1976; Key and Davidson, 1981). The species extends as far northwards as Spurn Head on the Humber estuary (NBN, 2010), although the East Coast REC Study Area findings show it is not widespread and is present in low abundance.

The barnacle *E. modestus* was first found in Chichester Harbour in Hampshire in 1945. The species is thought to have arrived there in the early 1940s transported from Australia or New Zealand on ships’ hulls or possibly as larvae in ships’ ballast water (Eno *et al*., 1997). In northern areas such as the British Isles, *E. modestus* competes with the native acorn barnacle *Semibalanus balanoides* (Crisp, 1958).

The amphipod *M. sextonae* was recorded as a new species in Plymouth in the 1930s (Crawford, 1937). It is native to New Zealand and it has been suggested that increased numbers of the species reduce the numbers of the native amphipod species *Crassicorophium bonellii* (Spooner, 1957).

6.7 Trophic relationships

6.7.1 Species interactions

The East Coast REC Study Area, and the wider southern North Sea, is an important area for seabirds and commercial fisheries (see Chapter 2). The area provides feeding grounds for gulls, guillemots and puffins, and there are internationally important breeding sites for little terns. There are also important fisheries in the East Coast REC Study Area, particularly for Atlantic cod, whiting, seabass, European plaice, sole, herring, turbot and rays. Some species will be temporary visitors to the area, but all will depend, to a greater or lesser extent, on the food resources available in the region.

Small fish such as sandeels are particularly important prey items for several bird species, and the importance of benthic invertebrate communities to higher trophic levels, including to commercial fisheries, is well recognised. Many marine fish species are opportunistic predators and will readily switch feeding preference in space and over time. Thus, most fish species have no highly developed preference for a particular food source and show great trophic adaptability, taking advantage of whatever food source happens to be abundant. Feeding habits may change on a seasonal or even interannual basis, and several fish species have significant behavioural shifts in diet throughout their development. For example, the larval and juvenile stages of cod, haddock and whiting feed predominantly on copepods and shrimplike euphausids whilst in the water column, switching to benthic invertebrate species such as the brown shrimp *Crangon* spp. as a bottom-dwelling adult.

Although the feeding strategy of many fish reflects the abundance of prey items available, there are still some observed differences between broad groups of fish. For example, in investigations conducted at a number of aggregate extraction sites, the majority of fish species were found to be benthic invertebrate feeders with a strong feeding preference for crustaceans, especially crabs (Pearce, 2009). In contrast, flat fish such as plaice, Dover sole, dab and lemon sole were found to be more likely to feed on polychaete worms.

Data on stomach contents from fish collected in the North Sea have been used to assess the most important prey items for a number of important commercial species. These data are stored in the Cefas DAPSTROM project (an Integrated Database & Portal for Fish Stomach Records – Pinnegar *et al.*, 2003) and include the Cross Sands stomach content data (Cooper, personal comm.) and data from an ALSF-funded project looking at the significance of benthic communities for higher trophic levels at a number of aggregate extraction sites (Pearce, 2008). The top five species, in terms of percentage occurrence in fish stomachs, have been selected for each of the commercial species for which data were available (Table 6.8). The most important prey species across a range of commercial fish species are the brown shrimp *Crangon* spp., sandeels, crustaceans (particularly crabs) and brittlestars.

Sandeels

Sandeels are an abundant and important component of food webs in the North Atlantic. They constitute important prey for many top marine predators, including marine mammals such as grey seals and harbour seals, harbour porpoise and important commercial fish species such as cod, whiting, haddock and mackerel (Table 6.8). They are also prey for several seabird species such as terns, guillemots and puffins. Like other short-lived species, sandeel stocks can be highly variable in time and space, as recruitment is dependent on many factors. High natural mortality also makes it difficult to assess stocks of this species.

Sandeels also support the largest industrial fishery in the North Sea, with recent annual landings in the region of 0.5–1 million tonnes. Of the five species of sandeels inhabiting the North Sea,

Common name	Species name	Most common prey items	Source
Cod	*Gadus morhua*	*Crangon* spp *Pandalus* spp. Crustaceans Sandeels Fish (incl. dragonets and gadoids)	Pinnegar, 2009[a]; Adlerstein & Welleman, 2000
Whiting	*Merlangius merlangus*	Sandeels Fish Euphausids *Crangon* spp. Crabs Polychaetes	Pinnegar, 2009[a]; Pearce, 2008
Haddock	*Melanogrammus aeglefinus*	Sandeels Crabs Polychaetes Brittlestars Starfish and urchins	Pinnegar, 2009[a]
European plaice	*Pleuronectes platessa*	Polychaetes Sandeels Bivalves Crustaceans (especially mysids) Brittlestars	Pinnegar, 2009[a]; Pearce, 2008
Dover sole	*Solea solea*	*Crangon* spp. Polychaetes (especially *Pectinaria koreni* and *Sabellaria spinulosa*)	Pinnegar, 2009[a]; Pearce, 2008; Cefas unpublished[b]
Common dab	*Limanda limanda*	Brittlestars Crabs Polychaetes (incl. *Sabellaria spinulosa*) Sandeels	Pinnegar, 2009[a]; Pearce, 2008
Lemon sole	*Microstomus kitt*	Polychaetes Gastropods Necklace shells Crabs	Pinnegar, 2009[a]
Raja rays	*Raja clavata*	*Crangon* spp. *Pandalus* spp. Sandeels Crabs Euphausids and mysids	Pinnegar, 2009[a]; Cefas unpublished[b]

[a]DAPSTOM North Sea data; [b]Cross Sands data.

Table 6.8 Most common prey items, as identified by stomach content analysis, for a number of commercially important fish species.

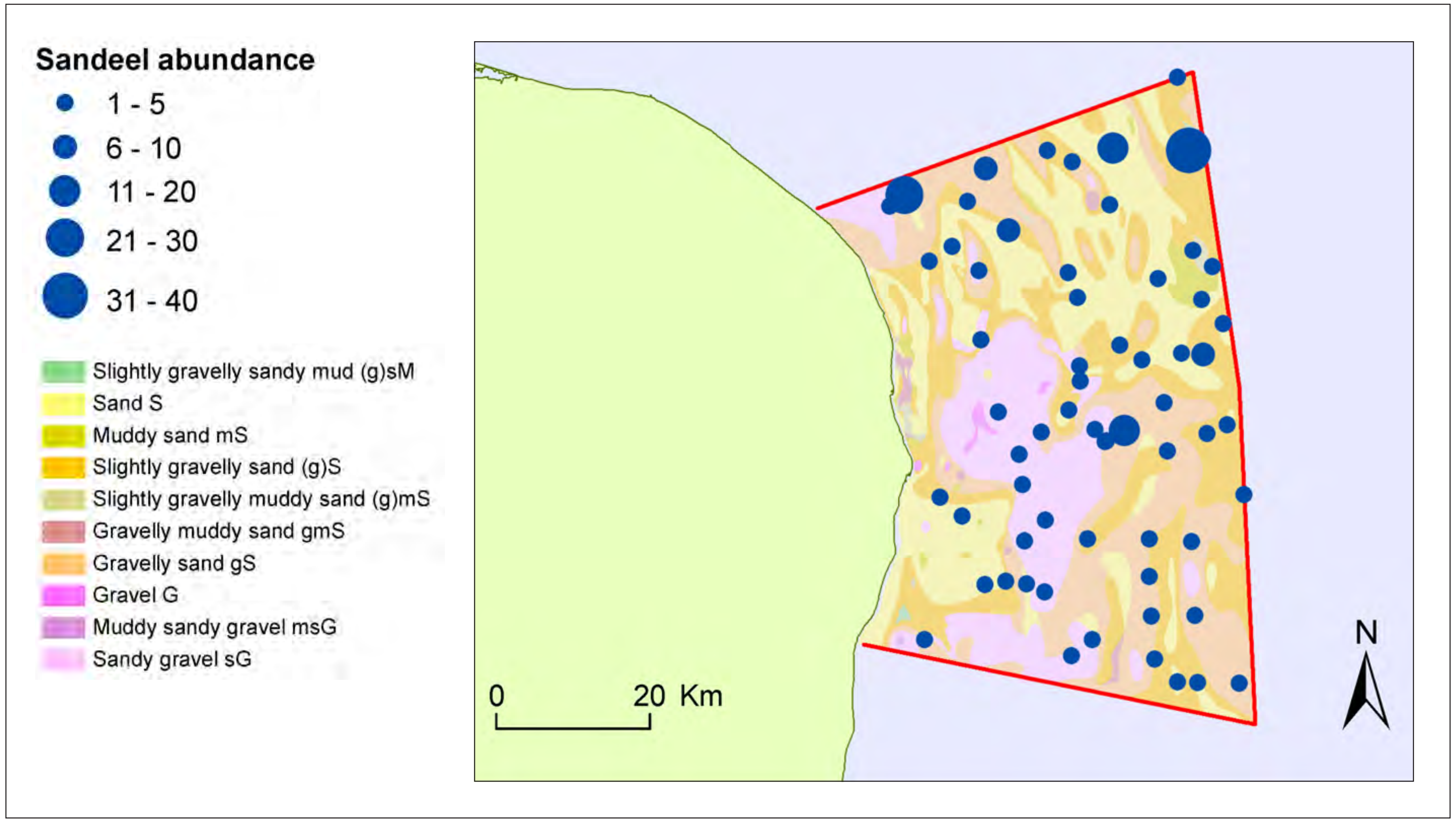


Figure 6.27 **Abundance of sandeels (*Ammodytes tobianus* and *Hyperoplus lanceolatus*) in 2 m beam trawls (5 mm mesh size) taken across the East Coast REC Study Area.**

the lesser sandeel *Ammodytes marinus* is the most abundant and comprises over 90% of sandeel fishery catches (Figures 6.27 & 6.28). Sandeels are used not for human consumption but as animal feed and fertilizer.

With so many predators dependent on sandeels, the level of exploitation has raised concerns regarding the impact on marine food webs (Holland *et al*., 2005). Many sandeel fishing grounds are close to seabird colonies, and there is considerable overlap in the distribution of sandeels, seabirds feeding at sea and industrial fishing activity (Wright and Begg, 1997). These conflicts have resulted in increasing concern about the potential impact of sandeel fishing on seabirds (Furness and Tasker, 2000), and research has indicated that declines in seabird breeding success appeared to be associated with increased sandeel fishing activity nearby (Monaghan *et al*., 1989). ICES recommend that in areas where stocks have been depleted, fishing should be closed to allow recovery (ICES, 2009c).

Figure 6.28 **The lesser sandeel *Ammodytes tobianus* and the greater sandeel *Hyperoplus lanceolatus*. © seasurvey.co.uk.**

Availability of suitable habitat is a key constraint to the distribution of sandeels. They are known to prefer medium to coarse sand and have been shown to avoid areas with high levels of coarse gravel, fine gravel and silts (Holland *et al*., 2005). Sandeels were observed in only 50% of the beam trawl samples (64 of a total of 127 trawls) deployed across the East Coast REC Study Area. Where sandeels were observed they were present in low abundance, with an average of three individuals per trawl. Only in 7 samples was the observed abundance greater than five individuals. These 7 samples were collected from areas of sand and gravelly sand, which are common habitats throughout the East Coast REC Study Area.

Brown shrimp (*Crangon* spp.)

The brown shrimp is a free-living mobile shrimp often abundant on sandy and muddy bottoms. *Crangon crangon* (Figure 6.29) and its congener *C. allmani* are the subject of an important fishery in the southern North Sea and a key prey item for several commercially important fish species, including cod, whiting, Dover sole and rays (Table 6.8). They are also consumed by seabirds, especially gulls and terns, species that are known to use the area for foraging.

As an opportunistic omnivore feeder of a wide range of plant and animal material, *Crangon* spp. represent an important link between the benthos and several fish species. *Crangon* will consume

Figure 6.29 ***Crangon crangon.*** **© seasurvey.co.uk.**

polychaetes, fish, molluscs and small arthropods such as mysids and amphipods. *Crangon* are widespread and abundant in the East Coast REC Study Area (Figure 6.30), with an average abundance of 145 individuals and a frequency of occurrence of 92% of all trawls. This species is likely to be an important element of the food web in the East Coast REC Study Area, providing food for fish and seabirds across the whole area.

Crabs

Crabs and other crustaceans form an important part of the diet for many fish and bird species. Several crab species are recorded throughout the area (Figure 6.31), and there does not appear to be any area that is especially important for this food source.

Brittlestars

Brittlestars are important prey items for haddock and for flatfish such as European plaice and common dab. Brittlestars (Figure 6.32) were widely distributed within the East Coast REC Study Area, being present in 65% of all trawl samples. Brittlestars were found in highest abundance in areas of slightly gravelly and gravelly sands and muddy sands (Figure 6.33), although they were not always present in all such habitats.

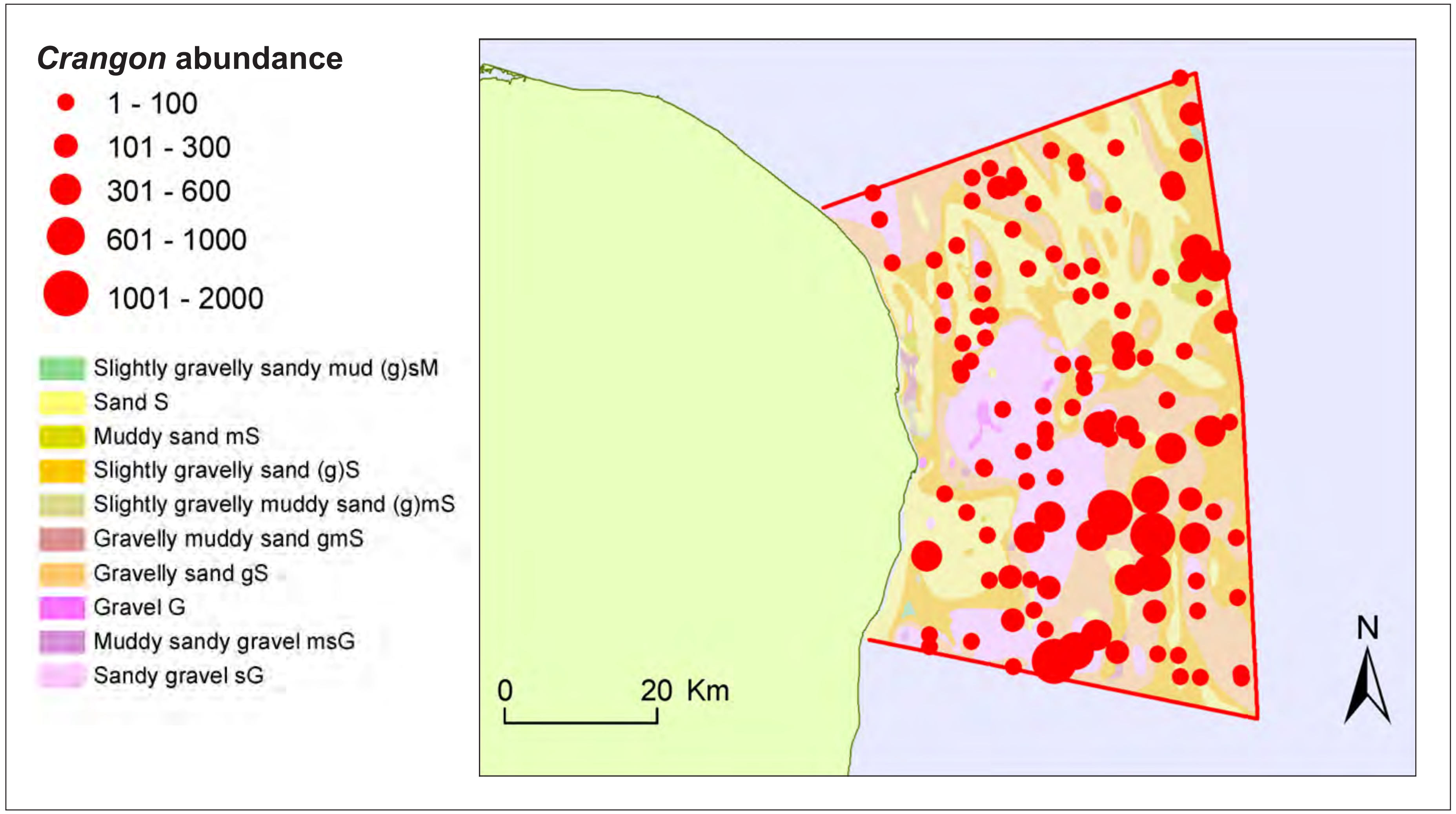


Figure 6.30 **Abundance of *Crangon* spp. in 2 m beam trawls (5 mm mesh size) taken across the East Coast REC Study Area.**

6.7.2 Foraging grounds

The distribution of the key prey species for white fish such as cod, haddock and whiting and for flatfish indicates there are potential foraging grounds right across the East Coast REC Study Area (Figure 6.34). There is no particular area that appears to be especially important, although high abundance of prey items such as small crabs (especially *Pisidia longicornis*) are found on dense *S. spinulosa* reefs.

Foraging areas for seabirds

There are several important bird areas in the East Coast REC Study Area (Figure 2.32) and many nesting sites along the whole coastline. The area is important for gulls, auks and terns. Terns use several nesting areas in the region as breeding grounds in the summer months. Research has shown great variation in the foraging distances of little terns, but the majority remain within the first 2 km of the coastline during breeding season (Perrow *et al.*, 2006). Terns have been known to be affected by fish shortages and are particularly vulnerable to predation by land animals (Parkin and Knox, 2010).

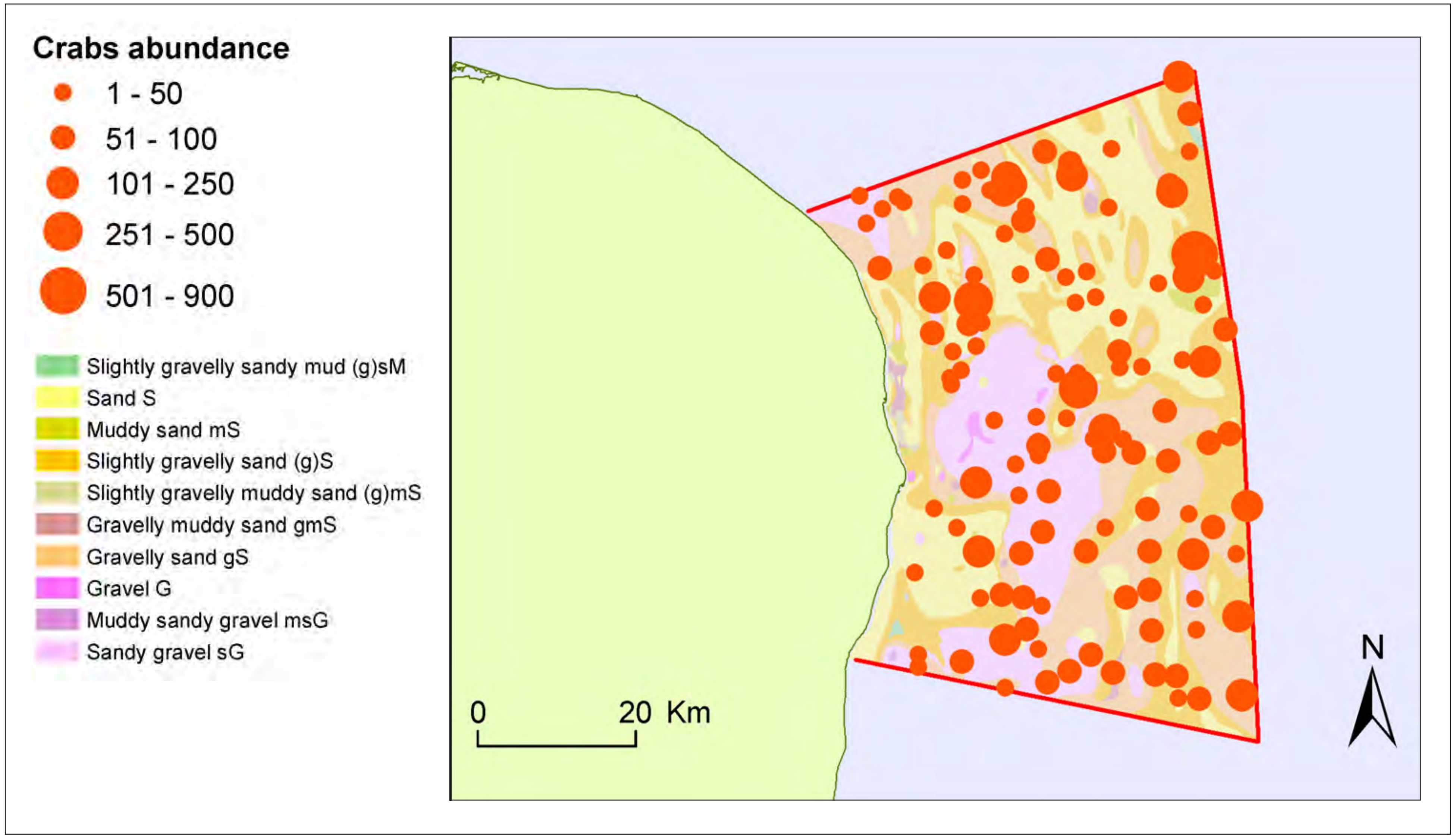


Figure 6.31 Abundance of crabs (Decapoda) in 2 m beam trawls (5 mm mesh size) taken across the East Coast REC Study Area.

Figure 6.32 An aggregation of *Ophiothrix fragilis*.

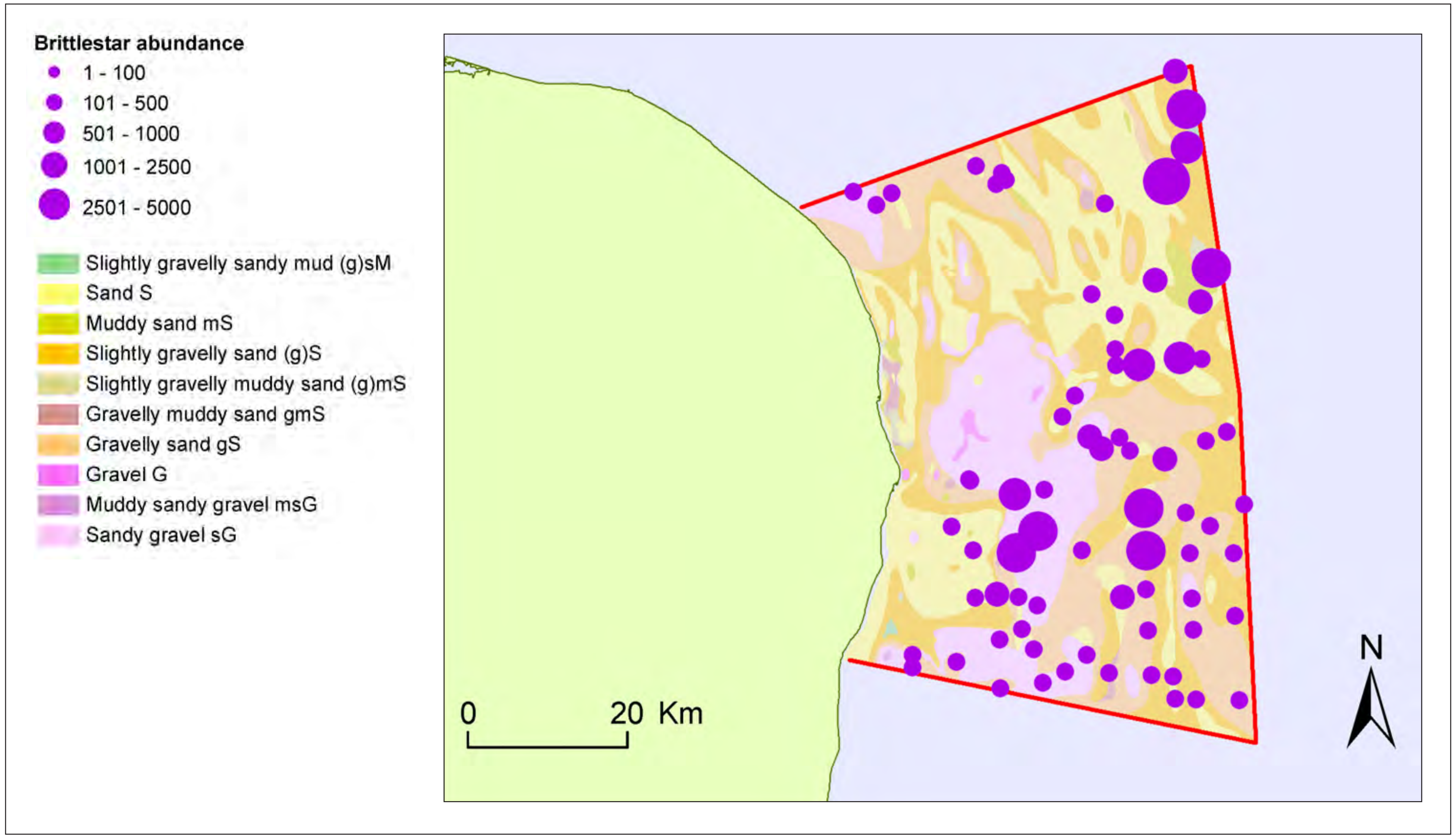


Figure 6.33 Abundance of brittlestars in 2 m beam trawls (5 mm mesh size) taken across the East Coast REC Study Area.

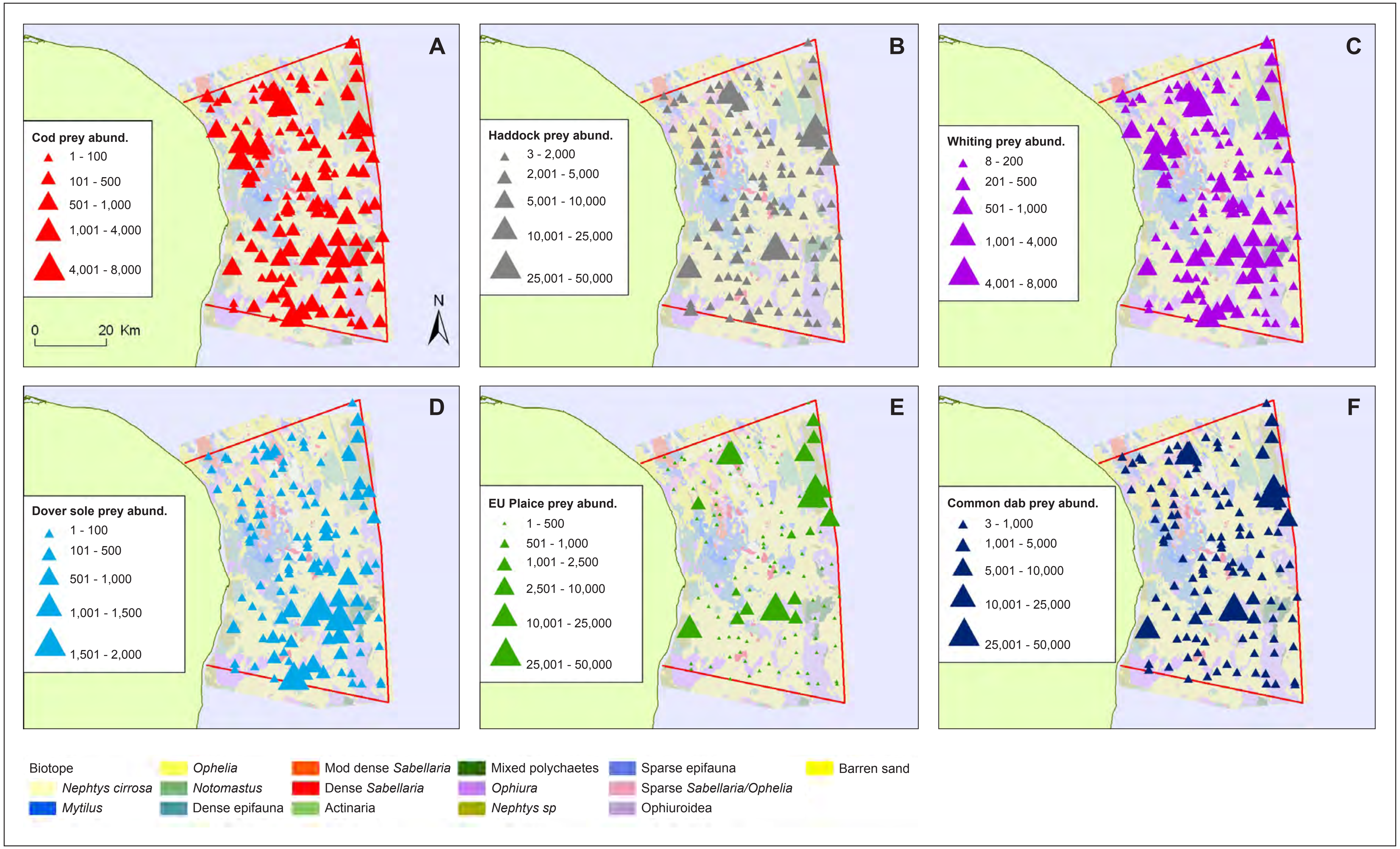


Figure 6.34 Abundance of key prey species (as described in Table 6.8) for several commercial fish species sampled with a 2 m beam trawl (5 mm mesh size) taken across the East Coast REC Study Area. Commercial white fish species are (A) cod, (B) haddock and (C) whiting, whilst flatfish species are (D) Dover sole, (E) European plaice and (F) common dab.

7 Biotope distribution modelling and data integration

7.1 Introduction

The UK Government wants sea-users, environmental bodies and other interested parties to have a prominent role in formulating advice on the creation of Marine Conservation Zones (MCZs) which will contribute to an ecologically coherent and well-managed network of Marine Protected Areas (MPAs) (The Marine and Coastal Access Act, 2009). For these organisations to formulate and provide the most pertinent and useful advice on the creation of MCZs, an understanding of the distribution of the resources being managed is essential. The purpose of this chapter is to improve the quality (information content and reliability) of one of the main outputs of the East Coast REC, namely the biotope (habitat) map. It is only with such a map that the qualities of habitat range, rarity, vulnerability and importance for key life stages, biodiversity and ecosystem function – essential for the identification and selection of MCZs – can be assessed.

Biotope maps combine the physical and biological characteristics of the seabed and allow any potential interactions between the wide-scale geology and biology to be understood (Valentine *et al.*, 2005). This knowledge helps scientists to predict more accurately the impact of human activities on the seabed and, in particular, impacts on those habitats of high nature-conservation and/or ecological value. In addition, biotope maps provide important information to assist in resolving conflicts arising from multiple uses of the seafloor and are also an essential underpinning for marine plans.

The MMO announced in October 2010 the development of marine plans for the East Inshore and East Offshore Areas, off the coast between Flamborough Head and Felixstowe (MMO, 2010). This whole area encompasses the East Coast REC Study Area, and therefore the marine biotope maps generated from this study will provide particularly useful information to help underpin the development of marine plans and inform licensing decisions.

Many studies have adopted a top-down approach to mapping the distribution of biotopes – for example, the European Nature Information System (EUNIS) habitat classification system (European Environment Agency, 2004), MESH (Van Lancker and Foster-Smith, 2007), and the JNCC's marine habitat classification system (Connor *et al.*, 2004). These approaches classify areas based on the environmental conditions that are considered important in determining the benthic assemblages that occur there. These environmental conditions include seabed character, whether it is rock or sediment, and the grain size of the sediment if there is any present, as well as hydrodynamic processes that are influential, like tidal and wave energy levels. Variables are usually handled in the form of layers in a GIS and represent either complete coverage or have been interpolated from point and line data to form layers of complete coverage. Experienced scientists interpret these multiple layers in terms of habitat suitability. The expert knowledge approach applies rules based on accumulated knowledge of the interpreter in a more or less systematic way.

One of the criticisms of the top-down classification system is that it assumes that biological communities align with discrete substrate units (ie, areas characterised by a particular substrate type) and ignores research to the contrary (Zajac *et al.*, 2000; Hewitt *et al.*, 2004; Stevens and Connolly, 2004; Zajac, 2008). Formalising rules that govern habitat suitability for biological communities is problematic for a number of reasons. First, communities of organisms contain many species that are also represented in other different communities. Each of these species will have its own habitat preferences, so that the relationship between any one community and its environment is often an average between the contributing species. Second, the habitat preferences for individual species can be very unclear and are often quite wide ranging. This may be particularly the case in disturbed environments where recruitment may be opportunistic. Third, it is difficult to know which environmental variables and cut-off values are going to be useful for the definition of boundaries between different communities – for example, one variable may be important to one species in a community, but of no great significance to another. In most biological systems the number of potentially relevant environmental variables is high so that using expert judgement becomes increasingly difficult and subjective. Fourth, because top-down habitat classification schemes are prescriptive, they severely limit their ability to provide universally applicable habitat information, because users must match their data to existing habitat lists. This makes the creation of meaningful maps difficult.

7.1.1 The mapping process

There are two main parts to the mapping process that must be reconciled with the aims of a project: selection of the appropriate units to be mapped and choosing the route for spatial analysis and interpretation of the environmental data to map the distribution of the mapping units. The mapping units can either be adopted from an existing classification system, such as EUNIS, and applied to the data or be derived from a statistical analysis of the data.

Likewise, there are two broadly different approaches to spatial analysis and interpretation. First, the key environmental thematic layers can be divided into zones on the basis of given cut-off points along the environmental continuum. The habitat classes are then assigned to the most appropriate combinations of the environmental zones and mapped accordingly. Second, the relationship between the mapping units and the various environmental variables can be analysed statistically and then displayed according to the probability of their occurrence throughout the mapped area.

Although there is no reason why the adoption of a classification scheme should preclude the use of statistical mapping techniques, the more obvious combination would be to use reclassification of environmental data together with an adopted classification scheme (a 'top-down' approach) and statistically derived mapping units together with probabilistic mapping techniques (a "bottom-up" approach).

An alternative approach for designating habitat maps is to use a bottom-up methodology. The purpose of this approach is to use an *a-priori* approach to establish the relationships between environmental and biological variables and then use these to describe and delineate the habitat map units. Assemblages are first examined based on biological similarity, then given environmental context by establishing statistical (eg, multivariate) relationships with the underlying geology, bathymetry and/or overlying water column characteristics. These relationships can then be used to interpolate between (often widely spaced) samples of fauna to create predictive biological assemblage maps (Hewitt *et al.*, 2004; Rooper and Zimmermann, 2007; McBreen *et al.*, 2008; Verfaillie *et al.*, 2009; Shumchenia and King, 2010). Although the bottom-up method is typically more resource-intensive and less rapid than the top-down method, it preserves species–environment relationships, and therefore it has better potential to generate habitat maps that are ecologically meaningful and advance our understanding of the benthic ecosystem in order to promote responsible management of its resources.

The following sections describe the bottom-up approach to habitat mapping using the data collected by the East Coast REC study, followed by a comparison between the map resulting from this approach and the more traditional top-down EUNIS classification.

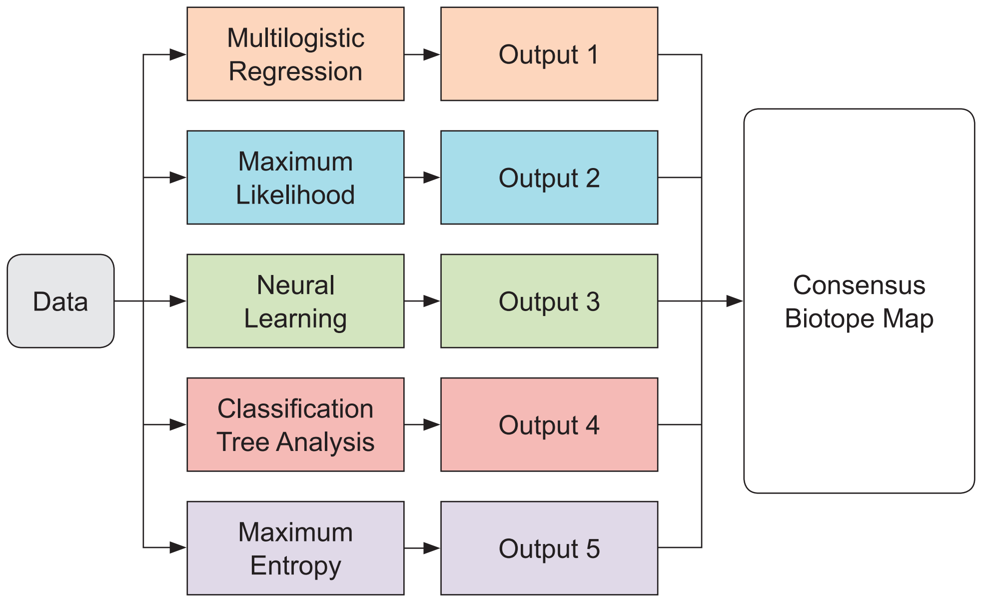


Figure 7.1 Schematic representation of the bottom-up biotope mapping approach.

7.2 Bottom-up habitat classification

Objective, data-driven approaches to mapping avoid the pitfalls of subjective interpretation, although the outputs must still be viewed critically by people with expert knowledge. Many different modelling techniques have been developed, particularly in the field of remote sensing, and the goal is ultimately to achieve total automation of mapping resources with high accuracy (Loveland *et al.*, 2002). One approach is to derive statistical relationships between the distribution of species and of environmental variables. Statistical modelling is particularly useful where there are a lot of data and the nature of the relationships are complex and not known. In the following account, five different modelling approaches have been applied to the same datasets. The outputs have been compared to see where the different approaches agree or disagree. Finally, the results from that comparison have been used to build a consensus map (Figure 7.1). In the following account, the term “assemblage” has been used interchangeably with “biotope” to refer to the faunal-environment classes whose distribution has been modelled.

Two statistical models have been tested for this study: multilogistic regression and maximum likelihood classification (MLC). Multilogistic regression is able to accommodate multiple categorical dependent variables (eg, the distinct Groups or assemblages identified in Section 6.3) and the different layers of environmental data that are continuous variables. The program produces an equation that can then be applied to the environmental data layers to calculate the probability of occurrence of certain assemblage–environment combinations (ie, biotopes). The outputs are both a map of the most probable biotope for each pixel and the underlying probability maps for each assemblage.

MLC is one of the most frequently used classification procedures in remote sensing and mapping applications. The technique uses the samples to train the data and derive statistical signatures that can then be applied to all of the pixels in the layers. It is a supervised classification since training using sample data is involved. MLC is also termed a “crisp” (or “hard”) classifier since it outputs a single map of the most likely biotope for each pixel. “Fuzzy” (or “soft”) likelihood classification can be used to derive separate probability images for each biotope so that every pixel is accorded a likelihood value for each of the biotope classes. Likelihood values are similar to probabilities and range from 0 to 1.

Other non-statistical approaches are designed to emulate biological neural learning processes. Supervised neural networks require a goal (in this case, the assemblage classes) in order to learn, and the network establishes a model that correctly maps the input variables (the environmental variables) onto the assemblages using samples for training (or learning) the model. The rules linking the inputs to the outputs are located in nodes that connect to the input variables and the output (the assemblages). The connections to the input variables are weighted so that connections to some environmental variables are more important than others for the node (for a particular assemblage) to trigger its output, in an analogous way to a neuron firing or not firing dependent upon multiple sensory inputs. Neural networks can be “crisp” (the nodes either fire or they don’t) or “fuzzy” (the strength of the connection to the output varies). The advantages of neural network systems are that they can formulate rules and see patterns in very complex and often incomplete data.

Two such models have been used. The first, ArtMap (ART = adaptive resonance theory), is a fuzzy learning neural network that has been found to outperform many other classification systems, including MCL (Carpenter *et al.*, 1991a, 1991b). However, it is a “black box” system in that the rules are internalised in the network and not explicit. Although the learning is fuzzy, the network hardens the output so that only one assemblage is assigned to each pixel.

The second model of this type that has been used is the Classification Tree Analysis (CTA), or the “decision tree” approach. The assemblages are set as the dependent variable, and the program searches the environmental variables and determines which variable and value best separates the assemblages. It successively splits the data until it reaches an end point where one assemblage predominates. The advantage of this method is that the rules are explicit and can be directly interpreted in terms of the environmental variables. However, the same assemblage may be found in different end points where the assemblage is naturally distributed over a wide range of environmental conditions (as appears to be the case in the East Coast REC Study Area). Although this effect makes the classification rules more difficult to interpret, it improves the accuracy of the map. Unlike ArtMap, CTA can produce maps showing where the various splits have been made (eg, areas above or below a specified depth) and a membership map for each assemblage. These membership maps show possibilities rather than probabilities, but are similarly ranged between 0 and 1.

The last model used is maximum entropy (MaxEnt). This model calculates the probability of the occurrence of a particular assemblage but not, at least directly, the most probable assemblage amongst the range of assemblages. MaxEnt is a statistical procedure based on information theory and calculates the probability of an assemblage occurring, making the least assumptions about the relationships with the environmental variables; it is a conservative estimator (Jaynes, 1982; Phillips *et al.*, 2004). One of the outputs is a set of response curves for each assemblage for each environmental variable, which are valuable for elucidating the environmental parameters that are correlated with the distribution of an assemblage. Being a conservative estimator, these response curves can be weak where the environmental variables are only loosely associated with the assemblage sample or the evidence from the data is not clear (see also Section 8.1). Another output is a probability map of the occurrence of an assemblage. Since these are calculated independently for each assemblage, they are not "in competition" for each pixel and are informative if the purpose of the model is to describe the likely occurrence of a particular biotope. Calculating a "crisp" map of the most probable biotope for each pixel can be attempted by normalising the probability images by the total of the probabilities for all assemblages and then hardening the images (eg, in the module HARDEN in IDRISI[1]).

[1]Source: www.clarklabs.org
[2]Source: www.cs.princeton.edu/~schapire/maxent

The outputs from the models (likelihood values or probabilities) are more suited to the real nature of the relationship between communities and the environment. However, interpretation of probabilities needs to be done with care. In a sense, the assemblages "compete" for pixels, and the underlying probability maps (for those models that output these for each assemblage) will usually indicate that two or more biotopes could be expected at a particular point location with different probabilities. It is often assumed for mapping purposes that the biotope with the highest probability for a pixel should be the one that is displayed, but this could have the consequence that the less common biotopes may rarely be indicated anywhere. Alternatively, individual biotopes could be mapped, but the chances of finding that biotope where it is indicated might be small.

An overall map of biotope distribution is clearly a very desirable output, despite the issues raised above concerning uncertainties and the process of "hardening" the probability of occurrence of individual assemblages. It must also be expected that each model will result in a different assessment of biotope distribution, and it will be important to measure the performance of each model. Additionally, the likely distribution of individual assemblages is also important for the management of biotopes of significant conservation interest. The aim of modelling is to derive the best overall distribution map of biotopes and the most likely distribution of individual assemblages.

7.2.1 Methodology

The modelling techniques used are all available in existing software packages, and this was considered an important factor in the choice: the techniques are well documented and supported and can be recommended for widespread use. Most of the techniques are included in IDRISI and although the latest version is commercially available, earlier versions can be downloaded free of charge from various web sites. The remaining technique, MaxEnt, is available as a download.[2]

Environmental data

The environmental data have been obtained from a variety of different sources. Their original format (points, grids, raster images, etc.), datum and resolution also differed greatly. It was necessary to transform these data to a raster format that conformed to the same datum, geographic range and pixel size. Some data, such as bathymetry, have been further processed to derive secondary datasets. The format details of the layers are presented in Table 7.1.

Some available layers were strongly correlated to other datasets and have been excluded from the analysis. The final layers used are described in Table 7.2. Some of these datasets may not be ideal for the purpose, but all may have some influence on benthic species and are justifiable to include. All are variables that are likely to be available for most areas for which similar surveys have been undertaken.

The environmental layers were created as Arcraster ASCII files (*.asc) and form part of the East Coast REC project GIS. The files were imported into IDRISI for statistical analysis in the IDRISI raster format (*.rst). The raster images of the environmental layers are shown in Figure 7.2.

Samples used for training

All of the grab samples that were assigned to distinct faunal groups (see Chapter 6) were used in the modelling process after transforming the points to polygons, termed "training areas". Training areas are used to extract data from the environmental layers. In order to create these training areas from the sample point locations, a radius of 150 m around each point was used to create

Ref. system	UTM31N	**Min. northing**	405,000
Resolution (pixel size)	50 m	**Max. northing**	460,000
Units	Metres	**Min. easting**	5,778,000
Columns	1,101	**Max. easting**	5,865,000
Rows	1,741		

Table 7.1 **Format of the environmental layers used in the modelling.**

	Environmental layer	Source	Transformation	Likely biotic influence
1	Bathymetry	BGS (point data)	Interpolation	Indirect: wave action and sedimentation
2	Small sandwaves	Derived from bathymetry	Moving window filtering	Disturbance to sediment
3	Sandbanks (mean height 20 m)	Derived from bathymetry	Moving window filtering	Disturbance and currents
4 5 6	Sand % Mud % Gravel % composition	East Coast REC PSA data and BGS data	Interpolation and smoothing	Supports different life forms and feeding types
7	Side-scan backscatter strength	East Coast REC survey data	Interpolation	Sediment surface characteristics: supporting different life forms
8	Side-scan backscatter standard deviation	East Coast REC survey data	Interpolation	Fine-scale heterogeneity: diversity
9	Wave crest density	East Coast REC survey	Quadrat counts and interpolation	Disturbance
10	Sediment load (June)	BERR[a] offshore energy	None	Feeding type relates to sediment load
11	Tidal strength (springs)	BERR[a] offshore energy	None	Related to bottom shear stress:

[a] Department for Business Enterprise & Regulatory Reform

Table 7.2 The environmental layers selected for inclusion in the modelling processes.

a circular polygon. This was large enough to capture sufficient data for analysis, but not so large that weakly associated environmental data were included.

The process of deriving the biological classification of the samples from the sample data has been described in Section 6.3. The distinct assemblages have been derived from the statistical analysis of the grab data primarily; other data (from video and trawls) have been used to inform the final classification and the description of the assemblages. It was also acknowledged that the samples were to be used for modelling, and this meant that assemblages with very few samples were avoided. Assemblages with only one or two samples were amalgamated into the nearest (most similar) assemblage. This was a pragmatic approach as far as spatial modelling is concerned and is recommended for all similar studies. The issues remaining are the following:

- *Similarity between assemblages*: despite the rigour with which the assemblages have been derived, many appeared to be quite similar in character (particularly those that had sparse infauna). This is likely to result in maps that sharply delineate biotope boundaries, whereas in reality there is great uncertainty about the boundaries and a strong probability that other biotopes might be found in the area apart from the biotope class indicated.
- *Differences in sample size*: there were huge differences in the number of samples in the different assemblages. This might very well reflect the true nature of the region where the majority of the sea floor can be typified by a few biotope classes. However, the imbalance in sample size might be expected to create problems for modelling with assemblages with few samples drawing upon insufficient environmental data to create a robust statistical signature. The effect might be that these assemblages will lose out to the assemblages with stronger signatures and, therefore, be under-represented in the final biotope map.
- *Clusters of biotope classes*: an exploration of the geographic spread of the various samples showed that other potential problems might occur during modelling. Some of the smaller assemblages were clustered, and the effect might lead to a very tight environmental signature, due to similar environmental conditions found within a small area. This could lead the model to predict that these assemblages would be found wherever those particular conditions prevailed, whereas, in reality, some unaccounted local condition could be the causative factor determining the occurrence of the biotope at that location not replicated elsewhere in the survey area.
- *Spatial heterogeneity*: samples that were close to each other were sometimes very different in character. This might be expected in environments that were heterogeneous over small distances. However, this will result in an overlap in the environmental conditions linked to the biotopes and, therefore, less certainty in the distribution of the biotope classes involved.

The issues concerning the nature and distribution of the classified samples, as outlined above, might be expected to affect the performance of the models. It should be expected that some artefacts may well have appeared in the outputs of the models, and distribution maps should be viewed critically with an understanding of the problems the training data might have caused.

Confidence and accuracy assessment

The most objective way of assessing accuracy of a map is to overlay samples onto the map and count the “hits” and “misses”. A simple percent-hit measure does not take into account the likelihood of achieving a certain level of hits simply by chance, and various metrics have been put forward that calculate the proportion of hits over and above that which could be due to chance. The Kappa index is commonly used in remote sensing and has been adopted in this project. The Kappa index ranges from 0 (level of agreement by chance) to 1 (complete agreement). A commonly cited scale for Kappa is: 0–0.2 = slight agreement; 0.21–0.4 = fair; 0.41–0.6 = moderate; 0.61–0.8 = substantial; 0.81–0.99 = almost perfect (Landis and Koch, 1977).

The training samples can be used to measure the success of the model (a measure of agreement), but they cannot strictly be interpreted as predictive accuracy since there is a circularity in the process of using the same samples as both training sites and validation samples. Ideally, a separate set of data should be used to assess predictive accuracy. However, it is rare that sufficient data are collected in marine surveys to permit the luxury of setting some of the samples aside for this purpose, since fewer samples reduces the robustness of the statistical signatures of the assemblages (especially when there are few samples in many of the assemblages). It is assumed that when a large number of samples are used (as is the case for the East Coast REC Study Area) the measure of agreement converges on a measure of accuracy. It is

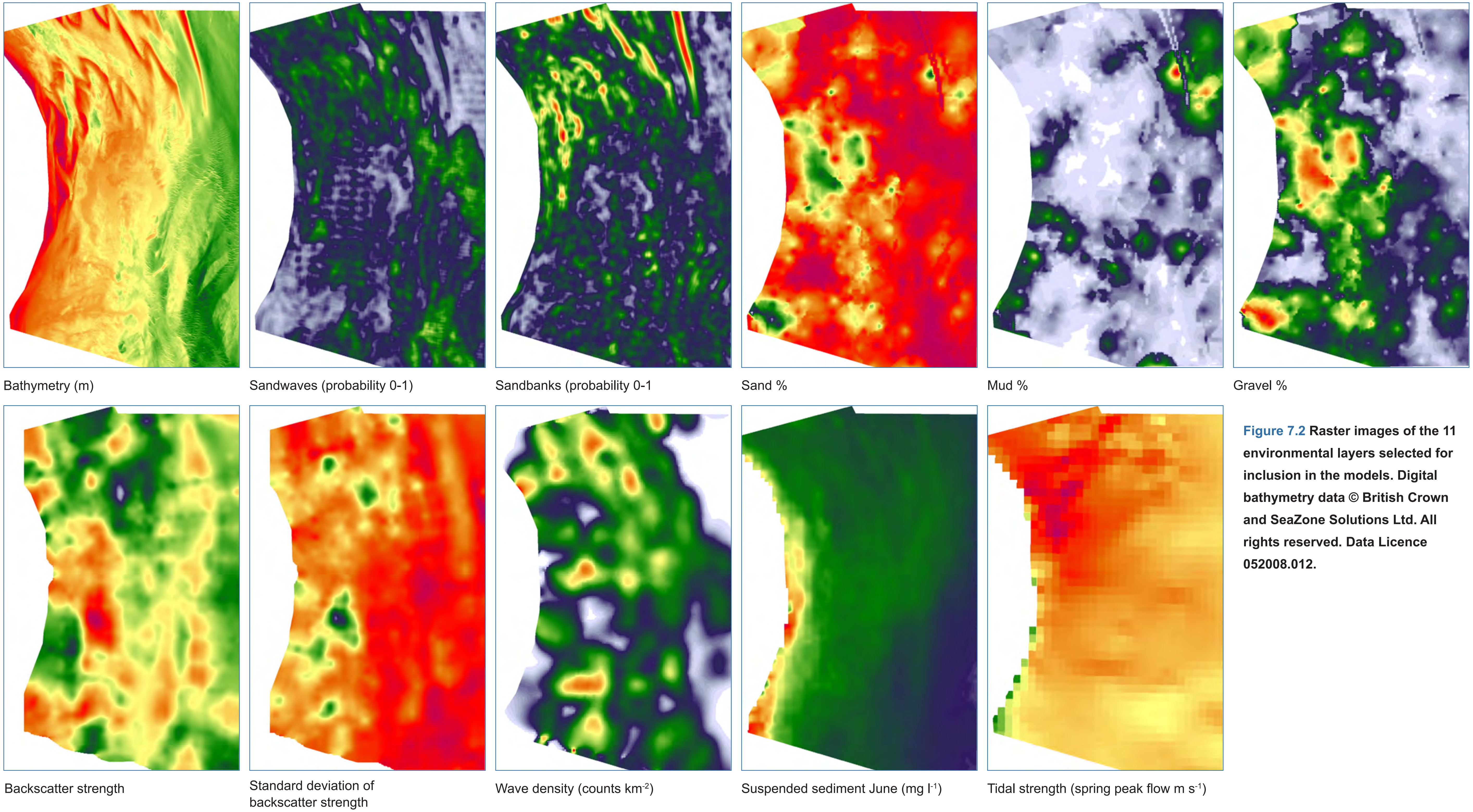


Figure 7.2 Raster images of the 11 environmental layers selected for inclusion in the models. Digital bathymetry data © British Crown and SeaZone Solutions Ltd. All rights reserved. Data Licence 052008.012.

assumed that the model (or models) with the highest levels of internal agreement will also be the best predictors in areas not supported directly with sample data. However, some downward adjustment needs to be made to the Kappa values. The measures of agreement, however, do serve a useful purpose in comparing the relative performance of competing models and have been used, in this context, in the present study.

7.2.2 Results of modelling

Multilogistic regression

The analysis was performed using the module MultLogisticReg in IDRISI. The training sites were used as the dependent variable, and all of the environmental layers were used as the independent variables. The layers were masked by an image file to restrict the analysis to the areas under the training sites only, and the module outputs an overall map showing the most probable class for each pixel (Figure 7.3). The resulting logistic regression was highly significant ($p << 0.005$), and the pseudo R^2 value of 0.62 indicates that much of the variation was explained by the analysis. The Kappa measure of agreement was 0.60 (moderate).

The map in Figure 7.3 shows a very mixed distribution of assemblages in the northern and western areas but a more uniform distribution of assemblages in the southern and central areas. The inshore region was classified as "*Ophiura*" but this was only supported by data in the south. Therefore, the distribution of this assemblage further north must be considered uncertain. The model may have over-predicted the distribution of "*Mytilus*" and "dense *Sabellaria*" assemblages in the north.

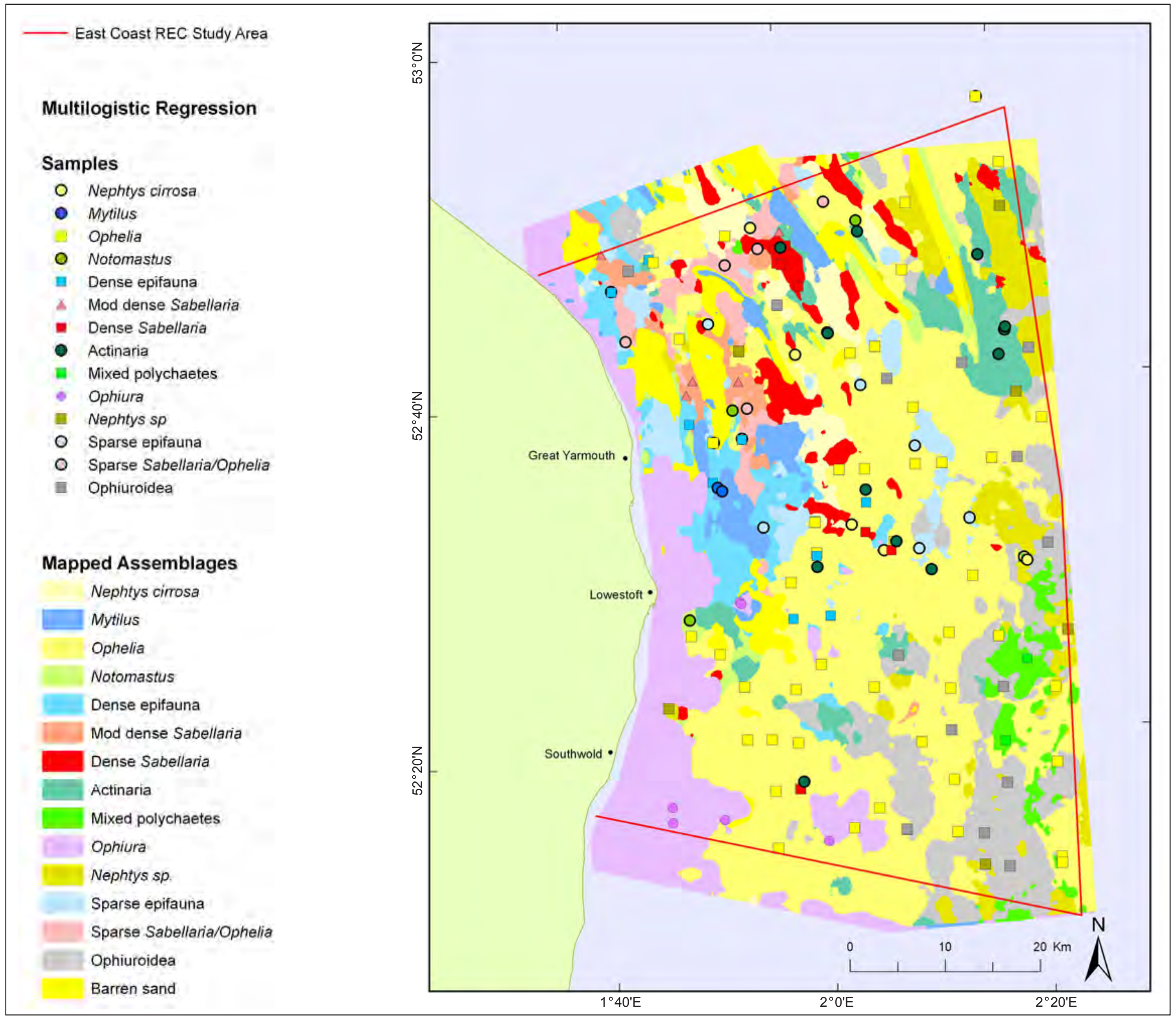


Figure 7.3 Biotope model derived from the multilogistic regression model. The colours represent the assemblage with the highest probability of occurrence for each pixel. The point sample data have been overlain and note that not all samples are located in the appropriate mapped unit.

Maximum likelihood

The analysis was performed using the module MAXLIKE in IDRISI after signatures had been developed using the module MAKESIG. The output is a single map of the most likely class for each pixel without indicating other classes that might also have been expected at lower likelihoods. For this reason, maximum likelihood is referred to as a "hard" classifier. The resulting map (Figure 7.4) has a Kappa agreement of 0.87.

Maximum likelihood has classified much of the area, including the inshore region, as "*Ophelia*", which is the most frequent assemblage recorded amongst the samples. The offshore region is predicted to have an almost continuous zone of "Ophiuroidea". However, the regions classified as "*Mytilus*" and "dense *Sabellaria*" are much smaller than they appear in other models.

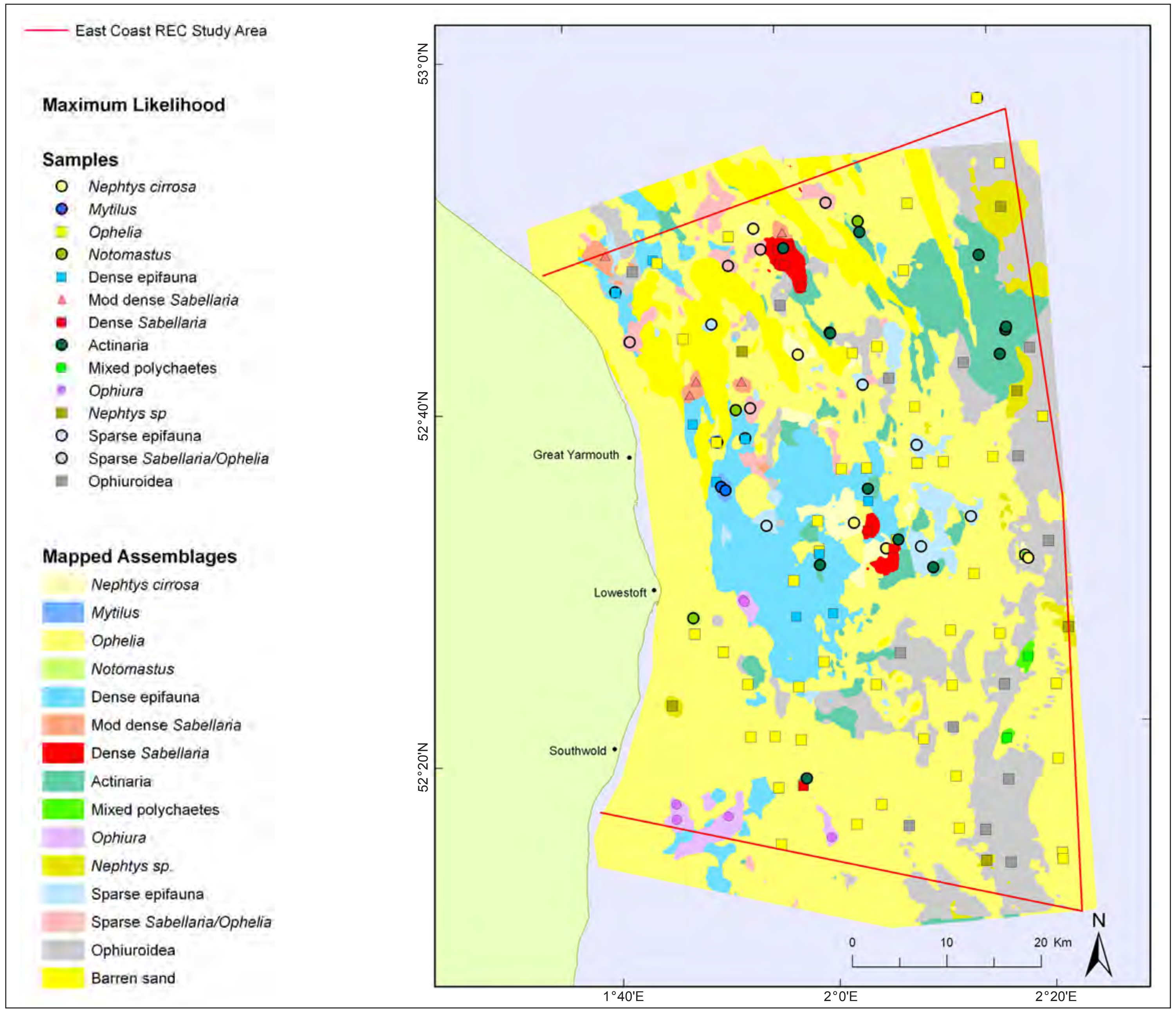


Figure 7.4 Biotope model derived from the maximum likelihood model. The colours represent the assemblage with the highest likelihood of occurrence for each pixel. The point sample data have been overlain and note that not all samples are located in the appropriate mapped unit.

ArtMap neural learning

The module Fuzzy ARTMAP in IDRISI was used with the default parameters in a supervised classification using the samples for training the system. The resulting map (Figure 7.5) was a good match to the training sites as judged by the Kappa agreement score of 0.92. This means that most of the samples are located on their corresponding mapped assemblage. However, the areas not directly supported by the sample data often exhibit a patchwork of assemblages and present an "over-fussy" appearance. Nevertheless, the broad trends in assemblage distribution are similar to the preceding models.

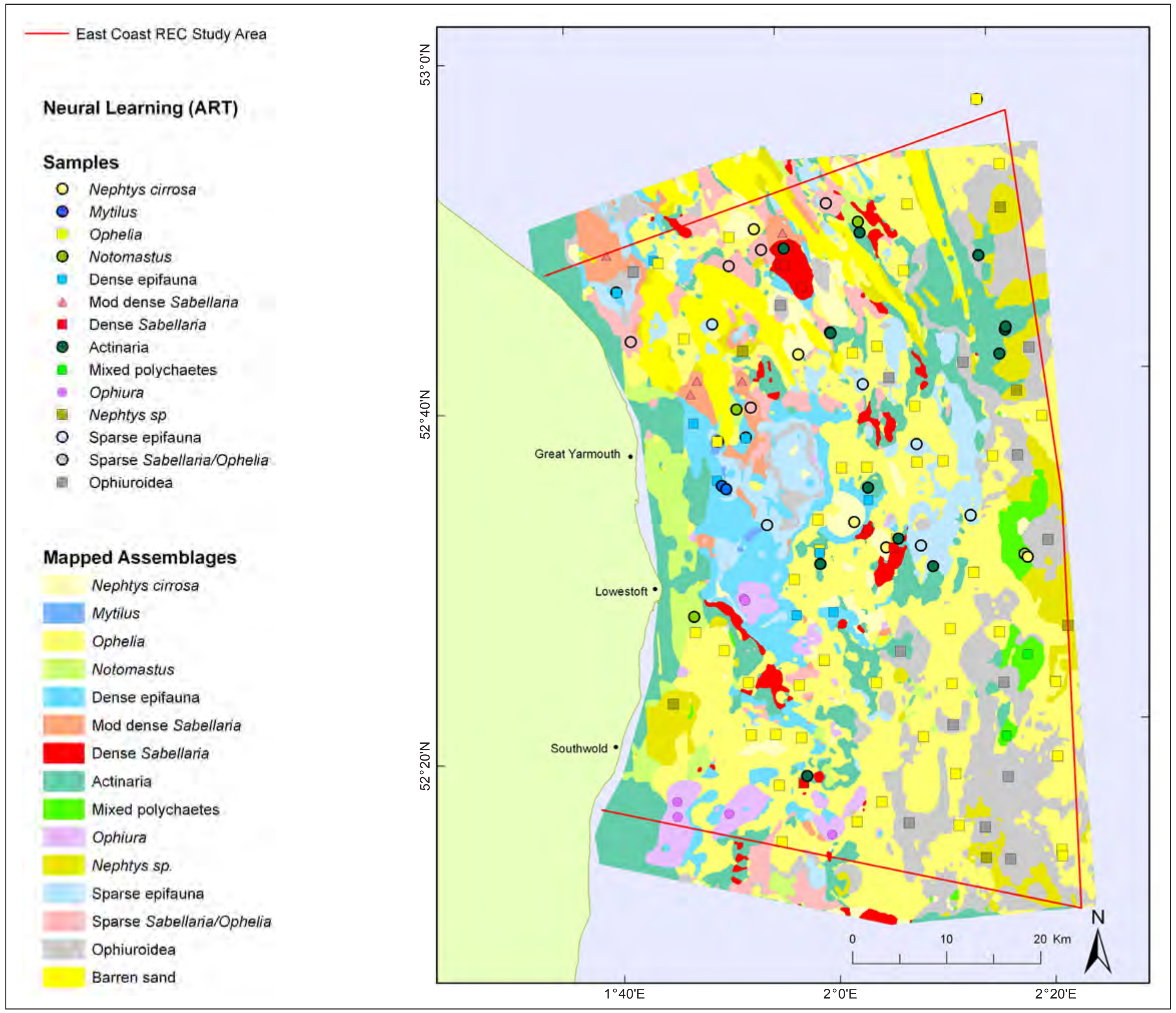


Figure 7.5 **Biotope model derived from the neural learning (ART) model. The colours represent the assemblage with the greatest strength of prediction for each pixel. The point sample data have been overlain and note that not all samples are located in the appropriate mapped unit.**

Classification Tree Analysis

The module CTA in IDRISI was used to perform the tree analysis (Figure 7.6). This model gave the highest Kappa score (0.97), and almost all of the samples are located on their corresponding mapped assemblage. As with the output from the ArtMap model, the map presents something of a patchwork in areas not supported by sample data.

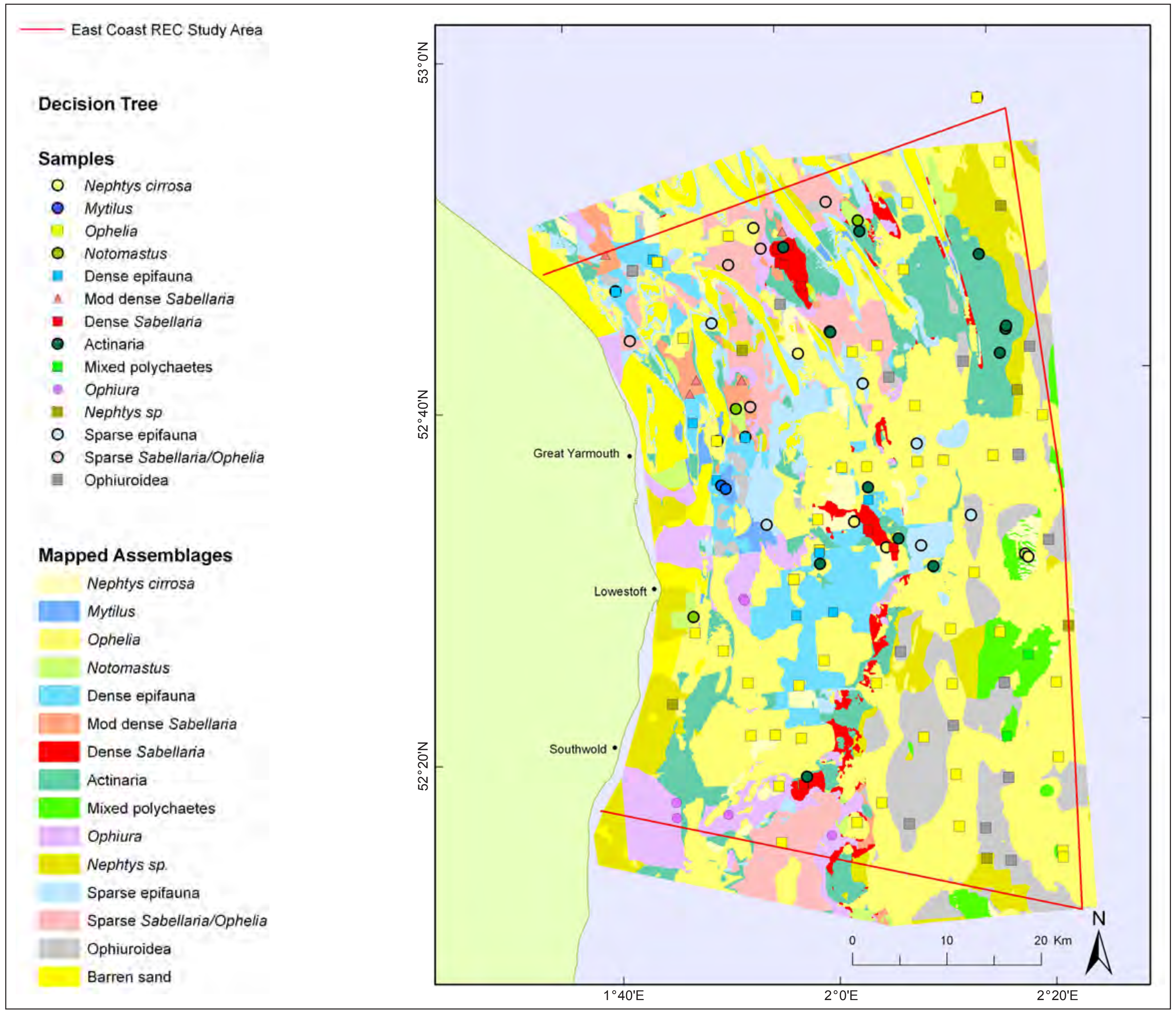


Figure 7.6 **Biotope model derived from the Classification Decision Tree Analysis model. The colours represent the assemblage with the greatest strength of prediction for each pixel. The point sample data have been overlain and note that not all samples are located in the appropriate mapped unit.**

Maximum entropy

Maximum entropy models have the advantage over maximum likelihood, ArtMap and CTA in that the relationships between the environmental parameters and the assemblages are explicit. However, MaxEnt is not ideally suited for deriving a single map of the most probable assemblage since it calculates the probability distribution of individual assemblages. The alternative process of normalising the individual probabilities for each assemblage and then displaying the highest amongst the assemblages performed moderately well, resulting in a map that "makes sense" (Figure 7.7), but with a much lower level of agreement (Kappa of 0.34) than other models.

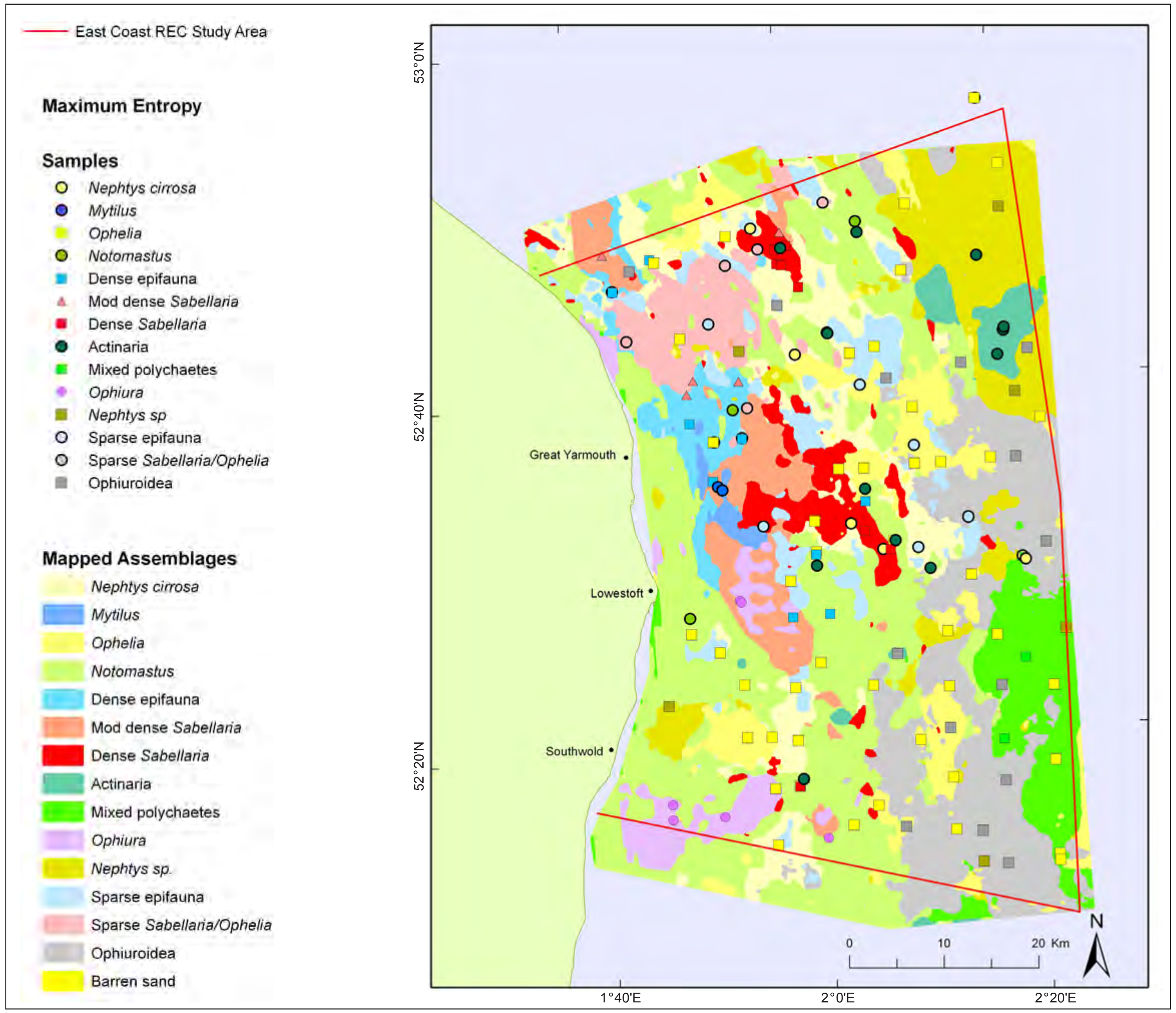


Figure 7.7 **Biotope model derived from the maximum entropy model. The colours represent the assemblage with the highest likelihood of occurrence for each pixel. The point sample data have been overlain and note that not all samples are located in the appropriate mapped unit.**

Summary of model performance: accuracy and confidence

The models used in this analysis are constrained to select one assemblage (the most likely) for display on the map output when the difference in probability between competing assemblages is very small. This potential confusion between assemblages could be due to real overlap in the conditions that support the competing assemblages or poor discrimination by the models given the environmental variables selected for the model. This uncertainty can be explored for models where the probabilities for each assemblage can be displayed separately.

The maximum likelihood model can output individual probability maps for each assemblage (through the module FUZCLASS in IDRISI), and the maximum value for all assemblages can be found (Figure 7.8). The results from this process show that most pixels have low maximum probability, indicating that it was likely that two or more classes were competing for first place. Note that for models where the total probability must total 1 for every pixel, spuriously high probabilities can be generated where there is only one assemblage “in the running”, even if this assemblage is not likely to be present. This situation occurs where there is a lack of sufficient training data to cover the full range of environmental variables. This has occurred close inshore in the study area, hence the predominantly red/pink colouring of the inshore waters in Figure 7.8.

It is difficult to interpret what it means when two or more assemblages have similar probabilities of occurring in a particular location (represented by a pixel). It could be interpreted as meaning that one assemblage has been correctly predicted and the others wrongly predicted, or it could also mean that both assemblages could be found given sufficient sampling. It may even be that the actual biota at that location is a combination of the two pre-defined assemblages. Modelling and representing this level of complexity is beyond the scope of this project, and we are constrained to working with the distribution of the most likely assemblages.

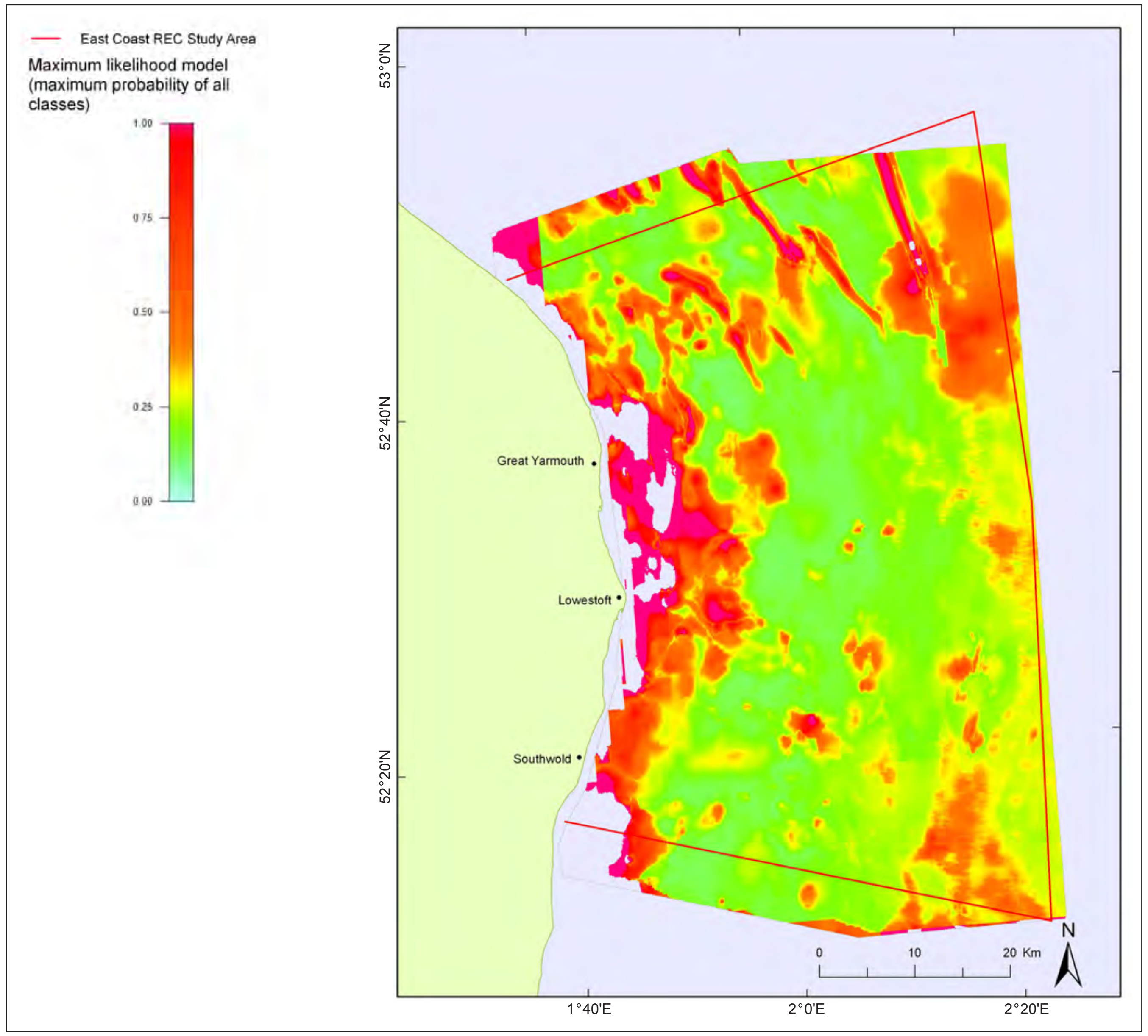


Figure 7.8 The probability of the assemblage with the greatest likelihood of occurrence at each pixel that underlies the outputs from the maximum likelihood model. The red colours indicate areas where one assemblage was predominant and other colours where the probability was shared between two or more assemblages, indicating that the classification using maximum likelihood is uncertain in these areas. Figure 7.4 shows the assemblage with the highest likelihood score.

The MaxEnt model can also generate individual probability maps for each assemblage class, although these will sum to more than 1 as they are generated independently. The extent of overlap in probability between assemblage classes for each pixel can be estimated from the ratio of the maximum probability to the sum of probabilities (Figure 7.9).

Although the two representations of uncertainty differ in detail, there is clearly a high level of uncertainty due to overlap between assemblage classes, resulting in pixels that could be assigned to two or more classes. This ambiguity leads to an “error” in the prediction of classes.

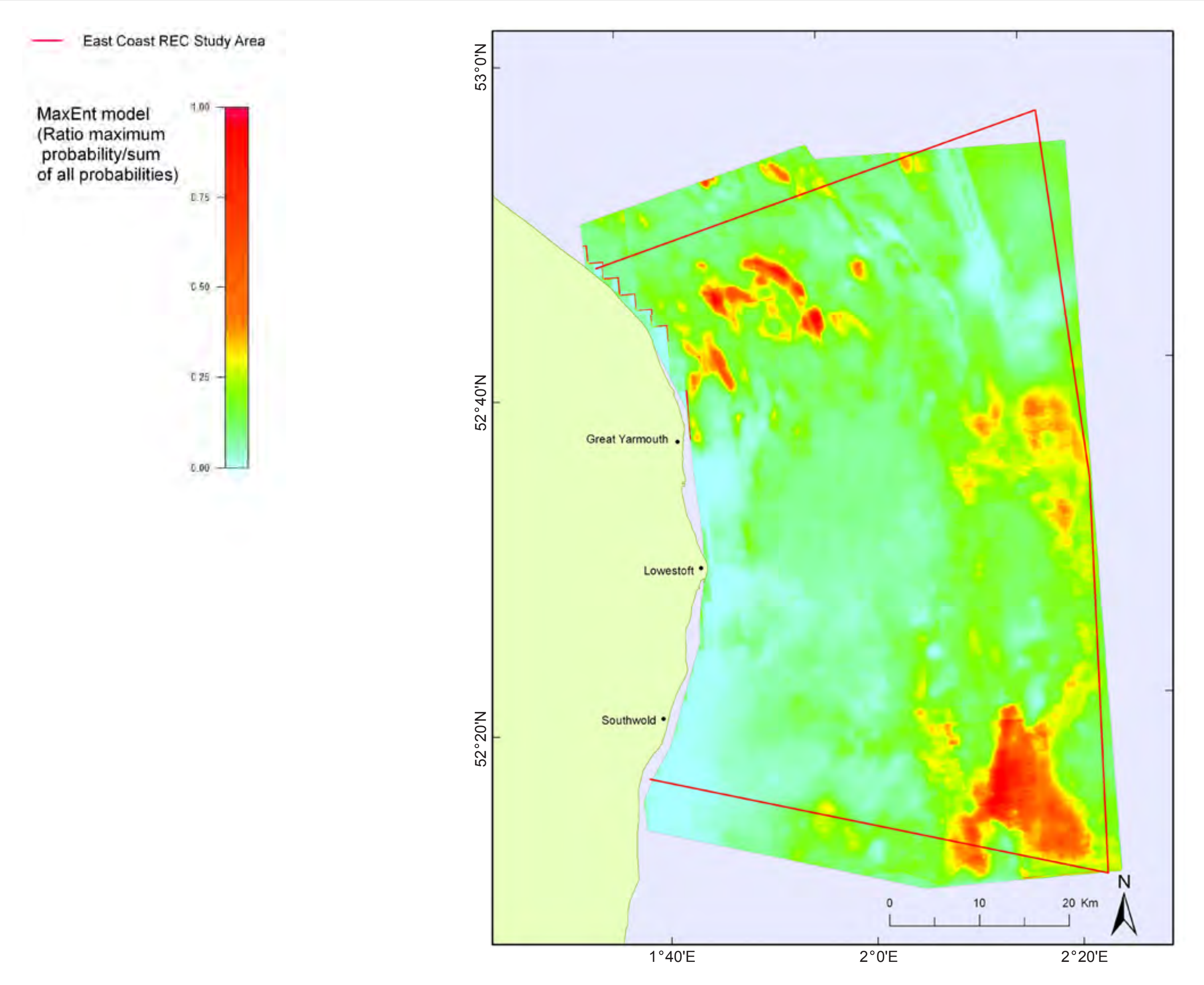


Figure 7.9 **The highest assemblage score from the Maximum Entropy model expressed as a proportion of the total score from all assemblages. The red colours indicate areas where one assemblage is predominant and other colours where more than one assemblage might be expected to occur with differing scores. Figure 7.7 shows the assemblage with the highest score.**

	CTA	ArtMap	MaxLike	MultiLogistic	MaxEnt
Kappa	0.97	0.92	0.91	0.60	0.34
% accuracy	98.00	93.50	91.95	67.51	41.10
Nephtys cirrosa	6.03	–6.64	–7.74	–14.96	9.80
Mytilus	8.57	–12.05	14.44	1.26	–76.25
Ophelia	–3.37	–1.29	–17.49	23.47	–25.22
Notomastus	0.00	3.82	0.00	–25.58	56.41
Dense epifauna	1.55	–4.56	33.92	–25.05	–7.60
Moderate *Sabellaria*	1.05	0.00	0.00	5.15	4.75
Dense *Sabellaria*	1.78	–7.19	11.40	–3.74	17.24
Actinaria	1.64	6.55	–11.14	–20.42	–67.56
Mixed polychaetes	2.27	26.60	16.50	4.10	70.09
Ophiura	0.93	0.00	0.00	0.73	4.01
Nephtys	–0.44	1.24	–0.44	7.98	0.55
Sparse epifauna	8.53	10.90	–1.72	–15.88	3.90
Sparse *Sabellaria*/*Ophelia*	–1.16	13.14	–3.46	–8.54	1.04
Ophiuropidea	–0.93	–8.27	18.30	–22.04	–25.06
Barren sand	–0.66	–0.09	0.00	2.79	n/a

Table 7.3 **Overall statistics (Kappa and % accuracy) derived from error matrices from the four major models used. Individual biotope % errors of commission (red) and omission (blue) are also given.**

The error matrices reveal more about the confusion made by the models for individual biotopes. The “errors” can be caused either by commission, where the predicted biotope has included samples other than the one predicted (over-prediction), or omission where a particular biotope should have been predicted, according to the sample, but was not (under-prediction). Note that error due to the overlap of the environmental conditions associated with the assemblage classes may be a true reflection of reality.

The errors have been summarised in Table 7.3, where the negative values indicate errors of omission which outweigh the errors of commission (the values are the differences between % commission and % omission). For example, CTA has slightly under-predicted the distribution of the “*Ophelia*” assemblage class and over-predicted the distribution of the “*Mytilus*”, “Sparse epifauna” and “*Nephtys cirrosa*” assemblages. ArtMap has under-predicted the distribution of the “*Mytilus*” assemblage and over-predicted the distribution of the “Mixed polychaetes” assemblage. Again, the

		ArtMap	MaxLike	Logistic	MaxEnt
MaxLike	Kappa agreement	0.35			
	% similarity	35.0			
Logistic	Kappa agreement	0.27	0.23		
	% similarity	38.0	42.0		
MaxEnt	Kappa agreement	0.14	0.10	0.23	
	% similarity	18.0	15.4	29.3	
CTA	Kappa agreement	0.15	0.24	0.14	0.11
	% similarity	29.0	50.8	30.7	17.2

Table 7.4 **Agreement between the biotope distribution maps derived from the five models used.**

Figure 7.10 **Levels of agreement between the five models: 1 indicates no agreement, and 2–5 the number of models that predicted the same classes.**

neural network models show the least difference between predicted and observed and the scale of over- and under-prediction is greater in the remaining models, and this is reflected in the lower Kappa scores. Interestingly, there is no consistent pattern in over- and under-prediction amongst the models.

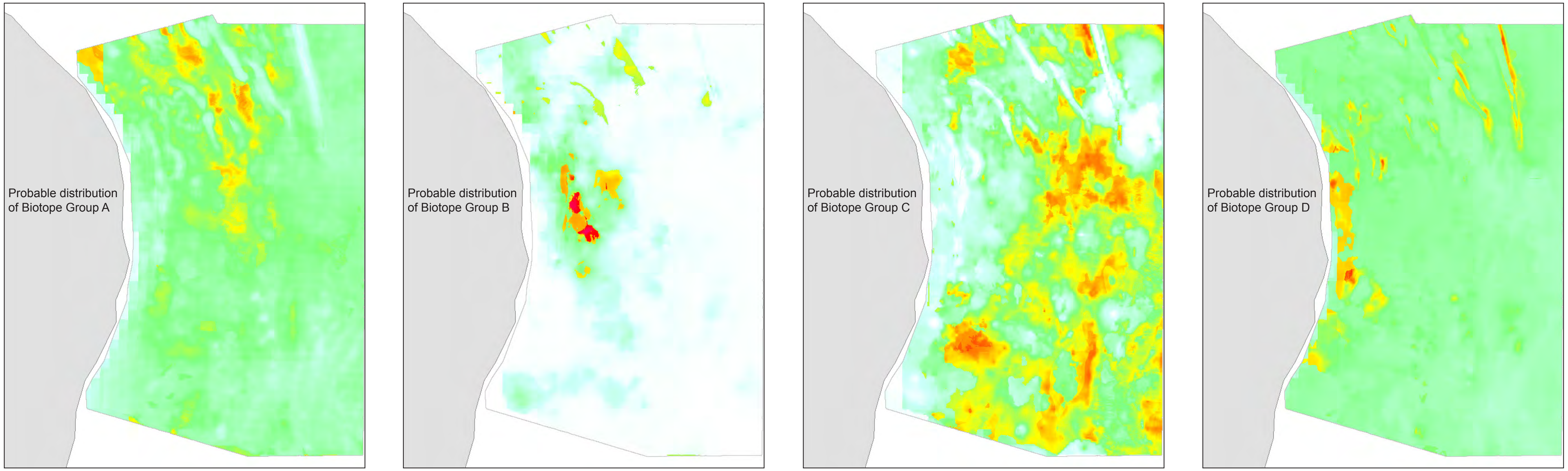
On the basis of these performance statistics, it is considered that the outputs from the CTA, ArtMap and maximum likelihood models should be accepted over the other two models. However, it must be remembered that this high level of agreement is only for areas encompassed by the training sites, and there must, by implication, be a high level of agreement between the models for these areas. Nevertheless, the agreement between the best-performing models for areas outside the training areas is only fair (Table 7.4).

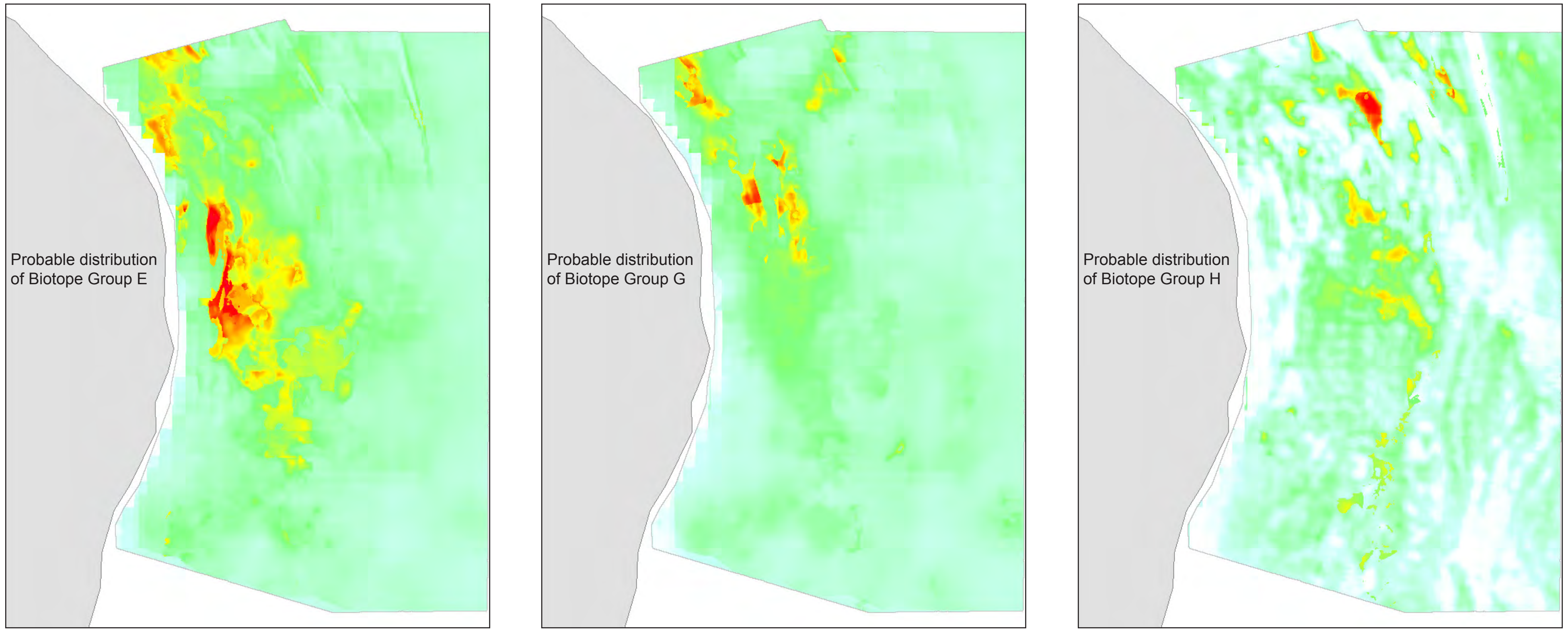
Consensus of models: ensemble mapping

Accommodating the differences in the outputs from the statistical models presents a problem, since we are faced with the necessity of deriving a single biotope map of the best estimate of the distribution of the most likely assemblages (note that working with mixtures and representing these on a map is possible, but is beyond the scope of this project as discussed in the section on model performance on pages 204–6). When different statistical models are available and the choice between the outputs is not clear, it may be helpful to see if there is a consensus amongst the ensemble of models (Figure 7.10). Two approaches to deriving a consensus map have been taken. The first determines the most probable assemblage from amongst the separate probability distributions for each assemblage determined by the different models. The second uses the level of agreement between the most likely assemblages predicted by each of the models.

Deriving individual biotope probability maps from the models

Four of the models – maximum likelihood, multiple logistic regression, CTA and maximum entropy – give maps of the likely distribution of individual assemblages with values ranging from 0 (absent) to 1 (present). The outputs from the four models can be added to derive a “consensus” distribution map for each assemblage (Figure 7.11). The values from each model have been summed but not standardised, so that the intensity of the colour gives some indication of the relative likelihood for each class on a common scale.





Group A. No clear sediment preferences; strong tidal areas; avoids large sandwaves.

Group B. Slightly gravelly, slightly silty sediments; moderately deep tidal waters; high backscatter.

Group C. Clean sandy sediments; areas with few sandwaves.

Group D. Shallow sandy sediments; moderately tidal and turbid waters; often associated with large sandwaves/sandbanks.

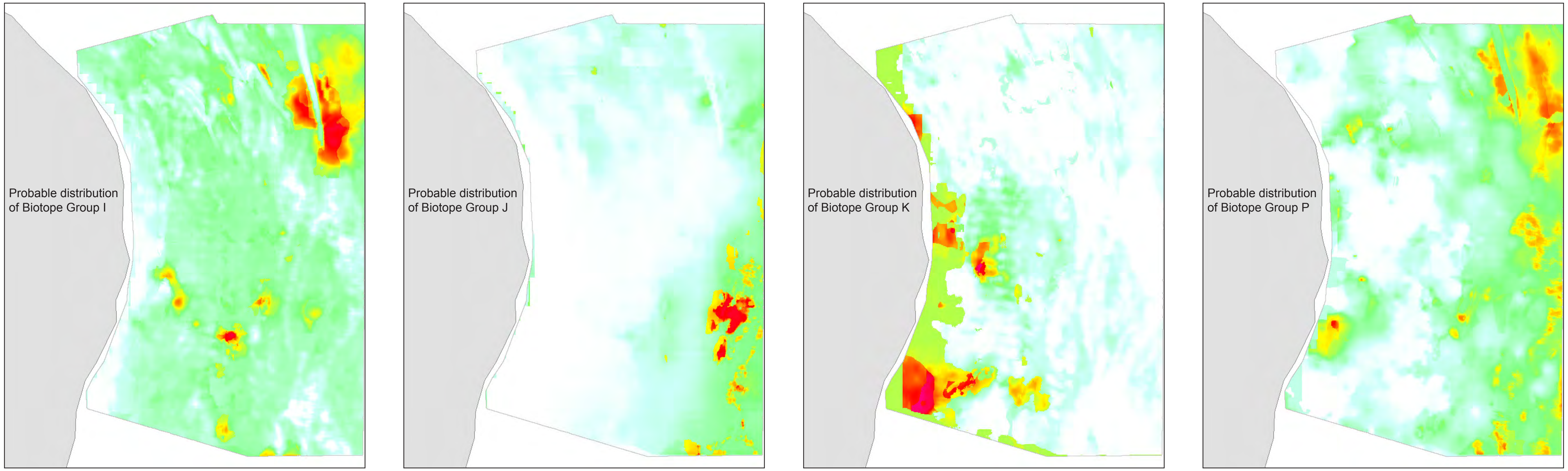
Group E. Shallow strongly tidal areas; gravelly sediments; high backscatter often associated with large sandwaves and sandbanks.

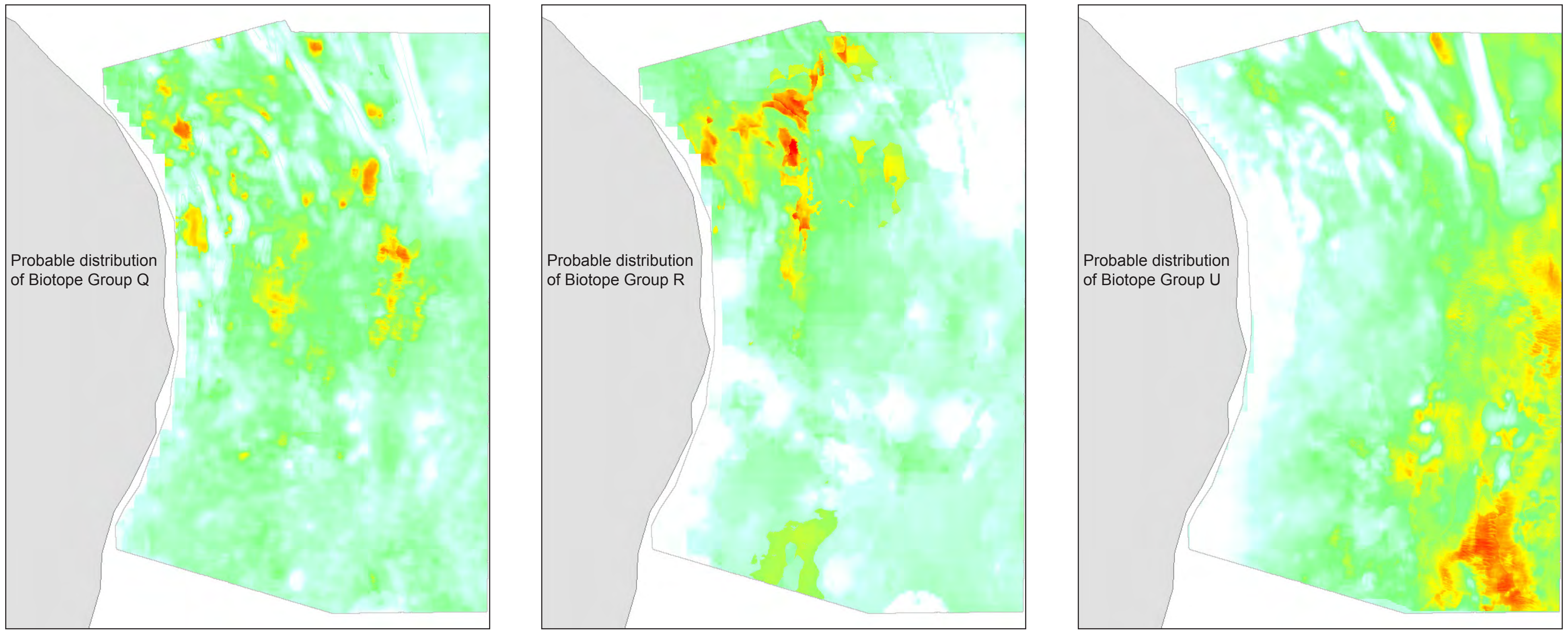
Group G. Moderately shallow strong tidal areas; gravelly sediments (low mud content); high backscatter; lower turbidity.

Group H. Moderately deep water; moderately tidal; no clear sediment preference; avoids small and large sandwaves.

Figure 7.11 **The likely distributions of the 14 asssemblages that have been derived from a consensus between the four models that output individual assemblage distribution maps (maximum likelihood, multiple logistic regression, CTA and maximum entropy). The probabilities from all four models have been added together for each assemblage and the total displayed on a common scale. Red indicates a very high probability, yellow moderately high, with green and blue low probability.**

Marine
Aggregate Levy
Sustainability Fund
MALSF





Group I. Muddy sediments; avoids sandwaves and sandbanks; lower water turbidity.

Group J. Muddy gravelly sediments; lower tidal currents and lower turbidity.

Group K. Low silt, gravelly sand; high backscatter; avoids sandwave areas.

Group P. Muddy sands; mostly deeper water.

Group Q. Sediments with low mud content; moderately strong tidal areas; associated with wave crests and small sandwaves.

Group R. Sediment with low mud content; strong tidal area; shallower.

Group U. Gravelly sand sediments with low mud content; often associated with small sandwaves.

Figure 7.11 **The likely distributions of the 14 asssemblages *(continued from previous page).***

The resulting maps give a plausible distribution for the assemblages with very distinct geographical distribution patterns for each one, with relatively little overlap in areas of greatest likelihood. Note that there are no definite cut-offs that determine if a particular assemblage will appear as the most likely, as this depends upon the levels of probability of competing assemblages for each pixel. The assemblage with the highest probability for each pixel can be determined using the module HARDEN in IDRISI. To do this, the probabilities were standardised by dividing the totals for each assemblage by the grand total for all assemblages. The accuracy of the resulting distribution map (Figure 7.12) was good, with a Kappa score of 0.71 and an accuracy of 74.9%.

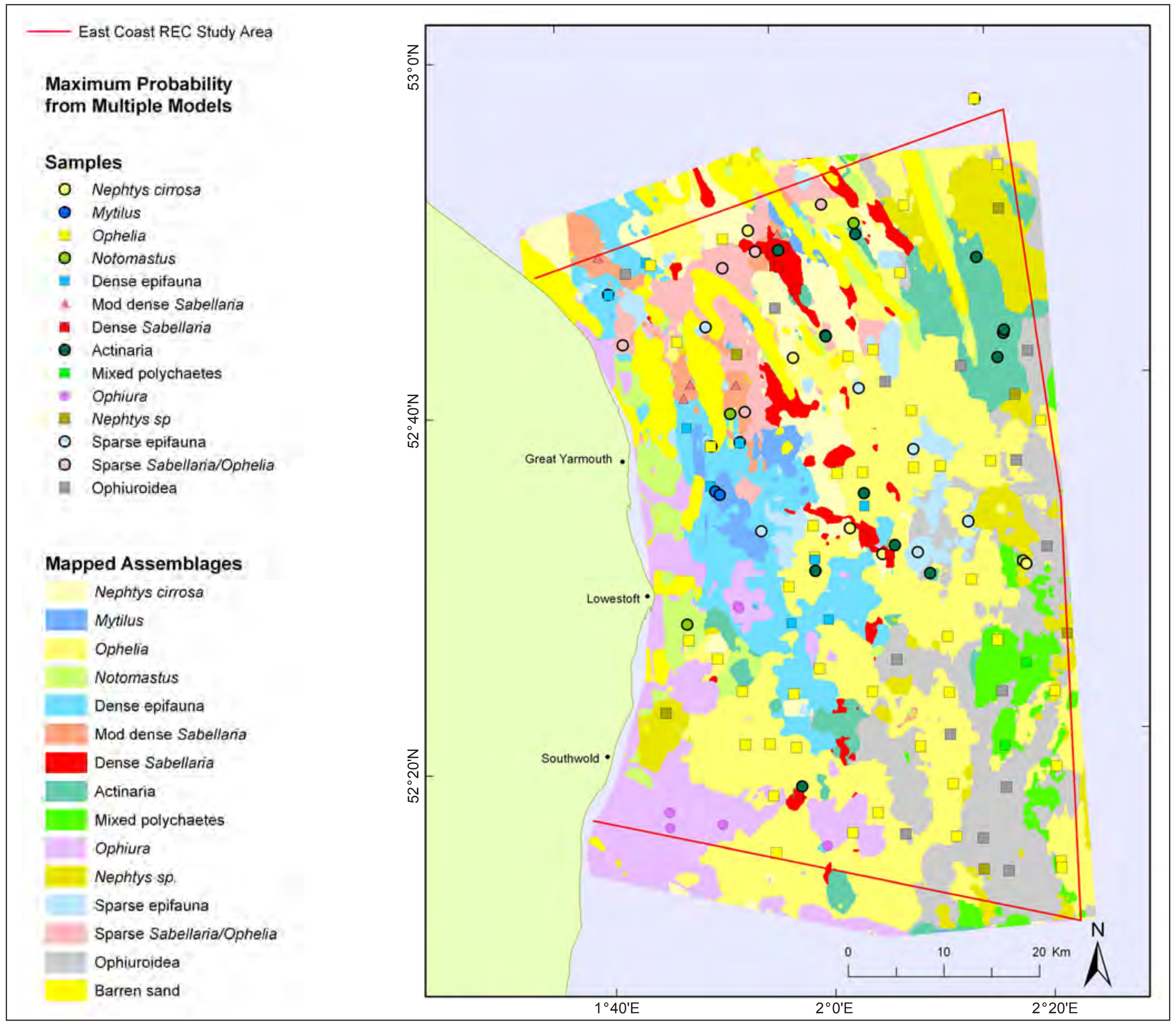


Figure 7.12 Distribution of assemblages derived by displaying the assemblage with the highest probability for each pixel from amongst the individual assemblage probabilities (see Figure 7.11).

Combining the map outputs from the models

To find levels of agreement between models (the second approach to finding a consensus between models), the outputs for the five models were overlain and agreement between them calculated on a pixel-by-pixel basis. The possibilities were as follows: no agreement, agreement between 2, 3, 4 or all 5 models. The following systematic procedure was then adopted to use the agreement levels to decide on the assemblages to display on the map: the consensus map was adopted where two or more models were in agreement. If there were two pairs of models in agreement, then the pair with the highest combined Kappa agreement was adopted. For those areas where there was no agreement, the model with the highest Kappa score was used. The final map (Figure 7.13) had an excellent level of agreement with the training data (a Kappa of 0.90 and an accuracy of 91.8%). Although this is not as high as the best-performing models, it must be remembered that these accuracy statistics only measure an internal agreement for the training areas (ie, no other data-set was used to test the predictive power of the maps). One of the drawbacks for reliance on internal accuracy measures is that they may not provide a good guide as to the accuracy of the maps some distance from the training samples. Given this, it is “safer” to rely on the consensus map, especially for areas outside of the training sites.

The bottom-up biotope map

The similarity between the outputs from both mapping approaches is high, although small differences are apparent. These differences could be due in part to the inability to include the ArtMap model in the first process, since this model does not output individual strength of belief maps for each assemblage separately. It is suggested that the output from the second approach (combining the most likely assemblage distributions from all five models) should be adopted as the best representation of the spatial distribution of the assemblages.

The lack of overlap between the probability distribution of each assemblage (Figure 7.11) and the fact that two methods for deriving a consensus map are very similar is strong confirmation that the consensus approach has produced a robust map based on largely non-overlapping assemblage distributions. The consensus approach has overcome one of the main concerns of the separate models, namely that other distributions could be derived if the probabilities between competing assemblages had been very slightly different due to the algorithms employed by the models.

The assemblage distribution maps can be related to the environmental variables using multiple regressions. The outputs from these regressions show which variables are most strongly associated with the assemblage distribution. Results indicate environmental relationships that are very similar to the response curves from MaxEnt, and both have been used to derive the short narrative descriptions of associated environmental variables that accompany the distribution maps (Figure 7.11).

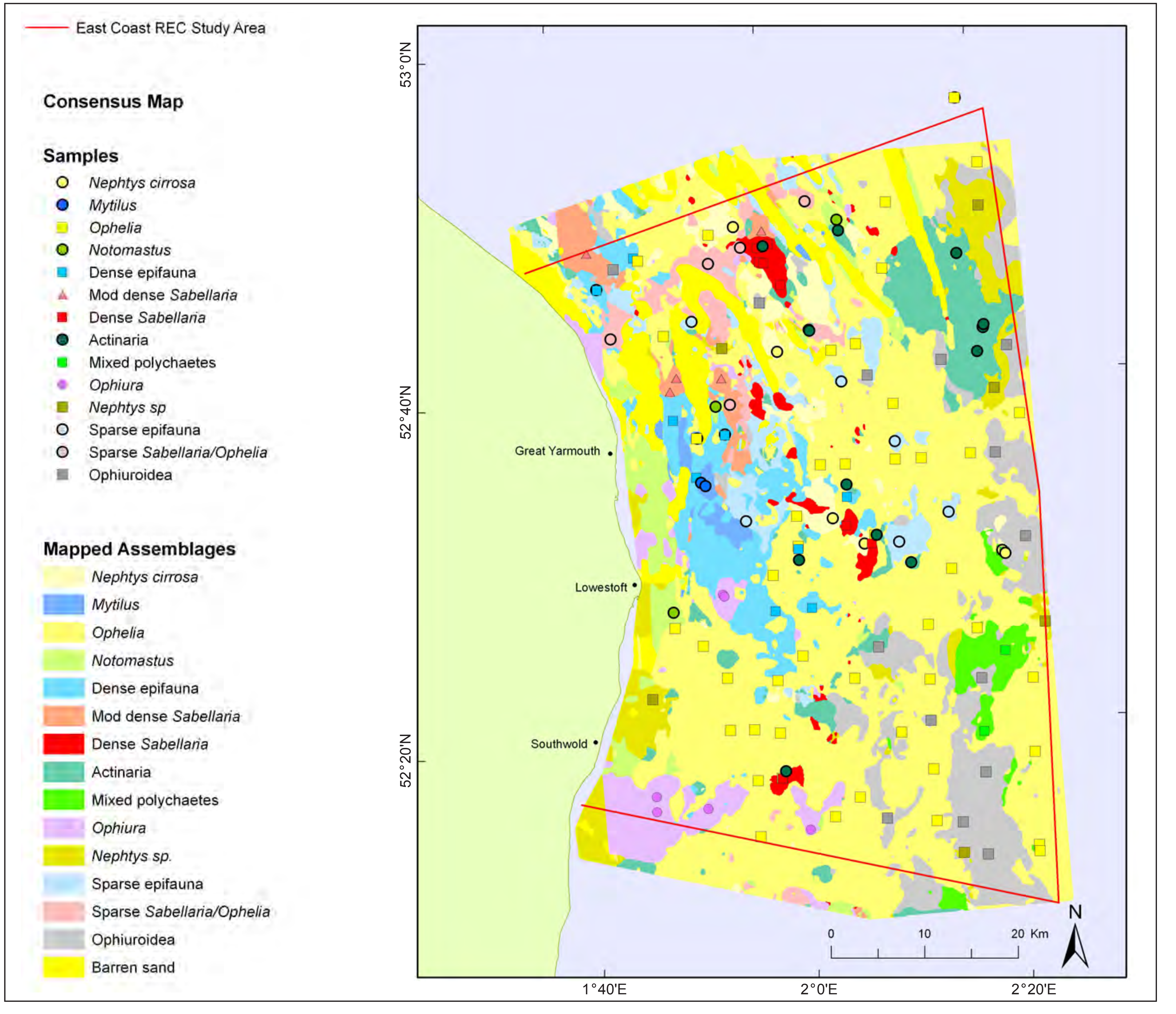
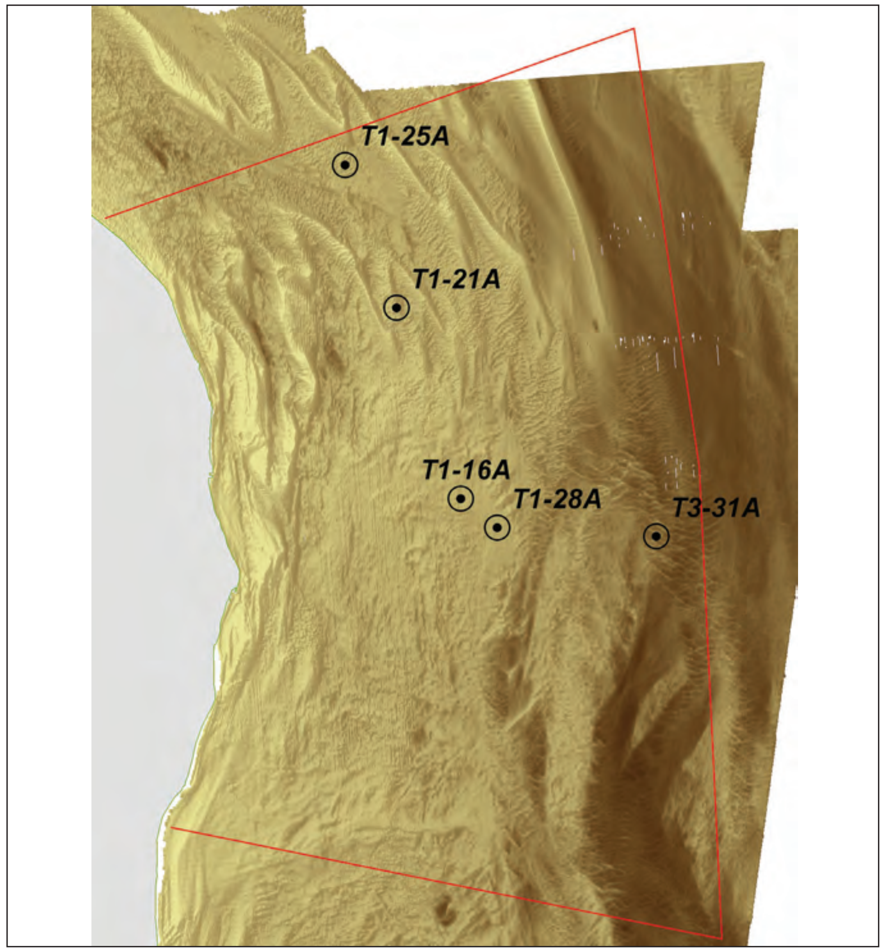


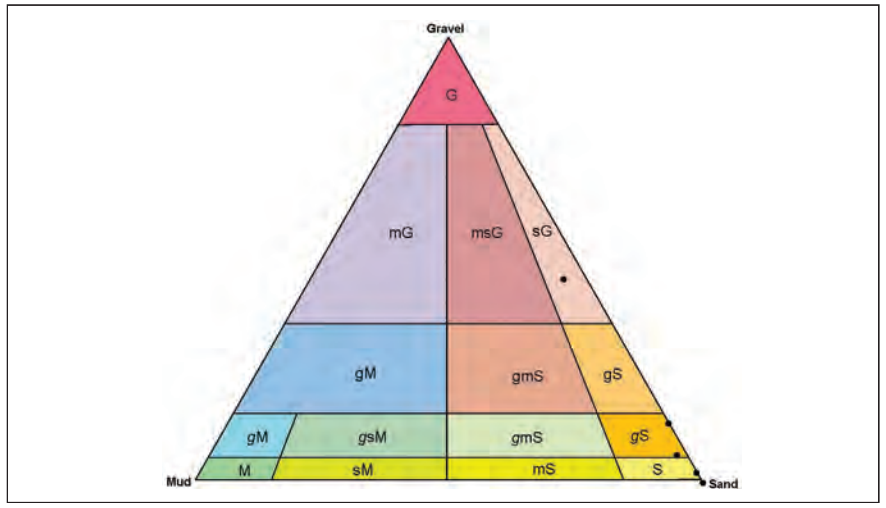
Figure 7.13 Ensemble biotope map derived from a consensus of all five models used.

7.2.3 Biotope characterisation

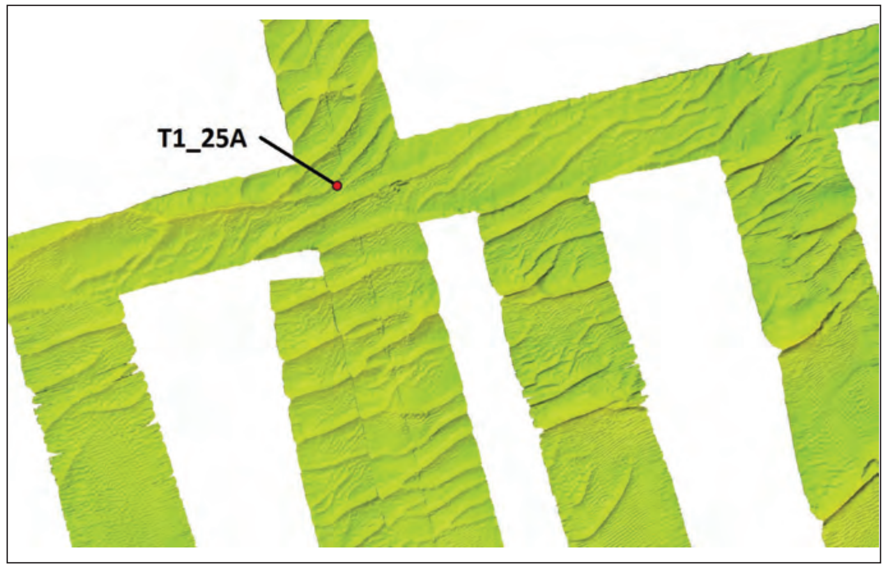
As described above, the five different analytical approaches have each provided a map of all 14 biotopes, which have been used to build a consensus map of the East Coast REC Study Area (Figure 7.13). In addition to this, the approaches have delivered a probability distribution map for each of the 14 individual biotopes (Figure 7.11). In this section, a summary of the physical and biological characteristics that define each of the 14 different biotopes is presented, with the purpose of assisting in the visualisation of where certain combinations of physical and biological attributes are likely to occur. The maps of most likely distribution of each particular biotope are central to this description. Naming of each biotope follows the nomenclature adopted in Section 6.3.2, where each assemblage is referred to as a “Group” followed by its assigned letter. Each biotope is also given a brief descriptor based on its most characterising atribute (eg, the *Nephtys cirrosa* assemblage).



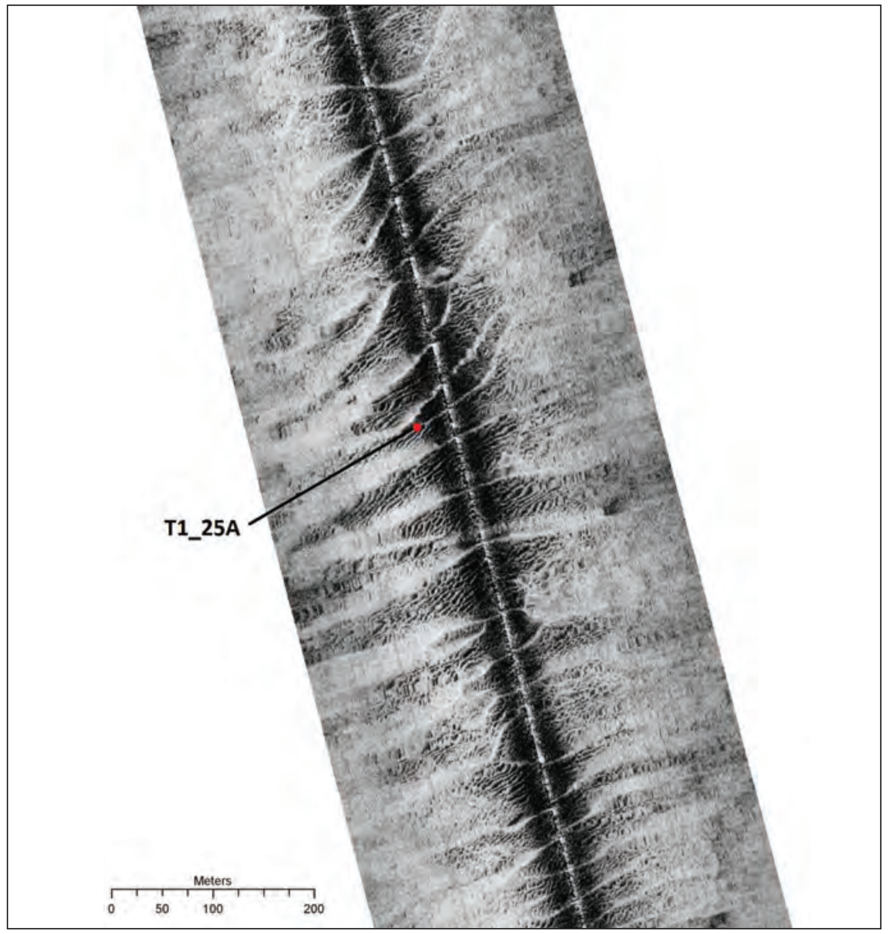
Map showing bathymetry and sampling locations[3]



Plot of each sediment sample's PSD profile against the Folk sediment triangle



Multibeam of representative sampling station



Side-scan of representative sampling station

GROUP A – PHYSICAL INFORMATION

Description

Four of the five stations belonging to Group A are found lying in an arc parallel to the coastline in the northern half of the survey area. The fifth station, T3_31A, lies in the deepest water furthest to the east. Most stations lie in sandwave-dominated areas with the exception of T1_28A, which lies in an area of predominantly linear parallel E–W-orientated megaripples with no adjacent sandwave features. At T3_31A, although still a sandwave area, the wavelengths are much longer, and the sampling station lies within the wave trough. Both T1_21A and T1_25A appear to lie on or close to the crests of sandwaves with a much shorter wavelength and associated parasitic megarippling. The relationship between the sample grouping and the bedforms is not clear, but there are megaripples at all of the sites and these features are clearly seen on the side-scan data at T1_25A (right).

Based on side-scan data, the substrate type is likely to be heterogeneous, as indicated by the high reflectivity (lighter shades) of the sandwave crests against the low reflectivity (darker shades) in the troughs of the megaripples. Particle size distribution (PSD) analysis of the samples reveals that the sediments are dominated by sand and slightly gravelly sand, with one station characterised by sandy gravel.

[3] Digital bathymetry data © British Crown and SeaZone Solutions Ltd. All rights reserved. Data Licence 052008.012.

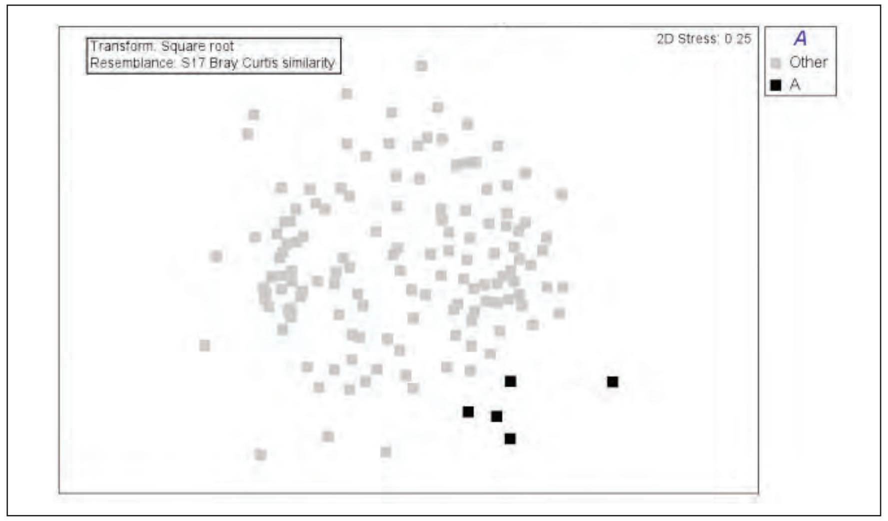
GROUP A – BIOLOGICAL INFORMATION

"*Nephtys cirrosa*" assemblage

Description

The assemblage identified as Group A is characterised by being relatively species-poor and dominated in abundance by just one or two taxa. *Nephtys cirrosa* is the only species present at all five sampling stations. All other taxa are recorded at fewer than half the stations within the group. *N. cirrosa*, *Mytilidae*, *Pisione remota*, *Sabellaria spinulosa* and *Glycera oxycephala* are the most abundant infaunal taxa. *Asterias rubens*, *Pagurus bernhardus*, *Crangon allmanni* and *Pandalus montagui* are the most conspicuous epifaunal species. Most of the taxa encountered are motile scavengers, characteristically found in current-swept mobile sandy sediment. Such substrates offer little opportunity for settling, either by permanent attachment or burrow/tube construction.

The map to the right shows the likely distribution of the assemblage in Group A, as predicted from an interpretation of the available physical and biological data (see page 206). It would appear that the assemblage has no definite sediment preferences, favours areas of strong tidal currents and avoids large sandwaves. The occurrence of such areas appears to be most probable in – but not restricted to – a band running N–S in the centre of northern half of the survey area.



Multidimensional scaling plot of samples in relation to all other samples

Species	Min. abund.[a]	Max. abund.	Mean abund.	Occur. %
Nephtys cirrosa	1	5	1.6	100
Mytilidae	1	2	0.6	40
Pisione remota	1	1	0.4	40
Sabellaria spinulosa	1	1	0.4	40
Sthenelais limicola	1	1	0.2	20
Glycera oxycephala	2	2	0.4	20
Aonides paucibranchiata	1	1	0.2	20
Pista cristata	1	1	0.2	20

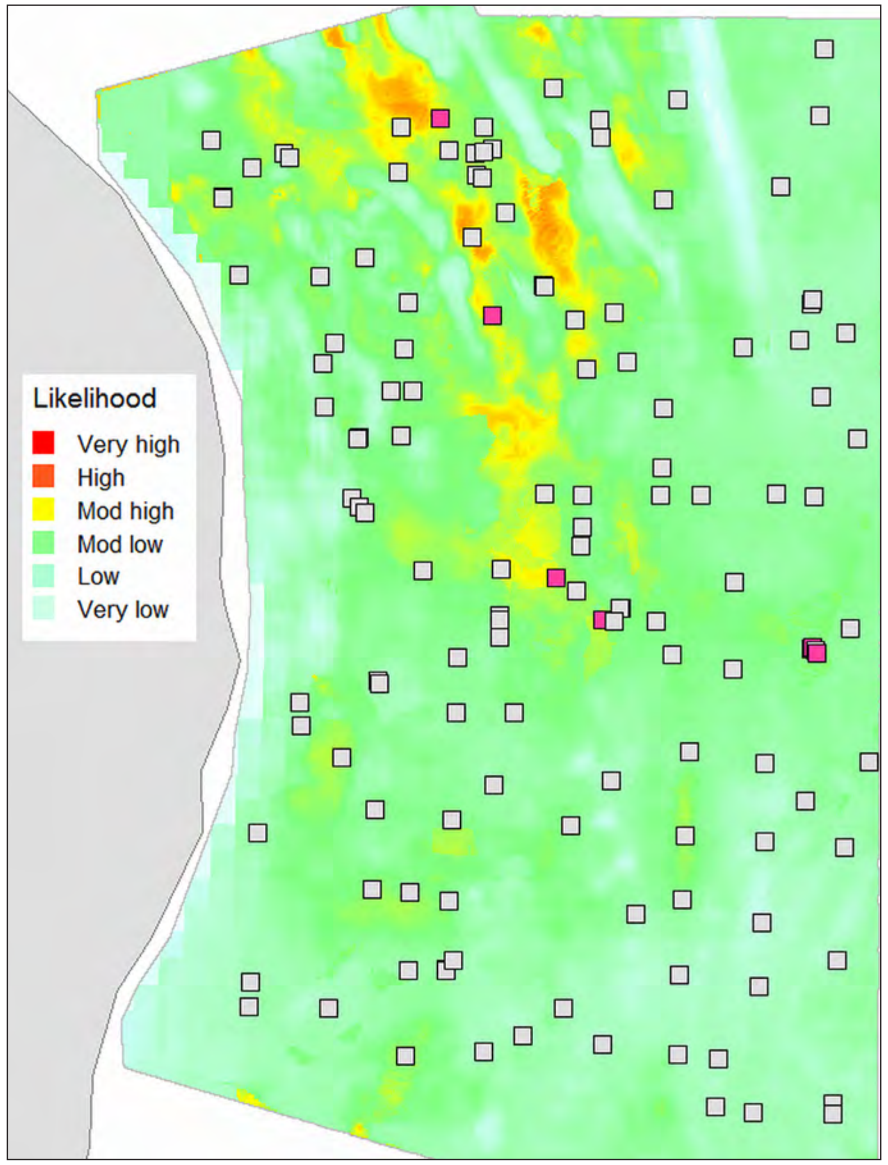
[a] Abundance values per 0.1 m² grab sample

Top species contributing to the similarity within the group in descending order of % contribution

	Minimum	Maximum	Average
Number of species	1	6	4.6
Abundance	7	8	5.6
Diversity (N1)	1.00	5.74	4.43
Evenness (N2/N1)	0.94	1.00	0.97
Taxonomic distinctness (Δ*)	0.00	94.44	70.68

Number of grabs = 5

Infaunal assemblage metrics per grab

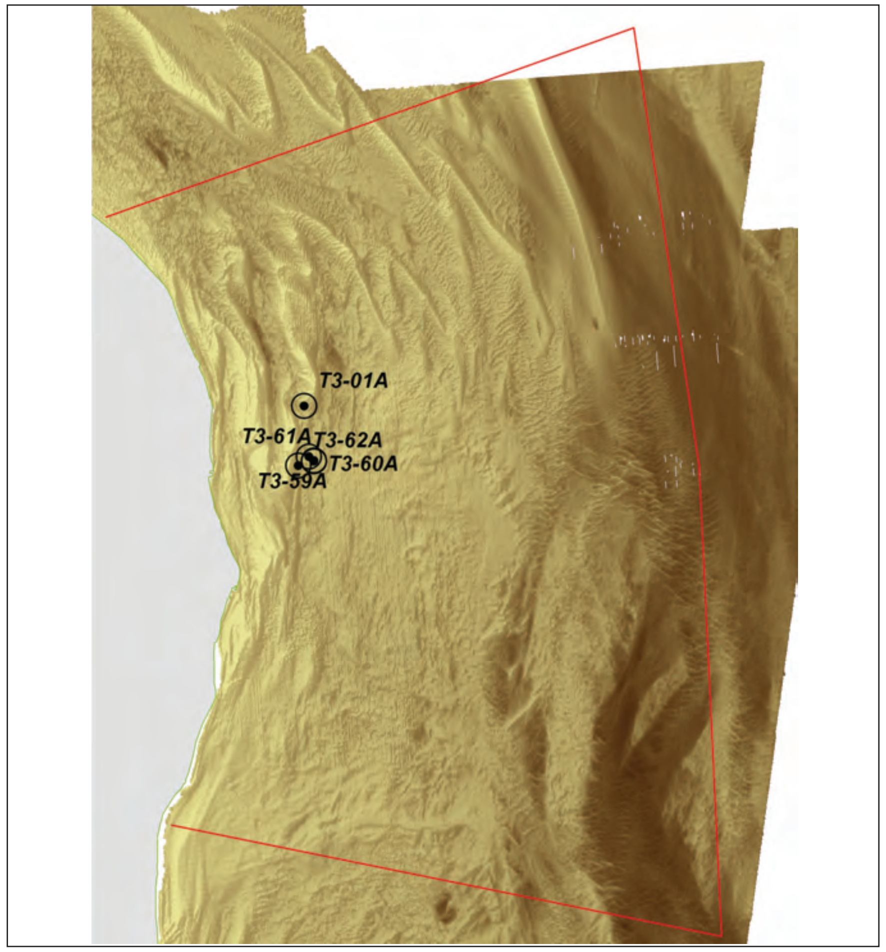


Modelled output showing the likely distribution of the assemblage

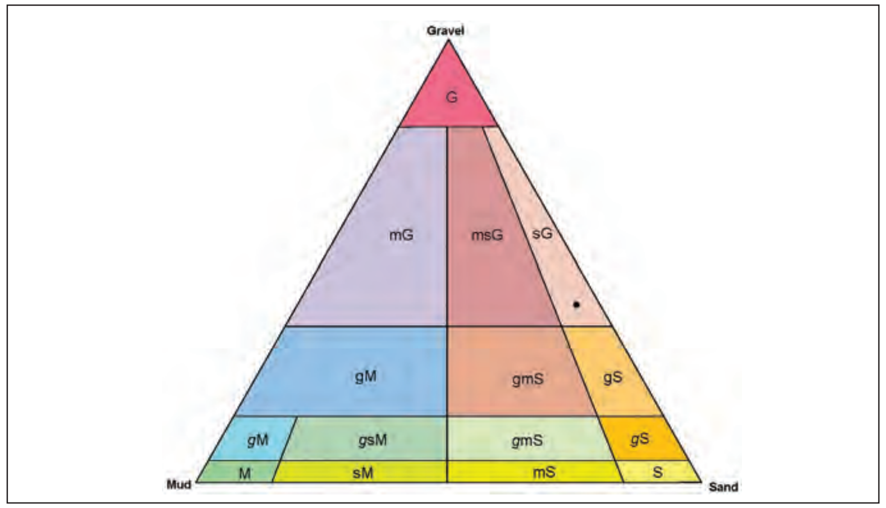
	Minimum	Maximum	Average
Number of species	12	23	19.3
Abundance	28	612	211.0
Diversity (N1)	3.60	10.55	7.97
Evenness (N2/N1)	0.59	0.73	0.67

Number of trawls = 4

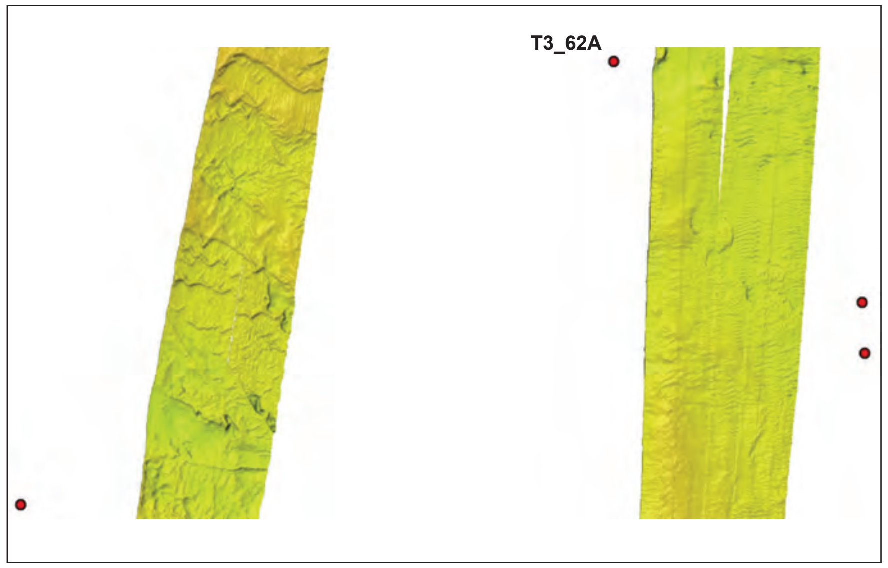
Epifaunal assemblage metrics per trawl



Map showing bathymetry and sampling locations[4]



Plot of each sediment sample's PSD profile against the Folk sediment triangle



Multibeam of representative sampling station

Side-scan of representative sampling station

GROUP B – PHYSICAL INFORMATION

Description

The five samples contributing to Group B are in a tight cluster in the central western part of the survey area. All but one of the sampling stations lie outside of the newly acquired multibeam tracks, so a definitive substrate description cannot be provided. The multibeam tracks near the sampling stations show the seafloor sedimentation to be driven by underlying sub-cropping geological formations. Defined sub-cropping lineations and small scarps, with small localised patches of rippling between and around sub-cropping features, can be also observed on the side-scan data.

Analysis of grab samples shows that the sub-cropping material is peat, covered by a thin veneer of sediment. Peat is likely to have been deposited near the coast and subsequently inundated by rising sea levels. The northernmost sampling station belonging to Group B (T3_01A) lies on a defined sub-cropping geological formation, covered by a thin sediment veneer, with nearby megarippling.

PSD analyses reveal that the sediment veneer is sandy gravel; however, sediment samples were not available for all five sampling stations.

[4]Digital bathymetry data © British Crown and SeaZone Solutions Ltd. All rights reserved. Data Licence 052008.012.

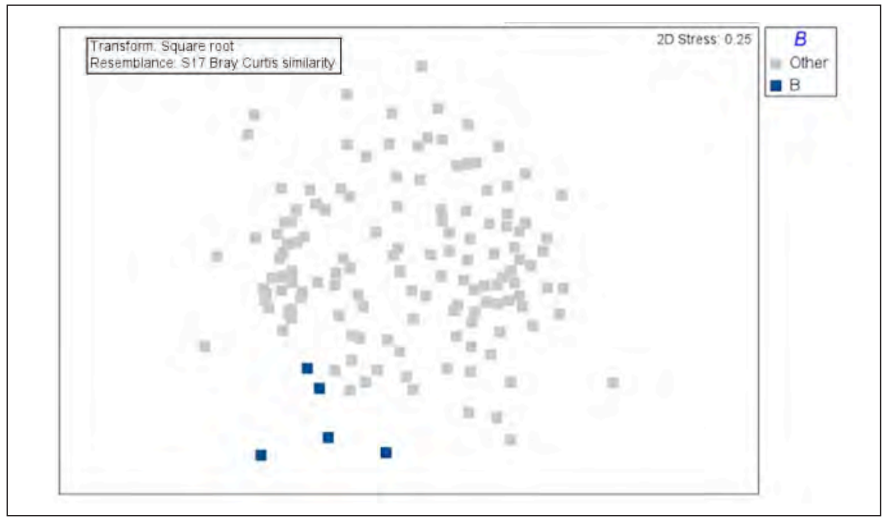
GROUP B – BIOLOGICAL INFORMATION

"*Mytilus*" assemblage

Description

The epibenthic assemblage in Group B is characterised by a relatively high abundance of the common mussel *Mytilus edulis* and organisms able to exploit the hard substrate provided by its shells. Such species include the hydroids *Sertularia* sp., *Obelia longissima*, *Calycella syringa* and the barnacle *Balanus crenatus*. Other species of note are the pycnogonid *Nymphon brevirostre* and the amphipod *Atylus swammerdamei*. Infaunal taxa, although not present in significant numbers, were often characteristic of relatively stable or consolidated substrates, such as peat or gravel. They included burrowing piddocks *Barnea candida* and deposit-feeding polychaetes Terebellidae and *Cirriformia tentaculata*.

The map showing the likely distribution of the Group B assemblage (right) as predicted from an interpretation of available physical and biological data (see page 206) suggests a much localised distribution of the assemblage. It would appear Group B favours slightly gravelly, slightly silty sediments, and moderately deep tidal waters. Such areas are very likely to occur in a relatively small area, close to the coast towards the centre of the survey area, extending northwards.



Multidimensional scaling plot of samples in relation to all other samples

Species	Min. abund.[a]	Max. abund.	Mean abund.	Occur. %
Mytilidae	2	30	16.8	100
Mytilus edulis	2	107	24.2	80
Sertularia	1	1	0.8	80
Cirriformia tentaculata	2	2	0.8	40
Barnea candida	2	20	4.4	40
Atylus swammerdamei	2	46	9.6	40
Eumalacostraca	2	1	0.4	40
Calycella syringa	1	1	0.6	60

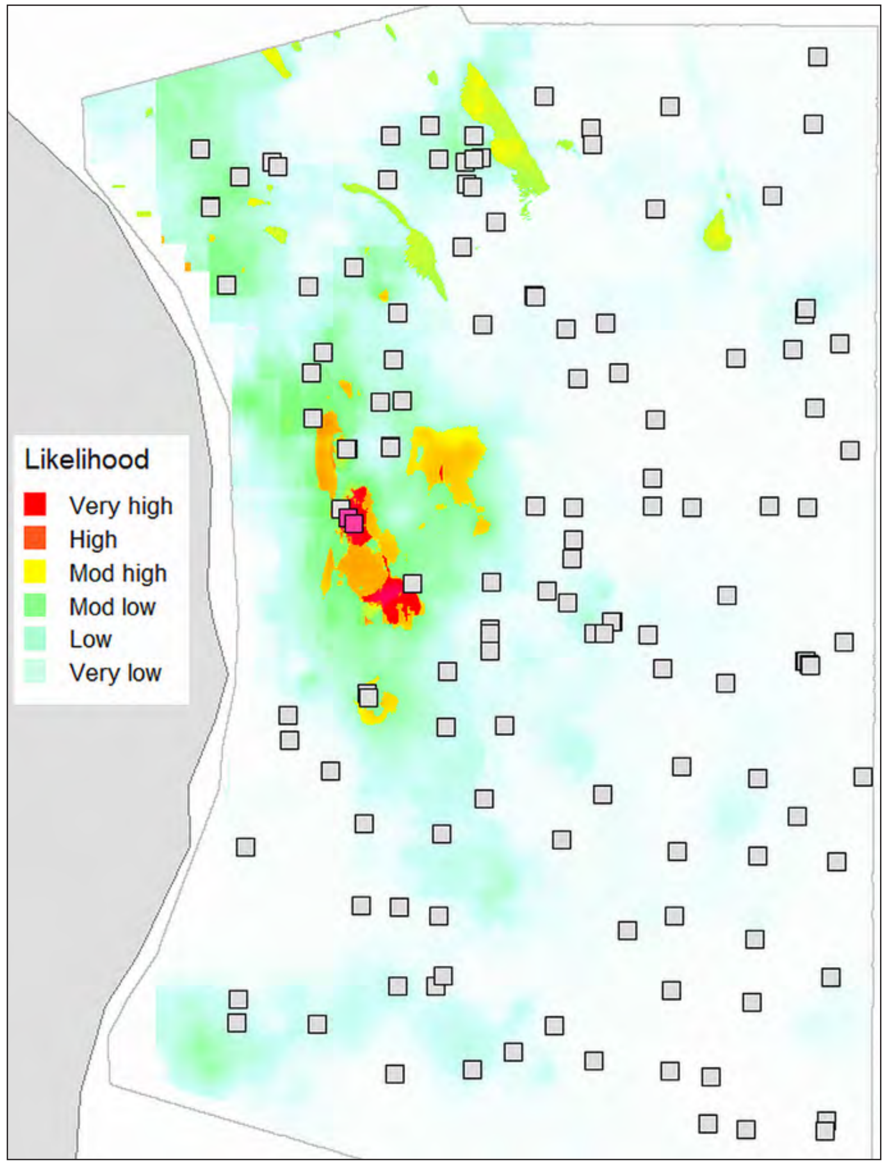
[a] Abundance values per 0.1 m² grab sample

Top species contributing to the similarity within the group in descending order of % contribution

	Minimum	Maximum	Average
Number of species	6	28	17.0
Abundance	15	545	154.4
Diversity (N1)	3.62	11.33	5.75
Evenness (N2/N1)	0.55	0.74	0.62
Taxonomic distinctness (Δ*)	73.42	95.80	87.40

Number of grabs = 5

Infaunal assemblage metrics per grab

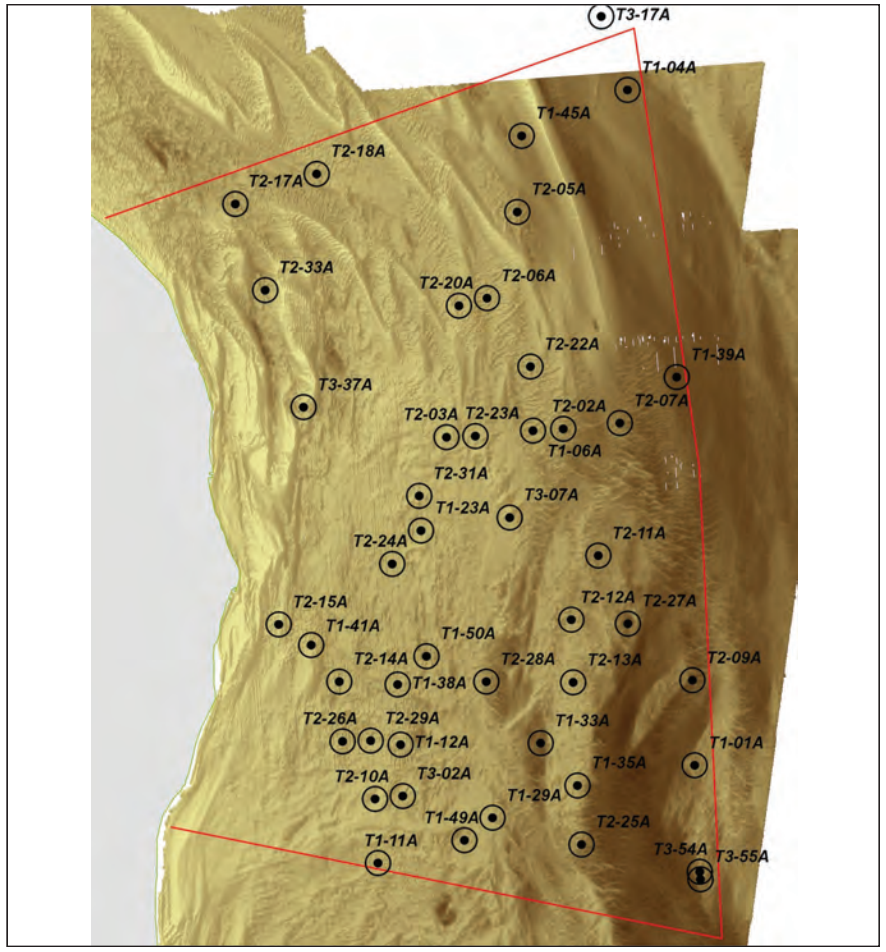


Modelled output showing the likely distribution of the assemblage

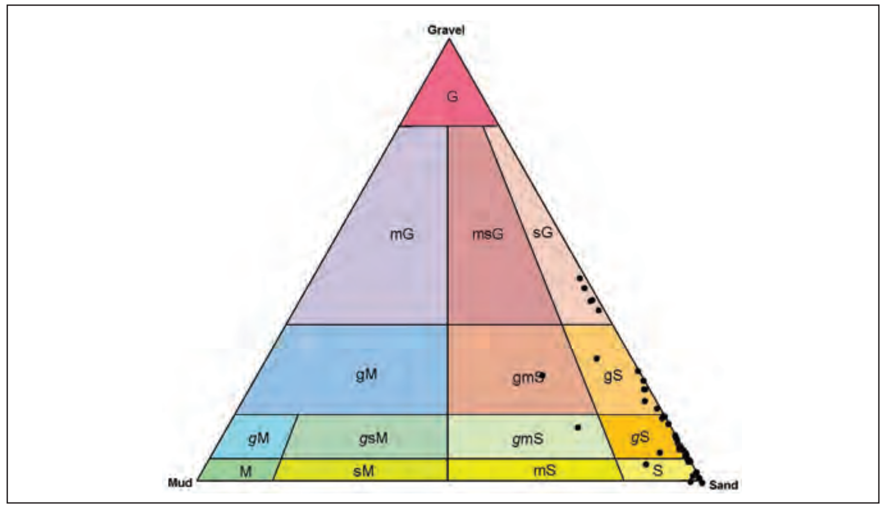
	Minimum	Maximum	Average
Number of species	-	-	-
Abundance	-	-	-
Diversity (N1)	-	-	-
Evenness (N2/N1)	-	-	-

Number of trawls = 0

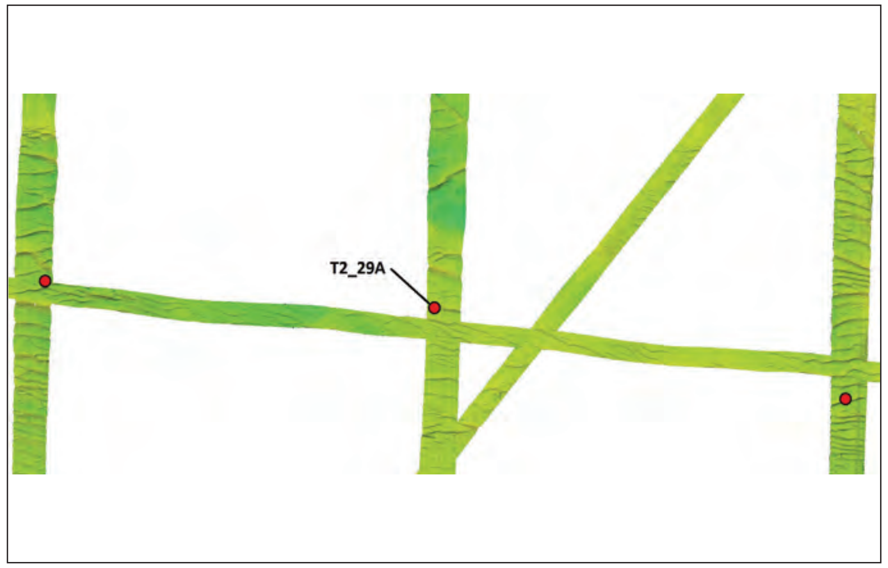
Epifaunal assemblage metrics per trawl



Map showing bathymetry and sampling locations[5]



Plot of each sediment sample's PSD profile against the Folk sediment triangle



Multibeam of representative sampling station

Side-scan of representative sampling station

GROUP C – PHYSICAL INFORMATION

Description

Group C is the most represented and widely spread group identified, ranging from north to south and east to west and from shallow to deep water. The most notable feature is the association with megaripples and sandwave fields, in particular, proximity to the crestlines of sandwaves (e.g. T2_29A). Approximately 85% of the sample sites assigned to Group C share this feature. However, as the sediments range from fine, well-sorted sands to sandy gravels, there is also variation in the seabed morphology. Some stations lie in areas with no significant bedforms, or with only very small-scale ripples present (e.g. T2_24A and T1_01A), or in areas surrounded by bedforms but with a lack of features at the sampling site itself (e.g. T3_37A). The area as a whole is subjected to significant tidal currents and a highly mobile sedimentary regime.

[5]Digital bathymetry data © British Crown and SeaZone Solutions Ltd. All rights reserved. Data Licence 052008.012.

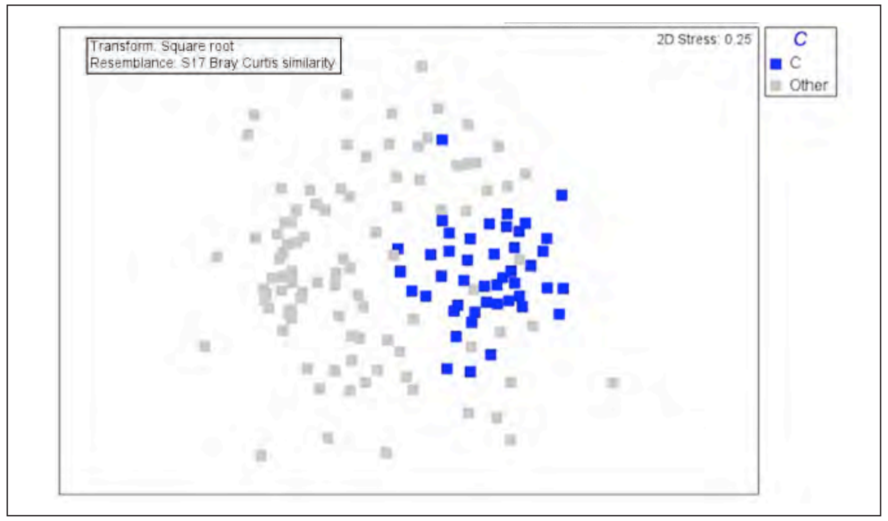
GROUP C – BIOLOGICAL INFORMATION

"*Ophelia*" assemblage

Description

The most widespread group is predictably characterised mostly by infaunal species that display a high tolerance to changes in physical conditions such as depth, disturbance regime and turbidity. Species like *Ophelia borealis* (found in 96% of all samples within this group), *Nephtys cirrosa* and *Gastrosaccus spinifer* demonstrate such traits and consequently have been found in almost every sample in the East Coast REC Study Area. *Sabellaria spinulosa* is also represented in this assemblage but not found in its reef-building form. Despite the ubiquitous and tolerant nature of some of its common members, the assemblage as a whole is far from depauperate. Many of the taxa within the group (128 in total) are less tolerant to the full range of conditions found over the extent of the study area, but occur where conditions are right for them. None, however, are sufficiently widespread or occur in significant numbers to influence or deserve an assemblage designation of their own. The epifaunal assemblage was equally varied, containing taxa such as *Ophiura ophiura*, *Asterias rubens*, *Pagurus bernhardus* and *Crangon allmanni*.

The likely distribution of Group C assemblage as predicted from an interpretation of the available data (see page 206) reinforces its ubiquitous nature. Larger areas where it is most likely to occur are in the south-western quadrant of the survey area and north-east of centre of the survey area. Most areas where it is likely to occur are characterised by moderately deep, clean sandy sediments.

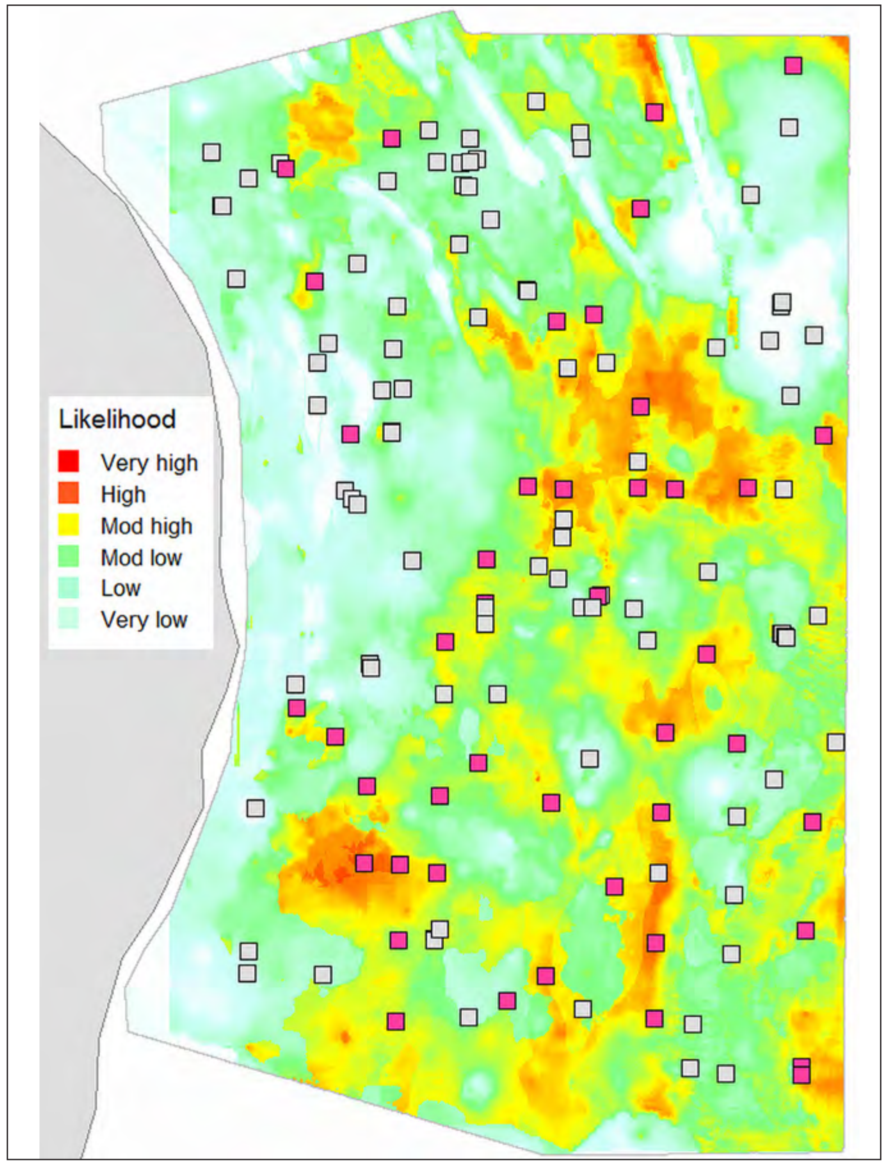


Multidimensional scaling plot of samples in relation to all other samples

Species	Min. abund.[a]	Max. abund.	Mean abund.	Occur. %
Ophelia borealis	1	45	6.2	96
Nephtys cirrosa	1	5	1.0	54
Gastrosaccus spinifer	1	11	1.2	43
Nephtys	1	3	0.5	39
Ophiuroidea	1	5	0.7	37
Sabellaria spinulosa	1	9	0.8	30
Ophiura albida	1	13	0.4	24
Conopeum reticulum	1	1	0.2	28

[a] Abundance values per 0.1 m² grab sample

Top species contributing to the similarity within the group in descending order of % contribution



Modelled output showing the likely distribution of the assemblage

	Minimum	Maximum	Average
Number of species	2	30	10.3
Abundance	7	81	20.9
Diversity (N1)	1.31	17.23	7.41
Evenness (N2/N1)	0.46	1.00	0.78
Taxonomic distinctness (Δ*)	66.67	97.22	87.73

Number of grabs = 46

Infaunal assemblage metrics per grab

	Minimum	Maximum	Average
Number of species	13	33	20.3
Abundance	19	6,283	678.0
Diversity (N1)	1.89	15.08	6.75
Evenness (N2/N1)	0.52	0.86	0.67

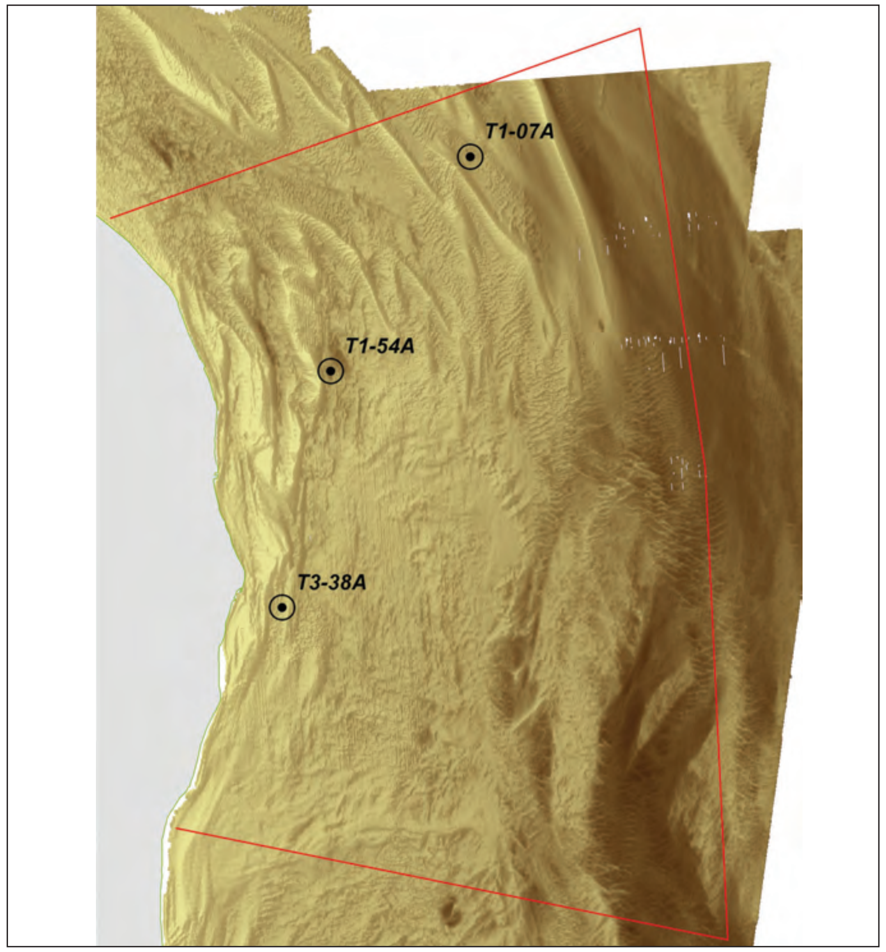
Number of trawls = 43

Epifaunal assemblage metrics per trawl

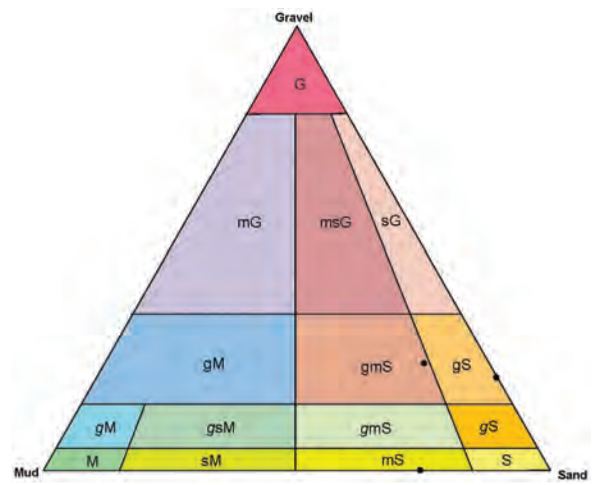
GROUP D – PHYSICAL INFORMATION

Description

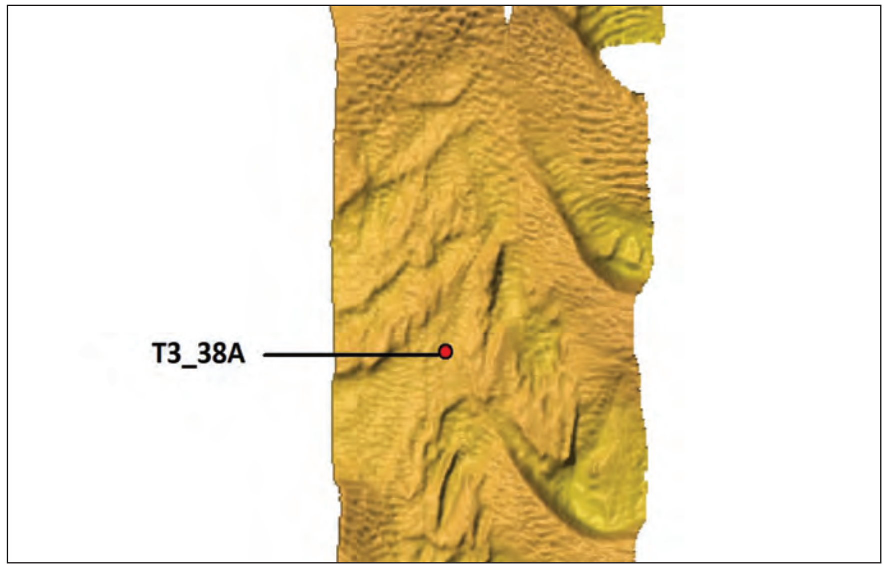
The three sample stations comprising Group D lie in three widely separated (>20 km) locations. T1_07A lies in a trough between two sandwave crestlines, in an area with associated linear in-phase megarippling. T1_54A and T3_38A both lie in areas that, as well as having significant bedform features including sandwaves and megaripples, also show evidence of near surface sub-cropping of underlying geological features (left). It is believed that the sediment deposition in these two areas is driven by the underlying geology whereas the sediment cover at T1_07A is thicker and so is not affected by the underlying geology. However, there is no clear difference in the sediment recovered from the samples, which is poorly sorted, occasionally muddy sands at all three sites.



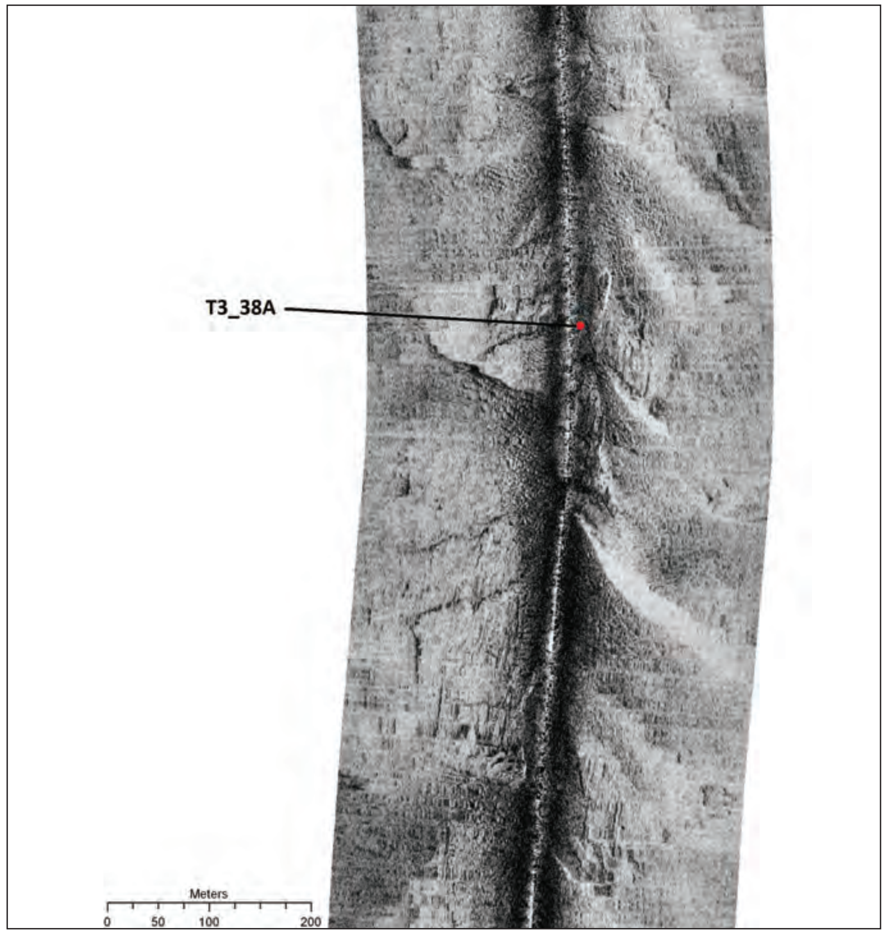
Map showing bathymetry and sampling locations[6]



Plot of each sediment sample's PSD profile against the Folk sediment triangle



Multibeam of representative sampling station



Side-scan of representative sampling station

[6]Digital bathymetry data © British Crown and SeaZone Solutions Ltd. All rights reserved. Data Licence 052008.012.

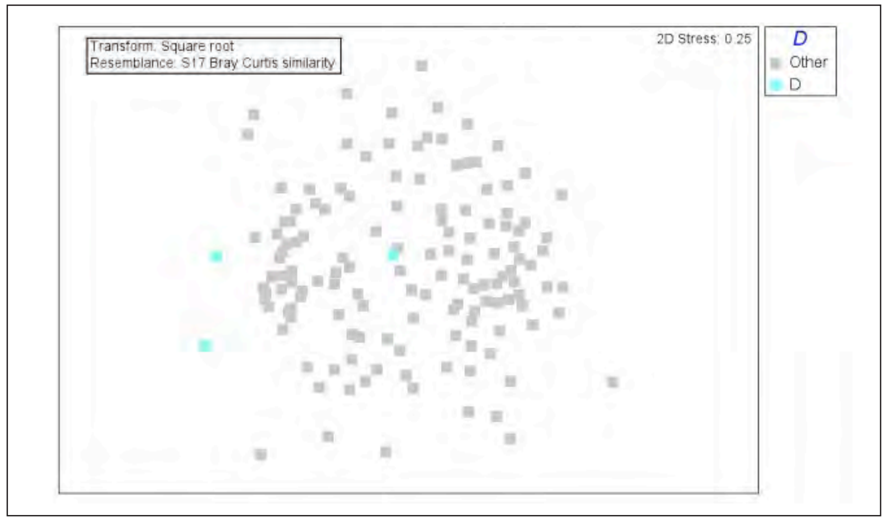
GROUP D – BIOLOGICAL INFORMATION

"*Notomastus*" assemblage

Description

The assemblage representing Group D is a relatively species-poor assemblage characterised by just 24 taxa. The only species present at all three sampling stations was *Notomastus latericeus*. This and other infaunal – mostly deposit-feeding – species such as *Scalibregma inflatum*, Terebellidae and Nemertea reflect a relatively low-energy environment allowing for deposition of fine organic material.

The likely distribution of Group D assemblage as predicted by the analysis of available data (see page 206) suggests it is found mostly close to the shore along the centre of the survey area, in shallow sandy sediments, in moderately tidal and turbid waters, and often associated with large sandwaves or sandbanks.



Multidimensional scaling plot of samples in relation to all other samples

Species	Min. abund.[a]	Max. abund.	Mean abund.	Occur. %
Notomastus latericeus	3	7	4.3	100
Actiniaria	1	1	0.7	67
Nemertea	1	2	1.0	67
Sertularia	1	1	0.7	67
Pisione remota	1	1	0.3	33
Pholoe baltica	1	1	0.3	33
Pholoe inornata	3	3	1.0	33
Glycera alba	1	1	0.3	33

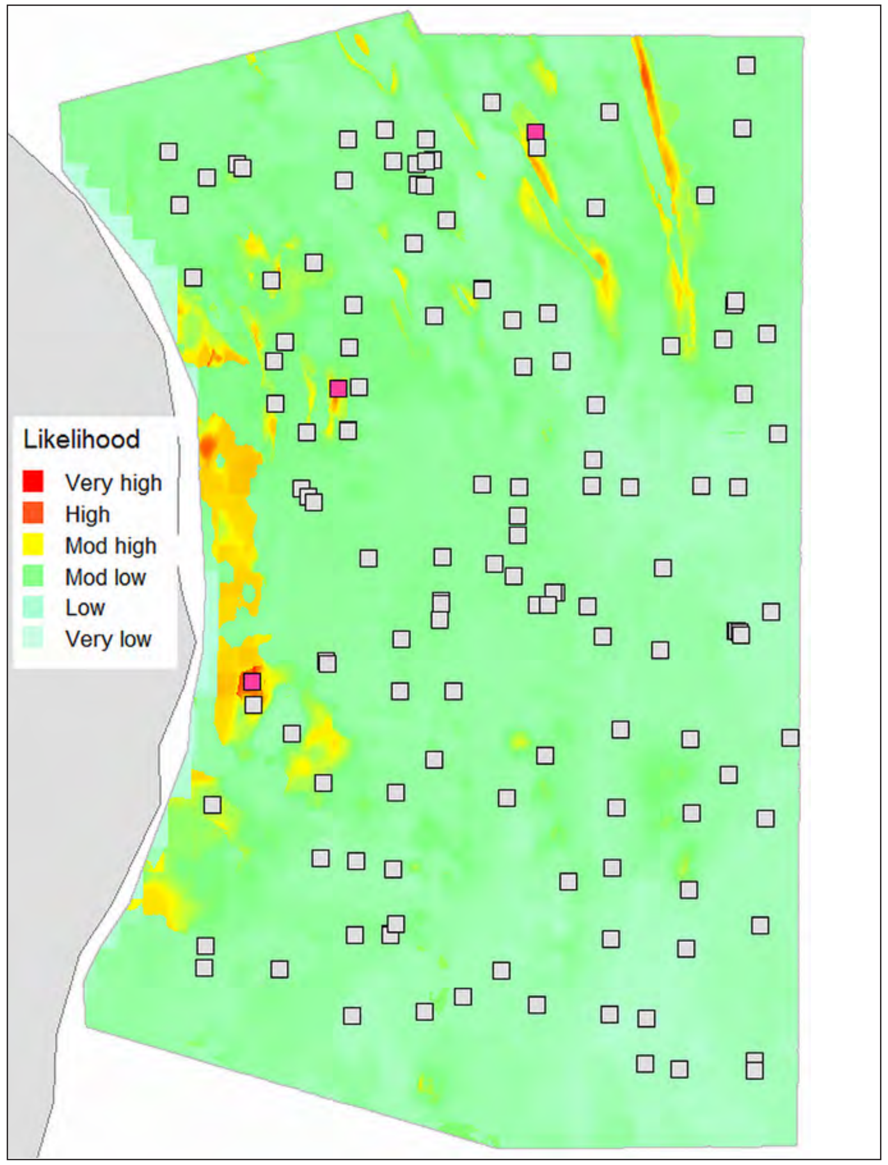
[a] Abundance values per 0.1 m² grab sample

Top species contributing to the similarity within the group in descending order of % contribution

	Minimum	Maximum	Average
Number of species	7	12	9.7
Abundance	15	39	25.0
Diversity (N1)	2.34	8.81	6.65
Evenness (N2/N1)	0.67	0.88	0.75
Taxonomic distinctness (Δ*)	75.76	85.37	80.95

Number of grabs = 3

Infaunal assemblage metrics per grab



Modelled output showing the likely distribution of the assemblage

	Minimum	Maximum	Average
Number of species	16	16	16.0
Abundance	161	416	289.0
Diversity (N1)	2.75	5.02	3.88
Evenness (N2/N1)	0.62	0.69	0.66

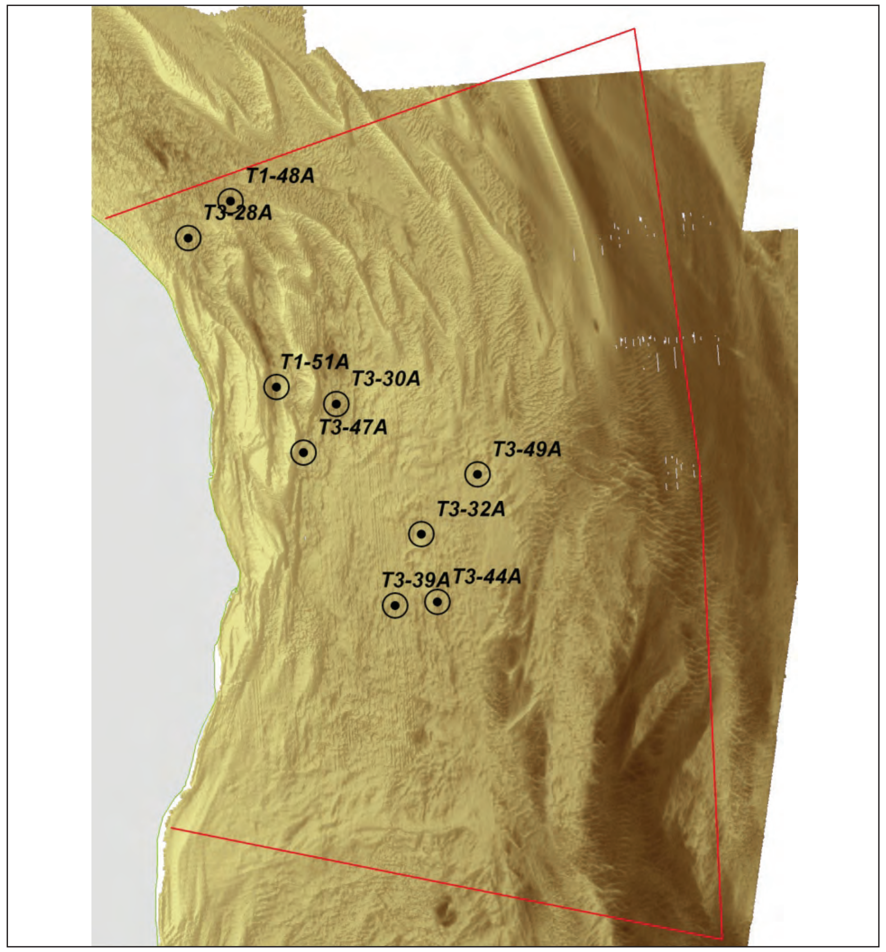
Number of trawls = 2

Epifaunal assemblage metrics per trawl

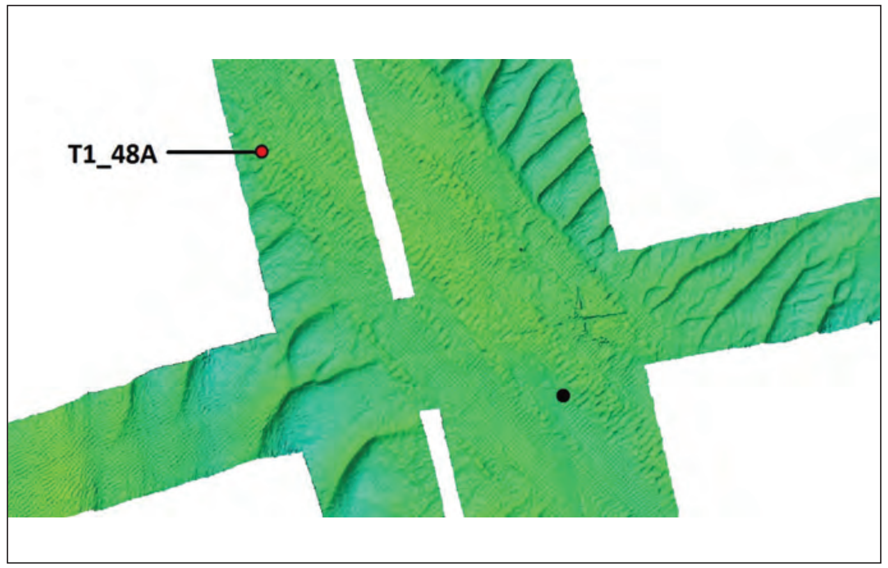
GROUP E – PHYSICAL INFORMATION

Description

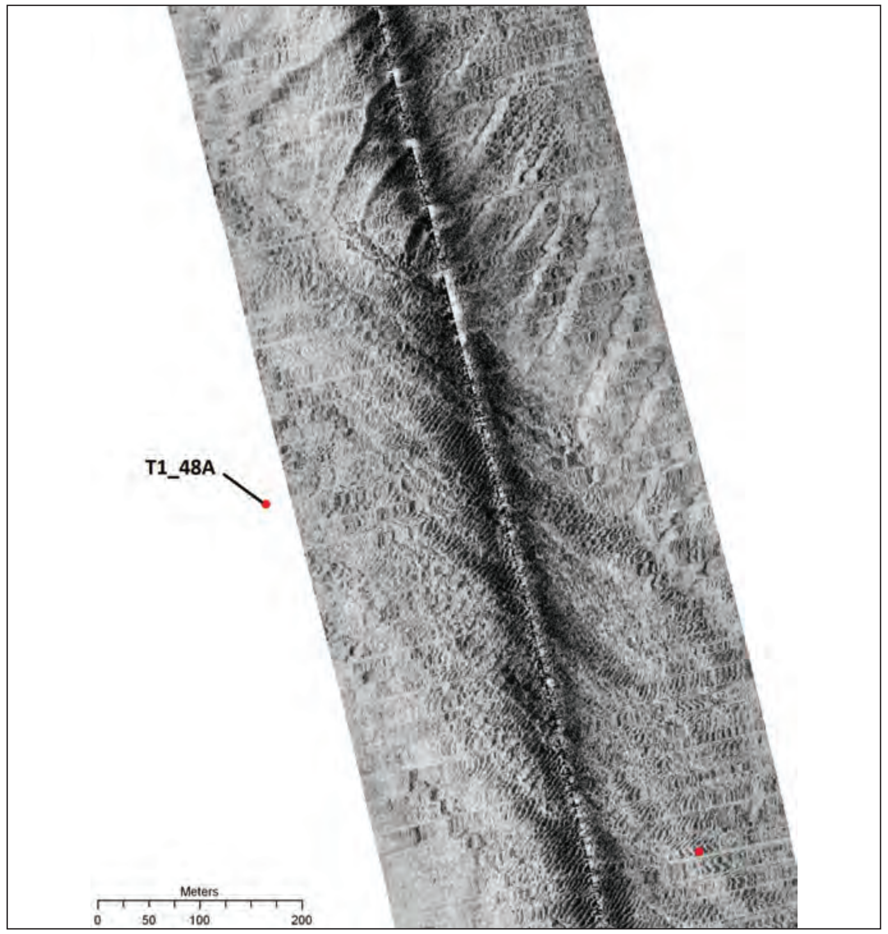
The nine sample stations comprising Group E are broadly in the north-western quadrant of the area and appear to be situated in areas where there are no, or only small-scale, bedforms (ripples) present, avoiding the larger scale sandwave features. Both multibeam and side-scan data reveal a rough seabed texture suggestive of the cementing of the sediments attributable to *Sabellaria spinulosa* (eg, T1_48A). The sample stations located in the shallower nearshore waters show some evidence of underlying sub-cropping geological formations, although this is not a common feature at all sites. However, the presence of a hard substrate at some of the sites may have assisted *S. spinulosa* in settling and attaching. From the side-scan data, the most striking feature of the sites is the presence of flow parallel features (sand ribbons/streaks). These elongate bedforms could indicate the presence of stronger currents. This hypothesis is supported by the sediment analysis, which shows that there is a strong skewing of the samples towards the coarser grain sizes, indicating that the finer, more transportable sediments may have been removed by strong currents. Again, stronger currents are compatible with the presence of *S. spinulosa*, which require a supply of mobile sand to construct their tubes.



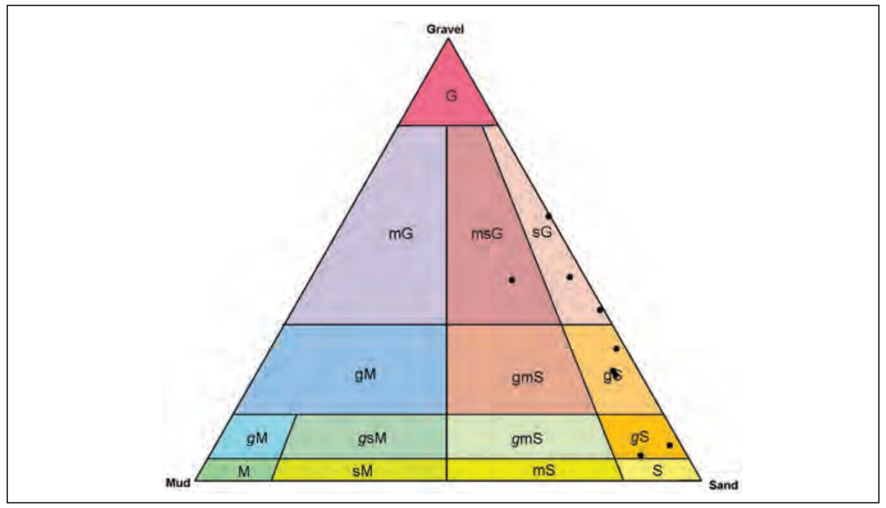
Map showing bathymetry and sampling locations[7]



Multibeam of representative sampling station



Side-scan of representative sampling station



Plot of each sediment sample's PSD profile against the Folk sediment triangle

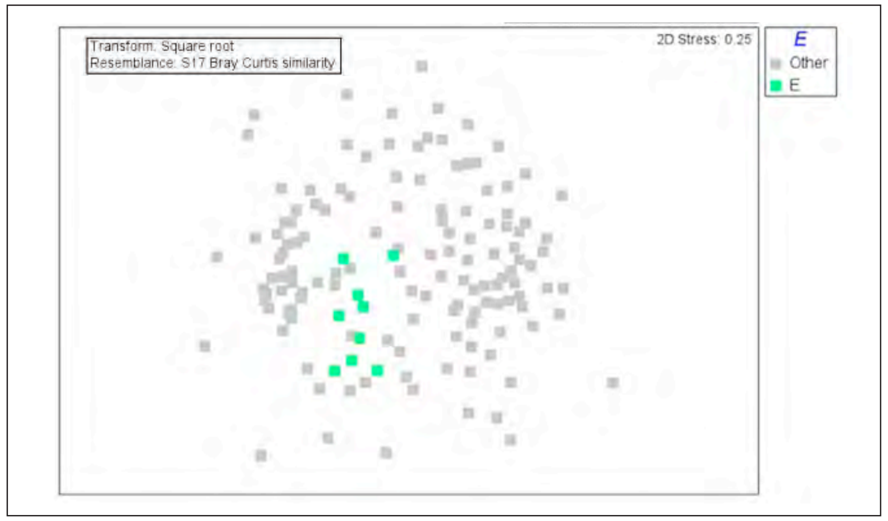
GROUP E – BIOLOGICAL INFORMATION

"Dense epifauna" assemblage

Description

Group E represents a relatively diverse macrofaunal assemblage dominated numerically by *Sabellaria spinulosa*, Actianaria, *Polycirrus* sp. and the amphipod *Gammarellus homari*. No prominent *S. spinulosa* reef structures are evident despite its relatively high – but not excessive – abundance. *S. spinulosa* is known to occur as a thin crust, which may be the predominant bedform identified acoustically at sites belonging to Group E. Most species identified appear to benefit from the increased stability, small-scale habitat heterogeneity and protection offered by the coarser, more stable elements in the sediment.

The most likely distribution of Group E as predicted by analyses of available data (see page 206) appears to be in shallow, strongly tidal areas close to the coast. Areas of highest likelihood of occurrence can be best identified from high backscatter, which is often associated with gravelly sediments and large sandwaves and sandbanks.



Multidimensional scaling plot of samples in relation to all other samples

Species	Min. abund.[a]	Max. abund.	Mean abund.	Occur. %
Sabellaria spinulosa	1	8	3.0	89
Actiniaria	1	14	2.8	78
Sertularia	1	1	0.8	67
Mytilidae	1	7	1.8	67
Conopeum reticulum	1	1	0.7	67
Polycirrus	3	9	2.2	44
Gammarellus homari	1	1	3.1	44
Goniada maculata	1	2	0.7	56

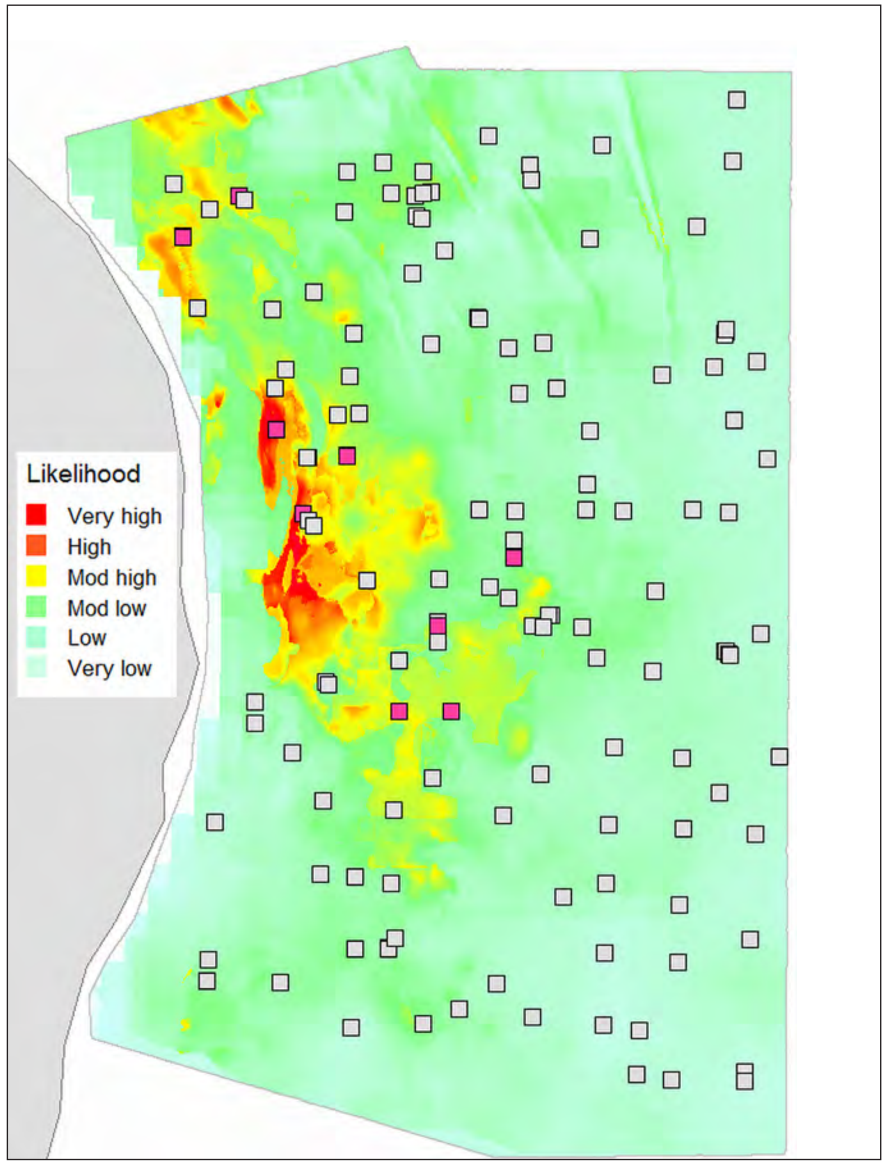
[a] Abundance values per 0.1 m² grab sample

Top species contributing to the similarity within the group in descending order of % contribution

	Minimum	Maximum	Average
Number of species	14	35	24.4
Abundance	22	72	42.1
Diversity (N1)	12.67	25.38	18.02
Evenness (N2/N1)	0.56	0.91	0.70
Taxonomic distinctness (Δ*)	81.02	97.44	90.36

Number of grabs = 9

Infaunal assemblage metrics per grab

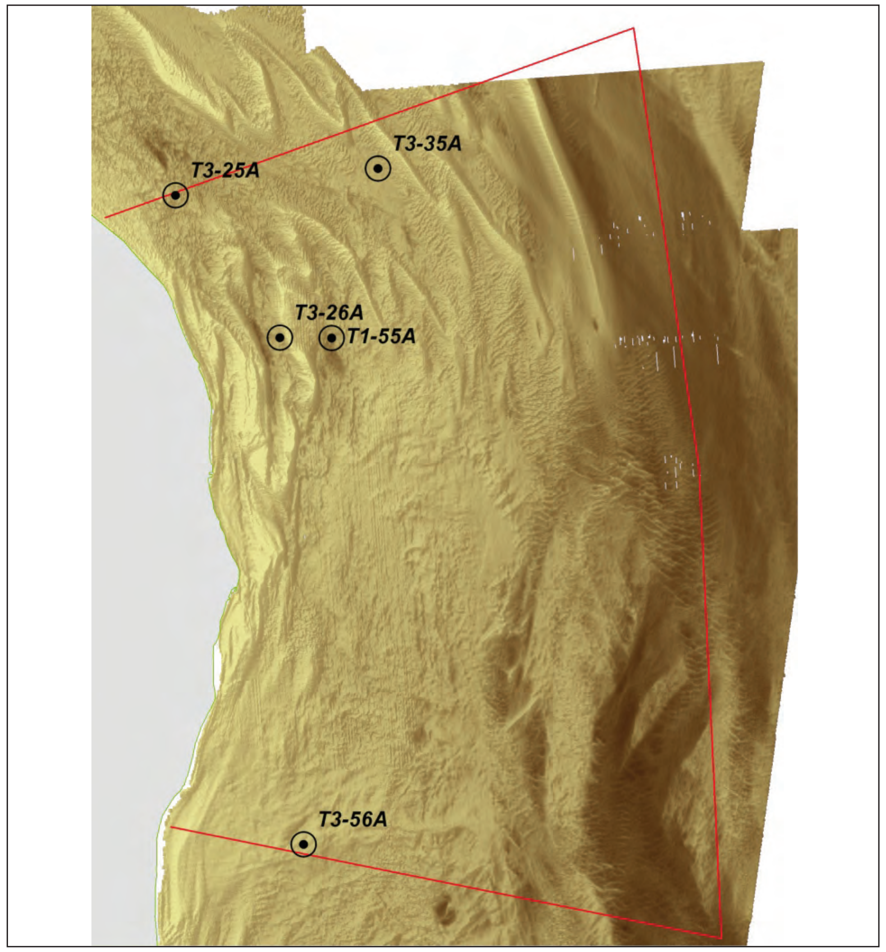


Modelled output showing the likely distribution of the assemblage

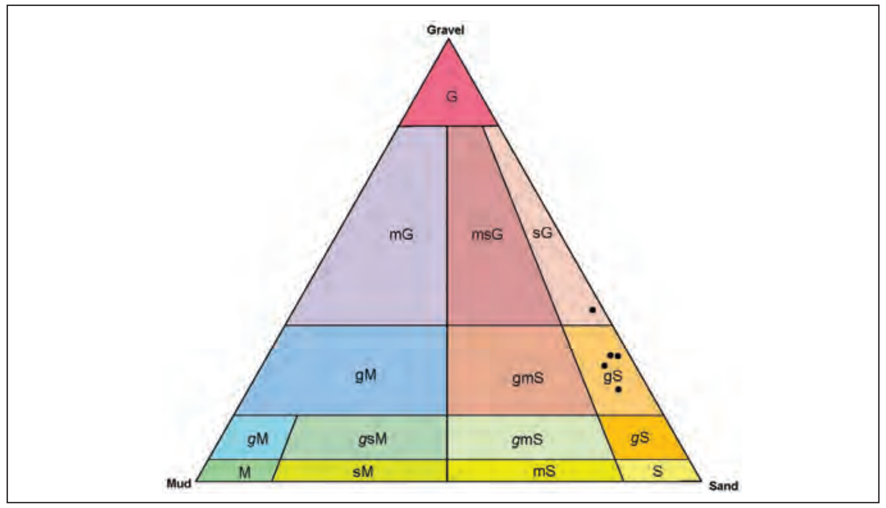
	Minimum	Maximum	Average
Number of species	19	32	26.3
Abundance	136	2,561	691.0
Diversity (N1)	1.94	12.34	6.85
Evenness (N2/N1)	0.52	0.71	0.61

Number of trawls = 7

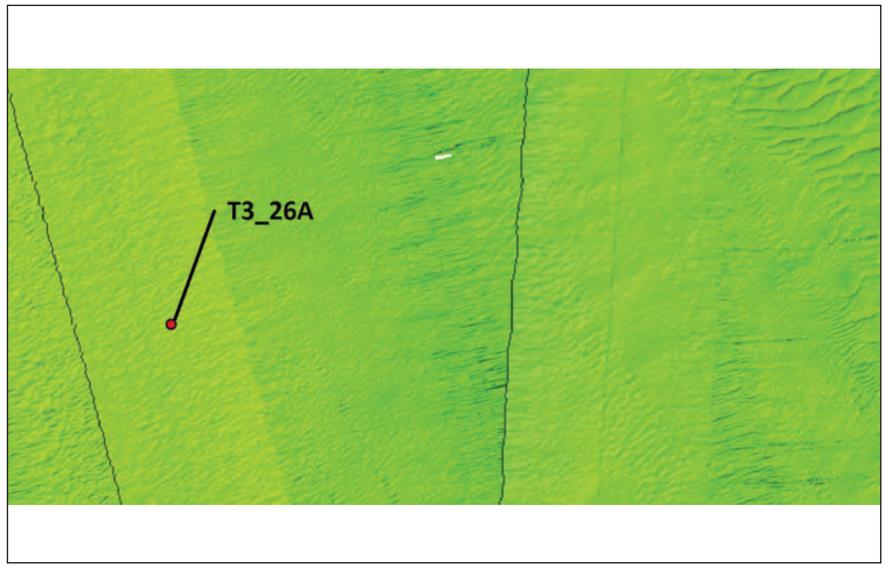
Epifaunal assemblage metrics per trawl



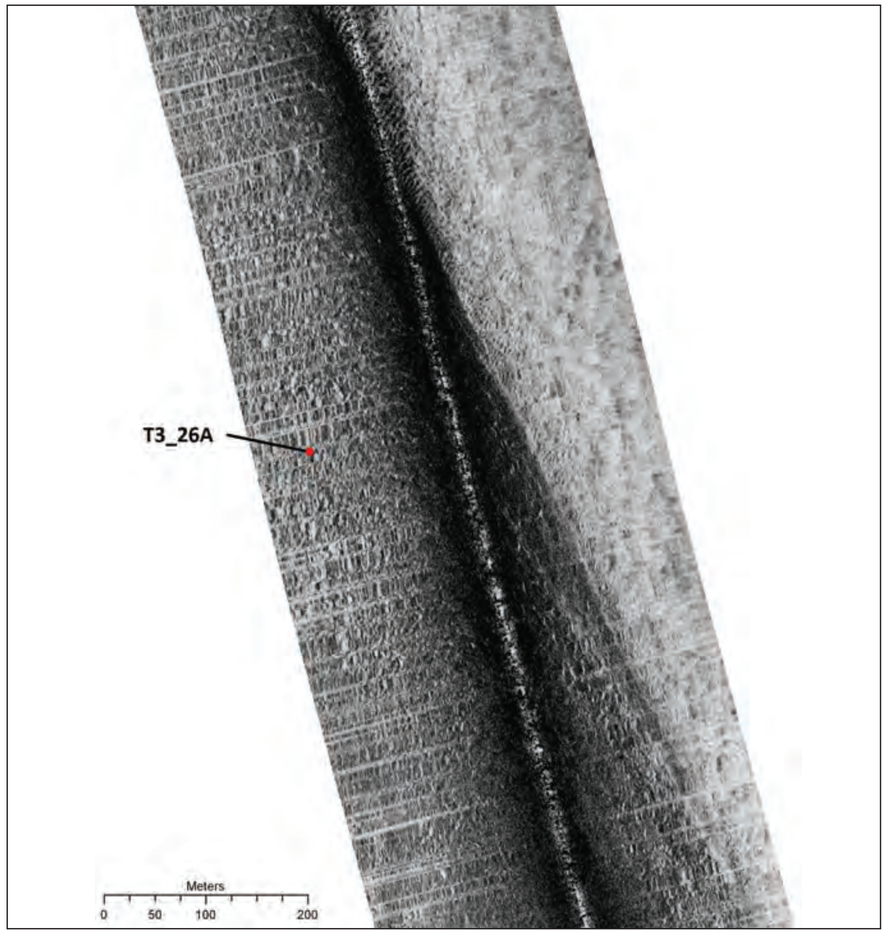
Map showing bathymetry and sampling locations[8]



Plot of each sediment sample's PSD profile against the Folk sediment triangle



Multibeam of representative sampling station



Side-scan of representative sampling station

GROUP G – PHYSICAL INFORMATION

Description

Group G sampling stations lie in areas where only small-scale bedform features are observed, such as sinuous bifurcated megaripples. There is some topographic differentiation between sampling locations, with some lying on a flat seafloor whilst others lie on a more undulating seafloor. A significant feature at all stations is the apparent stabilisation of the seabed by *Sabellaria spinulosa* to form a distinctive textured seabed visible both in the multibeam and in the side-scan sonar (eg, T3_26A).

Sediment samples consisted mostly of clean gravelly sand and sandy gravel.

[8]Digital bathymetry data © British Crown and SeaZone Solutions Ltd. All rights reserved. Data Licence 052008.012.

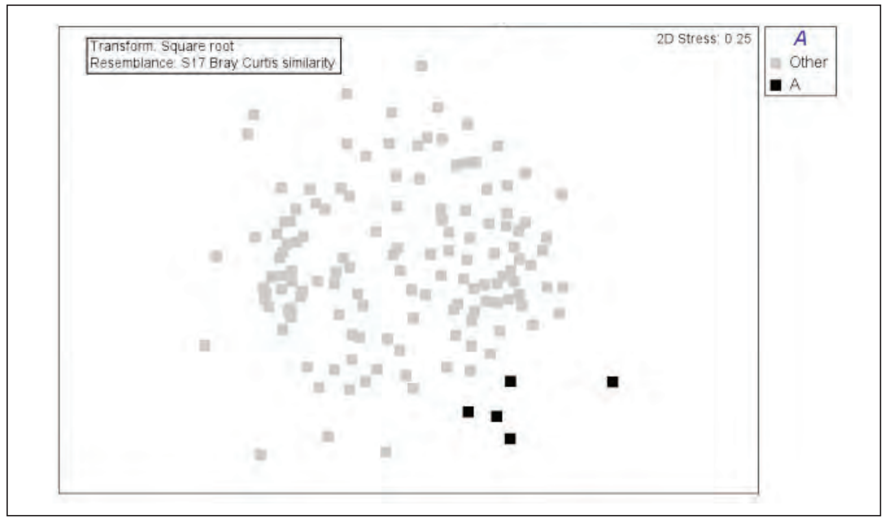
GROUP G – BIOLOGICAL INFORMATION

"Moderately dense *Sabellaria*" assemblage

Description

A total of 188 species collected by just five grab samples make this group one of the most species-rich assemblages identified in the East Coast REC Study Area. A combination of sediment-consolidating species like *Sabellaria spinulosa* and *Mytilus edulis*, both present in large numbers, is likely to be the cause behind this occurrence, as they serve as habitat engineers, providing a stable substrate for other organisms to colonise. In terms of diversity, however, the numerical dominance of just a few species reduces the overall diversity index value of the assemblage. Other conspicuous taxa include the brittlestar *Amphipholis squamata*, Nematoda, the ascidean *Molgula* and the amphipod *Dyopedos monacanthus*.

The likely distribution of the assemblage characterising Group G, as predicted by the analysis of available data (see page 206), is confined mostly to the north-western quadrant of the survey area. Likely areas are characterised as moderately shallow gravelly sediments with low mud content in strong tidal currents and low turbidity.

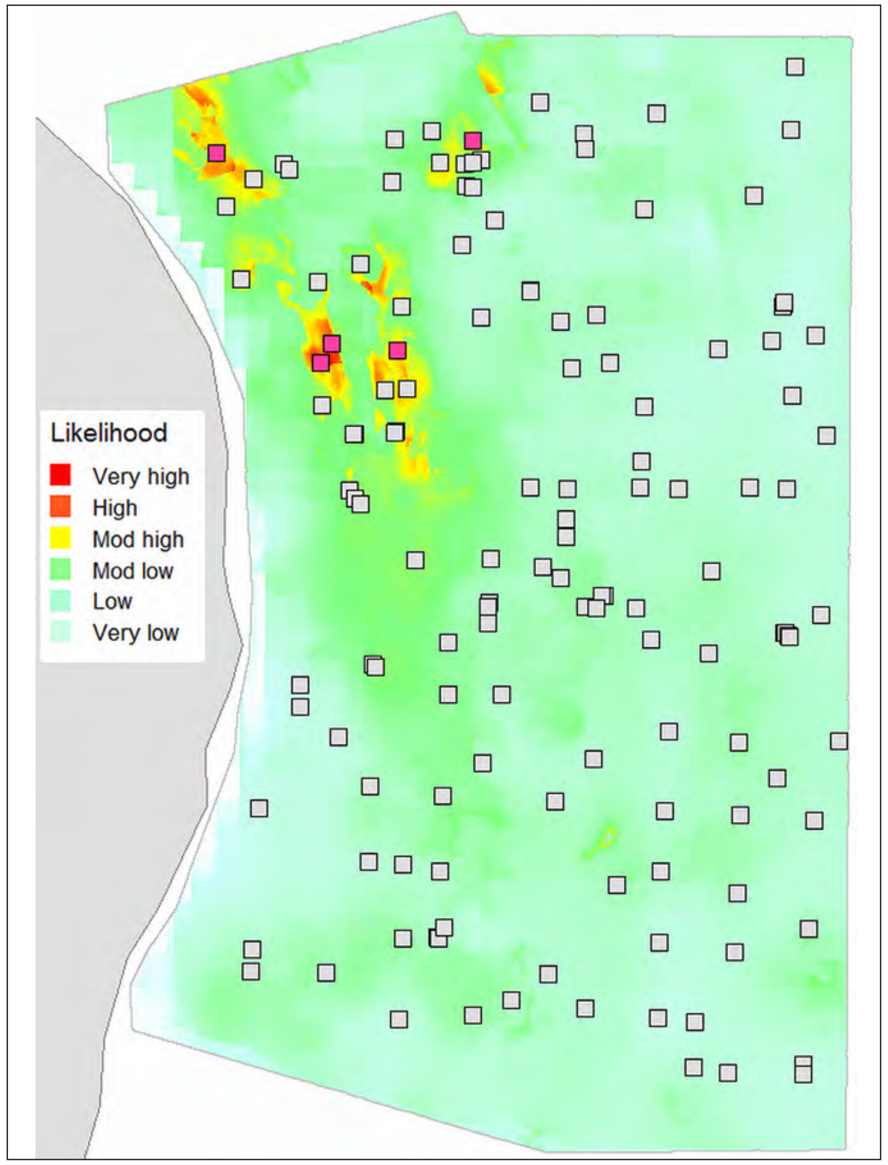


Multidimensional scaling plot of samples in relation to all other samples

Species	Min. abund.[a]	Max. abund.	Mean abund.	Occur. %
Sabellaria spinulosa	15	148	77.4	100
Mytilus edulis	1	206	72.6	60
Amphipholis squamata	1	23	12.5	100
Nematoda	1	30	12.5	100
Polycirrus	3	10	7.5	100
Lumbrineris gracilis	2	8	4.9	100
Nemertea	1	6	3.8	100
Mytilidae	51	267	63.5	40

[a] Abundance values per 0.1 m² grab sample

Top species contributing to the similarity within the group in descending order of % contribution



Modelled output showing the likely distribution of the assemblage

	Minimum	Maximum	Average
Number of species	41	121	76.6
Abundance	155	698	399.8
Diversity (N1)	7.81	25.08	15.92
Evenness (N2/N1)	0.27	0.54	0.48
Taxonomic distinctness (Δ*)	82.16	93.49	86.89

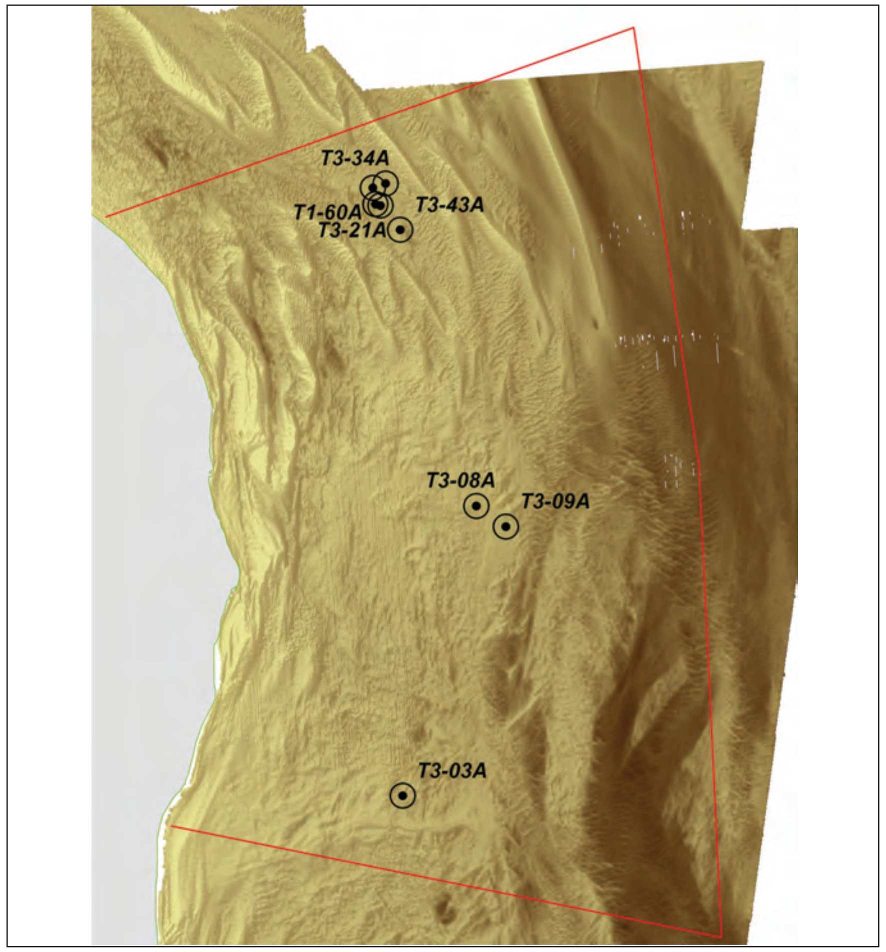
Number of grabs = 5

Infaunal assemblage metrics per grab

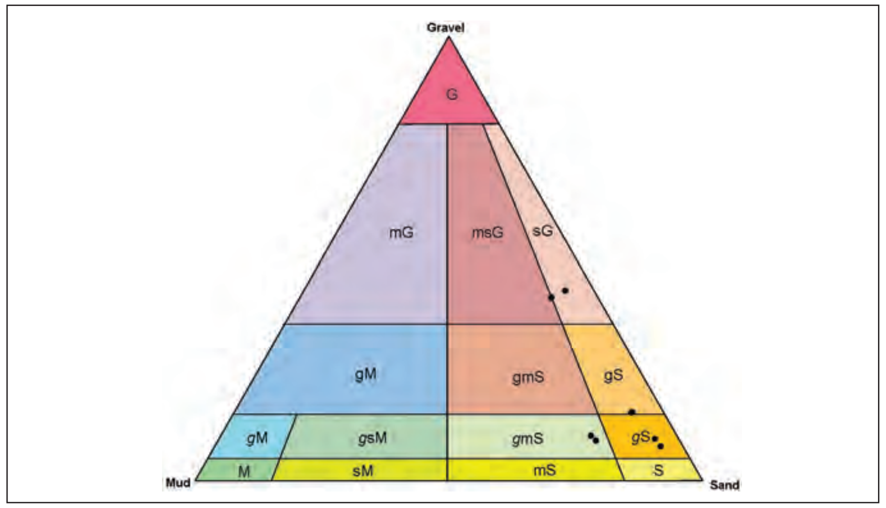
	Minimum	Maximum	Average
Number of species	19	39	29.0
Abundance	332	4,627	1,661.0
Diversity (N1)	3.24	9.66	5.44
Evenness (N2/N1)	0.56	0.77	0.66

Number of trawls = 4

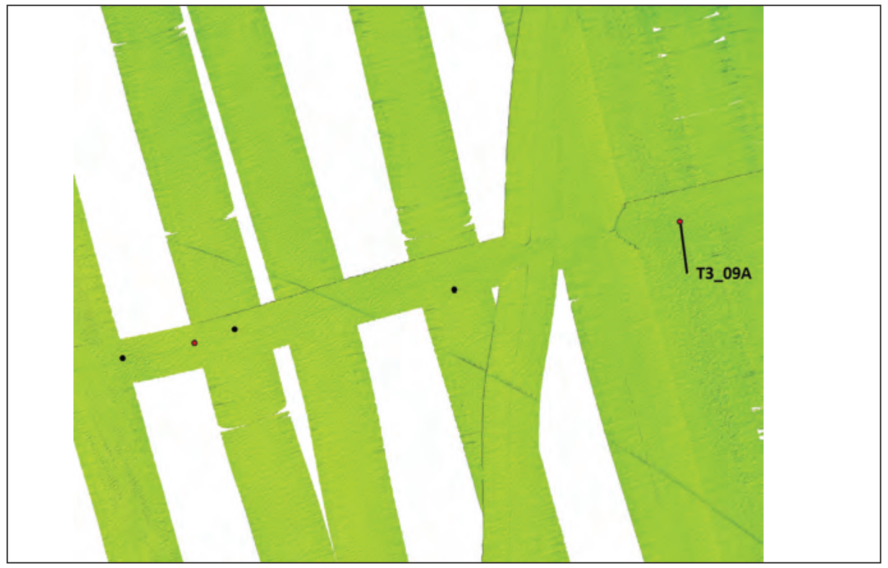
Epifaunal assemblage metrics per trawl



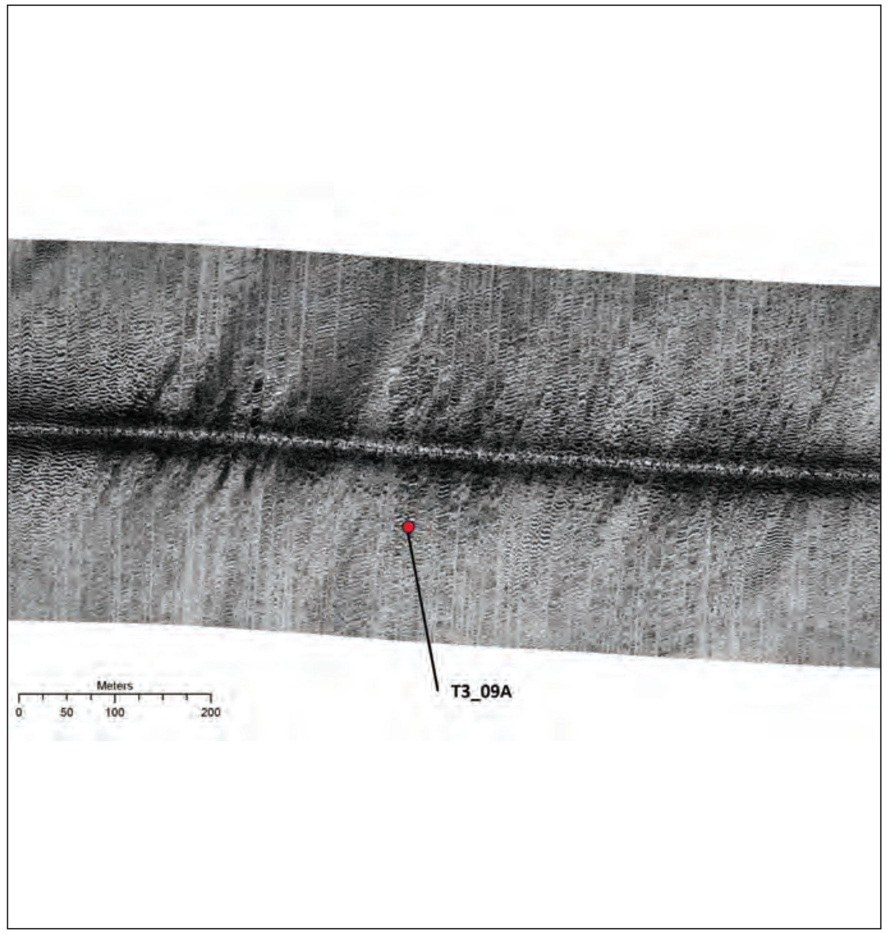
Map showing bathymetry and sampling locations[9]



Plot of each sediment sample's PSD profile against the Folk sediment triangle



Multibeam of representative sampling station



Side-scan of representative sampling station

GROUP H – PHYSICAL INFORMATION

Description

The stations comprising Group H cover an extensive area. However, they appear to favour a seafloor with a relatively flatter topography and covered with small-scale bedforms rather than large mobile sandwaves. The *Sabellaria spinulosa* formations appear continuous, forming extensive reefs (e.g. T3_09A). This is in contrast to *S. spinulosa* formations identified in Groups E and G, where they formed crusty elongate strips or patches. Whilst it can be difficult to distinguish *S. spinulosa* formations from non-biogenic bedforms of a similar scale, *S. spinulosa* reefs tend to have sharper, steeper edges than other bedforms, and the non-biogenic forms can appear to deflect around the more stable *S. spinulosa* patches.

PSD analyses revealed a mixture of sediment combinations including slightly muddy gravelly sand, gravelly sand and sandy gravel.

[9]Digital bathymetry data © British Crown and SeaZone Solutions Ltd. All rights reserved. Data Licence 052008.012.

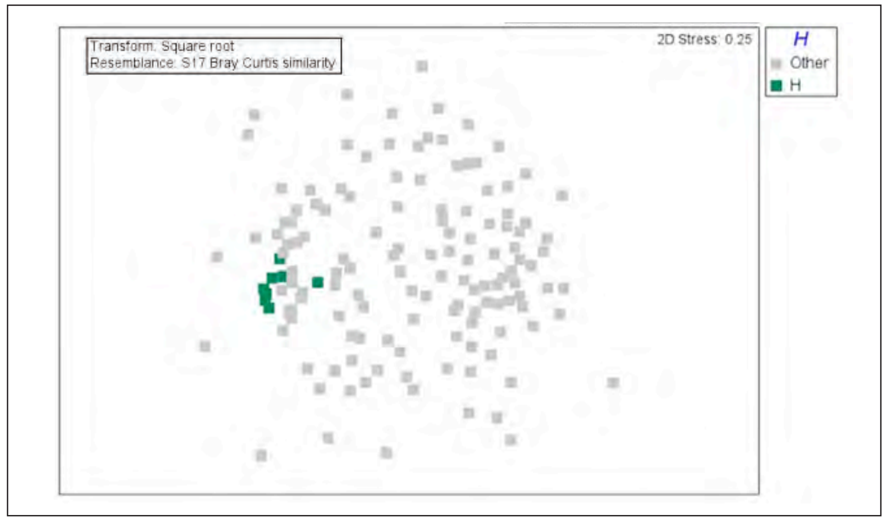
GROUP H – BIOLOGICAL INFORMATION

"Dense *Sabellaria*" assemblage

Description

A *Sabellaria spinulosa* reef assemblage, Group H is represented by 8 infaunal samples which together contain 258 macrofaunal species, the most species-rich and diverse assemblage in the East Coast REC Study Area. 18 taxa are represented in all 8 samples, including *Abra alba*, Actiniaria, *Polydora caulleryi* and *Pholoe baltica*. Other taxa not present in every sample but of notable abundance are *Polycirrus*, *Pisidia longicornis* and *Amphipholis squamata*. The epifaunal assemblage is also relatively diverse, despite only three epifaunal trawl samples being collected (in the interest of habitat preservation).

The most likely distribution of upstanding *S. spinulosa* reef habitat based on the analysis of available data (see page 206) is in moderately deep water, moderately tidal with no clear sediment preference and avoiding small and large sandwaves. Areas with the highest likelihood of harbouring this assemblage are confined to a relatively small patch in the centre of the far north of the survey area.

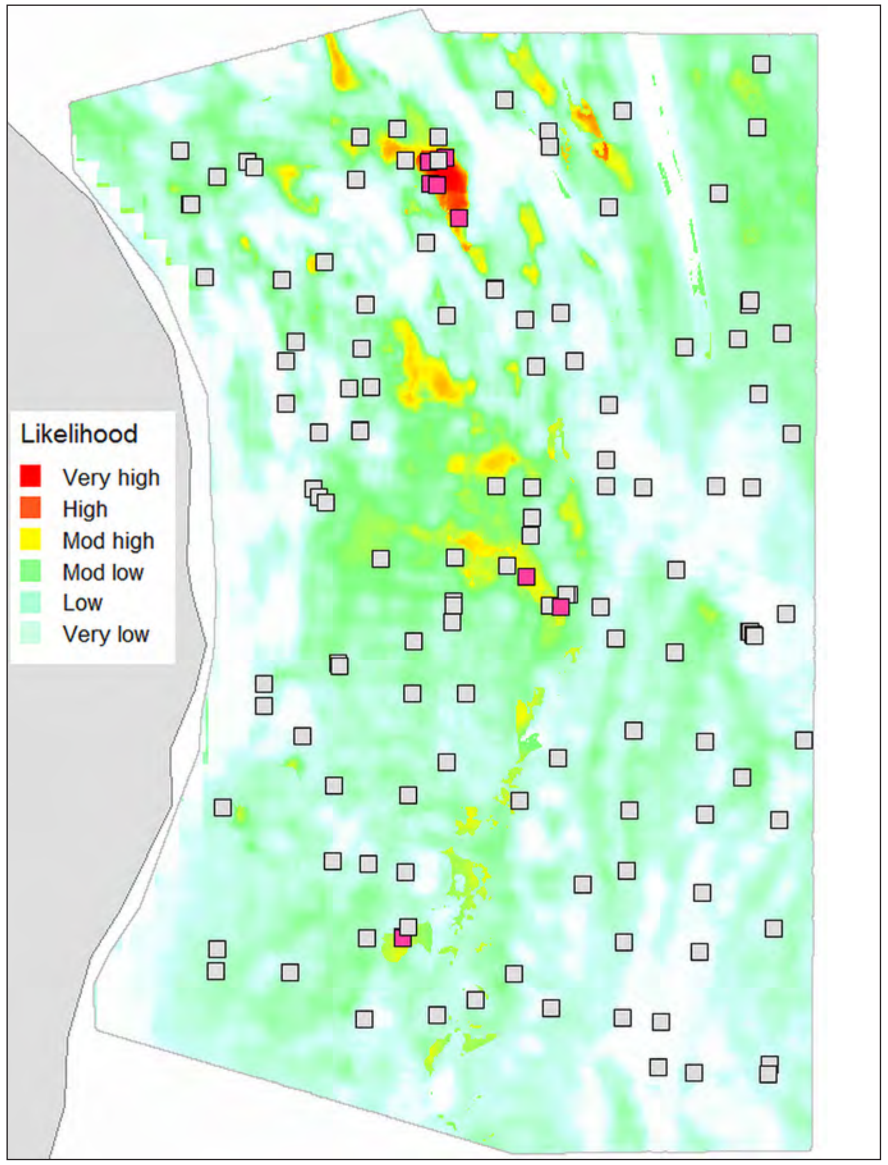


Multidimensional scaling plot of samples in relation to all other samples

Species	Min. abund.[a]	Max. abund.	Mean abund.	Occur. %
Sabellaria spinulosa	10	2,171	494.9	100
Actiniaria	10	100	34.3	100
Abra alba	3	113	43.7	100
Pholoe baltica	7	64	21.7	100
Amphipholis squamata	6	65	23.3	88
Ophiuroidea	2	39	16.8	100
Polycirrus	1	94	31.8	88
Polydora caulleryi	1	138	26.6	100

[a] Abundance values per 0.1 m² grab sample

Top species contributing to the similarity within the group in descending order of % contribution



Modelled output showing the likely distribution of the assemblage

	Minimum	Maximum	Average
Number of species	63	138	96.9
Abundance	253	2,630	966.2
Diversity (N1)	2.93	37.30	20.01
Evenness (N2/N1)	0.31	0.66	0.45
Taxonomic distinctness (Δ*)	83.78	92.50	87.23

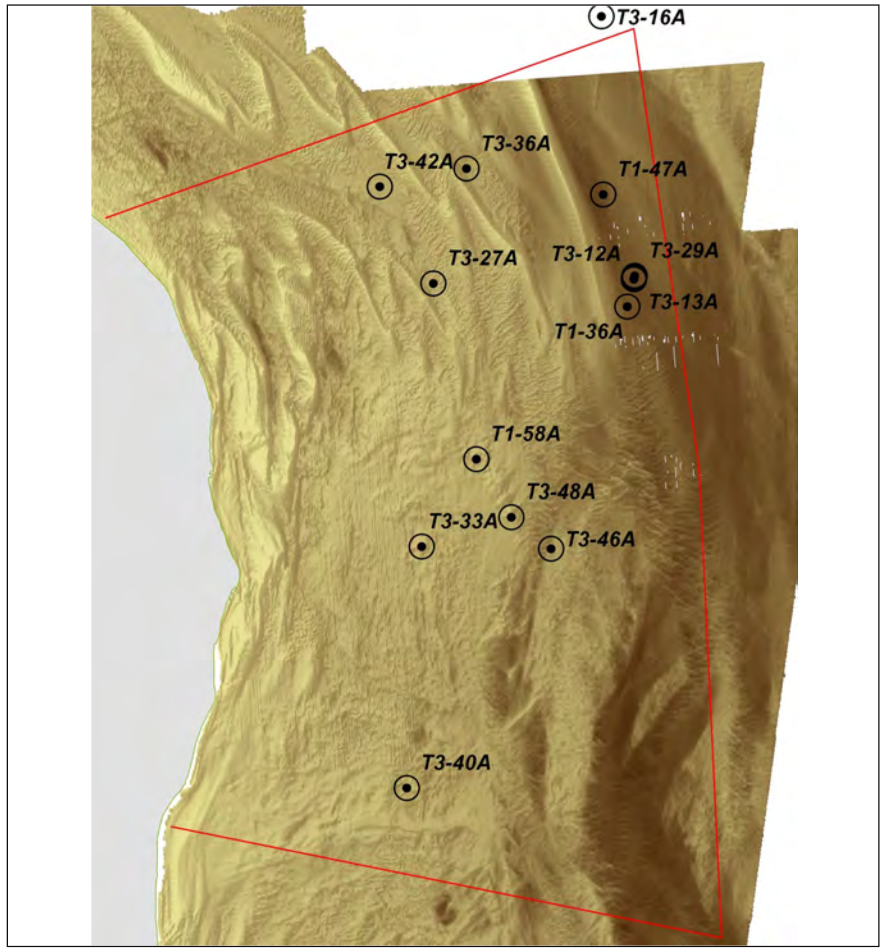
Number of grabs = 8

Infaunal assemblage metrics per grab

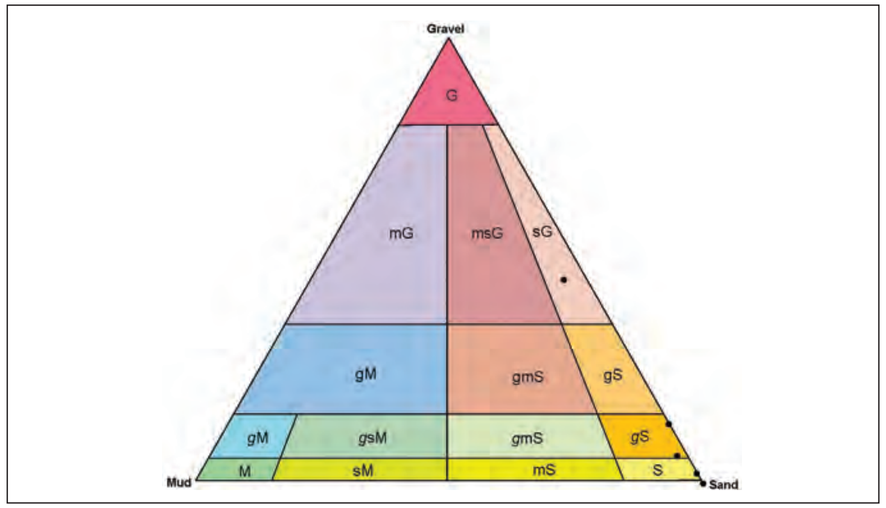
	Minimum	Maximum	Average
Number of species	18	35	28.7
Abundance	386	906	629.0
Diversity (N1)	3.19	12.86	8.37
Evenness (N2/N1)	0.57	0.64	0.61

Number of trawls = 3

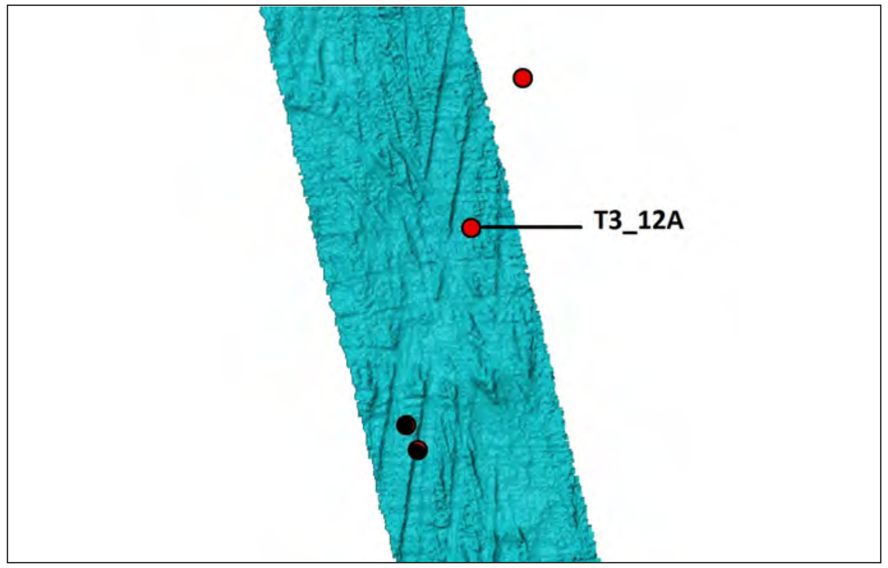
Epifaunal assemblage metrics per trawl



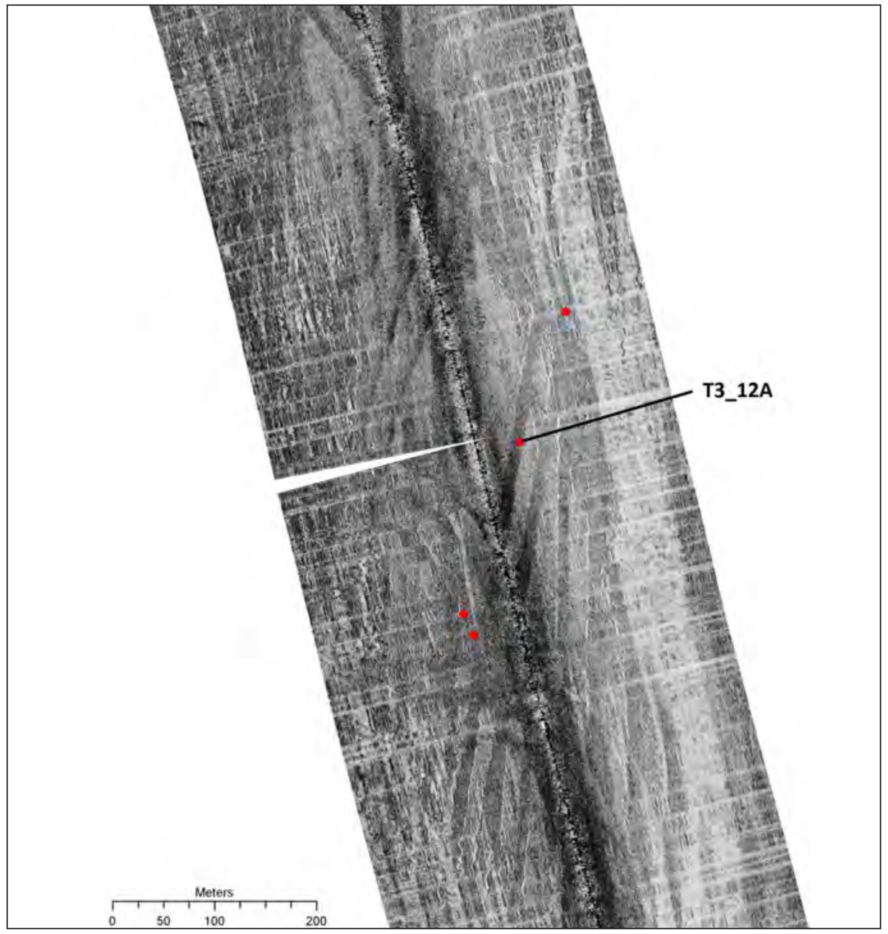
Map showing bathymetry and sampling locations[10]



Plot of each sediment sample's PSD profile against the Folk sediment triangle



Multibeam of representative sampling station



Side-scan of representative sampling station

GROUP I – PHYSICAL INFORMATION

Description

The sampling stations comprising Group I are located across a wide geographical area in a range of water depths. Approximately 90% lie within areas identified as having *Sabelleria spinulosa* growth on the seafloor (eg, T3_12A). In contrast to Group H, where *S. spinulosa* was also prevalent, the acoustic data reveal a more degraded reef with clear trawl marks through it. The remaining locations that are not associated with *S. spinulosa* lie in areas that appear devoid of significant bedforms or harbour just small-scale megaripples.

PSD analyses show a mixed sediment profile, ranging from gravelly sandy mud and muddy sand to clean sandy gravel and gravelly sand.

[10]Digital bathymetry data © British Crown and SeaZone Solutions Ltd. All rights reserved. Data Licence 052008.012.

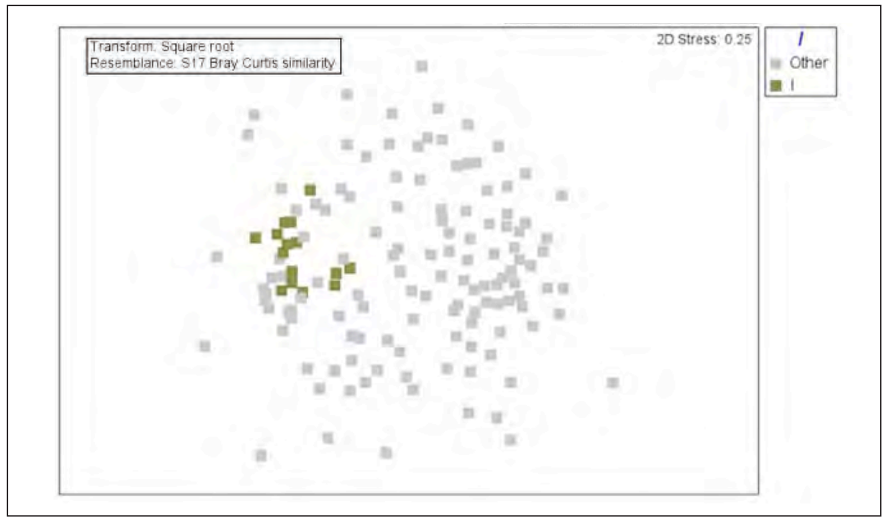
GROUP I – BIOLOGICAL INFORMATION

"Actinaria" assemblage

Description

Group I represents a relatively diverse and speciose assemblage. The most abundant of the 157 infaunal taxa encountered are the Actinaria and Nematoda, with *Abra alba*, *Polycirrus*, *Sabellaria spinulosa*, *Lanice conchilega* and Terebellidae in close succession, although not all of them are found at every sampling station. Actiniaria and *Pholoe baltica* are found at all sampling stations, with *S. spinulosa*, Ophiuroidea and Nemertea being the next most widespread taxa. *Ophiura albida*, *Ophiothrix fragilis* and *Ophiura ophiura* can occur in vast numbers (tens of thousands), as evidenced in some of the epifaunal trawls within this Group. The most characteristic taxa are indicative of a muddy habitat with some structural complexity afforded by *S. spinulosa* concretions (possibly older reefs, now largely uninhabited and undergoing gradual degradation) and some gravel.

The most likely distribution of Group I as predicted by analysis of available data (see page 206) is in a large area in the north-eastern corner of the survey area. This area is bisected by a prominent sandbank running approximately N–S. Other, smaller areas likely to harbour Group I assemblage are scattered in the southern half of the survey area. Such areas are characterised by muddy sediments and lower water turbidity. Group I assemblage appears to avoid sandwaves and sandbanks.

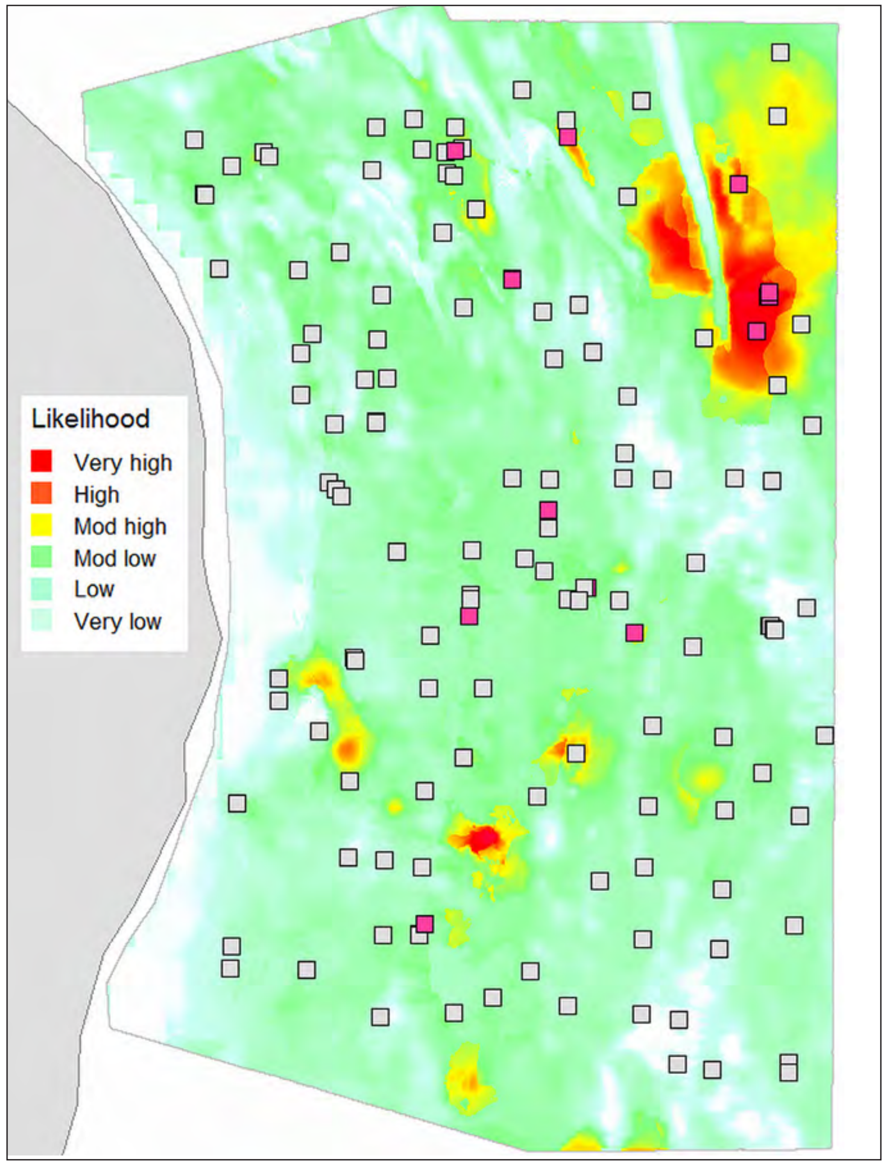


Multidimensional scaling plot of samples in relation to all other samples

Species	Min. abund.[a]	Max. abund.	Mean abund.	Occur. %
Actiniaria	1	62	18.5	100
Nemertea	4	31	10.0	87
Sabellaria spinulosa	1	284	26.3	93
Ophiuroidea	1	97	18.4	87
Lagis koreni	1	46	12.4	80
Pholoe baltica	1	21	7.3	100
Mysella bidentata	1	66	10.1	73
Mediomastus fragilis	1	31	7.4	80

[a] Abundance values per 0.1 m² grab sample

Top species contributing to the similarity within the group in descending order of % contribution



Modelled output showing the likely distribution of the assemblage

	Minimum	Maximum	Average
Number of species	21	78	38.8
Abundance	63	570	235.8
Diversity (N1)	3.10	21.00	14.24
Evenness (N2/N1)	0.41	1.00	0.59
Taxonomic distinctness (Δ*)	79.36	96.00	90.13

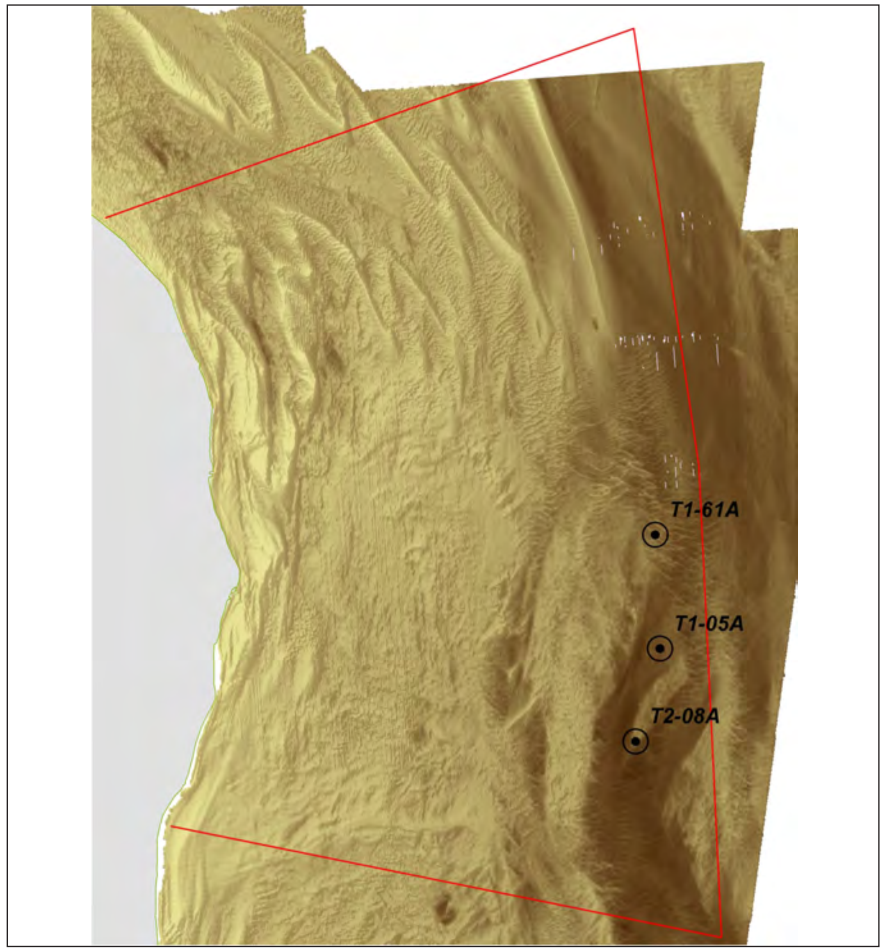
Number of grabs = 15

Infaunal assemblage metrics per grab

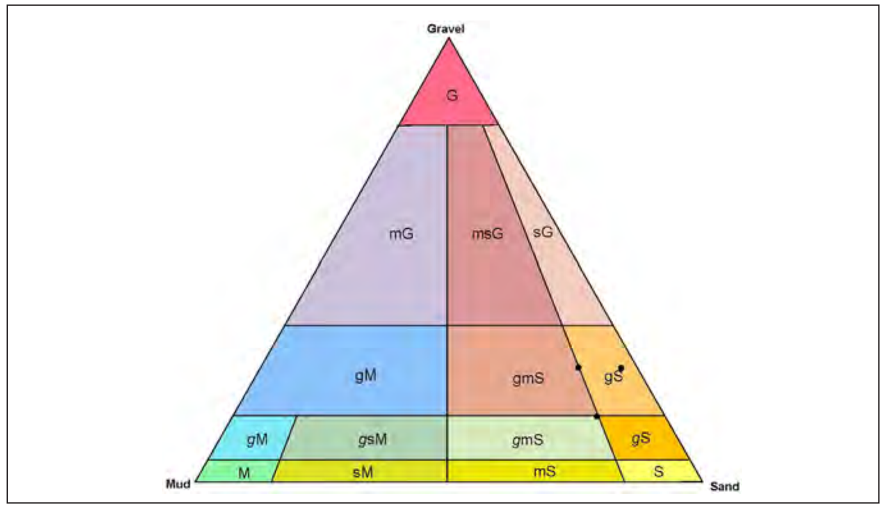
	Minimum	Maximum	Average
Number of species	24	36	29.3
Abundance	259	47,919	7,188.0
Diversity (N1)	1.18	11.10	5.89
Evenness (N2/N1)	0.57	0.89	0.70

Number of trawls = 10

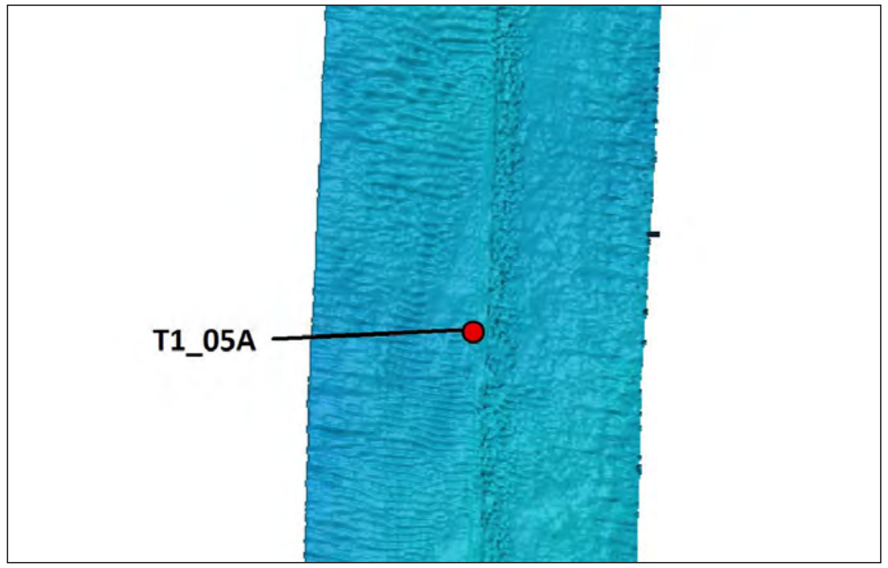
Epifaunal assemblage metrics per trawl



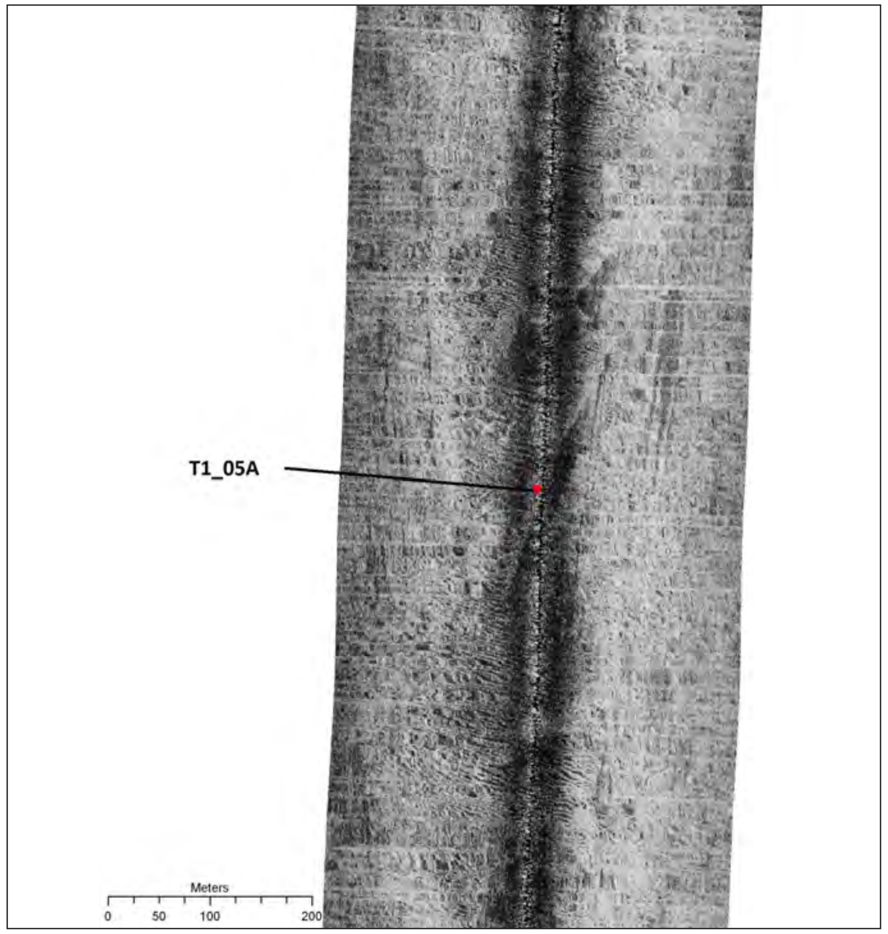
Map showing bathymetry and sampling locations[11]



Plot of each sediment sample's PSD profile against the Folk sediment triangle



Multibeam of representative sampling station



Side-scan of representative sampling station

GROUP J – PHYSICAL INFORMATION

Description

The three sample stations comprising Group J all lie in deeper water (>50 m depth). They are all located on or near slight topographic elevations, where underlying geological formations are observed sub-cropping (eg, T1_05A). They are associated with both bifurcating and linear megaripples. Sediment samples all contain some gravel, which may explain the small-scale raised topography observed.

[11]Digital bathymetry data © British Crown and SeaZone Solutions Ltd. All rights reserved. Data Licence 052008.012.

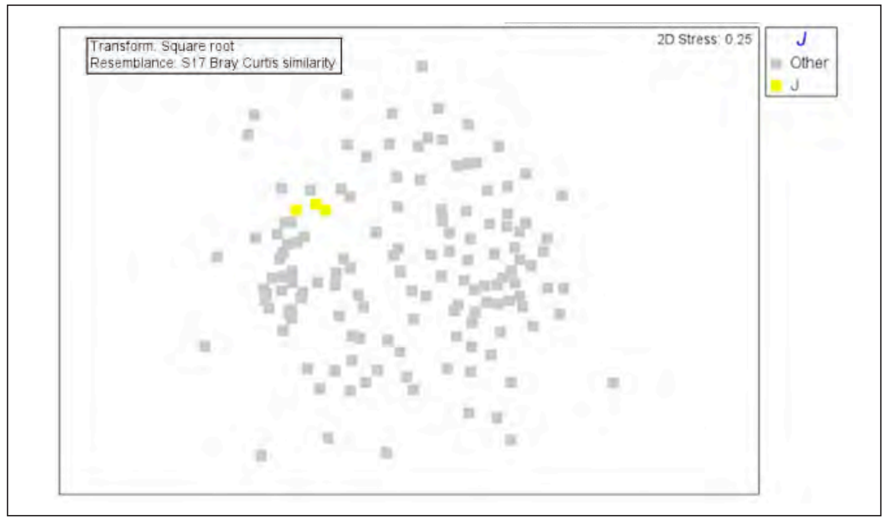
GROUP J – BIOLOGICAL INFORMATION

“Mixed polychaetes” assemblage

Description

A restricted assemblage only observed at three sampling stations. Eight of the 60 infaunal taxa contained within this assemblage are recorded from all three sampling stations, the most abundant of these being *Lumbrineris gracilis* and *Glycera lapidum*. *Echinocyamus pusillus*, *Lagis koreni* and Golfingiidae are observed in greater abundance but not at all stations. *Crangon allmanni*, *Pagurus bernhardus* and *Psammechinus miliaris* are also conspicuous members of the epifauna.

Based on analyses of available data (see page 206), the most likely distribution of Group J assemblage is in the extreme south-eastern corner of the survey area, where there are relatively deeper patches of slightly muddy gravelly sediments, and lower tidal currents and turbidity predominate.



Multidimensional scaling plot of samples in relation to all other samples

Species	Min. abund.[a]	Max. abund.	Mean abund.	Occur. %
Echinocyamus pusillus	13	23	12.0	67
Lagis koreni	9	14	7.7	67
Glycera lapidum	1	5	3.3	100
Glycera	1	3	2.3	100
Lumbrineris gracilis	1	7	3.3	100
Spiophanes bombyx	1	3	2.0	100
Callianassa subterranea	1	3	2.0	100
Nemertea	1	3	1.7	100

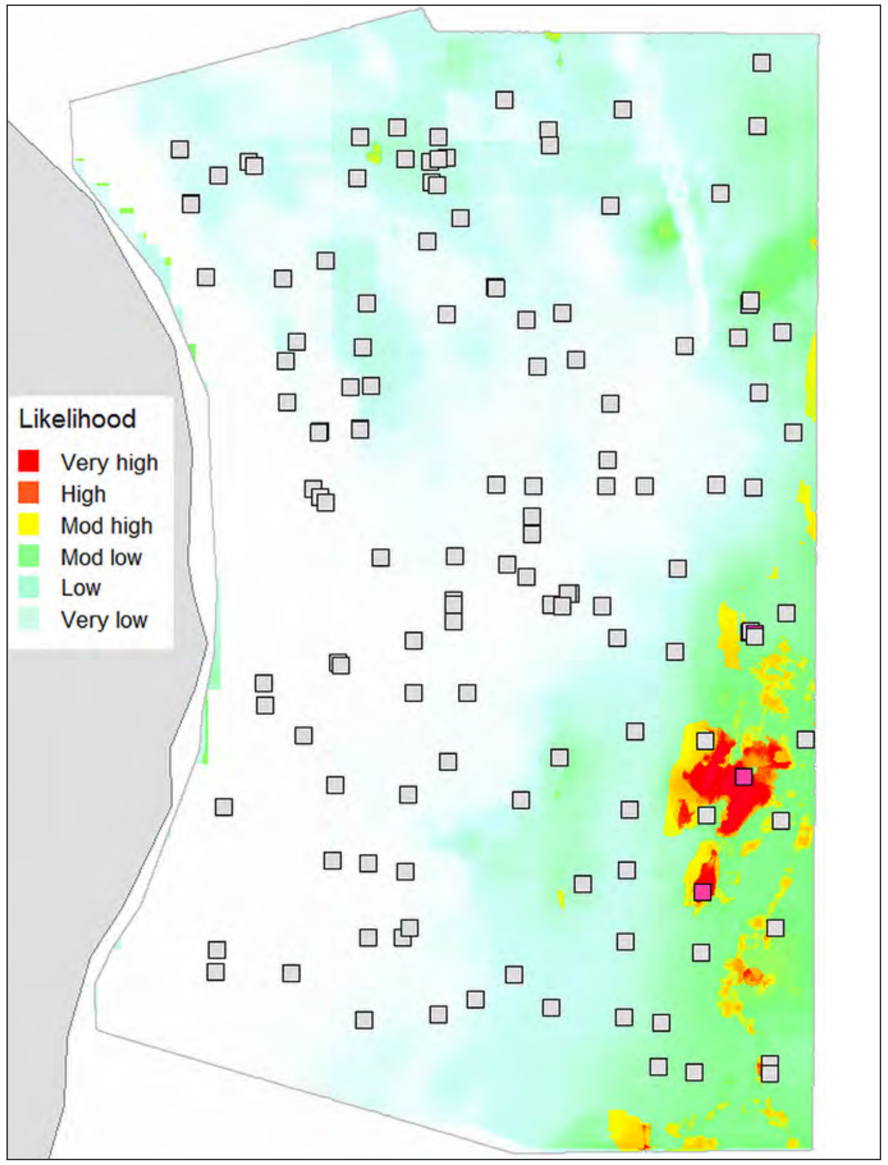
[a] Abundance values per 0.1 m² grab sample

Top species contributing to the similarity within the group in descending order of % contribution

	Minimum	Maximum	Average
Number of species	20	38	29.3
Abundance	31	136	81.3
Diversity (N1)	16.90	21.48	19.14
Evenness (N2/N1)	0.61	0.82	0.69
Taxonomic distinctness (Δ*)	80.57	88.96	84.97

Number of grabs = 3

Infaunal assemblage metrics per grab

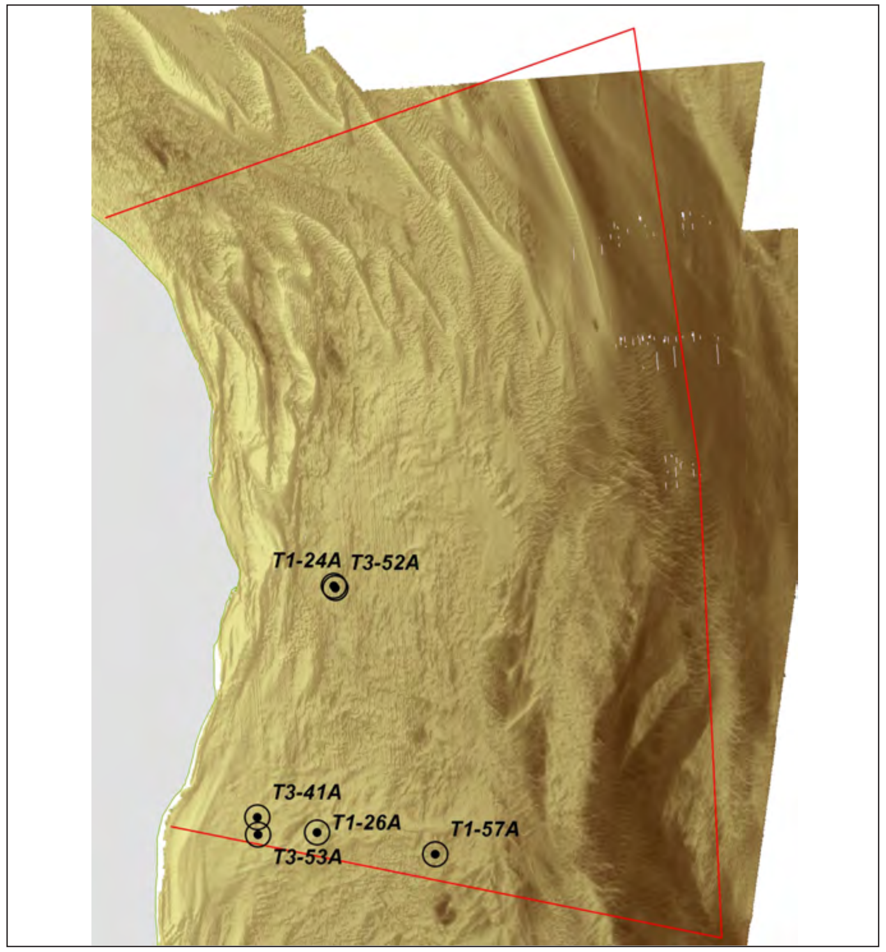


Modelled output showing the likely distribution of the assemblage

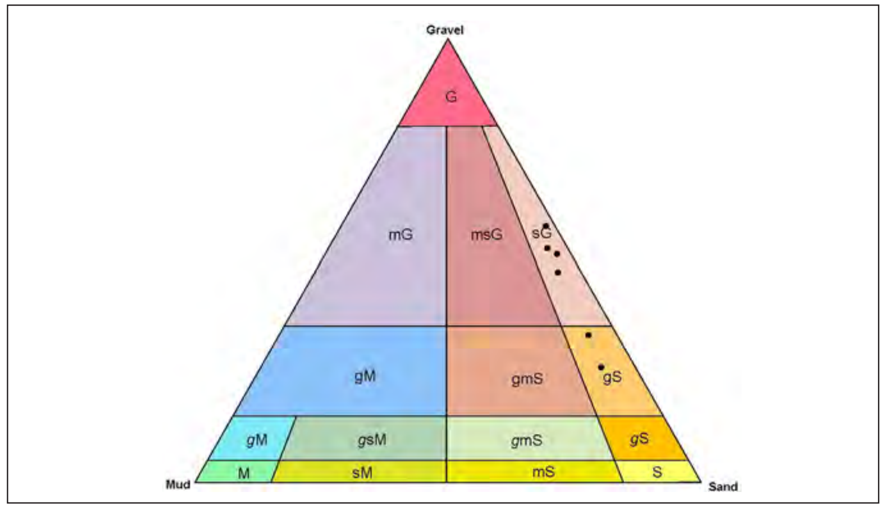
	Minimum	Maximum	Average
Number of species	12	27	20.3
Abundance	168	473	346.7
Diversity (N1)	3.02	9.43	5.44
Evenness (N2/N1)	0.59	0.72	0.66

Number of trawls = 3

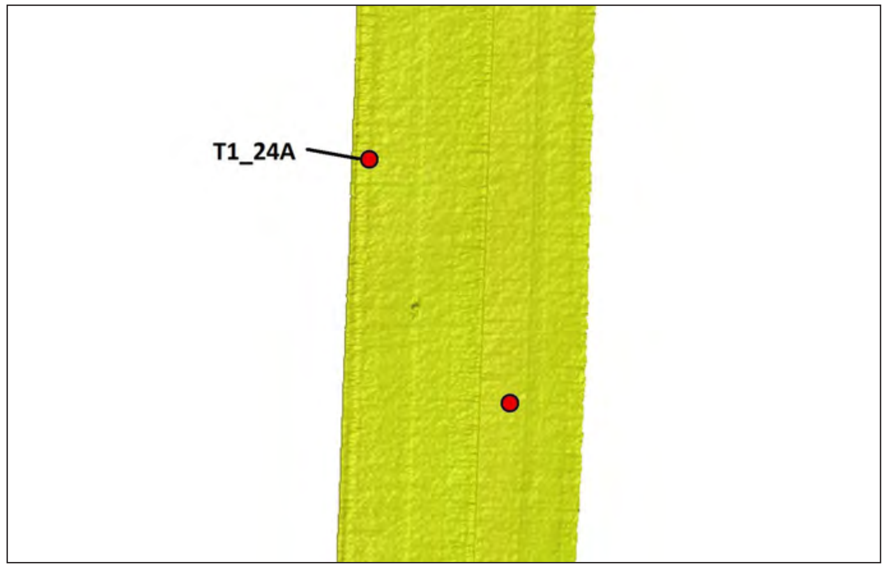
Epifaunal assemblage metrics per trawl



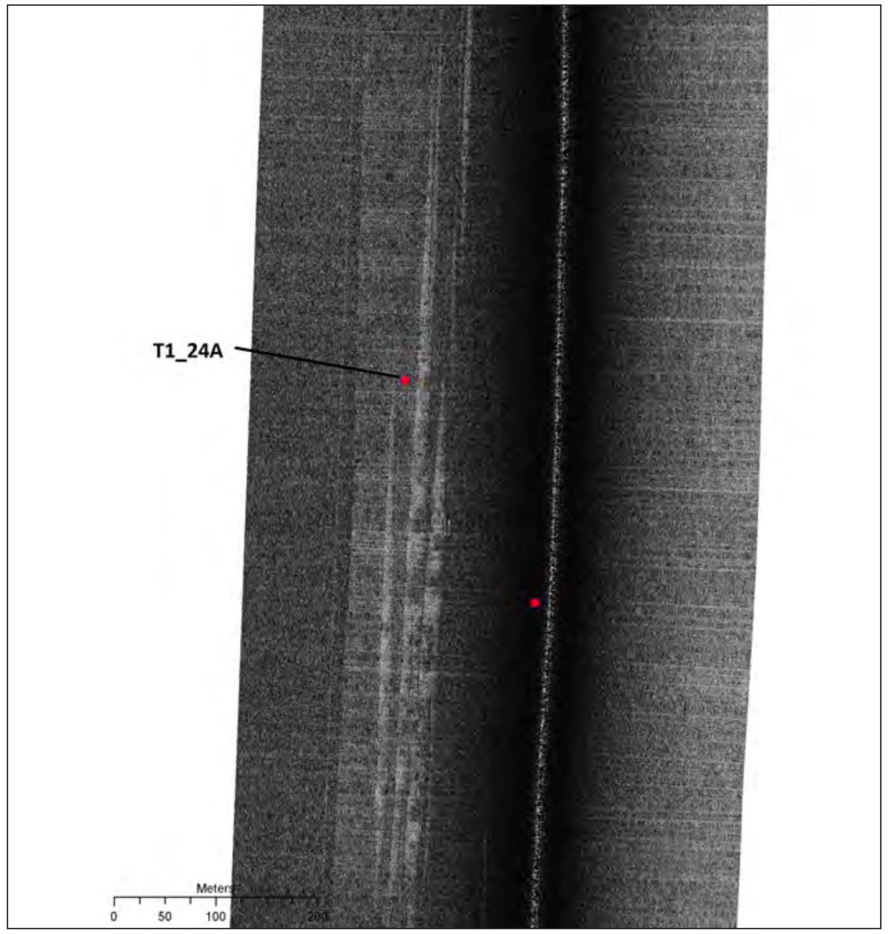
Map showing bathymetry and sampling locations[12]



Plot of each sediment sample's PSD profile against the Folk sediment triangle



Multibeam of representative sampling station



Side-scan of representative sampling station

GROUP K – PHYSICAL INFORMATION

Description

Sampling stations belonging to Group K are located predominantly in two geographical areas, in the south-west and mid-west of the survey area close to the coast, in waters shallower than 35 m. They are all located on featureless ground, where no bedforms are present (eg, T1_24A).

PSD analysis confirms the information gathered from backscatter, showing a very hard (highly reflective), medium to coarse sandy gravel. The lack of bedform features is likely a reflection of the coarse grade of the sediments, being relatively more resistant to the influence of currents typically present in the area.

[12]Digital bathymetry data © British Crown and SeaZone Solutions Ltd. All rights reserved. Data Licence 052008.012.

GROUP K – BIOLOGICAL INFORMATION

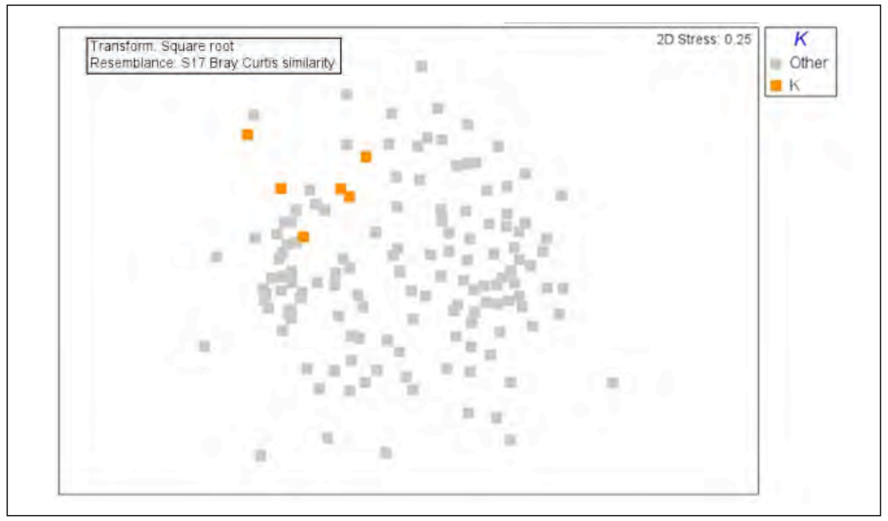
"*Ophiura*" assemblage

Description

An infaunal assemblage of 93 taxa, dominated numerically by *Lanice conchilega*, *Ophiura albida* and Terebelidae. *Psammechinus miliaris*, *Asterias rubens*, *Pagurus bernhardus* and *Crangon allmanni* are prominent members of the epifauna. No infaunal taxon is observed at all sampling locations, but six epifaunal taxa were observed at all stations.

L. conchilega qualifies as a reef builder, able to influence the abundance, composition and richness of benthic species. It is also important as a food source for juvenile flatfishes. The potential conservation importance of Group K assemblage, therefore, should not be underestimated.

The likely distribution of Group K assemblage as predicted by analysis of available data (see page 206) is close to the coast in relatively shallow sandy gravel with low silt content. The area most likely to contain Group K assemblage is in the south-western corner of the survey area, with smaller patches most likely further north devoid of large sandwaves.



Multidimensional scaling plot of samples in relation to all other samples

Species	Min. abund.[a]	Max. abund.	Mean abund.	Occur. %
Ophiura albida	1	17	7.0	83
Lanice conchilega	1	50	12.2	67
Ophiuroidea	1	14	4.3	83
Terebellidae	1	31	7.0	83
Pomatoceros lamarcki	4	7	3.0	50
Marphysa bellii	1	2	1.3	83
Clymenura	1	4	1.5	83
Actiniaria	1	5	1.5	50

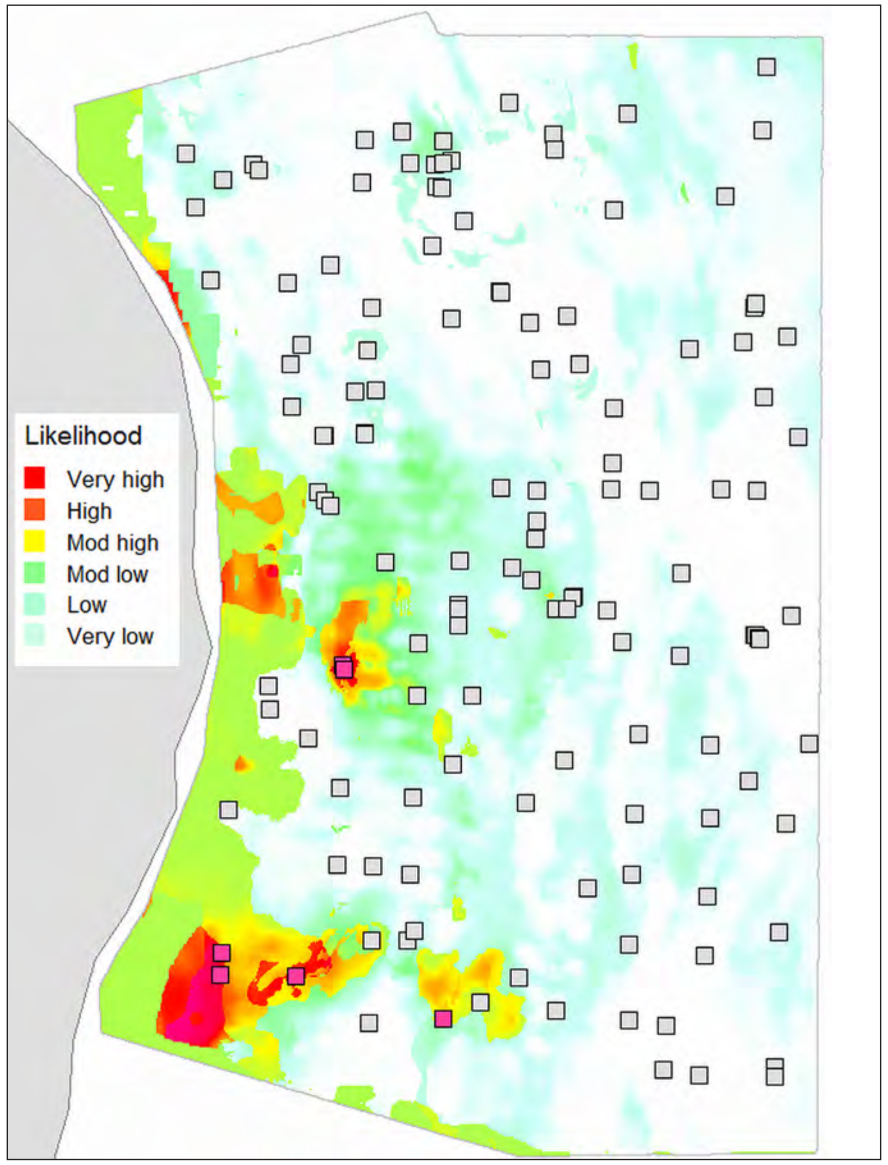
[a] Abundance values per 0.1 m² grab sample

Top species contributing to the similarity within the group in descending order of % contribution

	Minimum	Maximum	Average
Number of species	13	49	24.8
Abundance	28	170	72.5
Diversity (N1)	8.36	30.59	15.86
Evenness (N2/N1)	0.60	0.83	0.70
Taxonomic distinctness (Δ*)	79.34	93.46	86.48

Number of grabs = 6

Infaunal assemblage metrics per grab

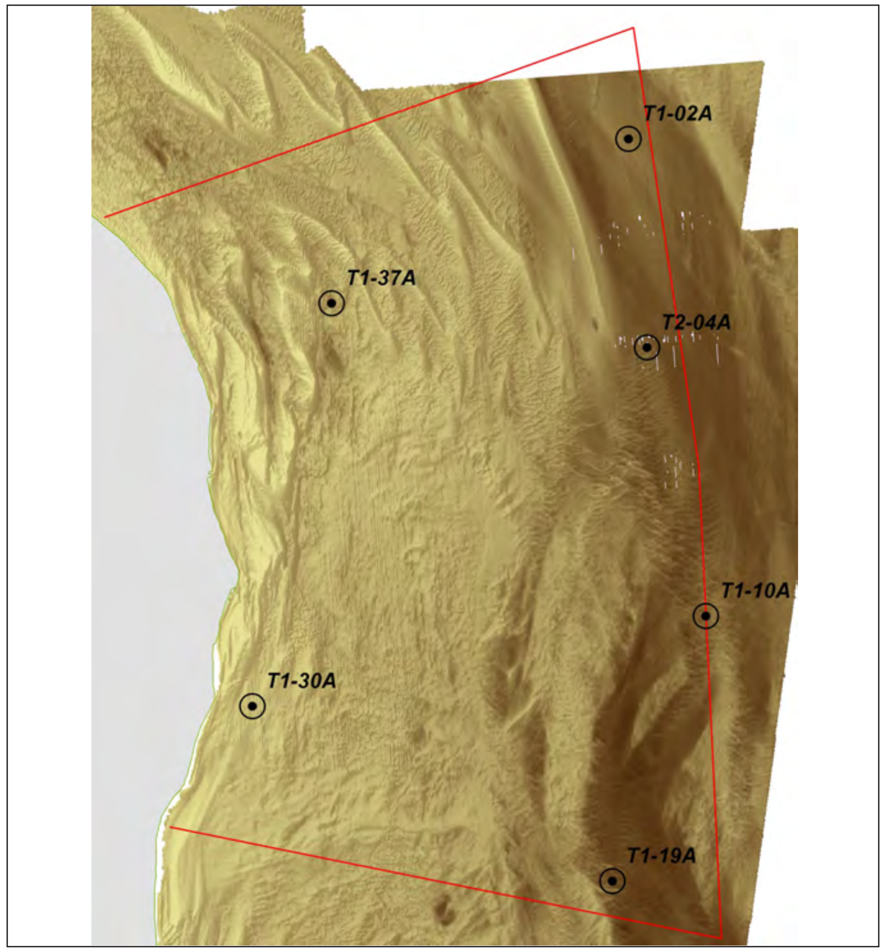


Modelled output showing the likely distribution of the assemblage

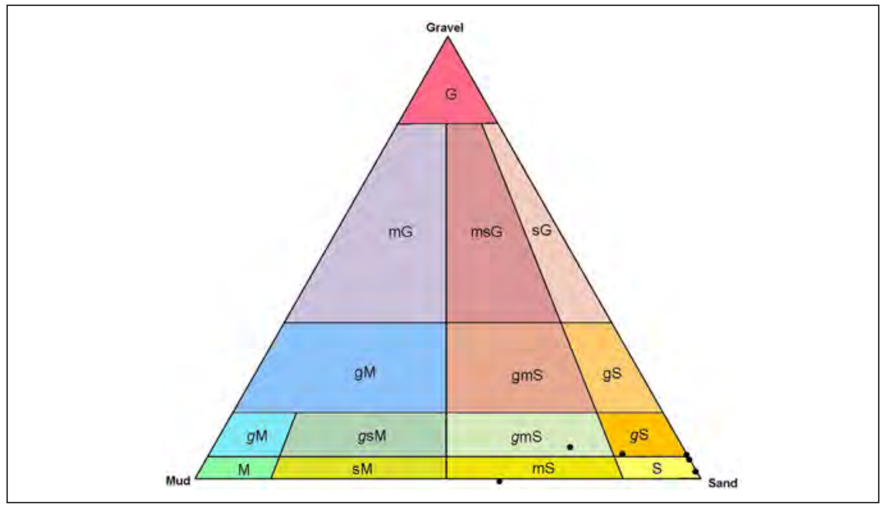
	Minimum	Maximum	Average
Number of species	13	30	22.3
Abundance	484	4,721	2,306
Diversity (N1)	1.46	5.52	2.65
Evenness (N2/N1)	0.52	0.79	0.68

Number of trawls = 6

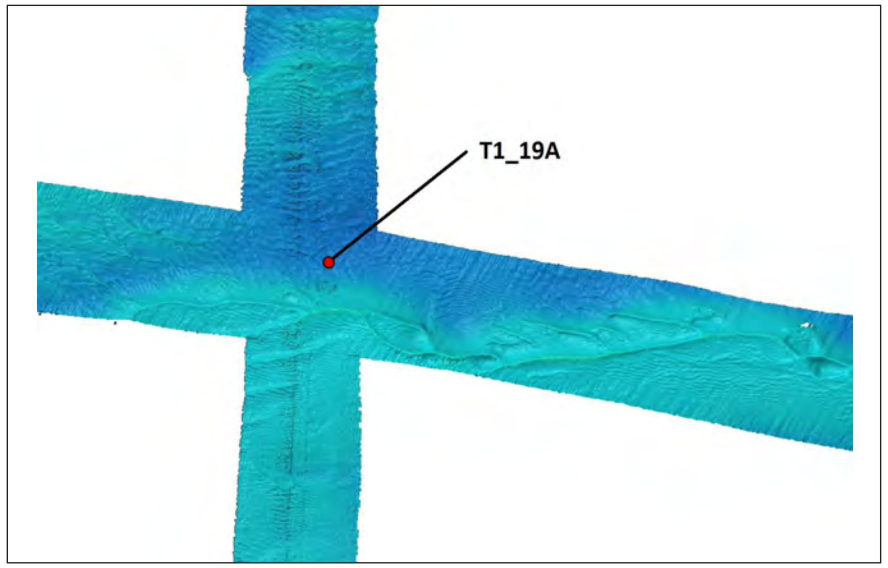
Epifaunal assemblage metrics per trawl



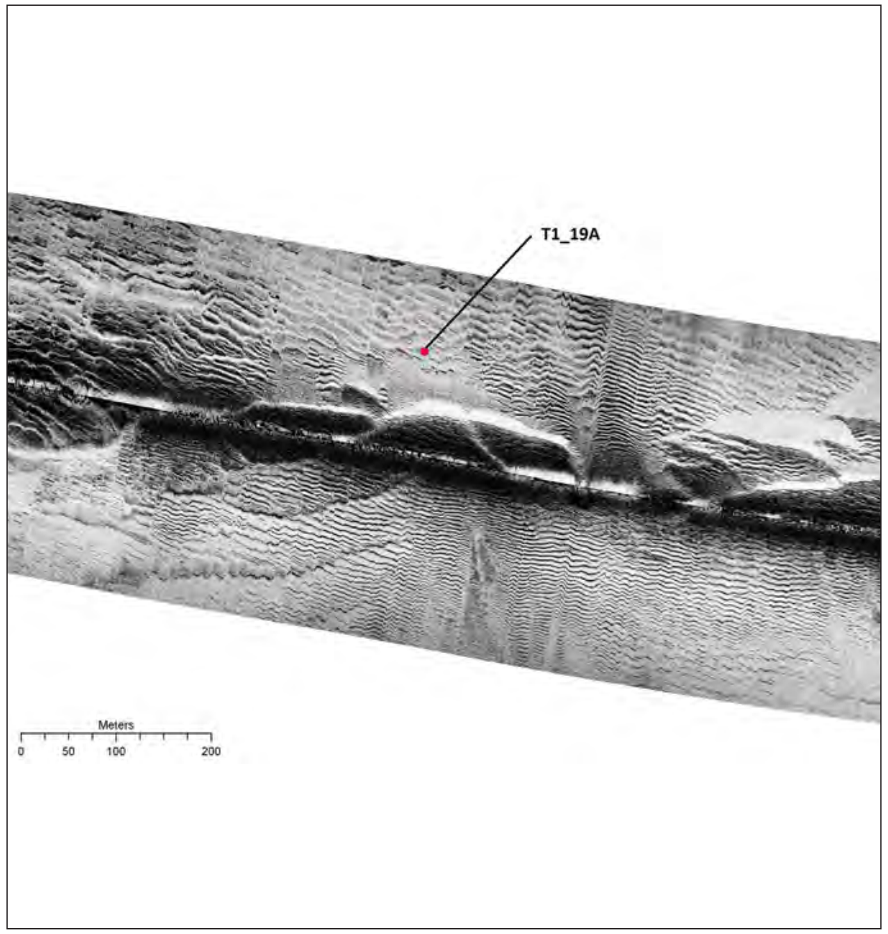
Map showing bathymetry and sampling locations[13]



Plot of each sediment sample's PSD profile against the Folk sediment triangle



Multibeam of representative sampling station



Side-scan of representative sampling station

GROUP P – PHYSICAL INFORMATION

Description

The six stations comprising Group P are scattered throughout the survey area, occurring in both very shallow and deep water (<20 to >45 m). The feature most of these locations have in common is the significant megaripple fields that they lie within. The megaripples are predominantly linear to slightly sinuous in phase. In one case (T1_19A), the megaripples lie within a large sandwave field; however, it is not believed that the small-scale formations are reliant on the larger scale surrounding bedforms. There is one site within this Group (T1_30A) that is the exception, lying in an area completely devoid of bedforms.

PSD analysis reveals that the bedforms are sandy or slightly gravelly sand with some mud content.

[13]Digital bathymetry data © British Crown and SeaZone Solutions Ltd. All rights reserved. Data Licence 052008.012.

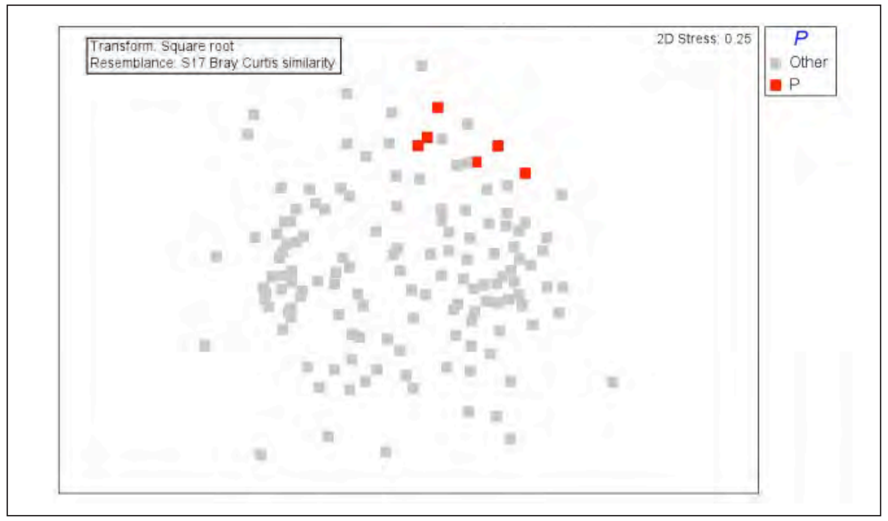
GROUP P – BIOLOGICAL INFORMATION

"*Nephtys*" assemblage

Description

This widespread assemblage is represented by just 32 infaunal taxa, the most abundant being *Gastrosaccus spinifer*, *Nephtys* sp., Ophiuroidea and *Mysella bidentata*. Only *Nephtys* sp. is found at all sampling locations. *Ophiura albida* and *Ophiura ophiura* were also present in vast numbers at some of the stations in Group P.

Based on the analysis of all available data (see page 206), the most likely distribution of this assemblage is in deeper water to the easternmost extreme of the survey area, more so in the northern half. Such areas are likely to be characterised by muddy, gravelly sands.



Multidimensional scaling plot of samples in relation to all other samples

Species	Min. abund.[a]	Max. abund.	Mean abund.	Occur. %
Gastrosaccus spinifer	1	4	2.3	83
Nephtys	1	4	1.8	100
Lagis koreni	1	2	0.7	50
Mysidacea	1	1	0.3	33
Scalibregma inflatum	1	1	0.3	33

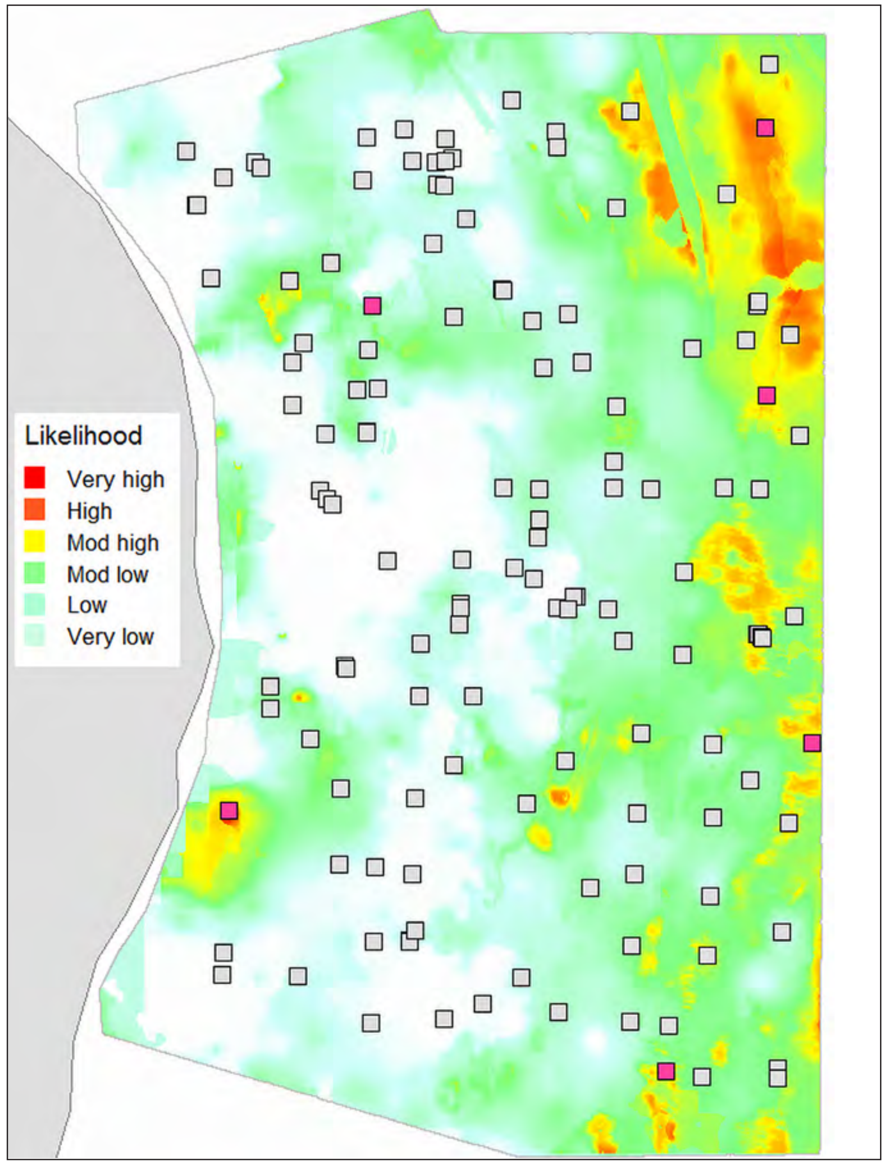
[a] Abundance values per 0.1 m² grab sample

Top species contributing to the similarity within the group in descending order of % contribution

	Minimum	Maximum	Average
Number of species	5	13	8.3
Abundance	7	26	14.2
Diversity (N1)	4.37	12.47	7.25
Evenness (N2/N1)	0.81	1.00	0.88
Taxonomic distinctness (Δ*)	82.41	97.49	90.67

Number of grabs = 6

Infaunal assemblage metrics per grab

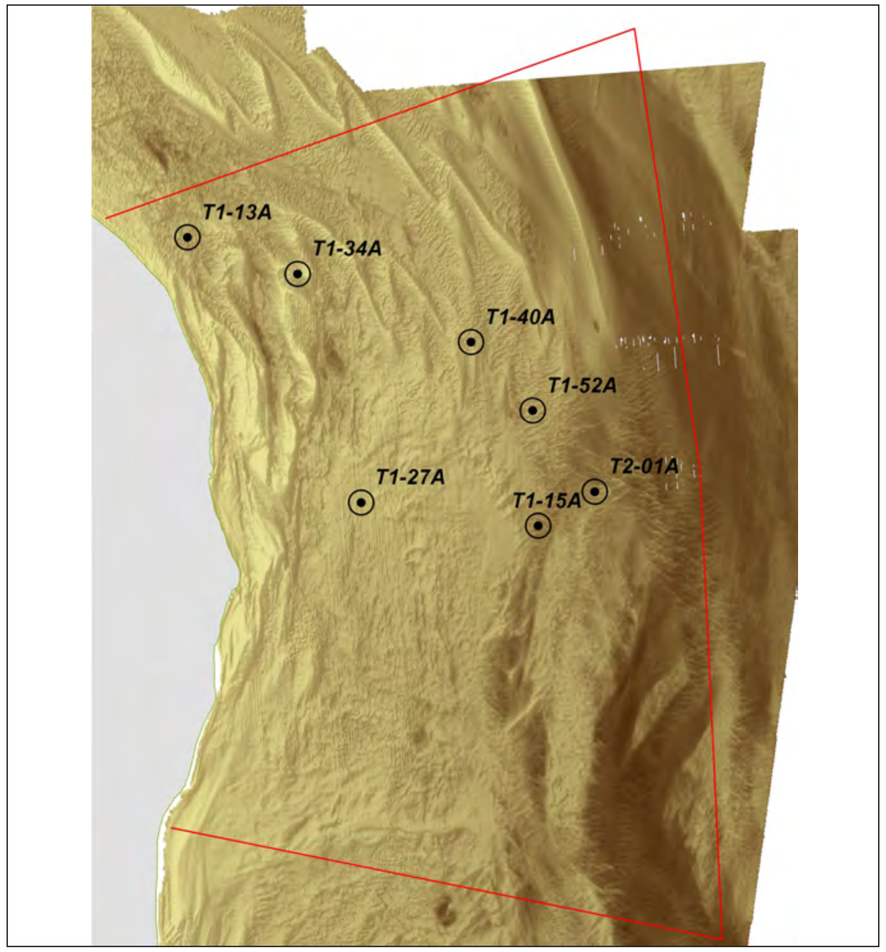


Modelled output showing the likely distribution of the assemblage

	Minimum	Maximum	Average
Number of species	15	27	20.7
Abundance	43	18,486	3,438.0
Diversity (N1)	2.19	10.54	6.46
Evenness (N2/N1)	0.61	0.82	0.69

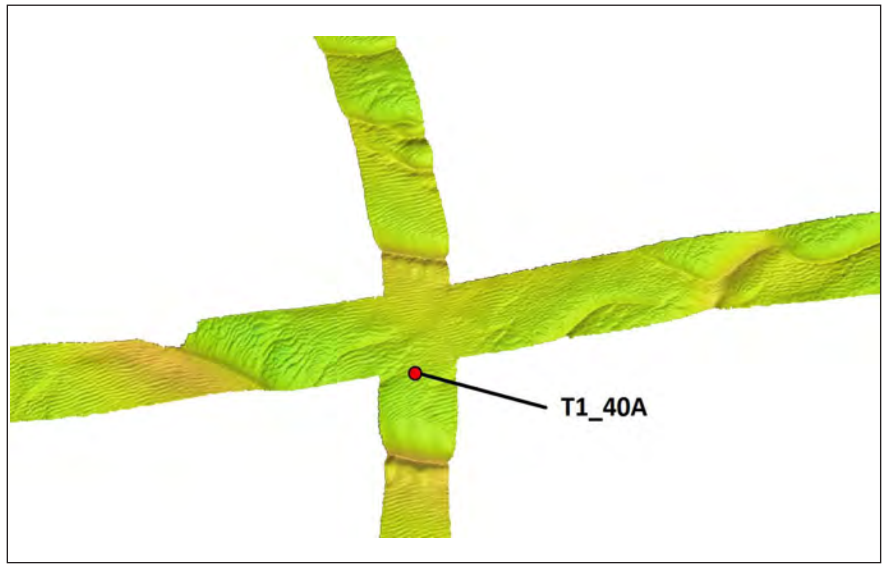
Number of trawls = 6

Epifaunal assemblage metrics per trawl

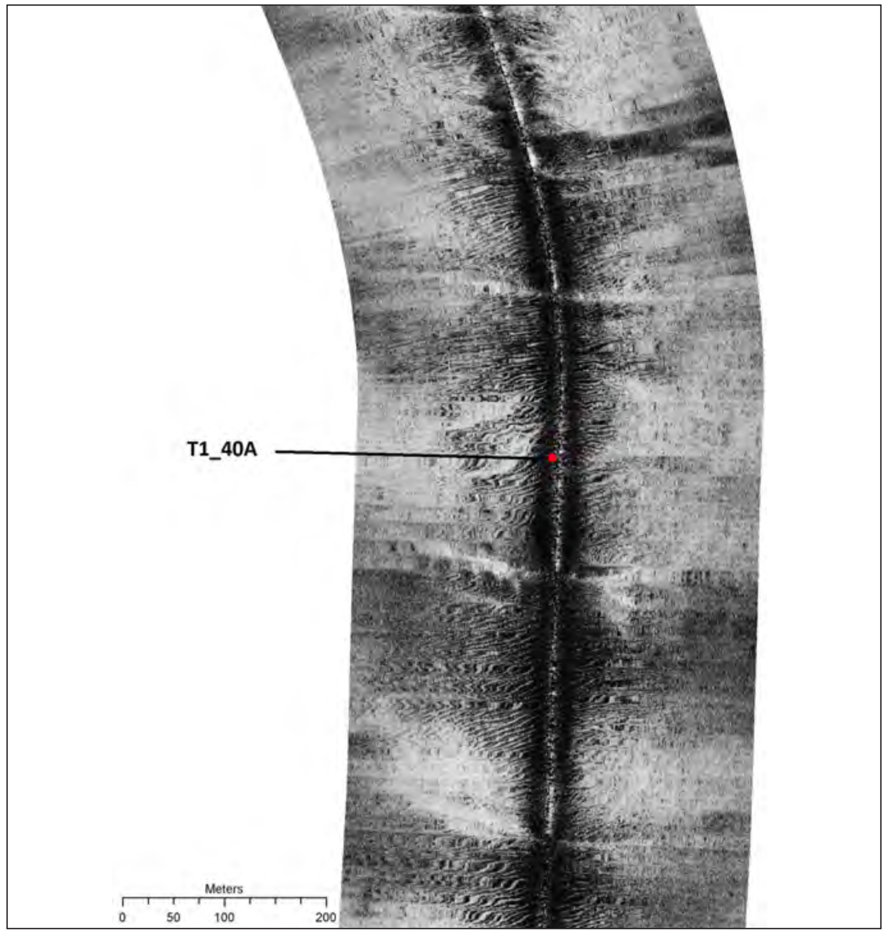


Map showing bathymetry and sampling locations[14]

Plot of each sediment sample's PSD profile against the Folk sediment triangle



Multibeam of representative sampling station



Side-scan of representative sampling station

GROUP Q – PHYSICAL INFORMATION

Description

The sampling stations comprising Group Q all lie within a broad oblong area stretching diagonally from north-west to south-east in the northern half of the survey area. The common link between most of these locations is their occurrence amongst megaripples in troughs of larger sandwave fields (e.g. T1_40A). Two sampling sites that do not conform to this situation are T1_13A and T1_27A. The former lies on a featureless area, whilst the latter lies in a complex area where bedform development is being driven by the underlying geology, although megaripples are present at this location.

PSD analyses reveal that all but one sampling location contain clean sand with some gravel, the exception having sandy gravel.

[14]Digital bathymetry data © British Crown and SeaZone Solutions Ltd. All rights reserved. Data Licence 052008.012.

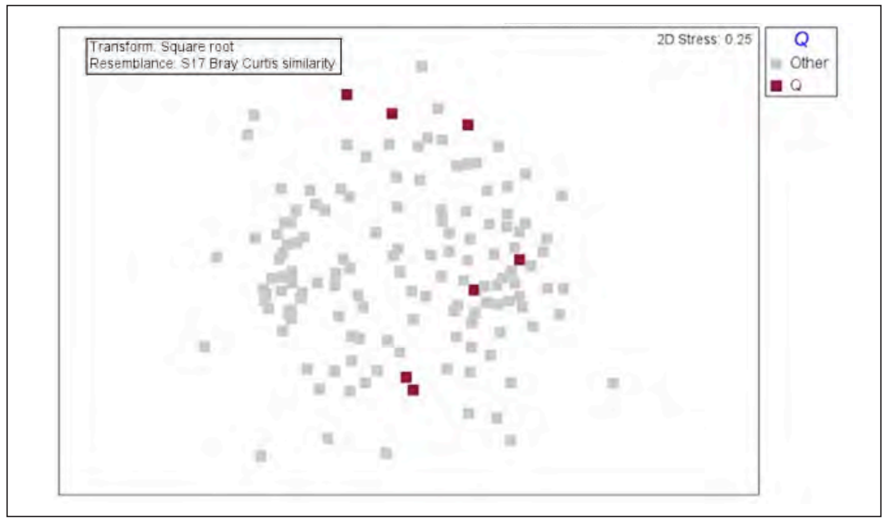
GROUP Q – BIOLOGICAL INFORMATION

"Sparse epifauna" assemblage

Description

A relatively poor assemblage represented by just 43 infaunal taxa, none of which occur at all sampling stations. The most abundant taxa are Mysidacea, *Gastrosaccus spinifer* and *Crangon crangon*. *Crangon allmanni* is also the most conspicuous member of the fauna sampled with the beam trawl. The faunal scarcity and central location of sampling sites forming this Group may indicate that it is representative of assemblages impacted by aggregate dredging activities, since this activity is known to be concentrated around the same area and can have a temporarily detrimental effect on the abundance and diversity of benthic assemblages.

The most likely distribution of this assemblage based on the analysis of all available data (see page 206) is in areas with moderately strong tidal areas, in sediments with low mud content and associated with wave crests and small sandwaves. Areas most likely to fit this description are few and are scattered in relatively small patches in the northern half of the survey area.



Multidimensional scaling plot of samples in relation to all other samples

Species	Min. abund.[a]	Max. abund.	Mean abund.	Occur. %
Campanulariidae	1	1	0.9	86
Amathia lendigera	1	1	0.7	71
Sertularia	1	1	0.6	57
Gastrosaccus spinifer	1	4	1.6	57
Mysidacea	1	16	3.4	43
Crangon crangon	1	4	1.1	43
Nephtys cirrosa	1	1	0.4	43
Polycirrus	2	2	0.6	29

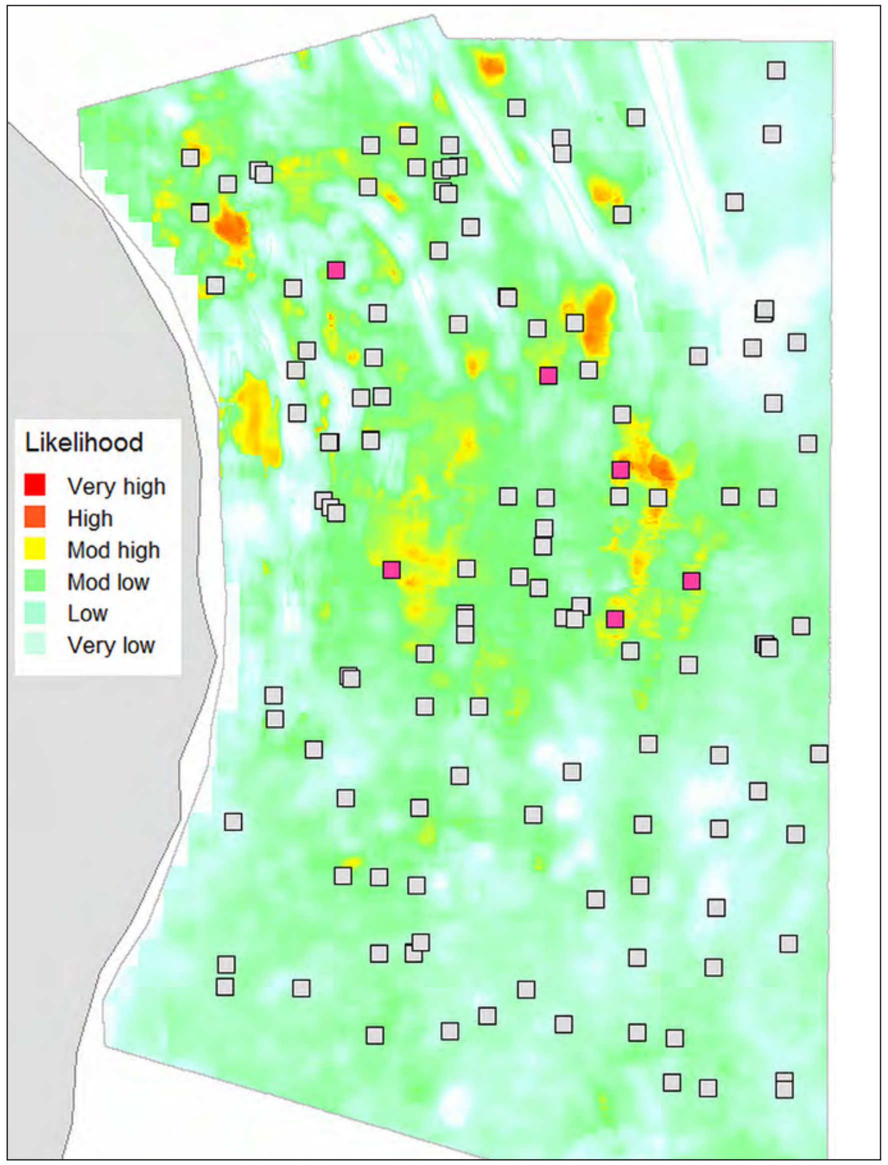
[a] Abundance values per 0.1 m² grab sample

Top species contributing to the similarity within the group in descending order of % contribution

	Minimum	Maximum	Average
Number of species	4	16	10.3
Abundance	4	28	16.7
Diversity (N1)	4.00	14.14	8.62
Evenness (N2/N1)	0.62	1.00	0.85
Taxonomic distinctness (Δ*)	78.35	94.44	88.55

Number of grabs = 7

Infaunal assemblage metrics per grab

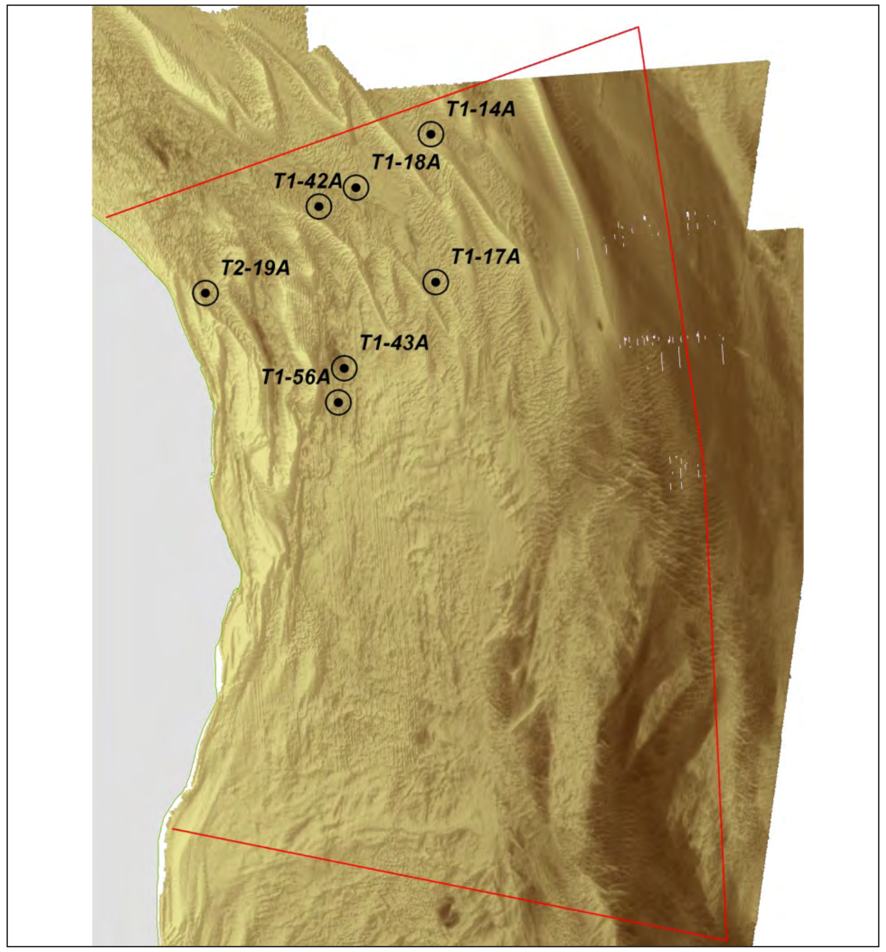


Modelled output showing the likely distribution of the assemblage

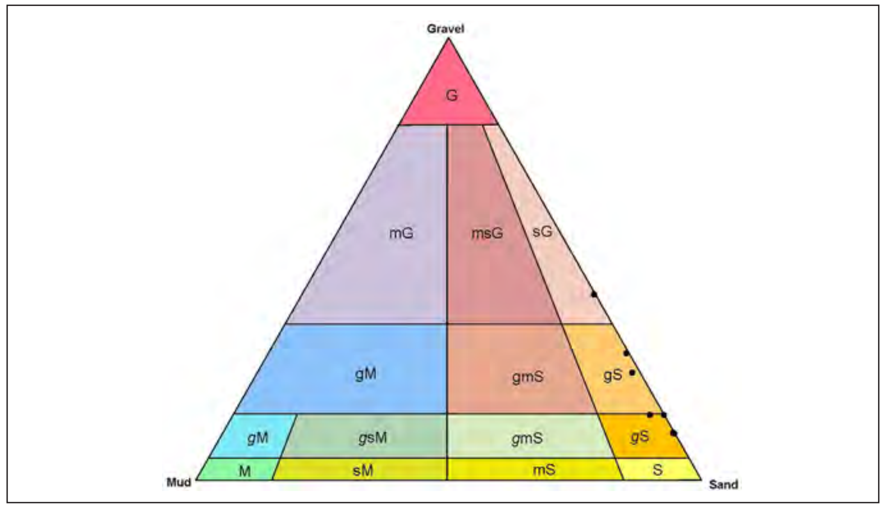
	Minimum	Maximum	Average
Number of species	7	24	16.4
Abundance	37	420	175.4
Diversity (N1)	3.19	11.62	5.86
Evenness (N2/N1)	0.51	0.77	0.61

Number of trawls = 7

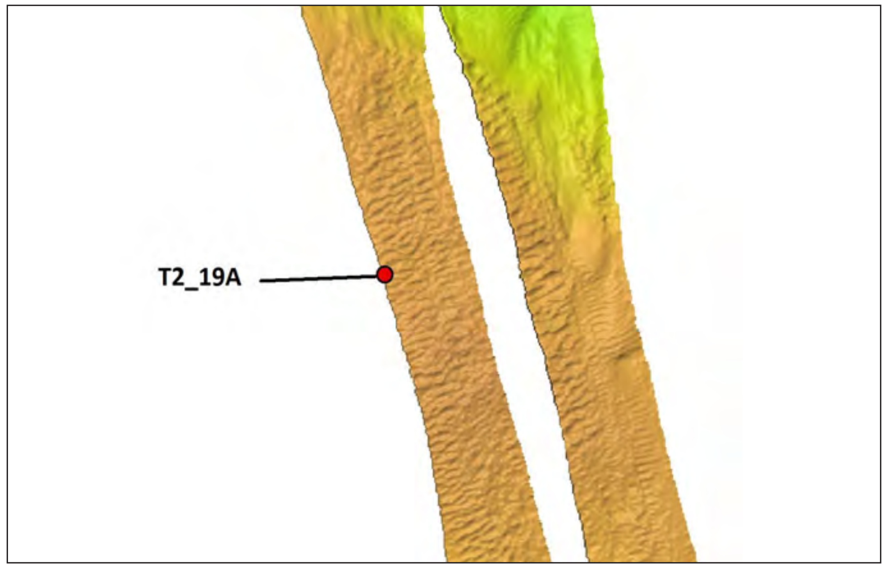
Epifaunal assemblage metrics per trawl



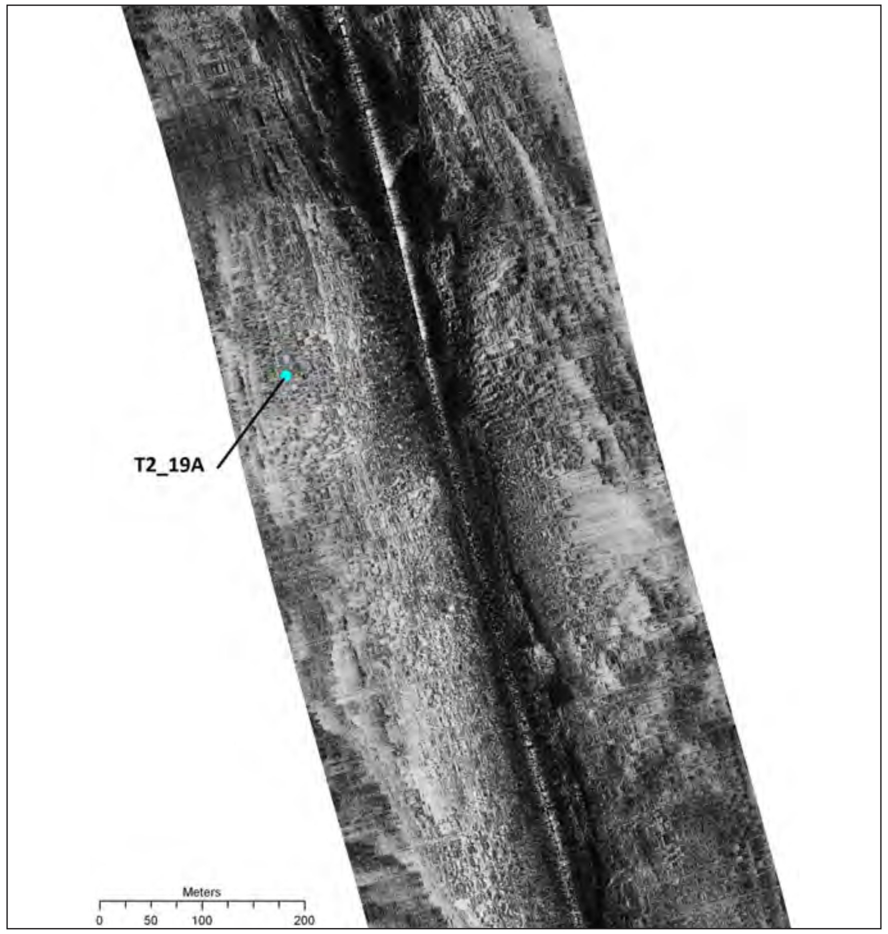
Map showing bathymetry and sampling locations[15]



Plot of each sediment sample's PSD profile against the Folk sediment triangle



Multibeam of representative sampling station



Side-scan of representative sampling station

GROUP R – PHYSICAL INFORMATION

Description

The sampling stations comprising Group R all lie within the north-western quadrant of the survey area, an area dominated by sandbanks. There appears to be no common geomorphological link between the stations, with some lying in megarippled sandwave areas (eg, T1_42A and T1_14A), some in megarippled and *Sabellaria spinulosa* reef-dominated areas (e.g. T1_18A and T2_19A), and one in a featureless area with a thin sediment veneer (T1_43A). The sediments sampled are gravelly sands and sandy gravels and in a region of high current speeds, which may be a contributing factor to the presence of *S. spinulosa* in the area.

[15]Digital bathymetry data © British Crown and SeaZone Solutions Ltd. All rights reserved. Data Licence 052008.012.

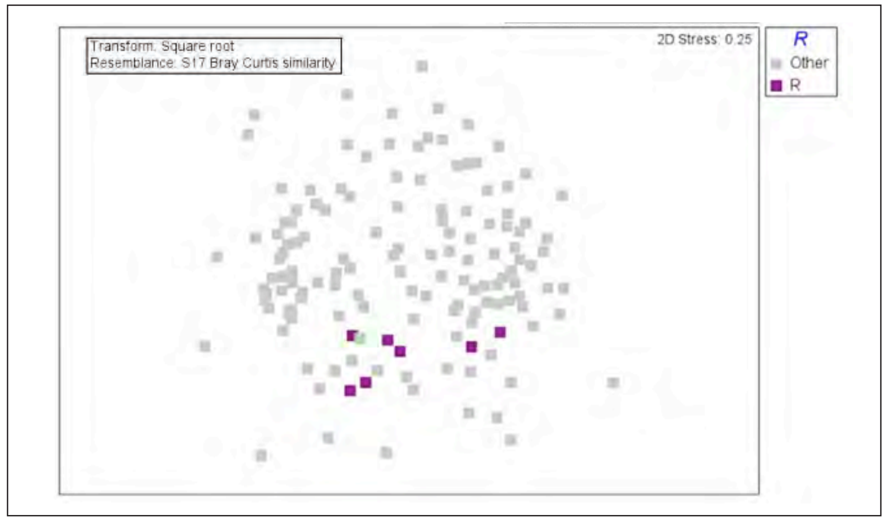
GROUP R – BIOLOGICAL INFORMATION

"Sparse *Sabellaria and Ophelia*" assemblage

Description

An assemblage not especially notable for its abundance, species richness or diversity, despite harbouring considerable numbers of *Sabellaria spinulosa*. It is comprised of a total of 66 infaunal taxa, the most abundant being *S. spinulosa*, *Ophelia borealis*, Mytilidae and *Polydora caulleryi*. None are represented at all seven sampling stations. Epifaunal taxa of notable abundance and extent are *Pandalus montagui*, *Asterias rubens*, *Crangon allmanni* and *Pagurus bernhardus*.

The likely distribution of Group R assemblage based on analysis of all available data (see page 206) is in the shallower northwest of the survey area where the sediment has low mud content and the tidal currents are strong.

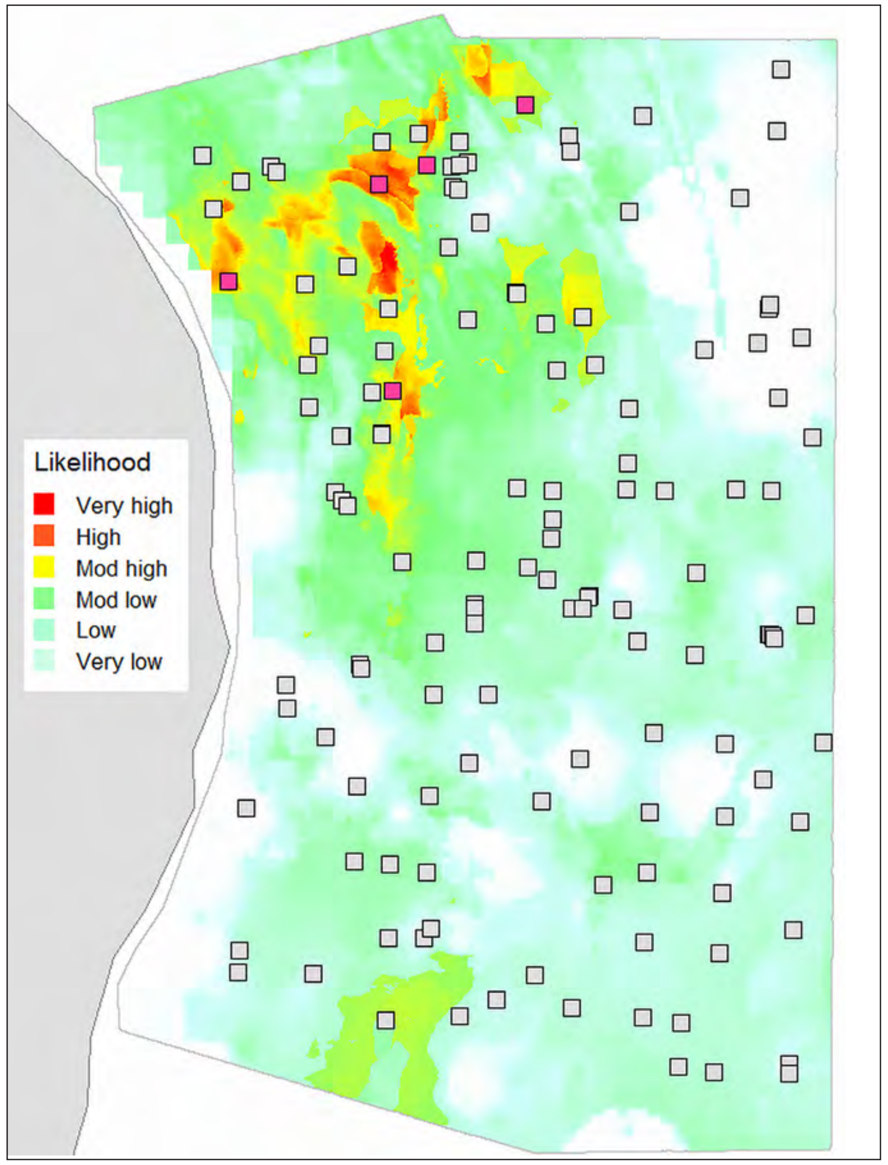


Multidimensional scaling plot of samples in relation to all other samples

Species	Min. abund.[a]	Max. abund.	Mean abund.	Occur. %
Sabellaria spinulosa	1	93	23.7	86
Ophelia borealis	4	21	6.3	71
Amphipholis squamata	3	5	1.7	43
Polycirrus	1	7	1.7	71
Pisidia longicornis	1	3	1.0	57
Polydora caulleryi	1	10	2.3	71
Mytilidae	1	16	3.4	57
Alcyonidium diaphanum	1	1	0.4	43

[a] Abundance values per 0.1 m² grab sample

Top species contributing to the similarity within the group in descending order of % contribution



Modelled output showing the likely distribution of the assemblage

	Minimum	Maximum	Average
Number of species	7	28	16.6
Abundance	12	166	57.6
Diversity (N1)	4.39	12.46	8.34
Evenness (N2/N1)	0.44	0.87	0.64
Taxonomic distinctness (Δ*)	81.87	92.28	85.85

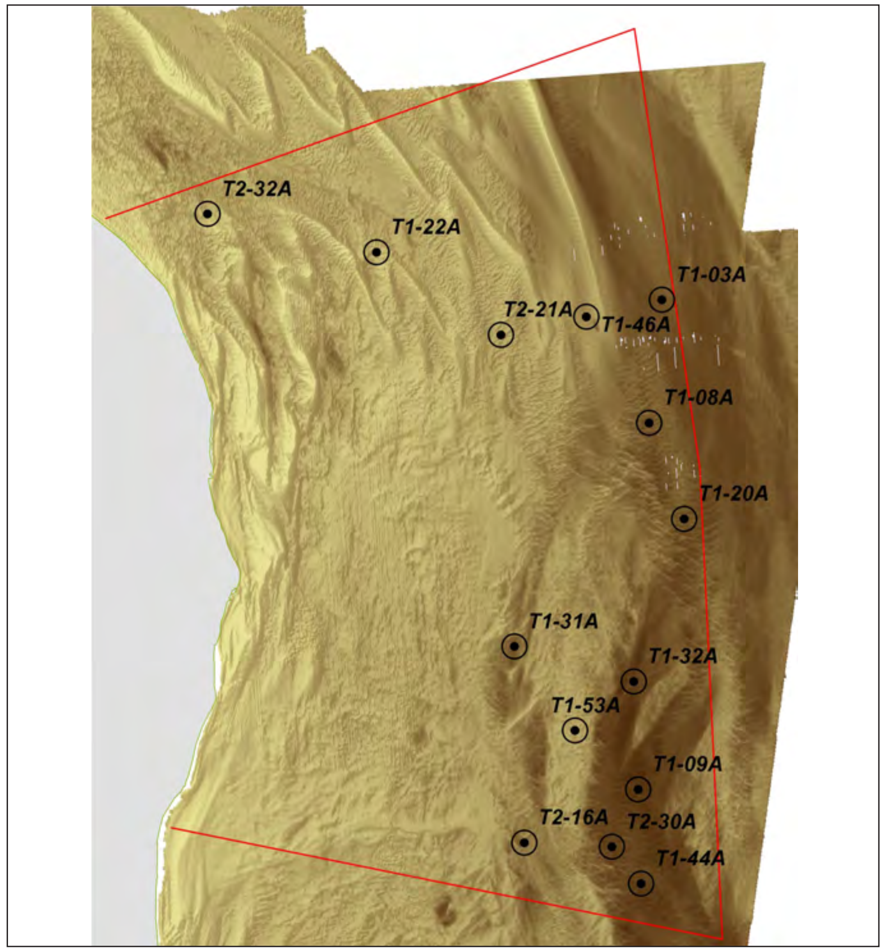
Number of grabs = 7

Infaunal assemblage metrics per grab

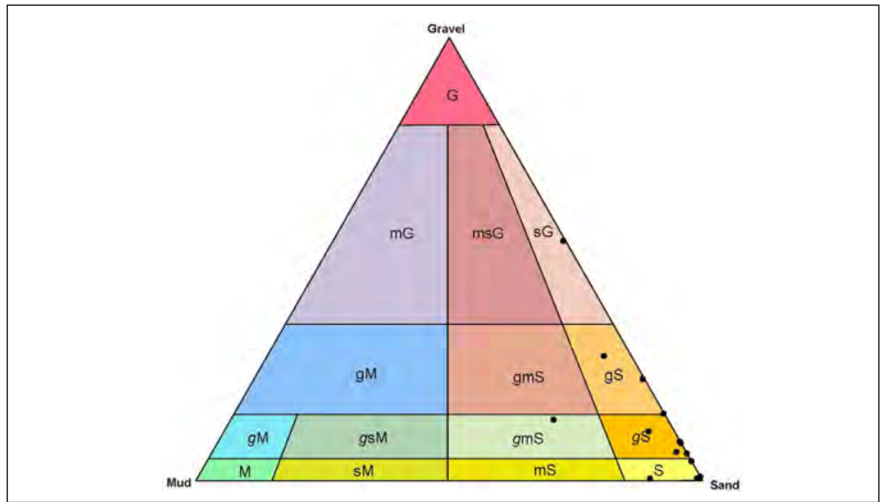
	Minimum	Maximum	Average
Number of species	16	32	21.6
Abundance	84	1,029	359.0
Diversity (N1)	2.86	8.44	6.37
Evenness (N2/N1)	0.49	0.87	0.61

Number of trawls = 7

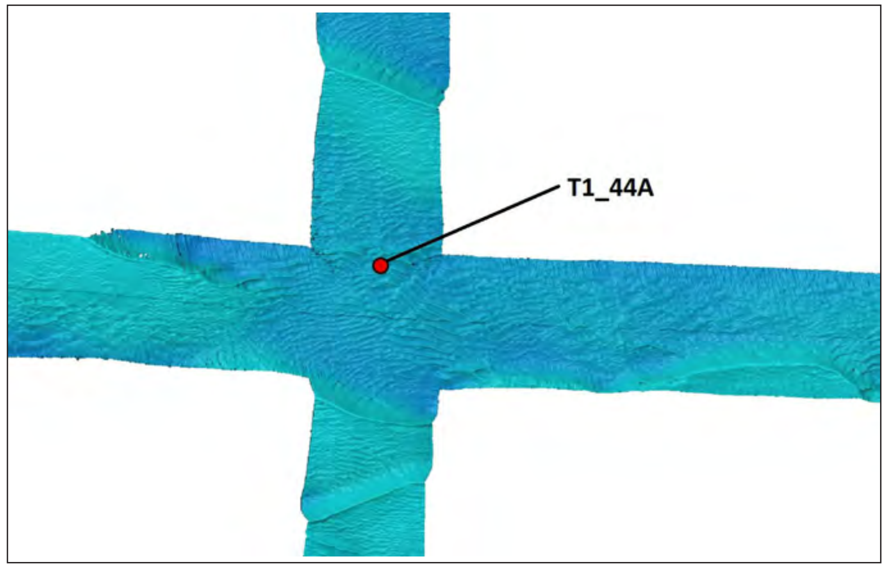
Epifaunal assemblage metrics per trawl



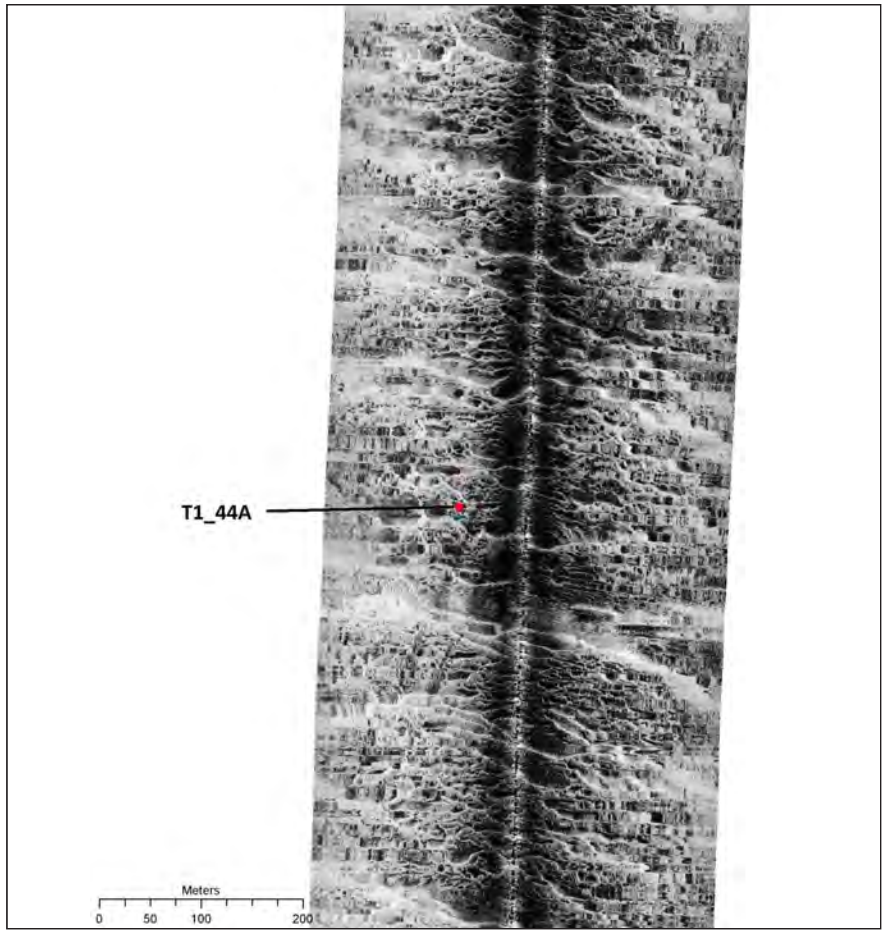
Map showing bathymetry and sampling locations[16]



Plot of each sediment sample's PSD profile against the Folk sediment triangle



Multibeam of representative sampling station



Side-scan of representative sampling station

GROUP U – PHYSICAL INFORMATION

Description

The sampling stations comprising Group U range from shallow to deep water and from north to south across the survey area, but occur more frequently in the eastern half of the area. The majority of the stations (>85%) lie in water depths >35m. The common feature amongst the stations is the presence of megaripples. Some stations lie within parasitic megaripples associated with larger sandwave fields (e.g. T1_44A), whilst others lie within areas where the megaripples are the largest bedform present. There is no continuity across the megaripple form; they range from linear in phase to sinuous bifurcated forms. The one anomalous station, located in the shallowest water closest to shore (T2_32A), is on an area of seafloor that appears relatively barren of bedforms, although localised patches of rippling can be observed in the topographic lows that surround it.

Sediments from Group U are relatively mixed but mostly represent clean sand and slightly gravelly sand, with the occasional occurrence of sandy gravel.

[16]Digital bathymetry data © British Crown and SeaZone Solutions Ltd. All rights reserved. Data Licence 052008.012.

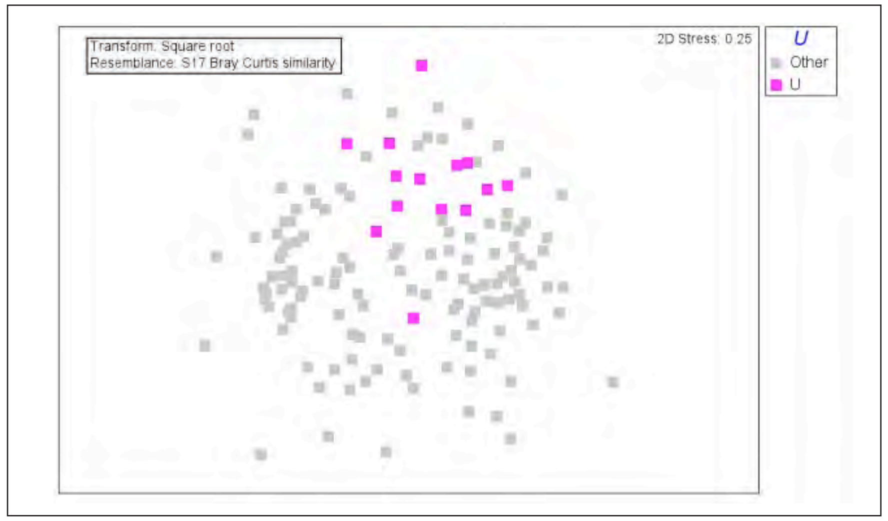
GROUP U – BIOLOGICAL INFORMATION

"Ophiuroidea" assemblage

Description

A sparse infaunal assemblage consisting of 76 taxa, with no one taxon being overwhelmingly numerically dominant. The only taxon present in more than half of the infaunal samples was the Ophiuroidea. The most conspicuous attribute within this Group is the large numbers of epifaunal *Ophiura albida* and *Crangon allmanni*, although these were not super-abundant at every sampling station.

The most likely distribution for Group U assemblage based on analysis of all available data (see page 206) is in a large area in the south-eastern corner of the survey area, as well as to the extreme east towards the centre of the area. Such areas are characterised by gravelly sand sediments with low mud content, often associated with small sandwaves.



Multidimensional scaling plot of samples in relation to all other samples

Species	Min. abund.[a]	Max. abund.	Mean abund.	Occur. %
Ophiuroidea	1	9	2.4	93
Ophelia borealis	1	4	0.7	43
Campanulariidae	1	1	0.4	43
Crangonidae	1	1	0.4	43
Spiophanes bombyx	1	3	0.6	36
Polycirrus	1	1	0.3	29
Pectinariidae	1	1	0.3	29
Caulleriella alata	1	1	0.3	29

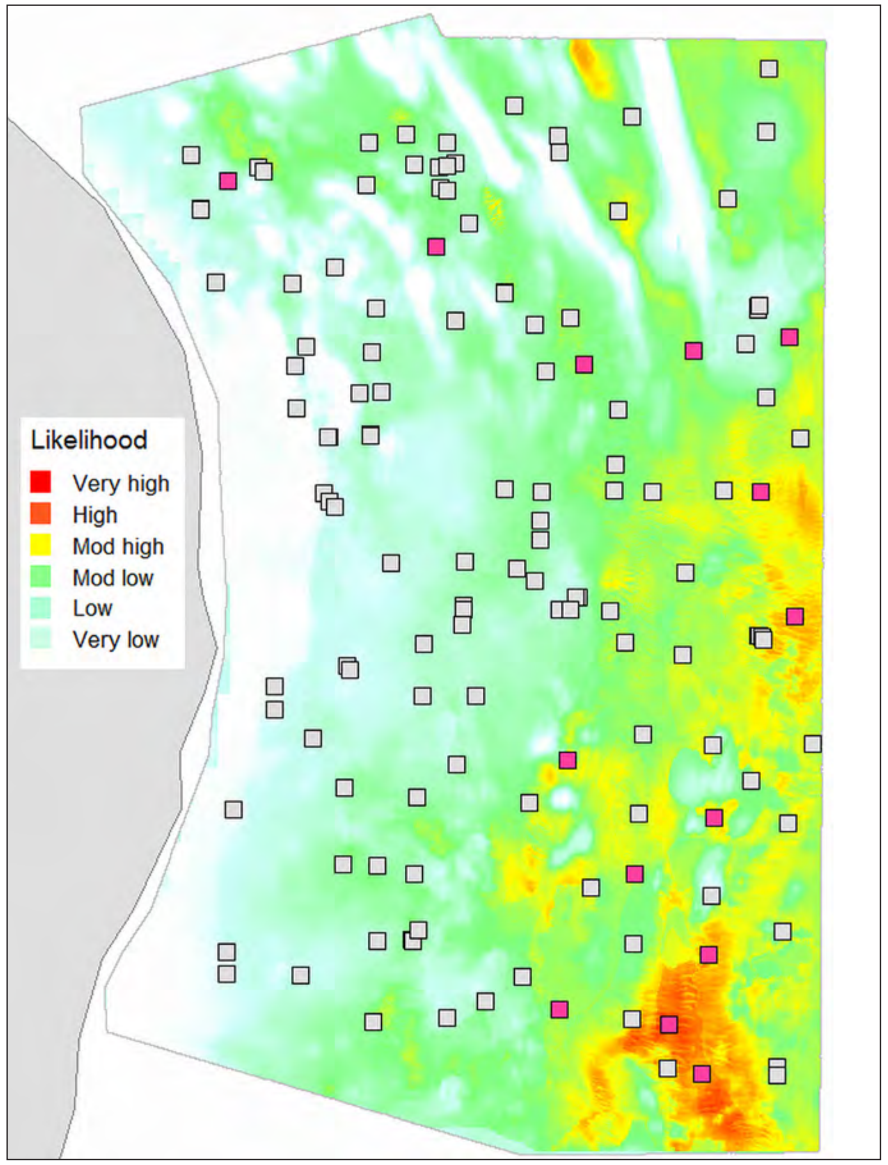
[a] Abundance values per 0.1 m² grab sample

Top species contributing to the similarity within the group in descending order of % contribution

	Minimum	Maximum	Average
Number of species	1	17	10.3
Abundance	2	44	19.0
Diversity (N1)	1.00	13.07	7.85
Evenness (N2/N1)	0.50	1.00	0.82
Taxonomic distinctness (Δ*)	0.00	100.00	84.67

Number of grabs = 14

Infaunal assemblage metrics per grab



Modelled output showing the likely distribution of the assemblage

	Minimum	Maximum	Average
Number of species	14	28	24.5
Abundance	60	38,257	3,135.0
Diversity (N1)	1.29	12.06	6.68
Evenness (N2/N1)	0.51	0.87	0.62

Number of trawls = 14

Epifaunal assemblage metrics per trawl

7.3 Top-down habitat classification

The EUNIS habitat classification is a pan-European system that was developed between 1996 and 2001 by the European Environment Agency (EEA) in collaboration with experts from throughout Europe. It covers all types of natural and artificial habitats, both aquatic and terrestrial.[17] The marine section of this classification has direct equivalents in the United Kingdom's own system, "The Marine Habitat Classification for Britain and Ireland" (Connor *et al.*, 2004), the present version of which was developed during the JNCC's Marine Nature Conservation Review.[18]

The EUNIS scheme has a hierarchical structure, with progressive layers or "levels" (1–7) dealing with different habitat features or characteristics. Level 1 splits marine (denoted "A") from the terrestrial environments. The differentiation between progressively lower levels is entirely based on physical and environmental characteristics, namely substrate type (rock and sediment, which is subsequently further subdivided into coarse sediment, sand, mud and mixed sediment), biological zone (littoral, circalittoral, etc.) and exposure to currents and waves (high, moderate and low energy). Hence, the term "habitat" is commonly applied to Level 3 for rock and Level 4 for sediment substrates. Beyond this, the classification system takes account of the species composition of the resident faunal communities to further discriminate the levels, so the terms "biotope" and "sub-biotope" are more frequently used. The EUNIS classification scheme is an evolving system and undergoes periodic revisions and refinements to accommodate changes in spatial coverage and habitat designations. There is a study presently underway to develop a representative regional set of biotopes or regional variants of existing biotopes in the East Coast REC Study Area (ALSF project 09/P93[19]). This is important, as more accurate mapping results will lead to a more informed environmental management strategy.

[17]Source: www.jncc.gov.uk/page-3365
[18]Source: www.jncc.gov.uk/MarineHabitatClassification
[19]Source: www.alsf-mepf.org.uk/projects--reports/2009/09p93.aspx
[20]Source: http://eunis.eea.europa.eu/habitats.jsp

7.3.1 Assigning EUNIS habitat codes to samples

In this section, the data derived from the East Coast REC study are matched to the EUNIS habitat classification scheme.[20] The range of options for matching the biological data from the samples to EUNIS Level 5 and 6 descriptions are very limited for the range of sublittoral sediments found in the survey area, and there were few clear and unambiguous matches. In consequence, most of the classes could only be defined in terms of EUNIS Level 4 criteria.

It also proved difficult to find a close correlation between the statistically defined assemblage classes identified in Chapter 6 using clustering algorithms and EUNIS Level 4 habitats, since the assemblage classes were often found on a range of habitat types. Table 7.5 gives the EUNIS Level 4 codes assigned to the samples within each class (multiple codes ranked in descending order of frequency) and the most likely equivalent. In some cases, the faunal composition of the samples corresponded fairly closely to a EUNIS biotope description, and this took precedence over other EUNIS habitats. Doubt remains with assemblages representing

Biota Class	EUNIS Level 4 code	Most likely EUNIS equivalent	EUNIS habitat	Comments
A	A5.25/.27	A5.25	Circalittoral fine sand	Closest habitat
B	A5.625/.14	A5.625	Mussel bed on sediment	Closest faunal class
C	A5.27/.15/.25	A5.251	*Ophelia* in circalittoral fine sand	Closest faunal class
D	A5.35	A5.35	Circalittoral sandy mud	Closest habitat
E	A5.15/.27	A5.15	Deep circalittoral coarse sediment	Faunal resemblance to A5.14?
G	A5.15	A5.15	Deep circalittoral coarse sediment	Faunal resemblance to A5.14?
H	A5.611/.27/.15	A5.611	Polychaete worm reef	Closest faunal class
I	A5.37/.15	A5.351	*Mysella* in circalittoral sandy mud	Closest faunal class
J	A5.45/.15	A5.45	Deep circalittoral mixed sediment	Closest faunal class
K	A5.14	A5.14	Circalittoral coarse sediment	Closest habitat
P	A5.27	A5.27	Deep circalittoral sand	Closest habitat
Q	A5.25/.27/.15	A5.25	Circalittoral fine sand	Closest habitat
R	A5.15/.27	A5.15	Deep circalittoral coarse sediment	Faunal resemblance to A5.14?
U	A5.27/.15	A5.27	Deep circalittoral sand	Closest habitat

Table 7.5 **Relationship between statistically derived classes and EUNIS habitats.**

Groups E and G (low-density *Sabellaria* assemblages, similar in composition to A5.14, but assigned to the deepwater A5.15), as the faunal assemblage resembled a biotope described from occurrences in much shallower waters.

In summary, doubt exists as to the EUNIS codes assigned to the samples because of (a) the poor correspondence between the faunal composition of the samples and the EUNIS descriptions, and (b) the range of physical habitat conditions of the assemblage classes. Because of this, it was considered that the EUNIS codes could provide corroborative evidence to support a EUNIS habitat map, but the map itself should be based on the defining physical parameters for EUNIS Level 4 habitats.

7.3.2 Mapping EUNIS habitat classifications

A EUNIS habitat map can be derived from the biotope map created by modelling the distribution of the different assemblage classes (ie, the bottom-up approach) by creating a conversion table that translates the assemblage classes into the closest match in the EUNIS classification. However, a map of EUNIS biotopes can also be produced knowing the distribution of the key environmental parameters that define the biotope classes at Level 4. The method follows the segmentation of maps of the key physical habitat variables underpinning the EUNIS classification (Figure 7.14). For a detailed explanation see the MESH website.[21]

Following the EUNIS classification approach, the most important environmental variables are deemed to be sediment and parameters controlled by water depth. Water depth is used to define the boundary between the photic zone (infralittoral) and the aphotic zone (circalittoral), as well as setting the approximate boundary for the wavebase below which sediments can be regarded as “deep”. Both of these boundaries vary with local conditions, and all sediments sampled in the survey were regarded as being below the photic zone (ie, all were considered to be circalittoral or deep circalittoral).

[21]Source: www.searchmesh.net/PDF/GMHM4_MESH_EUNIS_Model.pdf

A boundary of 30 m water depth was agreed to represent the depth of the wavebase and was used to differentiate between circalittoral sediment and deep circalittoral sediment (Figure 7.14). This boundary is somewhat arbitrary and open to question, since it is likely that the sediments below this depth were disturbed by currents, if not waves.

The source map for sediment used for segmentation was the interpolated mud, sand and gravel point sample data (samples were pooled from archive data made available to the project, as well as samples collected as part of the project). These interpolated gridded values were combined using the modified Folk system (Folk, 1954) into sediment classes (Figure 7.14), which were then grouped into broad sediment categories (coarse sediment, sand, mud and mixed sediment) according to the EUNIS system. The resulting raster image of sediment classes was filtered to remove isolated groups of pixels in order to simplify the image. The 30 m depth contour was derived from comprehensive water depth data for the survey area. This contour was overlaid on the sediment polygon layer to divide the polygons into circalittoral and deep circalittoral habitats. The polygons were then coded for the appropriate EUNIS Level 4 habitat. The survey sample data, coded according to the EUNIS system, were overlain, and polygons were re-coded if the samples they contained indicated a habitat other than those defined by the segmentation process – that is, biogenic habitats (worm reefs and mussel beds) or those where the sediment was likely to have been “mixed” (a sediment not identified by partitioning the mud, sand and gravel sediment fractions). This intervention was considered to better represent the habitats present than by disregarding this evidence.

The final map has shown the EUNIS classes coloured using the EUNIS colour coding scheme (Figure 7.15). It should be noted that the map is largely based on the information contained in the key environmental coverages and that there is very limited scope for incorporating the biological and physical sample data. The most direct way is through the PSD data associated with the grab samples contributing to the interpolated sediment maps. There is very little information on the biota within these EUNIS classes since there has been a reliance on the Level 4 habitats.

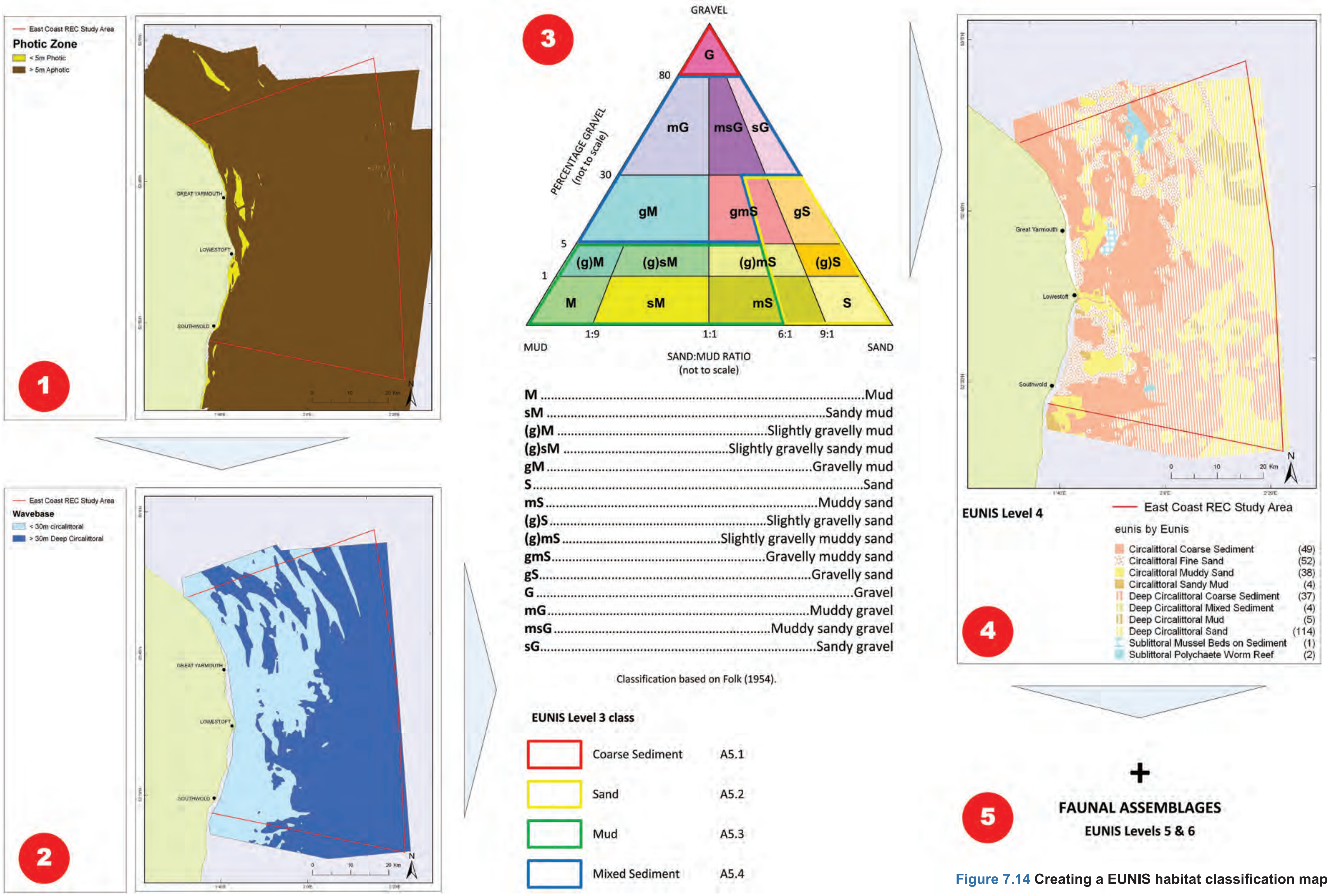


Figure 7.14 Creating a EUNIS habitat classification map following the MESH approach.

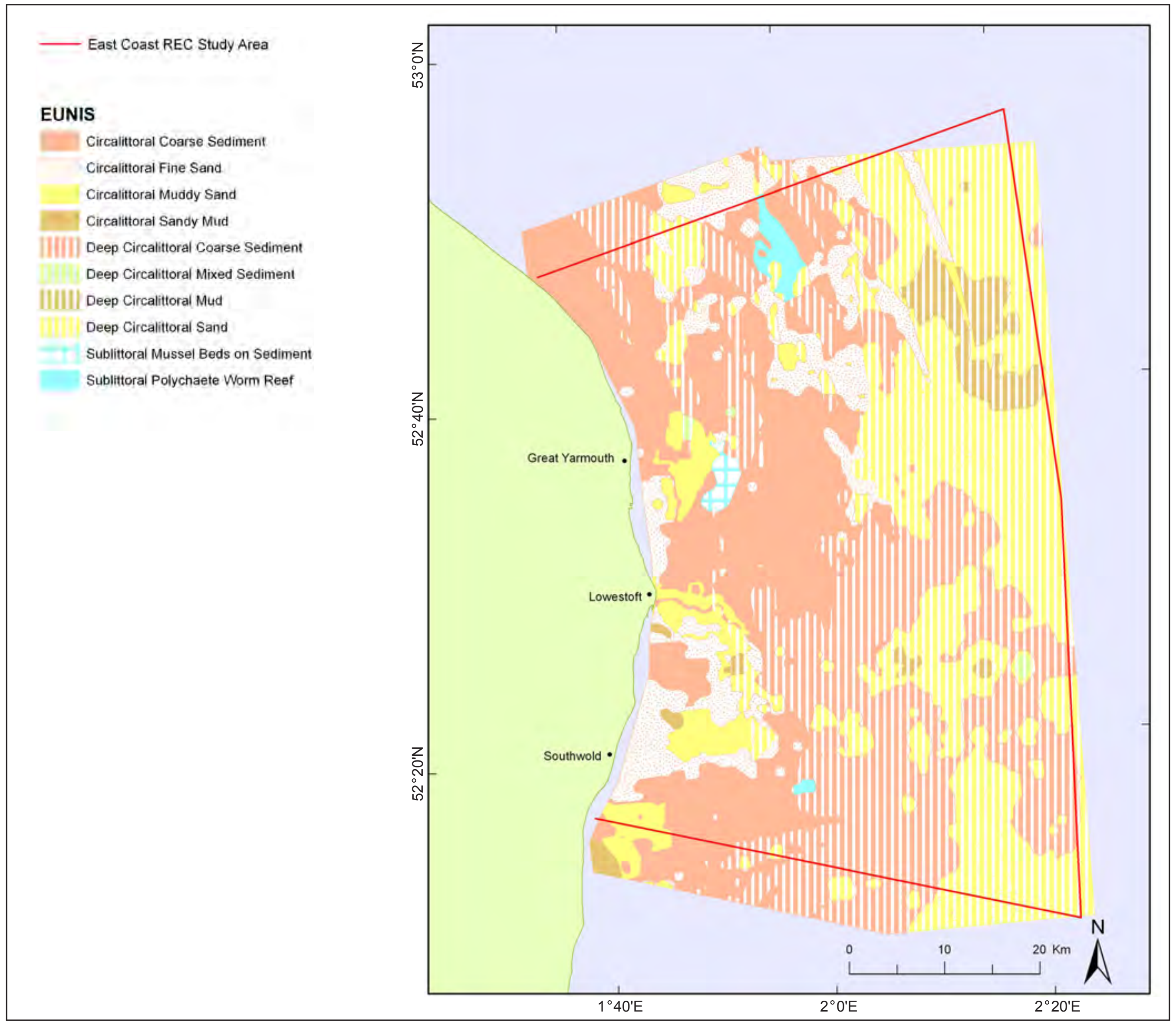


Figure 7.15 East Coast REC Study Area EUNIS biotope map.

7.4 Evaluation of habitat classification systems

The top-down EUNIS habitat hierarchical classification system can work at two levels. First, the system can be used to segment areas into broad habitat types on the basis of available coverages (particularly water depth and sediment). This can be very useful in providing some form of prediction of the likely habitats that might be expected within an area where there is little available data. It should be stressed that unless there is additional relevant information, all biotopes lower in the hierarchy (Level 5 and 6) might be expected within the broad Level 4 habitat categories.

The partitioning can be made more sophisticated by incorporating additional environmental variables (such as topography, bottom stress, etc.) or knowledge of biogeographic trends in habitat distribution, where the additional evidence can refine the range of habitats that might be expected. This process was used at the start of the East Coast REC ground-truthing surveys to partition the area of interest into potentially different habitat types for stratified sampling (Chapter 3).

The second application of the EUNIS classification system is to assign survey sample data to habitat categories. This is done through a process of matching the data to previously defined and described habitat classes. This can serve a useful purpose in providing a common system for classification that can be applied to datasets from different surveys. However, the matching process can be arbitrary, resulting in a poor fit between the data and EUNIS habitat. Although the EUNIS habitats are presented in the hierarchy as having clearly defined physical habitat parameters, it is clear from the descriptions of the habitats that they are meant to be interpreted simply. Instead, it is obvious that there is considerable overlap of both the environmental conditions and the faunal composition of the habitat classes. This is particularly the case for the sediment habitats sampled across the East Coast REC Study Area. The net effect of poor matching and overlapping parameters is that samples are likely to be classified with low certainty; a EUNIS habitat category may (as is the case here) include more than one assemblage class that has been derived through statistical analysis of sample data.

Perhaps more importantly, the opposite is also possible. Samples that are faunistically similar may be classified into different Level 4 classes because of differences in sediment/water depth values associated with the samples. Because the EUNIS system is hierarchical, if samples have been separated at Level 4, there is little scope for bringing them together on the grounds of faunistic similarity further down the hierarchy. This precludes any further investigation into associations between faunal assemblages and their environment (these investigations were undertaken when the EUNIS classification system was devised with the data that were available at that time, and there is a presumption against significant revision of the classification). Using sample data classified to the EUNIS system to model the distribution of habitats will simply reflect the distribution of the boundary values of key physical parameters that separate habitat classes.

Despite such shortcomings, there are good reasons for maintaining the integrity of the EUNIS classification structure to facilitate comparison between the results of different surveys within a region. However, classes that resulted from the bottom-up analysis of the faunal data allow much greater flexibility when investigating the distribution of biota within a particular study. This discrepancy does place investigators in a dilemma; should they "tell the story" of the biology within their survey from their data, or force their data into an existing classification structure that may be inadequate in many respects to portray the biology and habitat information in a way that they feel is justified by the data?

A summary of the advantages and disadvantages of the alternatives is presented in Table 7.6. Based on these, it is appropriate to provide two interpretations of the data: the first at a smaller spatial scale and based on statistical analysis whose aim is to explain the biology and distribution patterns, the second at a broader spatial scale and giving a more general account based on the EUNIS classification system with the aim of providing a product that can be integrated into other studies. Although it is possible to convert the bottom-up–derived biotope map to the EUNIS system, it is probably best to keep to the MESH system for mapping EUNIS classes. This is the strategy adopted in this survey.

Classification	Advantages	Disadvantages
Top-down (EUNIS)	Assigning samples to EUNIS Level 4 habitats is clear-cut	May not adequately reflect the biota and habitats within a survey
	Allows comparison between different surveys and regions and forms the basis for a national mapping system	Poor matching of sample data to EUNIS classes undermines the value of habitat maps
	Permits habitat prediction on the basis of known key physical variables, particularly useful where little available habitat data and for stratifying sampling	Samples will reinforce the basis for stratification if the classification of the biota is constrained by those physical parameters
	EUNIS models for habitat distribution are simple to use	EUNIS models have limited scope for investigation of distribution patterns because of the point made above
Bottom-up	Flexibility to investigate the association between fauna and habitat	Results dependent upon the sampling strategy (particularly intensity, sampling bias and spatial representativity)
	Maps can show subtle, but locally significant, distribution patterns in the biota	May be difficult to reconcile classes with other data from different times or neighbouring areas
	Sophisticated models can be used for probabilistic mapping, and levels of certainty of the outcomes can be assessed	Sophisticated models are research tools and have yet to be incorporated into mainstream analysis of survey data

Table 7.6 Summary of the advantages and disadvantages of top-down (EUNIS) and bottom-up classification systems.

7.5 Evaluation and application of biotope maps

The two biotope maps created by this study using different approaches to habitat classification show some elements of similarity (ie, congruence between certain habitat designations) and some points of difference. The most striking difference is perhaps the higher level of spatial resolution – or detail – provided by the bottom-up approach (Figure 7.16A), which in turn suggests a more heterogeneous or complex seabed habitat than may have been expected by habitual users of the marine resource in this area. The top-down EUNIS approach, on the other hand, presents a smaller number of different areas that intuitively represent more tangible units of management (Figure 7.16B).

It is important to remember that a habitat or biotope can be delimited as narrowly or as broadly as the data and purpose permit (Valentine *et al.*, 2005), and this flexibility of scale and resolution influences the development of habitat classification schemes. In the case of the map created by the bottom-up approach, its perceived complexity was pre-determined before the application of any statistical modelling by the choice of defining 14 distinct assemblages deemed to be significantly different based on statistical criteria (ie, following multivariate analyses of infaunal data). Consequently, what this map is actually depicting is the likely spatial distribution of 14 distinct assemblages, the extent of each derived from the multivariate correlation between each assemblage and its associated physical environment. For ease of interpretation, deliberately contrasting colours are used to differentiate the coverage of each distinct assemblage–environment combination (biotope), which reinforces any perceived habitat complexity over the survey area. Although statistical differentiation is a central tenet to objective scientific analyses, in reality these 14 distinct assemblages may not be as ecologically different as statistics and contrasting colours suggest. For example, the "*Nephtys cirrosa*" assemblage may be statistically distinct from the "*Nephtys*" assemblage, yet in terms of their functional attributes (ie, functional traits) they may be the same. Similarly, "Dense *Sabellaria*" and "Mod dense *Sabellaria*" may differ in the relative abundance of key

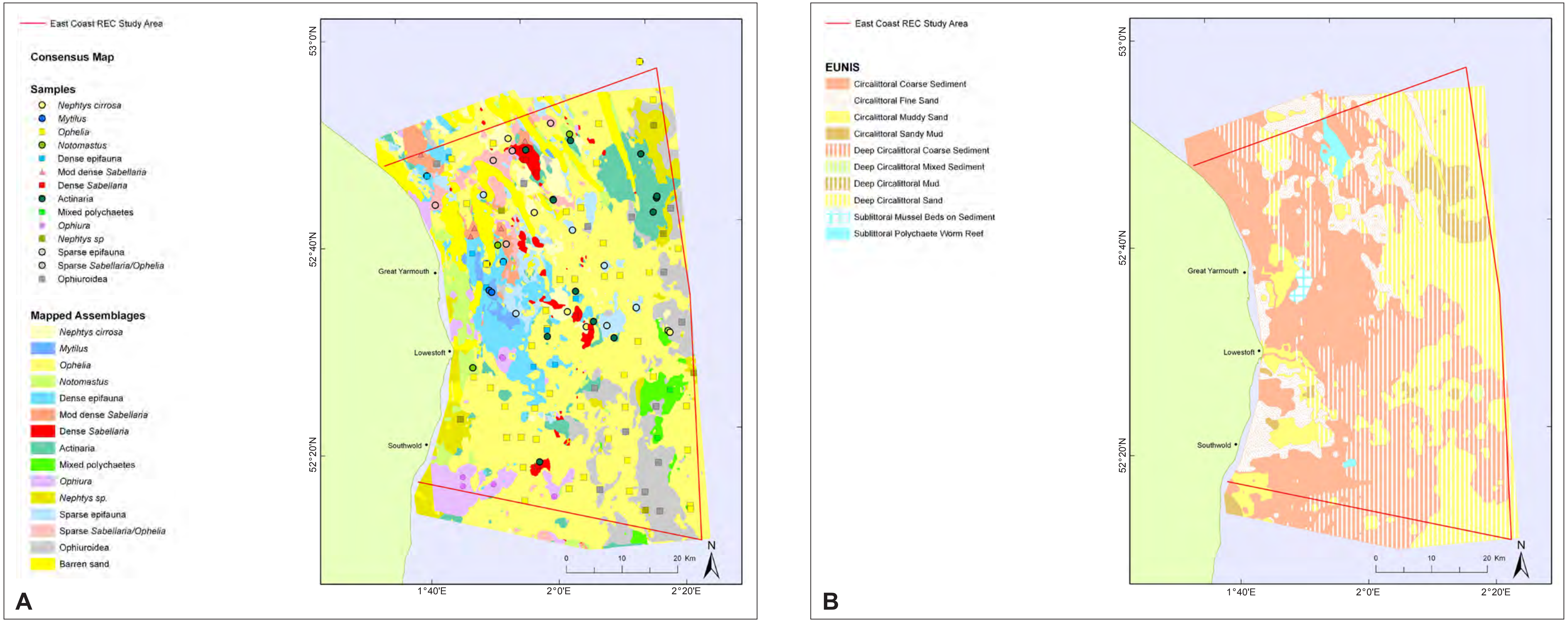


Figure 7.16 **(A) Bottom-up and (B) top-down habitat classification maps of the East Coast REC Study Area.**

characterising species, but again perform exactly the same ecosystem functions. Clearly, further work is necessary to confirm or refute such statements.

The top-down EUNIS classification map appears intuitively more appealing and manageable, as a more ordered gradient of change can be perceived from west (predominantly bold colours) to east (predominantly pale colours). However, this pleasing-to-the-eye pattern is primarily a function of the top-down decision-making process used to differentiate between "circalittoral" (<30 m water depth) and "deep circalittoral" (>30 m water depth – used as a proxy for above and below the wavebase). In shallow-sloping and relatively dynamic marine sedimentary habitats such as those in the East Coast REC Study Area, it may be unwise to differentiate and manage biotopes whose distribution (and by inference, their ecosystem function) is based on relatively arbitrary differences in water depth. In fact, some benthic organisms were observed inhabiting their preferred sediments regardless of the water depth at the sampling site, and the bottom-up multivariate approach to mapping clearly shows some assemblages spanning the depth range in the survey area.

Where both mapping approaches agree is in the identification of features considered to be of conservation importance, such as biogenic reefs (*Sabellaria* and *Mytilus*). Whilst this level of congruence between broadly different habitat mapping approaches is encouraging, habitat conservation planning is moving towards integrated ecosystem management (MMO, 2010). The ability to detect and secure the future of a select biogenic habitat only serves to conserve particular species and features, but it leaves out the third key element of ecosystems: ecological function. An important implication of this is the overt and exclusive prioritisation of charismatic organisms and features as necessary and sufficient proxies for the rest of nature. If conservation planning is to realise an integrated ecosystem approach to nature conservation and ecosystem management, all three aspects of ecological phenomena – species, features and function – will have to be incorporated across the board. To this end, the UK Government is already cooperating with nature conservation agencies and stakeholders to create and manage a nationwide network of protected areas and MCZs. It may be that the bottom-up approach, amended to reflect some element of ecosystem function, is best placed to provide the necessary tools (including distribution maps) that would enable the holistic, three-pronged management of marine natural resources. However, until sufficient good-quality data exist to undertake such analyses at large spatial scales, the top-down approach is equally capable of identifying priority areas for targeted species and feature conservation.

7.6 Conclusion

The results from the present investigation provide an example that mapping habitats with a bottom-up methodology can create ecologically relevant habitat units that best represent the relationships between macrofauna and their benthic environment. Macrofaunal assemblages were mapped relative to the environmental parameters found to be influential to their distribution and classified as biotopes compatible to an extent with the EUNIS classification scheme. The mappable data layers created in this study are flexible and can be keyed to highlight target species or areas where greater data density could improve habitat prediction. Our mapping and classification methods provide data supporting marine spatial planning efforts and ecological research and are applicable to a variety of coastal and offshore environments.

8 Features of interest

8.1 Features of conservation interest

In 1992, Europe adopted the EC Habitats Directive (Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora) through which it meets its obligations as a signatory of the Bern Convention on the Conservation of European Wildlife and Natural Habitats. The main aim of the EC Habitats Directive is to promote the maintenance of biodiversity by taking measures to maintain and restore natural habitats and wild species to a favourable conservation status, introducing robust protection for habitats and species of European importance.

Annex II of the EC Habitats Directive lists a number of terrestrial and marine species that are of conservation interest at a European level. No such species were identified during the course of our surveys of the East Coast REC Study Area. Annex I of the Habitats Directive lists habitats that are subject to special requirements for conservation under EU law. A representative proportion of the Annex I habitats are to be protected through a network of SACs, which, together with SPAs designated under the Birds Directive, make up the Natura 2000 Network. The Natura Network will be further supplemented by a new type of marine protected area in England and Wales named Marine Conservation Zones (MCZs) that will be designated under the Marine and Coastal Access Act 2009.

Eight of the 189 habitats listed in Annex I of the Habitats Directive are marine, and 7 of these occur in UK waters, namely:

- Sandbanks that are slightly covered by seawater at all times.
- Estuaries.
- Mudflats and sandflats not covered by seawater at low tide.
- Coastal lagoons.
- Large shallow inlets and bays.
- Reefs.
- Submarine structures made by leaking gas.

Within the East Coast REC Study Area, there are a number of habitats that have been identified that could fall into either the Sandbanks or Reefs categories and hence are likely to be of some conservation interest. Definition of these features is a somewhat complex issue driven by a need to define them in law coupled with a general lack of understanding with regard to the ecological functioning of these habitats. The European Commission published a guidance document called the *Interpretation Manual of EU Habitats* which was subsequently updated (European Commission, 2007a, 2007b). This manual gives descriptions for priority habitats, which establish clear, operational scientific definitions of habitat types taking into consideration regional variation. The most accessible definitions of the Annex I habitats are those provided by the JNCC (2010a, 2010b).

Annex I sandbanks slightly covered by seawater all the time occur where areas of sand are predominantly surrounded by deeper water and where the top of the sandbank is in less than 20 m water depth. However, the sides of these sandbanks, particularly in offshore waters, can extend into waters deeper than 20 m. Some shallow sandbanks are vegetated with eelgrass beds or maerl, and animals that live on sandbanks include worms, crabs, starfish, sandeels and flatfish such as plaice and sole. The presence of sandeels in particular also makes sandbanks a rich feeding ground for other wildlife, such as seabirds, seals and porpoises.

Annex I reefs occur where rocky areas or concretions made by marine animals arise from the surrounding seafloor. There are three main types of Annex I reef: bedrock reef, stony reef and biogenic reef. Bedrock and stony reefs are both types of rocky reef. These occur where the bedrock or stable boulders and cobbles arise from the surrounding seabed, creating a habitat that is colonised by many different marine animals and plants. Rocky reefs can be very variable in terms of both their structure and the communities that they support. They provide a home to many species, such as corals, sponges and sea squirts as well as giving shelter to fish and crustaceans such as lobsters and crabs.

Biogenic reefs are those that are created by the animals themselves. In the United Kingdom, these include coral reefs, made by cold-water corals such as *Lophelia pertusa* and *Madrepora oculata*. Biogenic reefs can also be made by reef-building worms such as the honeycomb worm *Sabellaria alveolata*, the Ross worm *Sabellaria spinulosa* and the serpulid worm *Serpula vermicularis*. Mussels such as the edible mussel *Mytilus edulis* and the horse mussel *Modiolus modiolus* can also create biogenic reef structures. In UK offshore waters, the main types of biogenic reef that the JNCC are trying to identify for SAC designation are those of *S. spinulosa* and *M. modiolus* and also deep cold-water coral reefs of *Lophelia*.

8.1.1 Sandbanks

Mapped sandbanks in the East Coast REC Study Area cover an area of 553 km^2, equivalent to nearly 17% of the study area (Figure 8.1). There are areas of potential sandbanks close to the shore and north-south sandbanks in the north of the area. These areas may warrant targeted surveys to establish their extent, form and elevation for comparison with the Annex I sandbank criteria.

8.1.2 Reefs

There are no significant areas of bedrock or stony ground that could be considered as geogenic reef within the East Coast REC Study

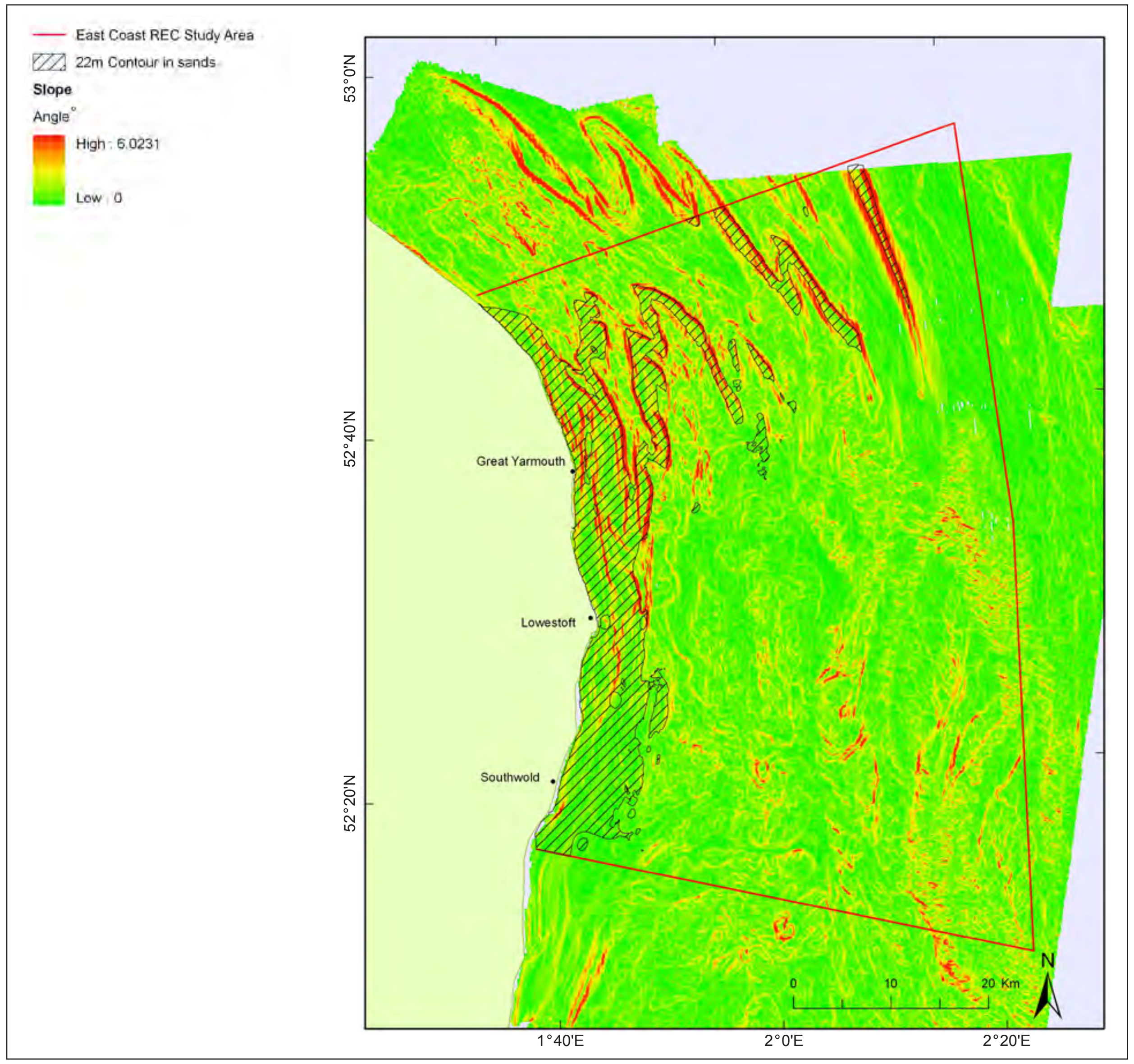


Figure 8.1 **Location of sandbanks in the East Coast REC Study Area mapped on the basis of sandy sediments in proximity to banks with a slope >1° where the top of the bank is in <20 m water depth. A depth contour of 22 m was chosen as the baseline for identifying features. Digital bathymetry data © British Crown and SeaZone Solutions Ltd. All rights reserved. Data Licence 052008.012.**

Area. However, there are a number of habitats that fall under the Annex I category of biogenic reef. The main reef-building species identified during this study are the Ross worm *S. spinulosa* and the blue mussel *M. edulis,* which are both listed as specific examples of biogenic reef in Annex I of the Habitats Directive. Brittlestar beds were also identified in the study area, and, whilst they are not considered to constitute a biogenic reef in themselves, they have been identified as sub-features of reef habitats (Hughes, 1998) and so have been included here for completeness.

Sabellaria spinulosa reef

Sabellaria spinulosa was by far the most abundant organism recorded during the survey of the East Coast REC Study Area, with over 12,000 individuals being recorded in 158 grab samples and considerably more captured in the trawl samples and video footage. To identify and classify areas of *S. spinulosa* reef, an assessment of "reefiness" was undertaken following guidance set out in Hendrick and Foster-Smith (2006) and Gubbay (2007). All observations relating to *S. spinulosa* recorded from grab, trawl and video samples (including absences) were collated and transformed into scores, where 0 = no evidence of reef and 3 = strong evidence of reef (Table 8.1). A confidence score based on the number and different types of observations (grabs, trawls and/or seabed pictures) as well as the consistency (standard deviation) of the observations was also calculated for each sampling station (Table 8.2). Stations identified as having moderate to high reefiness scores are widely distributed across the East Coast REC Study Area (Figures 8.2–8.4), indicating that the environmental conditions of this region are generally well suited to reef development. This is perhaps unsurprising since there is an ample supply of sand in the area, which this species requires for tube construction. There are, however, far more potential *S. spinulosa* reef features in this region than previously documented (JNCC & Natural England, 2010), highlighting the importance of survey work on this scale.

Modelling environmental controls on *Sabellaria* distribution

Using the multibeam data collected during the study, seven main areas for *Sabellaria* reef were identified and mapped (Figure 8.5). It is worth noting that as the line spacing of the preliminary acoustic grid survey was on average 2.7 km, there could be significant additional areas of reef not yet identified across the East Coast REC Study Area. A set of environmental variables were assembled (Table 8.3) in order to identify physical differences in the area that might explain the distribution of *Sabellaria*.

The maximum entropy (Maxent) method for modelling (Phillips *et al*., 2006) was chosen to model the distribution of *Sabellaria* across the East Coast REC Study Area, as it relies on presence only records (and is less sensitive to low sample numbers than are other methods: Wisz *et al*., 2008). This was considered appropriate for this study, as only a small number of stations had replicate samples (maximum of 3) and the infaunal densities were relatively low. Thus, the power of the grab sample data to characterise the environment is extremely low even when sampling is arranged within "strata" (Bartsch *et al*., 1998; Ramey *et al*., 2009; Rogers *et al*., 2008). Therefore, the approach of ignoring species associations within samples and comparing the relationship of species across all samples is considered appropriate in this case.

Grab observations									
No.	**SCORE**	**Weight (g)**	**SCORE**	**Volume (ml)**	**SCORE**	**Mean tube length (cm)**	**SCORE**	**Notes**	**SCORE**
0	0	0	0	0	0	0	0	Absent	0
1–10	1	1–50	1	1–50	1	1	1	Rubble	1
11–100	2	51–500	2	51–500	2	2.5	2	Veneers	2
>100	3	>500	3	>500	3	>5	3	Clumps	3
Trawl observations									
Presence	**SCORE**	**Volume (l)**	**SCORE**	**Mean tube length (cm)**	**SCORE**	**Max tube length (mm)**	**SCORE**	**Notes**	**SCORE**
A	0	0	0	0	0	0	0	Absent	0
P	1	1–5	1	1–2.5	1	1–5	1	Rubble	1
		6–20	2	2.6–5	2	6–10	2	Veneers	2
		>20	3	>5	3	>10	3	Clumps	3
Video observations									
Presence	**SCORE**	**Max Elevation**	**SCORE**	**Max % Cover**	**SCORE**	**Mean % Cover**	**SCORE**	**Notes**	**SCORE**
A	0	0	0	0	0	0	0	Absent	0
P	1	1–5	1	1–25	1	0.1–5	1	Rubble	1
		6–10	2	26–50	2	6–10	2	Veneers	2
		>10	3	>50	3	>10	3	Clumps	3

Table 8.1 Scoring system applied to observations of *Sabellaria spinulosa* where 0 = no evidence of *S. spinulosa* reef, 1 = low evidence, 2 = moderate evidence and 3 = strong evidence.

a. Adequacy of sampling				b. Consistency of observations		a. Overall confidence	
Sampling gear	**Score**	**Sum of observations**	**Score 1**	**SD**	**Score 2**	**Score 1*Score 2**	**Score**
Grab sample	1	0	0	0	3	1	1
Trawl sample	3	1–3	1	0.5	2	2	2
Video sample	3	4–5	2	1	1	5	3
		6+	3				

Table 8.2 Confidence assessment applied to observations of *Sabellaria spinulosa* where 0 = no confidence in the reefiness assessment, 1 = low confidence, 2 = moderate confidence and 3 = high confidence.

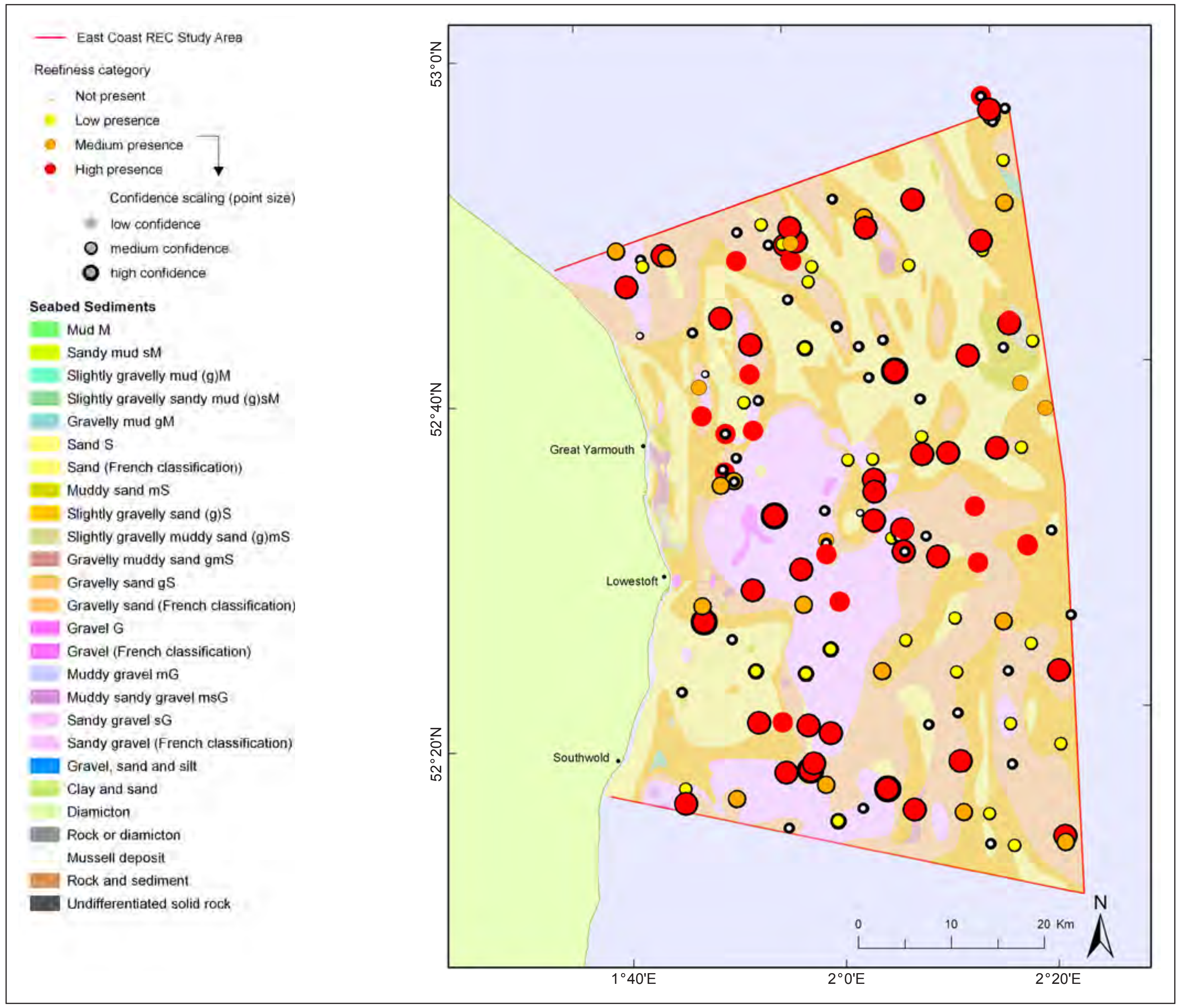


Figure 8.2 Chart showing the level of *Sabellaria spinulosa* "reefiness" detected, and associated confidence level, at each of the East Coast REC Study Area sampling stations using criteria set out in Tables 8.1. and 8.2., overlaid on the modelled sediment map.

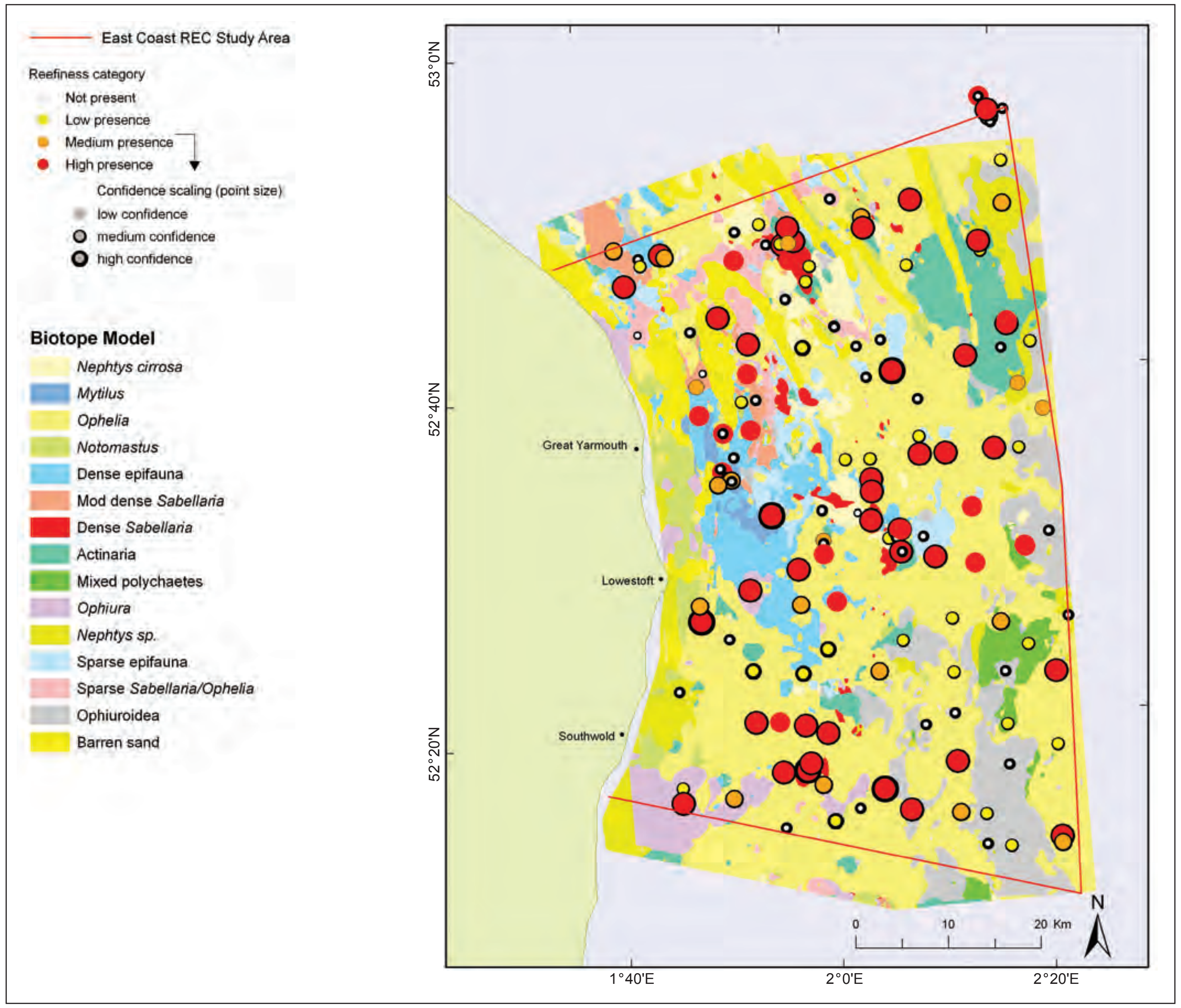


Figure 8.3 Chart showing the level of *Sabellaria spinulosa* "reefiness" detected, and associated confidence level, at each of the East Coast REC Study Area sampling stations using criteria set out in Tables 8.1 and 8.2, overlaid on the modelled biotope map.

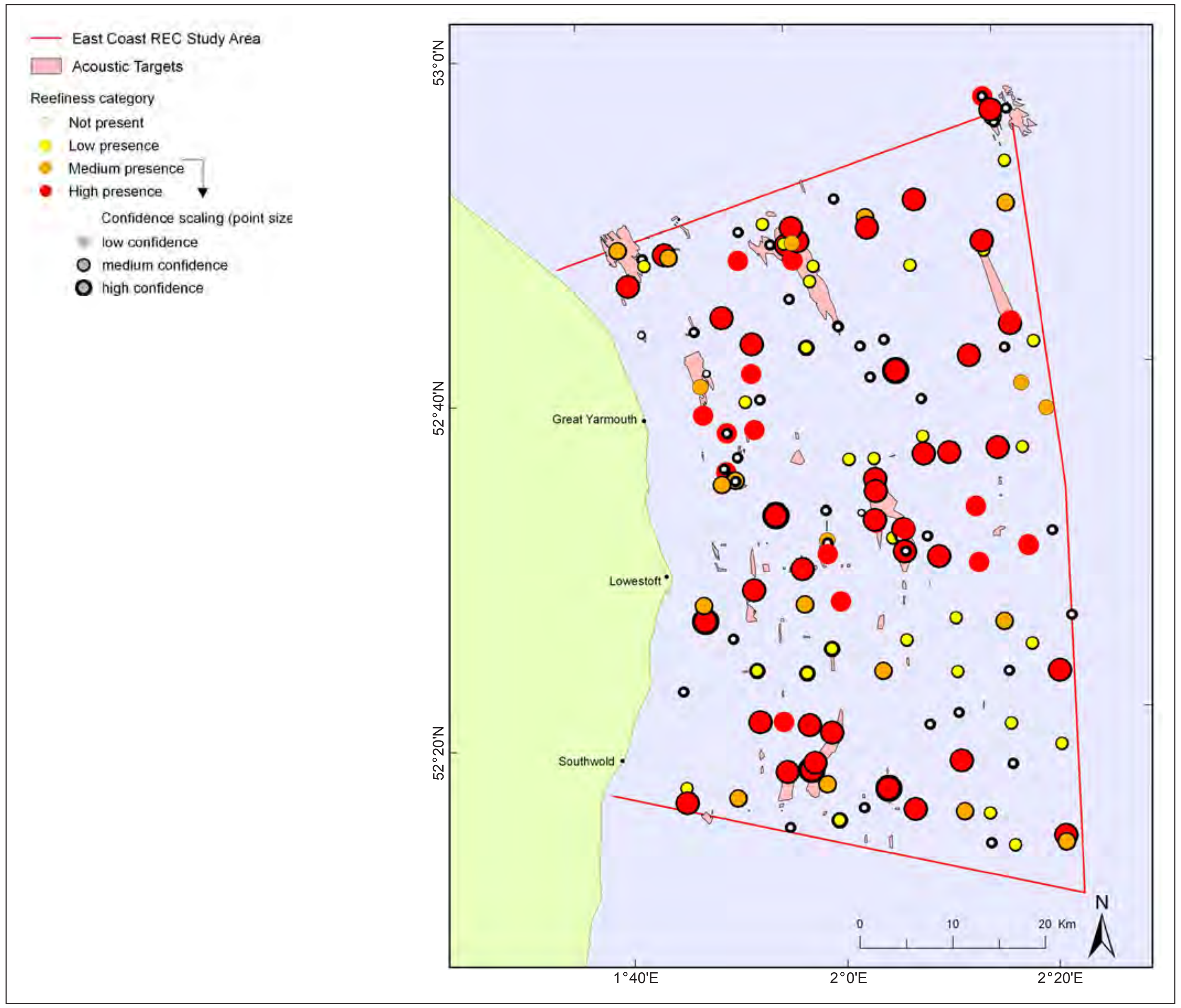


Figure 8.4 Chart showing the level of ***Sabellaria spinulosa*** "reefiness" detected, and associated confidence level, at each of the East Coast REC Study Area sampling stations using criteria set out in Tables 8.1 and 8.2, overlaid on the acoustic targets identified as likely ***S. spinulosa*** reefs.

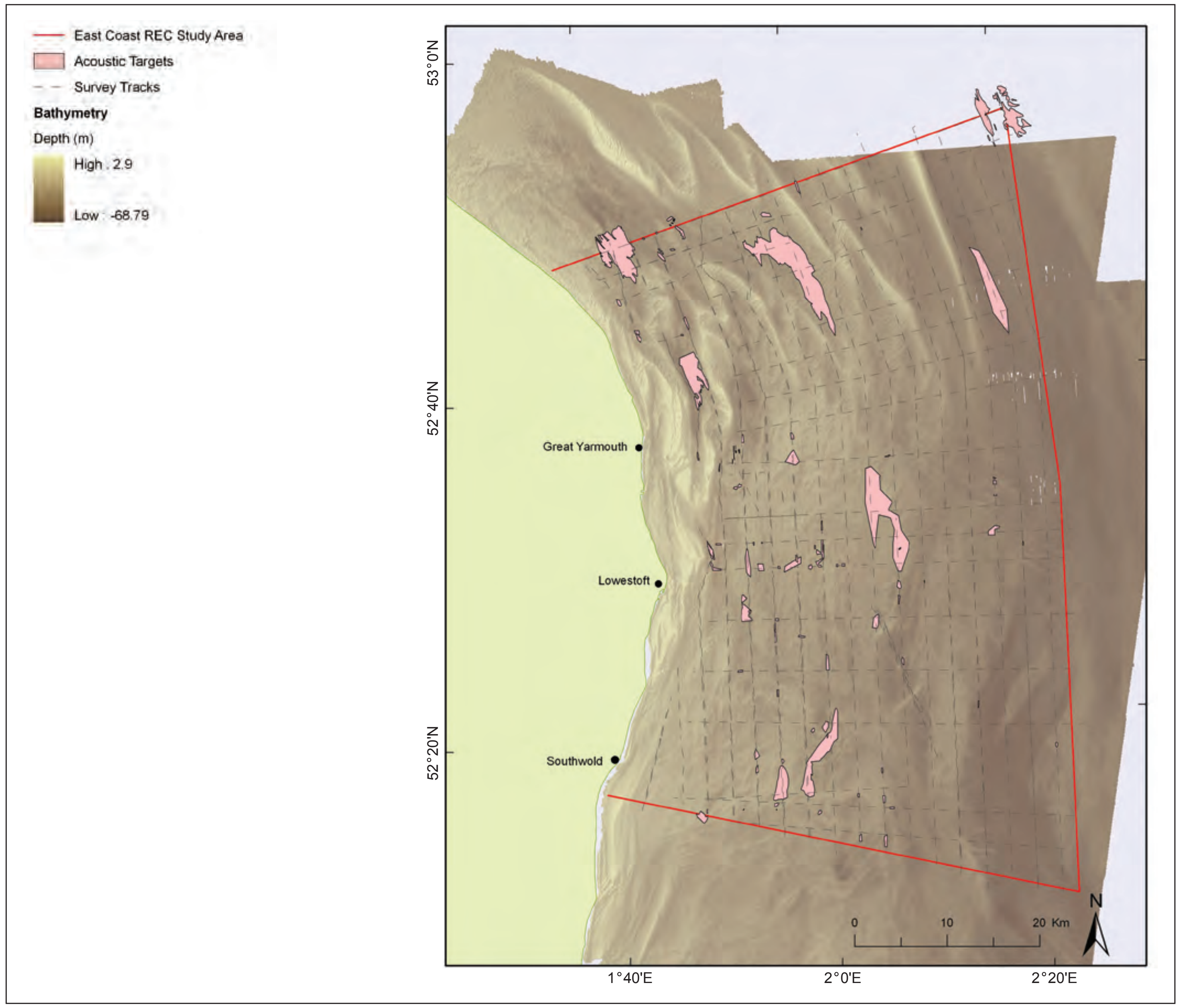


Figure 8.5 Map of study area with acoustic targets identified as likely ***Sabellaria spinulosa*** reefs overlaid on Digital bathymetry data (values given in metres relative to CD). © British Crown and SeaZone Solutions Ltd. All rights reserved. Data Licence 052008.012.

Environmental variables used in species distribution modelling	
Bathymetry – at various resolutions	Morphological regions based on multibeam interpretation
Seabed slope – at various scales	Textural surfaces based on multibeam interpretation
Slope aspect – at various scales	Classified seabed terrains – using BTM software
Rugosity	Proximity to wrecks and gridded surface of scour depth
Gridded seabed sediments – mud, sand and gravel layers	Gridded summary statistics of side-scan sonar data
Classified seabed sediment areas	Oceanographic variables (tidal strength and range)

Table 8.3 List of the compiled data-sets used in assessing the influence of physical drivers on *Sabellaria* spp. distribution.

In maximum entropy habitat modelling, the true distribution of a species is represented as a probability distribution over all sites/pixels across the study area. Each pixel will have a non-negative value derived from the sum of the probability distributions for each of the environmental variables investigated. The distribution of the probabilities (or response curve) for each variable is produced from the occurrence data. Since the set of response curves typically under-specifies the model, among all probability distributions satisfying the constraints, the one with the maximum degree of entropy is then taken as the best fit (for further references, see Phillips & Dudík, 2008). The model can be interrogated not only to show what the response of each species is to each environmental variable, but also which combination of variables combine spatially to produce "hotspots".

Table 8.4 gives estimates of the relative contributions of each of the environmental variables to the Maxent model.

Figure 8.6 shows an increase in the probability of *Sabellaria* occurrence with an increased density of mapped geological features. These features are typically underlying geological horizons that may provide a suitable stable substrate for *Sabellaria* to attach to than would the more common mobile sands across the area.

As *Sabellaria* require an adequate supply of sand and passing nutrients, it seems logical that there should be a strong positive correlation between habitat suitability for reef formation and tidal current strength. Figure 8.7 suggests that such a relationship exists in this area. Furthermore, it also appears that tidal currents in this area do not reach a speed at which they start to adversely affect the ability of *Sabellaria* to become established.

Figure 8.8 suggests that there is also a relationship between the occurrence of *Sabellaria* and water depth. This is surprising since there is no known biological reason as to why *Sabellaria* should prefer a particular water depth (within the limits of these shallow waters). The observed relationship may therefore be explained by the sampling strategy (with many more samples in the 20–40 m range), or it may be a reflection of another variable that is correlated with water depth (eg, storm wave disturbance of the seabed).

There is a positive correlation between the standard deviation of side-scan backscatter data and the probability of *Sabellaria* occurrence (Figure 8.9). Side-scan data records reflect the physical response of the seabed to acoustic energy, and thus they provide an indication of the physical composition of the seabed. In the East Coast REC Study Area, most of the variation in sediment type was between sands and gravelly sands. The relationship between backscatter records and *Sabellaria* distribution may therefore be explained by the preference of *Sabellaria* for a particular seabed type. However, the extensive nature of the reefs means that there may be a direct influence of *Sabellaria* on the backscatter data, producing a higher standard deviation where *Sabellaria* is present. By combining the response relationships, a probability map can also be constructed (Figure 8.10).

Variable	Percent contribution	Permutation importance
Geological features	21.6	12.1
Tidal power	17.7	20.6
Bathymetry	12.9	19.1
Side-scan statistics	10.5	25.7

Table 8.4 Assessment of the contribution of the top four environmental variables to *Sabellaria* distribution model.

One variable that has been left out of the analysis is the mapped extent of *Sabellaria* reef distribution based on an analysis of multibeam bathymetry records. This is because the grab sampling locations were based on the output of multibeam bathymetry data, which may therefore introduce an inherent bias in the predictions. However, when included, it accounts for 57% of the predictive power of the model (see Figure 8.10). The variation in *Sabellaria* occurrence explained by multibeam records is therefore almost as much as that accounted for by the top four variables combined in the previous model. That the multibeam bathymetry data do not account for a higher percentage of predictive power is not surprising, since acoustic methods such as these are only capable of discriminating well-developed aggregations of *Sabellaria* reef, not individual counts. Figure 8.11 shows the difference between the model that includes mapped *Sabellaria* extent based on an analysis of multibeam records and the model without it.

Both the modelled biotope map and the acoustic signatures map constructed as part of the East Coast REC Study Area programme go some way to predicting the occurrence of *S. spinulosa* reefs across the region. It is clear from Figures 8.3 and 8.4 that there is a good correspondence between the modelled distribution and the station-by-station reefiness assessment. However, there are certainly occurrences of reef which have not been picked up by either model. To quantify the correspondence between the two modelled distributions of *S. spinulosa* reefs and the reefiness assessment, the % matches, false negatives (prediction of no reef

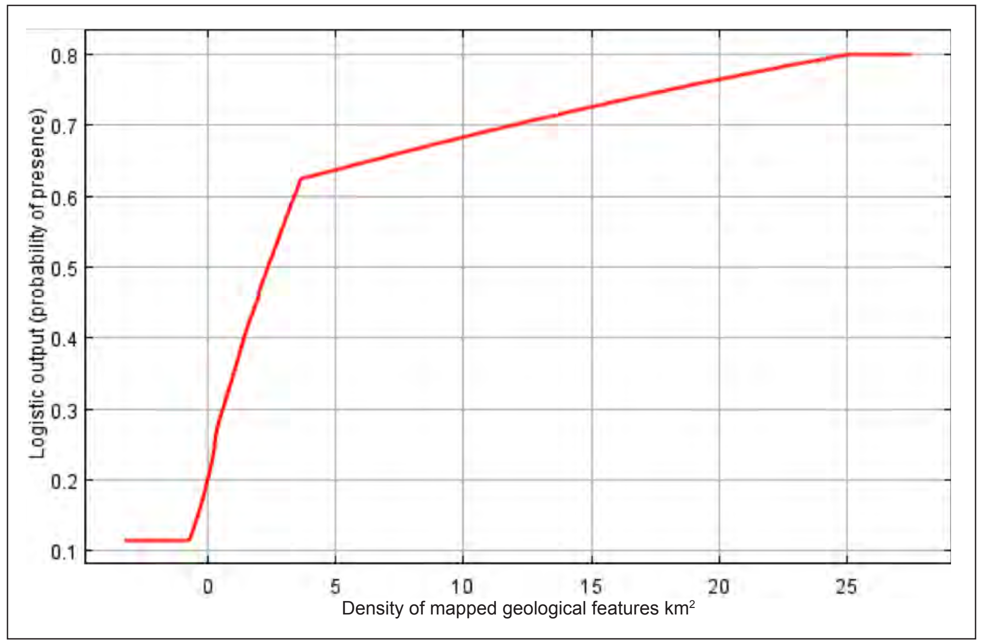


Figure 8.6 **Response of modelled probability of *Sabellaria* occurrence in relation to the variation in the density of mapped underlying geological features (eg, sub-cropping clay layers).**

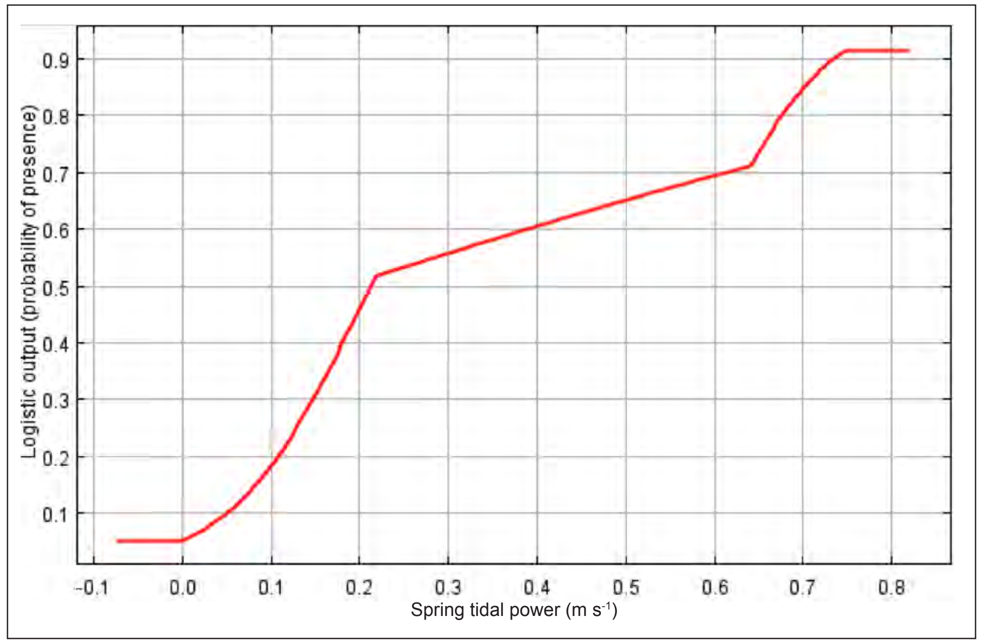


Figure 8.7 **Response of modelled probability of *Sabellaria* distribution to the variation in spring tidal power.**

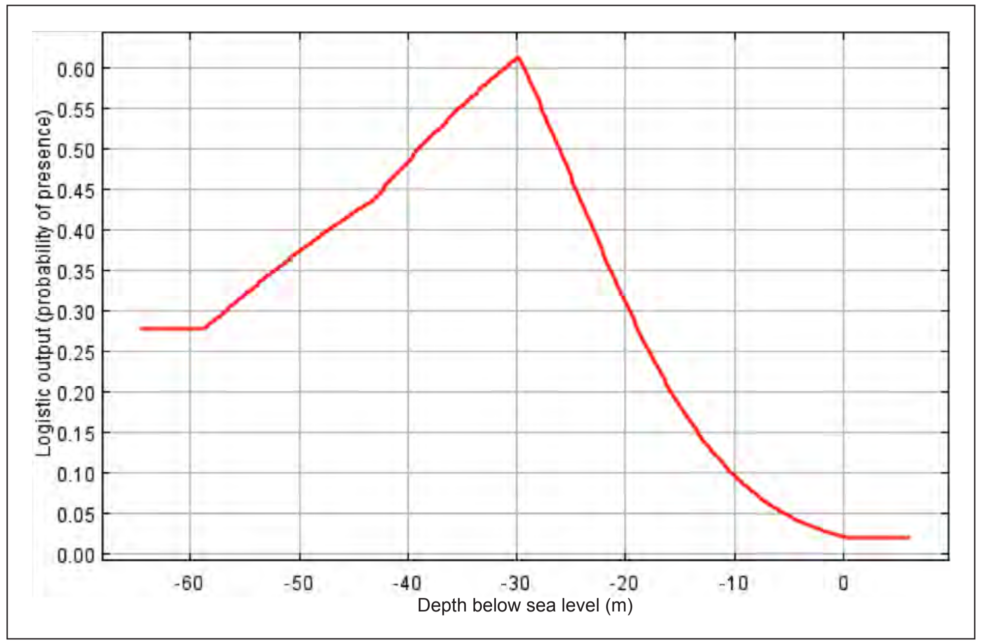


Figure 8.8 **Response of modelled probability of *Sabellaria* occurrence in relation to variation in water depth.**

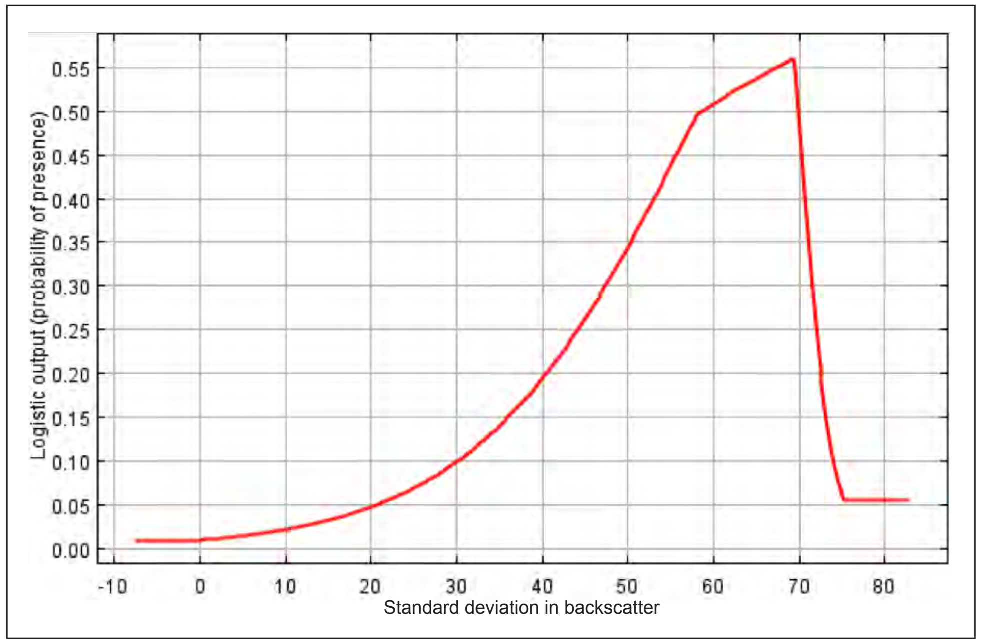


Figure 8.9 **Response of modelled probability of *Sabellaria* occurrence in relation to the variation in standard deviation of side-scan sonar backscatter values.**

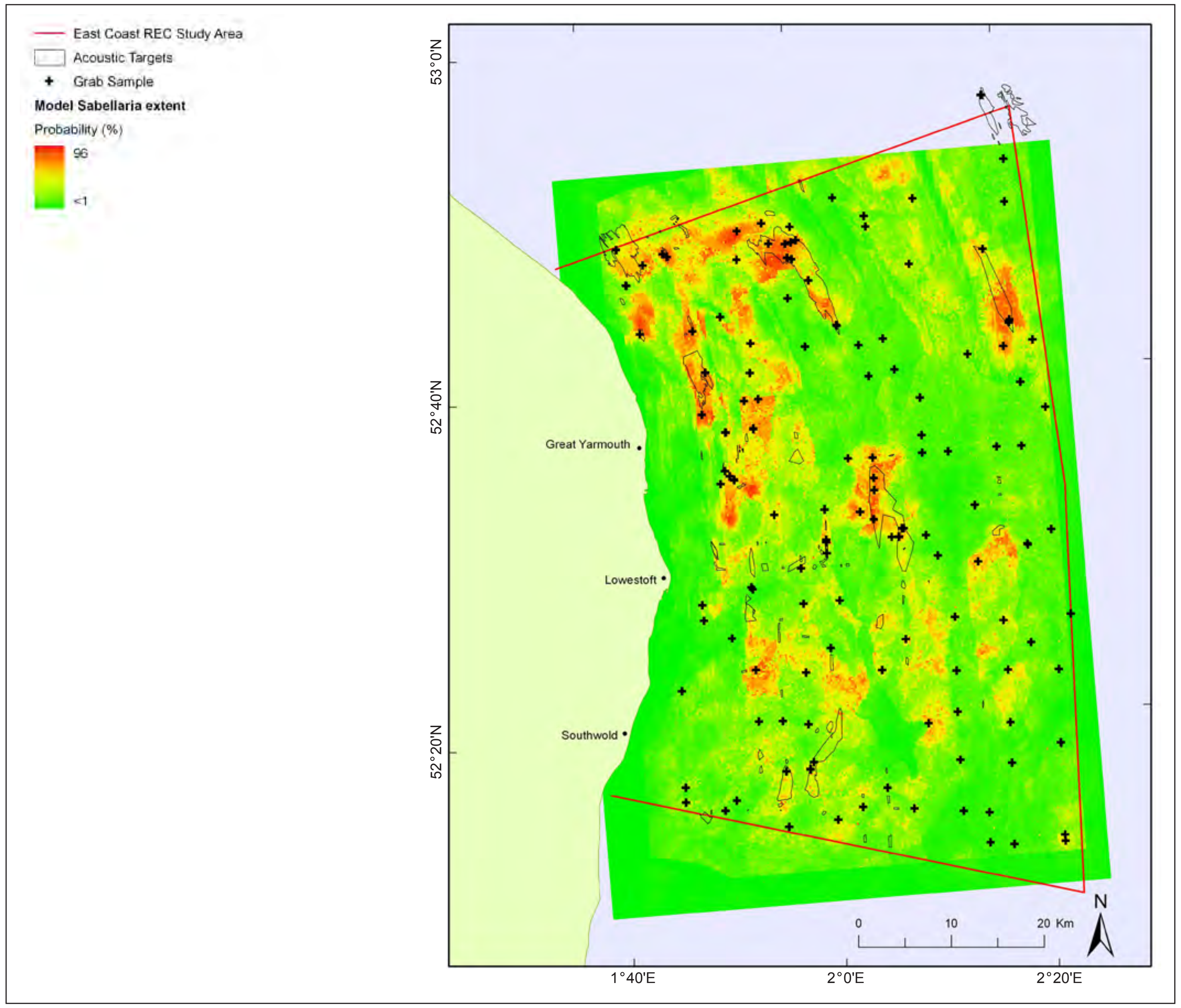


Figure 8.10 Probability distribution map for *Sabellaria* based on Maxent modelling.

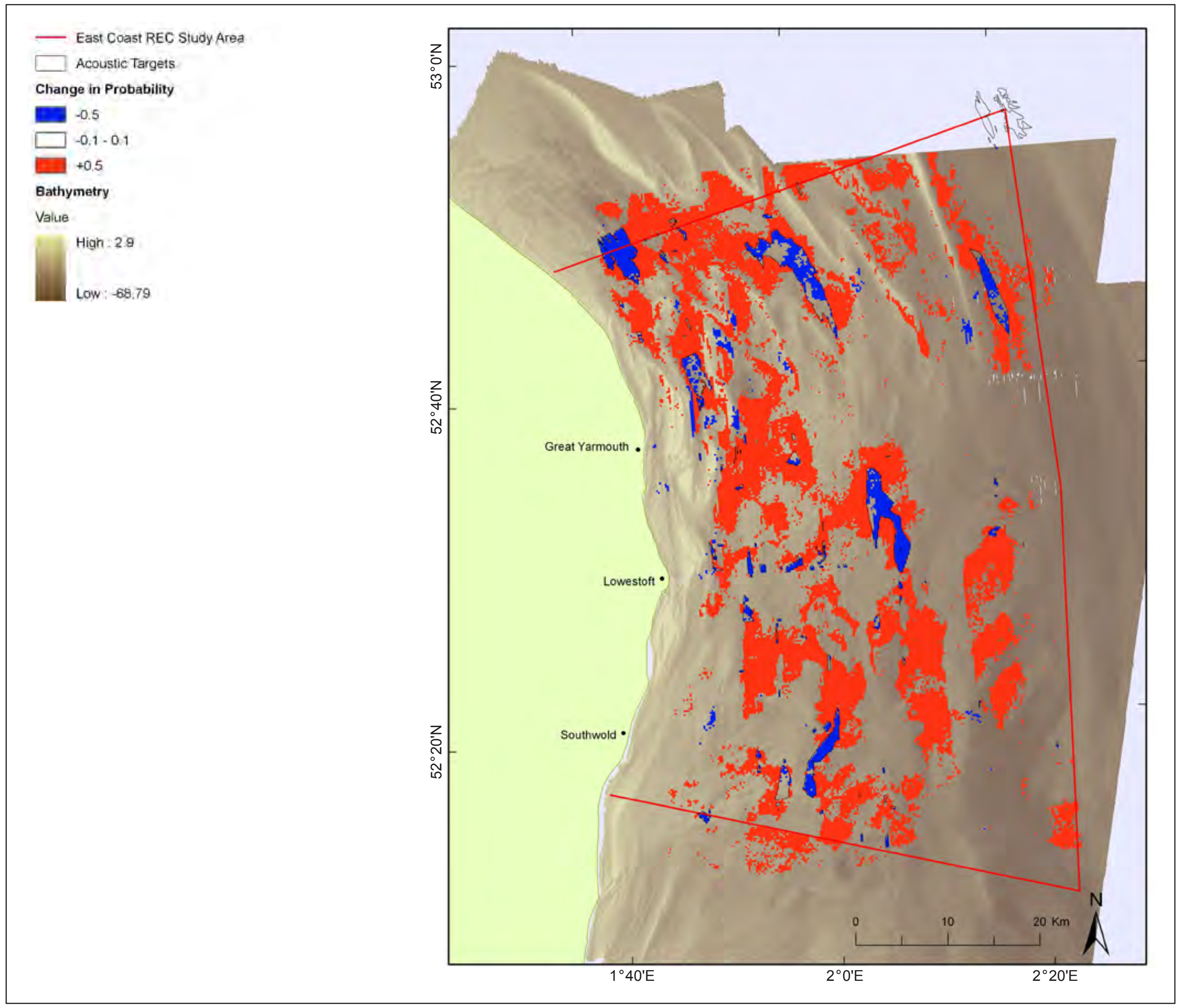


Figure 8.11 Map of the difference in *Sabellaria* probability between two models with and without acoustically mapped *Sabellaria* extent (values given in metres relative to CD). Digital bathymetry data © British Crown and SeaZone Solutions Ltd. All rights reserved. Data Licence 052008.012.

where samples show there is reef) and false positives (prediction of reef where there is no evidence from the samples) have been calculated and are summarised in Table 8.5.

Table 8.5 shows that both the modelled biotope map and the acoustic targets map have predicted the distribution of *S. spinulosa* reefs well, with between 71 and 86% matches, where the confidence in the reefiness classification was deemed to be high. The level of correspondence between the model and the reefiness assessment deteriorates as the confidence in the reefiness classifications decrease, and once the confidence assessment reaches the lowest level the percentage of false negatives increases to between 67 and 79%. Stations where a low level of confidence and high level of reefiness has been ascribed are likely to be composed of a single observation that is considered to be indicative of reef, for example over 500 *S. spinulosa* in a grab sample, but where there may be no evidence of *Sabellaria* in the trawl sample. It is unsurprising then that these observations do not correspond well with the model since it is very likely that they represent isolated clumps rather than an extensive reef structure.

	Modelled biotope map			Acoustic targets map		
Reefiness confidence level	**% Matches**	**% False negatives**	**% False positives**	**% Matches**	**% False negatives**	**% False positives**
High (*n* = 52)	86	4	10	71	6	23
Moderate (*n* = 79)	39	54	7	49	42	9
Low (*n* = 24)	21	79	0	33	67	0

Table 8.5 Summary of the % matches, % false negatives (predicted no reef where samples show there is reef) and % false positives in the modelled *Sabellaria spinulosa* reef distributions when compared with station-by-station reefiness assessment.

The percentage of false positives, where the model predicted the presence of *Sabellaria* but none was found, was 10% for the modelled biotope map and 23% for the acoustic map. A lack of evidence for the presence of *Sabellaria* in the areas where the biotope has been modelled with high confidence may be due to the highly patchy nature of reefs (Figure 8.12). It is possible that even in areas of well-developed reef, a grab sampler can fall into a small area which displays no evidence of reef whatsoever. There were more false positives in the acoustic targets map than in the modelled data, indicating that the model may be a more accurate prediction of *S. spinulosa* reef distribution.

The acoustic targets map has been created on the assumption that irregular texturing visible on multibeam backscatter data is created by *S. spinulosa* reef structures (Figure 8.13). Whilst *Sabellaria* reefs can be identified by an irregular texture in acoustic data, there are also several other habitat types, such as mussel beds or areas of cobbles, that may give a similar acoustic signature (Coggan *et al*., 2009). Distinguishing between these is extremely difficult and often results in a number of false positive identifications of *Sabellaria* reefs from acoustic data.

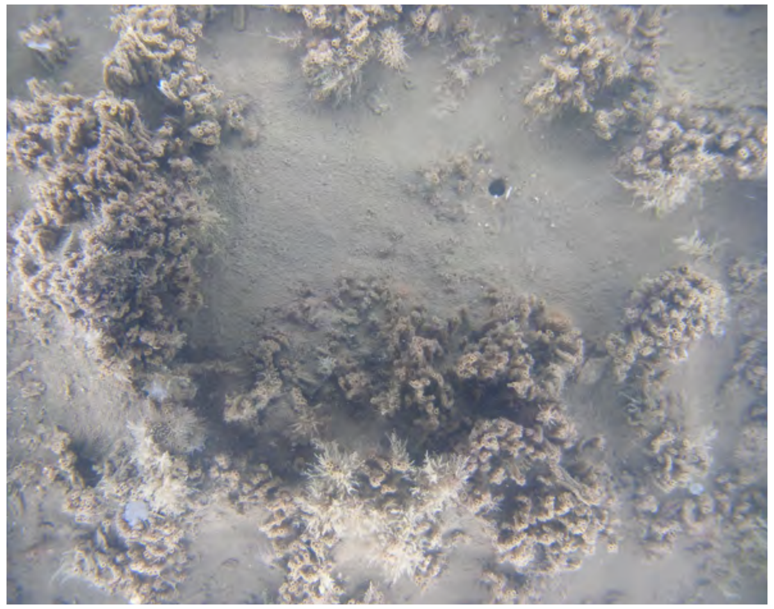


Figure 8.12 Photograph of a *Sabellaria spinulosa* reef in the Outer Thames sea area, demonstrating the often patchy nature of these features (© seasurvey.co.uk).

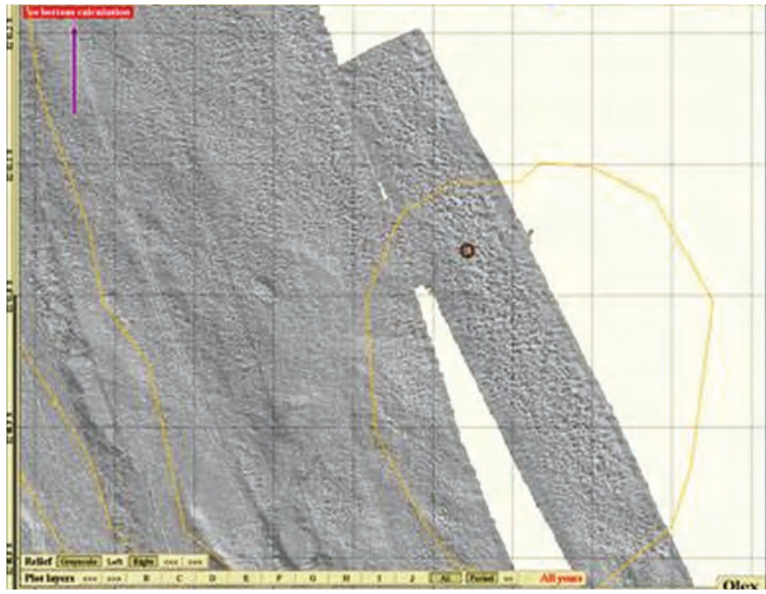


Figure 8.13 Shaded multibeam image showing the irregular texturing assumed to indicate the presence of *Sabellaria spinulosa* reef. Used with permission of Olex.

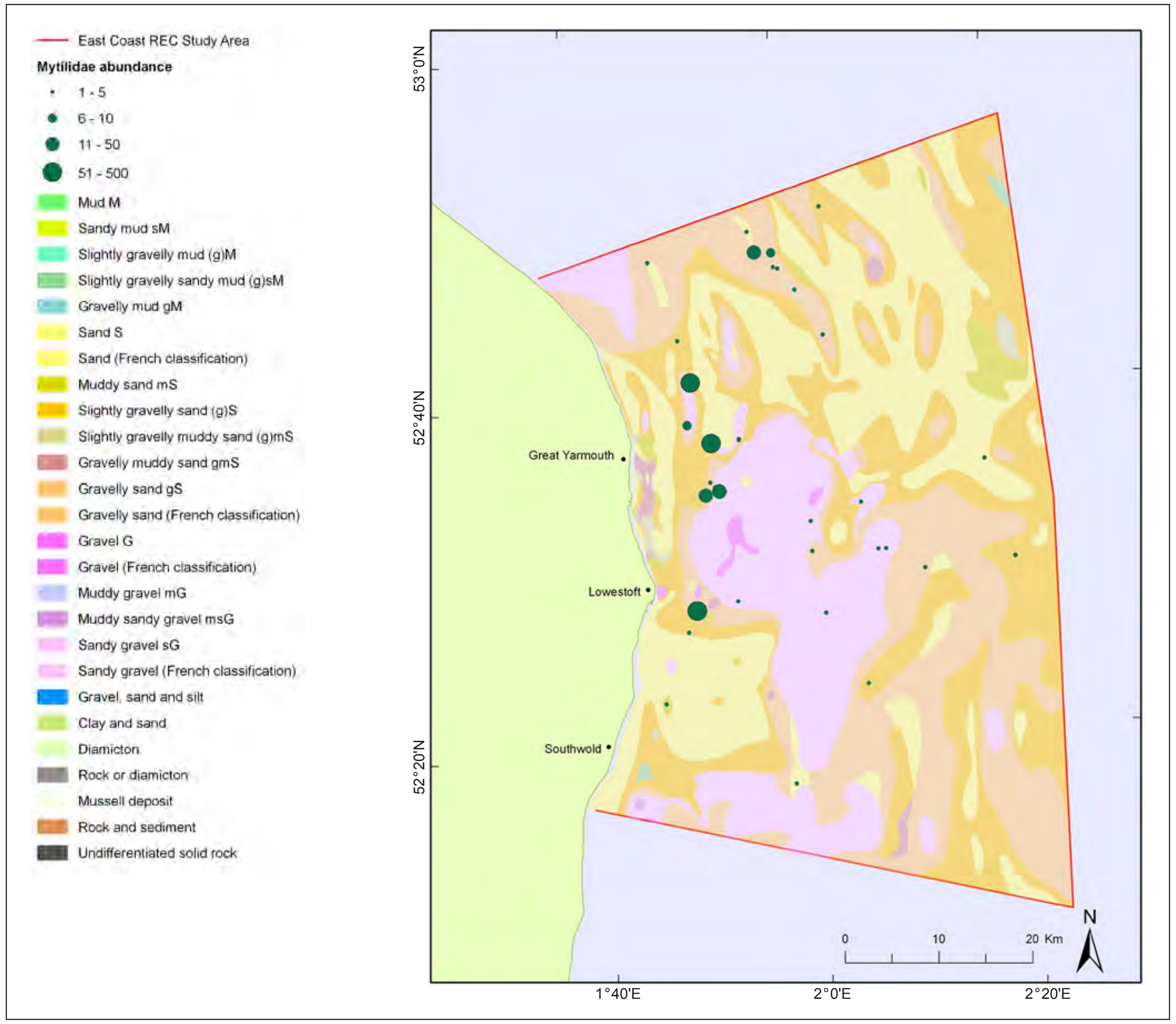


Figure 8.14 Chart showing the abundance of the edible mussel *Mytilus edulis* (0.1 m^{-2}), at each of the East Coast REC Study Area sampling stations, overlaid on the modelled sediment map of the area.

Figure 8.15 Photograph of a *Mytilus edulis* bed in the southern North Sea (© seasurvey.co.uk).

The edible or blue mussel, *Mytilus edulis*, is another reef-building organism that was present in the East Coast REC Study Area, albeit in lower abundances. Expansive mussel beds were not evident in any of the seabed footage, but areas of dense mussel aggregations were identified (Figures 8.14 & 8.15). Further investigation would be required to determine the suitability of these habitats for inclusion in the Natura 2000 Network. There is some overlap between the distribution of dense Mytilidae aggregations and *S. spinulosa* reefs (Figures 8.2 & 8.14) especially in the north of the study area. Both mussels and reef-building polychaetes require a solid surface upon which to attach and so do tend to occupy similar habitats. It is therefore possible that these aggregations may be responsible in part for the discrepancy between the acoustic signatures and *S. spinulosa* reefiness distributions.

Brittlestar beds

Brittlestar beds are defined by Hughes (1998) as the occurrence of brittlestars at high densities (hundreds or thousands per square metre), living epifaunally on bedrock, boulder, gravel or sedimentary substrata. Four brittlestar species – *Ophiothrix fragilis, Amphiopholis squamata, Ophiura albida* and *Ophiura ophiura* – were identified in the East Coast REC Study Area, and their distribution has been plotted in Figure 8.16.

The main bed-forming brittlestar species, *O. fragilis*, is present in densities indicative of beds at a single site in the north of the study area, where there are also high densities of *A. squamata* and *O. ophiura*. This area was identified as a *S. spinulosa* reef (Figure 8.2) and also contained dense aggregations of the blue mussel *M. edulis* (Figure 8.15). All of the evidence suggests that this area supports a complex of different biogenic reef habitats, and so this would certainly

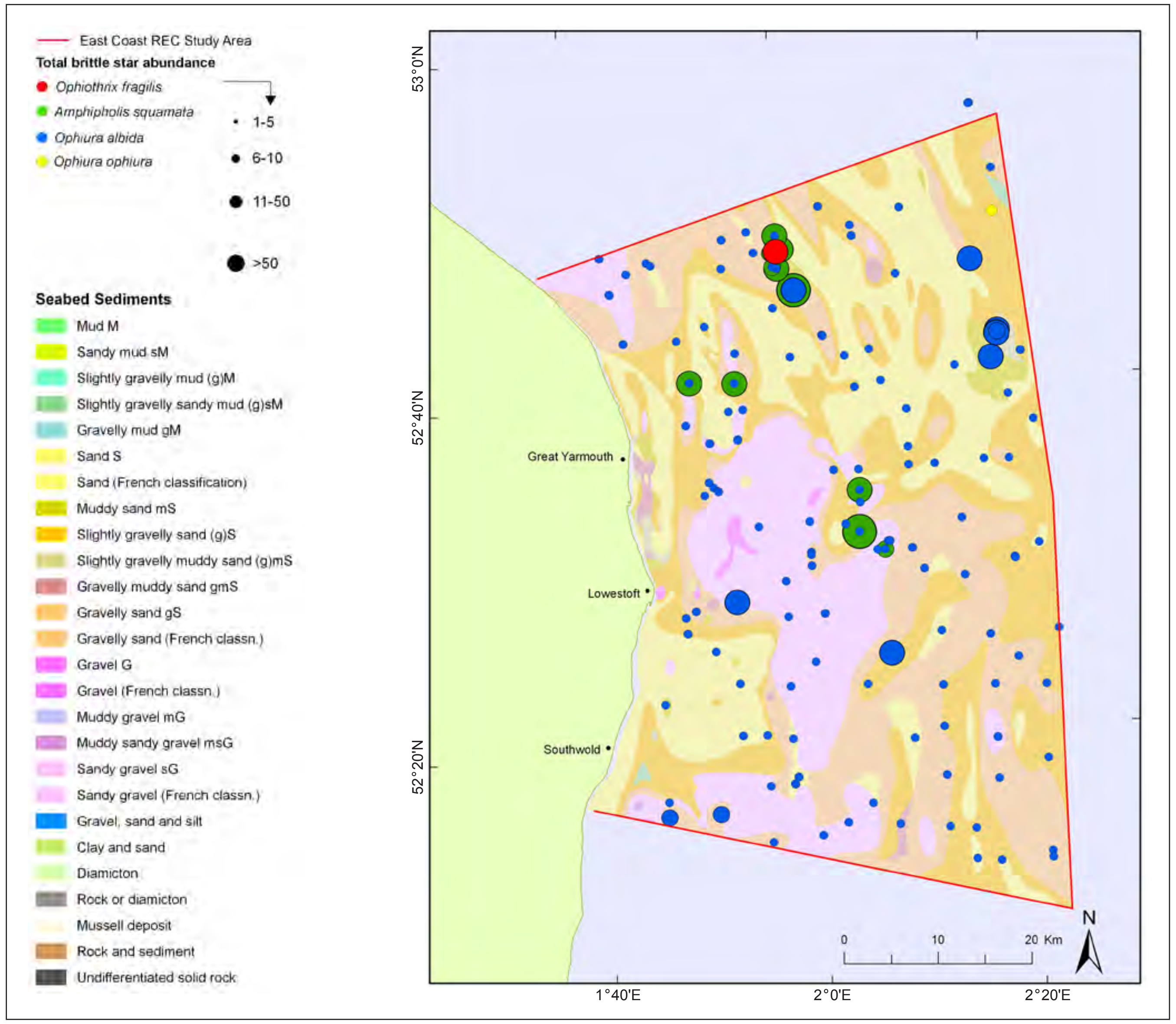


Figure 8.16 Chart showing the abundance of brittlestar species (0.1 m^{-2}), at each of the East Coast REC Study Area sampling stations, overlaid on the modelled sediment map of the area.

seem like a good focus for conservation efforts, since a wide variety of priority habitats could be protected in a relatively small area.

Amphiopholis squamata and *O. albida* were found in high densities elsewhere in the study area. These two brittlestar species are not known to actively associate with their conspecifics, as *O. fragilis* and other bed-forming brittlestars do, but the high densities identified across this region would suggest that there may be an element of gregariousness to their behaviour. Brittlestar beds currently have no economic value; however, they are of considerable scientific interest since they are known to have been successful over long periods of geological time (Schafer, 1972; Russel-Hunter, 1979). Their population size is also thought to be structured almost entirely by predation, so it is likely that they play an important function in the wider marine ecosystem (Hughes, 1998).

8.2 Archaeological features of interest

8.2.1 Features of interest 1: Hand axe discovery

Between December 2007 and February 2008, 75 Palaeolithic artefacts, including hand axes, flakes and cores, and a series of bones (including woolly mammoth, bison and reindeer) were discovered in stockpiles of gravel at the SBV Flushing Wharf, near Antwerp. The artefacts were recovered from a discrete area within Area 240, an aggregate dredging area licensed to Hanson Aggregate Marine Ltd (HAML), situated approximately 11 km off the coast of Great Yarmouth, within the East Coast REC Study Area.

The lithics are currently being assessed by Dr Dimitri de Loecker (University of Leiden), and the faunal remains are being assessed by Dr Jan Glimerveen. The deposits from which the finds were dredged are being investigated as part on an ongoing ALSF-funded project targeting these deposits using geophysical, geotechnical and seabed sampling methodologies. Further faunal remains and flint flakes have been recovered from the same area (Wessex Archaeology, 2010a), including a flint flake recovered from a Clamshell grab sample during the East Coast REC Study Area ground-truthing survey.

The finds were recovered from sediments deposited in an outer estuary or restricted shallow marine environment, which are probably associated with a buried channel feature (Figure 8.17). The infill sediments vary in composition and are indicative of a changing flow regime, with periods of high-energy and low-energy sediment deposition. There is also some evidence of sediment oxidation, which may be a result of weathering and exposure to air. The age of the channel cut-and-fill deposits is, at present, unknown, but the channel may have been cut during the late Elsterian/Anglian Glacial Stage (approximately 430,000 BP). Similar channels in the East Coast REC Study Area indicate dates of approximately 30,000 BP for the upper fill deposits, possibly indicating that these channels have continued to flow and infill throughout much of the middle and late Pleistocene.

The East Coast REC Study Area has provided regional, geological and environmental context in relation to the recovered Palaeolithic finds. As such, this information will provide an essential underpinning for decisions aimed at ensuring the sustainable management of offshore resources and protecting the marine historic environment.

8.2.2 Features of interest 2: Early Mesolithic channel

Extensive Mesolithic landscapes have been identified to the north of the East Coast REC Study Area (Fitch *et al.*, 2005), where 3D-seismic data were used to map late Pleistocene and Holocene depositional systems in great detail. The area was a vast plain with a complex meandering river system with associated tributaries and lakes, which later developed into a dendritic network of fluvial, estuarine and intertidal origin prior to inundation approximately 7,500 years ago.

Evidence of Mesolithic land surfaces in the East Coast REC Study Area is relatively sparse. Early Holocene deposits associated with the Palaeo-Yare are documented off the coast of Great Yarmouth (Arthurton *et al.*, 1994) and intertidal deposits off the Suffolk coast (Moorlock *et al.*, 2000), as well as a number of peat deposits along the Suffolk and Norfolk coast (Ward *et al.*, 2006).

The early Holocene channel identified in the East Coast REC Study Area originates from the valley of the River Yare onshore and flows eastwards for 10 km before meandering south (Figure 8.18). The channel is infilled with a transgressive sequence of marshland peats, deposited approximately 10,710 cal. BC overlain with progressively more estuarine sediments deposited as the channel was inundated at the start of the last transgression approximately 5970 cal. BC.

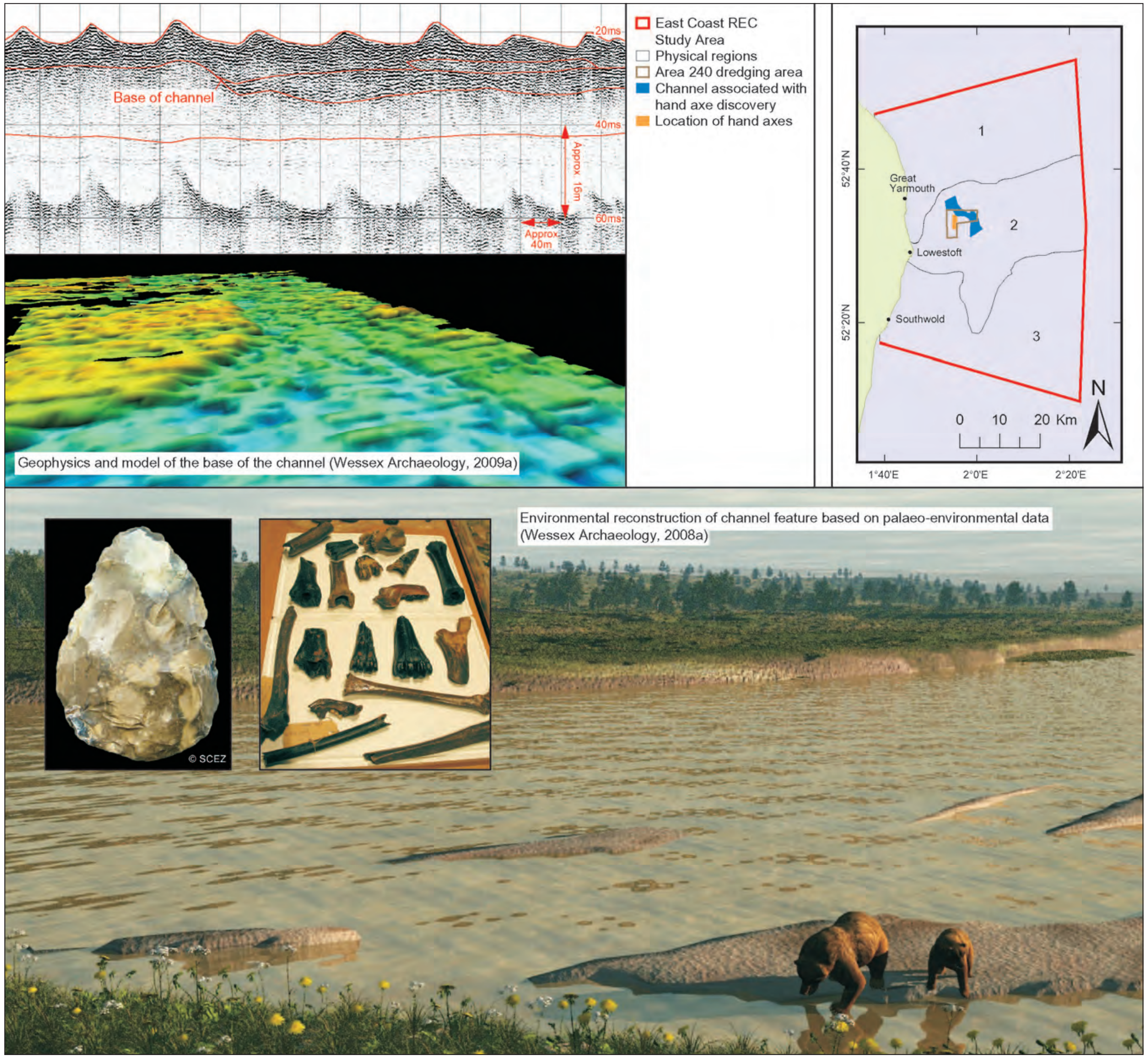


Figure 8.17 Geophysical data used to define the channel situated close to where the hand axes were discovered and a reconstruction of how the landscape may have looked around 100 ka.

The environment through which the channel flowed comprised a marshland with occasional shrubs with open shrub woodland within close proximity, which included birch, aspen and willow. Towards the outer regions of the channel the environment was more saltmarsh in character, with evidence of oak, elm and hazel being the dominant species.

The presence of this early Holocene channel indicates that there may be more extensive evidence of Mesolithic land surfaces now submerged. Mesolithic landscapes are also important in our understanding of how the environment changed during the last transgression as sea levels rose, and how humans would have had to adapt to the rising coastal sea levels.

8.3 Maritime features of interest

8.3.1 Sail, paddle and screw in the nineteenth century

Sail and rig were always the dominant traditions of vessel propulsion, and it was only at the beginning of the nineteenth century that a genuine but gradual alternative to sail was fully developed. The use of steam power was, however, to be a revolution for shipping, with many merchant companies quick to recognise its potential for even longer distance trade.

Initially using paddle wheels, single-cylinder engines and low-pressure boilers, vessels equipped with steam power soon illustrated strengthened reliability and speed. In the freshwater lochs of Scotland, experimental paddle-driven steam boats and ships proved successful. It would be American innovators who built the sail-assisted paddle steamer *Savannah*, the first passenger vessel of its type to cross the Atlantic Ocean, using paddle and sail, in May 1819. This was followed by the *Sirius* and Brunel's *Great Western* which completed the Atlantic crossing under sustained paddle steam power in 1838.

Sail-assisted steam paddle vessels gradually became more popular and an established mode of transport, despite definite limitations. Commercial vessels without sail-assist found it difficult transporting

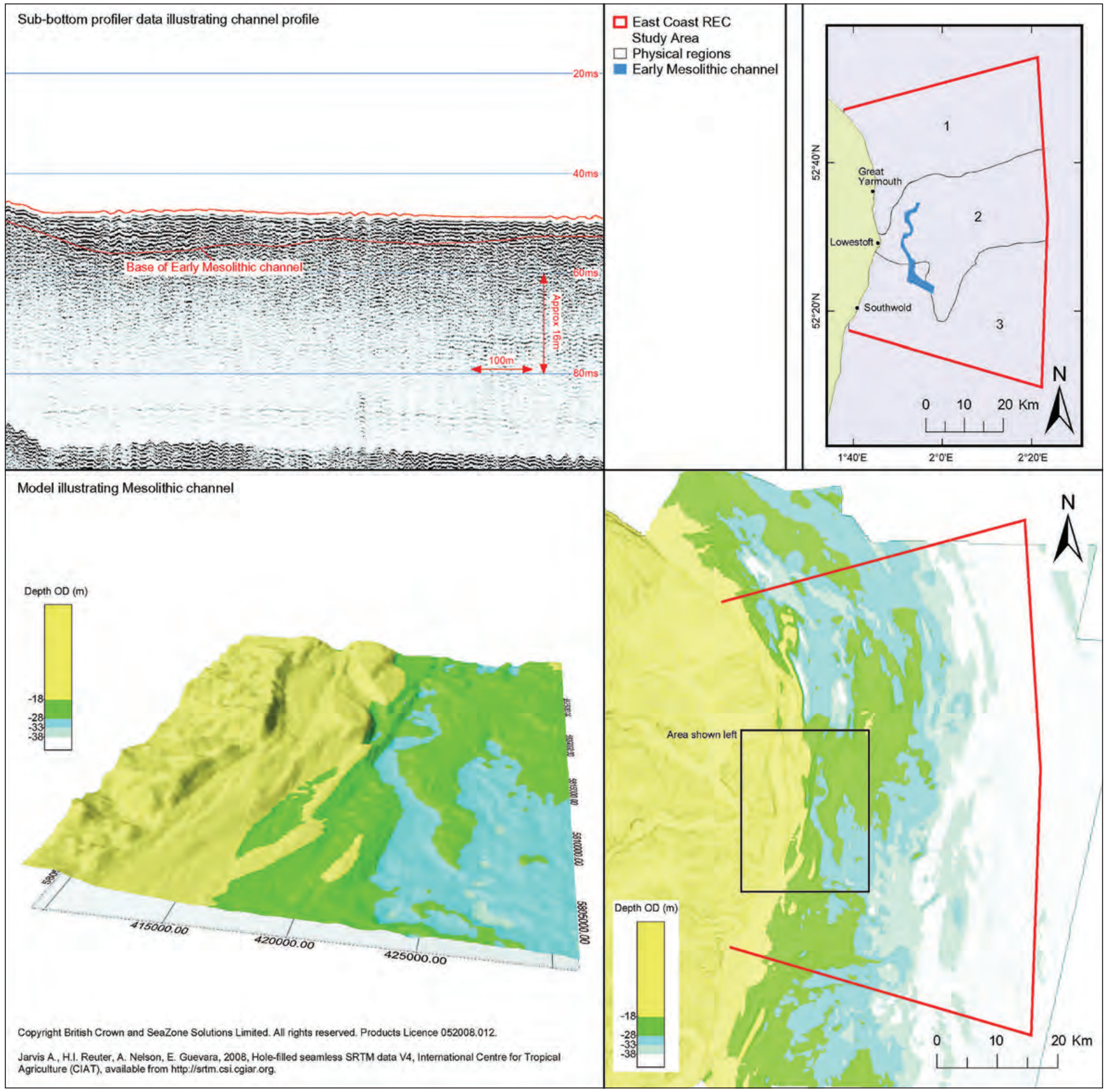


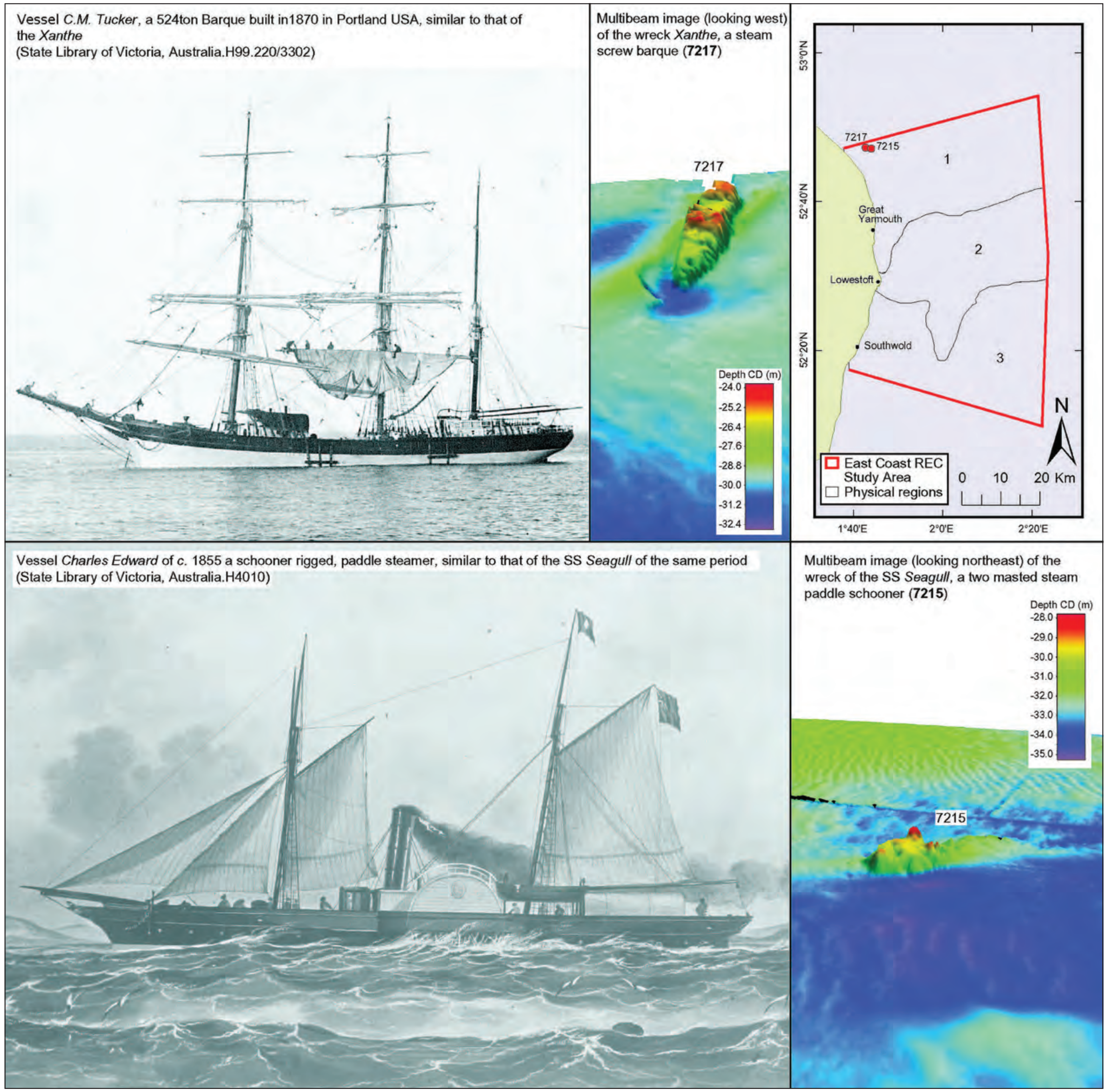
Figure 8.18 **The course of the Mesolithic channel and a cross section of the feature shown in sub-bottom profiler data. Digital bathymetry data © British Crown and SeaZone Solutions Ltd. All rights reserved. Data Licence 052008.012.**

variable amounts of cargo as the paddle wheels did not necessarily work well in the open ocean, and the large amount of coal needed to run the vessel was also a problem, especially with storage at such a premium.

An example of this type of vessel, built at the height of its popularity, is wrecked within the East Coast REC Study Area. The SS *Seagull*, a two-masted steam paddle schooner, was built in Belfast by Coates and Young at Lagan Foundry in October 1847 and was launched at Corporation Dock. The vessel had a successful career in cargo transport, with an apparent service history of around 20 years before it sank in February 1868 after a collision.

Paddle steamers are poorly represented within the archaeological record, especially early examples like the SS *Seagull*, and therefore are of great interest to archaeologists and heritage groups. One of the contributing factors to such rarity and public interest is that open-ocean paddle steamers were gradually superseded by screw/propeller-driven vessels (Allington and Greenhill, 1997), which provided an alternative and more efficient means of propulsion, from the 1830s onwards (Thomas, 1992). However, it was not until the development of the compound engine in 1854 that vessels equipped with screw propulsion could truly compete with the sail or paddle.

A notable example of the screw-driven vessel is the steam screw barque *Xanthe*, of some 689 tonnes, built in April 1862 in Hull by Messrs. Martin, Samuelson and Company. Coincidentally, it also sank after a collision, in December 1869, and is situated approximately 1.5 km to the west of the SS *Seagull*. The *Xanthe* was recorded to have carried commercial cargo in French and Mediterranean waters before being moved to Australia where it was advertised as shipping cattle to New Zealand from Newcastle (*Sydney Morning Herald*, 1864).



Vessel *C.M. Tucker*, a 524ton Barque built in1870 in Portland USA, similar to that of the *Xanthe* (State Library of Victoria, Australia.H99.220/3302)

Multibeam image (looking west) of the wreck *Xanthe*, a steam screw barque (**7217**)

Vessel *Charles Edward* of *c.* 1855 a schooner rigged, paddle steamer, similar to that of the SS *Seagull* of the same period (State Library of Victoria, Australia.H4010)

Multibeam image (looking northeast) of the wreck of the SS *Seagull*, a two masted steam paddle schooner (**7215**)

Figure 8.19 **Multibeam echosounder data of the wrecks SS *Seagull* and *Xanthe* with examples of the vessel types.**

Sail barques of this size and larger were still in commercial use in the 1930s, travelling between Europe and the Southern Hemisphere. However, the adaptation to screw, exemplified by the *Xanthe*, illustrates the diminishing reliance upon what was one of the most romantic, diverse and graceful periods of maritime history. Ultimately, the paddle wheel proved second best in the race to become the universal means of transporting cargo, belying its fundamental contribution as a pioneering form of mechanical propulsion at sea. The remains of both vessels typify two ways of adapting to technological innovations whilst staying true to ancient sail and rig traditions (see Figure 8.19).

8.4 Key geological features

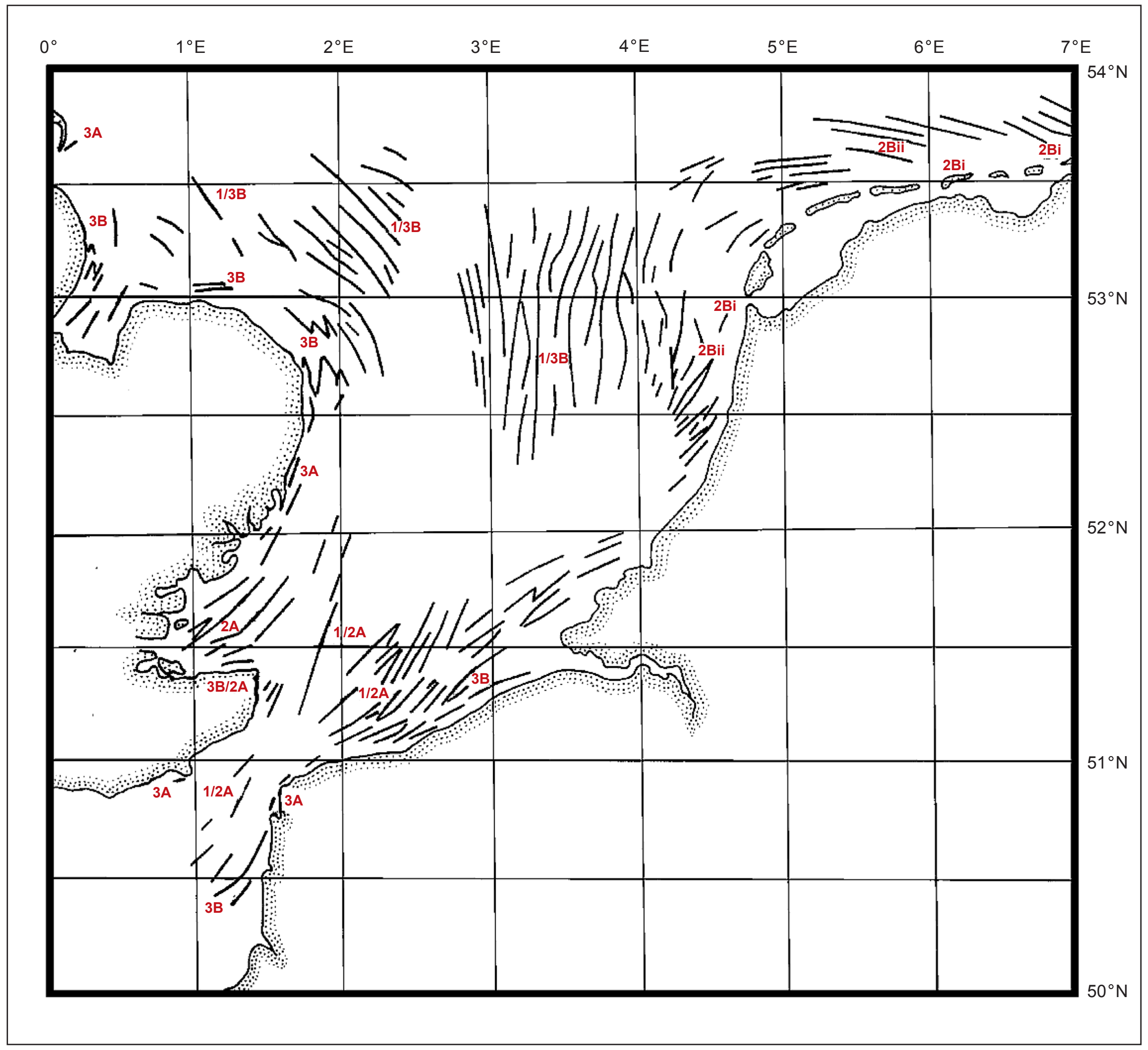
A wide range of geological features have been identified through the geological mapping using the East Coast REC Study Area-acquired data and archive data. Two of these are considered as significant or key geological features.

8.4.1 Sandbanks

In the northern part of the area there are a number of significant sandbank features, including North, Middle and South Scroby, Holm Sand, Corton Sand, Winterton Ridge, Smith's Knoll, North and Middle Cross Sand and Newcome Sand (Figure 4.1). These form the Great Yarmouth Banks (Cooper *et al*., 2008), a sub-set of the Norfolk Banks, which have often been cited as being amongst the best offshore examples of the "classic" sandbank bedform. They form the southern half of a candidate SAC – Haisborough, Hammond and Winterton (JNCC & Natural England, 2010). Associated with these N–S to NW–SE trending positive features are a number of channels such as Barley Picle, Holm Channel and Stanford Channel, which provide shipping ways between the sandbanks into Lowestoft and Great Yarmouth.

These sandbanks are part of a much larger grouping that extends over much of the southern North Sea (Figure 8.20). There are two distinct classes of sandbanks: coastal and offshore. The differences are that the coastal sand banks are more dynamic, changing their shape and position to a greater degree than the offshore banks. The offshore sandbanks are typically located in deeper water and so are less affected by storm events and in a less variable sedimentary environment in terms of likelihood of being affected by changes in sediment supply and transport patterns. Morphologically the coastal banks are more flat topped and closer together, whereas the offshore sandbanks have a more triangular profile and are more elongated.

Figure 8.20 Map of sandbanks in the southern North Sea (after Dyer and Huntley, 1999).



Dyer and Huntley (1999) refer to many of these banks as "recessional headland sandbanks" (annotated as 1/3B in Figure 8.20) yet some of them are tens of kilometres offshore, but the past evolution of the landscape must be borne in mind. As has already been described in Chapter 2, the changes in sea level since the last glaciation have led to large (>120 m) rises in sea level. As the southern North Sea is typically much shallower than this, such rising sea levels with associated rapid erosion rates would have changed the shape of the coastline. As the sea level rose and the coast retreated, the eroded sediments would have been firstly shaped into sandbanks attached to headlands and then gradually separated from the coast as the shoreline retreated ever further inland. These banks became ever more isolated from coastal processes and, as a result of reduced wave influence, less dynamic.

The largest sandbanks in the study area are offshore banks – Winterton Ridge and Smith's Knoll – being 1.3 to 1.7 km in width at their widest point, respectively, and approximately 20 and 30 km in length, respectively. The nearer shore banks are more sinuous in geometry, with crest lines linking the banks together and to the shore. The more nearshore sandbanks of Middle and South Scroby, Holm Sand, Corton Sand and Newcome Sand all have water depths above them of <2 m in places, whereas over the more seaward linear sandbanks, minimum depths are closer to 5 m. The inshore banks have a significant area that can be considered as intertidal and are located closer together than the outer banks (Figure 4.1).

Cooper *et al.* (2008) suggest that at about 5 ka, the coastline lay approximately 5 km offshore. Therefore the Inner Great Yarmouth Banks of Corton Sand, Holm Sand, Scroby Sands and Cross Sands will have had a much shorter period of evolution than the Outer

Great Yarmouth Banks of Winterton Ridge, Smith's Knoll and Newarp Banks, which may help account for differences in their present-day morphology (predominantly sinuous as opposed to linear).

Most of the sandbanks are between 10–20 m in height above the surrounding seafloor (Cooper *et al*., 2008). Between them, the Inner Great Yarmouth banks have an approximate volume of 620 × 10^6 m^3, with Smith's Knoll at ~390 × 10^6 m^3 and Winterton Ridge at ~105 × 10^6 m^3 (Reeve *et al*., 2001). They therefore represent a significant sink for sediments in the East Coast REC Study Area, with predictions by Reeve *et al.* (2001) suggesting that the volume of the Great Yarmouth Banks is growing at ~5 × 10^5 m^3 yr^{-1}.

The sandy sediments within the site are very mobile in the strong tidal currents that characterise the area (HR Wallingford, 2002). Large-scale bank migration or movement appears to be slow; Cooper *et al*. (2008) suggest it is to the north or north east and may only be 1 m yr^{-1}, though some of the inner banks such as Scroby Sands have been reported as having migrated 1.5 km northwards in the last 150 years (Horrillo-Caraballo and Reeve, 2008). However, within the sandbank system there is a level of sediment movement around, and also across, the banks. This is evidenced by megaripple and sandwave formations on the banks migrating clockwise around the banks. Changes in sandbank geometry also impact on the channels between them and the navigable routes to the ports of Great Yarmouth and Lowestoft.

Arthurton *et al.* (1994) observed that the banks exhibit an internal structure, as evidenced by seismic records from the north of South Cross Sand, which reveal internal northward-dipping reflectors, suggesting northerly bank movement but with no evidence of any lateral migration. Indeed, they noted that there was no evidence of earlier channels having incised the underlying sediments, signifying that the bank channel system may have formed *in situ*.

Cooper *et al.* (2008) suggested that littoral drift moves eroded material from the Norfolk and Suffolk cliffs, with a convergence zone offshore at Lowestoft. This sediment accumulates, forming nearshore sandbanks, with the Inner Great Yarmouth Banks formed by headland tidal meander channels resulting from the geometry of the coastline about 5,000 yrs ago. The channels are maintained by the current flood and ebb tidal meander along the modern coast. This feature is unlikely to have been present off the Great Yarmouth coast for more than 1,500–2,000 years, but the same mechanism could have existed further to the north, generating a nearshore bank system that has now become the Outer Great Yarmouth Banks, including the Winterton and Smith's Knoll Banks.

There have been numerous studies on the coastal sandbanks in the area that have attempted to quantify rates of change (eg, up to 70 m of lateral movement per year) and model the processes involved in their movement (Dolphin *et al*., 2007; Park and Vincent, 2007). Looking to the future, it has been suggested by Chini *et al.* (2010) that increases in sea level could result in more wave energy reaching the coast as the nearshore sandbanks become submerged, resulting in a greater risk of coastal flooding and higher extreme water levels. Although predictions can be made for the movement of the sandbanks based on detailed analysis of historical data (eg, Reeve *et al*., 2008), chance events such as storms can have a large impact on the geometry of sandbanks and the channels between them, making long-term predictions difficult.

8.4.2 Bedrock outcrop

In the western part of the East Coast REC Study Area, there are several occurrences of uneven seabed resulting from the outcrop of older strata. Although referred to as bedrock outcrop, the outcropping material is uncemented and poorly consolidated and thought to be part of the Westkapelle and Yarmouth Roads formations. This forms a distinct seabed type and may well influence the composition of the infauna. The local absence of Holocene sediment at these sites implies strong currents holding the sediment in suspension, causing erosion and preventing deposition of sediment. These outcrops affect mobile bedforms as seen on the multibeam data (Figure 4.12). The most dramatic of these outcrops is the Cross Sands Anomaly (Figure 4.15), a feature protruding west from the Middle Cross Sands sandbank into the Barley Picle Channel. It was first noted in a UKHO survey in 2006 (Chris Pater, personal comm.). It has a maximum length of 165 m and a maximum width of 30 m, with an elongated ovoid shape orientated E–W. The top is nearly flat at 33 m water depth, whilst its base, exposed by scouring, is at 46 m depth. It is interpreted as a glaciotectonic rafted block transported by an ice sheet and deposited during meltwater drainage. This would be similar to chalk rafts noted along the North Norfolk Coast, associated with ice movement during glacial times. Until the topographic feature is cored, uncertainty on its origin will, however, remain.

9 Gap analysis

Gap analysis – Survey design and data				
Issues	**Data gaps prior to East Coast REC Study Area project**	**Implications for East Coast REC Study Area project**	**Action through East Coast REC Study Area project**	**Current status**
Geophysical survey grid density	Data of variable quality and density. Survey lines not available as a systematic grid, only an amalgamation of several surveys built up over time.	Data did not allow confident interpolation across the survey area, particularly for sub-seabed features. Data not suitable to produce modelled habitat outputs.	New geophysical data collected that used a broad-scale regular grid over the entire area as well as focused surveys of areas of particular interest.	Regular grid coverage of approximately 2.7 km spacing across the East Coast REC Study Area. Tie-in lines run perpendicular to main grid. Areas of particular interest surveyed at high resolution.
Survey grid coverage	Surveys conducted with various techniques, and full range of geophysical-acquisition tools not deployed concurrently or consistently. Metadata not always available.	Existing data not suitable to enable sufficiently detailed interpretations of geological, archaeological or biological settings.	Full suite of geophysical techniques was deployed concurrently along survey lines. Metadata associated with the data to assist future data users.	Regular grid coverage of approximately 2.7 km spacing across the East Coast REC Study Area with sub-bottom profiler, multibeam echosounder, side-scan sonar, magnetometer and AGDS. Tie-in lines run perpendicular to main grid. Areas of particular interest surveyed at high resolution.
Sediment sample station density	Sediment data was widespread but resulted from varying sampling tools.	Data not stratified in a way that enabled delivery of East Coast REC Study Area objectives. Insufficient data to produce appropriate sediment distribution maps.	Existing data combined with new survey data to produce improved sediment distribution maps based on higher density evidence.	Density good when survey results were combined with historical data. However, in mobile areas repeat surveys would provide more information.
Seabed morphology feature correlation	Data of variable quality and density. Survey lines not available as a systematic grid but an amalgamation of several surveys built up over time. Surveys conducted with various techniques, and full range of geophysical acquisition tools not deployed concurrently or consistently. Metadata not always available.	Existing data not suitable to enable sufficiently detailed interpretations of geological or archaeological settings.	Used existing geophysical and sample data to guide the collection of new data that met the specific needs of the East Coast REC Study Area.	Understanding of the nature and extent of geomorphological features is improved. Shallow areas are still a gap as large survey vessels cannot access them.
Sample station density and placement inadequate for mapping biotope distribution	Existing sampling density and distribution did not enable the production of robust biotope maps.	Data was insufficient to develop robust, broad-scale maps that showed the distribution of biological communities.	Stratified biological sampling was guided by new geophysical survey data. Distinct habitats received targeted sampling at a density that enabled modelled, mapped outputs.	The distribution of biological communities over the East Coast REC Study Area can be more confidently predicted.
Biological sampling of Annex I Habitats	Few targeted surveys to sample for Annex I reef habitats over the wider East Coast REC Study Area.	Insufficient data available to either predict or confirm where Annex I reef habitats might be found.	Initial geophysical survey data used to focus further acoustic and biological sampling to validate areas where Annex I reef habitats were predicted. Biological/ GIS modelling techniques used to map predicted distribution of Annex I habitats.	Improved understanding of the distribution of Annex I reef habitats. Modelled outputs provide higher confidence of the presence of reef habitats in areas where data do not exist. Modelled maps still need some subsequent validation.
Biotope model	Insufficient number of suitable samples to produce robust modelled outputs.	Existing samples could only provide high-level modelled map.	Increased density of acoustic and biological data-sets.	Biological and geophysical data collected in such a way that traditional and novel modelled maps could be produced.
Vibrocores	Existing vibrocore sample data did not meet the requirements of the East Coast REC Study Area objectives.	Insufficient validation of geophysical data.	New vibrocore data were targeted at specific sub-bottom features identified during the geophysical survey.	Sub-bottom samples matched with existing geophysical data to validate geomorphological interpretations.
Pre-nineteenth-century maritime activity	Pre-nineteenth-century wrecks are not represented within the areas of data coverage.	Distribution and characterisation of pre-nineteenth-century maritime activity not possible to determine.	None	As original
Distribution of aircraft wrecks	Difficult to detect with current geophysical methods.	Underestimation of number of aircraft wrecks in the East Coast REC Study Area.	None	As original
Palaeo-environmental analysis and dating	Extremely limited palaeo-environmental data were available for the East Coast REC Study Area.	Poor understanding of the palaeo-environmental conditions across the East Coast REC Study Area.	Five of the 39 vibrocore samples collected underwent palaeo-environmental assessment, analysis and dating as part of the project.	Palaeo-environmental data collected for five key sites across the East Coast REC Study Area. The remainder of the vibrocores stored and available for future analysis and dating.
Magnetometer data	Existing magnetometer data was not systematic and did not encompass the full East Coast REC Study Area.	Potential to miss sites of archaeological value.	New magnetometer data collected across the East Coast REC Study Area grid. Magnetometer data co-located with side-scan data.	Greatly improved coverage of magnetometer data. Still gaps over shallow and intertidal areas due to draught of survey vessel.

Gap analysis – Non-survey data				
Issues	**Data gaps prior to East Coast REC Study Area project**	**Implications for East Coast REC Study Area project**	**Action through East Coast REC Study Area project**	**Current status**
Fisheries: effort	Official data on fishing landings and effort only available at the ICES rectangle level.	Specific figures for catch and effort within the East Coast REC Study Area cannot be given from official statistics.	New data on fishing intensity were sought to describe the distribution of effort within the East Coast REC Study Area, based on Vessel Monitoring System data and visual sightings.	Enhanced understanding of the distribution of fishing effort in the East Coast REC Study Area.
Fisheries: breeding and spawning	Recent data on fish breeding and spawning habitat were not available.	Fisheries review includes a comprehensive review of the East Coast REC Study Area in terms of its use for fish breeding and spawning, but this is based on historic data.	New data was sought but was not available within the timeframe of this project.	Revised data on fish breeding and spawning areas currently under review (2010) and should be published by Cefas shortly (see Ellis *et al.*, in prep.[a]).
Mammals	Data split over several databases (not centralised).	Underestimation of the use of the area by mammals.	All available published sources acquired.	Need unified database – single-source information.
Birds	Disparate databases for nesting sites and seabird observations. Gaps in nesting-site data.	Underestimation of the use of the area by seabirds.	All available published sources acquired.	Need unified database for bird-nesting sites and observations to aid the assessment of resources used by this group.
Sharks	Very minimal shark sightings available. Lack of consistent recording methods.	Insufficient data to estimate the use of the area by sharks.	All available published sources acquired.	Need unified database for shark observations that incorporates sport fishing catches to aid the assessment of resources used by this group.
Cables and pipelines	Limited published data. Limited access to industry survey data.	Not all human activities presented in the review.	Used Admiralty chart data and information supplied by a pipeline operator.	All available information incorporated.
Power cables	Information not available through Kingfisher (company responsible for mapping cable routes for Admiralty charts).	Not all human activities presented in the review.	Some data excluded from the review as could not be sourced within appropriate timeframe.	Largely the same as pre–East Coast REC Study Area status.
Shipping usage of the study area	No specific attention given to shipping within the East Coast REC Study Area.	Not all human activities presented in the review.	Main shipping routes identified and mapped. Inshore areas not represented.	Still a gap for the inshore areas of the East Coast REC Study Area.

Gap analysis – Interpretation and data analysis				
Issues	**Data gaps prior to East Coast REC Study Area project**	**Implications for East Coast REC Study Area project**	**Action through East Coast REC Study Area project**	**Current status**
Top-down EUNIS habitat/ biotope classification maps	No top-down habitat/biotope classification maps existed for the East Coast REC Study Area.	No implications as this was a primary aim of the East Coast REC Study Area project.	A high-level, modelled, EUNIS classification map was produced for the East Coast REC Study Area.	A EUNIS classified map has been produced for the East Coast REC Study Area. The available EUNIS biotope classes used for the East Coast REC Study Area are incomplete and too rigid for adequate implementation, particularly for offshore waters. However, new “Rock and Thin Sediment” biotope classes recently proposed under the South Coast and eastern English Channel Synthesis Project may provide useful classifications.
Bottom-up, “local” habitat/ biotope classification system	No bottom-up habitat/biotope classification maps existed for the East Coast REC Study Area.	No implications as this was a primary aim of the East Coast REC Study Area project.	A modelled, bottom-up habitat/biotope map was produced for the East Coast REC Study Area.	Bespoke and interpolated maps, modelled using the communities present across the East Coast REC Study Area, are available. Evaluation of the relative utility of bottom-up and top-down approaches presented in the final report.

[a] www.cefas.co.uk/our-science/fisheries-information/marine-fisheries/ecologically-important-fish-habitats/distribution-of-spawning-and-nursery-grounds.aspx

10 Conclusions and recommendations

Geological characterisation

- The East Coast REC study has revealed a geomorphologically diverse and complex area. This complexity is thought to be a result of the geological processes that have affected the area, principally over the last 100,000 years, through the last glacial cycle. The survey area is located at the southernmost limit of the last glaciation. Following the glacial maximum, the area was subjected to periglacial conditions in front of an ice sheet that was probably supplying the sediment. Subsequently, climate warming allowed a landscape to develop for ancient man to occupy before the marine transgression was completed, about 6000 BC. Evidence of earlier glaciations are represented by sub-surface, now infilled, channels that would have be cut beneath the ice sheets/glaciers. This study has suggested that some of these features are located further south than had previously been mapped.

- Beneath these sediments is an extensive suite of early Quaternary units of deltaic deposits, cut by glacial erosion and the development of ravinement surfaces, often with gravel deposits. These unconsolidated sediments overly bedrock of Eocene to Pliocene age.

- It is suggested that three physical regions can be recognised on the basis of the seabed geomorphology and Holocene seabed sediment distribution. The northern region is defined by the extent of the sandbank features as the dominant geomorphology. These extend northwards beyond the East Coast REC Study Area. These sandbanks change their geometry as sediment moves clockwise around individual banks in the form of sandwaves. They form part of the Haisborough, Hammond and Winterton Banks, which collectively have been proposed as a candidate SAC.

- The central physical region is an area recognised by its predominantly gravel-dominated surficial sediments. Over 95% of the active or licensed dredging areas within the East Coast REC Study Area lie within this central region. The southern region has a more irregular surface, with numerous ridges and frequent sandwaves. All three physically distinct regions show a trend of increasing depth towards the east, but significant local changes in water depth also occur between the sandbanks.

- The gravel component of the seabed sediments is flint-rich, mainly iron-stained, with the coarsest fractions (>16 mm) containing more diverse assemblages of lithologies, reflecting glacial transport from northern England and possibly Scotland.

Recommendations

- It would be useful to monitor the movement/migration of the sandbanks and their associated sandwaves in the region. This would require comparative studies of multibeam data-sets, but it could be integrated with hydrodynamic data to allow predictive models to be developed, which, if integrated with the habitat information, could be used to inform any future Regional Environmental Assessments. Additional multibeam data would improve confidence in the geomorphological mapping between the survey corridors.

- Careful sampling of the Cross Sands Anomaly would confirm the lithology and possible origin of this feature, which may have formed a significant feature on the palaeo-landscape before the marine transgression and now creates unusual habitats for benthic communities.

Archaeological characterisation

- The results of the East Coast REC study reveal that the whole area is rich in archaeology, with finds ranging from the Lower Palaeolithic to the Second World War. Archaeological material found on or beneath the seabed can be divided into three categories: prehistoric, maritime and aviation. The East Coast REC Study Area comprises elements of each of these categories in abundance.

- The characterisation of the prehistoric archaeology involved the integration of archaeological knowledge and theory with geological, geophysical and palaeo-environmental interpretations. This approach focused on identifying offshore the types of landscape features where archaeological material is found on land. The results of the characterisation have illustrated the presence, and further potential, of deposits associated with the key periods of human occupation, from the earliest known sites, such as Pakefield and Happisburgh, through the Palaeolithic to the Mesolithic. This is evidenced by the saltmarsh channel infilled just prior to the last inundation of the area, around 6000 BC. The characterisation of this area indicates that, under the appropriate preservation conditions, there is potentially a significant resource of prehistoric archaeology present.

- The results of the geophysical survey have enhanced and added to existing data-sets, such as the UKHO and the NMR, and the characterisation has produced a more reliable guide to the density of archaeological material on the seabed.

- The geophysical data interpretation has been successful in characterising the maritime archaeological resource of the East Coast REC Study Area, particularly in reference to the late-nineteenth-century and more recent wrecks. Wrecks of earlier periods are not well documented in the area, and the characterisation has not been able to further enhance these records. Given the known importance of ports such as Great Yarmouth, Lowestoft and Southwold from the sixteenth century onwards, it is considered that wrecks of earlier periods are underrepresented in the East Coast REC Study Area.

- Most aircrafts are recorded as named locations, with an approximate position based on the aircraft at the time of loss; few have been accurately located on the seabed. Since there are very few records concerning aircraft crash sites, a reliable understanding of the accurate distribution of the resource within the East Coast REC Study Area is unknown. However, the quantity of aircraft wrecks is very probably underestimated, especially considering the large scale of operations that passed over the area throughout the Second World War. Due to the difficulties in detecting and distinguishing aircraft on the seabed with geophysical methods, as the sites are often ephemeral due to the aircraft commonly breaking up on impact with the sea, it is considered that there is arguably a greater potential for any given area of seabed to contain unknown aircraft crash sites than to contain unknown shipwrecks.

Recommendations

- Future monitoring programmes should develop a new approach to the submerged heritage and take account of the significance of the findings of this study.

- Further analysis of the vibrocores acquired during the East Coast REC project for palaeo-environmental assessment, analysis and dating will further enhance the characterisation of the region.

Biological characterisation

- A total of 391 benthic invertebrate taxa were collected from the East Coast REC Study Area. By far the most numerous infaunal species encountered were the reef-building Ross worm *Sabellaria spinulosa* and the blue mussel *Mytilus edulis*. There was also high abundance of the T-headed worm *Scalibregma inflatum*, the bivalve *Abra alba* and sea anemones Actiniaria. Epifaunal species were dominated numerically by the brittlestars *Ophiura albida*, *Ophiothrix fragilis* and *Ophiura ophiura*. The brown shrimp *Crangon allmanni* and the hermit crab *Pagurus bernhardus* were also characteristically abundant. All of these species are characteristic of relatively dynamic sedimentary habitats in the southern North Sea, interspersed with the occasional patch of more stable ground provided by gravel deposits or biogenic reef.

- In-depth analysis of the infaunal samples revealed 14 discrete infaunal benthic assemblages. These became the units that were subsequently fed into the "bottom-up" habitat mapping approach to attain a modelled biotope map for the entire East Coast REC Study Area. According to this map, with the exception of highly localised habitats such as *Sabellaria* and *Mytilus* reefs, most other habitats showed a wide distribution throughout the East Coast REC Study Area. By far the most extensive assemblage was one characterised by infaunal species that display a high tolerance to changes in physical conditions such as depth, disturbance regime and turbidity. This assemblage (Group C) was found predominantly on clean sandy sediments and areas with few sandwaves.

- Given the predominantly sedimentary nature of the seabed in the East Coast REC Study Area, together with the fact that most of the discrete assemblages had a number of species in common, it is believed that there was considerable functional overlap between the different assemblages, with differences between some of them being due to relative differences in abundance of the same characterising species. The most influential environmental conditions contributing to the distribution of the different infaunal assemblages were the proportion of sand and gravel, near-bed temperature and latitude. Such findings are in keeping with those from other studies of the benthic ecology of the southern North Sea.

- The East Coast REC Study Area represents an important food resource in the form of benthic invertebrates, which sustain fish. These, in turn, are the food source for native and migratory seabird species, some of which are considered to be threatened or declining in numbers. Marine mammals, such as the grey and harbour seals, and white-beaked dolphin, common dolphin and harbour porpoise, also benefit from the area's productivity.

Recommendations

- Existing approaches to ground-truthing seabed habitats used in this study have relied upon assessments of abundance, diversity, biomass and trophic group compositions. These approaches could be enhanced through a consideration of ecosystem processes. Such processes are, in part, governed by the functional characteristics of the organisms involved (eg, trophic group), rather than by their taxonomic identity. It is therefore recommended that future habitat mapping studies in the area take account of the functional attributes of species found within mapped areas.

- Sandbanks and biogenic reefs, as defined under the EC Habitats Directive, have been recorded within the East Coast REC Study Area, though their extent and temporal stability is undetermined. Given their significance as features of nature conservation importance, further surveys to characterise and map the spatial extents of these features is warranted. Full-coverage acoustic techniques, together with targeted sampling, are required to fill data gaps. In particular, there is a need to enhance the resolution and coverage of data collected within the Haisborough, Hammond and Winterton Banks candidate SAC.

- The capability of acoustic techniques for characterising and mapping dense aggregations of benthic organisms or features (eg, *Sabellaria* reef or *Ophiothrix* beds), particularly those listed in Annex I of the EC Habitats Directive, should be further explored with a view to developing their predictive capability for application in marine resource management. Research conducted during this study has investigated this issue further for the southern North Sea region. The topic has also been addressed, in part, by the ALSF programme "Best Methods for Identifying and Evaluating Biogenic and Cobbly Reef" (see Limpenny *et al*., 2010). However, there is clearly a need for further research to develop a reliable predictive capability. In particular, it is recommended that a programme of work is directed towards establishing associations between acoustically distinct sediments and their biotic assemblages, to enhance the future application of acoustic surveys in predictive mapping of marine habitats. This would facilitate both marine resource management and marine spatial planning initiatives.

Modelling biota

- This study has demonstrated the value of adopting modelling approaches for mapping marine biotopes and species. The success of mapping and modelling of species distributions rests not only on the models themselves, but also on the validity of the environmental data used as inputs and the sample data used for ground-truthing. This is true whether the modelling is based simply on expert interpretation or on statistical analysis. Errors, poor resolution and uncertainty in any one input will affect the outcome of the model.

- A key feature of the survey designs of the East Coast REC study was their appropriateness for modelling the distribution of biotopes across a wide spatial area. This was supplemented by existing environmental data-sets. In order to extrapolate from point sample data to the whole area of interest, key environmental layers must be available as a continuous coverage. These are often provided from third-party sources, and the uncertainty (margin of error, resolution, etc.) is often not provided or is very hard to ascertain. Some, including layers from the current survey, have been derived from interpolation or modelling, and uncertainty has not been calculated. The data used to create these layers may have been accumulated over many years. Thus, whilst the data available were considered to be the best available, they may not have been always entirely appropriate for the purposes of the current survey.

- For the East Coast REC Study Area, it has been difficult to interpret the assemblages in terms of distinctive characterising species or function. Although the assemblages defined through multivariate analysis were statistically valid, there was considerable overlap in species composition between the samples along a continuum from high- to low-density samples. The samples with the highest numbers of individuals were largely biogenic biotopes, but there was no clear distinction (based either on species composition or on function) between these samples and those with slightly lower numbers of individuals, or between any samples close to each other along the continuum. All "hard" classification systems are artificial to some extent and place boundaries along continua. Whilst statistically derived assemblages may provide the best fit to the sample data, the limitations of the classification system, when used to model the distribution of biota, must be appreciated.

- The errors from the above sources will propagate through distribution models and undermine the confidence that can be placed in the outputs. Environmental managers should take this into account when applying new management measures, but, since uncertainty is often undeclared in the traditional map outputs from spatial surveys, in practice this may be very difficult to incorporate in the decision-making process.

Recommendations

- During this study we have demonstrated the use of a "bottom-up" approach for mapping marine biotopes, which can be adapted to suit a range of spatial scales and is suitable for environmental management and monitoring purposes. This approach is considered to be more scientifically rigorous than the more traditional EUNIS classification method. Both of these approaches have advantages and drawbacks. An important consideration in the use of such classification systems is the use to which the eventual map is to be put and the quality and density of available data, as these factors will determine the appropriateness of the classification approach adopted. If the map is to be used for the purpose of managing an area or identifying features of nature conservation significance, it will be important to consider what level of scientific accuracy is required. Revisions are currently being proposed to the EUNIS classification through a biotope matching programme to link characteristic benthic infaunal communities with existing EUNIS biotope descriptions and to develop new descriptions for offshore gravel and sand biotopes (Hooper *et al*., 2011). It is recommended that a new programme is initiated to compare and contrast the different approaches for classifying seabed habitats, focusing primarily on mobile and coarse substrates (gravels and sands). Such a programme should aim to establish a common framework for assessing faunal assemblages and their distribution.

- The scientifically rigorous approach adopted for this study has meant that emphasis has been placed on the statistical analysis of the sample data to provide the assemblage classes that have been used for interpreting the biology and as ground-truth classes for modelling assemblage distribution. However, the results from any analyses are ultimately dependent upon the samples available for analysis (eg, sample number, sample size, level of replication, representativity within the survey area and biogeographic area covered). The composition of assemblages may not match those from other studies, and this can complicate the comparison of results from other surveys and regions. Since this is likely to be an ongoing process as additional surveys become available, it is doubtful whether re-analysis of combined data-sets would be feasible. One solution would be to use the EUNIS biotope classification scheme. However, this has its own drawbacks, and the uncertainty in its application in offshore mobile sedimentary habitats encountered during the East Coast REC study can also seriously undermine any comparisons made. This points towards the need for a programme of work to establish the validity of any new framework in different geographic regions and across a range of environmental circumstances.

- Alternative approaches for establishing a common framework for comparing studies should also be explored. These might include the use of comparative statistics and a functional analysis of the faunal assemblages.

- In future studies, resources could be allocated for a thorough assessment of uncertainty and margins of error of the input data and an attempt to quantify these. Furthermore, a more thorough analysis of sample data may include the use of a "softer" classification, at least in the initial stages. Subsequently, the resulting distribution data could be generalised into "hard" classes for presentational purposes. The overlap of faunal composition amongst samples, and the implications for assemblage designation, require further study; the use of intelligent null models (eg, Gotelli and Graves, 1996) may provide a useful avenue of research.

- Attempts have been made in this study to point out where uncertainty exists. However, more research is required on the scale and importance of error through an analysis of error propagation. It is further recommended that representing uncertainty should be brought into the mainstream of habitat mapping and resource management.

General recommendations

- This study clearly benefited from the integration of scientific skills from a range of disciplines (ie, sedimentologists, marine surveyors, oceanographers, geologists, biologists, archaeologists, fisheries scientists and geophysicists). For the benefit of future seabed mapping programmes, it is recommended that this cross-disciplinary approach is adopted both during desk-based exercises and, wherever possible, within field programmes.

- The seabed maps generated from this study represent a “snapshot” in time. Further work is required to establish the temporal variability and stability of key features of nature conservation, particularly Annex I habitats and sandbanks. The location of biotopes may vary over time due to natural temporal variability or anthropogenic change, or as a result of climate change and related factors (eg, seawater temperature rise and/or increased storm activity affecting the distribution of species). It will, therefore, be necessary to determine the temporal variability of species and biotope distributions, seabed morphology and the integrity of key heritage features, through periodic repeat surveys of sites across the East Coast REC Study Area. This will help to determine the continued appropriateness of management measures that have been adopted as a result of information derived from this study.

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