Marine
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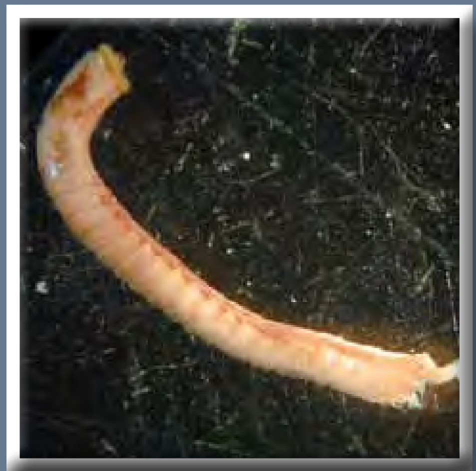
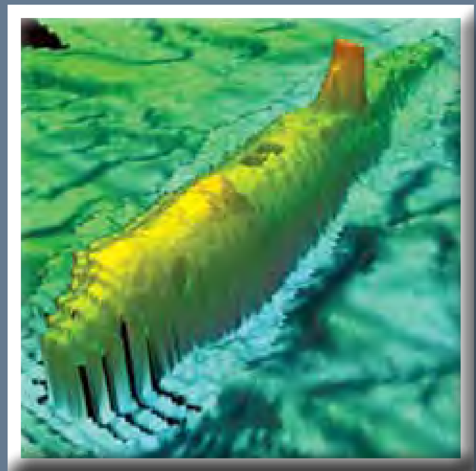
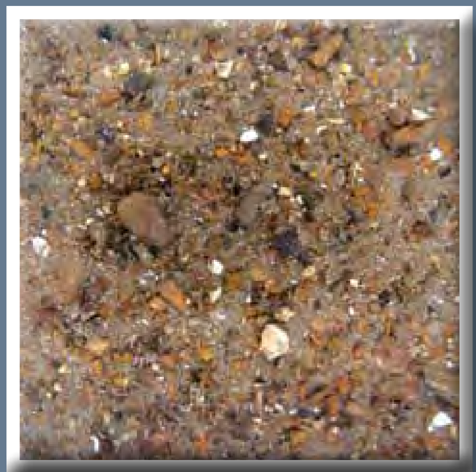
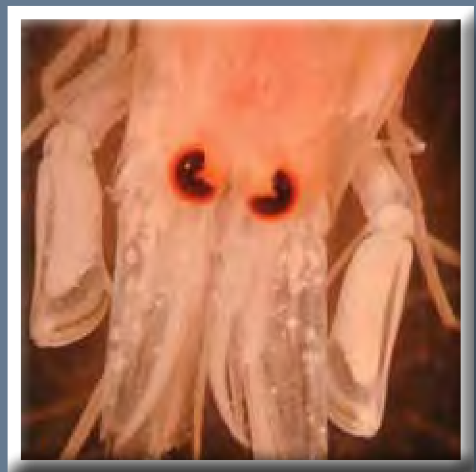
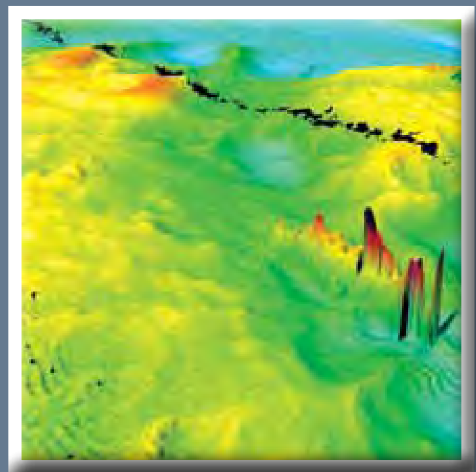
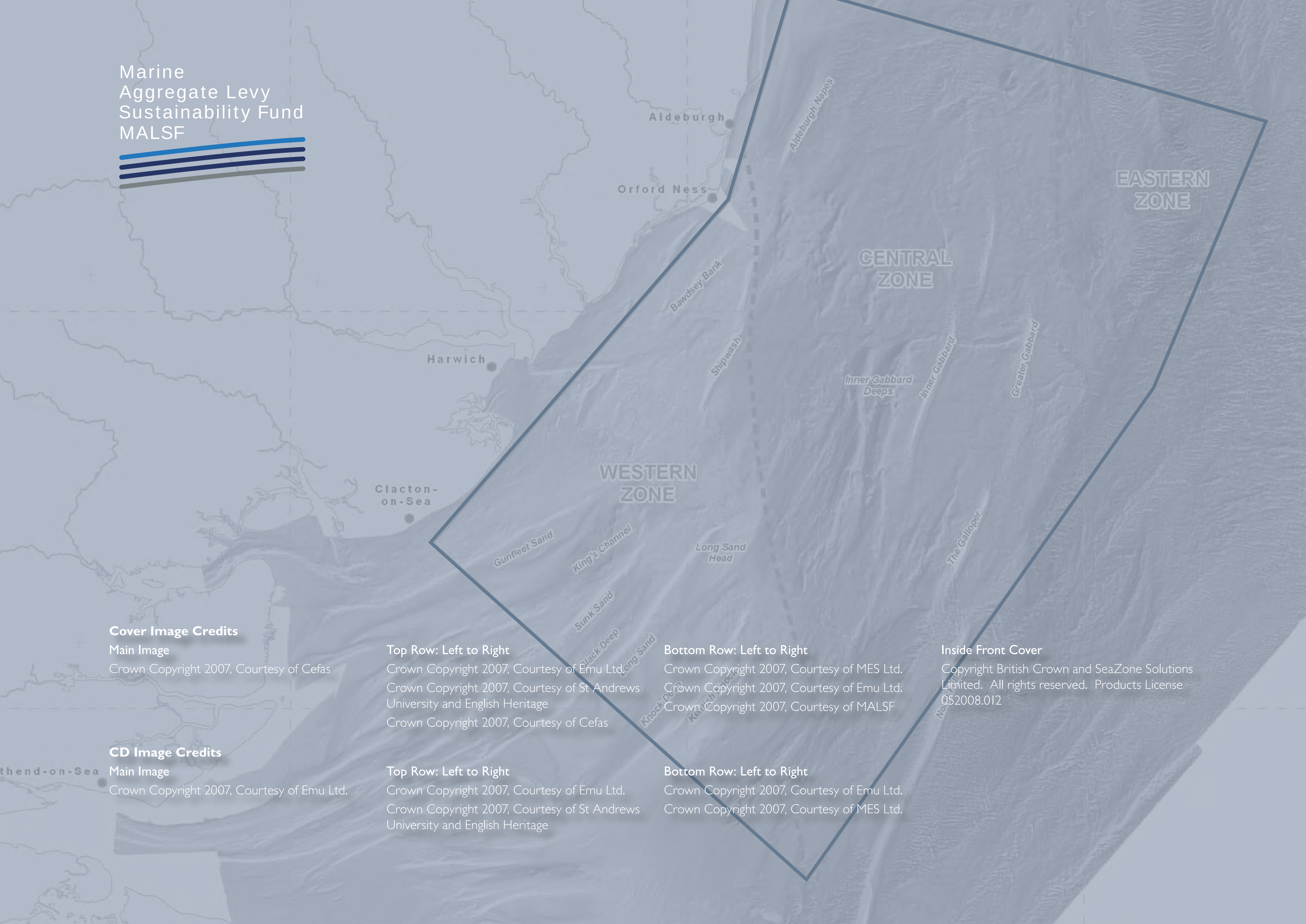
The Outer Thames Estuary Regional Environmental Characterisation



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Outer Thames Estuary
Regional Environmental Characterisation

Marine Aggregate Levy Sustainability Fund (MALSF)

Administered by:

marine environment protection ALSF

ENGLISH HERITAGE

Report written by:

EMU

UNIVERSITY OF Southampton

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Outer Thames Estuary Regional Environmental Characterisation

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This work was funded by the **Marine Aggregate Levy Sustainability Fund (MALSF)** and commissioned by the **Marine Environment Protection Fund (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 Marine ALSF is currently administered by two Delivery partners – the **MEPF** (based at Cefas, Lowestoft) and **English Heritage**.

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Executive Summary

Context

The Outer Thames Estuary Regional Environmental Characterisation (REC) provides an environmental reference statement defining marine and seabed conditions within the study area. Prior to this study, regional environmental assessment of the Outer Thames Estuary was based upon dispersed data acquired over several decades. The Marine Aggregate Levy Sustainability Fund (MALSF) has provided the opportunity to acquire and interpret an integrated physical and biological dataset for the first time in this region. The dataset was acquired along geophysical survey transects spaced 10 – 20 km apart and grab samples were recovered at the intersection of survey lines.

The Outer Thames Estuary REC provides a unique, robust scientific basis to define the regional marine environment, outlining the character of seabed conditions in the study area. This will permit informed, confident and consistent decision-making and consequently the Outer Thames Estuary REC will be of value to all stakeholders including government, marine industry, planners and environmentalists. The knowledge will contribute to the protection of the marine environment, promote the sustainable management of the seabed and focus future development investment.

The Outer Thames Estuary REC develops the approach initially adopted in previous marine aggregate regional characterisation studies but also makes a comprehensive assessment of the heritage issues. The characterisation process begins by reviewing the physical conditions in the area, for example tides, currents, seabed geology and seabed sediment transport. The heritage assessment has been combined with the interpretation of the Quaternary geology to produce an integrated assessment, whilst the wreck and other modern archaeology are treated separately. Analysis of the benthic infauna and epifauna communities is combined with an evaluation of their associated physical conditions to produce a habitat and biotope assessment. The principle characterisation is supplemented with high-level summaries of marine mammals, birds and anthropogenic activities for context. The characterisation process also highlights regional environmental sensitivities, for example sites of potential conservation, fisheries or heritage significance, as well as informing marine spatial planning.

Geology and Heritage

The seabed consists of three distinct morphological zones. The Western Zone is dominated by a large coast-parallel sandbank system. The sandbanks are composed of well sorted fine-medium grained sand whilst sandy gravels lie on the seabed in the troughs between the banks. The Central Zone consists of a bedrock platform typically overlain by a discontinuous, thin, gravelly lag deposit, dispersed sandy bedforms and isolated sandbanks. Two parallel, north-south trending troughs, the Inner Gabbard Deeps, have been eroded into the bedrock in this zone. The seabed in the Eastern Zone consists of an extensive sand dune field. In general there is a net seabed sediment transport to the south across the area.

The Outer Thames Estuary REC survey has revealed a geological and archaeological record of previously unquantified significance. The combined interpretation of bathymetry of varying resolutions, sub-bottom data, a limited amount of core and grab material and a full review of the extant geological and archaeological record, has achieved a significantly enhanced interpretation of the Outer Thames Estuary. Of central importance is the identification of c. 1,500 km^2 of submerged palaeo-landscape dating from c. 720,000 BP. This represents a significant feature of both geological and archaeological interest.

The seabed in the Outer Thames Estuary mainly comprises a thin, superficial layer of mobile and immobile sediments overlying exposures of Quaternary, Cenozoic and Cretaceous sediments. Ten enclosed deeps are identified and interpreted as being formed at the margin of the Elsterian-Anglian glacial maximum ice limit. The stratigraphic relationship of these features with the major east-west river system (the Thames-Medway) that cuts across the Outer Thames Estuary REC area suggests this channel must have been incised prior to this glaciation (Oxygen Isotope Stage (OIS) 12: c. 450 kaBP). Further, the spatial correlation of this channel system with terrestrial river terrace gravels on the Essex coast suggests it may have been formed as early as Cromerian Complex II (OIS 18: c. 720 kaBP), but at least by OIS 15 (c. 600 kaBP). The southern edge of the Outer Thames Estuary REC area does cross the northern margin of the post-Elsterian/Anglian Thames-Medway river courses as they migrate southwards and separate to become the modern Thames and Medway systems. Again, through spatial correlation with the terrestrial record, c. 40 m thick sections of river channel infill sediments have been identified, which may hold a record of 450,000 years of sedimentation.

The Outer Thames Estuary REC study reveals a potentially highly significant record from an archaeological perspective. There are two broad categories of submerged archaeological material that may potentially exist within the Outer Thames Estuary REC area: shipwreck sites and terrestrially deposited archaeological material subsequently inundated by rising sea levels. In terms of the wreck record 1,576 individual incidents are documented for the area, with an additional seven anomalies identified as a part of the characterisation process. The wrecks for which details were available date from between AD 1320 – 2005, and range in type from fishing vessels, through submarines, to second world war aircraft. Available survey data only covered a small proportion of the total area considered, and as such the location of only c. 6% of wrecks recorded in the UKHO could be verified.

With regard to submerged terrestrially deposited archaeology, the Outer Thames Estuary REC area parallels one of the most important stretches of coastline for Palaeolithic archaeology in the British Isles. Bracketed by the key internationally significant Lower Palaeolithic sites of Clacton (to the south) and Pakefield (to the north), the coastline in this region has produced evidence for the earliest occupation of the British Isles at c. 600 – 700,000 BP. As such, the determination of a large area of submerged landscape dating from 720,000 BP offshore of these sites is deemed to be highly significant and worthy of future investigation to evaluate its potential. This determination is based on the value of this landscape as a resource to inform about the broader changes which occurred through the Pleistocene and into the Holocene, as much as the possibility for preservation of primary and secondary context archaeological material. In addition, there is a third class of archaeological material found within the survey area; the modern terrestrial feature of Walton-on-the Naze Pier which extends c. 17 m into the Outer Thames Estuary REC. This is a significant local feature and forms part of a conservation area.

Ecology and Habitats

Three generic macrobenthic assemblages were identified from the Outer Thames Estuary REC study area, largely comprised of infauna. These comprised a rich and diverse macrofauna including the Ross worm *Sabellaria spinulosa*, the polychaetes *Lumbrineris gracilis* and *Notomastus* spp., amphipod *Ampelisca spinipes* and brittlestar *Ophiura albida* associated with a mixed, muddy sandy gravel from the central area of the sample array; an impoverished sand fauna including the white catworm *Nephtys cirrosa*, the mysid shrimp *Gastrosaccus spinifer* and polychaete *Ophelia borealis* within the clean sand sediments along the southern and eastern extents of the study area ; and a fauna characterised by the polychaetes *Nephtys hombergii*, *Spiophanes bombyx*, *Notomastus* spp. and *Lagis koreni*, the nut shell *Nucula nucleus* and bivalve *Abra alba* in muddy sand sediments, predominantly found along the inshore areas, including habitats in variable salinity conditions.

Colonial sessile epifauna were also associated with the mixed and coarse sediments within the central areas of the array. Typical assemblages included mixed hydrozoan and bryozoan turfs together with the keel worm *Pomatoceros* spp., common starfish *Asterias rubens*, brittlestars *Ophiura albida* and the green sea urchin *Psammechinus miliaris*. Shallow inshore locations supported considerable amounts of the fleshy bryozoan *Alcyonidium diaphanum* and quantities of green algae *Enteromorpha* spp. The larger and more mobile components of the epibenthos were dominated by various shrimps *Pandalus montagui*, *Pandalina brevirostris*, *Crangon crangon* and *C. allmani*, Gobies *Pomatoschistus* spp., flying crab *Liocarcinus holsatus* and sole *Solea solea*.

The generic communities identified were further refined to determine biotopes based on individual site attributes, including integration of seabed photography, 2 m beam trawls and grab samples. In total, 16 infaunal and 5 epifaunal biotopes were identified. The biotope data, at various levels of complexity, were combined with the physical data, including sediment character, depth, sediment mobility, estuarine influence and geomorphological processes, enabling an integrated chart of the area to be produced. Two potential Annex I habitats were identified; ‘Sand banks which are slightly covered by sea water all the time’ and ‘Reefs’. Within the latter habitat, two biotopes were described comprising potential biogenic *Sabellaria spinulosa* reef **SS.SBR.PoR.SspiMx** and potential geogenic reef **CR.MCR.SfR.Pid**. The geogenic reef habitat in particular was noted in the vicinity of the unusual seabed features referred to as the Inner Gabbard Deeps. Additional consideration of Marine Aggregate Regional Environmental Assessment (MAREA) data, as part of the current project, identified areas of potential biogenic *Ampelisca diadema* reef **SS.SMu.ISaMu.AmpPlon**.

1. Introduction

1.1 Aim

The aim of the Outer Thames Estuary Regional Environmental Characterisation (REC) is to provide an environmental reference statement defining marine and seabed conditions within the study area. Prior to this study, regional environmental assessment of the Outer Thames Estuary was based upon dispersed data acquired over several decades. The Marine Aggregate Levy Sustainability Fund (MALSF) has provided the opportunity to acquire and interpret an integrated physical and biological dataset for the first time in this region.

The Outer Thames Estuary REC therefore provides a unique, robust scientific basis to define the regional marine environment, outlining the character of seabed conditions in the study area. This will permit informed, confident and consistent decision-making and consequently the Outer Thames Estuary REC will be of value to all stakeholders including government, marine industry, planners and environmentalists. The knowledge will contribute to the protection of the marine environment, promote the sustainable management of the seabed and focus future development investment.

The Outer Thames Estuary REC reviews existing literature but is largely based upon the interpretation of recently acquired MALSF data. The data is used to define the physical and biological character of the seabed in the region and produce an integrated habitat dataset, thus producing a state of the art reference source. This is combined with a broad review of heritage issues and archaeological potential.

The Outer Thames Estuary REC has been funded through the Marine Aggregates Levy Sustainability Fund (MALSF – http://www.alsf-mepf.org.uk). The Aggregates Levy Sustainability Fund started in 2002, following the Finance Act 2001 (2006 Marine ASLF Science and Information Strategy). The MALSF has three main objectives which can be equally applied onshore or offshore:

- Minimising the demand for primary aggregates.
- Promoting environmentally friendly extraction and transport.
- Reducing the effects of local aggregate extraction.

New Government initiatives include a greater use of spatial planning in the marine environment together with the strategic management of human activities. The MALSF offers the opportunity to fund research that will help to reduce the environmental costs of aggregate extraction, including that from the sea. The Scientific research areas correspond with priorities of Government including Defra, the Office of the Deputy Prime Minster (ODPM, now the Department of Communities and Local Government) and Crown Estates (CEC), based on those identified at a stakeholder workshop held on 30th June 2003 and the Marine Aggregate R&D Review on 10th November 2003.

1.2 Regional Environmental Characterisation

Until recently, sources of offshore regional environmental information in the Thames Estuary have been largely confined to the geological maps and reports produced by the British Geological Survey, for example the Thames maps (1989; 1991a; 1991b) and the environmental summaries contained in the Strategic Environmental Assessment 3 (Geotek and Hartley Anderson, 2002). Complementing this data, more recently a range of site specific studies have also been undertaken by various industries to various specifications, for example the Greater Gabbard windfarm (see Section 2.7).

Elsewhere, as understanding the relationships between habitats and seabed geology have become more important, the demand for confidence in regional environmental characterisation has increased and the value of interdisciplinary regional studies has been recognised on a wide scale (for example Mapping European Seabed Habitats – MESH – www.searchmesh.com).

Subsequently two regional environmental characterisation studies for areas associated with marine aggregate extraction have now been completed;

- The marine habitat maps in the Eastern English Channel (James *et al.*, 2007); and
- The Outer Bristol Channel (Mackie *et al.*, 2006);

In addition, similar studies off the South Coast, East Anglia and the Humber are now underway.

The Outer Thames Estuary REC provides the first opportunity to assess a bespoke integrated dataset for the region. It develops the approach initially adopted in the previous marine aggregate characterisation studies but also makes a comprehensive assessment of the heritage issues which have been integrated with the Quaternary geology where necessary.

The characterisation process begins by reviewing the physical conditions in the area, for example tides, currents, seabed geology and seabed sediment transport. The heritage assessment has been combined with the interpretation of the Quaternary geology to produce an integrated assessment, whilst the wreck and other modern archaeology are treated separately. Analysis of the benthic infauna and epifauna communities is combined with an evaluation of their associated physical conditions to produce a habitat and biotope assessment. The characterisation process also highlights regional environmental sensitivities, for example sites of potential conservation, fisheries or heritage significance, as well as informing marine spatial planning.

1.3 Location of the Study Area

The study area lies in the Outer Thames Estuary offshore of south-east England and is centred at 51˚50'00"N, 1˚50'00"E, in the southern North Sea (Figure 1.1). The area extends north-eastwards from the mouth of the Thames Estuary, along the coast of Essex and Suffolk, between Clacton and Southwold, and offshore into the North Sea (Figure 1.2). The main study area extends for 70 km along the coast and continues up to 50 km offshore, covering an area of 3,800 km^2 of seabed. The boundary was selected on the basis that it reflects the areas of aggregate extraction in the region. Beyond this area the description of the seabed has been continued in places to provide further regional context, for example westwards up the Thames Estuary and in the south, towards the northern coast of Kent. A complementary Regional Environmental Characterisation is currently underway to the north of the area, off the coast of East Anglia.

Figure 1.1: Location of the Outer Thames Estuary REC study area in relation to the southern North Sea.

1.4 Study Team

The study team and the preparation of this report was lead by Emu Ltd. The team consisted of members from Emu Ltd, Geodata and the University of Southampton (Table 1.1).

Emu Ltd and the University of Southampton team are grateful for the support of the MALSF and the Steering Group, including Richard Newell, Richard Fifield, Julianna Measures, Ian Reach, Chris Vivian, Mark Russell, Chris Pater and Gareth Watkins.

1.5 Data Sources

The interpretation of the seabed conditions, character, composition and communities are largely based on high quality geophysical and biological data acquired during a bespoke MALSF high resolution seismic and sampling survey undertaken by Gardline Lankelma and Marine Ecological Surveys Ltd in summer 2007 (Figure 1.3 and Table 1.2).

A series of geophysical survey transects trending NE-SW and NW-SE were sailed across the study area acquiring around 700 line km of high resolution seismic profiling, side scan sonar, swath bathymetry and magnetometer data. NE-SW transects are 10 km apart and NW-SE transects are 20 km apart. Each transect consists of 3 seismic lines at a spacing of 50 m.

Boomer data was acquired on the majority of lines. Typically, a corridor of seabed geophysical data, 350 – 400 m wide, was acquired along each transect. Seventy Clamshell grab samples were taken from the seabed at the intersections of the survey transect lines. All bathymetric and seismic data has been stored digitally.

Biological data was acquired using 70 Hamon grabs, 20 beam trawls and 70 video drops recovered at the intersection of the seismic lines (Figure 1.3). Survey data is available from www.marinegis.org.uk and www.marinealsf.org.uk. The operations report for the 2007 MALSF survey provides a specification of the data collection methods, as well as the grab sample and beam trawl results, and seabed images. The report is provided in Appendix A and is available from www.alsf-mepf.org.uk.

Data acquired in 2008 by Emu Ltd and the University of Hull's Institute of Estuarine and Coastal Studies (IECS) for the Thames Estuary Dredging Association's (TEDA) Marine Aggregate Regional Environmental Assessment (MAREA), British Geological Survey (BGS), government and other developer's data has also been interpreted during the compilation of this report. Regional bathymetry data has also been acquired through SeaZone Solutions Limited under MEPF licence.

Organisation	Team	Role & Responsibility
EMU	Dr. Ian Selby	*Project Manager*
	Dr. Dafydd Lloyd Jones Dr. Ian Selby Dr. Justin Dix Dr. Joni Backstrom Edward Henden	*Dafydd Lloyd Jones – Physical Theme Leader.* Geological interpretation, Quaternary history and seabed sediment mapping and transport.
	Robin Newman	Hydrography.
	Dr. Nigel Thomas Paul English Leigh Marsh	*Nigel Thomas – Biological Theme Leader*. Ecology, habitat & biotope interpretation and mapping
	Joe Edgell Siân Herrington Justina Southworth	Project Administration
	Helen Cole Richard Marlow Matthew Powell	*Helen Cole – GIS Theme Leader* GIS, database creation and management, spatial data analysis, mapping outputs
University of Southampton	Dr. Justin Dix Dr. Fraser Sturt	*Justin Dix – Heritage Theme Leader*. Heritage assessment; anthropogenic features and characterisation of submerged palaeo-landscapes.
GeoData Institute	Chris Hill	Web-based interactive GIS.

Table 1.1: The Outer Thames Estuary Regional Environmental Characterisation study team.

1.6 Report Structure

The report consists of five main sections comprising descriptions of:

- The regional setting;
- Geology and heritage characterisation;
- Ecological characterisation;
- An integrated assessment of the habitats and biotopes;
- Conclusions and recommendations for further research.

The datasets and analyses which form the basis of the review are contained in the Appendices.

1.7 Outputs

The results of the Outer Thames Estuary REC study are presented as a report. Technical details are included as appendices on a CD accompanying each report.

An interactive web-based GIS resource accompanies the REC report.

Date Acquired	Data Source	Use	Quantity	Contractor	Availability
MALSF (REC) Survey 2007	Bathymetry (swath)	Seabed morphology and composition	700 line km (as corridors)	Gardline Lankelma and Marine Ecological Surveys Ltd	Data available from: www.marinealsf.org.uk Operations report: www.alsf-mepf.org.uk
MALSF (REC) Survey 2007	High resolution seabed profiling (boomer)	Seabed structure	700 line km (as corridors)	Gardline Lankelma and Marine Ecological Surveys Ltd	Data available from: www.marinealsf.org.uk Operations report: www.alsf-mepf.org.uk
MALSF (REC) Survey 2007	Seabed imaging (side scan sonar)	Seabed morphology and composition	700 line km (as corridors)	Gardline Lankelma and Marine Ecological Surveys Ltd	Data available from: www.marinealsf.org.uk Operations report: www.alsf-mepf.org.uk
MALSF (REC) Survey 2007	Seabed samples (300 litre Clamshell grabs)	Seabed composition	70	Gardline Lankelma and Marine Ecological Surveys Ltd	Data available from: www.marinealsf.org.uk Operations report: www.alsf-mepf.org.uk
MALSF (REC) Survey 2007	Benthic samples (0.1 m^2 Hamon grabs)	Benthic communities and seabed composition	70	Gardline Lankelma and Marine Ecological Surveys Ltd	Data available from: www.marinealsf.org.uk Operations report: www.alsf-mepf.org.uk
MALSF (REC) Survey 2007	Benthic samples (2 m beam trawls)	Benthic communities	20 (~ 500 m)	Gardline Lankelma and Marine Ecological Surveys Ltd	Data available from: www.marinealsf.org.uk Operations report: www.alsf-mepf.org.uk
MALSF (REC) Survey 2007	Seabed imaging (video and still images)	Benthic communities and seabed composition	70 (~ 80 m)	Gardline Lankelma and Marine Ecological Surveys Ltd	Data available from: www.marinealsf.org.uk Operations report: www.alsf-mepf.org.uk
SeaZone Solutions Ltd 2008	Bathymetry (various methods)	Seabed morphology and composition	10,500 km^2 (approximate area)	Sourced from SeaZone Solutions Limited	SeaZone Solutions Limited www.seazone.com
TEDA (MAREA) Survey 2008	High resolution seabed profiling (boomer)	Seabed structure	200 line km (as corridors)	Emu Ltd	Geophysical data available from TEDA
TEDA (MAREA) Survey 2008	Seabed imaging (side scan sonar)	Seabed morphology and composition	890 line km (as corridors)	Emu Ltd	Geophysical data available from TEDA
TEDA (MAREA) Survey 2008	Benthic samples (0.1 m^2 Hamon grabs)	Benthic communities and seabed composition	126	Institute of Estuarine and Coastal Studies (IECS)	Benthic data available from The Crown Estate
TEDA (MAREA) Survey 2008	Benthic samples (2 m beam trawls)	Benthic communities	16 (~ 500 m)	Institute of Estuarine and Coastal Studies (IECS)	Benthic data available from The Crown Estate

Table 1.2: Primary data sources used in the preparation of the Outer Thames Estuary REC.

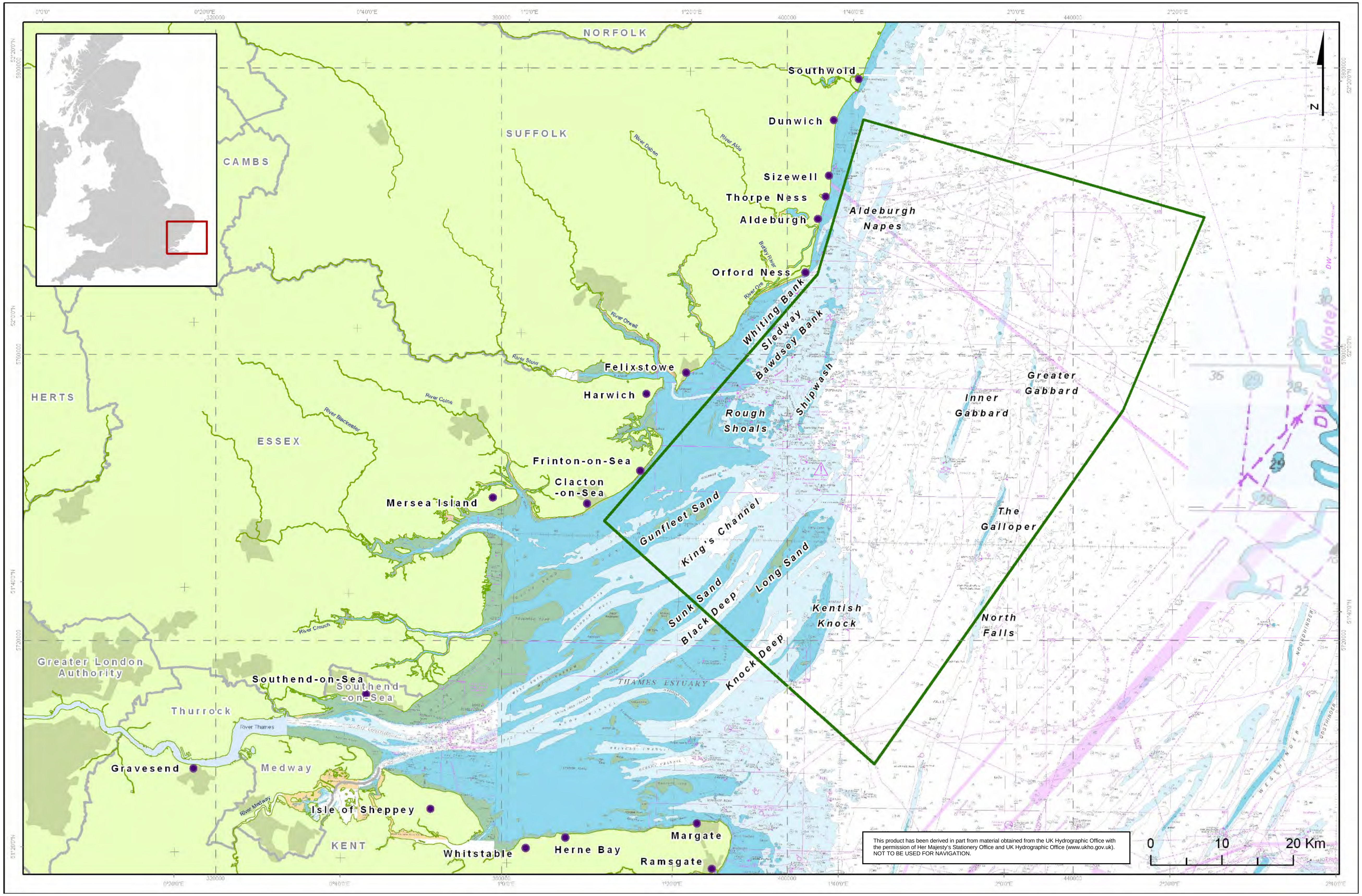

Figure 1.2: The Outer Thames Estuary REC study area. The area lies in the southern North Sea, immediately adjacent to the coasts of Essex and Suffolk and extends up to 50 km offshore.

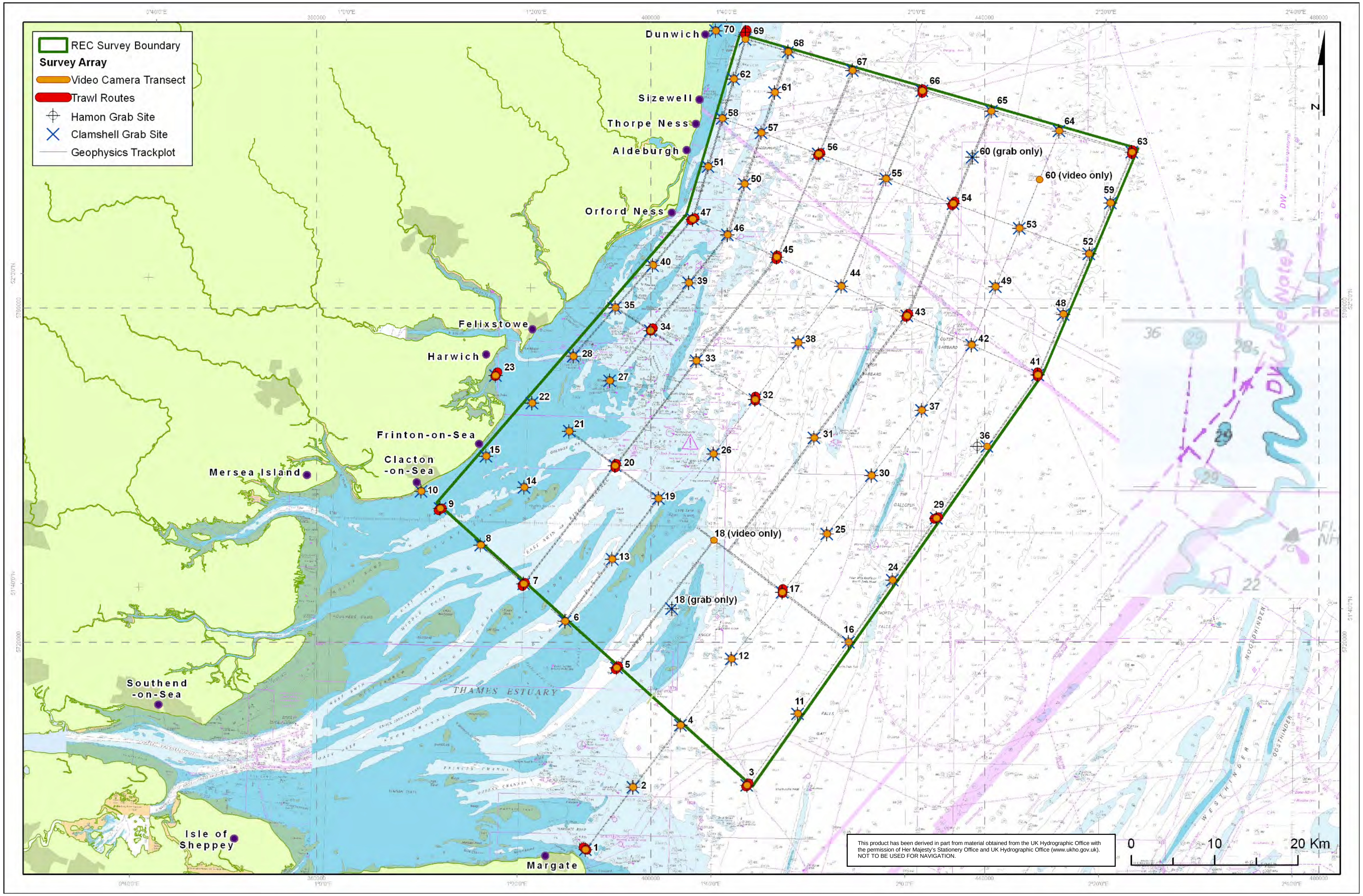

Figure 1.3: MALSF survey data acquired during 2007. The survey is composed of a high quality, integrated geophysical programme and biological dataset.

2. Regional Setting

The Outer Thames Estuary is a broad easterly-facing embayment lying offshore of south-east England on the south-western margin of the North Sea (Figure 1.1 and Figure 1.2). Offshore lies the southern North Sea, which is bounded in the east by The Netherlands and Belgium. The southern North Sea is approximately 150 km across in this region and becomes increasingly constrained towards the Dover Strait in the south and broader and more open towards the north. Across this area the North Sea is typically flat and shallow, lying at depths of 20 – 40 m, notable mainly for a series of coast-parallel sandbanks that fan out northwards from the Dover Strait.

In particular the Outer Thames Estuary is characterised by a series of prominent sandbanks trending north-south in the east, which become coast parallel to trend NE-SW farther landwards up the estuary to the west. Nearshore, the estuary is choked with muds and sands and the River Thames empties its insignificant sediment load into the rapidly broadening estuary off Sheerness.

Underlying geology in the study region is dominated by the silty clays, sandy silts and sands of the Palaeogene London Clay Formation, Woolwich Beds and Thanet Formation (BGS, 1989).

In the southern North Sea tidal currents are rectilinear and trend SSW (flood) to NNE (ebb), reaching a maximum of 2.7 knots (1.41 ms^{-1}).

2.1 The Coast

The Outer Thames Estuary lies to the east of the mouth of the River Thames and extends out into the southern North Sea (see Figure 1.2). Along the northern margin of the study area the Essex and Suffolk coastline is low lying and overlies London Clay bedrock. Relatively low coastal energy combined with supply and deposition of muds, silts and sands results in a coastline characterised by coastal mudflats and salt marshes with meandering creeks dissecting the coastal zone (Mouchel, 1997; Halcrow, 1998) (Figure 2.1 and Figure 2.2).

Farther to the north on the Suffolk coast, the exposed Crag bedrock consists of marine sands and gravel. The shoreline is a mosaic of estuaries, salt marshes, shallow creeks, low eroding cliffs and shingle banks. Several large rivers drain the immediate hinterland. The River Stour flows out to the North Sea at Harwich whilst the River Orwell broadens into an estuary at Ipswich and out in to the North Sea at Felixstowe. The Stour and Orwell estuaries consist of extensive mudflats, low cliffs, saltmarsh and areas of vegetated shingle. The River Ore flows out to the North Sea through marshland and shingle or sand beaches at Orford Ness (Figure 2.3).

The Kent coastline lies to the south-west of the study area and Margate is situated 25 km south of the Outer Thames Estuary REC margin. The Kent shoreline is generally low lying (Figure 2.4), apart from the vicinity of Margate, where the chalk cliffs rise to 20 m, and towards the west at Herne Bay, where London Clay bedrock is visible around Whitstable and the Isle of Sheppey. The shoreline along this coast is varied – ranging from sandy beaches to marshes.

The River Medway catchment area is the largest in southern England and flows into the Outer Thames Estuary between the Isle of Grain and Sheerness.

Much of the East Anglian and Kent coastline is protected by some form of sea defences, such as groynes, concrete piles, sea walls, grassy bunds or a shingle bank. Almost the entire coastline of Essex is protected by sea walls (in excess of 400 km of protective measures). Most of the defences consist of flood embankments, but where shoreline and cliff erosion are taking place other forms of coastal defence are present (Mouchel, 1997). Sea defences are also common along the Suffolk and Kent coastlines where a range of coastal defence structures are present, from groynes at Whitstable to a breakwater at Herne Bay.

Figure 2.1: Hamford Water National Nature Reserve, Essex (©John Lemay).

Figure 2.2: Marshland south of Harwich, Essex (©David Kemp).

Figure 2.3: Orford Ness Beach and National Nature Reserve, Suffolk (©NTPL/Joe Cornish).

Figure 2.4: Walpole Bay, Margate, Kent (©Thanet District Council, www.visitthanet.co.uk).

2.2 Bathymetry and Seabed Morphology

Offshore, the Outer Thames Estuary is divided into three distinct bathymetric and morphological zones (Figure 2.5 and Figure 2.6):

- The Western Zone,
- The Central Zone, and
- The Eastern Zone.

All water depths are reported as depth below Chart Datum (CD) and bathymetry charts are based on data from Seazone Solutions Limited and the Outer Thames Estuary REC survey data described in Appendix A.

2.2.1 The Western Zone

The seabed in the Western Zone is dominated by a series of coast-parallel, regularly spaced, NE-SW trending sandbanks and associated channels and troughs (Figure 2.6). The sandbanks, for example, Long Sand, Sunk Sand, Gunfleet Sand, Kentish Knock and Shipwash are 1 – 5 km across, 10 – 30 km long and the crests are commonly dry at low water. Sunk Sand has a maximum width of approximately 3.5 km and Long Sand has a maximum width of 5.5 km, with their crests at approximately 0 m CD. The sandbank 'heads' lie at the north-eastern termination of the banks.

The Sunk Sand, Long Sand and Kentish Knock (Figure 2.6) sandbanks rise relatively steeply from the adjacent seabed with slopes of around 1 in 10. The channels lying between the banks – The King's Channel, Black Deep, Knock Deep, Shipwash and Sledway, are 2 – 5 km across and typically reach depths of about 20 m. The troughs, particularly in the north, are typically of similar widths as the sandbanks, but become progressively narrower further south.

Inshore, the Whiting Bank and Bawdsey Bank sandbanks are approximately 1 km across and the crests lie at depths around 0 m. These banks are classified as headland-associated banner banks (Burningham and French, 2008). Burningham and French believe both of these features have been relatively stable for the last 350 years, although there is some evidence that Bawdsey Bank has accreted vertically about 19 mm yr^{-1} since the 20th century.

The seabed between the banks in the zone is often smooth, with rare, more irregular areas, for example at Rough Shoals. Nearshore, the seabed is irregular and shallows gradually with the 10 m isobath lying >5 km off the coastline. A single deep water channel is dredged for the approach to Harwich. The seabed to the east of the sandbanks is uniform, ranging in depth between 20 – 25 m. There is a notable change in seafloor relief along the outer margin of the Western Zone where it adjoins the Central Zone. Low relief polygonal patterning of the seabed occurs in places, including the Early Eocene Oldhaven Beds near The King's Channel, potentially created by periglacial freeze-thaw processes (Figure 2.7).

2.2.2 The Central Zone

The seabed in the central zone forms a flat, relatively rough platform characterised by isolated troughs and sandbanks (Figure 2.6). At the offshore limit of the zone, water depths reach around 40 m, but across the majority of the zone, depths lie around 20 – 30 m. The platform becomes slightly more irregular in the east with a stepped appearance.

The sandbanks in the Central Zone include the Inner Gabbard, Greater Gabbard, The Galloper and the North Falls. The sandbanks trend NNE – SSW, are approximately 10 km long, 1 – 2 km wide and their crests lie at depths of 5 – 10 m. These banks are often asymmetrical (steeper slopes facing west) and sub-parallel to the dominant tidal flow direction, offset in an anticlockwise orientation (Kenyon *et al*., 1981). There is no evidence for any (underlying) geological control in the location of the banks, i.e., they are not stranded on bedrock highs. Inshore, there are minor banks off Sizewell and Minsmere, as well as the Aldeburgh Napes.

These banks correspond to the second sub-group of the Thames sandbanks (Cameron *et al*., 1992) and are also classified as open-shelf ridges according to Dyer and Huntley (1999) and Burningham and French (2008). Bathymetric comparisons over 400 years by Burningham and French (2008) suggest that the ridges have shown no significant erosional or depositional change over the last 200 – 300 years since they were first charted.

Around 51° 56'N, 001° 50' E the flat seabed is disrupted by two 2 km wide, 20 km long, parallel troughs trending north-south immediately west of the Inner Gabbard (Figure 2.6), separated by a 1 km wide ridge which is level with the adjacent seafloor. These troughs are named the Inner Gabbard Deeps. The bases of the troughs lie 20 – 30 m below the adjacent seabed and reach depths of 59 m. The Deeps are characterised by an irregular seabed, a poorly defined wider, open southern limit and a narrow northern termination. A series of minor, less well developed deeps exist 5 km to the NNW and 20 km to the south of the Inner Gabbard Deeps where they reach depths of up to 43 m. There is a maximum elevation change of 41 m between the deepest portion of the Deeps and the adjacent Inner Gabbard sandbank, over a distance of less than 5 km (a slope of 1:120).

At least two east-west trending unfilled channels around 1 km wide extend across the zone, including channels emanating from the mouth of the Rivers Stour and Orwell which are traceable across the zone to the eastern limit (Figure 2.6). The bases of the unfilled channels lie up to 10 m below the adjacent seabed. Note that the Inner Gabbard, Greater Gabbard and Shipwash sandbanks overlie these east-west trending channels. In addition, several other unfilled channel-like features trending north-south are also present.

2.2.3 The Eastern Zone

The seabed in the offshore Eastern Zone is flat and lies at depths of 40 m to 55 m. The zone is devoid of sandbanks and is dominated by a series of NW-SE trending dunes with wavelengths >100 m and amplitudes of up to 15 m. The dunes decline in size to the south. The zone is commonly bounded to the west by an abrupt step margin adjacent to the central zone platform, although in the north the margin becomes less abrupt and less clearly defined. Immediately to the east of the study boundary and the Galloper bank, two poorly defined NNE – SSW trending troughs are present.

Within the dune field two unusual east-west and ENE-WSW trending symmetrical ridges occur around 52°03' N and 2°17' E (Figure 2.8). The well defined ridges are 350 – 450 m long, up to 50 m wide and the crests lie at a depth of 45 m. Distinct symmetrical scour pockets occur at either end of the ridges reaching depths of 70 m.

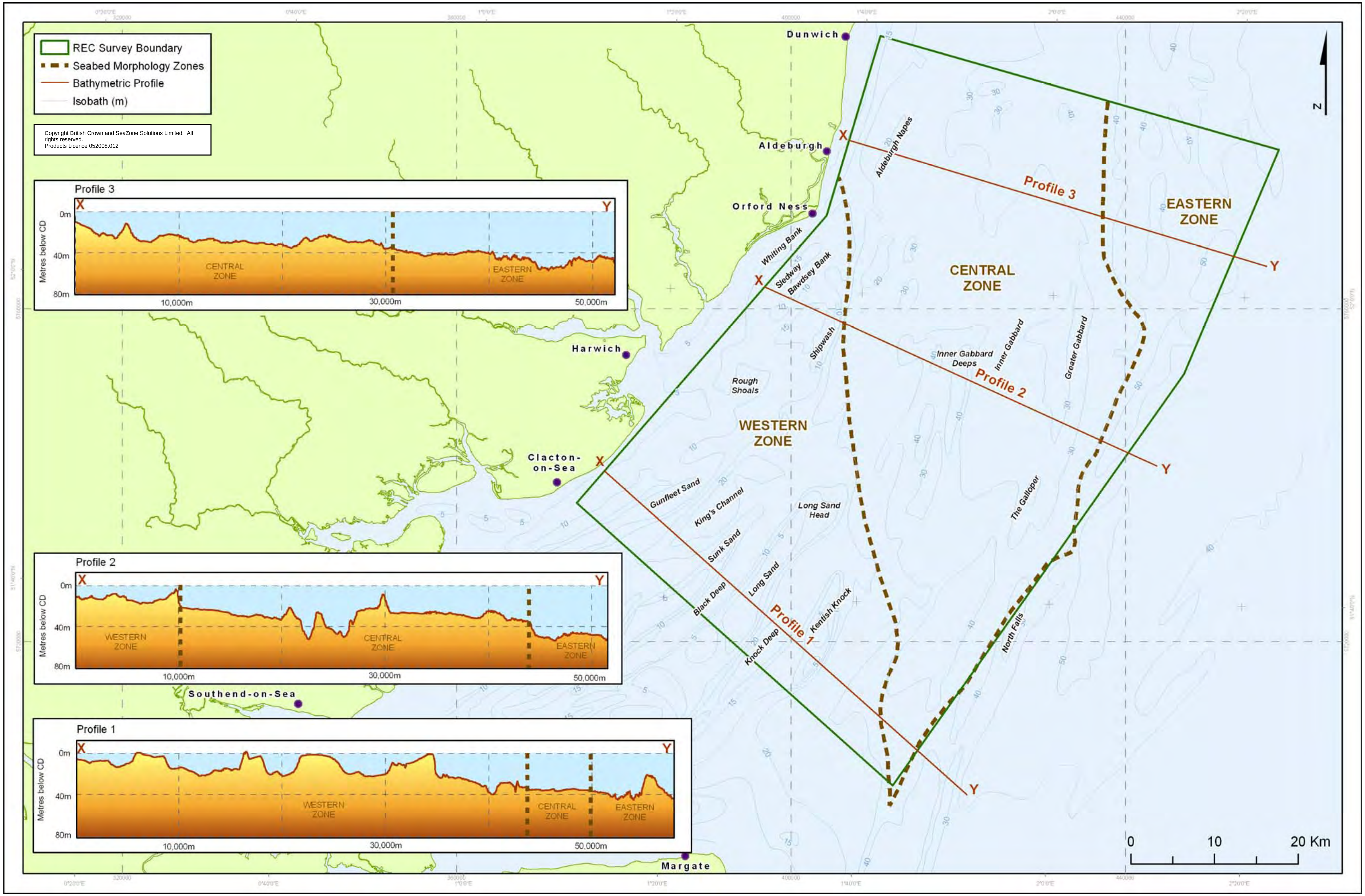

Figure 2.5: Bathymetry of the Outer Thames Estuary REC area. Depths range from near 0 m along the drying sandbank crests in the west of the area to around 60 m at the NE limits of the area. Note the Central Zone forms a platform lying at depths of around 20 – 30m, whilst the Eastern Zone lies at depths of around 40 – 50 m.

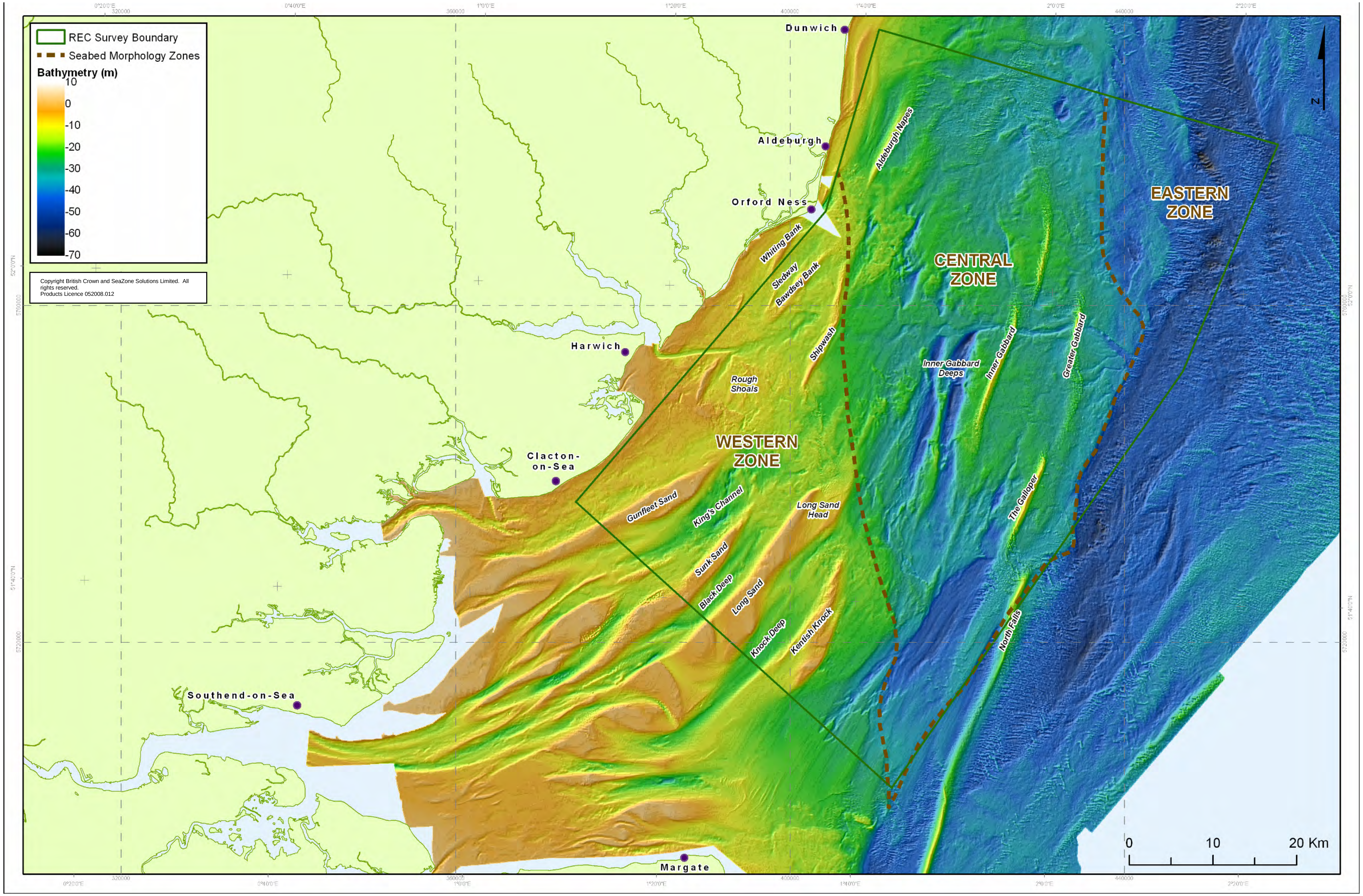

Figure 2.6: The Outer Thames Estuary REC bathymetry and morphological zones (based on Seazone Solutions Limited data gridded at 75 m). The sandbanks of the Central Zone clearly overlie a flat platform which is also characterised by several elongate depressions, for example the Inner Gabbard Deeps.

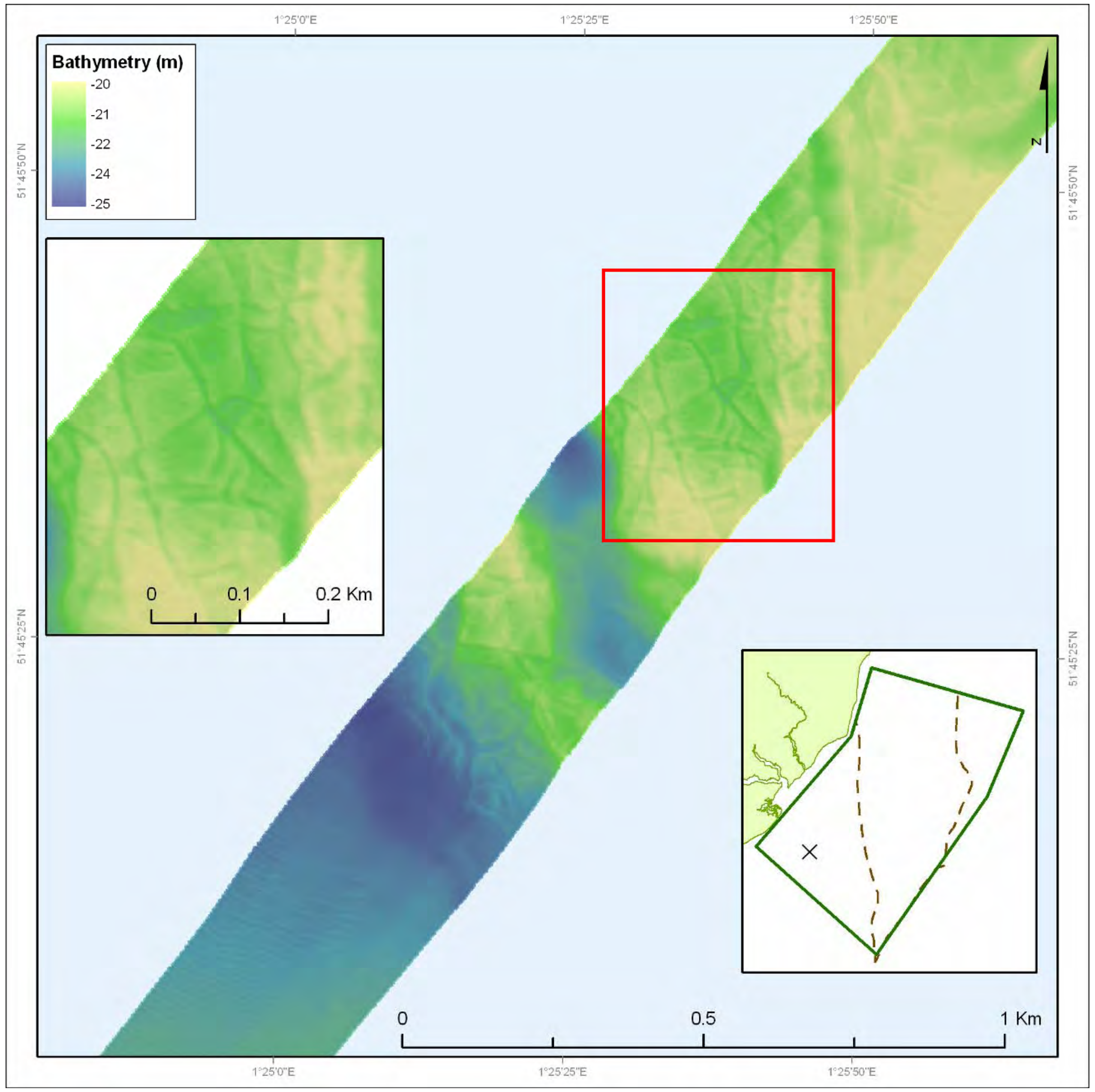

Figure 2.7: Polygonal patterned seabed in the Western Zone where the Early Eocene Oldhaven Beds are exposed at the seabed. There is no evidence in seismic profiles for diagenetic/tectonic structures and the patterns may be periglacial in origin.

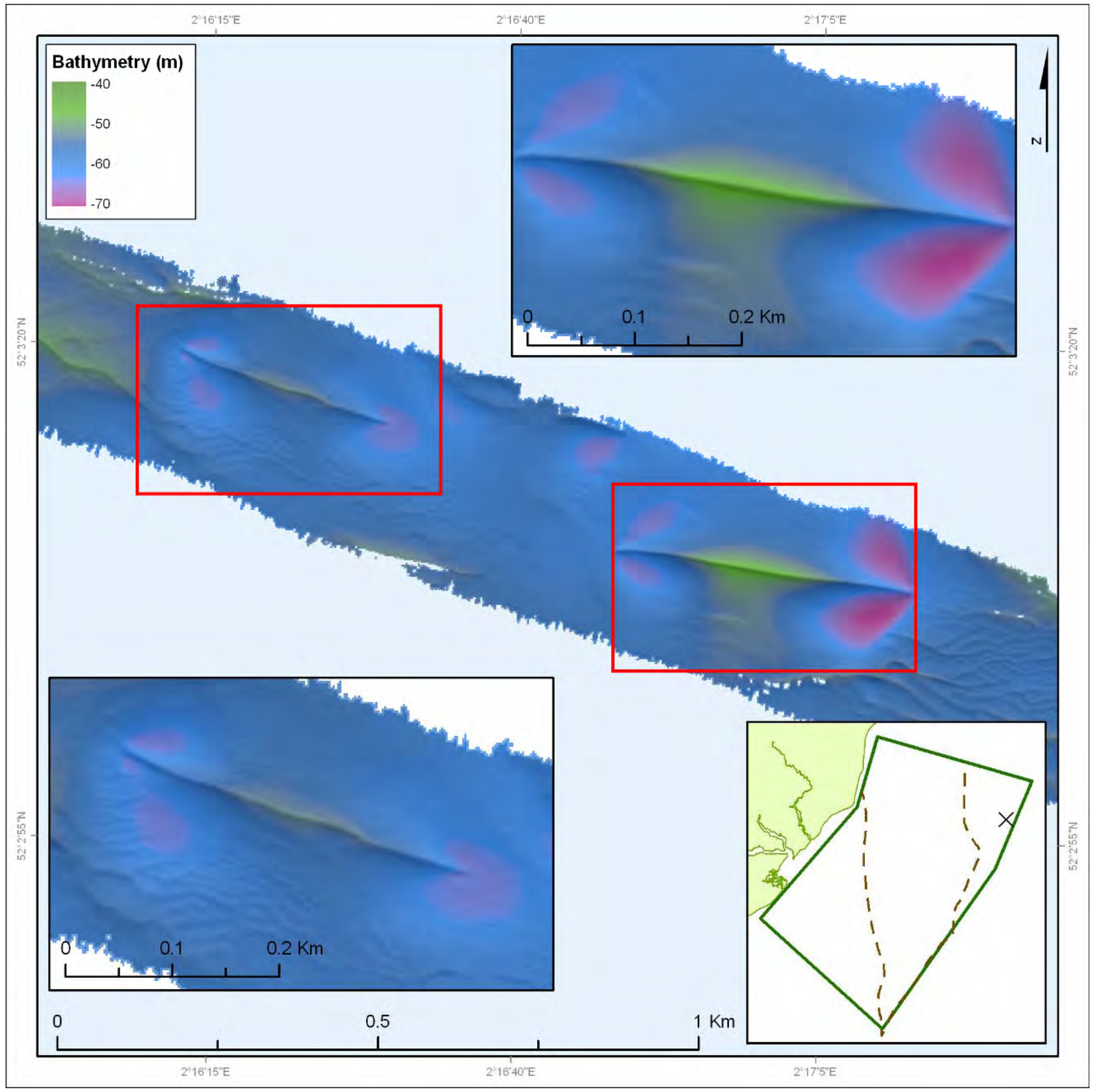

Figure 2.8: Isolated, sharp-crested linear ridges with symmetrical scour pockets located in the Eastern Zone. These features are clearly distinct from the large dunes located immediately to the east and west.

2.3 Seabed Sediments and Sediment Transport

The seabed of the Outer Thames Estuary consists of a diverse mix of sediments and exposed bedrock. Whilst some areas of the seabed are relict, recent erosional and depositional processes have influenced many areas of the seabed in this region. In particular these processes include the marine transgression following the Last Glacial Maximum (see Section 3) when sea levels rose >100 m and the action of waves, tides and currents over the last 5,000 years. The combination of the older components and recent processes has resulted in the morphological and compositional framework of the modern seabed. The recent processes have also created a range of existing active bedforms within the study area.

The interpretation of seabed sediments and bedforms is primarily based on multibeam bathymetry, side scan sonar, and Clamshell and Hamon grab samples (Figure 1.3) (see Appendix A). The Clamshell grab samples tended to contain higher proportions of mud derived from the underlying bedrock than the Hamon grabs, particularly in the central zone. Mean grain sizes and sorting parameters for grab samples are based on Folk and Ward (1957).

The data has also been supplemented by the inclusion of a number of other datasets including:

- Interpretation of seabed video and camera data obtained for the Outer Thames Estuary REC study (see Appendix A).
- Side scan data collected as part of the Outer Thames Estuary Marine Aggregate Regional Environmental Assessment (MAREA) project for TEDA (ERM, in preparation).
- UKHO bathymetric data from various surveys of the study area.
- British Geological Survey interpretations (BGS, 1990).

The seabed in the Outer Thames Estuary REC area is dominated by various mixtures of sands and gravels which are occasionally muddy (Figure 2.9 and Figure 2.10). These may be subdivided on the basis of composition and distribution to recognise four principal types of seabed sediments present in the Outer Thames Estuary REC area (Table 2.1).

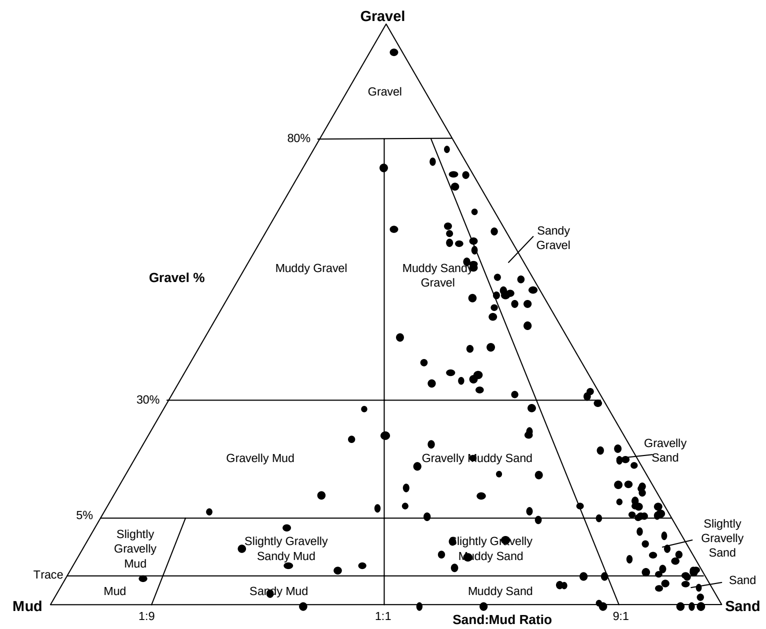

Figure 2.9: Sediment classification (Folk, 1954) of the Clamshell and Hamon seabed grab samples recovered for the Outer Thames Estuary REC study.

Bedforms are common within the study area (Figure 2.10). A variety of small and large-scale bedforms are present which include:

- Sandbanks
- Submarine dunes (Ashley, 1990)
  - o small (0 – 6.5 m wavelengths)
  - o medium (5 – 10 m wavelengths)
  - o large (10 – 100 m wavelengths)
  - o very large (>100 m wavelengths)
- Sand patches, sand ribbons and sand streaks

The orientation of bedforms provides evidence for inferred dominant sediment transport directions at the time the surveys were conducted. The majority of the bedforms in the study area are transverse to the dominant north-east to south-west tidal flow; however some flow (tide) parallel bedforms are also present. Other bedforms may contain both types of elements (e.g. tide parallel sandbanks with small scale, superimposed flow-transverse dunes). The seabed sediments in each zone are considered separately below.

Seabed Sediment	Location	Morphological zones
Mixed (muddy) sands and gravels	Predominantly nearshore	Western and Central Zones
Fine to medium sand that is moderately to well sorted	On large sandbanks and thin localised sand sheets and streaks	Western and Central Zones
Thin veneers (tens of cm to a few meters) of sand and gravel overlying bedrock	Much of the study area	Central Zone
Coarse sands, slightly gravelly sands and gravelly sands	Bedform field along the eastern margins of the study area.	Eastern Zone

Table 2.1: Principle seabed sediment types identified in the Western, Central and Eastern Zones of the Outer Thames Estuary REC study area.

2.3.1 Western Zone

The seabed in the south-east of the Outer Thames Estuary REC study area is dominated by a series of SW-NE trending sandbanks forming wide estuary mouth ridges or estuary mouth banks (Cameron *et al*., 1992; Dyer and Huntley, 1999 and Burningham and French, 2008). Present day fluvial contribution to the sediment budget of the area is very small; the sources of sand for the sandbanks are a result of the earlier reworking of fluvially deposited sediments, erosion of cliff sediments in Essex and Suffolk, exposure of Lower London Tertiary lithologies and, to a lesser extent, glacio-fluvial outwash within channel systems (British Geological Survey, 1990).

Seabed Sediments

The main features of the Western Zone are largely depositional in origin and the zone contains the thickest succession of unconsolidated sediments in the region. A complex pattern of muddy, sandy and gravelly areas are present outside of the large estuary mouth sandbanks which are composed of well sorted fine-medium grained sands.

Twenty five Clamshell grabs from within the Western Zone are composed of 7 gravel, 16 sand and 2 mud samples. The coarsest gravel sample from the region is sample station 27 (mean grain size 52.0 mm) and sample stations 39 and 47 are also gravelly (mean grain sizes of 4.9 and 4.8 mm). Two mud samples are located at landward sample stations (9 and 21). The mean grain size for all 25 samples in the zone is 2.8 mm. Sorting is highly variable, ranging from extremely poorly to moderately well sorted (Figure 2.12).

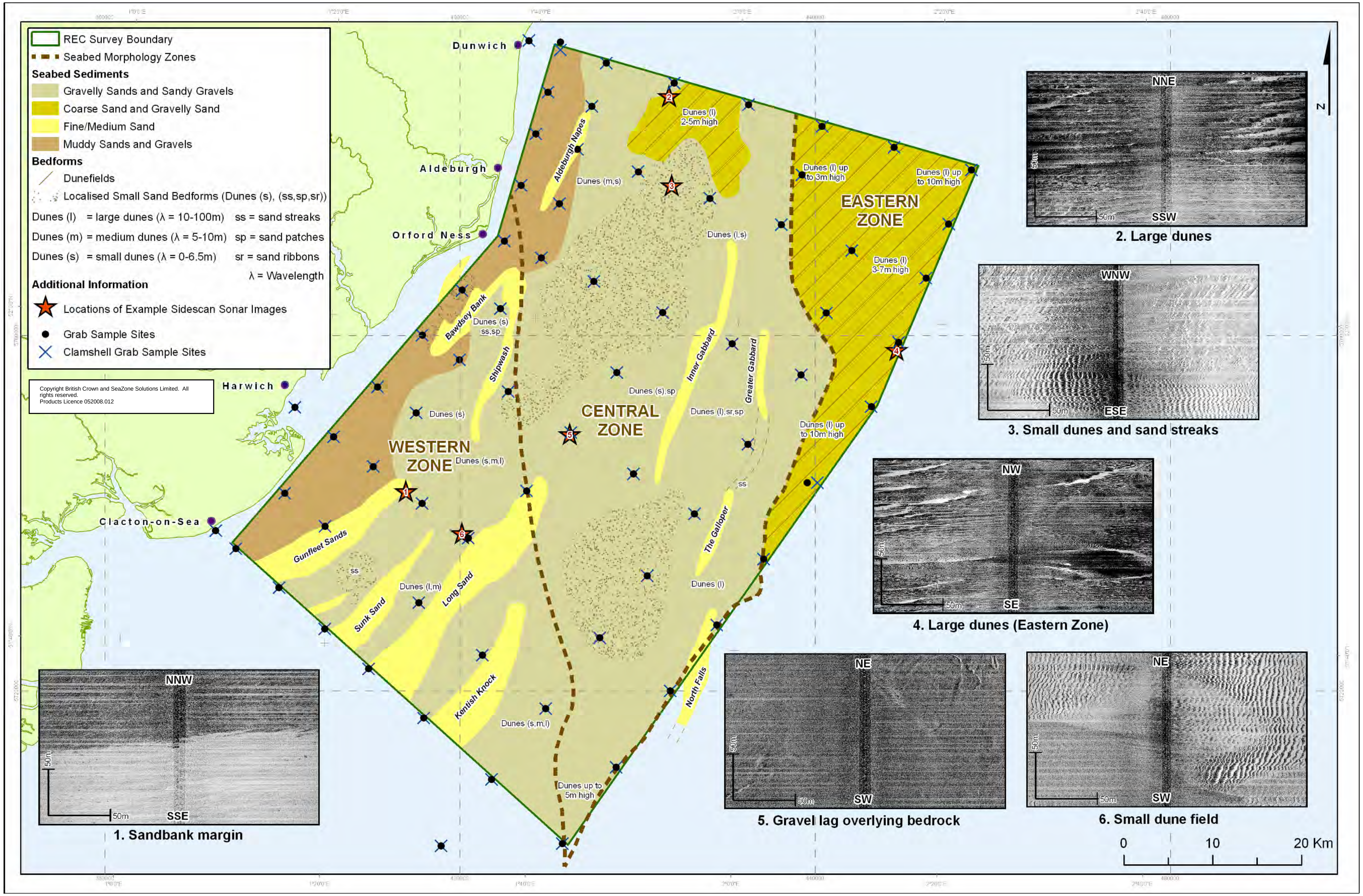

Figure 2.10: Seabed sediment distribution map of the Outer Thames Estuary REC area. Side scan sonar examples illustrate the range of seabed types in the area.

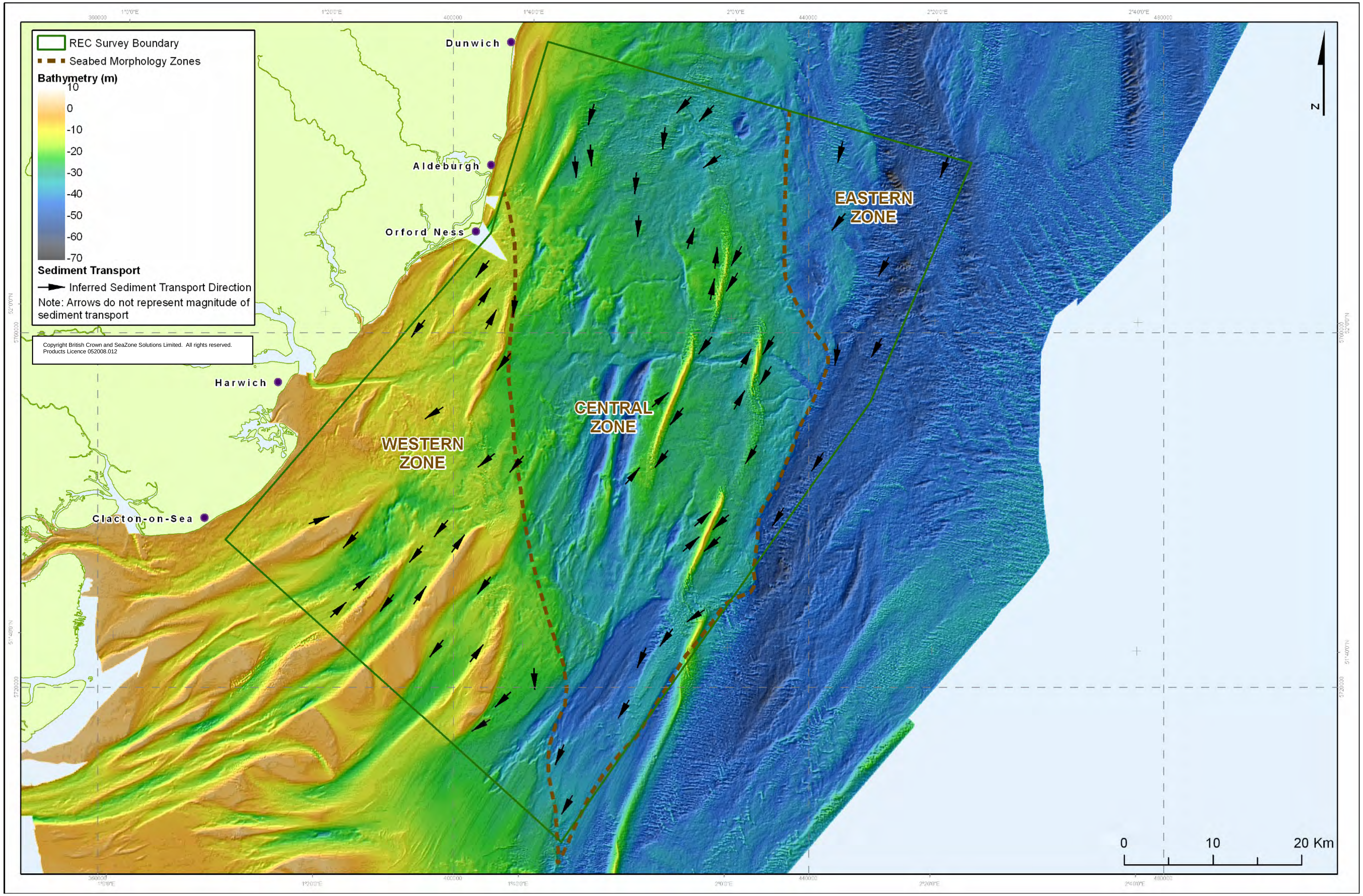

Figure 2.11: Inferred seabed sediment transport directions in the Outer Thames Estuary REC area. The interpretation is based on side scan sonar and bathymetry data.

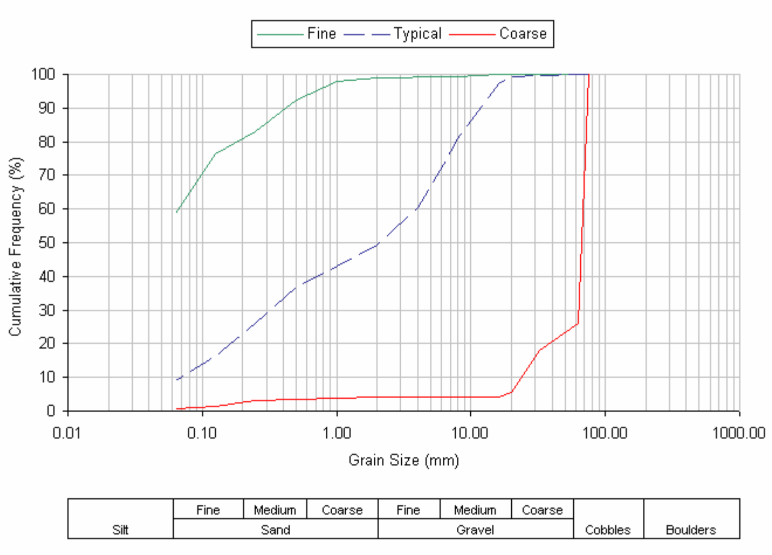

Figure 2.12: Cumulative frequency envelope and estimated typical particle size distribution in the Western Zone of the Outer Thames Estuary REC area.

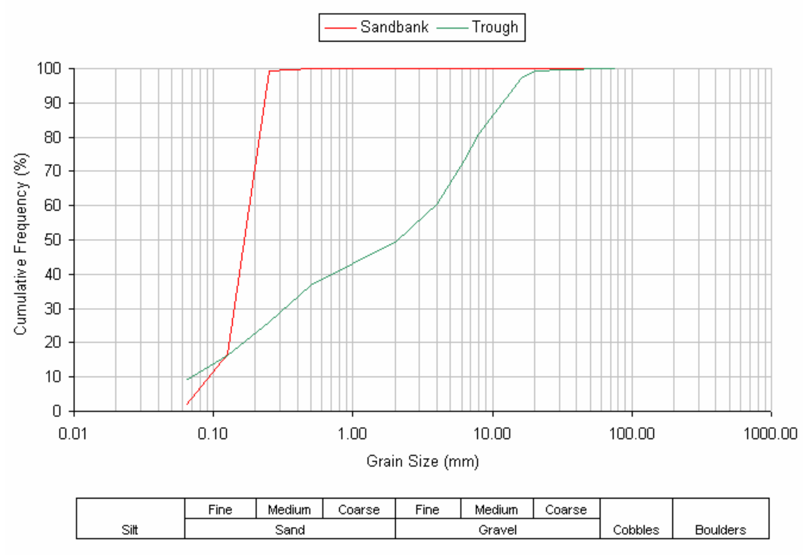

Figure 2.13: Cumulative frequency distribution curves comparing typical samples from the margin of a sandbank and an inter-bank trough in the Western Zone.

Figure 2.14: Sandy flint and shell gravel seabed from a trough between the sandbanks in the Western Zone (grab sample location 7).

Samples from the large sandbanks indicate that they are largely composed of fine to medium grained sands (mean grain size of around 0.16 mm) that are moderately well to very well-sorted, with little to no gravel (Figure 2.13). Typically there are abrupt boundaries between the sandbanks and inter-bank areas and sediments in the troughs are a poorly sorted mixture of gravels, sand and mud up to 1 m thick (Figure 2.13 and Figure 2.14). The percentage of mud is greatest nearshore and reduces progressively offshore.

Bedforms and Sediment Transport

The majority of the region is covered with a range of different-sized bedforms, from sand patches and ribbons to very large dunes and sandbanks (Figure 2.10). The crests of the large sandbanks do not show evidence of superimposed bedforms, however, dunes of various sizes are commonly present on the flanks. On the flanks of the sandbanks the crests of the submarine dunes are typically oriented NW-SE, suggesting south-westerly (on the east flank) and north-easterly (on the west flank) sediment transport directions, inferring a clockwise circulation of sand around the large estuary mouth ridges (Figure 2.11).

Clockwise sediment transport around these sandbanks concurs with previous studies, for example Caston (1981) and the North Sea Sediment Transport Study 2 (HR Wallingford, 2002) (Figure **2.15**). Bedforms on the northern heads of the sandbanks show a variety of orientations, implying that transport in these ‘convergence’ zones is neither constant nor unidirectional.

Localised small scale sand bedforms occur on the seabed east and north of the sandbanks and orientations suggest a minor dominance of southerly transport, with other areas indicating neutral or variable directions. The SNSSTS-2 (HR Wallingford, 2002) shows variable sediment transport directions for this area, although storm surges tend to increase the likelihood of transport towards the south.

Bedforms are often absent in the troughs and interbank areas, although small dunes and occasional sand streaks are present in the vicinity of the sandbanks, oriented parallel to the bank margins.

There is evidence of northerly sand transport in the trough between the headland-associated banks, Bawdsey Bank and Shipwash, with southerly transport on the landward margin of Bawdsey Bank and on the seaward margin of Shipwash (Figure 2.11).

2.3.2 Central Zone

The Central Zone is primarily associated with erosional features and is typified by a flat-lying, slightly irregular seabed that is punctuated by a series of depressions and ridges oriented mostly north-south. The ridges consist of five sandbanks located towards the eastern margin of this zone including the Inner and Greater Gabbard, The Galloper and North Falls *(*Figure 2.10).

Seabed Sediments

Around 80% of the Central Zone seabed comprises sandy gravels and gravelly sand and exposed bedrock. The sandy gravels and gravelly sands of the Central Zone often form only a thin veneer (tens of centimetres) overlying Tertiary bedrock (London Clay).

Where the superficial sediments are absent the bedrock is exposed at the seabed. Limited samples from the Inner Gabbard Deeps indicate that the seabed is commonly composed of bedrock (Figure 2.16). The bedrock surface is interpreted as a ravinement and the sparsity of sediment is attributed to a lack of sand supply coupled with strong currents that prohibit sediment deposition (as evidenced by the low percentage of fines). The gravelly sediments are interpreted as a lag deposited during the last transgression (Figure 2.16).

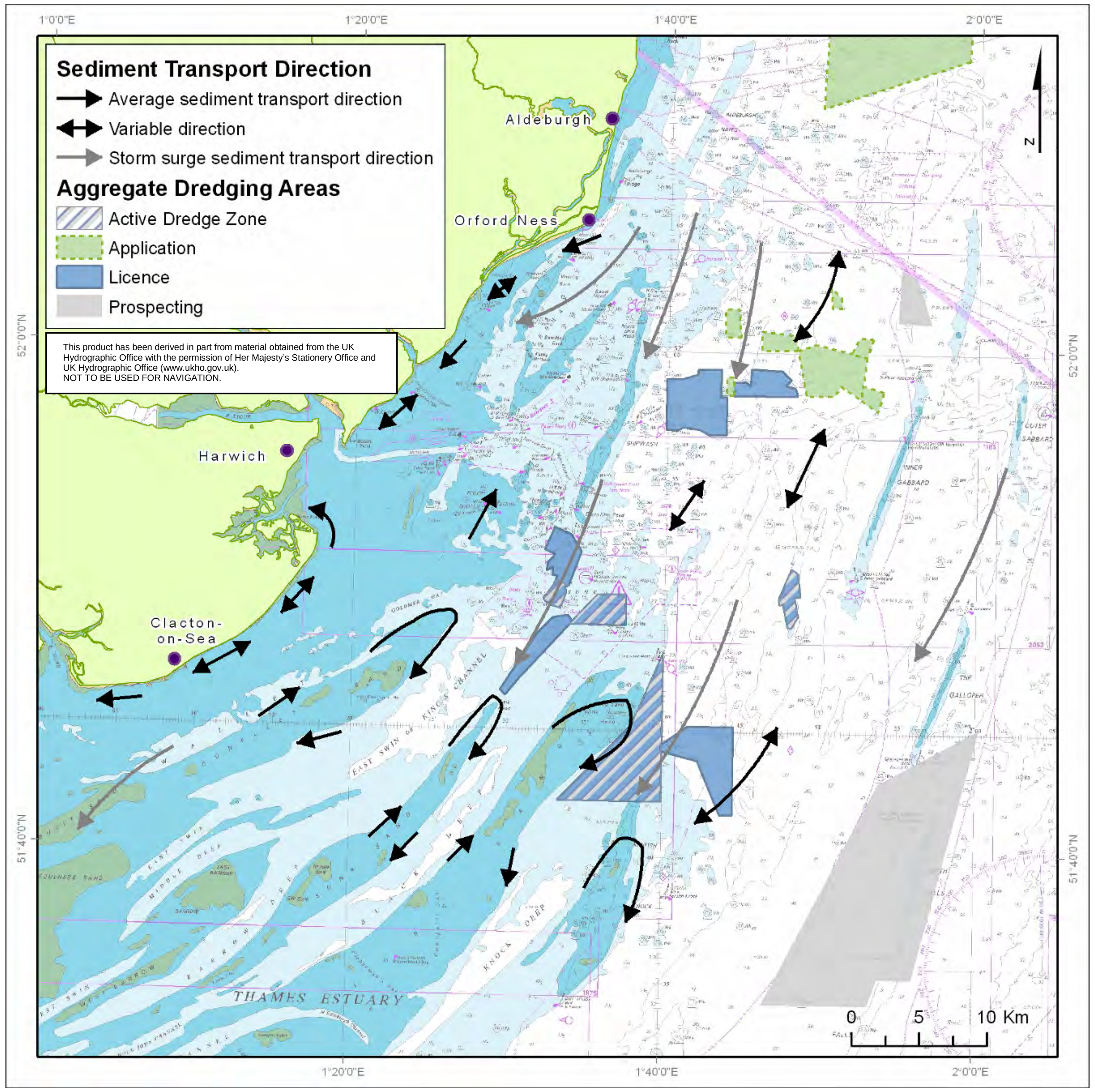

Figure 2.15: Generalised sand sediment transport pathways for the Outer Thames Estuary REC study area as determined by SNSSTS-2 (2002). Note the clockwise transport around estuary mouth ridges, with variable transport elsewhere and surge-driven southwards sand transport.

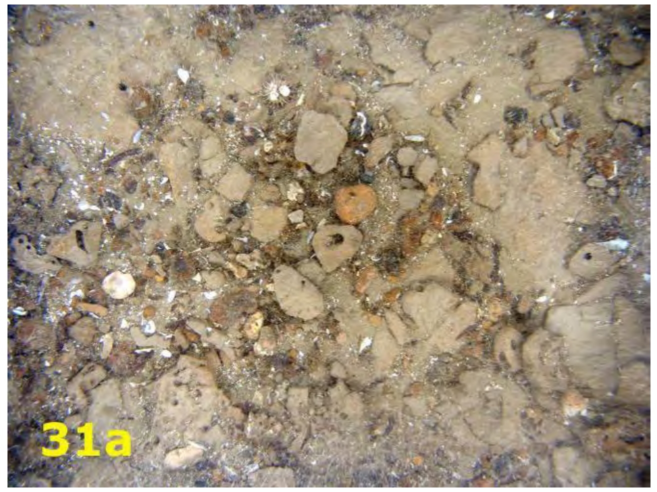

Figure 2.16: Bored bedrock fragments and occasional flint and shell gravels along the eastern margin of the Outer Gabbard Deep (grab sample location 31).

The gravels consist largely of flint derived directly from the Chalk and Quaternary fluvial deposits that existed prior to the Flandrian transgression (BGS, 1990, Veenstra, 1971, D'Olier, 1975). In places, sandy bedforms overlie the lag deposit. The bedforms are typically small-scale and commonly consist of small dunes, sand streaks, sand ribbons, and sand patches (Figure 2.10). The remaining seabed consists of sandy sediments forming sandbanks and large dune fields.

The 28 Clamshell grab samples recovered from the Central Zone contain 9 gravel, 12 sand and 6 mud samples. Mean grain-size for all 28 samples is 1.26 mm. The majority of the samples are poorly to extremely poorly sorted sands and gravels (Figure 2.17), reflecting the composition of the highly variable gravelly lag deposits. Sandbank sediments are mostly composed of fine to medium sands with little to no gravel.

Large submarine dune fields are found in two locations, along the northernmost portion of the Central Zone and between The Galloper and North Falls in the south east (Figure 2.10). Samples from the large dunes are composed of poorly sorted gravelly sands and sandy gravels, similar to the dune fields of the Eastern Zone.

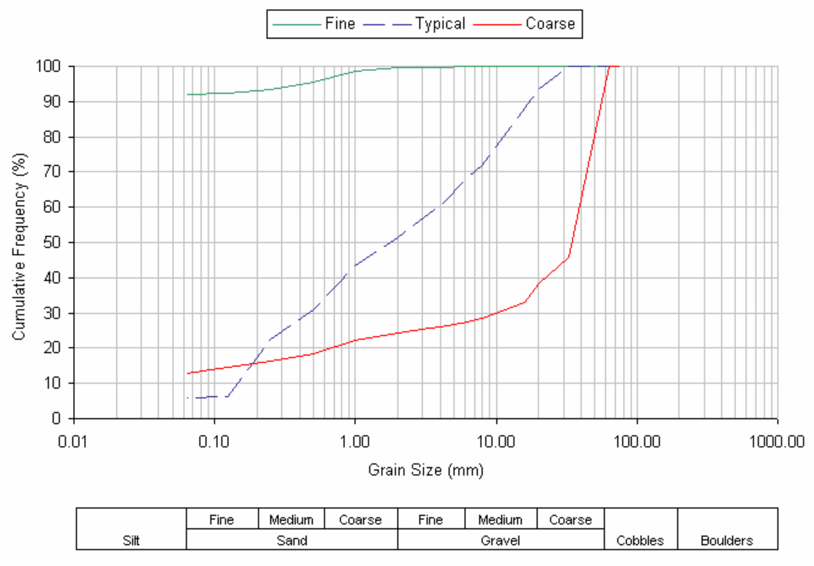

Figure 2.17: Cumulative frequency envelope and typical particle size distribution for samples in the Central Zone of the Outer Thames Estuary REC area.

Bedforms and Sediment Transport

Sand bedforms in the Central Zone are commonly dispersed and small in scale, for example small dunes and sand streaks. In many areas of the lag deposits no bedforms are visible, implying insignificant transport of sandy sediment occurs under the current scouring hydrodynamic regime. Where small scale bedforms are present, the sand patches, sand ribbons and sand streaks are oriented parallel to tidal currents (NE-SW). Streaks may be up to a few kilometres long, with widths of tens of meters and thicknesses of less than a meter.

The large to very large dunes located between North Falls and The Galloper are oriented NW-SE with wavelengths of up to 100 m. Smaller-scale dunes, oriented more E-W are superimposed and sediment transport is strongly suggestive of being towards the south-west in this area. Large bedforms are not present in the east where water depths increase. As in the Western Zone, dunes migrate to the north on the western flanks of the sandbanks and to the south on the eastern flanks inferring a clockwise sand circulation around the banks (Figure 2.11).

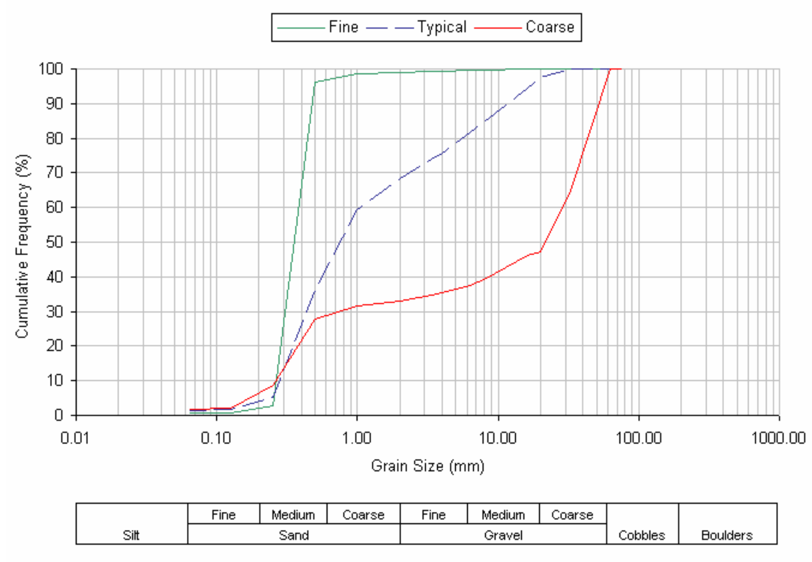

Figure 2.18: Cumulative frequency envelope and typical particle size distributions sampled in the Eastern Zone of the Outer Thames Estuary REC area.

2.3.3 Eastern Zone

The Eastern Zone is located in significantly deeper water than the other zones to the west and it is divided from the Central Zone by an abrupt change in seabed depths from approximately 30 to 50 m.

Seabed Sediments

The Eastern Zone is sediment rich when compared to the adjacent Central Zone, a result of significant sediment supply from the north and from localised erosion of the underlying Plio-Pleistocene Crag deposits (BGS, 1988).

The zone is composed predominantly of coarse sands and gravels (Figure 2.18). Twelve grab samples from within this Eastern Zone consist of 6 gravel and 6 sand samples. The sediments are clean with mud constituting less than 2% of the samples by weight. Over time the strong N-S currents have winnowed out any potential fine-grained (muddy) sediments, resulting in a coarse sand and gravelly sand seabed in the form of large submarine dunes.

A large proportion of the samples are medium – very coarse sand (typically a mean grain size of 0.7 mm), with varying amounts of gravel, including shell and flints (Figure 2.19). There is limited evidence of a southwards fining trend, particularly along the eastern margin where there is a decrease in the percentage of gravel-sized lithic and carbonate fractions. Mean grain-size for all 12 samples was 1.8 mm, and the sediments exhibit a range of sorting, from very poorly to moderately well sorted.

Bedforms and Sediment Transport

Extensive areas of the zone consist of large to very large submarine dunes separated by a relatively uniform seabed. The amplitudes and wavelengths of the bedforms vary with location. For example, the largest dunes, with heights of up to 10 meters and wavelengths of 100 – 200 m, are found in the far north-east corner and along the southern margin of the zone (Figure 2.10). Smaller dunes lie along the north-west and central portions of the Eastern Zone. These bedforms range from about 2 – 7 m high and have wavelengths of approximately 50 m.

The dunes are highly asymmetric indicating a net southerly sand transport (Figure 2.11). Smaller-scale bedforms are present on the flanks of the dunes, with orientations that are mostly parallel to the main crests. All of the dunes in the zone are interpreted as being mobile, particularly due to their sharp and distinct crests, although their mobility is not estimated to be high.

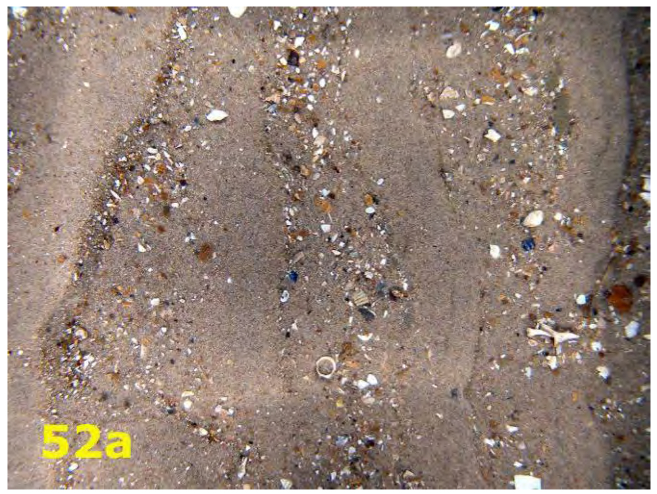

Figure 2.19: Coarse sands with occasional fine shelly gravels typically forming large submarine dunes in the Eastern Zone (grab sample site 52).

2.4 Hydrodynamic Characteristics

2.4.1 Tides

The mean spring tidal range in this region varies from around 2 m in the NE of the region to 4 m in the SW of the region. The variability of the tidal range and phase is the result of an amphidromic point lying to the north-east of the region (Figure 2.20). Predicted water elevations (Table 2.2) for three stations along the coast in the region of interest reflect this variability, with the greatest tidal range at the most southern of the three sites. Measurements carried out in the region of the Gabbard and Galloper Banks returned a maximum astronomical tidal range of approximately 4 m.

Tidal Level	Walton-on-the-Naze	Harwich	Lowestoft
	Height (m) above CD	Height (m) above CD	Height (m) above CD
Highest Astronomical Tide (HAT)	+4.6	+4.4	+2.9
Mean High Water Springs (MHWS)	+4.2	+4.0	+2.4
Mean High Water Neaps (MHWN)	+3.4	+3.4	+2.1
Mean Sea Level	+2.2	+2.1	+1.6
Mean Low Water Neaps (MLWN)	+1.1	+1.1	+1.0
Mean Low Water Springs (MLWS)	+0.4	+0.4	+0.5
Lowest Astronomical Tide	0.0	-0.1	0.0
Ordnance Datum Newlyn	+2.16	+2.02	+1.50

Table 2.2: Summary water elevation data for Walton-on-the-Naze, Harwich and Lowestoft.

The most significant cause of surges in the southern North Sea are coastally trapped waves. These waves, which propagate parallel to the shore but transfer their energy onshore, are common in the southern North Sea. They travel in an anti-clockwise direction southwards along the coast with a period of 24 to 48 hours and may often have heights of 2 m or greater. Surges may also be caused by differences in atmospheric pressure and wind forcing.

Low atmospheric pressure can cause the water level to rise and northerly winds drive water southwards causing a massing of water in the south of the North Sea. At Sheerness, the highest surge in 2007 was + 2.369 m, which occurred in November (British Oceanographic Data Centre, 2009) and was the result of a combination of both atmospheric forcing and a coastally trapped wave. The worst surge on record in the North Sea occurred in 1953 when water levels along the Thames were over 3 m higher than predicted.

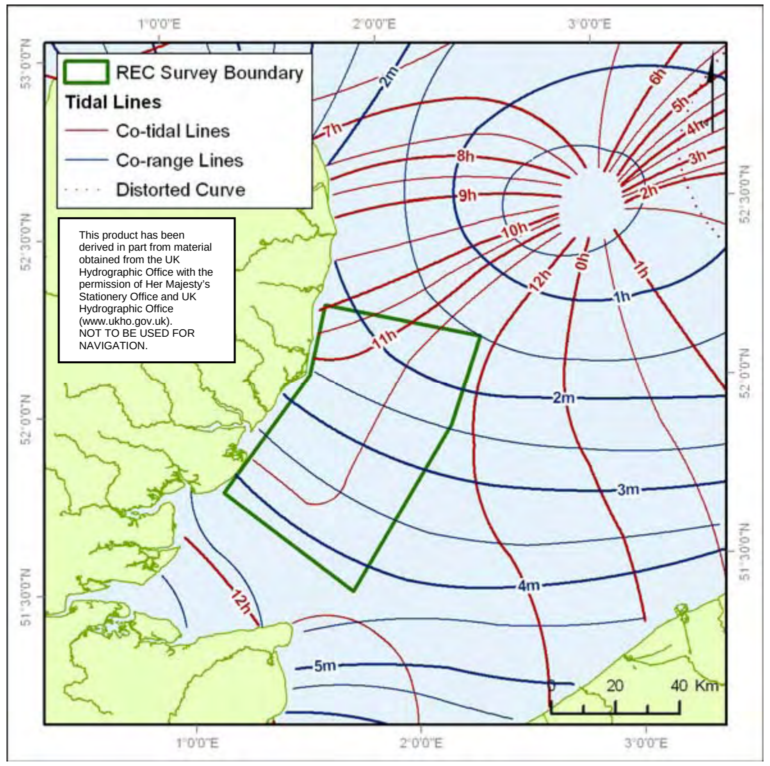

Figure 2.20: Co-tide and co-range chart for the Outer Thames Estuary REC study area.

2.4.2 Currents

The currents in this region are dominated by the tidal flow, which runs parallel to the coast inshore and north-south farther offshore. The flood is to the south or south-west and the ebb is to the north or north-east, flowing around the sandbanks. Surface current charts presented by the Admiralty indicate that current speeds peak at 1.36 ms^{-1} on the flood and 1.41 ms^{-1} on the ebb.

In general, the current speeds in this region are greatest closer to the coast, diminishing offshore. Observations of the currents in the offshore part of this region showed the current speeds to peak at 1.8 ms^{-1} at the surface. The observed flow axes ranged from 25°/205° to 48°/228°. The flow directions were influenced by the local bathymetry. There was no significant difference between the speed of the flood flow and the ebb flow.

2.4.3 Waves

The waves in this region are predominantly generated by south westerly and north-easterly winds. The prevailing south westerly winds generate short period waves, whereas the north-easterly winds generate longer-period waves due to the greater available fetch distance and the propagation of swell waves from the northern North Sea and Atlantic. The largest waves occur in conjunction with the north-easterly winds. There are several historical datasets for the study region, with two active moorings currently deployed in the area as part of the Cefas wavenet system (www.cefas.co.uk) at West Gabbard and South Knock waverider.

Significant wave height distribution, as derived from satellite observations over 16 years (Table 2.3 and Figure 2.21), indicates that the wave climate is more energetic from September to May, with June to August being calmer.

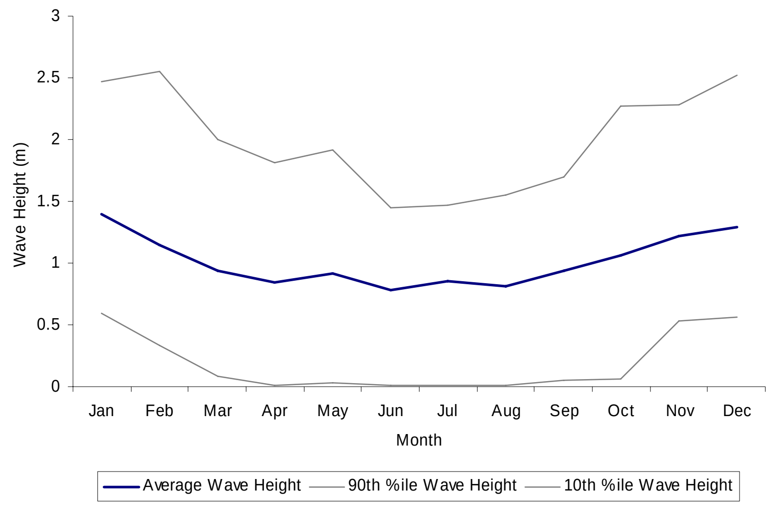

Figure 2.21: Monthly significant wave height distribution in the Outer Thames Estuary (ARGOSS 2008, www.waveclimate.com).

2.4.4 Wind

The dominant wind direction in the North Sea was from the south-south-west and south over the period 1854 to 1994 (UK Meteorological Office). The predominant wind speeds throughout the year are moderate to strong breezes (6 – 13 ms^{-1}), with gales (>17.5 ms^{-1}) occurring most frequently from November to March (Figure 2.22) (Geotek and Hartley Anderson, 2002).

The wind climate is closely linked with the North Atlantic Oscillation. In recent decades, this has resulted in more westerly winds, bringing warmer air and increased mixing within the North Sea (Geotek and Hartley Anderson, 2002). NEXT modelling (Fugro, 2001) north of the study area suggests that the strongest winds are in December and January, with average wind speeds of 9.65 ms^{-1} and 9.64 ms^{-1} respectively.

Although the predominant wind direction is from the south-west, strong winds can also occur from the north. Satellite observations of wind distribution throughout the year (Table 2.4 and Figure 2.22) indicate that the highest winds occur in January and February, with less than 14% of winds being lower than 6 ms^{-1} during January on average. June is the most benign month with only 5% of winds over 10 ms^{-1}.

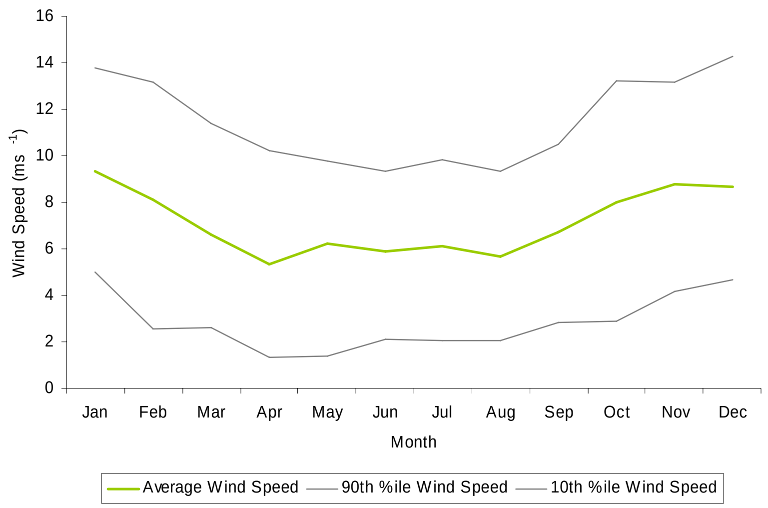

Figure 2.22: Average monthly wind speed distribution in the Outer Thames Estuary **(ARGOSS 2008, www.waveclimate.com).**

Significant Wave Height (m)	Jan (%)	Feb (%)	Mar (%)	Apr (%)	May (%)	Jun (%)	Jul (%)	Aug (%)	Sep (%)	Oct (%)	Nov (%)	Dec (%)
0.0 – 0.5	4.7	10.6	13.4	21.1	17.0	20.8	19.9	20.6	14.5	14.1	7.3	5.5
0.5 – 1.0	22.5	31.7	40.1	37.9	37.7	45.9	39.1	42.1	39.4	32.3	26.7	27.1
1.0 – 1.5	28.0	22.5	23.7	22.0	26.6	25.7	32.4	26.2	30.2	25.0	32.5	27.5
1.5 – 2.0	20.4	17.7	12.8	13.4	10.3	4.4	7.0	9.0	13.8	14.3	18.5	15.6
2.0 – 2.5	15.2	6.6	5.0	4.0	6.0	1.8	1.6	1.4	1.7	7.8	8.6	13.9
2.5 – 3.0	4.8	6.8	4.4	1.0	1.7	0.8	0	0.5	0.3	3.9	5.0	7.4
3.0 – 3.5	3.6	2.3	0.6	0.5	0.5	0.3	0	0	0.1	0.5	1.0	2.9
3.5 – 4.0	0.8	0.6	0	0	0.1	0.4	0	0.1	0	1.3	0.5	0.1
4.0 – 4.5	0	0	0	0	0.1	0	0	0	0	0.9	0	0
4.5 – 5.0	0	0	0	0	0	0	0	0	0	0	0	0
5.0 – 5.5	0	0.5	0	0	0.1	0	0	0	0	0	0	0
5.5 – 6.0	0	0.5	0	0	0	0	0	0	0	0	0	0
6.0 – 6.5	0	0.1	0	0	0	0	0	0	0	0	0	0
6.5 – 7.0	0	0	0	0	0	0	0	0	0	0	0	0
Total	100	100	100	100	100	100	100	100	100	100	100	100

Table 2.3: Significant wave height distribution in the Outer Thames Estuary between 1992 and 2007 * **(ARGOSS, 2008, www.waveclimate.com).**

Wind Speed (ms^{-1})	Jan (%)	Feb (%)	Mar (%)	Apr (%)	May (%)	Jun (%)	Jul (%)	Aug (%)	Sep (%)	Oct (%)	Nov (%)	Dec (%)
0 – 2	2.3	5.6	3.8	10.7	10.6	8.8	9.5	9.6	4.3	3.9	2.9	0.5
2 – 4	3.5	12.2	16.2	22.2	15.1	18.6	21.6	16.1	11.4	11.4	5.9	2.8
4 – 6	7.6	11.8	21.5	24.3	21.2	23.7	17.5	28.2	22.6	15.8	13.4	18.2
6 – 8	20.9	19.3	25.3	18.4	26.0	27.4	28.0	28.2	30.7	18.9	16.2	21.9
8 – 10	23.1	19.4	18.0	13.5	19.2	16.6	14.7	11.4	18.5	24.9	27.7	18.8
10 – 12	17.8	15.8	7.2	6.8	2.4	1.7	8.5	3.8	9.8	10.2	19.9	14.5
12 – 14	16.6	9.8	6.4	3.6	4.6	1.7	0.4	2.3	2.2	7.6	6.6	11.9
14 – 16	5.5	3.9	1.5	0.5	0.5	1.3	0	0.4	0.5	5.2	6.6	9.3
16 – 18	2.6	1.0	0.1	0	0.5	0.1	0	0	0	1.9	0.8	2.0
18 – 20	0.1	1.2	0	0	0	0	0	0	0	0	0	0
20 – 22	0	0	0	0	0	0	0	0	0	0	0	0
Total	100	100	100	100	100	100	100	100	100	100	100	100

Table 2.4: Wind speed distribution in the Outer Thames Estuary between 1992 and 2007 * **(ARGOSS, 2008, www.waveclimate.com).**

* Wave height and wind speed statistics are derived from satellite altimeter data (Geosat, ERS 1 and 2, Topex/Poseidon, GFO, Jason 1 and 2, Envisat and Quikscat). Data applies to 50 km x 50 km area centred at 51° 45'N, 002° 00'E, and the results based on 9,858 samples from 1,295 passes. The ARGOSS global database is updated and validated annually using a total least squares fit of linear relationships between altimeter and offshore NOAA buoy data. Wave height data has a root mean square error of 0.32 m. Wind speed data has a root mean square error of 1.61 ms^{-1} (ARGOSS, 2008, www.waveclimate.com; Groenewoud & Melger, 2009). Directional components of the data were unsuitable to produce a wind rose diagram for the specified area.

2.4.5 Water Column and Quality

A number of beaches within Suffolk, Essex and Kent are recognised for their good water quality, 17 of which have been awarded Blue Flag status, including Felixstowe South, Clacton-on-Sea, Dovercourt Bay, Southend-on-Sea, Margate and Minnis Bay, Birchington (Blue Flag, 2009). In 2007 and 2008, coastal bathing waters between Ramsgate in Kent and Southwold in Suffolk were found to have 100% compliance with the mandatory water quality standards set by the Bathing Water Directive (76/160/EEC) – not exceeding 10,000 total coliforms per 100 ml and 2,000 faecal coliforms per 100 ml in 95% of samples. Compliance with more stringent guideline standards set by the Directive (not exceeding values of 500 total coliforms per 100 ml and 100 faecal coliforms per 100 ml in 80% of water quality samples, and 100 faecal streptococci per 100 ml in 90% of samples taken) is required to fulfil the water quality criterion of the international Blue Flag award scheme. In 2007, 61% of these coastal bathing waters complied with this pass level, increasing to 66% in 2008 (Defra, 2008).

In general, inshore estuarine locations have the highest levels of chemical contamination as a result of industrial activity. Total Hydrocarbon Concentrations (THCs) in the Outer Thames Estuary were shown to be 1.1 – 1.2 $\mu g l^{-1}$ in 1990 – 1992, however, much higher concentrations can be found within estuaries (over 10 $\mu g l^{-1}$). Polyaromatic Hydrocarbons (PAHs) display a similar trend, with concentrations exceeding 1 $\mu g l^{-1}$ in the Thames estuary (Cefas, 2001).

2.4.6 Salinity

Levels of salinity are not only driven by the seasonal freshwater input from local estuaries, but also from the Atlantic water inflow, which causes annual changes within the North Sea. This has led to relatively high salinities in the 1920s, late 1960s, and 1989 – 1995, with very low salinities in the late 1970s and 1980s (HR Wallingford, 2002).

Although colder northern water causes stratification as it meets the warmer southern water within the central and northern North Sea, the Outer Thames Estuary REC area maintains mixed water throughout the year. This is due to the relatively shallow water depths and the fast rate of tidal flow. Southern North Sea water has a salinity of 34 – 34.75 ppt (HR Wallingford, 2002).

2.4.7 Temperature

As a result of the relatively shallow water and the strong tidal flows through the English Channel the water in the region remains mixed throughout the year with temperatures between 4° and 14°C.

There is a strong annual cycle of temperatures due to seasonal warming. In addition, this region is influenced by the inflow through the Channel, creating a mean sea surface temperature of 10 – 11°C. In general, the long-term average sea surface temperature within the North Sea is stable, although, as with salinity, the variability is linked to changes in the North Atlantic Oscillation and associated inflow (HR Wallingford, 2002).

2.4.8 Suspended Sediments

Commonly the sediments in the North Sea are continually modified by wave and current action. Spring tidal currents in the study area are capable of suspending muds and transporting sediment of 0.5 – 2.0 mm diameter across the majority of the region. Sediment transport is not only regulated by regular events, but can also be greatly influenced by occasional extreme storm events.

In general, suspended sediment concentrations are higher in estuaries than farther offshore. For example recent OBS measurements conducted by Emu Ltd (2008) indicate nearshore concentrations ranging from 0.2 – 977 $mg l^{-1}$ and offshore concentrations ranging from 1.7 – 219 $mg l^{-1}$.

The River Thames discharges up to 700,000 tonnes of fine suspended sediments per year at the mouth of the estuary (H.R. Wallingford, 2002). Orford Ness also has relatively high concentrations during the summer. The source of the greater summer concentrations is not well defined, as it does not appear to be associated with any spring tidal current maximum. Possible sources are from the Orford area, or from increased biological activity (HR Wallingford, 2002).

In the winter, a similar pattern of concentrations is seen, but the concentrations are double those in the summer. Satellite imagery often shows a 'hook' of suspended sediment off the Suffolk coast at Orford Ness.

2.4.9 Nutrients

The National Monitoring Programme (NMP) found that dissolved oxygen levels are relatively low in the Outer Thames Estuary around 5.7 $mg l^{-1}$. Nutrient levels vary seasonally, being dependent on input from rivers, as well as growth of phytoplankton.

2.5 Background Benthic Conditions

2.5.1 The North Sea

There has been a long history of benthic ecological study in the North Sea and the presence of discrete faunistic areas, corresponding to sediment type, water depth, thermal stability of bottom waters, food availability and food quality has long been recognised (Glémarec, 1973; Dyer *et al.*, 1983; Eleftheriou and Basford, 1989; Duineveld *et al.*, 1990; Heip and Craeymeersh, 1995; Künitzer, 1990; Künitzer *et al.*, 1992; Jennings *et al.*, 1995 and Rees *et al.*, 1999).

The Outer Thames Estuary REC study area falls within a distinct shallow water southern North Sea assemblage corresponding to Glémerec's "infralittoral étage" which extends from the inflows from the English Channel to the Dogger Bank. The water body is well mixed and consequently bottom fauna are exposed to greater extremes of temperatures compared to the deeper, stratified waters north of the Dogger Bank. The shallow and well mixed nature of the overlying waters also allows for the majority of the products of primary (phytoplankton) production to reach the sea floor for consumption by benthic assemblages, leading to comparatively high benthic biomass (Künitzer, 1990).

Within Glémerec's "infralittoral étage", the ICES Benthic Ecology Working Group (Künitzer *et al.*, 1992) recognised a shallow water, coarse sediment group (Group 1a [■] in Figure 2.23) encompassing the REC study area and stretching across the inshore waters of the Dutch, German and Danish coasts. Characteristic infaunal species of this Group are listed in Table 2.5.

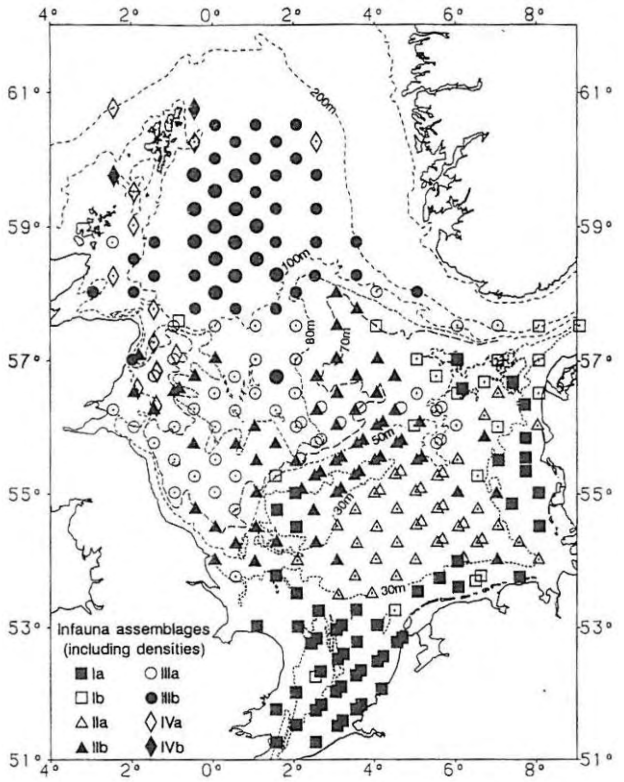

Figure 2.23: Distribution of classified station groupings based on faunal abundance data (Künitzer *et al.*, 1992).

The larger and more mobile epibenthic components of the southern North Sea benthic fauna have been sampled by trawl and headline camera surveys (Dyer *et al.*, 1982, 1983; Jennings *et al.*, 1999; Rees *et al.*, 1999 and Callaway *et al.*, 2002). Southern North Sea assemblages are characterised by brown shrimps *Crangon crangon* and *C. allmani*, hermit crab *Pagurus bernhardus*, flying crab *Liocarcinus holsatus*, common starfish *Asterias rubens*, brittlestars *Ophiura ophiura* (Figure 2.26*)*, *O. albida*, and the green urchin *Psammechinus miliaris* (Figure 2.24 [▲]) together with non-commercial fish species such as solenette *Buglossidium luteum*, dab *Limanda limanda* and dragonet *Callionymus lyra*. Higher densities of *L. limanda* and long rough dab *Hippoglossoides platessoides* within the vicinity of the Outer Thames Estuary REC study area correspond with fish assemblages in the central and northern parts of the North Sea (Figure 2.25 [■ and ∆]).

Most Frequently Occurring Species	Most Abundant Species (Mean Density)
Polychaete worm *Spiophanes bombyx*	Amphipod *Bathyporeia elegans*
Amphipod *Bathyporeia elegans*	Polychaete worm *Magelona* sp.
White catworm *Nepthys cirrosa*	Polychaete worm *Scoloplos armiger*
Polychaete worm *Scoloplos armiger*	Amphipod *Urothoe poseidonis*
Polychaete worm *Ophelia borealis*	Polychaete worm *Ophelia borealis*
Polychaete worm *Spio filicornis*	Tellinid bivalve *Tellina (fabulina) fabula*
Sea potato *Echinocardium cordatum*	Bamboo worm *Nicomache* sp.
Polychaete worm *Magelona* sp.	Trough shell *Spisula subtruncata*
Alder's necklace shell *Euspira pulchella*	Amphipod *Bathyporeia guilliamsoniana*
Amphipod *Bathyporeia guilliamsoniana*	Polychaete worm *Spiophanes bombyx*

Table 2.5: Characteristic infaunal species occurring in the southern North Sea.

A combination of grab and trawl sample data allowed Rees *et al* (1999) to distinguish a southern North Sea, mobile, medium sand association, characterised by an infauna comprising polychaetes, *Ophelia borealis* (Figure 2.27*), Nepthys* spp. and *Spio filicornis*, with the bivalve *Spisula elliptica*, oligochaetes, and the amphipod *Bathyporeia elegans*. This association was overlain by an "Estuarine" epifaunal assemblage including pink shrimp *Pandalus montagui*, and brown shrimp *Crangon crangon* (Figure 2.28) with the bryozoan *Electra pilosa*, starfish *Asteria rubens*, hermit crabs Paguridae, the hydroid *Sertularia cupressina* and the barnacle *Balanus crenatus*.

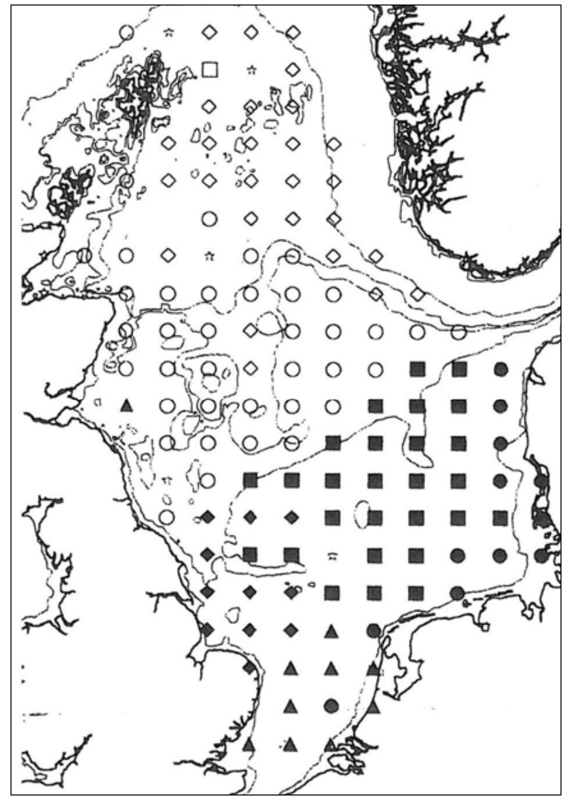

Figure 2.24: Distribution of epibenthic communities (Callaway *et al.*, 2002).

The wider area may also be characterised on the basis of mixed demersal and pelagic fish species, as caught in larger commercial Otter trawls. A southern North Sea assemblage exists, typified by species such as whiting *Merlangius merlangus*, scad *Trachurus trachurus*, dab *Limanda limanda*, mackerel *Scomber scombrus*, plaice *Pleuronectes platessa* and the lesser weever fish *Echiichthys vipera*.

Sessile colonial fauna have been found to play only a minor role in the southern North Sea. Typical species include *Hydractinia echinata*, *Electra pilosa*, *Hydrallmania falcata*, *Alcyonium digitatum*, *Flustra foliacea* and *Sertularia argentea*.

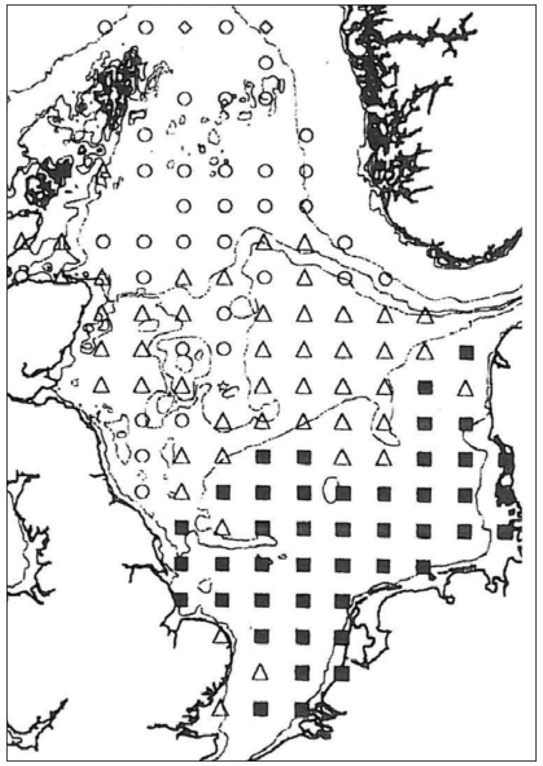

Figure 2.25: Distribution of classified fish communities sampled by 2m beam trawl (Callaway *et al.*, 2002).

2.5.2 Outer Thames Estuary

The Outer Thames Estuary area is characterised by many long linear, shallow and tidally aligned sandbanks which are typically composed of well sorted mobile sand substrates (Emu Ltd, 2006). Irving (1998) highlights the apparent lack of hard seabed substrata throughout the south-east of England and describes strong tidal current streams and associated disturbed sediment conditions which result in a patchy distribution of sediment assemblages.

The deeper water areas comprise more mixed sediments, including shell material with gravel and mud which may also include thin veneers of sand and / or gravel over clay bedrock. Muddy gravels and gravelly muds have also been identified in places. Variation in the amounts of silt within the sediments has been attributed to the variable inputs from the local fluvial sources and differences in depositional and erosional regimes.

The variability in substrate type and stability throughout the region is reflected by a variable macrofauna. Evident differences from the wider southern North Sea assemblages described above reflect the different sediment conditions available at the local level. Previous benthic surveys at the local and regional level (Unicomarine, 1995; RPS, 2005; Emu Ltd, 2006; GGOWL, 2008) have found a number of frequently occurring species including the polychaetes – *Spiophanes bombyx*, *Scoloplos armiger*, *Pomatoceros lamarcki*, *Magelona johnstoni*, *Sabellaria spinulosa* and *Lumbrineris gracilis*, amphipod crustaceans – *Bathyporeia* spp., *Urothoe* spp. and *Ampelisca* spp., echinoderms – *Echinocardium cordatum*, *Echinocyamus pusillus* and *Ophiura* spp. and the long-clawed porcelain crab *Pisidia longicornis*.

Attaching colonial epifauna are infrequently recorded and have included the barnacle *Verruca stroemi*, bryozoans (sea mats) *Flustra foliacea* and *Electra pilosa* and hydroids (sea firs) *Hydrallmania falcata* and *Setularia* spp. In the absence of suitable stable substrata these species attach to dead shells such as the valves of oysters, cockles and razor shells.

Disturbed sand sediments are generally impoverished, frequently supporting very low density macrofauna. Species typically found include the polychaetes *Nepthys cirrosa* and *Ophelia borealis*, the amphipod *Bathyporeia* spp. and sandeels *Ammodytes* spp. As disturbance decreases, the comparatively greater rates of sedimentation and accumulation of finer grained particles allows settlement by deposit feeding organisms such as the bivalve shells – *Abra alba*, *Nucula nitidosa* (Figure 2.29) and *Fabulina fabula* and the polychaetes – *Magelona* spp. and *Lanice conchilega*.

Areas of stabilised gravel support a more diverse macrofauna due to the greater availability of micro-niches which can support a range of co-existing taxa. Coarse sediment material may support encrusting worms – *Pomatoceros lamarcki* and *Sabellaria spinulosa* (Figure 2.30 and Figure 2.31), bryozoans and hydroids such as *Sertularia cupressina* whilst the interstitial spaces between coarser sand and gravel particles provide habitat for small polychaetes – *Polygordius* spp. and *Pisione remota*. Disturbed sand and gravel sediments may be characterised by the polychaete *Glycera lapidum* and a comparatively reduced macrofauna.

Figure 2.26: Brittlestar *Ophiura* sp.

Figure 2.27: Polychaete *Ophelia borealis.*

Figure 2.28*:* Brown shrimp *Crangon crangon.*

Figure 2.29*:* Bivalve *Nucula* sp.

Figure 2.30: Keel worm *Pomatoceros lamarcki.*

Figure 2.31: Ross worm *Sabellaria spinulosa*.

Mixed muddy sediments contain the polychaetes – *Lumbrineris gracilis* and *Aonides oxycephala* and the crustacean amphipod – *Ampelisca spinipes*. Hard substratum species such as the long-clawed porcelain crab *Pisidia longicornis* are also common.

Highest macrofaunal richness and diversity is associated with areas of *Sabellaria spinulosa.* The encrusting growth form of this species can stabilise mixed sandy gravel substrates permitting colonisation by a variety of disturbance intolerant species and epibenthic fauna, thus promoting increased diversity (Holt *et al*., 1998).

Epibenthic communities are characterised by the brown shrimp *Crangon crangon*, Gobies (Family Gobidae), hermit crabs (Family Paguridae), small spider crabs *Macropodia* spp. and a range of colonial sessile epifauna, *Alcyonidium diaphanum*, *Vesicularia spinosa*, *Hydrallmania falcata* and *Flustra foliacea*.

Beam trawl sampling further offshore has recorded abundant and frequently occurring brown shrimp, velvet swimming crab *Necora puber* and the flying crab *Liocarcinus holsatus* together with queen scallops *Aequipecten opercularis*, common whelk *Buccinum undatum* and painted topshell *Calliostoma zizyphinum*. The circular crab *Atelecyclus rotundus* and the masked crab *Corystes cassivelaunus* were found at softer sediment sites whilst deeper water coarse gravel sediment areas supported nut crabs *Ebalia* spp.

2.6 Conservation Designations Surrounding the Thames REC Area

The offshore Outer Thames Estuary REC study area is not currently identified for any national or international conservation designation, although potential Annex I habitats (EC Habitats Directive 92/43/EEC) have been identified and several important protected sites for nature conservation exist along the adjacent foreshores of Suffolk, Essex and Kent (Figure 2.32). In addition to statutory conservation designations, two Marine Environmental High Risk Areas (MEHRAs) have been identified in the Harwich and Felixstowe area with consideration to environmental sensitivity and shipping risk, (Department for Transport, 2006).

2.6.1 International Designations

International designations have been established along the coast in recognition of the high quality estuaries, intertidal flats and wetland habitats as well as the nationally and internationally significant numbers of wildfowl and waders that regularly use these areas. Several Special Protection Areas (SPAs), Ramsar sites and Special Areas of Conservation (SACs) are present in the region (Table 2.6 and Figure 2.32), but do not overlap with the study area.

Offshore, potential Annex I type habitats (reefs, sandbanks which are slightly covered by seawater at all times and mudflats and sandflats not covered by seawater at low tide) lie within, as well as to the south and west of the Outer Thames Estuary REC region.

Natural England, through consultation with the Joint Nature Conservation Committee, have made recommendations to Defra for 8 areas as suitable for selection as new SACs and 2 areas for selection as SPAs. These sites include the Margate and Long Sands draft SAC, the boundary of which extends into the Outer Thames Estuary REC area, and the Greater Thames SPA for red-throated divers. The statutory consultation process for these designations will begin in November 2009 and run until February 2010 prior to Defra submitting new SACs and SPAs to the EC in August 2010. For further information on these existing and proposed sites and their features and species of qualifying interest, see www.jncc.gov.uk.

2.6.2 National Designations

National Nature Reserves (NNRs) are intended to represent good examples of natural or semi-natural environments. NNRs along the foreshore adjacent to the REC study area include Orfordness, Havergate, Hamford Water, Colne Estuary, Blackwater Estuary and Dengie.

The stretch of foreshore and surrounding land areas adjacent to the Outer Thames Estuary REC study area also contain a large number of Sites of Special Scientific Interest (SSSIs). Many of the SSSIs within the region are representative of coastal, fresh/brackish-water and terrestrial habitats and features. Coastal SSSIs over 100 ha in size include Orfordness - Havergate, Alde-Ore Estuary, Deben Estuary, Orwell Estuary, Stour Estuary, Hamford Water, Holland Haven Marshes, Colne Estuary, Tollesbury Marshes, Old Hall Marshes, Blackwater Estuary, Dengie, Crouch & Roach Rivers, Foulness, Benfleet & Southend Marshes and the Thanet Coast.

Site Name	Type of Designation	Area (ha)	Qualifying Interest
Abberton Reservoir	SPA & Ramsar	726	Nationally and internationally significant numbers of wintering waterfowl and the winter feeding and autumn moulting of waterbirds.
Alde-Ore Estuary	SPA & Ramsar	2,417 / 2,547	Rare species, nationally and internationally significant assemblages of wetland birds including seabirds, wildfowl and waders. The site provides important breeding habitat for several species of seabird, wader and raptor.
Benfleet & Southend Marshes	SPA & Ramsar	2,251	Nationally and internationally significant numbers of feeding and roosting waterfowl.
Deben Estuary	SPA & Ramsar	979	Rare species, nationally and internationally significant numbers of waterfowl and wintering migratory species.
Hamford Water	SPA & Ramsar	2,187	Nationally and internationally significant numbers of waterbirds during the passage and winter periods and breeding terns in summer.
Stour & Orwell Estuaries	SPA & Ramsar	3,677	Rare species, nationally and internationally significant numbers of wintering waterfowl. The site supports important numbers of breeding avocet *Recurvirostra avosetta* throughout the summer.
Mid Essex Coast – Blackwater Estuary	SPA & Ramsar	4,395	Representative wetland, rare species, high ecological diversity, nationally and internationally important numbers of overwintering waterbirds and important summer tern breeding.
Mid Essex Coast – Colne Estuary	SPA & Ramsar	2,701	Representative wetland, rare species, high ecological diversity, nationally and internationally important numbers of wintering wildfowl and waders and breeding little tern *Sterna albifrons*.
Mid Essex Coast – Croach and Roach Estuaries	SPA & Ramsar	1,736	Representative wetland, rare species, nationally and internationally important numbers of waterfowl, including dark-bellied brent geese *Branta bernicla.*
Mid Essex Coast – Dengie	SPA & Ramsar	3,127	Representative wetland, rare species, high ecological diversity, nationally and internationally important numbers of wintering populations of hen harrier *Circus cyaneus*, wildfowl and waders.
Mid Essex Coast – Foulness	SPA & Ramsar	10,969 / 10,933	Representative wetland, rare species, high ecological diversity, nationally and internationally important numbers of waterfowl
Thanet Coast & Sandwich Bay	SPA & Ramsar	1,870 / 2,169	Rare species, nationally and internationally significant numbers of waterfowl including the ruddy turnstone *Arenaria interpres*, and is also used by large numbers of migratory birds.
Benacre to Easton Bavents	SPA	517	Site is of importance for populations of bittern *Botaurus stellaris*, little tern *Sterna albifrons*, marsh harrier *Circus aeruginosus*.
Medway Estuary and Marshes	SPA	4,684	Tidal channels, saltmarsh and grazing marsh supporting internationally significant numbers of wintering birds and breeding waders.
Minsmere-Walberswick	SPA	2,019	Nationally important numbers of breeding and wintering birds. In particular breeding bittern *Botaurus stellaris* and marsh harrier *Circus aeruginosus.*
The Swale	SPA	6,514	Site is of importance for marsh harrier *Circus aeruginosus*, breeding waders and the Mediterranean gull *Larus melanocephalus*.
Alde, Ore and Butley Estuaries	SAC	1,562	Estuaries, Atlantic salt meadows *Glauco-Puccinellietalia*, mudflats and sandflats not covered by seawater all of the time.
Benacre to Easton Bavents Lagoons	SAC	367	Coastal lagoons.
Essex Estuaries	SAC	46,141	Estuaries, mudflats and sandflats not covered by seawater all of the time, *Salicornia* and other annuals colonising mud and sand, *Spartina* swards (*Spartinion maritimae*), Atlantic salt meadows (*Glauco-Puccinellietalia maritimae*), Mediterranean & thermo Atlantic halophilic scrubs, Sandbanks which are slightly covered by sea water all the time.
Minsmere-Walberswick Heaths and Marshes	SAC	1,266	Annual vegetation of drift lines, European dry heaths, perennial vegetation of stony banks.
Orfordness – Shingle Street	SAC	901	Coastal lagoons, annual vegetation of drift lines, perennial vegetation of stony banks.
Sandwich Bay	SAC	1,138	Fixed dunes with herbaceous vegetation (‘grey dunes’), embryonic shifting dunes, shoreline shifting dunes with European marram grass *Ammophila arenaria* (‘white dunes’) and fixed dunes with herbaceous vegetation.
Thanet Coast	SAC	2,804	Reefs, submerged or partially submerged sea caves.
Haisborough, Hammond and Winterton Inshore & Offshore AoS	Area of Search (AoS)		Headland associated sandbanks in full salinity, representation of sandbank subtype in regional sea.
Margate and Longsands AoS	Area of Search (AoS)		Headland and estuary mouth sandbanks and sandy mounds in full salinity, representation of sandbank subtype in regional sea.

Table 2.6: International coastal conservation designations in the vicinity of the Outer Thames Estuary REC study area (JNCC, 2009).

Marine Aggregate Levy Sustainability Fund MALSF

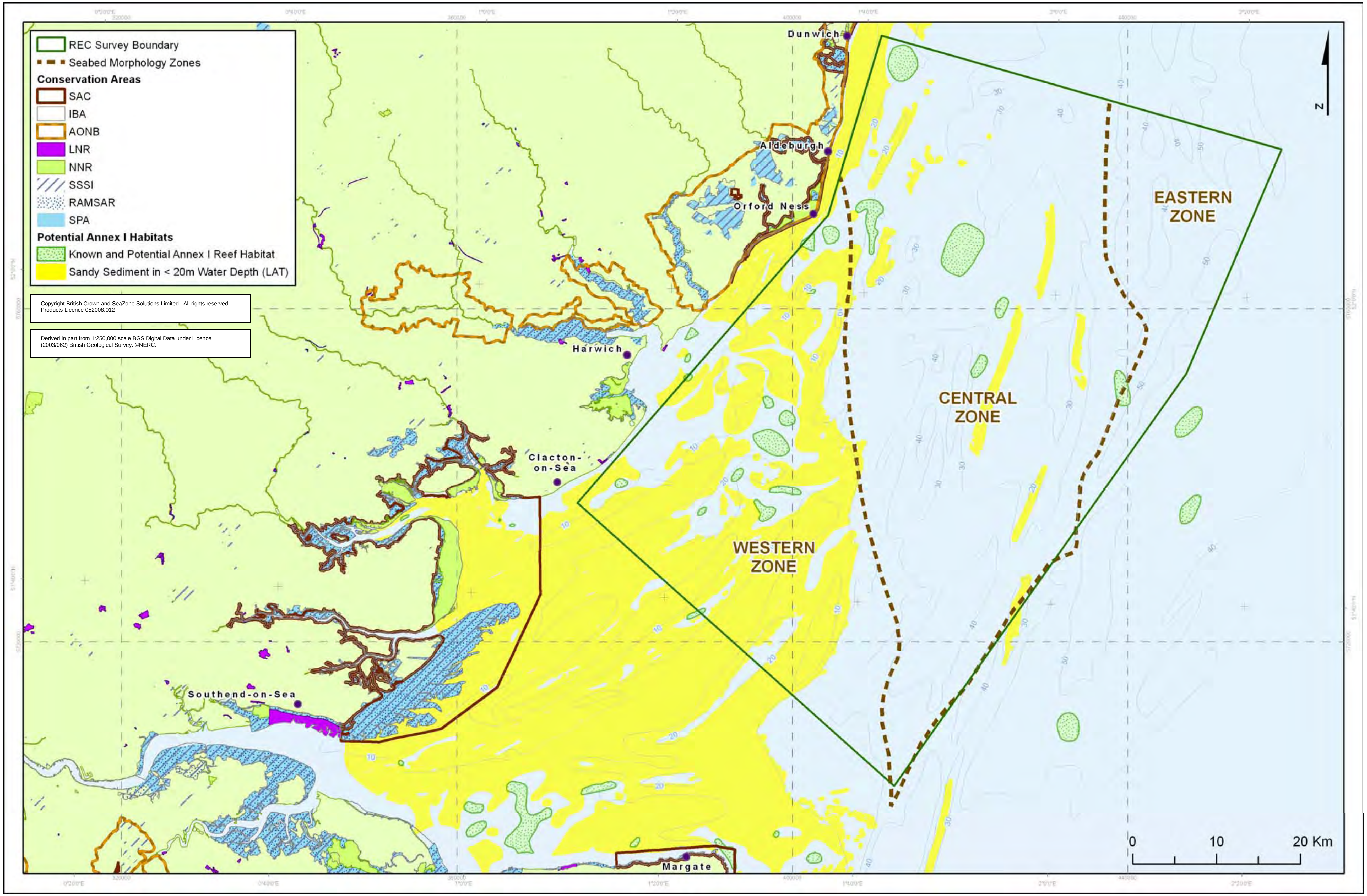

Figure 2.32: International coastal conservation designations and potential Annex 1 habitats in the vicinity of the Outer Thames Estuary REC study area (Graham *et al*., 2001; JNCC, 2009 and www.jncc.gov.uk).

2.7 Marine Development Activity

A wide range of marine activities occur in the study area including renewable energy developments, marine aggregate dredging, ports, commercial shipping and fisheries and recreation. These activities are briefly described below.

2.7.1 Renewable Energy

A number of offshore windfarms sites in various stages of development are located in the wider Outer Thames Estuary REC region (Figure 2.33 and Table 2.7). In total the current Thames projects are planned to provide 2.06 GW of electricity.

2.7.2 Shipping and Ports

The Thames Estuary is a busy area for commercial shipping, with a very high density of >30,000 shipping movements per annum (Port of London Authority, 2004). Big ship movements in the northern approaches to the Thames estuary are controlled by the Sunk Traffic Separation Sceme (TSS). The Sunk TSS is comprised of three two-way traffic lanes from the north, south and east, a two-way deep-water through route, inner and outer precautionary areas and the south-east orientated Gabbard recommended route, all of which converge at a central turning mark near Long Sand Head (Figure 2.34). An offshore deep-water route runs north from the North Hinder junction, passing to the east of the study area, before turning north-east into Dutch waters (Navin, 2007). Around 60% of movements into the Thames estuary itself are via a southern access route in the Prince's Channel, predominantly comprising general cargo ships, RoRo ferries and small tankers heading to or from London and Medway ports. Deep draft vessels use the Black Deep, Fisherman's Gat and Knock John Channel (Figure 2.34) (Port of London Authority, 2004). Two ports in the wider Thames Region fall within the top ten UK ports in terms of tonnage – London is second (52.7 million tonnes) and Felixstowe is eighth (25.7 million tonnes) (Table 2.8, Department for Transport, 2007).

Recreational sailing is also an important activity, with many sailing and yacht clubs based along the Essex and Kent estuarial coastlines. Activities inshore also include windsurfing. Currently, there are over 55 rowing, sailing and canoe clubs and eight water sports centres in the Greater Thames Estuary area (Thames Estuary Partnership, 2008).

Site	Location	Status	Capacity	Developer
Greater Gabbard	26 km off Orford, Norfolk	Approved	500 MW	Airtricity/Fluor
Gunfleet Sands I	7 km Clacton-on-Sea	Under construction	108 MW	DONG Energy
Gunfleet Sands II	8.5 km off Clacton-On-Sea	Under construction	64 MW	DONG Energy
Kentish Flats	8.5 km offshore from Whitstable	Operational	90 MW	Vattenfall
London Array	24 km off Clacton-on-Sea	Approved	1,000 MW	DONG Energy-Farm Energy/Shell/E.On UK Renewables
Thanet	11 – 13 km Foreness Point, Margate	Under construction	300 MW	Warwick Energy

Table 2.7: Existing and proposed Round 1 and Round 2 renewable energy installations in the Outer Thames Estuary REC area.

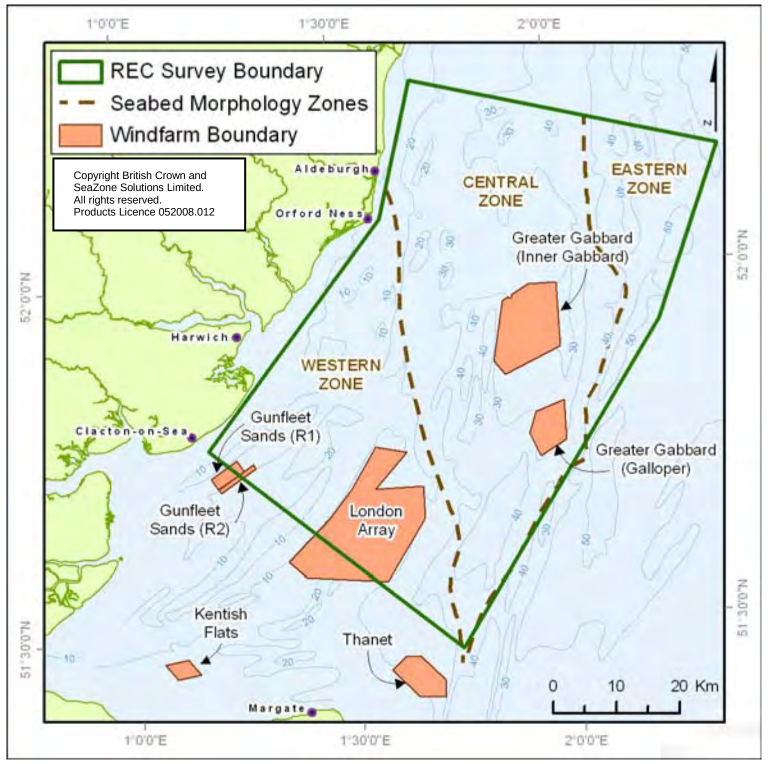

Figure 2.33: Proposed Round 1 and Round 2 renewable energy installations in the Outer Thames Estuary REC area.

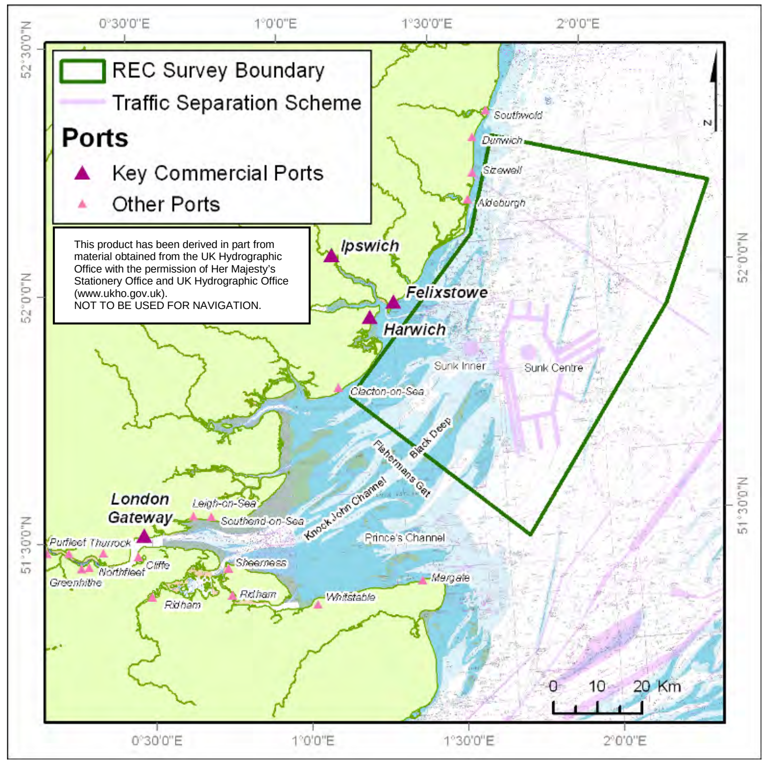

Figure 2.34: Ports and Traffic Separation Schemes located in the Outer Thames Estuary REC region including the site of the London Gateway project and the Sunk TSS.

Port	2006	2007
	Million tonnes	
Harwich	4.18	3.78
London	51.91	52.64
Felixstowe	24.37	25.69
Ipswich	3.51	2.80
All UK traffic	583.74	581.08

Table 2.8: Foreign and domestic goods handled by ports in the Thames region (Department for Transport, 2007).

The London Gateway Port Project

The London Gateway container port will be built on a 1,500 acre brownfield site of a former oil refinery (Shell Haven) on the River Thames. The work is planned to be completed within a period of 60 months (by mid 2013). The dredging and reclamation work will include dredging of 30 million m^3 of material from the River Thames to create a 100 km long approach channel and is due to commence in early 2009. This will increase shipping activity in the Outer Thames Estuary REC region.

Harwich Port

Harwich port is a multi purpose freight and passenger port with RoRo, ferry, container and bulk operations facilities. The Harwich Haven channel is the deepest approach to any UK container port at a depth of 14.5 m.

2.7.3 Cables and Pipelines

There are no pipelines passing through the Thames Estuary Region (Figure 2.35). There are seven active telecommunication cables and one out of service cable within the area (Table 2.9, KIS-CA 2008). The BritNed power cable between the Isle of Grain in Kent and the Netherlands is expected to be operational by 2011 (BritNed, 2008).

2.7.4 Aggregate Dredging

The Thames Estuary region aggregate dredging licenses occupy a seabed area of 103.05 km^2, with an annual permitted extraction of 3,950,000 tonnes.

In 2007 the seabed area available to dredge was 69.75 km^2 and the total actual area dredged was 11.6% of the total licensed area (11.93 km^2). In 2007 the total removal of primary aggregates from the Thames Estuary region was 977,072 tonnes (The Crown Estate, 2007). Seven marine aggregate companies currently have commercial interests in the Thames Estuary region and active, licensed and proposed dredging areas are shown in Figure 2.36.

The amount of marine aggregate landed in the region exceeds dredging from the region (Table 2.10) with the majority of the aggregate being dredged from East Anglia and the Eastern English Channel.

Telecommunication Cable	Status	Operator
Atlantic Crossing 1	Active	Global Crossing
Concerto 1N	Active	Flute
Concerto 1S	Active	Flute
Farland	Active	BT
Hermes North	Active	Global Telesystems
Hermes South	Active	Global Telesystems
Rembrandt 2	Active	KPN Telecom BV
UK-Netherlands 12	Out of Service	BT

Table 2.9: Cables within the Outer Thames Estuary REC area.

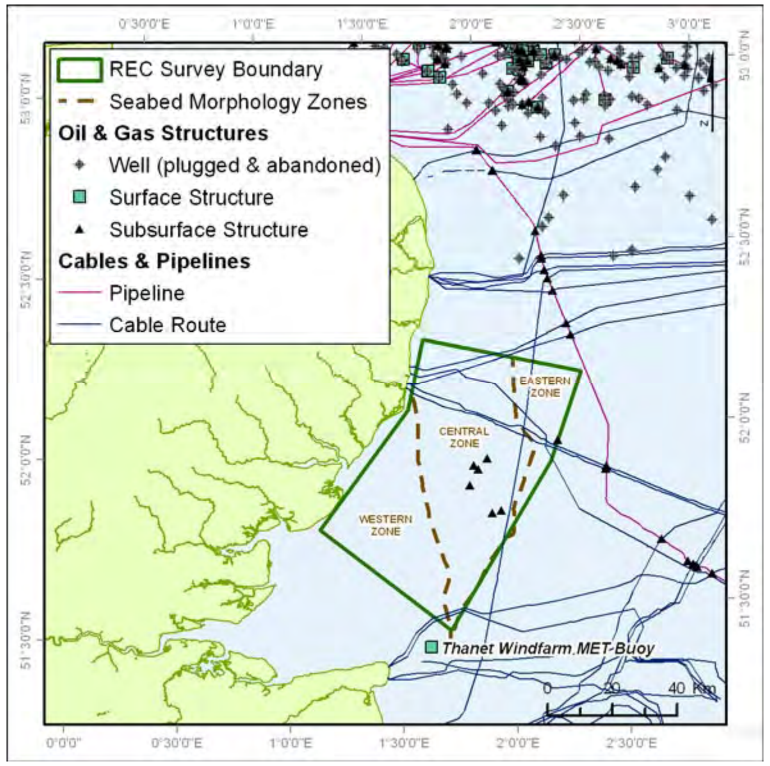

Figure 2.35: Oil and Gas Structures, Cables and Pipelines in the Outer Thames Estuary REC study area.

Landing Locations	Tonnage
Angerstein	912,580
Cliffe	1,124,982
Dagenham	935,929
Denton	323,421
Erith	258,165
Greenhithe	355,698
Greenwich	1,375,124
Northfleet	945,418
Purfleet	168,128
Ridham	195,199
Rochester	457,309
Sheerness	8,715
Thurrock	296,276
TOTAL	**7,356,944**

Table 2.10: Aggregate landing wharves in the Outer Thames Estuary REC area and London (The Crown Estate, 2007).

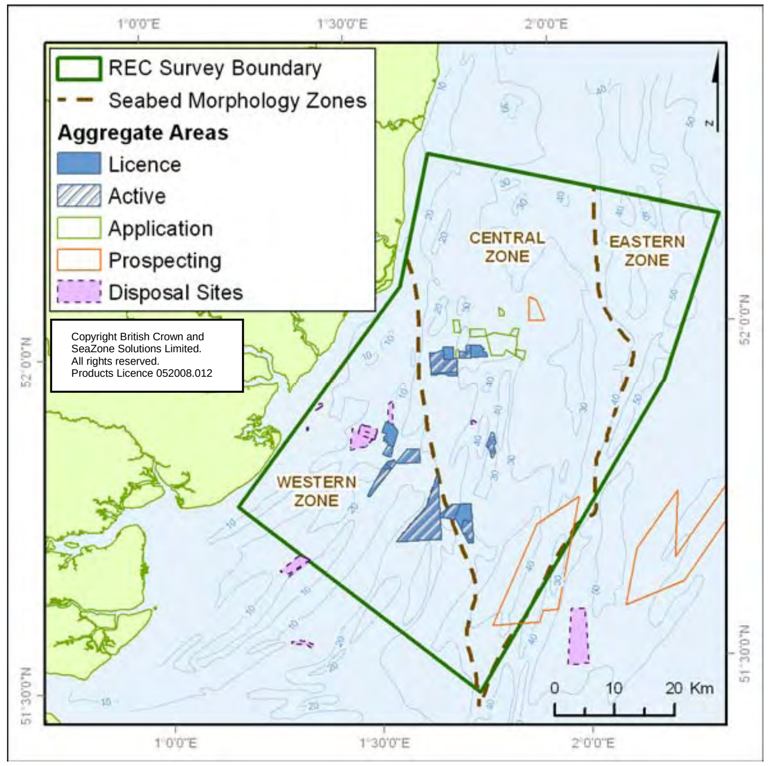

Figure 2.36: Aggregate dredging areas and disposal sites Outer Thames Estuary REC area (Source: Crown Estate, 2008).

2.7.5 Dredge Disposal Sites

Dredging disposal sites are located in the Western and Central Zones of the Outer Thames Estuary REC study area, as well as to the south and east (Figure 2.36). One particular site, located near to the Inner Gabbard Deeps in the Central Zone, was used for the disposal of 2.75 Mt of sediments in 1999, 1.6 Mt in 2002 and approximately 2 Mt in 2003 (HR Wallingford, 2002; Cefas, 2006). The Inner Gabbard site is being used further during a redevelopment of the Port of Felixstowe, with a predicted 140,000 m^3 of mud and 2.96 million m^3 of stiff clay, sand, gravel and rock to be deposited between 2008 and 2014 (Royal Haskoning, 2003; Port of Felixstowe, 2008).

2.7.6 Commercial Fishing

Commercial fishing takes places across the Outer Thames Estuary REC area. In general fishing fleets have distinct fishing grounds within 10 km of their home ports. Ports with registered fishing vessels in the region are listed in Table 2.11.

Commercial fishing is an important economic activity in the Thames Estuary with trawling in some channels and drift nettings around some banks. The most important commercially fished species are the Dover Sole and Herring; there is also a well-established cockle industry. This industry provides over 50% of all local cockle landings. Commercial fisheries are discussed further in Section 4.9.

Home Port	Under 10 m	Over 10 m
Aldeburgh	8	
Clacton	5	
Dunwich	1	
Felixstowe	15	
Harwich	20	2
Leigh-on-Sea	8	22
Margate	4	
Sizewell Beach	1	
Southend-on-Sea	16	
Southwold	16	
Whitstable	13	2

Table 2.11: Fishing ports and associated vessel sizes in the Outer Thames Estuary REC study area (DEFRA Fisheries Statistics Unit, 2008).

3. Geology and Heritage Characterisation

3.1 Geology and Heritage Overview

The Outer Thames Estuary lies within the Cenozoic London Basin, which although traditionally regarded as a distinct sedimentary basin is more likely a southerly extension of the North Sea Basin. To the south it is commonly regarded as being separated from the Hampshire-Dieppe Basin by the Weald-Artois High, although there is currently growing support for a more open palaeogeographic model where a single depositional regime extends from the southern north sea across SE England and adjacent areas, for much of the Palaeogene & Neogene (King, 2006). Throughout the study area this open Cenozoic basin is underlain by Upper Cretaceous chalk. These Cretaceous, Paleogene and Neogene sequences have subsequently been either eroded and exposed at seabed, or are covered by sediments deposited during the Quaternary (Section 2.3). Quaternary deposits and eroded, relict land surfaces are the product of the climatically driven growth and decay of major continental ice sheets and the attendant sea level fluctuations that dominate the evolution of the north-west European shelf. In particular, the Outer Thames Estuary has been strongly influenced by the slow migration of the Thames-Medway drainage system southwards, as the hydrological regimes and sea-levels have changed (Bridgland, 1994). The stratigraphy represented in the Outer Thames Estuary REC study area is presented in Table 3.1.

Era	Period	Epoch	Stage Age	Formation
Cenozoic (65 Ma – present)	Quaternary (2.5 Ma – Present)	Holocene (11.7 ka – Present)	Holocene (OIS 1)	
		Pleistocene (2.5 Ma – 11.7 ka)	Wechsalian-Devensian (OIS 5d-2)	
			Eemian-Ipswichian (OIS 5e)	
			Saalian-Wolstonian (OIS 10-6)	
			Holsteinian-Hoxnian (OIS 11)	
			Elsterian-Anglian (OIS 12)	
			Cromerian Complex (OIS 20-13)	
	Neogene (23 – 2.5 Ma)	Pliocene (5 – 2.5 Ma)	Plio-Pleistocene (2.6 Ma)	Red Crag
			Mid-Pliocene (c. 3.5 Ma)	Coralline Crag
		Miocene (23 – 5 Ma)		
	Palaeogene (65 – 23 Ma)	Oligocene (34 – 23 Ma)		
		Eocene (56 – 34 Ma)	Ypresian (56-49 Ma)	London Clay Formation
				Harwich Formation (Harwich Member & Oldhaven Beds)
		Palaeocene (65 – 56 Ma)	Upper Thanetian/Earliest Eocene (c.56 Ma)	Lambeth Group (Reading & Woolwich Formation)
			Thanetian (59-56 Ma)	Thanet Sand Formation
Mesozoic (251 – 65 Ma)	Cretaceous (145 – 65 Ma)	Upper (100 – 65 Ma)		Upper Chalk Group
		Lower (145 – 100 Ma)		

Table 3.1: Cretaceous to Quaternary geological stratigraphic column for the Outer Thames Estuary REC region.

From an archaeological perspective, the deposits found within the Outer Thames estuary have been identified as having "Immense potential" (Wilkinson and Brown, 1999). This potential relates not only to the chance of finding archaeological sites, but recognition of the fact that understanding the nature and rate of landscape change from the Pleistocene onwards will greatly enhance our interpretation of the past. As such, the cultural heritage resource is seen to extend beyond material culture and out into the physical, biological and chemical environment found offshore. In particular the geometry of past river systems and insights into changing environmental conditions are seen as a high priority (Wilkinson and Brown, 1999; Flemming, 2002). Further, the recent work on the geological and archaeological reconstruction of the Mesolithic landscape of the central southern North Sea (Gaffney *et al*., 2007) and the current reassessment of the scattered pre-historic finds on the Dutch shelf (Glimmerveen *et al*., 2004) show the intense interest in the shelf pre-historic archaeology of this area.

Through the combined analyses of bathymetry of varying resolutions, sub-bottom boomer data, a limited amount of core and grab material and a full review of the extant geological and archaeological record, all acquired as part of this Regional Environmental Characterisation study, a significantly enhanced interpretation of the geology and archaeology of the Outer Thames Estuary has been made possible.

3.2 Geology and Heritage Method Statement

3.2.1 Geology

For a full interpretation of the near surface geology boomer data has been correlated with side scan sonar and regional and multibeam bathymetric datasets; BGS published maps and reports (in particular the British Geological Survey, 1989; 1990; Cameron et al., 1992) and academic and industry papers and reports. In order to define the nature, extent and thickness of bedrock and the orientation and extent of the palaeochannels, the seismic lines were processed with Coda GeoSurvey software and the bounding reflectors of bedrock, Quaternary stratigraphic units and palaeochannel margins were digitised. The results were then filtered and processed (to allow for tidal variation and datum corrections) and the digitised surfaces interpolated between the surveys corridors to create outcrop and isopach maps. The interpreted boomer data were correlated with the multibeam and side scan sonar data and loaded into a Geographical Information System (GIS). The quality of the seismic data is good and a sound speed of 1,600 ms^{-1} has been used to convert the two-way travel time (TWTT) to a depth below sea-bed (BSB) and the sections have been analysed according to the depth of seismic penetration beneath the seabed (sometimes up to 100 ms^{-1}).

3.2.2 Heritage

Following the guidelines published by the Institute for Archaeologists (IFA, 2008) the method chosen within this project to achieve integration has been a scaled approach, incorporating different data through use of Geographical Information Systems (GIS). An initial large-scale literature review has been carried out into the geological and archaeological record of southern Britain, focusing in on the areas around Kent, Sussex and Essex. This has been augmented through interrogation of regionally held archaeological databases (Historic Environment Records (HERs), and Sites and Monuments Records (SMRs)) as well as national data sources including the National Monuments Record and the United Kingdom Hydrographic Office Record (Appendix B).

Figure 3.1: Extent of the search area of the SMR, HER, NMR and UKHO record.

In order to provide a more representative characterisation of the Heritage record and its potential, these records needed to be queried for an area larger than the Outer Thames Estuary REC limits. As such, a 20 km buffer was applied to the Outer Thames Estuary REC boundary (Figure 3.1). This buffer was wide enough to cover both an extended marine area, as well as allowing characterisation of the terrestrial record along surviving channel systems and inland areas.

From an archaeological point of view it is not enough to simply find artefacts, and assemblages of artefacts. It is essential to understand the physical context within which the material was found and deposited. It is only through understanding how things have come to be deposited that we can construct an understanding of the more difficult to interpret social conditions of the past, or for that matter, characterise the potential of a given area. This is because the distribution of artefacts and their variation through time plays an important role in interpretation. As such it is worth considering two broad categories of archaeological evidence which are referred to in the text below:

Primary contexts are assemblages in which the artefacts are still located in the context of deposition. This does not mean to say that the artefacts are exactly at their point of deposition, merely that the overall artefact movement caused by intervening taphonomic processes is small on a regional scale, i.e. not beyond the confines of an individual site (Schiffer, 1987). Since the spatial relationships between artefacts have not been altered to a significant degree, the best examples of these contexts have the potential to provide ‘snapshots’, or very finely detailed images, of past behaviour (Gamble, 1999). This allows detailed interpretations of past tool manufacturing techniques, subsistence behaviour, settlement strategies and social lives to be made. Primary contexts are what the majority of people assume archaeological sites to look like. However, as will be demonstrated below, there are other categories of evidence, which may be more commonplace in submerged environments.

Secondary context sites are those in which artefacts have been derived or moved from their original point of deposition by environmental processes. They make the form of collections of material from a range of distances and time periods (Gamble, 1999; Hosfield, 2004). When considering the archaeological record of the past 700,000 years, the most widespread form of secondary context consists of artefact bearing fluvial sediments typically, associated with terrace landforms. Terraces form as a result of the lateral movement and downcutting of rivers over the course of a glacial/interglacial cycle in response to climate changes and tectonic uplift (Bridgland *et al.*, 2004). Archaeological material on floodplains, riverbanks and valley slopes is subject to these processes and hence is incorporated into the terraces. Evidence from secondary context terrace sediments is both spatially and temporally coarse in that the artefacts within a given river system may represent a sample derived from an area of several tens or hundreds of square kilometres, over a period of up to tens of thousands of years. Recent work (e.g. Ashton & Lewis, 2002; Hosfield, 2004) has demonstrated that these deposits have the potential to provide information as to long term patterns of hominin demography and land use. Individual terraces may also contain lenses of fine sediment which could reflect periods of lower energy deposition, and it is possible that these may contain material in primary context and associated palaeoenvironmental evidence (Wenban-Smith, 2002).

Secondary contexts may also form as a result of other geological processes, such as permafrost action, glacial movement, solifluction and more importantly, from the perspective of this report, marine processes. A recent review of coastal and marine processes, such as wave action and tidal currents, operating during sea level rises and stillstands has highlighted that a large proportion of the submerged archaeological record is likely to be composed of these types of deposit (Westley *et al.*, 2004).

Secure knowledge of the relationship between topography, ecology, geography and the archaeological material is essential if an understanding of its location is to be obtained. This is based on the principle that sites tend to recur in environmental settings favourable to human occupation and use (Wescott & Brandon, 2000). Thus, knowledge of terrestrial patterns of site location could be applied to the seabed, assuming that the submerged palaeo-land surface can be reconstructed from the geological evidence and that the hominins which occupied the presently submerged area followed similar settlement patterns to their terrestrial counterparts.

Table 3.2 defines the archaeological periods used to classify the heritage record. Only one period sub-division has been made here (Lower and Upper Palaeolithic) due to the time depth represented by this record. Furthermore, given the aims of this document to broadly characterise the heritage of the Outer Thames Estuary REC region, the chronological resolution offered below is considered appropriate.

Archaeological Period	Date Range
Modern/Industrial	AD 1750 – Present
Post-medieval	AD 1540 – 1750
Medieval	AD 410 – 1540
Roman	AD 43 – 410
Iron Age	800 BC – AD 43
Bronze Age	2,200 – 800 BC
Neolithic	4,000 – 2,200 BC
Mesolithic	10,000 – 4,000 BC
Upper Palaeolithic	40,000 – 10,000 BC
Lower Palaeolithic	c.700,000 – 40,000 BC

Table 3.2: Simplified period-based heritage chronology for Britain (after Pollard, 2008).

3.3 Geological History

3.3.1 Cretaceous

The Upper Cretaceous Chalk (c. 100 – 65 Ma) forms a minor component of the seabed solid geology in the area but underlies Cenozoic sediments across the region. At the beginning of the Cretaceous, the southern North Sea was a marine province separated, by the Anglo-Brabant massif, from a series of inter-connecting basins which experienced long periods of non-marine deposition (Rawson, 2006). The current study area represented the 'London Uplands' which occupied the south margin of this massif and therefore no Lower Cretaceous marine deposition occurred in the Outer Thames Estuary REC study area (Jenkins and Murray, 1989). Sea level rise throughout the Aptian and Albian (c. 125 – 100 Ma) resulted in a north-eastward transgression across the Angle-Brabant Massif and the creation of a single marine province from the North Sea to the south-west approaches. With the development of these open marine conditions came a significant decrease in the amount of terrigenous sedimentation and the preferential deposition of pure calcareous chalk, in water depths of 100 – 500 m, thus creating the ubiquitous Chalk Group (c. 100 – 65 Ma). These rocks comprise the seabed at the south west margin of the Outer Thames Estuary REC (see Figure 3.2) and are associated with the terrestrial chalk outcrop of the North Kent coast (probably Campanian-Maastrictian in age).

The sub-divisions of the Upper Cretaceous Chalk is based primarily on faunal assemblages (macro- and micro-), minor changes in sedimentation and lithification state, in particular the presence of hardgrounds and nodular horizons. Consequently, accurate location within the sequence is very difficult to determine from seismic data. The internal seismic character of the chalk identified from the Outer Thames Estuary REC data is massive with no recognizable internal sedimentary structures (Figure 3.3).

The top reflector of the chalk is clearly resolvable as an erosion surface, with the Tertiary sediments lying unconformably over the chalk. At the Cretaceous-Tertiary boundary in the south of the study area, the top reflector of the chalk is not horizontal, but has an apparent dip (approximately 1.5º) towards the north (Figure 3.3).

3.3.2 Cenozoic

The London Basin sequence of Cenozoic sediments unconformably overlies the Upper Cretaceous Chalk within the study area. The sediments of this basin are dominated by the interplay of marginal marine sedimentation and fully marine deposition, in response to several phases or transgression and regression during the Palaeogene (Late Palaeocene to Middle Eocene: Table 3.1).

The earliest Palaeogene sediments in the study area are the Thanetian (c. 59 – 56 Ma) Thanet Sand Formation, which are unconformably overlain by the Lambeth Group (the interdigitating, non-marine, Reading, and marine, Woolwich Formations - King, 2006). A further, regression driven unconformity, separates these sequences from the overlying 'earliest' Eocene/Late Palaeocene Harwich Formation. A further transgressive episode results in an unconformable boundary of these units with the early Eocene (Ypresian: c. 56 – 49 Ma) London Clay Formation.

Finally, the Neogene in the Outer Thames Estuary is confined to the north of the area and is represented by the mid-Pliocene Coralline Crag Formation and the Plio-Pleistocene Red Crag (Table 3.1 and Figure 3.2). In this report we have included a description of the minor sub-crops of the Red Crag deposits with the more closely allied Neogene Crag deposits.

Thanet Sand Formation (Upper Thanetian)

The Thanet Sand Formation consists of glauconitic sands, sandy clays and muds lying unconformably on the Upper Chalk and is restricted to the eastern London Basin and the adjacent parts of East Anglia. The formation is only identified in the south of the Outer Thames Estuary REC area (Figure 3.2). Offshore the formation has a variable thickness of between 10 and 15 m and is characterised seismically by sub-parallel reflectors decreasing in amplitude towards the top of the Formation suggesting the sequences represent a fining upwards sequence (Figure 3.4). This is supported by offshore BGS vibrocore data.

Lambeth Group: Reading and Woolwich Formations (Upper Thanetian – Earliest Eocene)

The Reading and Woolwich Formations are interpreted as being deposited in a wide shallow embayment, with the coastal Reading Formation inter-digitating eastwards with the marginal-marine Woolwich Formation. The Reading formation comprises mainly clays and silts deposited in an aggrading coast plain whilst the low-energy marginal marine Woolwich Formation consists of fine-grained and muddy sands which are locally lithified to form resistant sandstone bands. The Woolwich Formation also locally contains abundant shell fragments, and occasional pyroclastic ash layers.

Offshore, the Woolwich Formation rests unconformably on either the Thanet Formation or the Upper Chalk. On the seismic records the Woolwich Formation is characterized by multiple reflectors (Figure 3.5).

The internal reflectors are sub-parallel with internal incisions and fill. The Woolwich Formation crops out at the seabed in the south and within an uplifted dome within the Harwich region of the study area (Figure 3.2). Locally the sands are lithified to form hard, resistant sandstones which form high amplitude reflectors. In places within the seismic records the base of the formation can be seen cutting down into the underlying Thanet Formation (see also Henriet *et al.*, 1989).

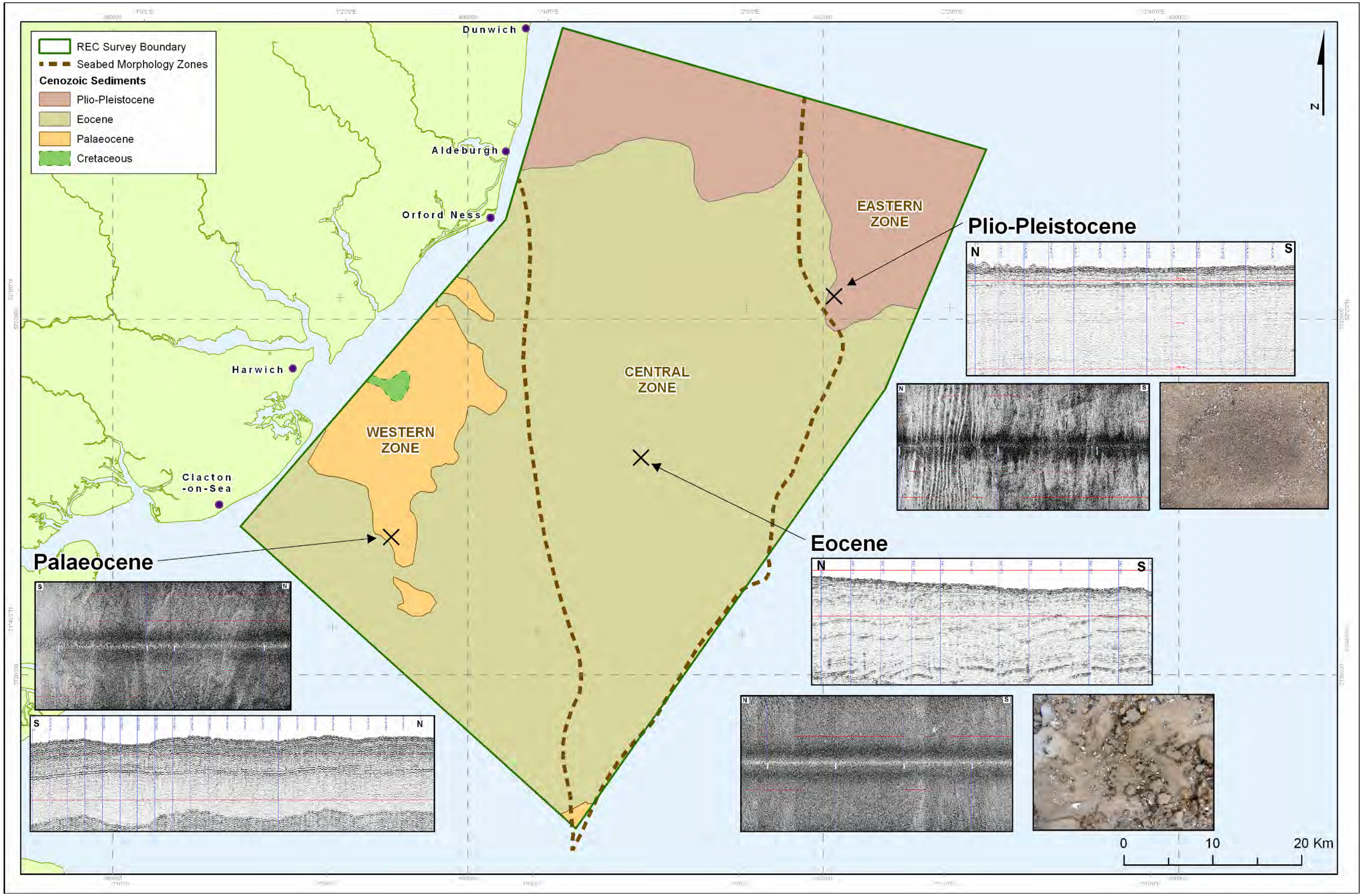

Figure 3.2: Extent of bedrock formations cropping out at the seabed within the Outer Thames Estuary REC study area, mapped from the Outer Thames Estuary REC seismic data.

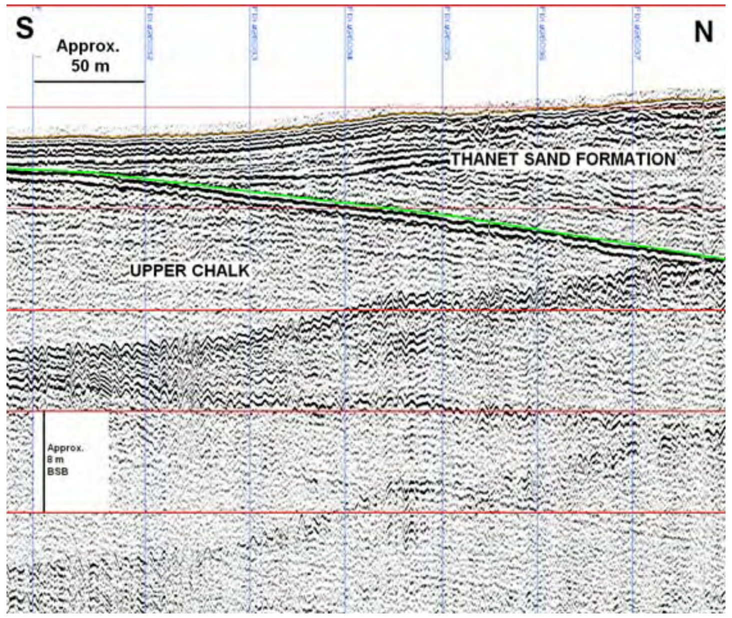

Figure 3.3: Outer Thames Estuary REC high resolution seismic record showing contact between Chalk and overlying unconformable Tertiary Thanet Formation.

Harwich Formation (Early Eocene)

The Harwich Formation consists of sands and silts deposited in the shallow sub-littoral environment on the southern margin of the North Sea Basin. The Harwich Member is characterized seismically by a sequence of high amplitude, chaotic reflectors at the base (the Oldhaven Beds), passing upwards into a 2 – 3 m thick layer with weak reflectors, and finally into a sequence of strong sub-parallel reflectors which may represent the multiple ash layers described in boreholes elsewhere (Figure 3.6).

London Clay Formation (Early Eocene: Ypresian)

Early Eocene (Ypresian) deposition throughout SE England and the southern North Sea was dominated by fine-grained deep-water marine clayey silts, silty clays and clays, which produced the thick (commonly >100 m) sequences of the London Clay Formation. The London Clay Formation dominates the seabed geology across the Outer Thames Estuary (Figure 3.2).

The London Clay Formation is represented by a seismic facies dominated by weak internal reflectors, but with occasional prominent offset reflector couplet horizons (Figure 3.7). These offset (faulted) horizons do not affect the upper or lower boundaries and when plotted as a three-dimensional surface they present a polygonal form. They have fault spacing of 12 – 80 m, fault throws of < 3 m and fault lengths of 15 – 100 m. These features have been interpreted as soft sediment deformation features caused by post-depositional compaction (De Batist *et al*., 1989; Henriet *et al.*, 1991). They almost certainly represent second or third order variants of polygonal fault systems (with dimensions at least an order of magnitude larger) that have been identified in conventional 3D seismic volumes, from fine grained sequences, in sedimentary basins from across the world.

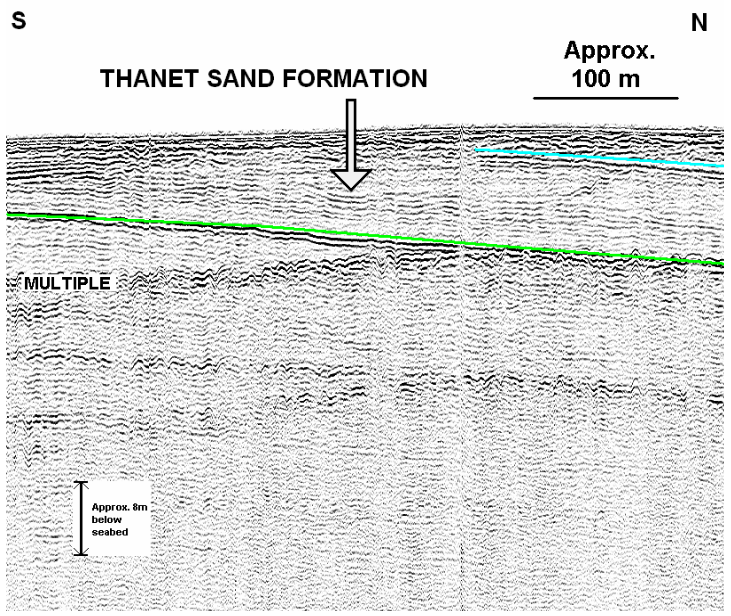

Figure 3.4: Outer Thames Estuary REC high resolution seismic record illustrating the seismic character of the Thanet Sand Formation, with the strongest reflectors at the base of the unit.

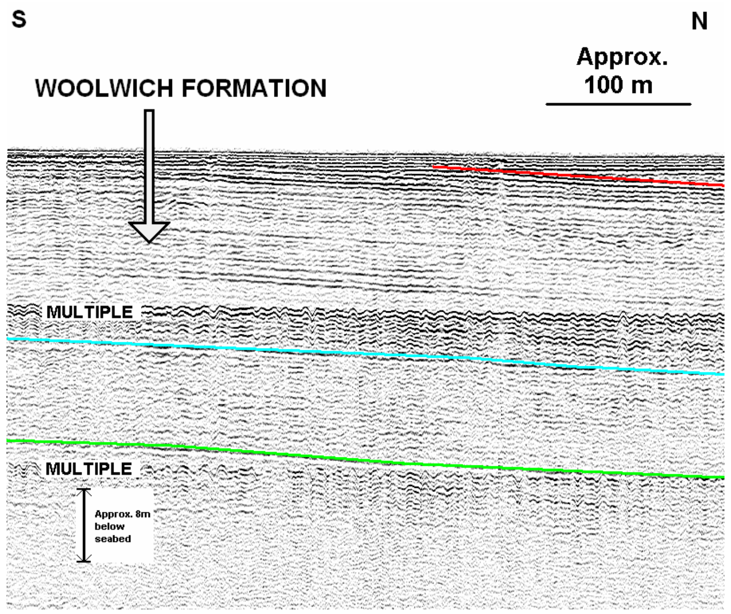

Figure 3.5: Outer Thames Estuary REC high resolution seismic record illustrating the seismic character of the Woolwich Formation.

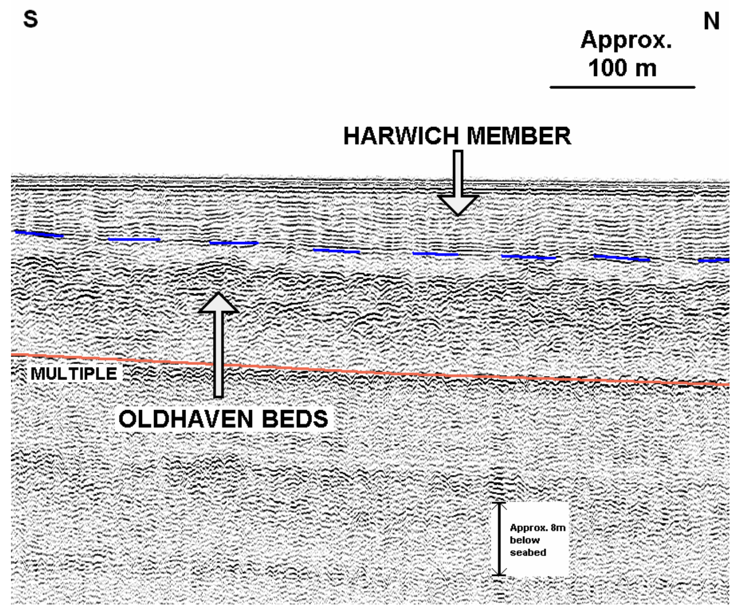

Figure 3.6: Outer Thames Estuary REC high resolution seismic record illustrating the seismic character of the Harwich Formation with the basal chaotic reflectors of the Oldhaven Beds.

Coralline Crag (Mid-Pliocene)

Pliocene deposits are restricted to isolated exposures within the Outer Thames Estuary REC. In this area the Pliocene is represented by the Coralline Crag Formation which comprises bioclastic carbonate sands and silty sands that have been deposited in a shallow marine, high-energy environment, probably within an embayment of the southern North Sea Basin. The Crag deposits lie unconformably over the London Clay Formation. The Coralline Crag Formation is represented in seismic records by a unit with high amplitude, hummocky reflectors (Figure 3.8).

Red Crag (Plio-Pleistocene)

The Red Crag, comprising marine, shelly sands and gravels, lies unconformably over the London Clay Formation within the northern section of the study area (Figure 3.2). These sediments were probably deposited in an open marine embayment under the influence of powerful tidal rotary currents, which became a more restricted estuarine environment with time. The Red Crag Formation and overlying Quaternary sediments; the Westkapelle and Brown Bank formations, are shown seismically as units with high-amplitude continuous reflectors above the faulted London Clay. Nearer the seabed, reworking and transport of these sediments has formed dunes and therefore a more chaotic seismic character (Figure 3.9).

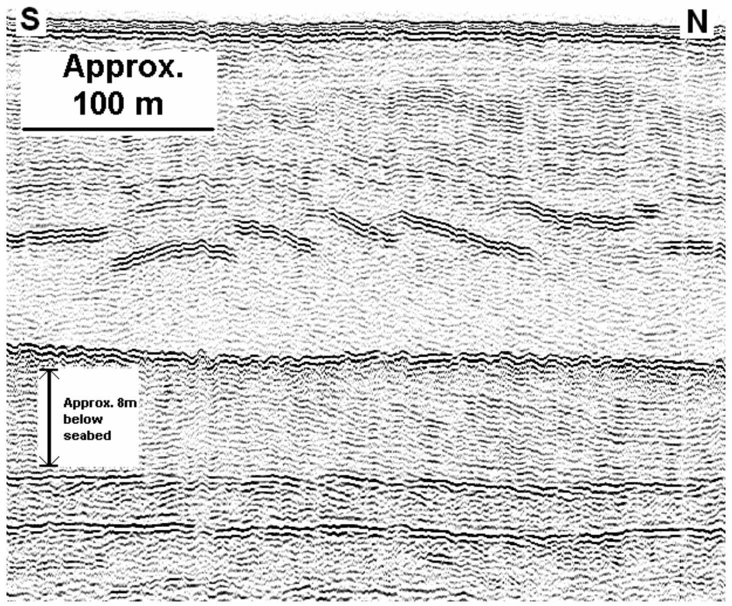

Figure 3.7: Outer Thames Estuary REC high resolution seismic record showing small scale faulting at depth within the London Clay Formation.

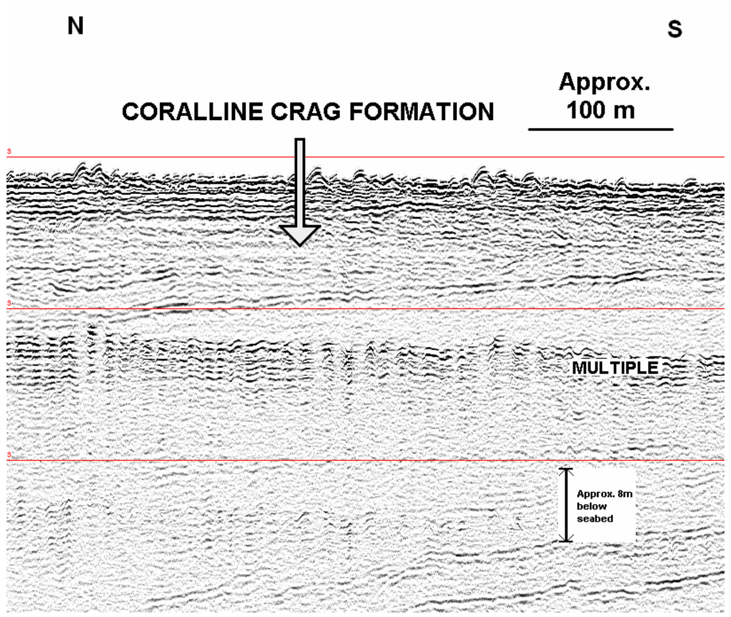

Figure 3.8: Outer Thames Estuary REC high resolution seismic record showing the high amplitude reflectors of the Coralline Crag Formation.

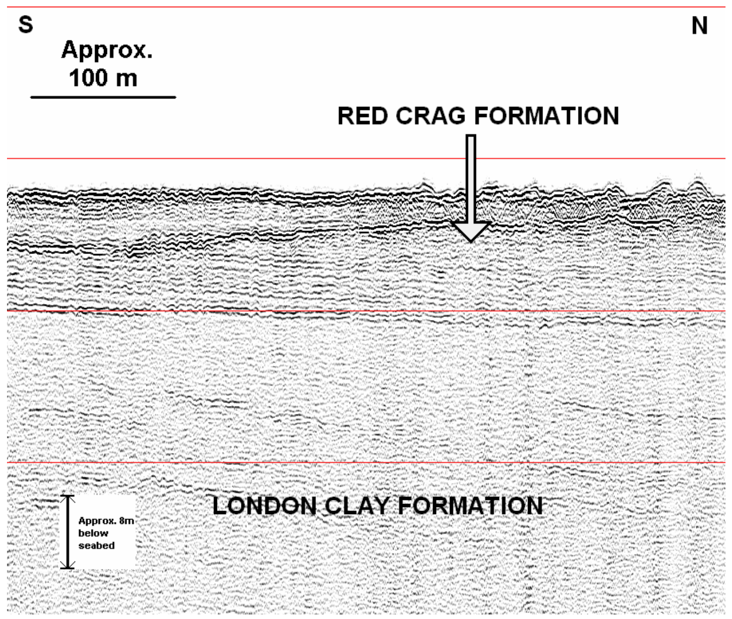

Figure 3.9: Outer Thames Estuary REC high resolution seismic record displaying the Red Crag Formation.

3.3.3 Quaternary

As with the Cenozoic, the Quaternary history of the Outer Thames Estuary is dominated by the interplay between climatically driven glaciations, sea level fluctuations and interglacial flood plains and marginal marine conditions. Although the onshore sequences have been extensively studied over the last century, and in particular the last 35 years (see Bridgland, 2006 for most up to date review), our knowledge of the offshore sequences have received only limited attention, with our understanding being dominated by the BGS Thames Estuary 1:250,000 Map Sheet (1990) and the work of D'Olier and Bridgland (numerous papers between 1975 and present e.g. D'Olier, 1975; Bridgland & D'Olier, 1995; Bridgland, 2006). This work has been based primarily on first or second generation sub-bottom profiler records and the collation of the BGS borehole archive. Furthermore (as described in Section 3.4) the rich Lower Palaeolithic archaeology of the adjacent coast (including the earliest known occupation site of the British Isles) makes any preserved landscape fragments of significant archaeological potential.

Pleistocene

Whilst the seabed morphology is described in Section 2.2, for the purpose of this assessment, the bathymetry has been re-gridded (50 x 50 m – Figure 3.10). In addition to the major sandbanks that dominate the Western Zone, there are two striking large-scale morphological features in this dataset:

- Firstly, the major enclosed deeps, including the Inner Gabbard Deeps, located in the Central Zone (51˚55' N, 1˚45' E) and
- Secondly, a major west-east oriented river channel that starts with the linear section of the Harwich dredged channel in the west and terminates at the break in slope that defines the boundary between Central and Eastern Zones at 51˚58' N, 2˚10' E.

These two features crucially underpin the proposed chronology of the offshore region of the Outer Thames Estuary REC and represent the basis of the Pleistocene reconstruction.

Enclosed deeps (or over-deepened valleys) are found throughout the North Sea Basin and adjacent glaciated land masses and have been the subject of much discussion over the last twenty years. Huuse & Lyke-Andersen (2000) present the best review of these features for which they describe a set of diagnostic features (some values modified after Praeg, 2003 and Graham *et al.*, 2007) for these valleys as:

- Being over deepened, with incised to depths of up to 500 m below seabed.
- Being typically ≤ 6 km wide, with general depth to width ratios of c. 1:10, an anastomosing pattern and can be traced for several tens of kilometres.
- Generally beginning and terminating abruptly with longitudinal valley profiles show no consistent slope direction.
- Having relatively steep sides (10 – 35˚) and flat bottoms.
- Occurring within the ice limits of the Elsterian, Saalian and in some cases Weichselian glaciations, and are generally oriented perpendicular to the inferred ice front.
- Being empty or filled with a complex mix of glaciolacustrine, glaciomarine and glaciofluvial sediments.

The origin of these features has also been strongly debated (Huuse & Lyke-Andersen, 2000) with the two favoured theories being either formation under steady-state sub-glacial drainage of meltwater and groundwater driven by hydrostatic pressure gradients within a few kilometres of the ice front, or catastrophic ice proximal meltwater discharge (jökulhlaups). Either way they are indicative of formation close to the ice margin.

The two major enclosed deeps have a relief of between 15 – 35 m, widths of c. 2.5 km, depth-width ratios of c. 1:10, steep c. 9˚ marginal slopes, irregular longitudinal profiles of up to 30 km in length and an orientation of c. NNE-WSW. In addition, to the two principal deeps and on the basis of slope analysis as well as bathymetric interpretation, a further eight incipient deeps are identified within the area.

Although all of these features are an order of magnitude smaller in terms of relief they are in fact comparable to similarly generated features ('tunnel valleys') identified by Woodland (1970) throughout East Anglia and classified by Huuse & Lyke-Andersen (2000) as being end-member over-deepened valleys. Indeed, the shallow nature of the East Anglian terrestrial features is proposed to be a product of them having only undergone a single glacial advance whereas most of those in the North Sea have been re-occupied by ice sheets on at least two or three occasions. Figure 3.11 shows the location of these deeps in relation to the known glacial limits of the last three major glaciations: Elsterian-Anglian, Saalian and the Weichselian (after Ehlers & Gibbard, 2004). This Figure demonstrates that they lie in very close proximity to the inferred offshore limit of the Elsterian-Anglian limit, and indeed can now be used to modify this limit (dashed line in Figure 3.11), and extend it southwards at least 50 km from the nearest post-Elsterian glacial limit. The other feature of note of the deeps is the lack of sediment accumulation within them (limited core data and seismic interpretation suggests they are covered by a maximum of 20 – 30 cm of unconsolidated material with bedrock commonly exposed along their length. The absence of material is at odds with both the terrestrial East Anglian sequence and the submerged North Sea variants, albeit unfilled forms are found in Denmark. The absence of significant accumulation of material is probably a combined product of: having not been glaciated; being incised almost exclusively in to the very fine grained London Clay Formation deposits which would not produce an easily deposited erosion product; the strong tidal currents that are initiated at every high stand since their inception and which have at the very least maintained them as being sediment free throughout the historic record (Section 2.2) and probably for much of the Holocene considering near modern sea-levels were reached at c. 5,000 BP (Shennan *et al.*, 2000). It is therefore proposed that these enclosed deeps were formed subglacially, in close proximity to the ice margin at the maximum extent of the Elsterian-Anglian glaciation (Oxygen Isotope Stage (OIS) 12).

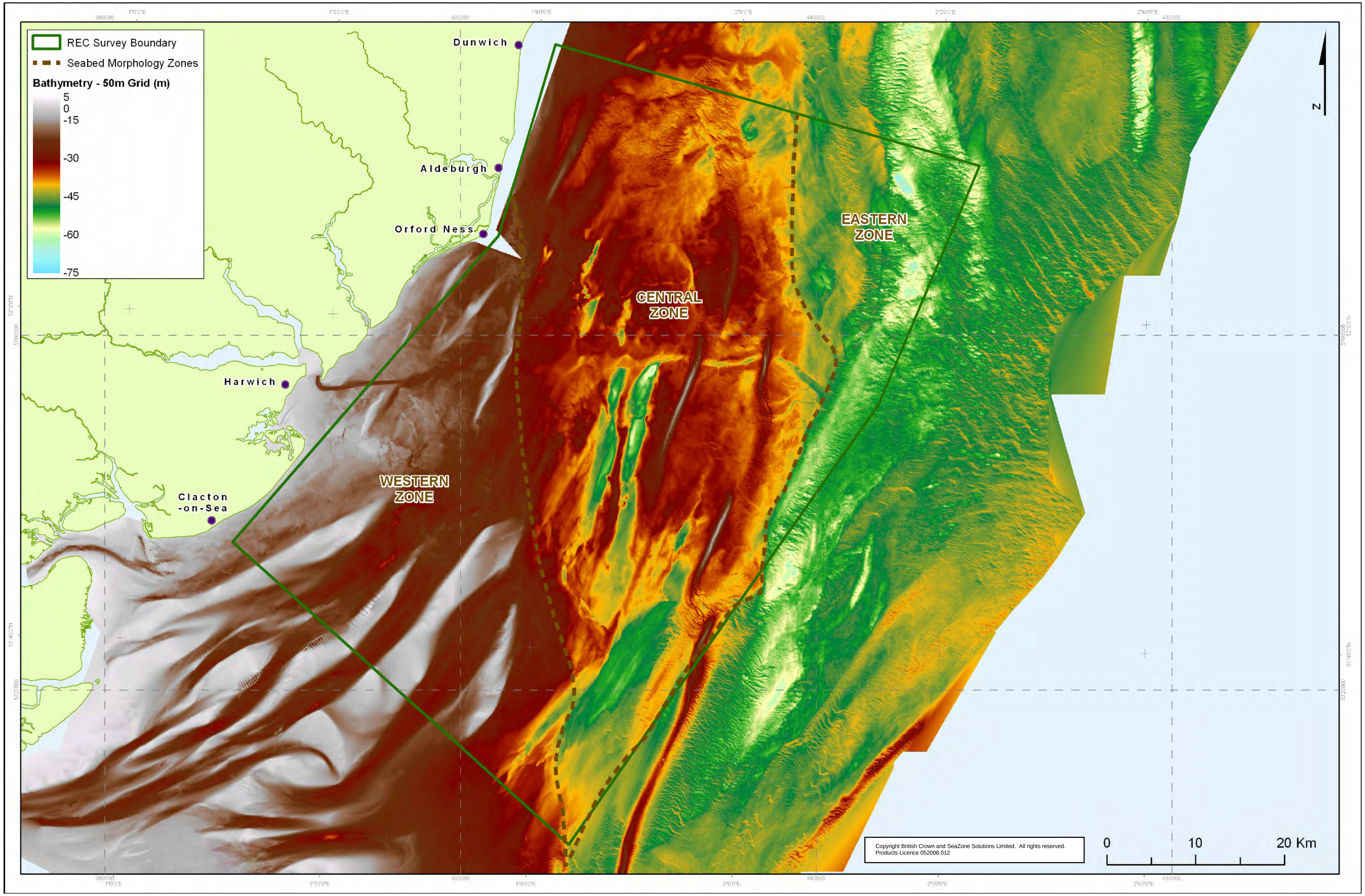

Figure 3.10: A 50 m x 50 m resolution bathymetric map of the Outer Thames Estuary REC area on which the interpretation of the Quaternary geology was based.

The second morphological feature is the almost linear channel system that extends from the entrance to Harwich harbour in the west to almost the edge of the Outer Thames Estuary REC survey area in the east, a total distance of 55 km. Although expressed as a relatively clear, almost linear channel system on the bathymetric chart, transects from the sub-bottom data show it to be a narrow, shallow braidplain, typically covering a width of between 350 and 1,000 m. Within this braidplain, the sub-bottom data suggests the actual channel represents only c. one-tenth of this width and achieves only a maximum depth of < 7.5 m (Figure 3.12). This high width-depth ratio is typical of a river system incised at a glacial lowstand (Vandenberghe, 2008). Feeding into the main floodplain are a series of smaller river systems, many just at the limit of the resolution of the regional bathymetric data (unfortunately the corridor approach to surveying makes it difficult to identify any of these features in the swath data). Figure 3.13 shows two exceptional examples of the channels that are within the resolution limits whilst Figure 3.14 shows an interpretation of the full river system based on the bathymetry, slope analysis, ArcGIS hydrological analysis and sub-bottom interpretation.

The chronology of this river system can start to be determined by its stratigraphic relationship to the enclosed deeps which have been interpreted as being Elsterian-Anglian in age. As can be seen from Figure 3.15 the braidplain of the main river system is clearly incised by the tunnel valley, whilst one of its tributaries is clearly truncated by a smaller deep. The erosional nature of this relationship can also be seen clearly in the sub-bottom section shown in Figure 3.12. The erosional nature of these contacts suggests that this river system and all its attendant tributaries must clearly predate the Elsterian-Anglian glaciation (OIS 12). Further, GIS based mapping (Figure 3.14) of the well studied terrestrial gravel sequences as described by Bridgland (2006) shows the best spatial correlation with the High Halstow/Belfairs/Mayland Terrace Formations of the Medway which have been relatively dated to OIS 18 – Cromerian Complex II (Westaway *et al.*, 2002). If this correlation is correct this places this river system and its attendant landscape (which covers an area of c. 1,500 km^2) at c. 720 kaBP and concomitant with one date for the earliest evidence of hominid activity in the British Isles at Pakefield.

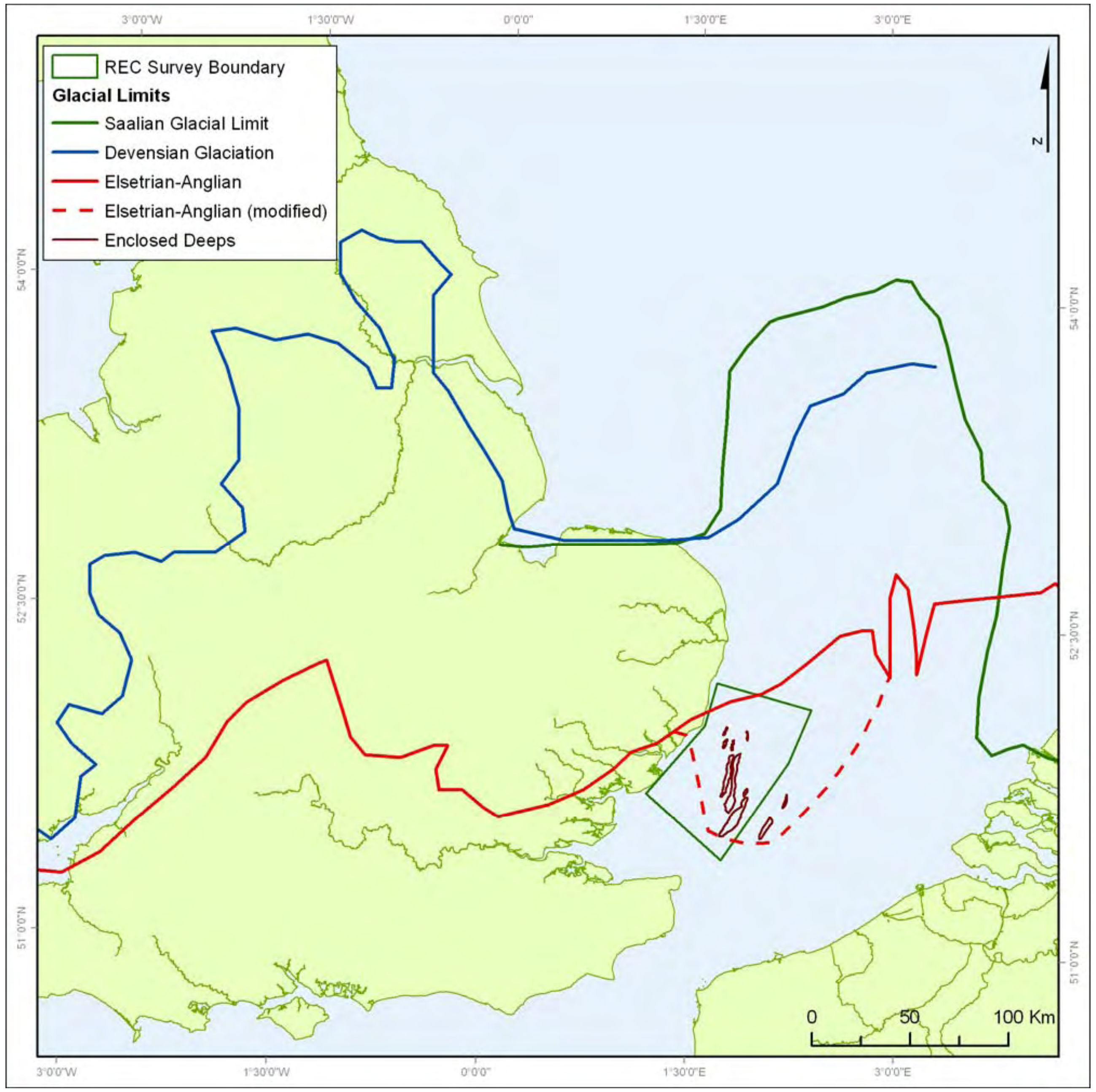

Figure 3.11: Location of the Elsterian-Anglian (Red), modified Elsterian-Anglian (Red) based on this work (Red-dashed), Saalian (Green) and Weichselian (Blue) glacial limits in Britain and the southern North Sea. The interpreted enclosed deeps are shown in purple.

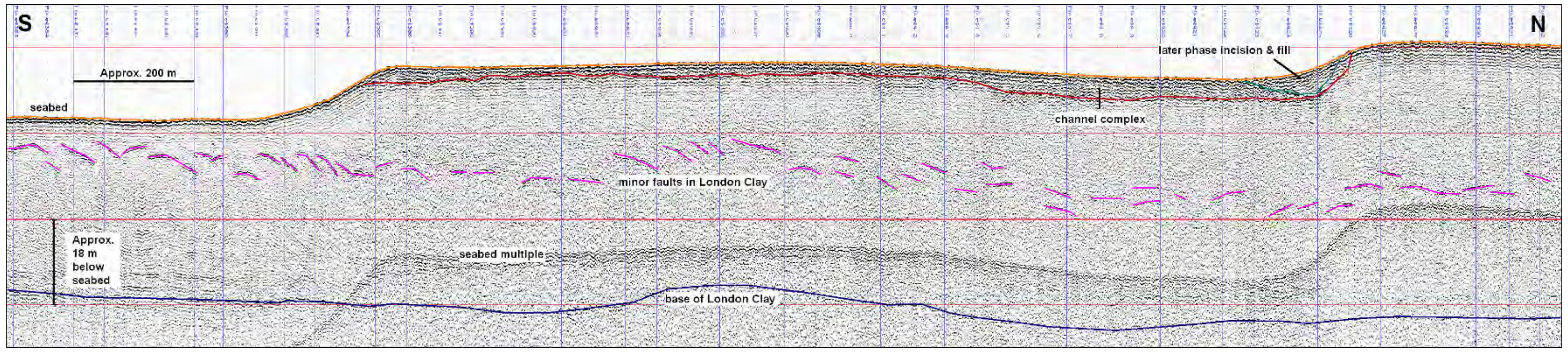

Figure 3.12: Seismic record of a section of the shallow northern palaeochannel which extends from near Harwich to the east of the Outer Thames Estuary REC study area.

Equally interesting at the eastern margin the well defined margin of this fluvially incised plateau landscape is represented by a drop of between 10 – 15 m, albeit at a slope angle of < 3.5˚ (Figure 3.14). Traditionally, this boundary is believed to represent the Lobourg Channel, which drained into the southern North Sea, however an alternative interpretation is that it could represent a remnant lake margin associated with the ice-damming that is believed to have occurred at each glacial maximum, the catastrophic breaching of which could have been the process by which the English Channel River system developed. It is not clear from the bathymetric data alone (and the location at the margin of the Outer Thames Estuary REC does not provide useful sub-bottom data) whether the margin formed concomitantly with the river system or whether it post-dated it.

The full palaeo-channel interpretation of the Outer Thames Estuary is shown in Figure 3.14 and this includes a first-order interpretation of the larger and deeper channel systems that have been previously been identified in the southern part of the Thames estuary. The interpretation shown here is primarily based on the BGS 1:250,000 which has been modified slightly by the smaller number of lines from the Outer Thames Estuary REC survey that crossed the interpreted northern margin of this area.

As can be seen in Figure 3.17, by comparison to the very limited sedimentary fill of the early Cromerian Complex river system these rivers have in places a multi-phase record of sedimentation which exceeds 40 m thick in places.

Further geo-rectification of the paths of the terrestrial sequences of Bridgland (2006) compared against the inferred palaeo-channel routes of a combined BGS – Outer Thames Estuary REC interpretation, suggests that these rivers could have been cut as early as the Elsterian-Anglian glaciations when the maximum advance of the ice pushed the river systems southward (Figure 3.16). The terrestrial channels that reach the current coastline around Clacton are dated to c. OIS 12-10 and could potentially feed into the northern tributaries of this east-west southerly complex. If this is the case then these relatively fined grained sediments, in parts organically rich as evidenced by the presence of shallow gas could provide a (disrupted – due to presence of erosive boundaries) record of c. 450,000 years of sedimentation. Unfortunately, more sub-bottom data is required between the coast and the westerly margin of the Outer Thames Estuary REC to convincingly make the link between these onshore & offshore systems. It is important to note that Bridgland & D'Olier (1995) did suggest an early Elsterian-Anglian Clacton channel that ran almost due west from Clacton and which should have crossed many of the Outer Thames Estuary REC lines. However, there is no evidence of a major river system in this central location between the southerly and northerly river systems and so this has to be discounted.

Holocene

The Holocene is dominated by the marine transgression that followed the end of the Devensian/Wechselian Glacial maximum (Funnell, 1995: Figure 3.18). During the beginning of the transgression the area consisted of a shallow sea, however gradual flooding of the region, via the English Channel, continued until at c. 8 to 8,300 BP sea levels were roughly 30 m below present sea level (bpsl), and a connection between the North Sea and English Channel via the Deep Water Channel was established (Stride, 1989; Shennan *et al.*, 2000). Coastline configurations roughly approximating today's were reached by the Mid-Holocene (c. 5,000 BP). Coincident with these were increases in tidal range and tidal current strengths until near present ranges and velocities were reached (Scourse and Austin, 1995; Shennan *et al.*, 2000).

Formations present include the Elbow, which consists of clays and fine sands interpreted as being laid down in intertidal or subtidal conditions and the Bligh Blank, which is a blanket deposit consisting of medium sands with local mud laminae. These sands were deposited under marine conditions and appear to have been derived from the reworking of Middle and Upper Pleistocene fluvial and marine sediments from between the Dover Strait and the Southern Bight (Cameron *et al*., 1989, 1992). Within the Outer Thames Estuary REC data it is considered that re-working of sediments and the build-up of the major sandbanks (discussed in Section 2.2) was the dominant physical process operating in the area. However, even these processes were localised as the level of preservation of Pleistocene landscapes either exposed on the seabed or buried within the southerly channel system is exceptional.

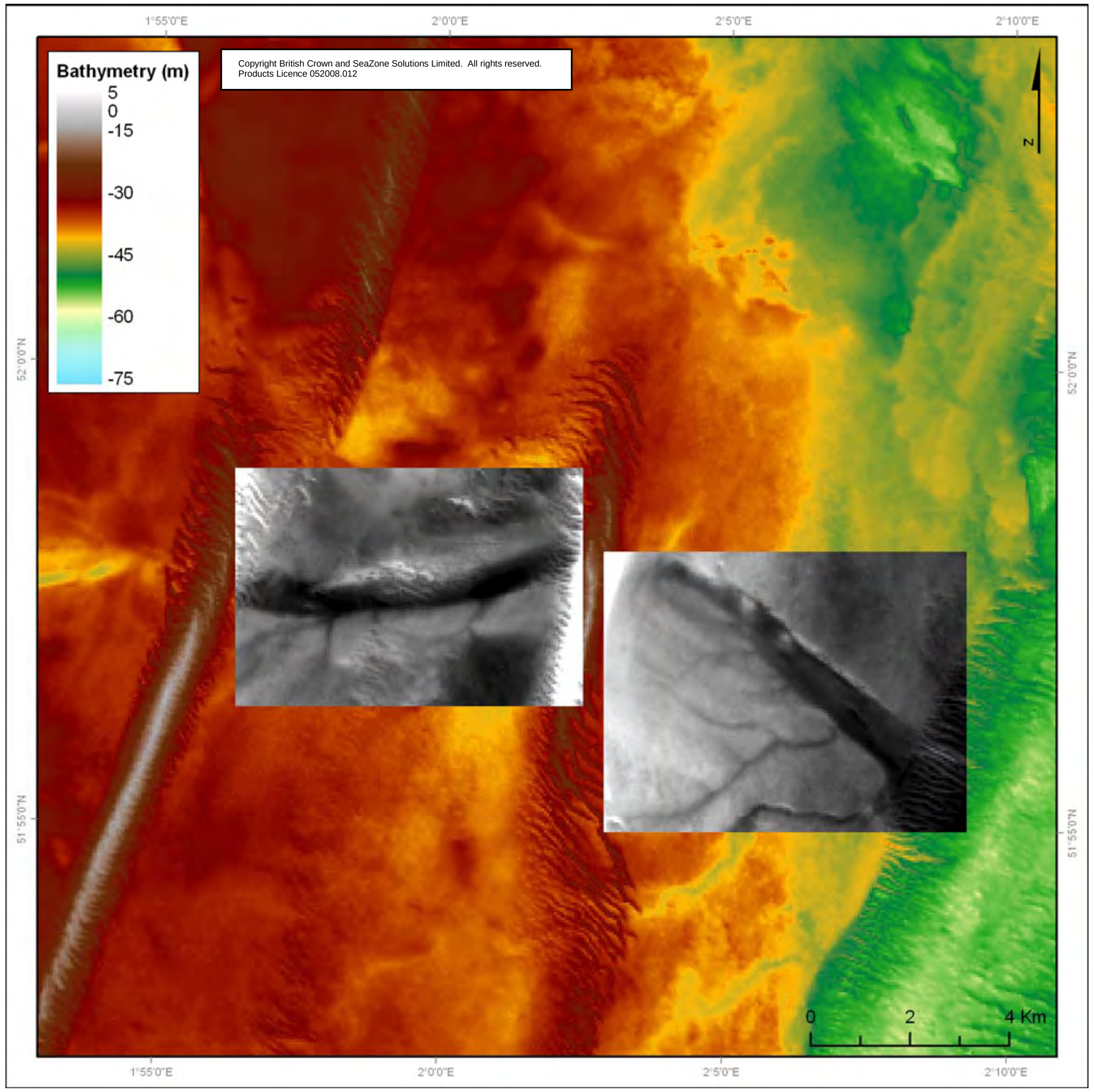

Figure 3.13: Small scale channel systems at the eastern margin of the early Cromerian route of the Thames-Medway system. The eastern topographic boundary could represent a remant of the Loubourg River or a lake margin associated with the Quaternary glacial maximums.

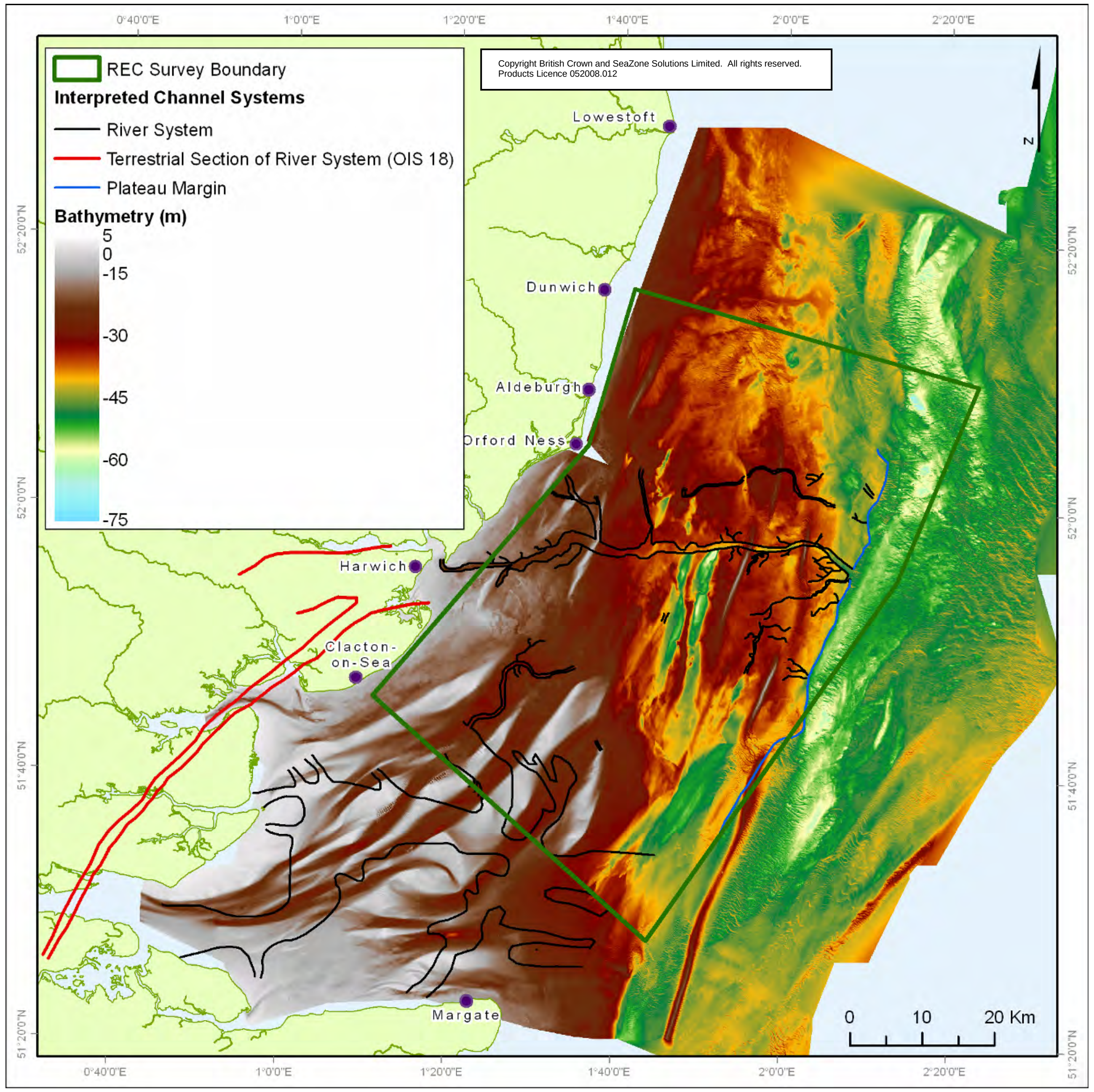

Figure 3.14: Interpreted channel systems of the Outer Thames Estuary including the early Cromerian Thames-Medway river system, the terrestrial section of the system (after Bridgeland, 2006), the eastern plateau margin and the later Quaternary Thames-Medway system (Based on BGS 1:250,000).

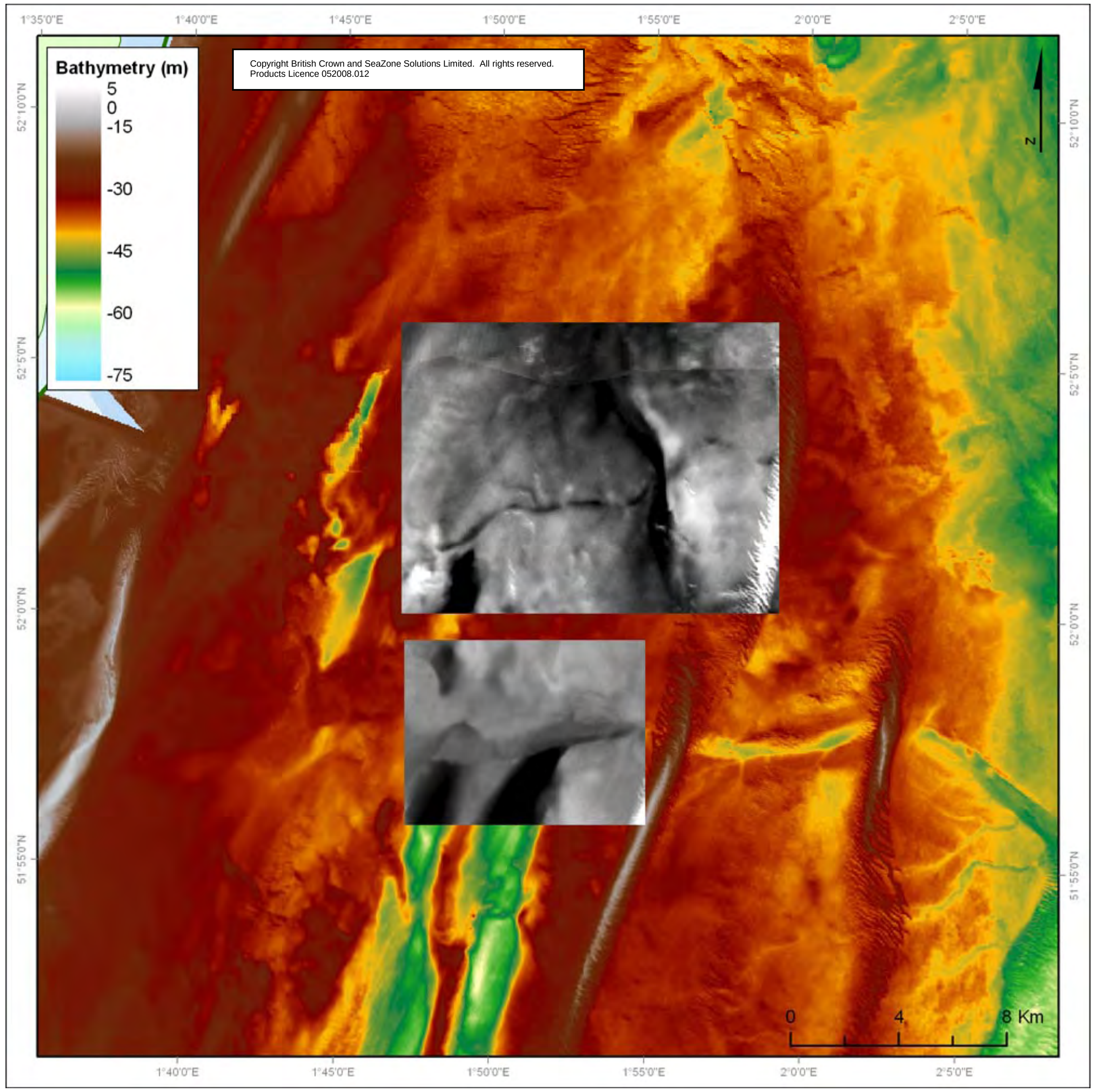

Figure 3.15: A close-up of the cross-cutting relationship of the Elsterian-Anglian enclosed deeps and the probably Cromerian Complex II (OIS18) age Thames-Medway river system.

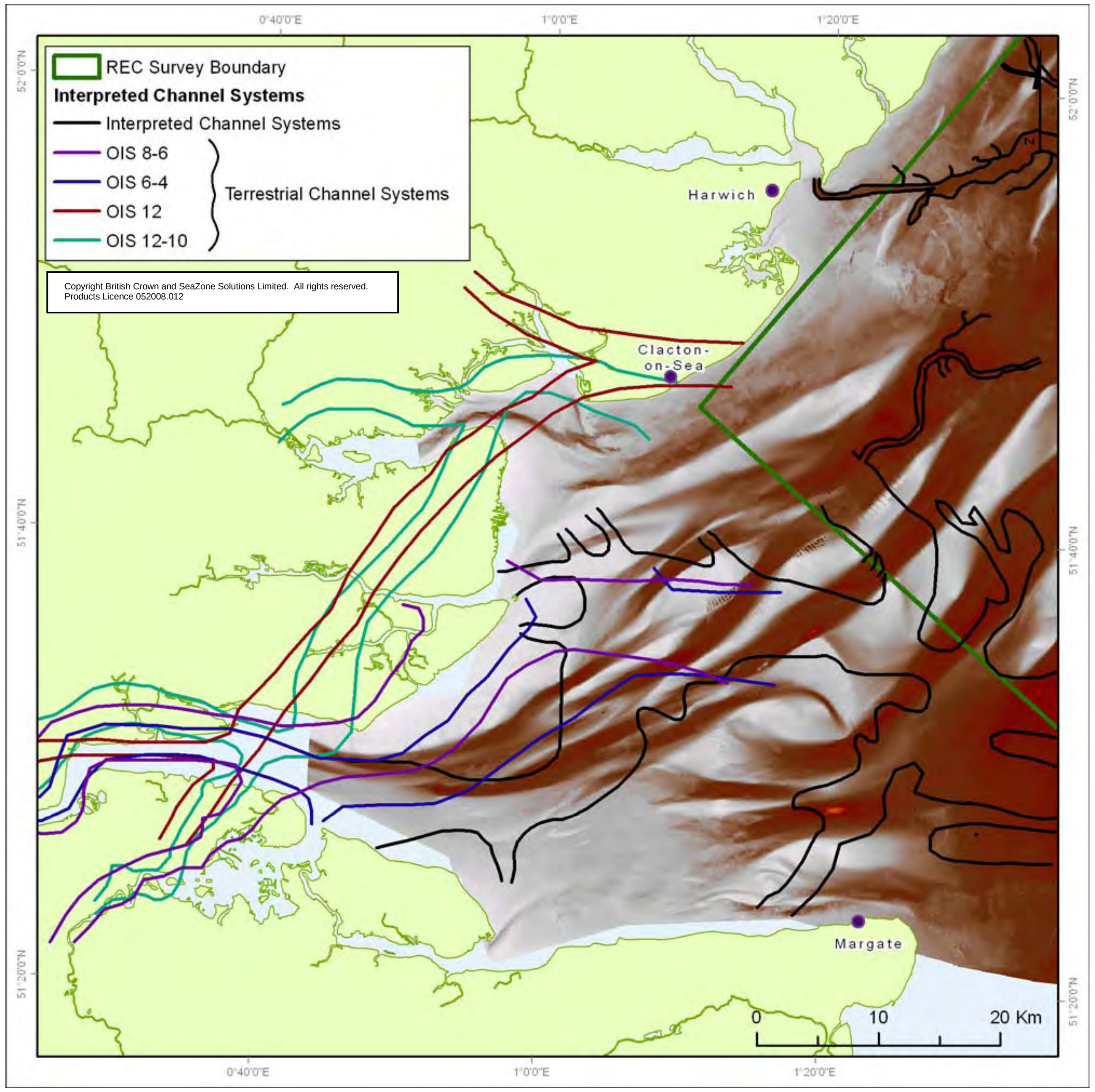

Figure 3.16: A map of the interpreted channel systems of the Outer Thames Estuary focusing on the post Anglian river system and its terrestrial correlatives that abut the Outer Thames Estuary REC survey area (Based on BGS 1:250,000).

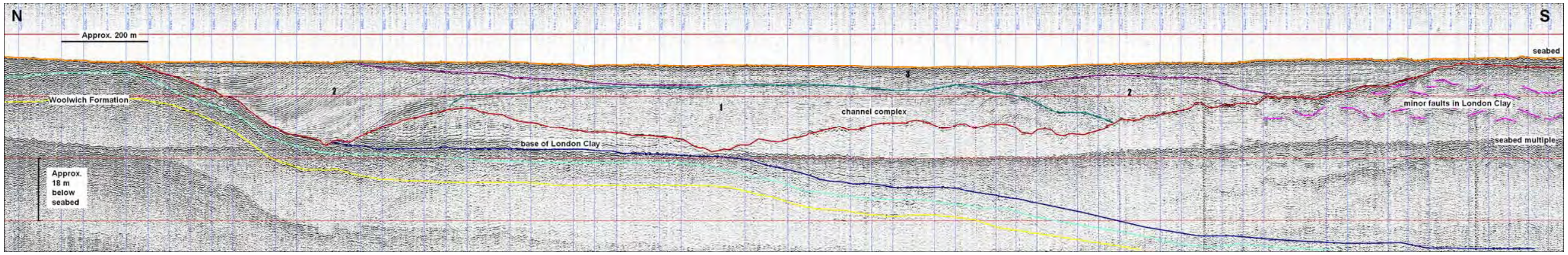

Figure 3.17: High resolution seismic profile showing the multi-phase record of sedimentation within the deeper palaeo-channel systems found in the southern part of the Outer Thames Estuary.

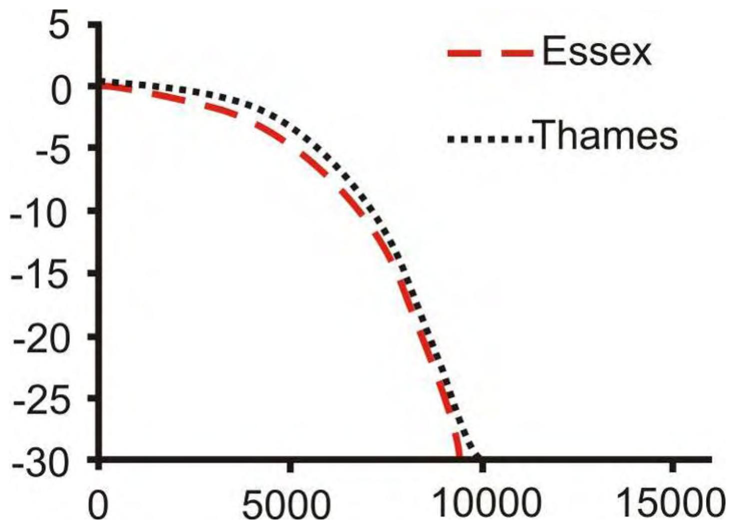

Figure 3.18: Holocene sea-level curves for the Essex coast and Thames estuary areas (after Shennan and Horton, 2002). The vertical axis gives depths in metres in relation to ordnance datum. The horizontal axis relates to dates in years before present (BP).

3.4 Heritage

The Outer Thames Estuary REC area encompasses and abuts to regions of Britain known to hold great archaeological potential; from the Lower Palaeolithic finds at Pakefield (Suffolk) and Clacton (Essex), through to twentieth century military installations at Orford Ness (Suffolk), let alone a rich shipwreck record. Characterising the heritage record of this area is complicated by the dynamism of the environment being considered. As made clear in Section 3.3, over the seven hundred thousand years considered in this section, the Outer Thames Estuary has oscillated between being exposed as dry habitable land and submerged underwater. As such, in order to characterise the heritage of this region, we also have to be able to account for the processes of change.

The following section broadly characterises both the known archaeological material within the Outer Thames Estuary REC (mostly ship and aircraft wreck sites) as well as an analysis of the potential of submerged deposits for informing our understanding of the deeper past. In doing this, the significance of the argument made in Section 3.3 for the survival of pre-Anglian land surfaces within this region will be made clear.

3.4.1 Archaeology and Sea-Level Change

From an archaeological perspective the Quaternary sea-level fluctuations which control the near-surface geology of the Outer Thames Estuary become of interest when they correspond to periods when landmasses were occupied by Hominins, or our more remote ancestors. Within Europe the earliest evidence for Hominin activity currently dates to c. 900,000 BC (McNabb, 2007). McNabb reminds us that this is a fragmentary record, and in reality we should be thinking about a movement of people out of Africa and Eurasia into Europe from one million years BC onward. Within what today we term the British Isles, the earliest evidence for Hominin activity, at c. 700,000 BC, comes from only 20 km north of the Outer Thames Estuary REC at the site of Pakefield (Parfitt *et al.*, 2005, shown in Figure 3.19), although recent work by Westaway (2009) questions this date placing it at, OIS 15 (c. 600,000 BC). Thus, as Flemming (2002) makes clear, any account of the potential heritage of the submerged North Sea must take into account this deep time record and changes in palaeogeography.

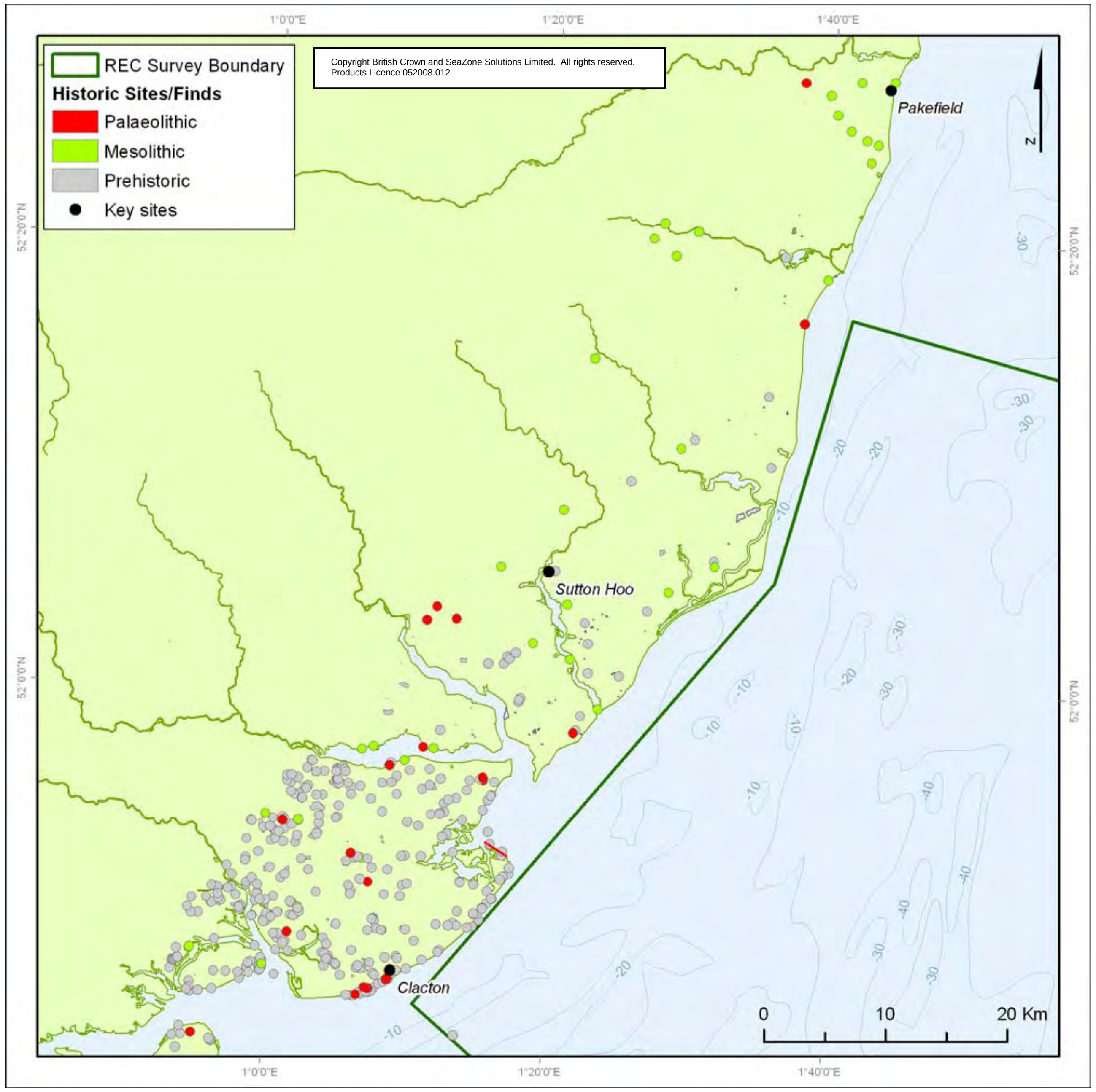

Figure 3.19: Map showing the location of Palaeolithic, Mesolithic and 'Prehistoric' material along the coastal boarder of the Outer Thames Estuary REC area.

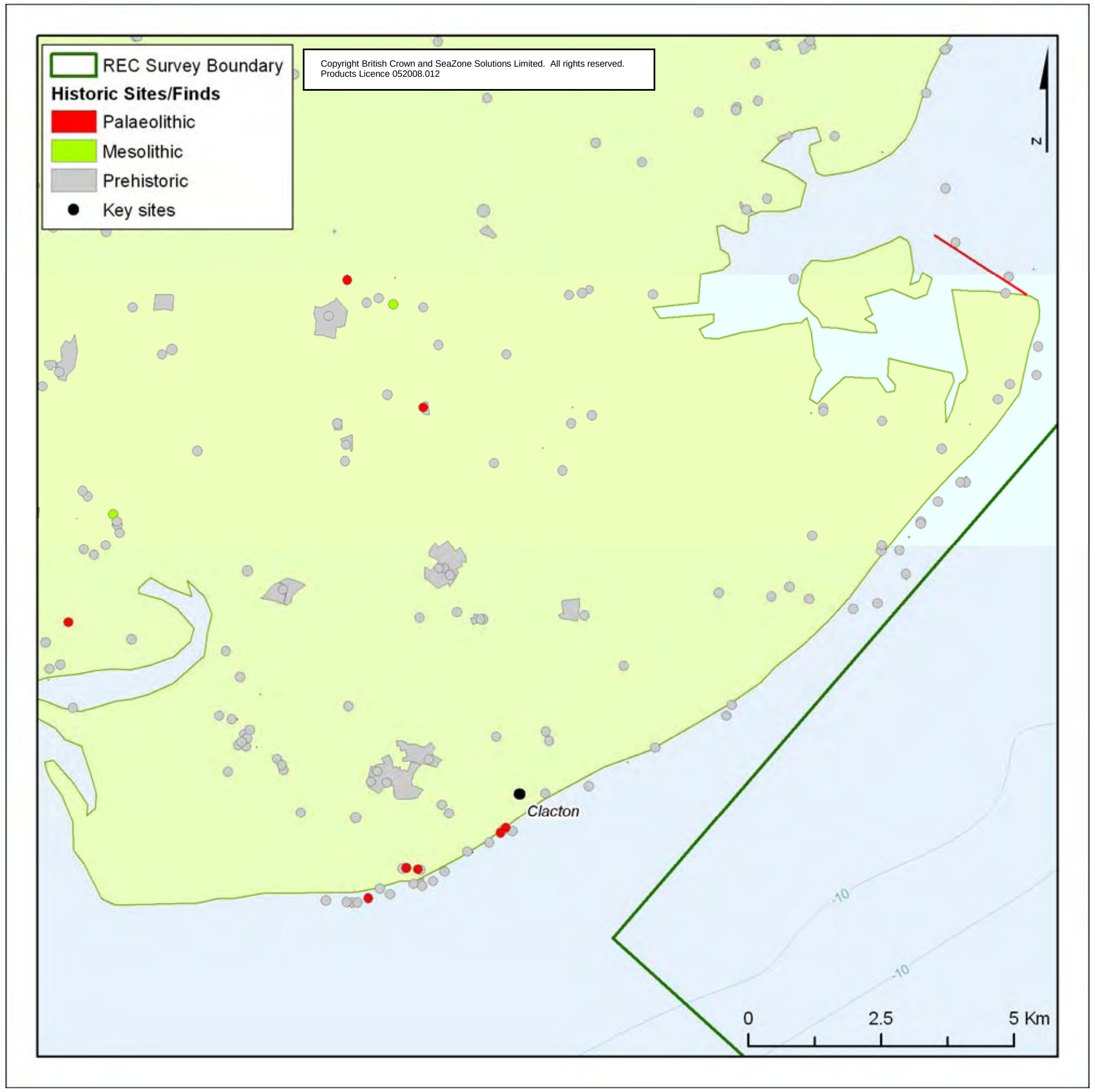

Figure 3.20: Map showing a close-up of Palaeolthic, Mesolithic and 'Prehistoric' sites and findspots near Clacton.

As has been demonstrated in Section 3.3, fluctuations in sea-level are not only the preserve of the deep-time record. Over the last 12,000 years there has been a dramatic change in coastal formation, particularly over the period 10,000 BP (c. 8,000 BC) and 5,000 BP (3,000 BC). Models of coastal change based on the constructed sea level record (Shennan *et al.*, 2000) suggest that in the actual Outer Thames Estuary REC study area, the vast majority of submerged terrestrial archaeology will predate the mid Holocene (c. 3,000 BC) as sea levels and coastal configurations had approximately reached those of the present day by this time. Between the mid-Holocene and the present, coastal change (e.g. erosion) and a limited amount of sea level fluctuation (c. <5 m) has meant that some archaeological material dating to later periods (i.e. the post-Neolithic: Bronze Age, Roman/Iron Age, Anglo-Saxon, Medieval and post- Medieval) has been submerged. Nevertheless, the scale of the sea level changes has been such that most of this category of material exists almost exclusively in or adjacent to, the modern intertidal zone. Within the Outer Thames Estuary REC, it is only in the very south and west extremes of the zone considered (a kilometre from Clacton) that such shallow depths adjacent to the coastline are reached.

3.4.2 Archaeological Review

Lower and Upper Palaeolithic

The Outer Thames Estuary REC survey area parallels one of the most important stretches of coastline for Palaeolithic archaeology in the British Isles. Bracketed by the key internationally significant Lower Palaeolithic sites of Clacton (to the south) and Pakefield (to the North), the coastline in this region has continued to produce evidence for the earliest occupation of the British Isles.

As indicated in Table 3.2, the Palaeolithic of what we now know as Britain, is currently seen to span 690,000 years. Over this period the landmass was first occupied by *Homo heidelbergensis* (c. 700,000 BP), then by *Homo neanderthalensis* (c. 40,000 BP), and *Homo sapiens sapiens* (c. 40 – 35,000 BP) (McNabb, 2007; Pettit, 2008). These different Hominins all carried out a hunter-gatherer lifestyle, reliant on stone tool and organic technologies. They had to live, adapt and cope with the at times dramatic changes in environment which occurred over this long time frame. The archaeological record left by such groups is largely disparate and fragmentary. This means that any additional data which can be gathered is of great potential. The majority of finds made to date have come from secondary contexts (Austin, 1999), which only serves to add importance to the few primary context sites investigated, such as Clacton (Singer *et al.*, 1973) and Pakefield (Parfitt *et al.*, 2005).

Searches of the Essex and Suffolk historic environment records (HERs) and the National Monuments Record (NMR) returned eighty five results for the search area (Table 3.3). An additional 665 records were returned from all three sources combined indicating generic 'prehistoric' activity (Table 3.4). The locations of these sites and findspots are shown in Figure 3.19. Whilst images like these are a useful visual aid, they are problematic due to the nature of the underlying data. Here a findspot point might relate to one artefact or hundreds. As such, it is how this patterning fits with a broader understanding of the regions past that is important for the characterization process undertaken here. Significantly, material is found along coastline margins, down river valleys and also in the inter-fluves.

Palaeolithic Data from the Outer Thames Estuary REC Heritage Search Area			
	Suffolk HER	Essex HER	NMR
Point data	0	3	18
Polygon/Polyline	9	1	54

Table 3.3: Numbers of Palaeolithic findspots and sites held in the databases searched.

Prehistoric Data from the Outer Thames Estuary REC Heritage Search Area			
	Suffolk HER	Essex HER	NMR
Point data	6	410	57
Polygon/Polyline	48	76	68

Table 3.4: Number of 'Prehistoric' findspots and sites held in the databases searched.

Figure 3.20 shows a close-up of the search results for the area around Clacton. Here a regular string of 'prehistoric' findspots can be seen to follow the coastline, along with the presence of directly identified Palaeolithic sites. In the north-east corner of Figure 3.20 a clear red line denotes an identified area of Palaeolithic material (NMR Unique Identified 389527 (TM22 NW12)). The material recovered includes 37 handaxes, 1 roughout, 1 core, 10 retouched flakes, 19 flakes and 1 Levallois core, indicating the possibility of both Lower and Upper (as indicated by the Levallois core) Palaeolithic activity. This collection of artefacts was only documented in 1997 as part of the English Rivers Palaeolithic Project carried out by Wessex Archaeology (1997) on behalf of English Heritage.

Further south around Clacton there is a cluster of Palaeolithic finds and sites (EHER record 17686, NMR nos. 387806, 387804, 387790, 32039, 1234205). These relate to numerous artefacts (including the famous wooden spear found by Hazzledine Warren (1911) found between Lions point to the south and Clacton. McNabb (2007) argues that we should not see these as signifying different 'sites', but rather we should envisage a continuum of activity in this region.

Figure 3.21 shows a close-up of the mouth of the River Deben (near Felixstowe). The red polygon visible in the centre of the map relates to Suffolk HER site FEX090, a collection of Clactonian (Lower Palaeolithic) artefacts along the coastal margin. Again, these are relatively recent discovery after a Rapid Coastal Zone Assessment. Significantly, Suffolk HER classifies this region as of high potential for Palaeolithic archaeology. This, along with the evidence from Clacton, indicates that the areas in close proximity to palaeochannels of high potential for Palaeolithic artefacts in this region. Again, this adds significance to the identification of surviving pre-Anglian land surfaces and channel systems within the Outer Thames Estuary REC area (Section 3.3)

Given the international significance of the material found along this shoreline, it is unsurprising that a considerable amount of research has been carried out into it. As such, a clearly documented research strategy has emerged (Austin, 1999, 2000) and is currently being updated by the South East Research Framework (SERF) working group (Wenban-Smith Forthcoming). These documents identify that the Pleistocene deposits of the Cromer Forest Bed Tills and the Quaternary palaeo-channel terraces as being of prime importance. These deposits are a rich source of artefacts in secondary contexts and potentially also primary contexts. Notable sites already explored further inland include Swanscombe (inshore), Purfleet, Crayford (inshore) and Grays (Williams & Brown, 1999; Bridgland, 2000) along with those mentioned above. Recent work in historic landscape characterisation (Brown *et al.*, 2008) for the Maldon district of Essex has highlighted the complexity and importance of this deep time archaeological record. In particular it draws out the contribution that the Essex coast has already made to our understanding of very early (c. 600 – 700,000 BP) Palaeolithic groups. This document, along with those produced by Williams and Brown (1998) and Murphy (forthcoming), adds emphasis to the above discussion of sea-level change and submergence.

Mesolithic

The Mesolithic approximately spans the period from the end of the Devensian Glaciation (c. 10,000 BC) through to the start of the Neolithic (c. 4,000 BC). As with the Lower and Upper and Palaeolithic, those living within this period relied on hunting and gathering to survive. Typically the Mesolithic had been identified in the field by the presence of microliths and small blades (Tollan-Smith, 2008). As Section 3.3.3 (Holocene) and 3.4.1 have commented up on, the Outer Thames Estuary REC survey area underwent considerable change (from largely exposed dry-land to submerged) over this period of time.

Austin (1999) comments that East Anglia as a whole is relatively rich in Mesolithic sites. However, beyond those found within the Fens (such as Peacocks Farm) and within the Blackwater estuary, few of these sites are discussed at depth within the literature. Within Mesolithic archaeology, research has tended to focus on the South/South-East/North-East of England and Scotland. In part this may be explicable through relative visibility of material to collectors. Palaeolithic hand axes and Neolithic arrowheads and axe heads have a long history of collection. The more difficult to spot microliths are generally less well represented in our national archives.

This pattern of representation is borne out by the results of the archive search carried out for this project. Table 3.5 reveals that in total only seventy records were returned. Of these, the majority related to single finds rather than assemblages or ‘sites’ (e.g. 20 out of 30 NMR points). Figure 3.19 indicates that these sparsely spaced data points are mostly found along river valleys systems near the present coastline, and with some further back towards the uplands in Suffolk. However, a significant site is documented at the south eastern extent of the search area. Essex HER no. 13636 relates to an intertidal settlement of Mesolithic date discovered by Wilkinson & Murphy (1995) as a part of the Hullbridge and Blackwater estuary coastal zone survey.

Mesolithic Data from the Outer Thames Estuary REC Heritage Search Area			
	Suffolk HER	Essex HER	NMR
Point data	2	2	30
Polygon/Polyline	6	1	29

Table 3.5: Number of Mesolithic findspots and sites held in the databases searched.

These results are considered surprising because of the detailed survey of the Essex coast undertaken in the 1980s. This and subsequent work located a large quantity of archaeological material on the coast and in the intertidal zone ranging from the Mesolithic to the post-Neolithic (Wilkinson & Murphy, 1995). Concentrations of Mesolithic sites were also located further inland at Marylandsea (Blackwater Estuary). At the time of occupation, these would have been dry land sites situated by freshwater rivers (Wilkinson & Murphy, 1995; Murphy & Brown, 1999). Murphy (forthcoming) notes that reason for the relative paucity of finds registered in the archives may come from a deliberate policy of non-reporting in an openly accessible manner, to prevent damage to sites from visitation. This suggests that for Prehistoric archaeology along this stretch of shoreline the records retrieved should be viewed as a bare minimum baseline of activity.

Within Austin’s (2000) research framework for the Mesolithic of East Anglia, developing an appreciation of the changing landscape is identified as a major priority. Thus, although relatively little material emerged from the archival research carried out for this project, it is clear from the discussion in Section 3.3 that the Outer Thames Estuary REC area has much to offer in terms of addressing key questions already identified for the region by the archaeological community.

Neolithic

The potential for submerged terrestrially deposited archaeology post dating the Mesolithic being found within the Outer Thames Estuary REC area is reduced to a narrow coastal margin (Shennan *et al*., 2000). Thus, given the aims of this document, these periods will receive less direct attention within the text presented here. However, even though the percentage chance of primary context Neolithic, Bronze and Iron material may be reduced, the Outer Thames Estuary REC area still has the potential to contribute to our knowledge of these (and subsequent) periods in this region.

Firstly, the question of how the transition from mobile hunting and gathering communities in the Mesolithic, to sedentary, farming, monument building groups in the Neolithic occurred is highly significant and much debated (Thomas, 2001, 2003, 2005, 2008; Whittle, 2003). One area within which data may be found, but which has been understudied is that of coastal communities at the point of transition (Sturt, 2006, 2007). In order to do this, refined data on the nature and rate of environmental and social change is required. Given its close proximity to the coast, and the shallow depths at its south and western most extent, and the presence of palaeochannel systems, it is possible that the Outer Thames Estuary REC area may contribute to this discussion.

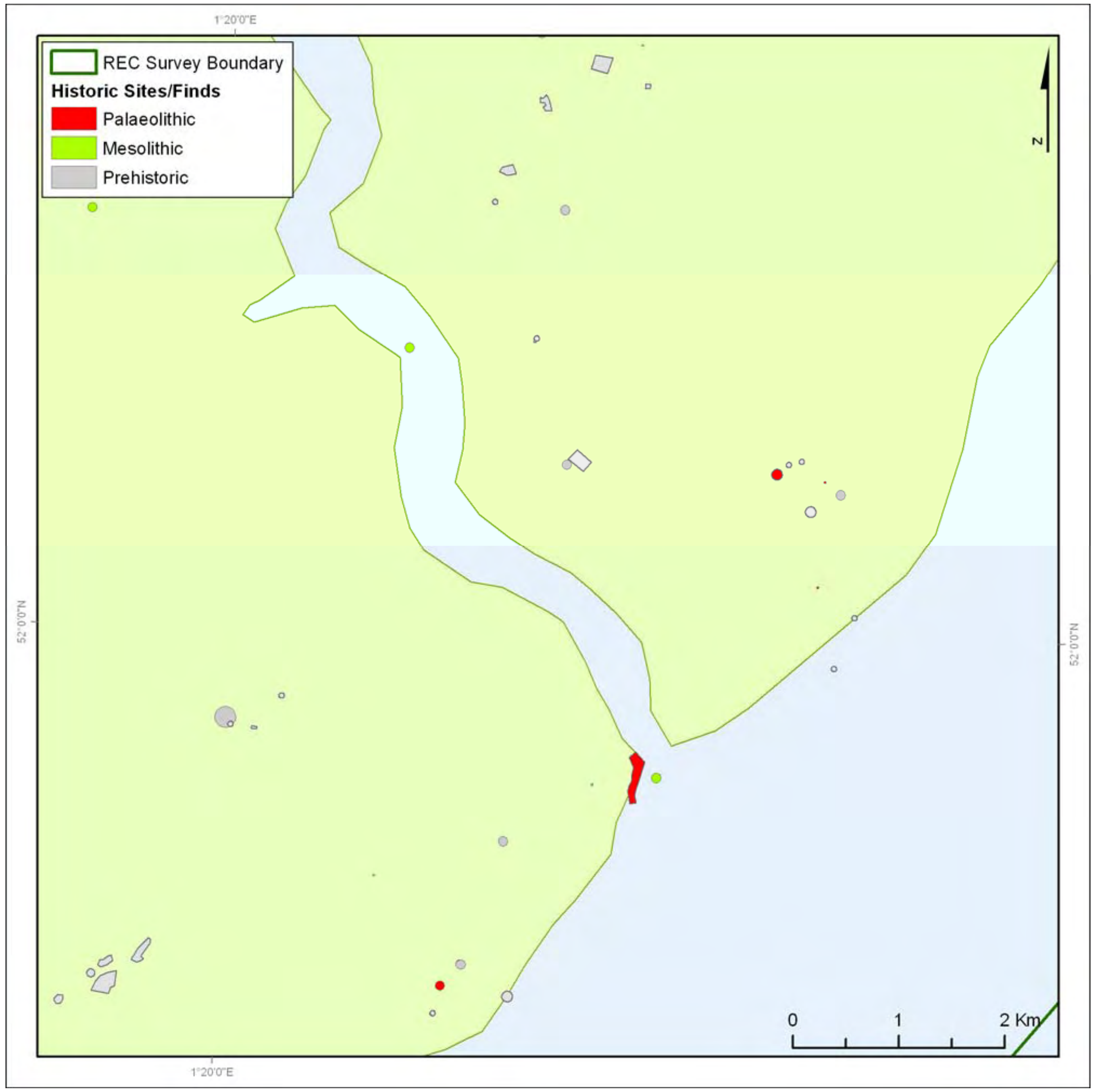

Figure 3.21: Map showing a close-up of the area around the mouth of the River Deben. Note the Palaeolithic site.

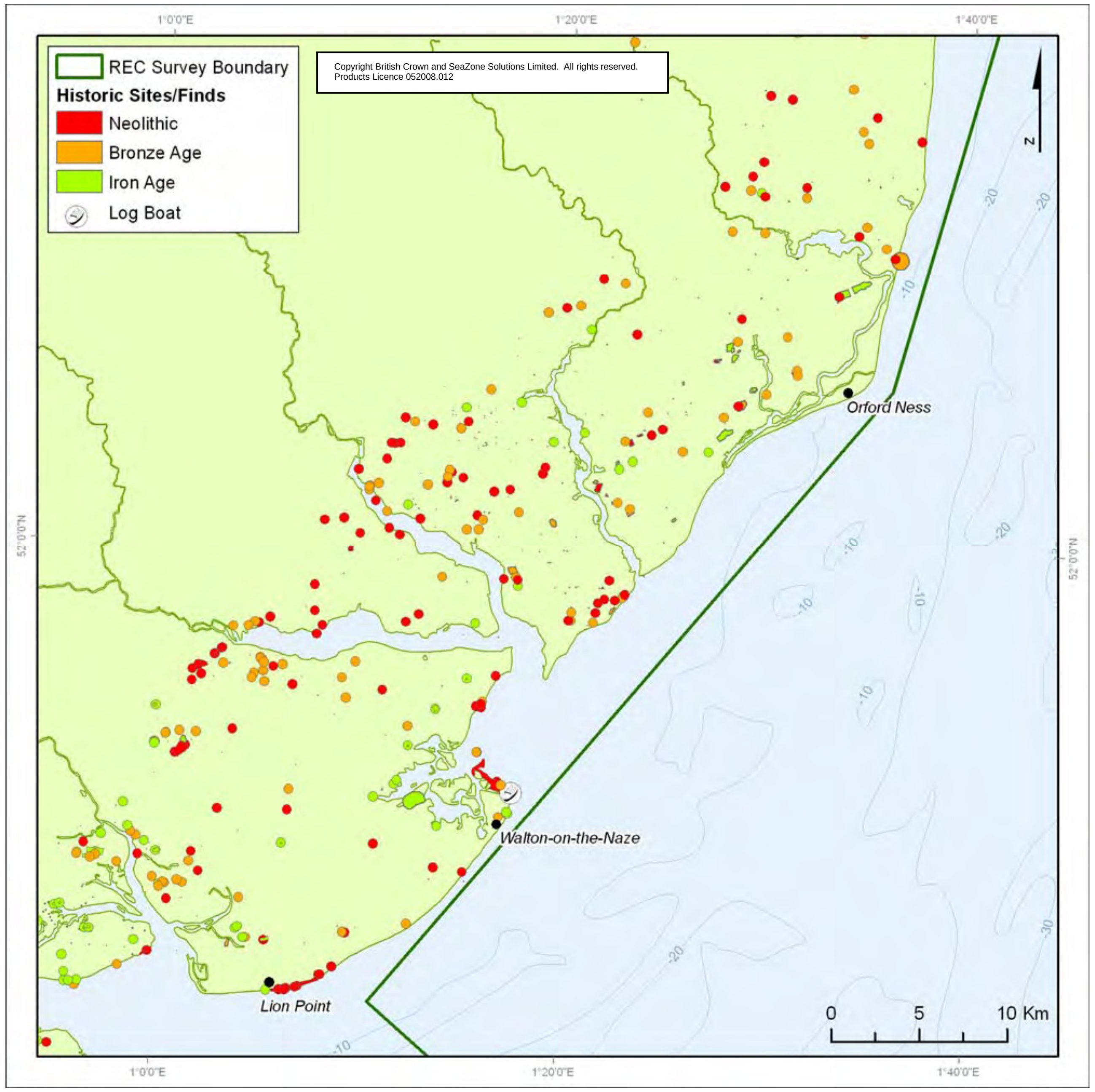

Figure 3.22: Map showing the location of Neolithic, Bronze and Iron Age material found along the Outer Thames Estuary REC margins.

Archival searches produced a relatively high density of sites along the Outer Thames Estuary REC margin (Table 3.6 and Figure 3.22). Significantly, Neolithic material is found in dense concentrations along the Essex coastline, with large sites to the north-east of the Essex coastline at Walton (Essex HER ID: MEX 12789) and the south west at Lion Point (Essex HER ID: Mex10079). Both of these sites have produced significant quantities of pottery, as well as evidence for hearths and other prehistoric material. It is significant that site MEX 12789 corresponds with the concentration of Palaeolithic material (NMR ID: 389527) discussed above. In addition, a log boat was also recorded as having been recovered from this location in 1936 (NMR ID: 925071), although sadly no further records are available for this find. However, it does tantalizingly point to potentially prehistoric use of this coastline. The picture developed from such distributions is of a rich prehistoric record eroding out of beach sediments and cliff faces along the Essex and Suffolk coastline.

Neolithic Data from the Outer Thames Estuary REC Heritage Search Area			
	Suffolk HER	Essex HER	NMR
Point data	9	19	99
Polygon/Polyline	54	8	103

Table 3.6: Number of Neolithic findspots and sites held in the databases searched.

An extensive Neolithic occupation was also located further west in the intertidal zone of the Blackwater Estuary (The Stumble and Rolls Farm sites). This included evidence of structural features, pits and large quantities of lithics and pottery. Palaeo-environmental analysis of the area was also possible and revealed that at the time of occupation the area would have been a wooded landscape. Significantly, the evidence from the intertidal zone contains large quantities of charred plant remains (in contrast to the poorly preserved remains from the adjacent terrestrial gravels), which provide important information as the subsistence strategies of these societies (Murphy & Brown, 1999). Smaller quantities of evidence (e.g. spreads of charcoals, stone tools, buried soils) occur at many other locations along the coast. Submerged forests, sometimes associated with flint artefacts, have been located at Hullbridge, North Fambridge and Purfleet (Bradley *et al*., 1997).

The Neolithic and Early Bronze Age signature from this region is not limited to lithic and pottery scatters, but also includes monumental architecture in the form of crop marks and Henges (Brown & Murphy, 2000). These signify investment in this area during later prehistory, an engagement by people with the coastal zone over a long term basis. As such, the Outer Thames Estuary REC area becomes significant for how it may have been used. The presence of coastal marshland at Walton-on-the-Naze reminds us of how much this coastline has changed and how relative sea-level fluctuations and erosion will have significantly transformed coastal morphology. Thus, if we wish to understand the terrestrial record, the Outer Thames Estuary REC sedimentary archive may hold key data to recontextualise these sites.

Concentrations of Neolithic material are also known from the marshes in Kent, on the southern shore of the Medway and the coast between Reculver and Whitstable. In addition, an old land surface at Minnis Bay (Isle of Thanet) has produced some Neolithic pottery (Bradley *et al*., 1997), pointing to the potential of these environments. However, to reiterate, from the Neolithic onwards the coastline is thought to have approximated that of the present day, accounts from this and later periods thus must focus on past coastal activities. Thus it is also significant that historical period (mostly Medieval) fish weirs have been identified along the Essex and Suffolk coastlines, however these are features which conceivable could also date back to earlier prehistory and are worthy of further study.

Bronze Age

The Bronze Age sees an intensification of farming and forest clearance activities within the British Isles (Johnston, 2008). The nature of society also appears to change, with a shift to individual rather than communal burial practices, interpreted as evidence for stratification of society (Jones, 2008). In comparison to the Neolithic, settlements enlarge and field systems begin to spread out from them in more recognisable form. Furthermore, whilst we have little direct evidence for activity in the water during the Palaeolithic, Mesolithic and Neolithic of the British Isles, within the Bronze Age a suite of finds clearly demonstrates seafaring. Barker and Branigan's (1978) discovery of Bronze Age material off the coast of Devon has been interpreted as evidence of a 'wrecking' incident. Similarly, the Dover Bronze Age boat (Clark, 2004) and the work of Van Der Noort (2004a, 2004b, 2006) on the Humber Wetlands area during the Bronze Age all demonstrate the significance of seafaring during this period. As such, at this point in time the chance for finding 'wreck' material becomes slightly increased (although still exceptionally rare) over that of the preceding periods.

Archival searches revealed a rich record for the Bronze Age along the Outer Thames Estuary REC margin. Table 3.7 and Figure 3.22 document the number and location of sites revealed. These included evidence for occupation and burial in the same area of Walton highlighted for Palaeolithic and Neolithic material (NMR ID: 389508). In addition the area around the river Deben contains numerous sites, from cropmarks and hoards, to pit sites (such as Suffolk HER ID: MSF2767). Significantly, there are a large number of sites reported along the coastal margin, eroding out of beach contexts. Thus the chance for secondary context material finding its way offshore is increased.

Bronze Age Data from the Outer Thames Estuary REC Heritage Search Area			
	Suffolk HER	Essex HER	NMR
Point data	12	11	79
Polygon/Polyline	73	1	110

Table 3.7: Number of Bronze Age findspots and sites held in the databases searched.

Within Essex there is additional evidence from coastal surveys for the remains of wooden trackways, fish traps, landing stages and salt making facilities from the Bronze Age right up to the post-Medieval period. Similarly, Bronze Age metalwork has also been located on the coast, including: hoards of fine objects ritually deposited in watery locations above the inter-tidal zone; and broken fragments of metal distributed along the coast have been interpreted as evidence of the production and exchange of bronze artefacts. A number of sites (e.g. Minnis Bay, Kent) have evidence of metalworking residues and contemporary settlement. These may be terrestrial sites which have been inundated by sea level rise. Minnis Bay in particular has a large pottery and metal artefact assemblage, associated plant remains and waterlogged wooden structures. These latter features may in fact be structures (fish weirs) constructed after the site had been inundated (Allen *et al*., 1997; Bradley *et al.*, 1997). Again, this indicates the potential of inter-tidal zone in close proximity to the margins of the Outer Thames Estuary REC boundary.

Iron Age

By the start of the Iron Age at c. 800 BC, sea-levels would have closely resembled those of today. However, it must be remembered that coastal progradation will have transformed coastal morphology. Thus, as with the Bronze Age, from the Outer Thames Estuary REC perspective the Iron Age is of interest in terms of what it indicates about the intensity of activity along this shoreline. Archive searches (Table 3.8) again revealed a relatively high density of sites and findspots strung along the coastal margin (Figure 3.22). Many of these related to 'Red Hills' or salterns (such as that found near Walton, Essex HER ID: 12819, in close association with an Iron age con (NMR ID: 389556)). To continue the trend, just as there is evidence for Iron Age activity at Walton, there is also an alleged Iron Age settlement on Lion point (NMR ID: 387811) further reinforcing the documented prehistoric activity along the Essex shoreline.

Iron Age Data from the Outer Thames Estuary REC Heritage Search Area			
	Suffolk HER	Essex HER	NMR
Point data	3	27	31
Polygon/Polyline	21	20	70

Table 3.8: Number of Iron Age findspots and sites held in the databases searched.

Suffolk demonstrates a similar pattern of coastal salterns, as well as inshore crop marks and evidence for settlement (such as Suffolk HER ID: MSF11015 pottery scatter near Orfordness). Further south, the North Kent marshes have considerable evidence of Iron Age salt making, pottery manufacture and oyster cultivation. In addition the marshes have produced evidence of settlement, which includes burials, pottery, building materials, metalwork and coins. In particular, two hoards of coins have been recovered at Warden Bay (Isle of Sheppey) and Slayhills. At present, relatively little systematic work has been done on this material (Bradley *et al.*, 1997).

Overall there is a relatively even distribution of material along river valley and in the interfluves. However, given the scale of Iron Age society it may be that within the twenty kilometre search radius true settlement patterning is not emerging. As Bryant (2000) notes, whilst there is considerable evidence for the Iron Age of East Anglia more work needs to be done to investigate crop mark sites and to date known settlements/scatters.

In addition to the settlement evidence, Cunliffe (2004, 2009) and McGrail (2004) point to amount of evidence for seaborne trade in the Iron Age. Thus, with its open estuary systems and considerable evidence for settlement and salt working, the chance remains for evidence being found for this prehistoric maritime commerce. Similarly, just as in the Bronze Age and later periods, use of the foreshore may have left its mark in the shallow exposures close to Clacton.

Roman Period

With the end of the Iron Age and beginning of the Roman period, the British Isles enters the historical era (Going, 1999). Accordingly, due to the increase in data sources and the reduced time depth, the record for Roman activity is substantial. Table 3.9 and Figure 3.23, provide details as to the number and location of records returned within the search area. Part of the reason for the intensity of finds made in this region will be the presence of the major Roman city of Colchester.

Within Suffolk, Roman evidence consists of stray finds of coins or pottery amongst isolated larger sites (shown in red in Figure 3.23). Major collections have been noted at Covehithe beach, and the shore between Aldeburgh and Orford. A possible cemetery has also been located in the vicinity of the Roman fort at Walton Castle (now eroded into the sea), while the remains of other substantial Roman structures have been reported from the cliffs north of Lowestoft (Dinah's Gap, Caister and Corton). South of Dunwich, finds of pottery, coins and metalwork may provide an indication of the location of the walled Roman town of Sitomagus. Salt making sites are also apparent on the estuaries of the Stour, Blyth and Alde rivers, though at the same concentration as on the Essex coast (Bradley *et al*., 1997).

Of particular significance to the Outer Thames Estuary REC in terms of Roman Maritime activity is Suffolk HER site MSF16016, the Roman port of Felixstowe (visible in Figure 3.23 as a concentration of point and polygon features on the coast between the rivers Orwell and Deben). Newman (1994) points to the significance of this site, as it represents a localised and discernable concentration of activity. Going and Plouviez (2000) add to significance by identifying work on the Roman Ports and maritime activity in Eastern England as a key research objective for East Anglia.

Roman Period Data from the Outer Thames Estuary REC Heritage Search Area			
	Suffolk HER	Essex HER	NMR
Point data	10	28	171
Polygon/Polyline	174	95	137

Table 3.9: Number of Roman findspots and sites held in the databases searched.

Examining Figure 3.23 further, it is possible to see it as a northern extension of a spread of increasingly intense roman activity as you move south towards Colchester. However, as Going (1999) has argued, this may reflect a research history which has focused on urban centres and high status locales. When the record is interrogated further there is settlement evidence in the form of post-hole and pottery assemblages stretching to the north (e.g. MSF2671, 1st – 4th century pottery and settlement evidence near Orfordness).

Within Essex Roman or Iron Age salt making sites are particularly dense, with a concentration of some 300 find sites (the Essex Red Hills) situated between the River Colne and Canvey Island. The presence of settling tanks and evaporation does imply that tidal waters were close by, however, the exact position of the shoreline is still unclear for this period. Establishing this is somewhat difficult given the preference for estuarine locations which means that salt making sites can be situated several kilometres inland of the contemporary coastline. In addition, significant concentrations of oyster pits have been noted from the Blackwater, Crouch and Roach estuaries (Williams & Brown, 1999). Discoveries of pottery and other domestic refuse from the intertidal zone of Canvey Island may indicate the presence of settlements. However, these have yet to be investigated in significant detail.

To the south and beyond the search area work in Kent identifies other important sites including a Roman fort at Reculver, and finds of pottery at Minnis Bay, St Mildred's Bay, Westgate and a possible Iron Age/Roman quarry at Birchington (Bradley *et al*., 1997; Williams & Brown, 1999). A significant amount of Roman material including amphorae and pottery is located offshore at the Pan Sands, east of the Isle of Sheppey. At present, up to 400 items have been recovered, though most have yet to be inputted in the National Monuments Record (M. Walsh, personal communication). The most likely origin of this is shipwrecks rather than inundated terrestrial sites. With the presence of the Roman port of Felixstowe in such close proximity to the Outer Thames Estuary REC area, the possibility of Roman Shipwrecks has to be considered (although none have been found within the search area to date).

Medieval Period Data from the Outer Thames Estuary REC Heritage Search Area			
	Suffolk HER	Essex HER	NMR
Point data	29	455	193
Polygon/Polyline	483	138	159

Table 3.10: Number of Medieval findspots and sites held in the databases searched.

Medieval Period

As Figure 3.23 and Table 3.10 make clear, there is a dense collection of Medieval sites and findspots within the search area. It is worth noting that internationally renowned site of Sutton Hoo also lies within the search area, on the banks of the rive Orwell. This site serves as a distinct reminder of the significance of this coastline during the Anglo-Saxon and later periods. It also demonstrates the connection and reliance upon the sea that Medieval people had, from its earliest Anglo-Saxon roots.

Not all sites are as spectacular as Sutton Hoo, but the extensive fish trap evidence in this region (particularly numerous on the Essex coast, notably at Sales Point, Bradwell on Sea (Murphy & Brown, 1999; Williams & Brown, 1999) Essex HER ID: Mex7199) is well worth consideration. As Wade (1999) notes, evidence of fishing and maritime activity along the Essex coast is helping to reshape our understanding of the Medieval period in eastern England.

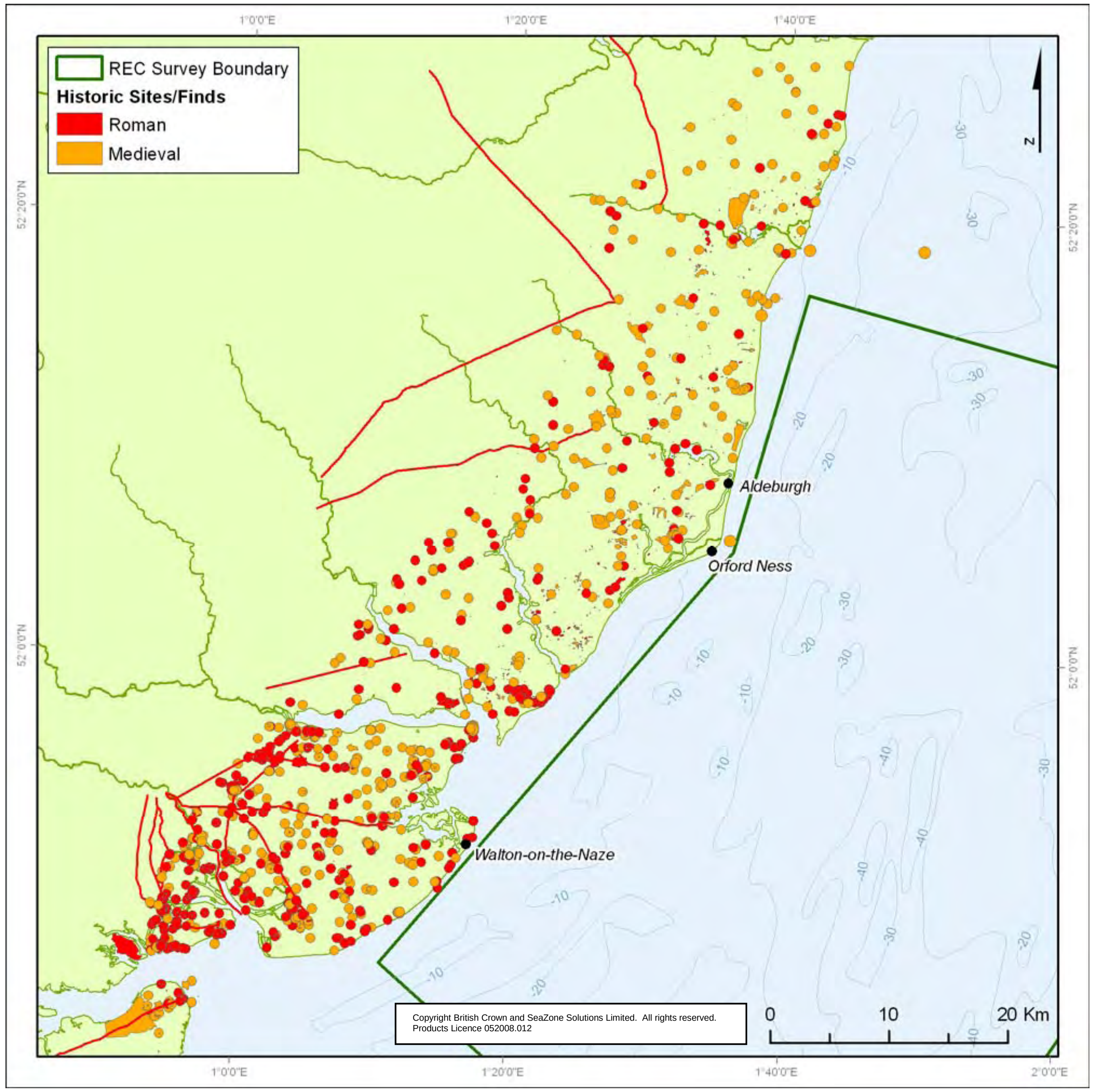

Figure 3.23: Map showing the location of Roman and Medieval material along the coastal boarder of the Outer Thames Estuary REC area.

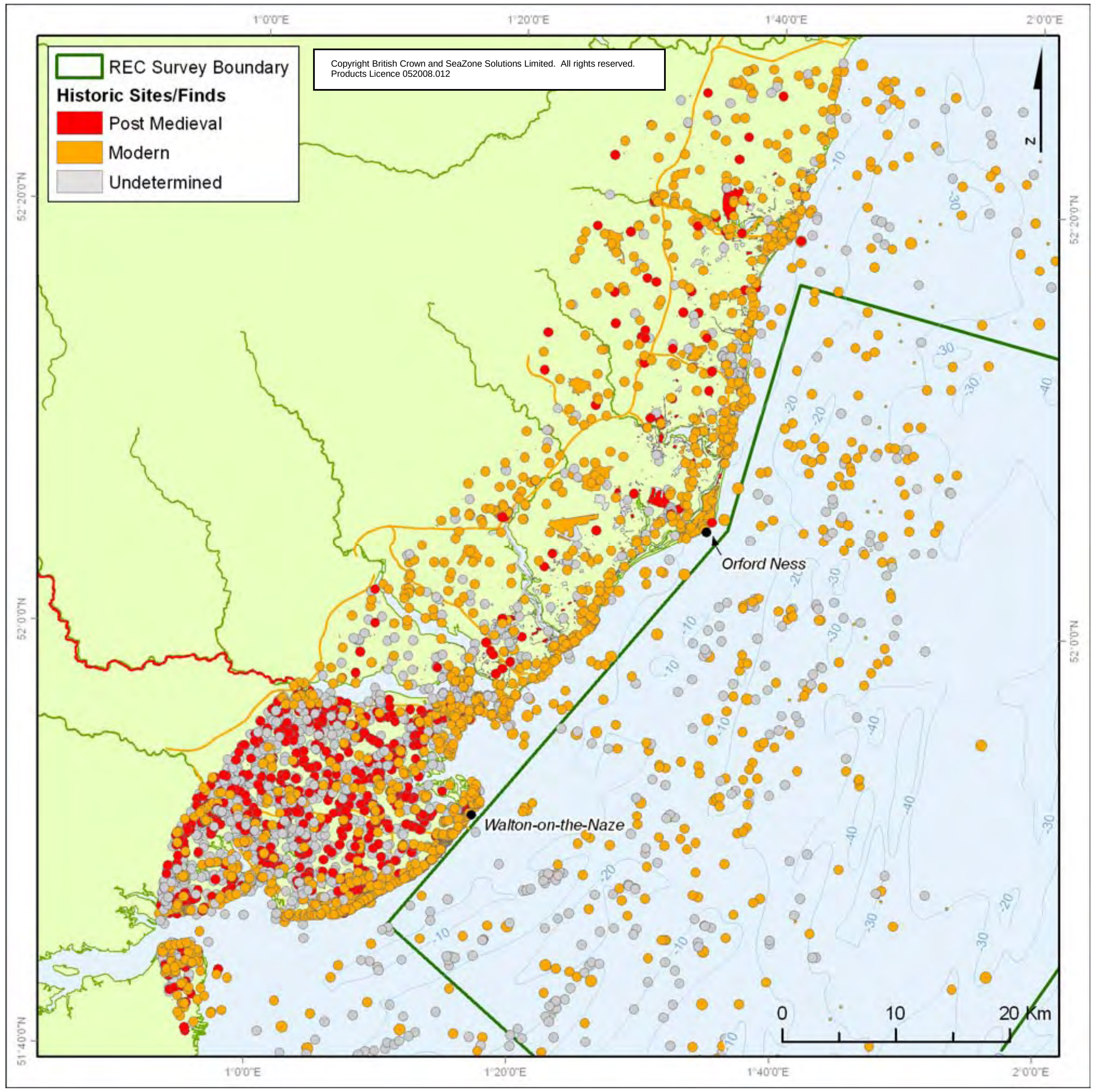

Figure 3.24: Map showing the location of Post Medieval, Modern and undetermined material along the coastal boarder of the Outer Thames Estuary REC area.

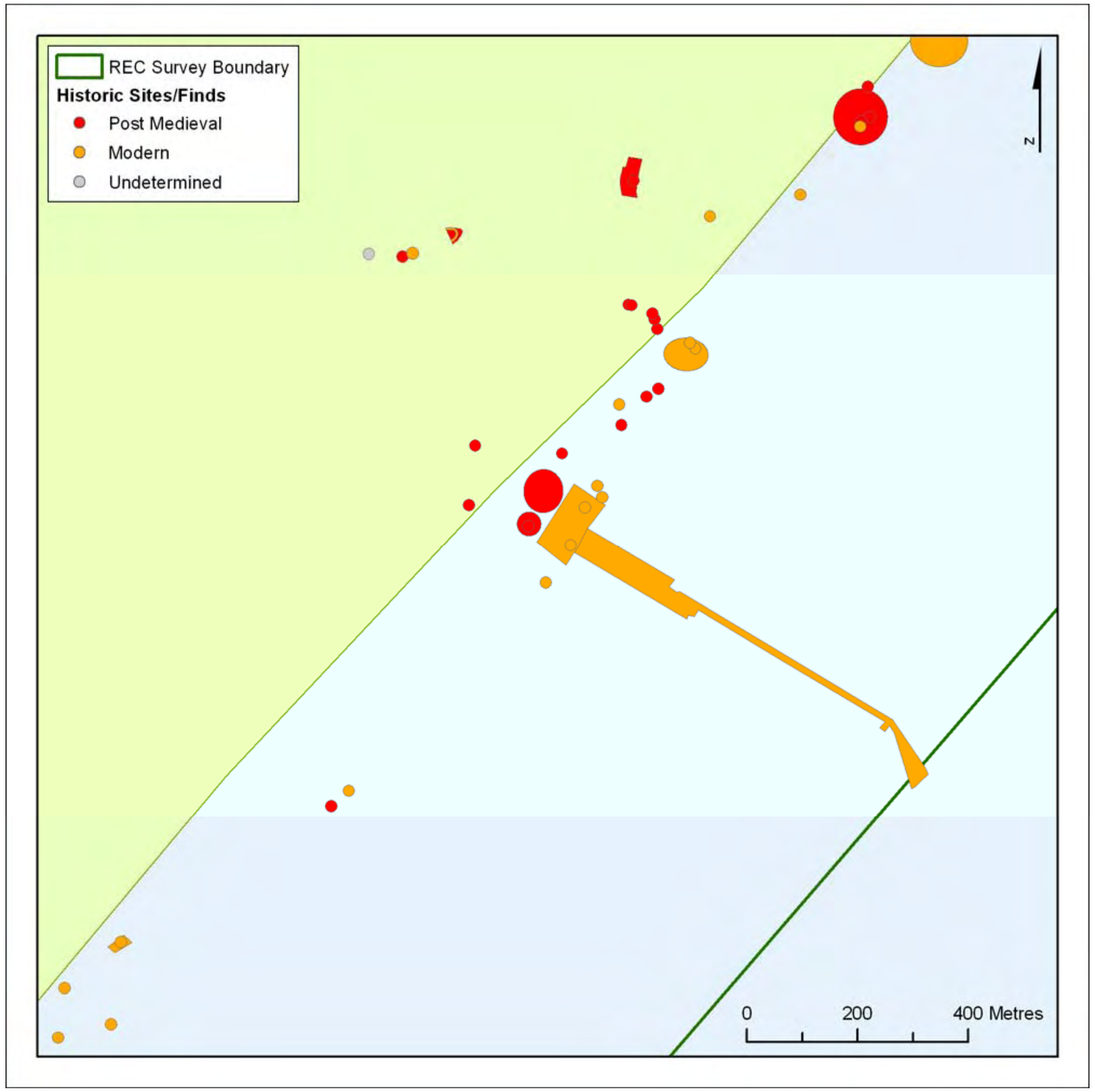

Figure 3.25: Map showing a close-up of Post Medieval, Modern and undetermined finds in the area around Walton-on-the-Naze.

Just as the economic and domestic sties can add to our understanding, the presence of a number of early medieval shore forts is of significance (some with roman pre-cursors) (e.g. Essex HER ID: Mex350 (Wilkinson & Murphy, 1995; Bradley *et al*., 1997). This demonstrates that people were not only living by the sea, using it is an economic resource both on foot and by boat, but were actively concerned about the threat it meant in terms of attackers from overseas or down the coast.

The medieval period was a time of great maritime expansion and exploration and it is of interest that three medieval wrecks emerged in the wider study area. The wreck record is considered in more detail below.

Post-Medieval and Modern Periods

Following the general trend, data density increases into the Post-Medieval and Modern periods. Table 3.11 and Table 3.12 indicate the number of finds from each period, whilst Table 3.13 documents the number of records returned for which a period is as yet undeterminable. Figure 3.24 graphically displays this superfluity of data and its strong coastal distribution.

During the post-medieval period the coastline along the Outer Thames Estuary REC boundary saw considerable investment in terms of maritime infrastructure, urban development and agricultural activity. Sea defences became more prominent (as seen at Essex HER ID: 1031526 at Beaumont-cum-Moze (near Walton)), new coastal forts began to be built (e.g. Languard Fort) along with a string of Martello towers. The completion of the Chelmer and Blackwater navigation helped to reshape maritime trade in East Anglia during the 18th century, and increased the volume of commercial traffic traversing the Outer Thames Estuary REC region. Thus, throughout the Post-Medieval period we see an intensification of the use of the coastal zone and, as will be seen in the section on wrecks below, the sea itself.

As in Essex, the Suffolk coastline holds an important modern archaeological record, in the form of settlements, sea defences, pleasure piers and military bases and defences. Both the First and Second World Wars have also left considerable marks on the landscape, in the form of military installations and naval bases (Brown *et al.*, 2008). These represent a nexus in maritime communication pathways which in turn increase the potential for wreck evidence, purely due to increased shipping activity. The large concentrartion of modern sites at Orford Ness in Figure 3.24 relates to military installations, which saw intense training and testing activity all the way through until the end of the cold war.

The majority of the 'modern' points shown along the coastal margin in Figure 3.24 above relate to beach defences (old minefields, anti-aircraft guns and pillboxes from the Second World War). This density of activity means that whilst material dating from this period is unlikely to be terrestrially deposited within the Outer Thames Estuary REC area, it does indicate how heavily used the maritime space along this shoreline would have been. This is reflected in the evidence from the UKHO and NMR data discussed below in relation to shipwrecks.

Post-Medieval Period Data from the Outer Thames Estuary REC Heritage Search Area			
	Suffolk HER	Essex HER	NMR
Point data	1,245	25	72
Polygon/Polyline	252	479	96

Table 3.11: Number of Post-Medieval finds and sites held in the databases searched.

Modern Period Data from the Outer Thames Estuary REC Heritage Search Area			
	Suffolk HER	Essex HER	NMR
Point data	547	2	1,223
Polygon/Polyline	152	1,008	2,914

Table 3.12: Number of Modern Period finds and sites held in the databases searched.

Unknown Period Data from the Outer Thames Estuary REC Heritage Search Area			
	Suffolk HER	Essex HER	NMR
Point data	786	104	714
Polygon/Polyline	687	1,711	42

Table 3.13: Number of Unknown Period finds and sites held in the databases searched.

Figure 3.25 shows a close up of the Essex coastline near Walton-on-the-Naze. Extending out into the sea (and 17m into the Outer Thames Estuary REC survey area) is Walton-on-the-Naze pier (Essex HER no. 3575). The pier constitutes part of the Frinton and Walton Conservation area and is considered of historic interest. Originally built in the 1830's the pier has undergone numerous modifications and now houses an amusement complex. This structure serves as a reminder to the fact that the heritage value of the Outer Thames Estuary REC area extends beyond what lies in or under the seabed, but also relates to a history of use and interaction. This incorporates past occupation, trade, travel, transport and also entertainment.

The Wreck Record

The only material culture concretely identified within the Outer Thames Estuary REC area relates to wrecks (both ship and aircraft). As noted previously, of the two HER resources, only Essex returned a single record within the Outer Thames Estuary REC survey boundary. All other data that fell within the survey area came from the UKHO and NMR. Table 3.14 details the large number of results that this search produced, whilst Figure 3.26 displays the distribution of these results.

Proximity analysis was carried out in order to ascertain redundancy between the NMR and UKHO data sets. The results of this analysis are available in Appendix B and confidently point to 401 of the NMR points directly relating to a UKHO counterpart. As such, the total number of records for Outer Thames Estuary REC survey area relating to wreck material falls from 2,239 to 1,838. Of the seven hundred and thirty-eight UKHO records, four hundred and seventy are classified as 'live' (All other wrecks, charted or uncharted: UKHO abbreviations) and two hundred and sixty 'dead' (Not detected by repeated surveys, therefore considered not to exist), while two are 'lift' (A salvaged wreck). However, the geophysical data acquired for the Outer Thames Estuary REC only covers the location of forty-eight of these wrecks (twenty-eight 'live' and twenty 'dead'), this represents 6.5% of the total recorded resource, and only 6% of the 'live' wrecks. Of the twenty-eight 'live' wrecks twenty-five have clear swath and/or side scan sonar signatures (such as the TerukuniMaru shown in Figure 3.27), with three live sites which have no identifiable signature associated with them (Appendix B).

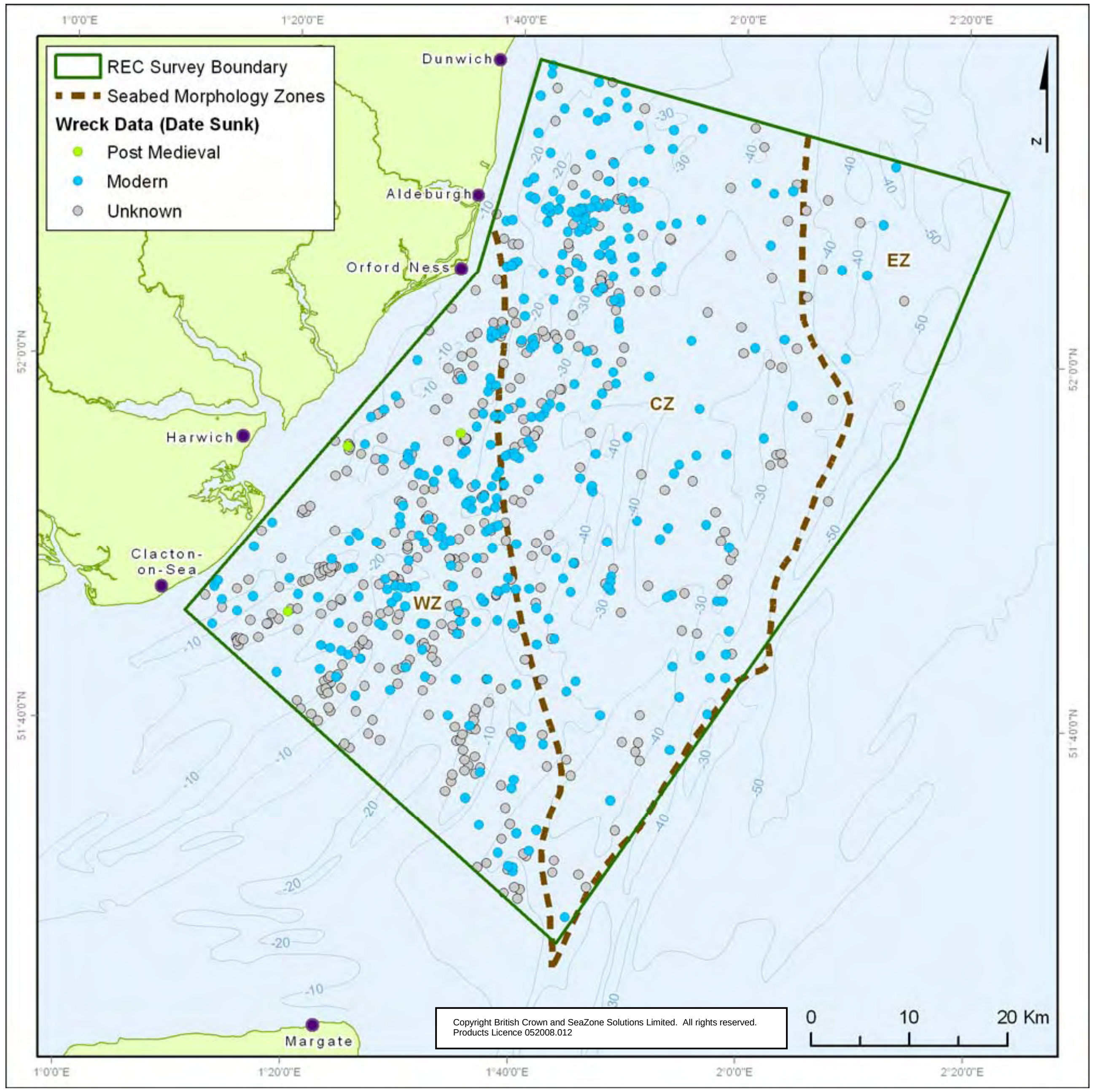

Figure 3.26: Chart detailing the distribution of wreck records in the Outer Thames Estuary.

Where data from the NMR corresponded with a UKHO record and survey data was available, surface expression of wreckage was visible. However, no examples were found within the Outer Thames Estuary REC data of clearly identifiable wreck material corresponding with isolated NMR points or polygons. In the case of the polygons this was often because the survey line clipped the edge of the designated area. However, this should not be taken to indicate that the NMR records do not represent potential wreck sites, only that the limited area surveyed for the Outer Thames Estuary REC did not find positive evidence for them. In addition, as a part of analysing the data for the Outer Thames Estuary REC document, seven sites have been identified that correspond with no known records (the locations of which are listed in Appendix B).

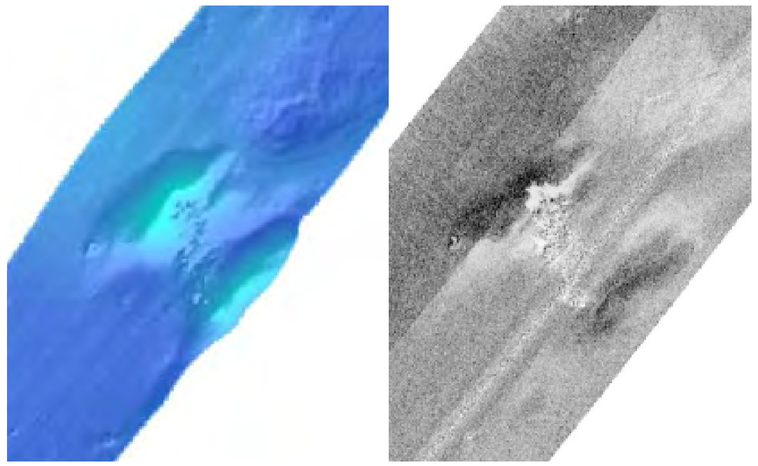

Figure 3.27: Swath bathymetry (left) and side scan sonar image (right) of the wreck of the TerkuniMaru. The wreck lies in a water depth of 14.5 m and exhibits strong symmetrical scour pits with a total length of 225 m and is aligned flow-parallel.

Period	UKHO point data	NMR Point Data	NMR Polygon Data	Essex HER	Suffolk HER
Medieval	-	-	3	-	-
Post medieval	-	-	53	-	-
Modern	332	194	975 (43 relate to aircraft)	-	-
Unknown	406	229	7	-	-
Total	778	423	1,038	no records	no records

Table 3.14: Table showing the number of records returned within the Outer Thames Estuary REC survey boundary from sources searched. Note Essex HER did return one record relating to a core sample (discussed above), but no shipwreck data for this area.

It is clear from Table 3.14 and Figure 3.26 and the data presented in Appendix B, that there is a high density of shipwrecks within the Outer Thames Estuary REC area. These potentially range in date from the 1320 wreck of La Trinite (NMR no. 1445730) to the 2005 wreck of Persistent Whisper (UKHO no. 66041). The 1,838 individual records range from small fishing vessels to Second World War submarines and destroyers. The data set also includes forty three different Second World War aircraft, found at nine different locations (shown in Figure 3.28). As such, it is not possible to account for each and every wreck within this document. However, this density of material represents a considerable heritage resource which needs to be engaged with in a considered manner. Unsurprisingly the intensity of wrecking activity increases towards the Thames Estuary and the shoreline.

3.5 Integrated Geological and Archaeological Chronology

The previous sections have discussed the Outer Thames Estuary REC geology and heritage characteristics. An overview of these findings, summarising the key processes contributing to the development of the Outer Thames Estuary seabed is presented in Table 3.15. The majority of the notable seabed elements were formed by processes occurring 500,000 to 700,000 years ago.

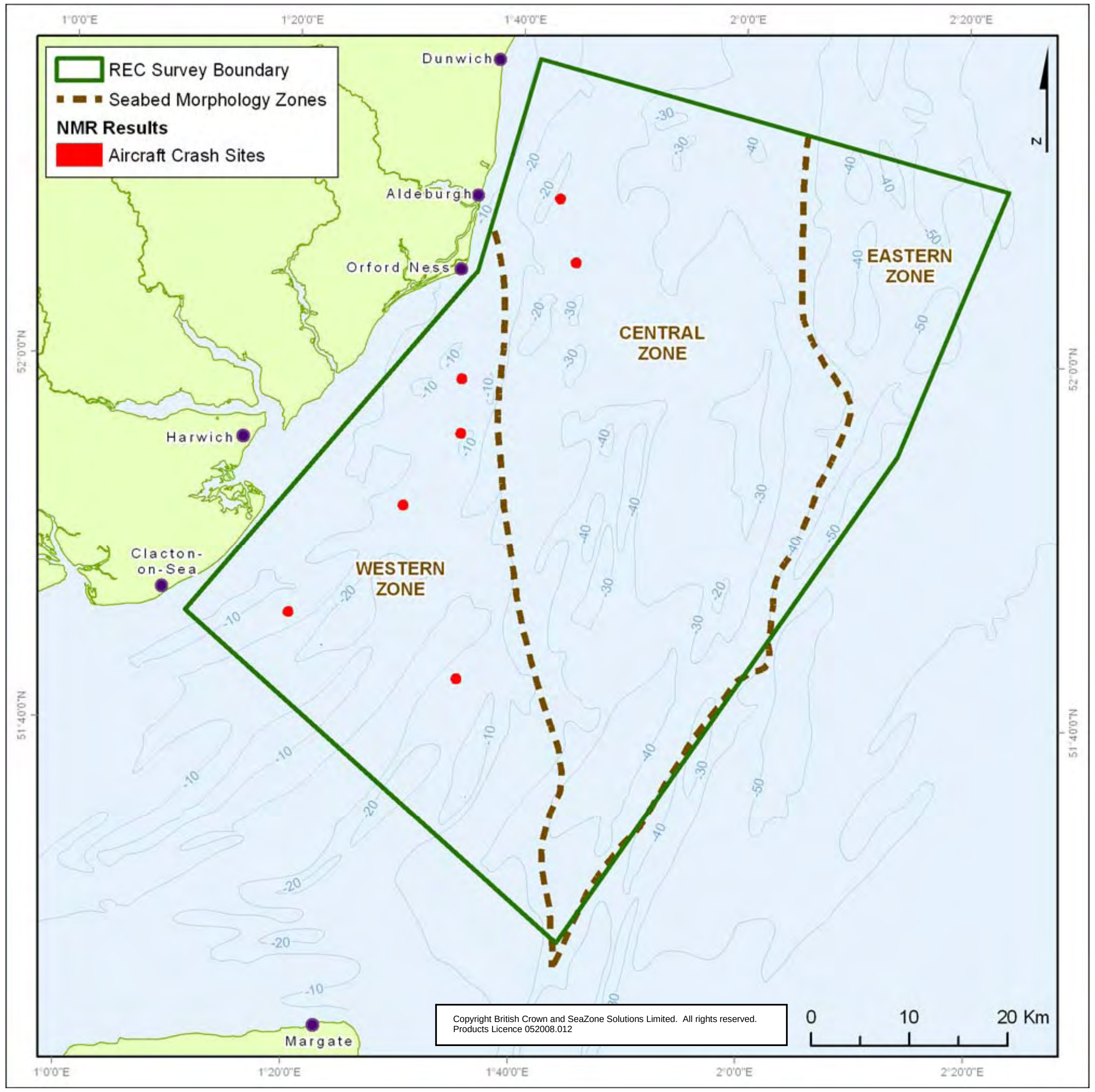

Figure 3.28: Map showing the location of aircraft crash sites recorded in the NMR.

Geochronology: Era	Geochronology: Period	Geochronology: Epoch	British Archaeological Record: Period	British Archaeological Record: Date	Outer Thames Estuary Regional Environmental Characterisation
Cenozoic **(65 mya to present)**	**Quaternary** (2.5 mya to present)	*Holocene* *(11.7 kya – present)*	Modern	AD 1750 – Present	The characterisation is one of an intense zone of civilian and military use, for which there is associated evidence within the designated area. This is takes the form of the Walton-on-the-naze pier, which extends into the Outer Thames Estuary REC survey area, as well as numerous wrecks (both ship and aircraft). Given the intensity of activity evidenced in this region, there is still the possibility of locating more material through additional survey.
			Post-Medieval	AD 1540 – 1750	The characterisation is one of a zone of intense civilian and military use, for which there is a possibility of finding associated evidence within the designated area. This is most likely to take the form of wreck material, many of which have already been documented.
			Medieval	AD 410 – 1540	The characterisation is one of a zone of use, for which there is a possibility of finding associated evidence within the designated area. This might take the form of inter-tidal structures at the shallowest extents of the survey area, but is more likely linked to wreck material. The smaller number of wrecks documented for this period in the sections above is considered a 'base line', with the possibility of more being found in later surveys.
			Roman	AD 43 – 410	The characterisation is one of a zone of use, for which there is a possibility of finding associated evidence within the designated area. This might take the form of inter-tidal structures at the shallowest extents of the survey area, or wreck material. The presence of the Roman port of Felixstowe adds weight to this possibility.
			Iron Age	800 BC – AD 43	The characterisation is one of a zone of use, for which there is a possibility of finding associated evidence within the designated area. This might take the form of inter-tidal structures at the shallowest extents of the survey area, or wreck material.
			Bronze Age	2,200 – 800 BC	As above, sea-levels had risen to a point approaching their current elevation. However, there is extensive evidence for Bronze Age coastal activity. The characterisation is thus one of a zone of use, for which there is small possibility of finding associated evidence within the designated area.
			Neolithic	4,000 – 2,200 BC	By the Neolithic, post glacial sea-level rise will have led to a coastal configuration more closely resembling the present. As such, the shallower western extent of the Outer Thames Estuary REC area is characterised as of some potential for submerged terrestrially deposited archaeology.
			Mesolithic	10,000 – 4000 BC	Geologically, the Holocene record is dominated by the marine transgression that followed the end of the Devensian/Wechselian glacial maximum. Archaeologically, the area is characterised as a palaeo-landscape of high potential for Mesolithic studies, both in terms of palaeoenvironmental and material cultural evidence.
		Pleistocene *(2.5 mya – 11.7 kya)*	Upper Palaeolithic	40,000 – 10,000 BC	Archaeologically, the area is characterised as a palaeo-landscape of high potential for Palaeolithic studies, both in terms of palaeoenvironmental and material cultural evidence. The lack of disturbance visible within deposits within the survey data indicates an environment conducive to preservation of both environmental and material culture data.
			Lower Palaeolithic	c. 700,000 – 40,000 BC	The geological record is characterised here through the presence of the enclosed deeps and palaeo channel systems. These provide an important framework for dating palaeo-landscapes. Identified in section 3.3.3 are fluvial landscapes of c. 720,000 BP, cut by enclosed deeps from the Anglian glaciation (c. 480,000 BP). This indicates great archaeological potential, with the earliest site of Hominin activity found to the north of the survey area at Pakefield (700,000 BP), and the import lower Palaeolithic site of Clacton (c. 400,000 BP) at its south western extent. Such exposures of submerged palaeo-landscapes are rare. The south of the Outer Thames Estuary REC is dominated by thick infilled river channels that would have been incised at the lowstands of the Elsterian/Anglian and subsequent glaciations. The fill sequences represent transitional fluvial-marine environments during subsequent transgressive events.
	Neogene **(23 – 2.5 mya)**	*Pliocene* *(5.3 – 2.5 mya)*	Currently, there is no direct evidence for Hominin activity in the British Isles prior to 700,000 BP		The Neogene deposits are confined to the north of the area and are represented by mid-Pliocene and Plio-Pleistocene bioclastic carbonate sands and silty sands. These were deposited in a shallow marine, high-energy environment, probably within an embayment of the southern North Sea Basin. Miocene deposits are absent from the Outer Thames Estuary REC study area.
		Miocene *(23 – 5.3 mya)*			
	Palaeogene **(65 – 23 mya)**	*Oligocene* *(33 – 2 3mya)*			Early Eocene deposits consist of glauconitic sands and silts deposited in the shallow sub-littoral environment on the southern margin of the North Sea Basin. At times they are locally lithified to form resistant sandstone bands. These deposits have been known to contain abundant shell fragments, and occasional pyroclastic ash layers. Within the area surveyed these silt/clay deposits display polygonal faulting.
		Eocene *(55.8 – 33 mya)*			
		Palaeocene *(65 – 55.8 mya)*			The sequence of Cenozoic sediments unconformably overlies the Upper Cretaceous Chalk within the study area. The sediments of this basin are dominated by the interplay of marginal marine sedimentation and fully marine deposition, in response to several phases or transgression and regression.
Mesozoic **(251 – 65 mya)**	**Cretaceous** **(145 to 65 mya)**	*Upper* *(100 – 65 mya)*			The Upper Cretaceous Chalk (c. 100 – 65 Mya) forms a minor component of the seabed solid geology in the area but underlies Cenozoic sediments across the region. Where the chalk forms the seabed it is either overlain by sand waves or thin layers of coarse lag sediments.
		Lower *(145– 100 mya)*			

Table 3.15: Outer Thames Estuary REC geology and heritage characteristics, summarised in chronological order of occurrence.

4. Ecological Characterisation

4.1 Benthic Macrofauna

The term 'benthos', meaning depth, is commonly used to refer to the aquatic environment on the seabed. Benthic macrofauna are the mobile and sedentary animals which live in close association with the seabed either as active burrowers and swimmers or as sedentary tube dwellers or encrusting colonial forms. They are usually divided into two groups; infauna, animals that live within the sediment e.g. burrowing and tube-dwelling worms, bivalve molluscs and amphipod crustaceans; and epifauna, animals which live on the seafloor surface on other organisms and objects e.g. sedentary sponges, hydroids and bryozoans, barnacles motile crabs, shrimps and bottom-dwelling fish. For the purposes of the Outer Thames Estuary regional characterisation, the macrofauna are further defined as those animals that are >1 mm in size.

There has been a long history of study of benthic macrofauna in the north-west of Europe and Mediterranean regions and their responses to the physical and chemical environmental influences at the community and species level are well understood. As a result, benthic macrofauna are used as indicators of environmental condition and commonly studied as part of site characterisation investigations, impact assessments and for monitoring purposes. Their predictable responses to a range of physical and chemical factors makes them useful in forecasting of potential consequences of anthropogenic activities on the environment including effects on higher trophic levels, such as fish, which utilise the macrobenthos as food.

In this study a number of different field techniques have been used to sample both the infauna and the epifauna in the Outer Thames Estuary. These include 0.1 m^2 mini-Hamon grab sampling, 2 m beam trawling and seabed photography. The sample sites were chosen to correlate with the seismic survey lines so that biological communities can be correlated with seabed habitat types. Figure 4.1 shows the sampling locations.

The field collection and laboratory analyses of the grab and trawl samples together with the acquisition of image data were completed under a separate contract. The survey methods, treatment and analysis of samples and collection of image data are reported in Gardline Lankelma (2008, Appendix A). The following sections describe the character of the data collected using the different types of sampling gear.

4.1.1 Hamon Grab Data

The Hamon grab (Figure 4.2) provides quantitative information on macrofaunal assemblages and sediment composition. This includes information on infaunal taxa living within the substrate and sessile colonial animals living at the seabed surface along with cryptic and motile surface fauna. A sub-sample from each grab was taken for subsequent particle size analyses. Sediment composition influences the structuring of the benthic communities and therefore is an important tool for interpretation of the ecology of the benthic environment.

The vast majority of macrofauna exist within the uppermost 30 cm of the seabed surface where oxygen is present at sufficient levels to allow for respiration. In finer grained sediments, the oxygenated upper layer may be considerably less thick than this. Below the oxygenated layer, macrofauna would need to maintain some contact with the overlying waters to ensure a sufficient supply of oxygen either through an open 'U'-shaped burrow, as in the common lug worm *Arenicola marina*, or via siphons, as in the cockle *Ceratoderma edule* or the sand gaper *Mya arenarius*. Because of the close relationship with the sediment / water interface, biological grab samplers only tend to penetrate the seabed to around 30 cm.

The grab sample dataset for the Outer Thames Estuary REC comprises macrofaunal species abundance data (animals retained on a 1 mm aperture mesh) from 70 individual sample sites (Figure 4.1) as well as raw wet weight (biomass) data for each phylum.

Prior to statistical analyses, the faunal dataset was rationalised by removing species from faunal groups for which quantitative sampling by grab techniques and subsequent processing via a 1mm aperture mesh is not appropriate, such as nematodes which are not considered as part of the macrofaunal community i.e. groups that are retained on a 1 mm mesh. Further rationalisation was undertaken by aggregating entries denoting the few juvenile specimens and indeterminate species to the next higher taxonomic level. Sessile organisms such as sponges, bryozoans and hydroids are colonies made up of many individuals which perform various functions. Therefore enumeration is impractical. These types of animals were therefore not counted but were instead given a 'P' present value.

Standard corrections were applied to the biomass data to provide equivalent Ash-Free Dry Weight (AFDW) biomass data following the approach laid out by Eleftheriou & Basford (1989). The conversion factors applied are given below. Porifera (sponges) and bryozoa (sea mats) were submitted to the biomass analysis the results of which were incorporated within the "Miscellaneous" group (Gardline Lankelma, 2008).

- Polychaeta : 15%
- Crustacea : 22.5%
- Echinodermata : 8.0%
- Mollusca : 8.5%
- Miscellaneous : 15.5%.

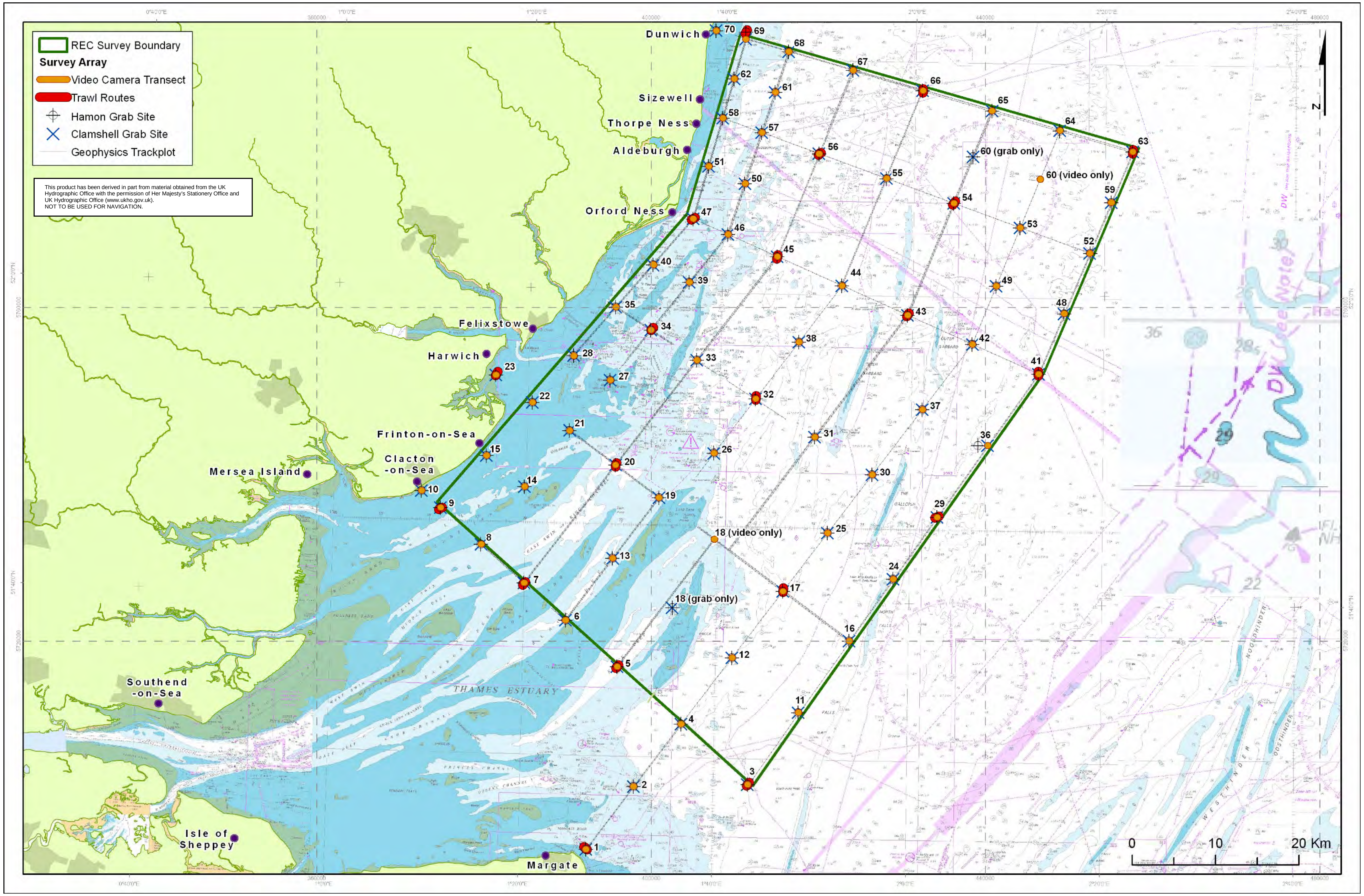

Figure 4.1: The Outer Thames Estuary REC survey array.

4.1.2 2 m Beam Trawl Data

Trawling with a small scientific 2 m beam trawl (Figure 4.3) collects qualitative or semi-quantitative information on larger, more mobile epibenthic animals which live in close association with the seabed, such as shrimps, crabs and flatfish and which are not adequately sampled by grab techniques. Because they sample comparatively large areas of seabed, trawls are able to identify species and features that may occur infrequently, thus enhancing the more discrete grab data.

On the seabed, any animal and other material entering the mouth of the trawl is funnelled to the cod end at the rear of the trawl. This comprises a fine mesh bag in which the trawled material is collected. The mesh aperture of the cod end is usually around 5 mm in size so that very small animals and sediment particles can pass through the net leaving the larger target macrobenthic fauna.

The beam trawls used in macrobenthic surveys are intended to skim just above the surface of the seabed so that little, if any, sediment material is caught. Nevertheless, some sediment material, such as pebbles and cobbles and particularly any lighter shell material can be retained in the cod end. Captures of these larger sediment particles can provide useful information on the distribution of attaching and encrusting colonial sessile organisms.

Figure 4.2: Deployment of a typical 0.1 m^2 mini-Hamon grab.

These data supplement the grab data as well as offer some additional insight into the seabed habitat types associated with the epibenthic assemblages.

The 2 m beam trawl data set from the Outer Thames Estuary REC comprised both abundance and wet weight (biomass) data from a total of 20 tow locations (Figure 4.1). Again, colonial sessile animals were given a ‘P’ present value.

4.1.3 Seabed Images

Seabed photography provides useful information on the low scale heterogeneity of seabed types and epifaunal benthic communities which may not be immediately apparent in single grab datasets. It is particularly useful for the assessment of habitats and associated communities in coarser sediment habitats and over hard ground where grab sampling may be unsuitable.

4.1.4 Data Analysis

The rationalised biological and physical data were imported into PRIMER 6.0 (Clarke & Warwick, 2001) and subjected to transformation. In the case of the current faunal data, a 4th Root (or Root-Root) transformation was applied. This transformation down-weights the influence of the dominant species, taking a much greater account of the lower abundance species, and allowing the underlying community structure to be assessed.

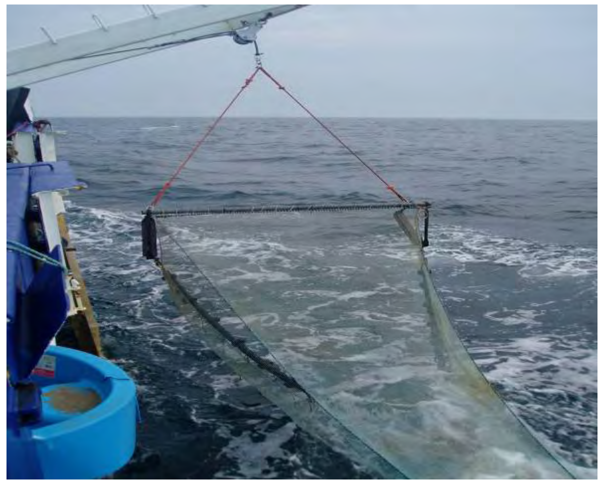

Figure 4.3: A typical 2 m scientific beam trawl.

The transformed data were then subjected to hierarchical clustering during which the relative similarities between every pair of samples were calculated. Macrofaunal data were compared using the Bray-Curtis similarity measure, whilst physical data were compared using the Euclidean distance measure of similarity. The calculated pair-wise similarities were then used to group the faunal and sediment samples based on the group averages and to construct a sample dendrogram and MDS and PCA sample ordination plots.

The cluster analysis was combined with a permutation test (SIMPROF) to identify the presence of significant clusters within the dataset. In all cases a 5% similarity level was used to define the clusters. This was because this level not only generated a convenient number of sample groupings for community assessment but also that the groupings themselves matched the Marine Habitat Classification at a sufficiently high level of detail to allow biotope description of both habitat and associated species.

The similarity percentages routine (SIMPER) was used to identify those species that were most responsible for both the “within” sample cluster similarity and for the “between” sample cluster dissimilarity.

The significance of any relationships between the sediment and faunal datasets was investigated using the RELATE procedure. BIOENV was then employed to reveal those environmental variables which best matched the observed clustering of faunal samples (Clarke & Warwick, 2001).

A range of univariate measures were also calculated for each sample. These included Margalef’s index of Richness (*d*), Pielou’s Evenness index (*j*), the Shannon-Wiener Diversity index (*H*) and Simpson’s index of Dominance. (λ). Such univariate indices are useful in reducing large macrofaunal data sets to a single figure that may be used to compare community structure. All four analyses are calculated within the PRIMER suite (version 6.0) and are based on the following:

Margalef's Index of Richness (d)	
$$d = \frac{(s-1)}{\ln(N)}$$	S = The number of species in the sample. N = The total number of individuals in the sample.

Pielou's Evenness Index (j)	
$$j = \frac{H_s}{H_{max}}$$	H_s = The Shannon-Wiener Diversity Index. H_{max} = The theoretical maximum value for H_s if all species in the sample were equally abundant.

Simpson's Dominance Index (λ)	
$$\lambda = \sum_{i=1}^{s} \left(\frac{n_i}{N} \right)^2$$	s = Total number of species. n_i = Number of individuals in the 'ith' species. N = Total number of individuals.

Shannon-Wiener Diversity Index, (H_s)	
$$H_s = \sum_i p_i \log(p_i)$$	p_i = proportion of the total count arising from the ith species.

Growth Form			Size of Individuals/Colonies				Density
% Cover	Crust /Meadow	Massive /Turf	<1cm	1-3cm	3-15cm	>15cm	
>80%	S		S				>1/0.001m^2
40-79%	A	S	A	S			1-9/0.001m^2
20-39%	C	A	C	A	S		1-9/0.01 m^2
10-19%	F	C	F	C	A	S	1-9/0.1 m^2
5-9%	O	F	O	F	C	A	1-9/ m^2
1-5%	R	O	R	O	F	C	1-9/10 m^2
<1%		R		R	O	F	1-9/100 m^2
					R	O	1-9/1,000 m^2
						R	<1/1,000 m^2

Table 4.1: Abundance Scales used for both littoral and sublittoral taxa from 1990 onwards (Hiscock, 1996).

Key: S = Superabundant, A = Abundant, C = Common, F = Frequent, O = Occasional, R = Rare, P = present (used when the abundance of an organism could not be estimated accurately).

Margalef's richness index is simply an expression of the number of species within a sample but which is roughly normalised across the number of species to mitigate, in some part, for sample size. Pielou's eveness and Simpson's dominance are essentially the reciprocal of each other and express how evenly the individuals are distributed among the different species. For example, a low eveness value means that one or a few species are represented by a comparatively high number of individuals so that dominance is high. In turn, the lack of any numerically dominant species within a sample is reflected by a low dominance value but high eveness. The Shannon Weiner index of diversity takes account of both of the values for eveness and richness.

Static digital stills images were analysed to acquire further information on epibenthic communities and surface substrate habitat conditions. The species identified from the images were given a semi-quantitative abundance score based on the SACFOR (Super-abundant, Abundant, Common, Frequent, Occasional and Rare) scale (Hiscock, 1996) (Table 4.1). Sediments were described in terms of estimates of the percentages of silt, sand, gravel, cobbles and boulders present.

Semi-quantitative species abundance data were then given a numerical equivalent based on a 1 – 6 scale (1= rare, 6 = superabundant). These values were then input into the multivariate analyses to assist the description of epibenthic community structuring within the Outer Thames Estuary REC study area.

4.2 Analysis of the Macrofauna from the Hamon Grab Samples

Following rationalisation of the faunal grab data, the total species count for the Outer Thames Estuary REC area was 316 represented by 14 phyla and other major taxonomic groupings. The distribution of the numbers of taxa amongst the different phyla and major taxonomic groups are presented in Table 4.2.

A list of enumerated species for each grab sample and data relating to the biomass of each macrofaunal phylum obtained from the grab samples are presented in Appendix C.

Taxonomic Group	Number of Species
Enumarated fauna	
NEMERTEA (Ribbon worms)	1
SIPUNCULA (Peanut worms)	3
ANNELIDA (Polychaeta and Oligochaeta) (Worms)	113
CHELICERATA (Sea spiders)	10
ECHINODERMATA (Sea urchins, brittle stars, starfish)	12
PHORONIDA (Horseshoe worm)	1
HEMICHORDATA *(Amphioxus)*	1
CRUSTACEA (Amphipods, crabs, barnacles)	99
MOLLUSCA (Bivalves, chitons, gastropods)	35
PISCES (Fish)	1
Total number of infaunal species	276
Non-enumerated fauna	
PORIFERA (Sponges)	2
CNIDARIA (Sea firs, sea anemones and jellyfish)	21
BRYOZOA (Sea mats)	9
TUNICATA (Sea squirt)	8
Total number of epifaunal species	40
Total	**316**

Table 4.2: Numbers of species within each major taxonomic group derived from the Outer Thames Estuary REC Hamon grab sampling survey.

The overall tally of 316 taxa compares with 187 taxa previously recorded from a similar sized survey completed for Natural England in the Outer Thames Estuary (Emu Ltd., 2006), 198 taxa in a comparable number of grabs collected at a proposed aggregate site offshore of Harwich (Unicomarine, 1995) and 371 taxa at the London Array proposed offshore wind farm grab survey in the Outer Thames Estuary. The greater number of taxa found within the Outer Thames Estuary REC is likely to be a function of the widely dispersed nature of the current survey array and the variety of sediment habitats encountered compared to the other studies. In contrast, the Natural England study was focused on sandbank habitats within the Outer Thames Estuary and therefore fewer habitat types were encountered. Sediments associated with sandbank areas are typically impoverished as a result of the natural adverse effects of substrate mobility and reduced habitat complexity. A lower species count would therefore be expected compared to the current Outer Thames Estuary REC study.

The Harwich survey also recorded a lower species variety but this may be attributed to the more spatially restricted survey array which was focused around the application aggregate area, so that again, comparatively fewer habitat types were sampled. The higher species tally at the proposed London Array is most likely a result of a greater number of grab samples collected at the proposed wind farm site. There may also be differences in the level of taxonomic discrimination applied.

In common with many benthic ecological studies of North-western European sediment habitats, including those undertaken at the wider bio-geographic level of the southern North Sea, annelids were found to dominate the macrofauna within the current Outer Thames Estuary REC survey area. This phylum alone contributed to 36% of the total species variety and 40% of the countable fauna.

Annelids were also the most important contributors to the overall biomass. Figure 4.1 presents the relative contributions of the major phyla to the overall species diversity, abundance and biomass.

Crustaceans (mainly amphipods) were also well represented within the study area contributing to 31% of the species variety and 33% of the total numbers of individuals of countable fauna. The comparatively low crustacean biomass (12%) is indicative of the small body size of the individuals sampled by the grab.

Molluscs, on the other hand, contributed 20% of the total biomass despite only comprising 10% of the species diversity and 8% of the overall abundance. Epifauna were comparatively less well represented within the Outer Thames Estuary REC grab samples and only contributed to 13% of the total species diversity within the "Miscellaneous" group. Echinoderms were similarly poorly represented in the grab samples and only accounted for 4% of the species variety and 7% of the total abundance.

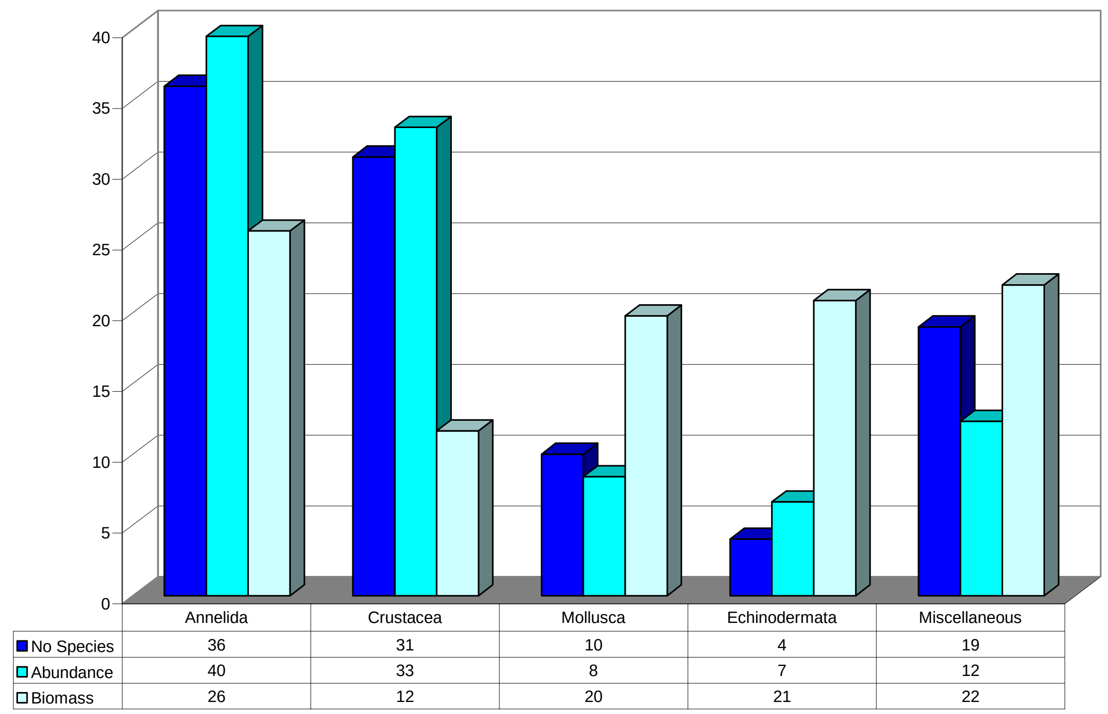

Figure 4.4: Relative contributions of the major phyla to the total species diversity, abundance and biomass.

These observations broadly agree with those drawn from other benthic ecology surveys in the Outer Thames Estuary region. Emu Ltd. (2006) and Unicomarine (1995) for example, both found the macrofauna to be dominated by the Phylum Annelida which comprised 40% and 43% of the overall macrofaunal diversity recorded respectively. The site specific benthic ecology survey supporting the London Array offshore wind farm application similarly recorded a dominant Annelida component within the grab samples and which accounted for 39% of the total species variety and 63% of the overall macrofaunal abundance. Annelida were also noted to be the largest contributors (75%) to the total abundance of macrofauna at an aggregate site offshore of Harwich (Unicomarine, 1995).

Figure 4.5, Figure 4.6 and Figure 4.7 show the distributions of the numbers of species, numbers of individuals and biomass respectively. These figures show that whilst there is considerable variation in these biological measures between sample sites, there is nonetheless a high degree of correspondence between the variables themselves. High species numbers, for example, correspond to high numbers of individuals and biomass whilst low abundance and biomass occur where there is low species diversity. The distributions of richness, evenness, diversity and dominance values (Figure 4.8, Figure 4.9, Figure 4.10 and Figure 4.11) also show comparable spatial patterns and clearly reflect the inter-dependency between biological univariate measures.

Overlay of these values onto the morphological interpretation allows for some visual assessment of potential relationships with sediment habitat types. Richness and diversity measures are particularly reduced in areas dominated by sand sediments including those areas corresponding to the major sandbanks units to the south and the deeper water sandy bedforms located to the north and east.

The numbers of species associated with seabed types ranged from as low as three species per 0.1 m^2 to around 20 species / 0.1 m^2 whilst the densities of macrofauna typically measured less than 25 individuals per 0.1 m^2. Biomass values at these sandy locations were consistently low across the region (<0.2 grams AFDW / 0.1 m^2).

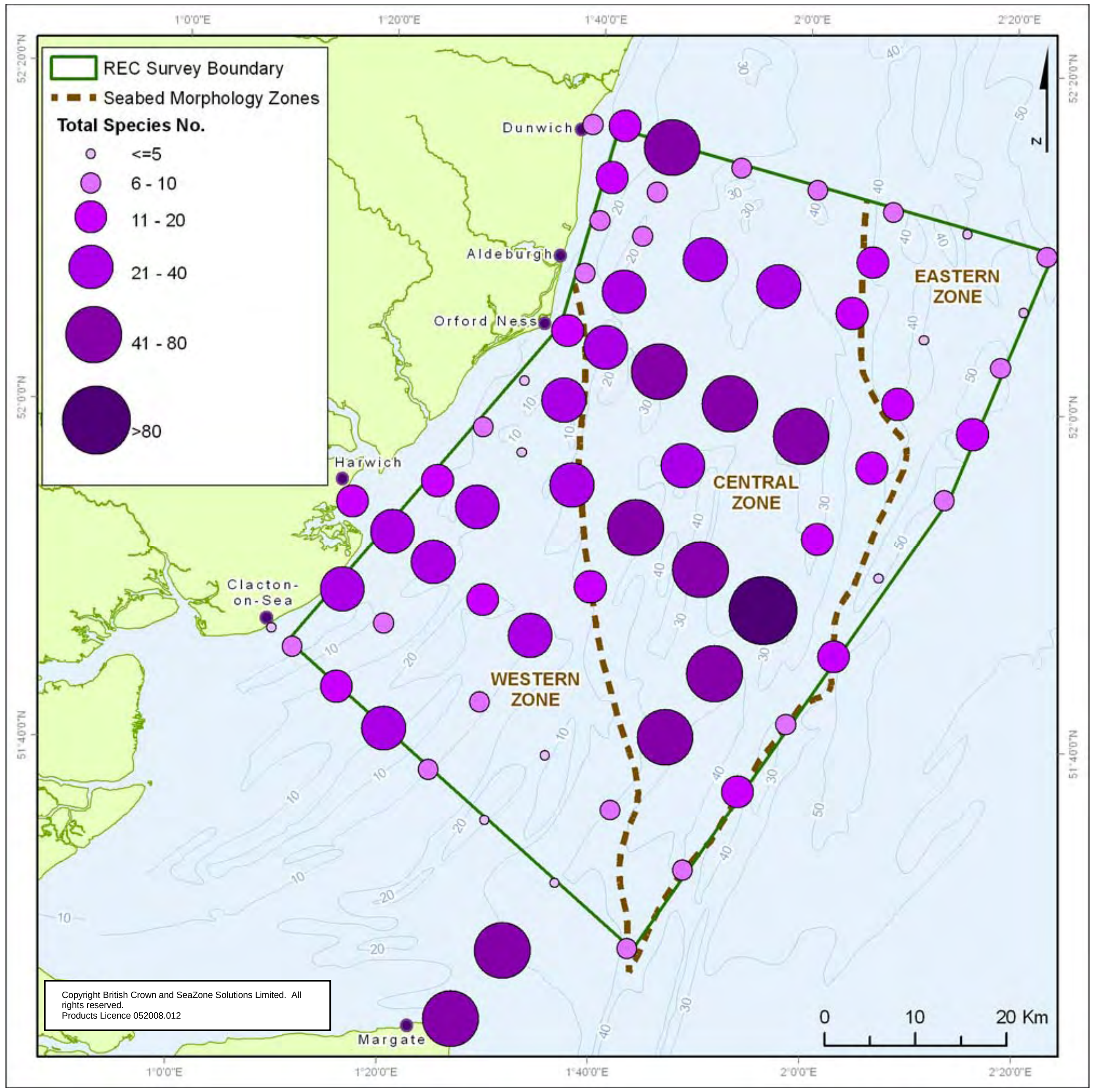

Figure 4.5: Total number of species within the Outer Thames Estuary REC area, calculated from the grab samples.

Greater species variety, abundance and associated richness and diversity measures are found in areas away from the main sand banks and sand bedform features. These include areas within the centre of the array corresponding to the mixed muds and sand and gravel sediments. Here, species numbers reached a maximum of 85 species per 0.1 m^2. Greater species richness and diversity are often associated with increasing sediment variability as a result of the greater availability of niche habitats. This allows a variety of macrofauna to coexist so that mixed sediment types typically have greater species carrying capacities than simpler sediment such as the sand substrates associated with the sandbanks and deeper water bedforms.

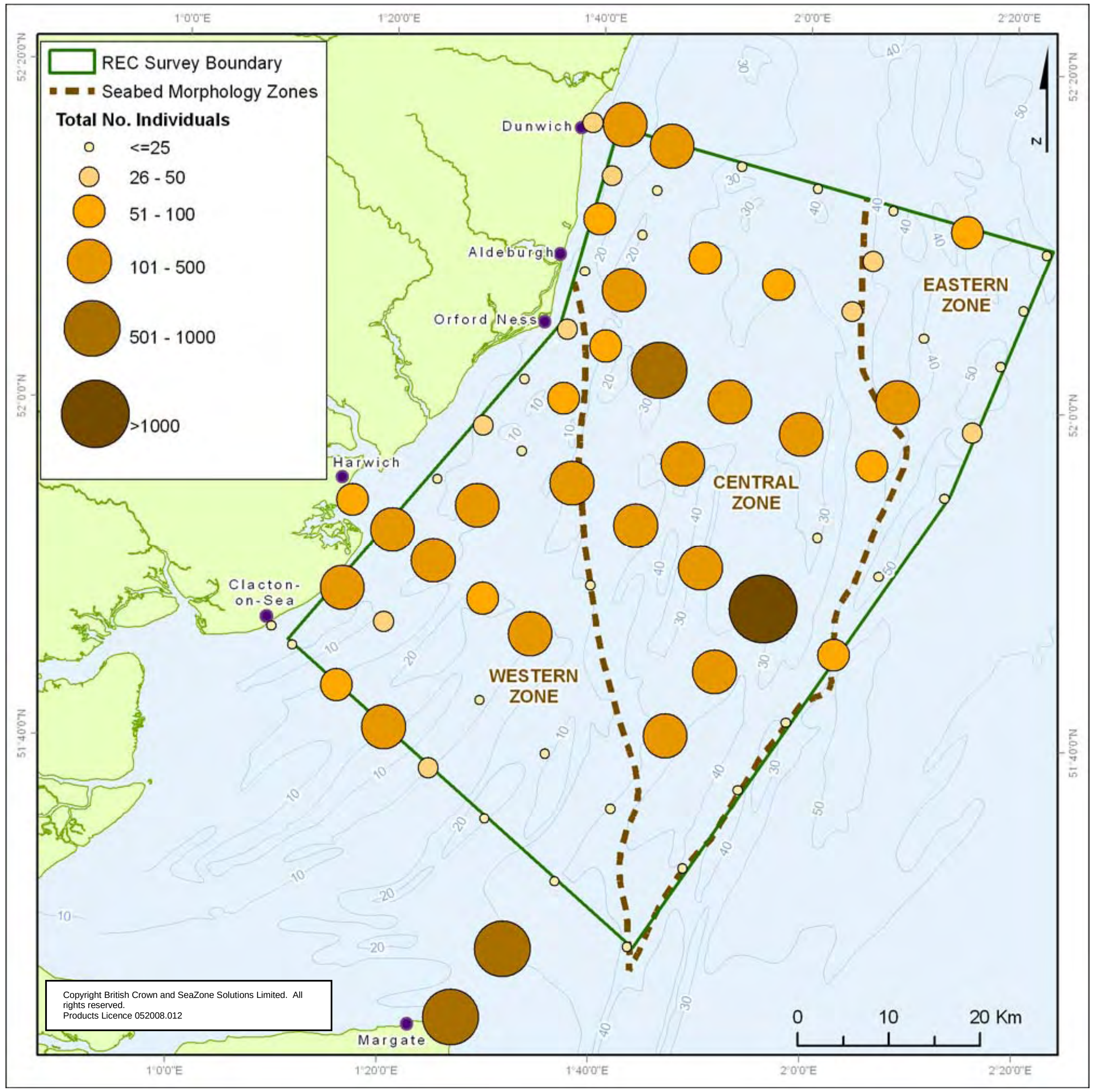

Figure 4.6: Total number of individuals within the Outer Thames Estuary REC area, calculated from the grab samples.

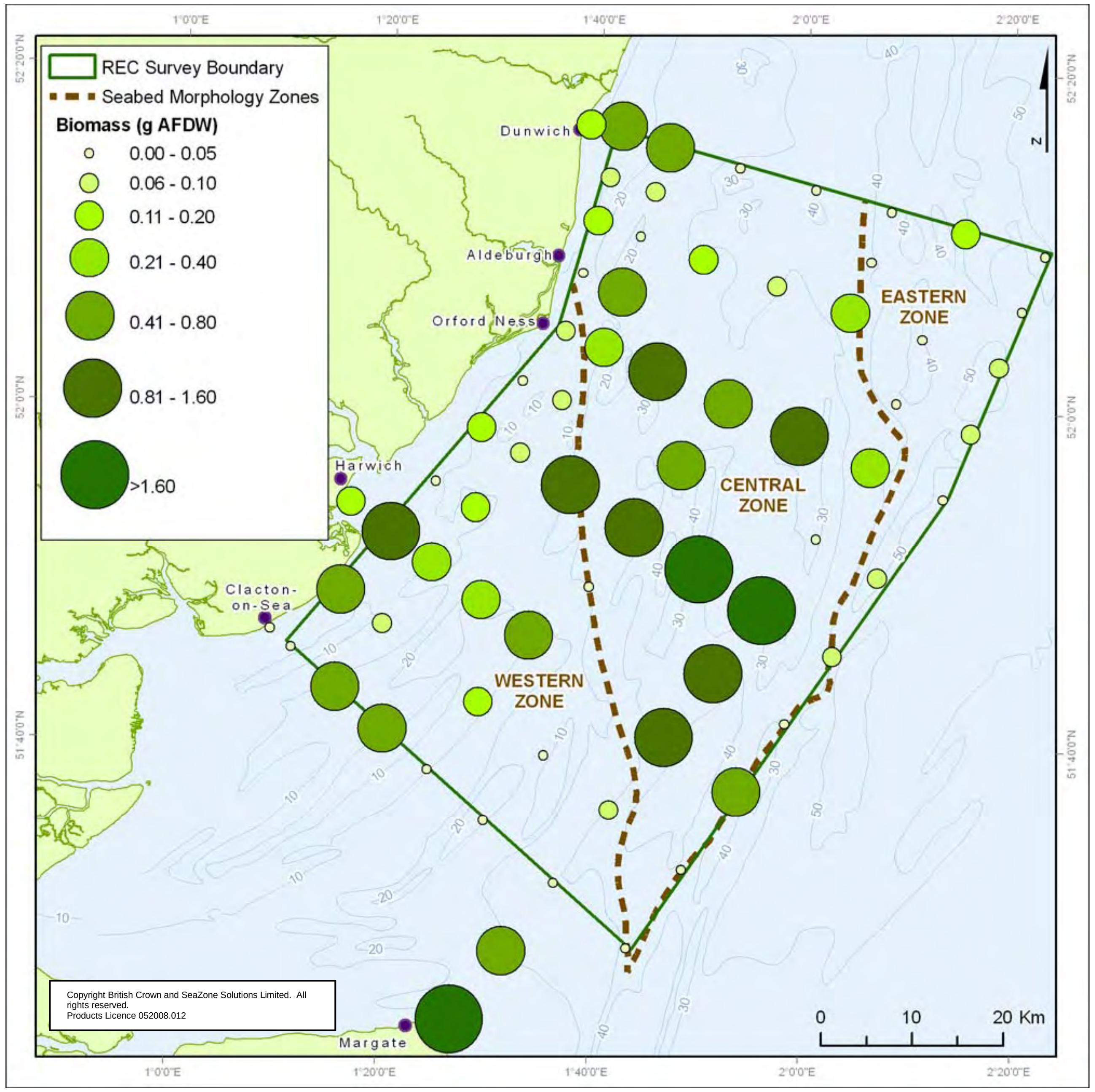

Figure 4.7: Total biomass (grams Ash-Free Dry Weight) within the Outer Thames Estuary REC area, calculated from the grab samples.

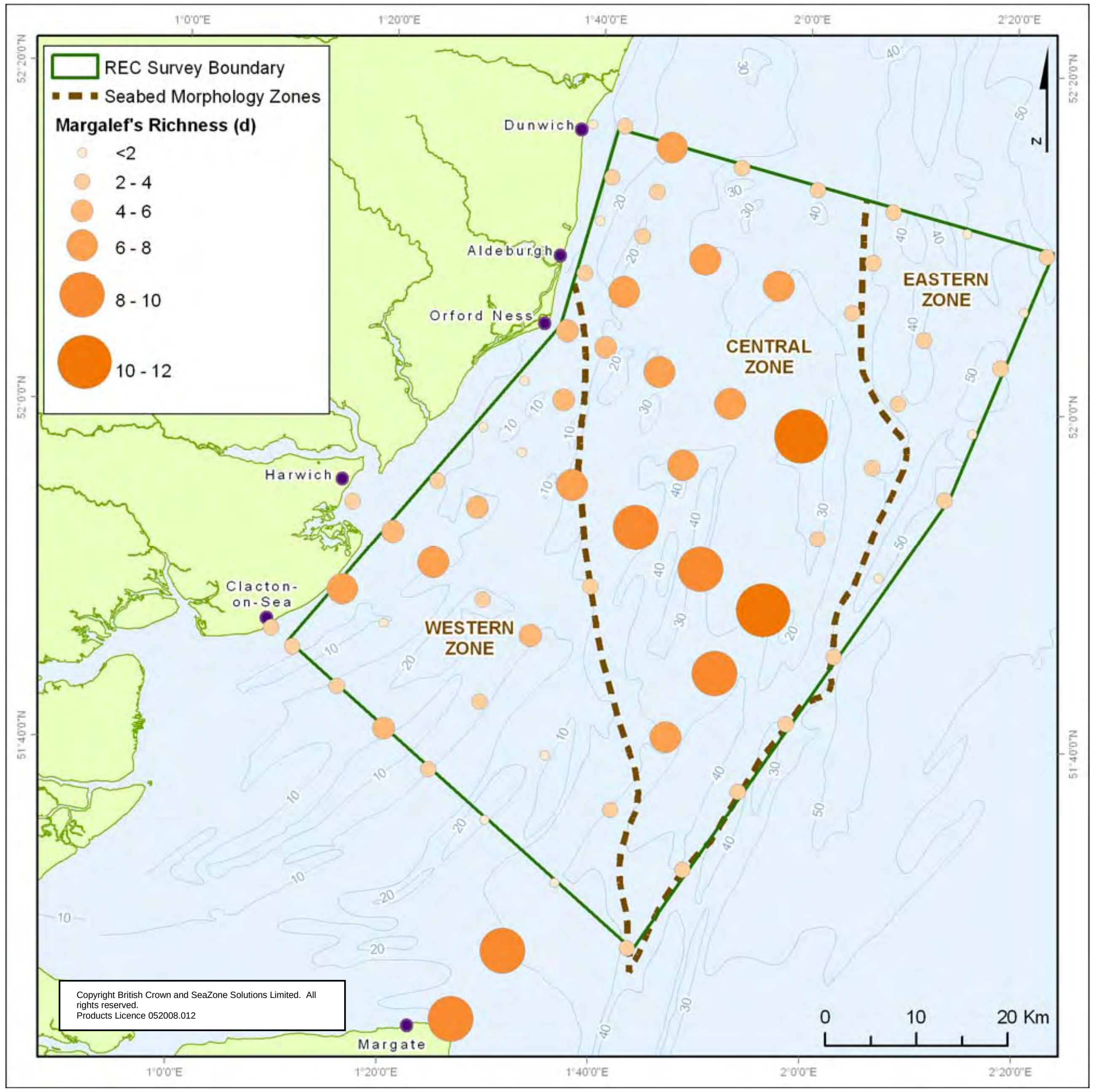

Figure 4.8: Margalef''s Richness values calculated from the Outer Thames Estuary REC grab samples.

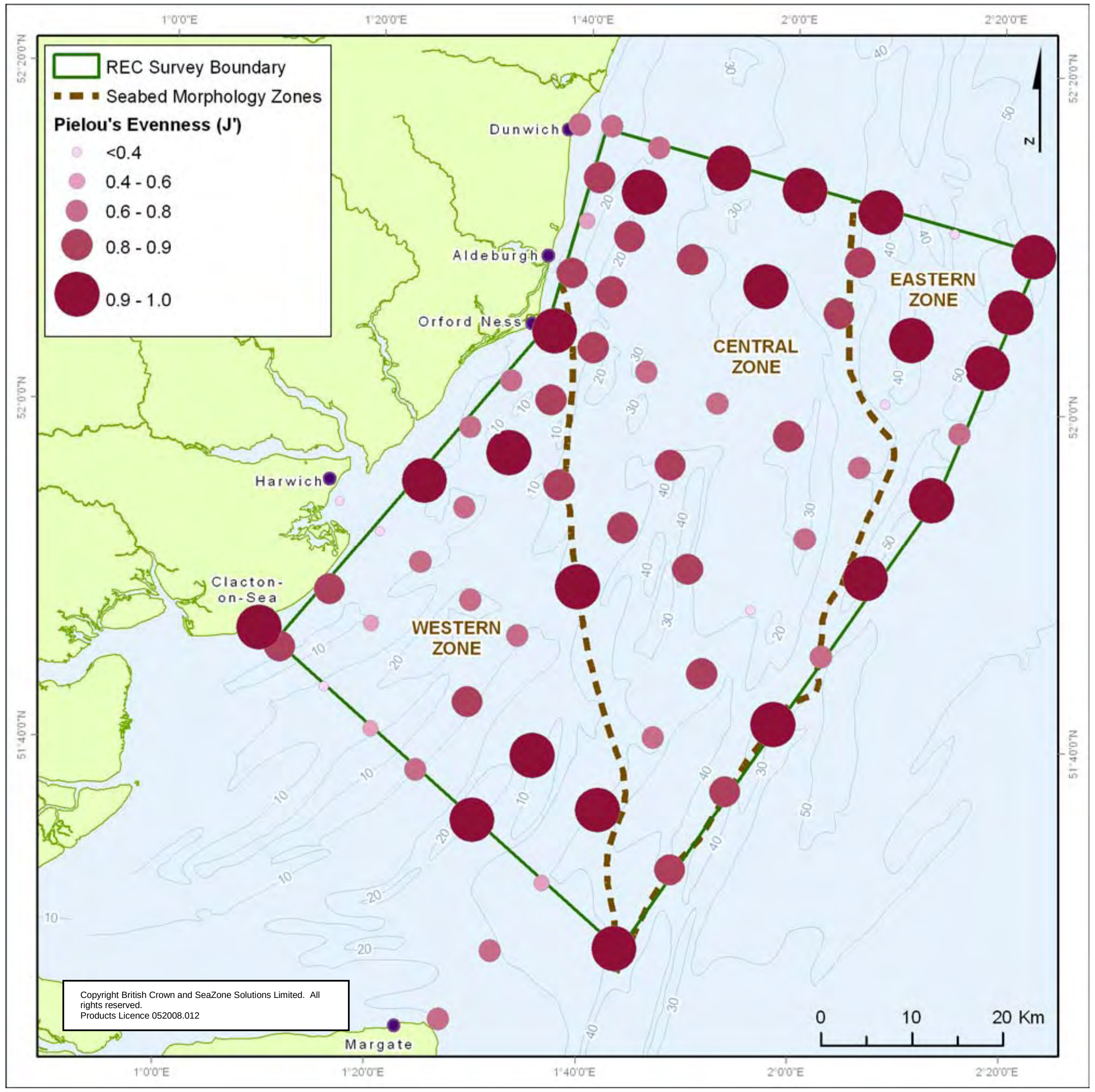

Figure 4.9: Pielou's Evenness values calculated from the Outer Thames Estuary REC grab samples.

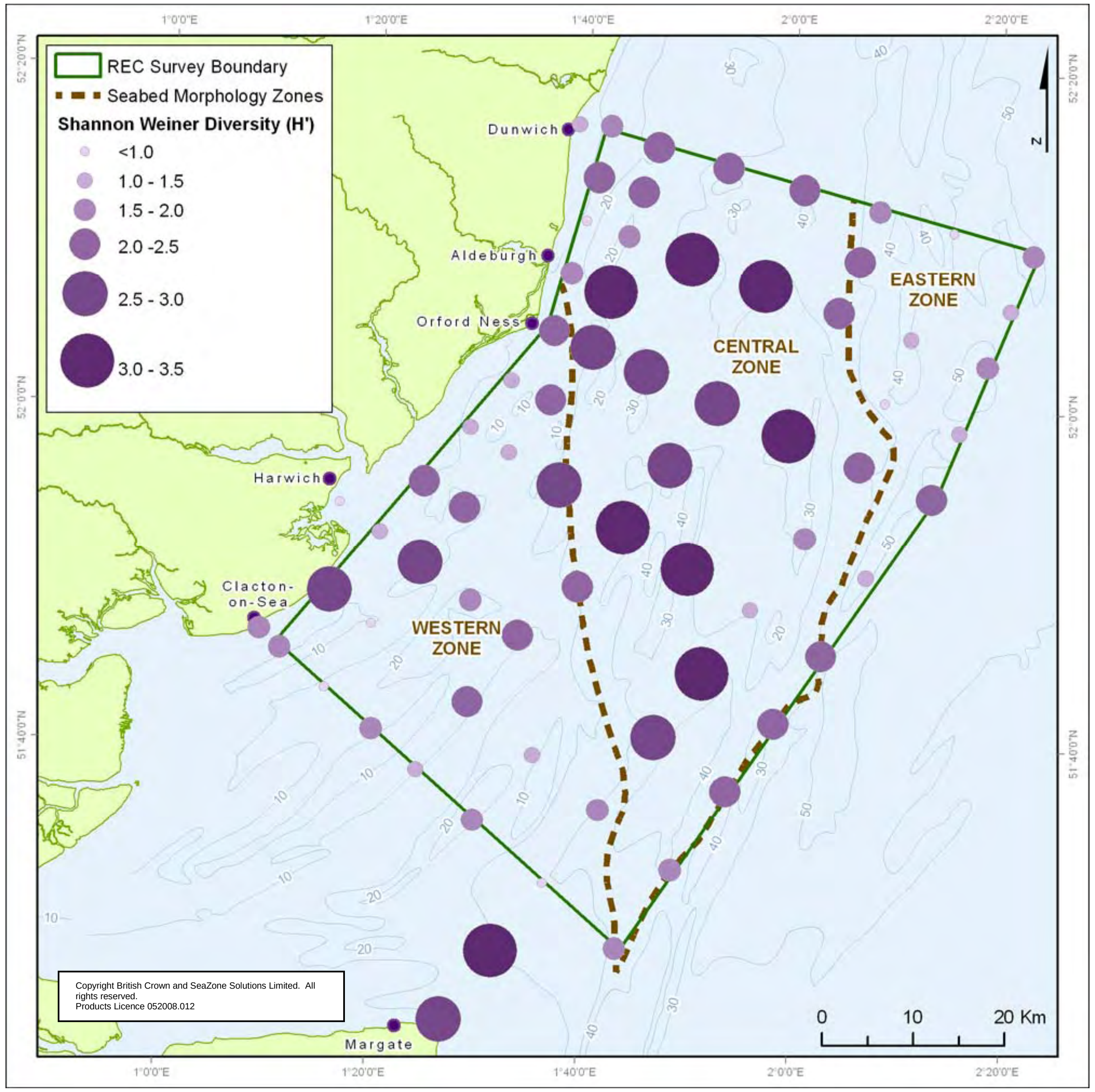

Figure 4.10: Shannon Weiner Diversity values calculated from the Outer Thames Estuary REC grab samples.

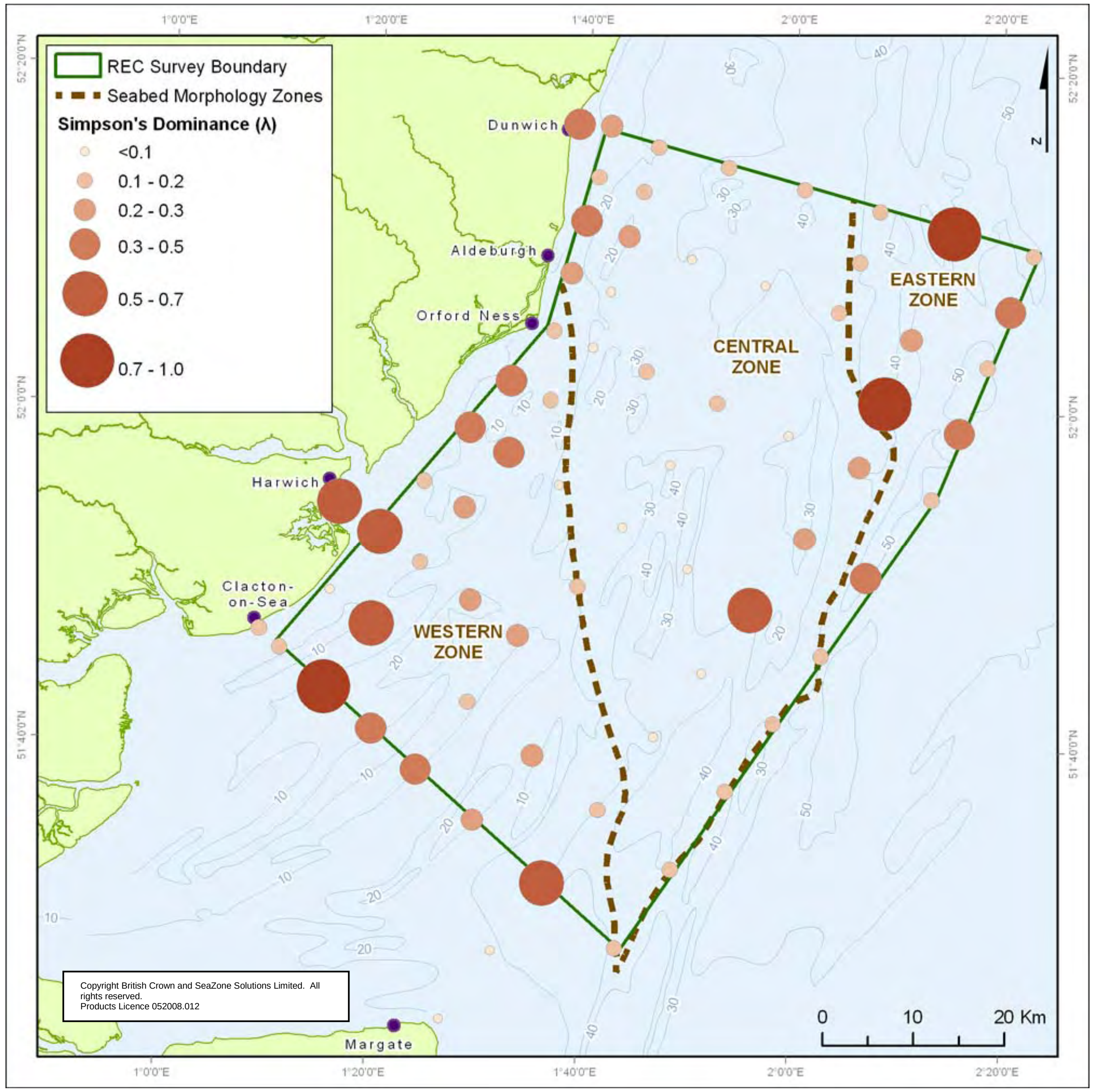

Figure 4.11: Simpson's Dominance values calculated from the Outer Thames Estuary REC grab samples.

Relationships between macrofauna and sediment environments are further explored in Section 4.5 but a relatively simple demonstration of the effect of sediment complexity on macrobenthic diversity within the Outer Thames Estuary region is presented in Figure 4.12. This plots values of sediment diversity (derived from the DIVERSE routine in PRIMER) against the number of species for each sample and broadly shows a gradient of increased species variety with increased sediment diversity. Sediment diversity in this instance is intended as an indicative measure of substrate complexity and has been calculated using the DIVERSE routine available in the PRIMER package of statistical routines. Figure 4.13 illustrates the relationship between the total number of species and seabed sediments found in the Outer Thames Estuary REC area. The seabed sediments in this instance were derived from an interpretation of geophysical and sediment survey data (see Section 2.3).

Although there appears to be a broad relationship between increasing sediment variability and species diversity, there are a number of varied sediments that are nevertheless associated with low species diversity. From the sample datasets, it was found that these were collected from shallow inshore waters adjacent to the Essex and Suffolk coastlines. The reasons for an apparent suppression of macrofauna within inshore waters is unclear although it is possible that other factors such as estuarine influences including salinity effects and/or fine sediment inputs may play a part.

Farther offshore the mixed and coarse sediments support larger numbers of encrusting and attaching epifauna and particularly high population densities correlate with areas of coarse sandy gravel and cobbles onto which these types of animals can attach. Such areas are typically characterised by higher dominance and / or lower eveness values indicating the numerical superiority of these epifaunal species where they occur. Particular examples are sites 1 and 22 where high abundances of the ascidian *Molgula manhattensis* and brittlestar *Amphipholis squamata* have elevated the dominance value and depressed eveness. Other examples include sites 7 and 30 where the total numbers of individuals of macrofauna are dominated by the keel worm *Pomatoceros* spp. and the barnacle *Verruca stroemia* resulting in comparatively elevated dominance. It is worth pointing out that certain populations of infaunal species can also dominate finer grained sediment habitats. *Lagis koreni*, *Lanice conchilega* and Maldanid worms for example are particularly numerous within the softer sediments at sites 2 and 23 and comparatively high densities of the amphipod *Bathyporeia elegans* have been found in grab samples collected at site 14. As a result high dominance and lower eveness values can also be a feature of the sand and muddy sand substrates.

A number of the species found were among those that are particularly characteristic of the wider southern North Sea as discussed in Section 2.5, such as polychaetes *Spiophanes bombyx* and *Nephtys* spp. and the brittlestar *Ophiura albida*. The majority of the top ranking species, however, showed a closer correspondence with other studies which have been conducted at a more local and/or regional level and reflect the greater sampling density and localised variability at these smaller spatial scales.

In particular, *Pomatoceros lamarcki*, *Nephtys cirrosa*, *Verruca stroemia*, *Sabellaria spinulosa*, *Ampelisca spinipes, Ophiura* spp., *Lumbrineris gracilis* and *Pisidia longicornis* have all been previously recorded as commonly occurring in the region. The top 20 most abundant and frequently occurring macrofaunal species in the grab samples are presented in Table 4.3.

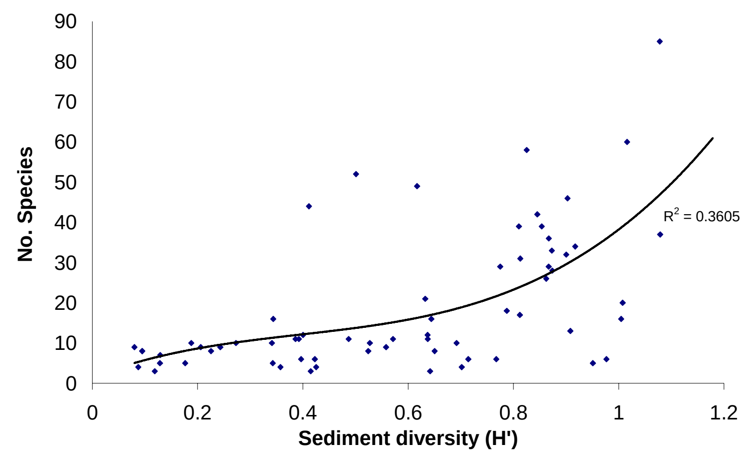

Figure 4.12: Relationship between sediment diversity and numbers of species.

Abundant Species				Frequently Occurring Species			
Species	Type of Organism	Total Abundance	% Frequency of Occurrence	Species	Type of Organism	Total Abundance	% Frequency of Occurrence
Verruca stroemia	Barnacle	1378	7.1	*Nephtys* spp	Catworm	102	58.6
Sabellaria spinulosa	Ross worm	1011	35.7	*Notomastus* spp.	Polychaete	107	42.9
Molgula manhattensis	Sea squirt	374	5.7	OPHIUROIDEA	Brittlestar	144	40.0
Photis longicaudata	Amphipod	246	14.3	Sertulariidae	Hydroid (Sea fir)	-	40.0
Spiophanes bombyx	Polychaete	235	24.3	*Sabellaria spinulosa*	Ross worm	1011	35.7
Pomatoceros lamarcki	Keel worm	202	17.1	*Lumbrineris gracilis*	Polychaete	189	34.3
Pisidia longicornis	Long-clawed porcelain crab	194	20.0	*Lagis koreni*	Polychaete	189	34.3
Lumbrineris gracilis	Polychaete	189	34.3	*Nephtys cirrosa*	White catworm	50	34.3
Lagis koreni	Polychaete	189	34.3	NEMERTEA	Ribbon worm	69	32.9
ACTINIARIA	Sea anenome	182	21.4	*Ampelisca spinipes*	Amphipod	158	30.0
Amphipholis squamata	Amphipod	172	25.7	PELECYPODA	Bivalve	84	30.0
Lanice conchilega	Sand mason worm	167	25.7	*Amphipholis squamata*	Brittlestar	172	25.7
Nucula nucleus	Nut shell	165	21.4	*Lanice conchilega*	Sand mason worm	167	25.7
Ampelisca spinipes	Amphipod	158	30.0	*Ophiura albida*	Brittlestar	146	25.7
Ophiura albida	Brittlestar	146	25.7	*Spiophanes bombyx*	Polychaete	235	24.3
OPHIUROIDEA	Brittlestar	144	40.0	*Abra alba*	Bivalve	78	22.9
Mytilidae	Mussel	117	14.3	*Glycera lapidum*	Polychaete	35	22.9
Barnea candida	White piddock	113	2.9	*Glycera* sp.	Polychaete	22	22.9
Notomastus spp.	Polychaete	107	42.9	ACTINIARIA	Sea anenome	182	21.4
Nephtys spp.	Catworm	102	58.6	*Nucula nucleus*	Nut shell	165	21.4

Table 4.3: Top 20 most abundant and frequently occurring macrofaunal species, derived from grab samples collected from within the Outer Thames Estuary REC study area.

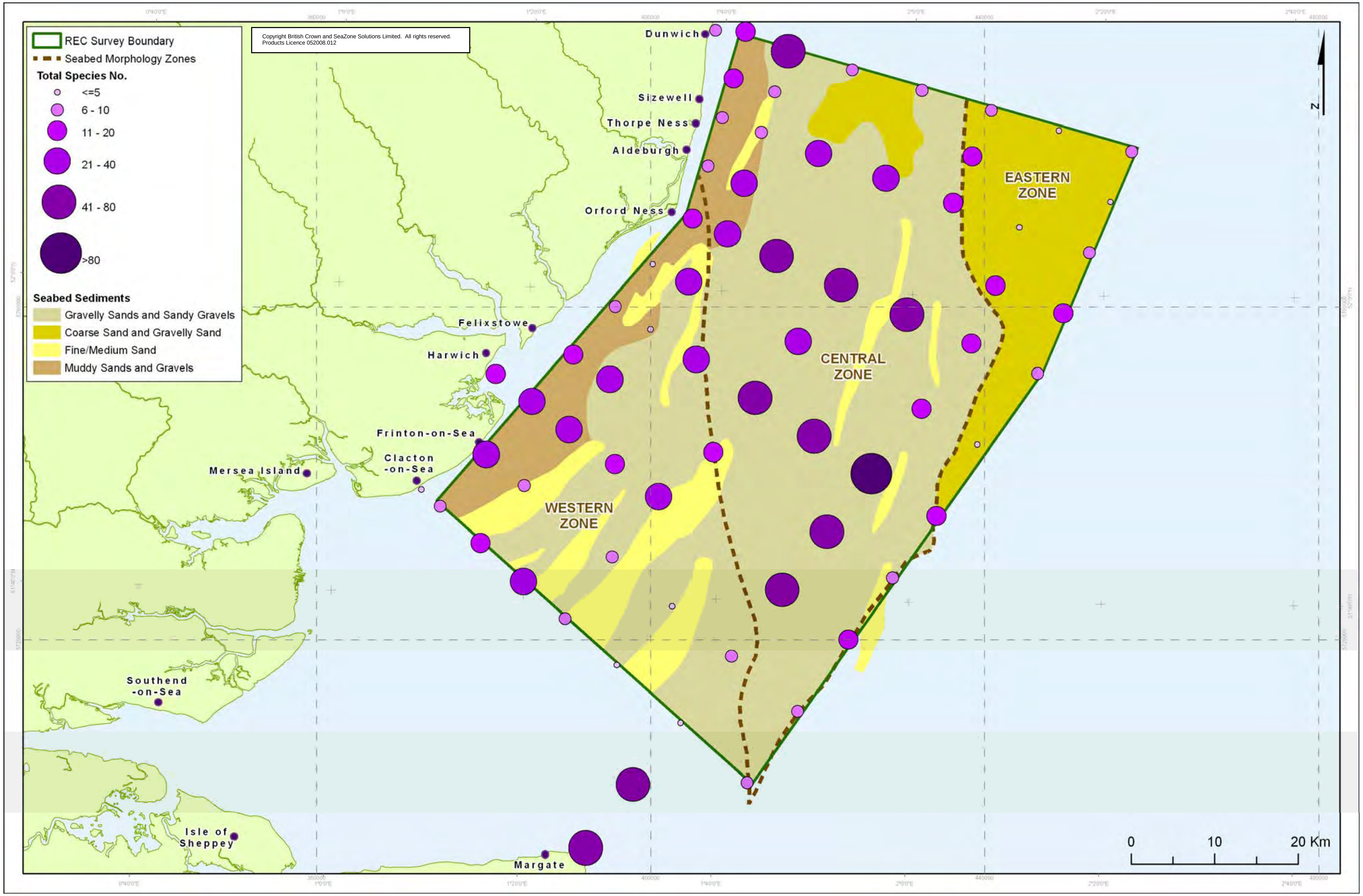

Figure 4.13: Total number of species within the Outer Thames Estuary REC area and the relationship with with seabed sediment composition and seabed morphology.

Of those listed, there were no species which could be considered as particularly characteristic of the Outer Thames Estuary REC region although several have been previously highlighted as commonly occurring over the wider southern North Sea region. On the whole, each species was found in 40 % of the samples or less, highlighting the irregular and patchy distribution for infaunal populations within the Outer Thames Estuary REC, a feature previously described for this coastal area by Irving (1998).

The most frequently occurring genera of polychaetes were the catworms *Nephtys* of which *Nephtys cirrosa* the white catworm (Figure 4.14) was the most commonly observed.

Nephtys cirrosa, is a free living, active burrowing and carnivorous polychaete. Although found in a range of sediment types it shows a preference for comparatively clean sands and median grain sizes of between 250 and 550 µm (www.vliz.be, 2009). It is common around the UK and has often been found in grab samples collected during other benthic surveys conducted in the Outer Thames Estuary. Locally the highest densities of *N. cirrosa* occur in sand and slightly gravelly sand sediments although smaller numbers are also found in muddy sand and muddy sandy gravels.

The capitellid polychaete, *Notomastus* spp. (Figure 4.15) is also relatively frequently recorded in the grab samples collected from the Outer Thames Estuary REC area. This infaunal species is a common constituent of benthic surveys of marine sediment habitats and is typical of clean to muddy sands and mud deposits from littoral areas to deeper water sites. It feeds on organic material although it is a relatively sedentary tube-dweller and an inactive burrower. Data from the current study indicate that greatest numbers are associated with deposits of mixed muddy gravelly and sand substrates.

The Class Ophiuroidea includes the brittlestars (Figure 4.16). Classification of to the level of Ophiuroidea is usually performed where particularly small body size as found in juvenile stages or excessive damage to specimens prevent any further taxonomic discrimination. The Ophiuroidea are widely distributed through the Outer Thames Estuary REC area with highest densities associated with mixed muddy, sandy, gravel sediments. Specific species of brittlestars have been identified within the Outer Thames Estuary REC region the most abundant and frequently occurring being *Amphipholis squamata* and *Ophiura albida*.

Both species are common throughout the UK and occur on a variety of sediment types. *Amphipholis squamata* is more normally associated with rocky substrates and is often found underneath gravel or amongst algae and hydroid / bryozoan turfs within rock pools. It is also known to inhabit gravelly and shelly substrates offshore (Rowley, 2006). Within the Outer Thames Estuary region low and moderate numbers of *A. squamata* are most commonly associated with coarse muddy, gravelly substrates but numbers increase markedly on very coarse cobble ground where there is algal cover or dense hydroid turf. Particularly high densities of *A. squamata* were found within the very coarse cobble sediments at site 1 located to the far south and offshore of the Thanet coastline

Ophiura albida lives on the surface of various sediment types and within the Outer Thames Estuary region is common on sand, muddy sand and fine gravel. It preys upon small polychaetes, bivalve mollucs and crustaceans but may also exhibit surface deposit feeding and scavenging. Numbers of *O. albida* are loosely correlated with mud content, the lower abundances occurring in areas of cleaner sediments.

Another conspicuous species within the grab samples was the Ross worm *Sabellaria spinulosa* (Figure 4.17). This animal is a filter feeding, tube-dwelling polychaete found commonly on coarse sandy gravel substrates throughout the UK. It is a naturally gregarious worm and can grow either as individuals or more commonly as aggregations of coalescing tubes forming sheets or crusts over the surface of seabed sediments.

In certain conditions, and particularly where there is a constant and sufficient supply of suspended sediment material, *S. spinulosa* can form erect and tightly packed tubiculous reefs which are elevated above the surface of the seabed. These erect encrustations are able to stabilise sediments and provide surfaces for attaching sessile animals as well as refuge for other species so that species diversity can be comparatively enhanced over that of the surrounding seabed areas. It has long been thought that *S. spinulosa*, along with other species, are an important food of the pink shrimp *Pandalus montagui*. This assertion is often supported by the close relationships observed between commercial pink shrimp fishing effort and the locations of clumps of *Sabellaria* reef.

Figure 4.14: The white catworm *Nephtys cirrosa*.

Figure 4.15:The capitellid worm *Notomastus* spp.

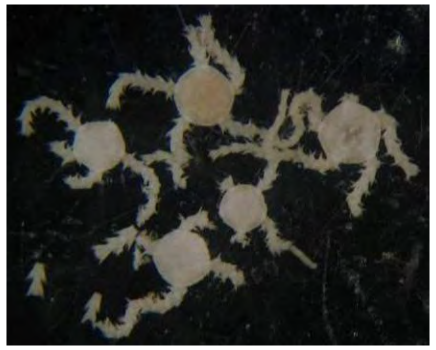

Figure 4.16: Typical juvenile Ophiuroids (brittlestars).

Figure 4.17: The Ross worm *Sabellaria spinulosa*.

Within the Outer Thames Estuary region, it is the coarsest sandy gravel and cobble substrates that support the highest densities of *S. spinulosa*. Greatest numbers are found to the centre and north of the survey area and to the far south off the Thanet coast corresponding to the coarsest substrates although relatively high numbers were also found in sandy gravel and gravelly sand sediments.

Although colonial epifauna appear to be comparatively poorly represented from the Outer Thames Estuary region, the Sertulariidae (Figure 4.18) nevertheless occurred in 40% of the samples. This is a family of erect hydroids representing around 26 species in UK Waters. They are found attached to the surfaces of gravel and cobbles, shells, algal fronds and foliose bryozoans such as *Flustra foliacea*. Their distribution is therefore highly dependant on the availability of suitable substrate for settlement. The most conspicuous member of the Sertulariidae within the Outer Thames Estuary REC area is *Hydrallmania falcata*. This is a particularly common hydroid found off all UK coasts and is typical of tide-swept and sediment scoured site attached to stone, boulders and bedrock (Cornelius 1995).

Figure 4.18: Sertulariidae.

Other apparently abundant epifauna occurred only infrequently. For example, the barnacle *Verruca stroemia* was only found at 5 of the 70 locations sampled by the Hamon grab. Indeed its high ranking in Table 4.3 relates to the occurrence of a particularly dense population of this barnacle at site 30 (1,203 individuals) accounting for 87% of the total number of individuals found for the entire region. Equally, the tunicate *Molgula manhattensis* and the boring piddock *Barnea candida* were only found at less than 6% of the sample sites despite being represented by comparatively high numbers of individuals. Although this may be seen as a further reflection on the patchy distribution of fauna within the region, these observations may also be partly a result of their close association with coarse and harder sediments which are generally inadequately sampled by the grab. *Barnea candida* bores into soft rock and so again would be difficult to quantitatively sample using grab techniques. *Molgula manhattensis* and *Verruca stroemia* grow on coarse cobbles and hard substrata and so again may be inadequately sampled by the grab. Data regarding the distribution of these epifaunal animals are instead dependant on the chance capture of larger stones or cobble sized material which have attached to or bored into in the grab.

4.3 Macrofaunal Assemblages

Analysis of the quantitative benthic infaunal dataset by PRIMER (Appendix C) revealed three main clusters (termed A, B and C) together with a fourth, smaller cluster which comprised just two samples (D). Initial biotope interpretation has also been completed based on matching the biological and physical attributes of each of the multivariate grab sample clusters to the Marine Habitat Classification (Connor *et al.*, 2004) using expert judgement. A complete list of habitats and biotopes, as defined in the Marine Habitat Classification is provided in Appendix C for guidance.

One of the inevitable consequences of biotope attribution of large groups of samples taken over a wide geographical area is a loss in the resolution of the overall classification. This is because the "between" sample variability is progressively diminished to satisfy the similarity requirements for increasing sample aggregation leading to a more homogenised and often more broad 'umbrella' classification to encompass a large number of samples. For this reason, a more detailed examination of the biotopes present based on individual grabs data has been presented in Section 5. This also draws upon photographic evidence to establish the presence and relationship between overlying epifaunal biotopes. The following however, provides information on the infaunal assemblages and the generic biotopes which are represented. Epifaunal assemblages based on the analysis of the qualitative (presence) grab data are addressed separately.

4.3.1 Infaunal Assemblages

Table 4.4 presents a summary of the biological and physical characteristics of each of the infaunal assemblages. Figure 4.19 shows the distribution of these infaunal assemblages overlaid onto the seabed morphology zones.

Infaunal Assemblage A

Comprising eight grab samples this assemblage was dominated by mixed sand and mud sediments most of which were collected from within a narrow belt along the shallow inshore areas. Possible estuarine influences can be inferred from satellite imagery which shows plumes of suspended fine sediments fringing the Essex and Suffolk coastlines. Settlement and entrainment of this material in sheltered inshore areas would contribute to the mud component of the sediment habitat and explain, in part, the distribution of soft mud and muddy sand substrates in the region. Seabed photography confirms the presence of fine grained muddy sand substrates with quantities of shell material (Figure 4.20), possibly originating from the bivalve species *Abra* spp. and *Ensis* spp., together with a number of ophiuroids (brittlestars) on the seabed surface.

This muddy sand infaunal assemblage was moderately diverse comprising a total of 78 species and an average of 17 species per 0.1 m^2 Hamon grab sample. Mean biomass was comparatively low (0.2 g AFDW / 0.1 m^2) suggesting a generally small body size for the species present. Characteristic species include the polychaetes, *Nephtys hombergii*, *Spiophanes bombyx*, *Notomastus* spp. and *Lagis koreni* (Figure 4.21) together with the bivalves, *Nucula nucleus* (Figure 4.22), *Abra alba* and *A. nitida*. All of these species are considered to be typical of fine sand and muddy sand sediments.

The species and sediment characteristics broadly match the **SS.SSa.CMuSa.AalbNuc** classification describing *Abra alba* and *Nucula nitidosa* in circalittoral muddy sand or slightly mixed sediment. The presence of raised numbers of the polychaete *L. koreni* and the occurrence of ophiuroids suggested that this habitat and species association may be transitory between a closely related but more muddy **SS.SMu.CSaMu.LkorPpel** biotope at some locations (site 2, Figure 4.20). Both biotopes are considered, by Connor *et al*, (2004), to alternate temporally.

Infaunal Assemblage B

Cluster B encompassed 30 grab samples comprising comparatively coarser mixed muddy, sandy gravels and gravelly sands. Species richness and diversity, together with biomass, were high in comparison to the other sample clusters. Conspicuous species included the polychaetes, *Sabellaria spinulosa*, *Lumbrineris gracilis*, *Notomastus* spp., the amphipod *Ampelisca spinipes*, brittlestars Ophiuroidea and sea anemones Actiniaria.

Further division within this cluster was based on three sub-clusters (Table 4.5) evident from the similarity dendrogram in Appendix C. SIMPER analysis identified that rather than differences in species identities, the principal driver behind the creation of these sub-clusters appeared to be differences in the relative abundances of the most conspicuous species and also on the relative densities of a number of less prominent species including the barnacle *Verruca stroemia*, the tunicate (sea squirt) *Molgula manhattensis*, the calcareous tube dwelling keel worm *Pomatoceros lamarcki*, the amphipod *Photis longicaudata* and the long-clawed porcelain crab *Pisidia longicornis*.

Infaunal Assemblage B1

This represented a community in muddy sandy gravels, sandy gravel and gravelly muddy sand (Figure 4.23). The community is dominated by *Ampelisca spinipes* (Figure 4.24), *Lumbrineris gracilis*, *Lagis koreni*, *Photis longicaudata*, *P. lamarki* and ophiuroids, including *Ophiura albida*. This community type is widespread throughout the Outer Thames Estuary region.

The species and sediment types present fitted a **SS.SCS.CCS.MedLumVen** biotope classification. This tends to be a large 'catch-all' biotope describing the polychaetes *Mediomastus fragilis* and *Lumbrineris* spp. (Figure 4.25) together with venerid bivalves in circalittoral coarse sand or gravel. This broad biotope probably encompasses a number of different types of habitats and species complexes. With regard to the Outer Thames Estuary REC data there is a reasonable correspondence although one of the characteristic polychaetes *Mediomastus* spp. was present in relatively low abundance (example site 32).

Raised abundances of *Ampelisca* spp. and *Photis longicaudata* at some southernmost sample sites (2, 7, 17 & 19) probably represent a **SS.SMu.ISaMu.AmpPlon** classification describing tube-building amphipods and polychaetes in infralittoral sandy mud (example site 2).

	Infaunal Assemblage A		Infaunal Assemblage B		Infaunal Assemblage C		Infaunal Assemblage D	
Generic biotopes	**SS.SSa.CMuSa.AalbNuc SS.SMu.CSaMu.LkorPpel**		**SS.SCS.CCS.MedLumVen SS.SMu.ISaMu.AmpPlon SS.SCS.CCS SS.SBR.PoR.SspiMx CR.MCR.SfR**		**SS.SSa.IFiSa.MoSa SS.SSa.IFiSa.NcirBat**		**SS.SSa.CMuSa**	
No. of Samples	8		30		29		2	
Ranked species according to frequency of occurrence in grab samples.	*Nephtys* spp. *Nephtys hombergii* *Nucula nucleus* *Lagis koreni* *Spiophanes bombyx* *Abra alba* *Notomastus* spp. *Lanice conchilega*		*Notomastus* spp. *Sabellaria spinulosa* *Lumbrineris gracilis* *Ampelisca spinipes* OPHIUROIDEA NEMERTEA *Amphipholis squamata* ACTINIARIA		*Nephtys* spp. *Nephtys cirrosa* *Ophelia borealis* *Gastrosaccus spinifer* OPHIUROIDEA *Glycera oxycephala* *Bathyporeia elegans* *Urothoe brevicornis*		*Scalibregma inflatum* *Abra alba* *Notomastus* spp. *Corophium volutator* *Eteone longa* *Anaitides mucosa* *Podarkeopsis capensis* *Lumbrineris gracilis*	
Ranked species according to their contribution to the group internal similarity.	*Nephtys* spp. *Nephtys hombergii* *Nucula nucleus* *Lagis koreni* *Spiophanes bombyx* *Abra nitida* *Notomastus* spp. *Nucula nitidosa*		*Sabellaria spinulosa* *Ampelisca spinipes* *Lumbrineris gracilis* *Ophiura albida* *Notomastus* spp. OPHIUROIDEA *Lagis koreni* ACTINIARIA		*Nephtys* spp. *Nephtys cirrosa* *Ophelia borealis* *Glycera oxycephala* *Gastrosaccus spinifer* OPHIUROIDEA *Bathyporeia elegans* *Urothoe brevicornis*		*Scalibregma inflatum* *Abra alba*	
Total No. of Species	78		249		82		10	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
No. of Species	17.4	15.1	36.5	18.8	7.8	3.1	6.0	0.0
Abundance	113.5	166.2	243.4	330.2	21.1	20.5	37.0	35.4
Biomass	0.2	0.2	0.7	0.7	0.1	0.1	0.1	0.1
% Coarse gravel	2.9	5.3	15.1	14.9	1.8	3.4	0.0	0.0
% Medium gravel	4.0	5.5	12.1	9.2	1.6	3.3	0.0	0.0
% Fine gravel	8.1	15.1	13.3	6.5	2.9	3.5	2.9	0.8
% Coarse sand	4.2	4.1	16.0	11.4	12.8	12.4	10.1	1.6
% Medium sand	6.7	4.7	19.8	13.6	39.6	27.7	6.4	2.2
% Fine sand	39.4	22.0	12.8	9.9	35.1	33.4	48.0	4.4
% Silt/clay	34.7	23.1	11.0	15.8	6.2	13.7	32.5	9.0
Sorting (φ)	3.8	1.0	3.2	1.2	1.3	0.9	3.7	0.3

Table 4.4: Summary of the biological and physical characteristics of the infaunal assemblages (enumerated data).

Infaunal Assemblage B2

This encompassed a number of coarser sediment types including muddy sandy gravel (Figure 4.26) and sandy gravel as well as the very coarse cobble sediments and compacted mud/clay substrate. Mixed gravelly mud was also included in this cluster. The associated macrofauna was particularly diverse and totalled 189 species and was characterised by *Sabellaria spinulosa*, *Molgula manhattensis*, *Photis longicornis* (Figure 4.27), the brittlestar *Amphipholis squamata* (Figure 4.28) and Actiniaria. In common with assemblage B1 above this community type is patchily distributed throughout the region.

Given the variable fauna and sediment types represented within this group a well defined biotope classification was not possible.

Instead, the lower resolution classification **SS.SCS.CCS** was considered to be more appropriate. This classification describes circalittoral coarse sediment (example site 1) which were widely spread throughout the survey area and supported a diverse fauna. Some of the conspicuous species included *Sabellaria* which occurred in abundances which suggests the occurrence of the biotope **SS.SBR.PoR.SspiMx** (*Sabellaria spinulosa* on stable circalittoral mixed sediment). However, no potential reef habitat could be determined from the grab survey (isolated clumps of *Sabellaria* were recorded in one of the replicate seabed photographs taken at site 49). The complexity of this group of sites is also illustrated by the presence of exposed compacted clay, which relate to the biotope classification **CR.MCR.SfR**. describing very soft chalk rock or clay with bivalve borers including piddocks (example site 45).

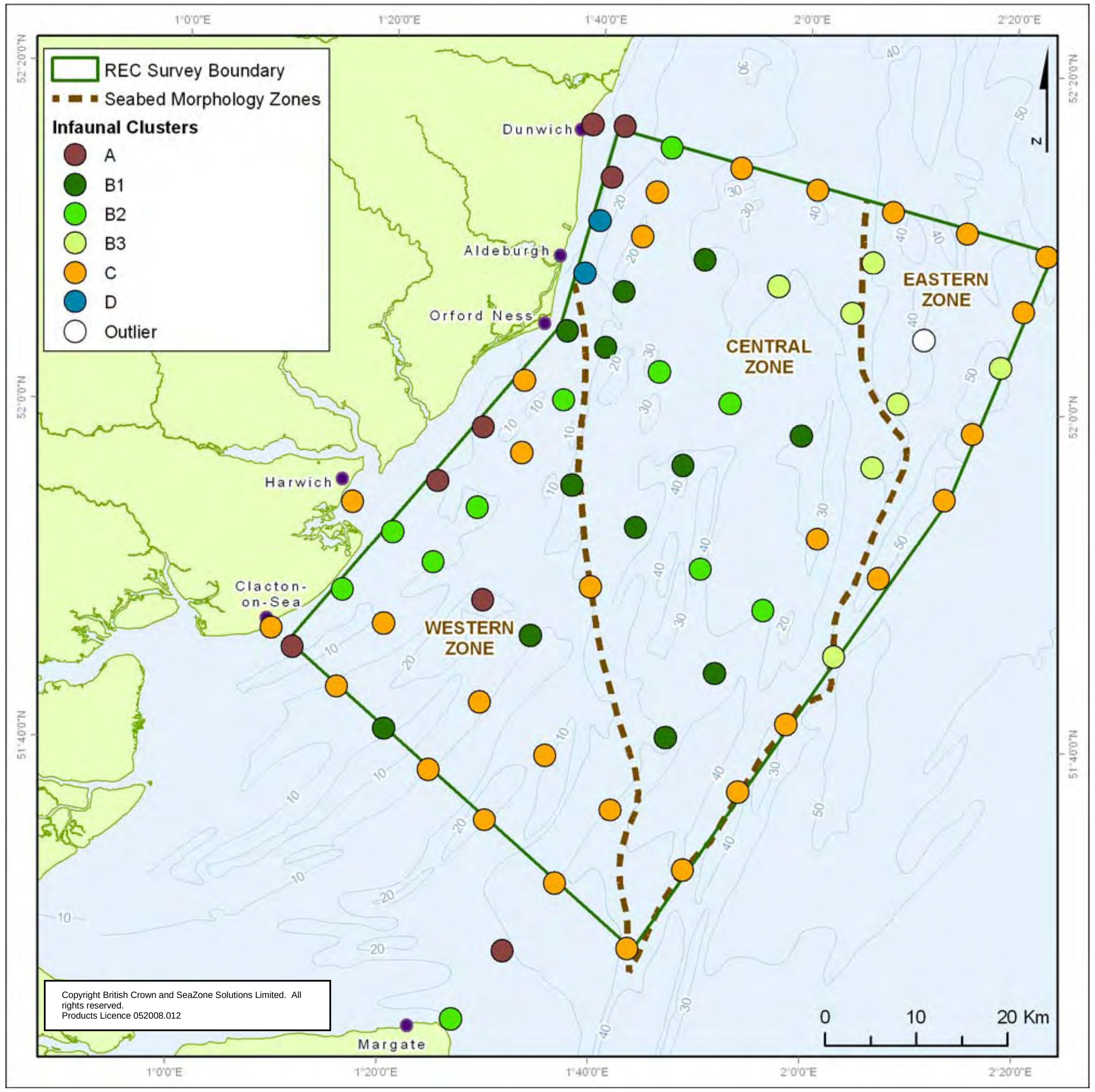

Figure 4.19: Distribution of infaunal clusters derived from Hamon grab data.

Infaunal Assemblage B3

This included generally cleaner mixed sandy gravel and gravelly sand sediments (Figure 4.29) characterised by the brittlestar *Ophiura albida*, the pea urchin *Echinocyamus pusillus*, the small caprellid crustacean, *Pariambus typicus*, ribbon worm, Nemertea and the polychaetes *Spiophanes* bombyx and *Notomastus* spp.. In comparison with assemblages B1 and B2, species numbers, numbers of individuals and biomass were low. This sediment/faunal association was distributed to the north and west of the study area and towards the deeper water impoverished sandy bed form areas.

The sediment types within this grouping correspond with those describing a circalittoral coarse sediment biotope classification **SS.SCS.CCS**. However, the samples are dominated by *Echinocyamus pusillus*, *Ophiura albida* (Figure 4.30) and *Notomastus* spp. (Figure 4.31), which currently do not correspond with described biotopes in Connor *et al*, 2004 (example site 42). As such no increase in the resolution of classification of the group of samples is possible and these may simply represent impoverished or sandy variants of group B2.

Infaunal Assemblage C

Cluster C was dominated by comparatively clean sand and slightly gravelly sand sediments (Figure 4.32) collected from peripheral locations around the Outer Thames Estuary REC study area and particularly in areas associated with the principal sandbanks and the deeper water sandy bed-forms to the extreme north and east.

The associated macrofauna within each grab sample were sparse in comparison with the other faunal groupings and were characterised by a range of typical sand and gravelly sand species such as the polychaetes *Nephtys cirrosa* (Figure 4.33), *Ophelia borealis* and *Glycera oxycephala*, the amphipods *Bathyporeia elegans* (Figure 4.34) and *Urothoe brevicornis*, the mysid shrimp *Gastrosaccus spinifer* and Ophiuriodea. This cluster was also subject to a further sub-division associated with the dominance of *Glycera oxycephala*, *G. lapidum* and Ophiuroidea in slightly gravelly sand.

The paucity of macrofauna is likely to be a result of the mobility of the sediments and the associated adverse compaction and abrasion effects. Fauna may also be subject to displacement limiting colonisation success to those species capable of maintaining position and rapid re-burial. The continuous winnowing and erosion removes fine material and limits organic food material for deposit feeding organisms whilst sediment scouring effects and lack of suitable stable surfaces precludes filter feeding sessile epifauna.

The biological and sediment attributes of this grouping correspond well with the **SS.SSa.IFiSa.IMoSa** classification describing infralittoral mobile clean sand with sparse fauna. This biotope is defined principally on the basis of the highly mobile nature of the sandy sediments and is characteristically populated by few infaunal species, generally at very low abundances. Particularly characteristic are those species that are adapted to regularly destabilised sands, such as the mysid *Gastrosaccus spinifer*. Areas of relatively increased abundances of *Bathyporeia elegans* and *Nephtys cirrosa* match the **SS.SSa.IFiSa.NcirBat** classification.

Infaunal Assemblage D

Cluster grouping D incorporated just two samples comprising slightly gravelly muddy sand (Figure 4.35). These were collected from shallow near-shore locations to the north-west of the survey array and offshore of Aldeburgh and Thorpeness. Both samples contained just six species with only the polychaete *Scalibregma inflatum* and the bivalve *Abra alba* common to both. The grouping represents a particularly impoverished variant of the muddy sand association identified as assemblage A above and is best represented by the classification **SS.SSa.CMuSa**.

One sample from site 53 was left un-grouped following the analysis of the quantitative grab sample data. This comprised poorly sorted sandy gravel containing just one individual of each of the polychaetes *Paradoneis lyra*, *Chaetozone zetlandica* and *Sabellaria spinulosa* and one individual shrimp *Philocheras trispinosus*.

	Infaunal Assemblage B1		Infaunal Assemblage B2		Infaunal Assemblage B3	
Ranked species according to frequency of occurrence in grab samples.	*Ampelisca spinipes* *Lagis koreni* *Lumbrineris gracilis* *Psammechinus miliaris* OPHIUROIDEA *Ophiura albida* PELECYPODA *Ampelisca* sp.		*Sabellaria spinulosa* *Lumbrineris gracilis* *Lepidonotus squamatus* ACTINIARIA *Amphipholis squamata* *Notomastus* spp. NEMERTEA *Anoplodactylus petiolatus*		*Notomastus* spp. NEMERTEA *Echinocyamus pusillus* *Spisula elliptica* *Ophiura albida* *Glycera* sp. *Sabellaria spinulosa* OPHIUROIDEA	
Highest % contribution to internal similarity.	*Ampelisca spinipes* *Lumbrineris gracilis* *Lagis koreni* *Photis longicaudata* OPHIUROIDEA *Ophiura albida* *Ampelisca* sp.		*Sabellaria spinulosa* ACTINIARIA *Lumbrineris gracilis* *Pisidia longicornis* *Ampelisca spinipes* *Molgula manhattensis* *Amphipholis squamata*		*Ophiura albida* *Echinocyamus pusillus* *Notomastus* spp. *Spisula elliptica* NEMERTEA *Glycera* sp.	
Total No. of Species	148		189		63	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
No. of Species	38.2	12.9	47.3	20.2	16.9	38.2
Abundance	151.3	67.5	444.0	483.7	86.0	151.3
Biomass	0.7	0.4	1.1	0.9	0.1	0.7
% Coarse gravel	3.4	0.5	3.6	1.5	2.1	3.4
% Medium gravel	16.9	15.9	17.9	15.8	7.5	16.9
% Fine gravel	13.7	7.5	10.7	10.1	11.1	13.7
% Coarse sand	13.4	4.9	13.2	8.7	13.1	13.4
% Medium sand	12.8	3.6	12.7	7.3	26.5	12.8
% Fine sand	17.0	8.8	16.4	16.7	30.0	17.0
% Silt/clay	17.1	10.6	10.2	7.9	7.6	17.1

Table 4.5: Biological and physical characteristics of the faunal sample Cluster B.

Geophysical data have indicated the presence of localised bedrock outcrops at site 53 and local surrounding areas to the north-east but this was not supported by the benthic grab and seabed image data which showed a sandy, coarse gravel sediment possibly representing a thin and mobile sediment veneer overlying harder bedrock. This is confirmed to some extent by the occurrence of the *Nemertesia* spp. (Figure 4.36).

Figure 4.20: Muddy sand seabed overlain with shell material found associated with infaunal assemblage A (survey site 2).

Figure 4.21: Polychaete *Lagis koreni*.

Figure 4.22: Bivalve *Nucula nucleus*.

Figure 4.23: Muddy sandy gravel typical of infaunal assemblage B1 (survey site 32).

Figure 4.24: Amphipod *Ampelisca spinipes*.

Figure 4.25: Polychaete *Lumbrineris gracilis*.

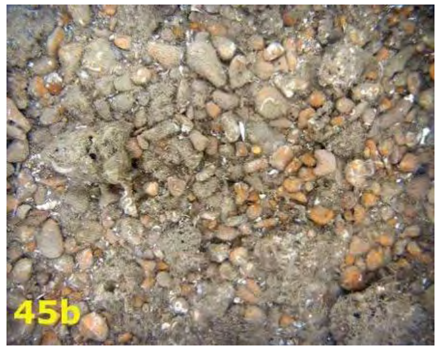

Figure 4.26: Example of muddy sandy gravel characteristic of infaunal assemblage B2 (survey site 45).

Figure 4.27: Long-clawed porcelain crab *Pisidia longicornis*.

Figure 4.28: Juvenile Brittlestar *Amphipholis squamata*.

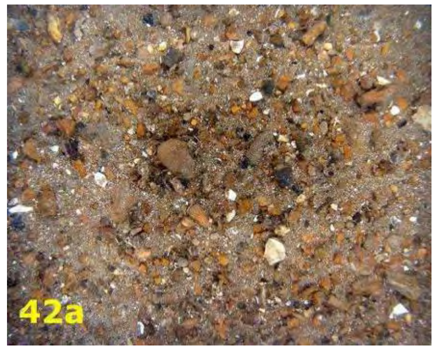

Figure 4.29: Mixed sand and gravel seabed associated with infaunal assemblage B3 (survey site 45).

Figure 4.30: Brittlestar *Ophiura albida*.

Figure 4.31: Polychaete *Notomastus* spp.

Figure 4.32: Predominantly sandy sediments associated with infaunal assemblage C (survey site 13).

Figure 4.33: Polychaete white catworm *Nephtys cirrosa*.

Figure 4.34: Amphipod *Bathyporeia elegans*.

Figure 4.35: Example of a muddy sand sediment relating to infaunal assemblage D.

Figure 4.36: Mobile sand over a hard substrata with *Nemertesia* sp. (survey site 53).

4.3.2 Epifaunal Assemblages

Whilst infauna and epifauna are collectively part of the same community type they are often treated differently because of the different equipment used to sample each component. Also, unlike infaunal species, it is often difficult to enumerate certain colonial sessile species such as hydroids and bryozoans so that analysis of faunal data usually results in the creation of both a quantitative and qualitative dataset. This has contributed to a dichotomy in the Marine Habitat Classification so that in many cases it is necessary to attribute communities on coarse substrates with both an infaunal and epifaunal biotope coding.

The quantitative infaunal components of the grabs have been addressed above and several generic infaunal biotopes have been identified. The grab data also provide qualitative information on the distribution of epifaunal assemblages although this will be mostly limited to sessile species which are more amenable to grab sampling compared to larger mobile fish, crab and shrimps which are better sampled by trawls. Nevertheless, it is possible to undertake a cursory assessment of the epifaunal assemblages based on qualitative grab data which helps to build a picture of the distribution of the sessile colonial fauna in the Outer Thames Estuary REC area.

Further analyses of the grab data therefore revealed a number of discrete assemblages of epifauna, the distributions of which are shown in Figure 4.37. None of the assemblages appear to show any geographical relationships but it is clear that they mostly correspond with coarser gravely seabed sediment types, as would be expected. Sandy sediments tend not to support any epifauna with the exception of some of the slightly gravelly sand and shell sand substrates which by virtue of the shell component supported assemblages of the hydroid *Obelia bidentata* together with the almost ubiquitous Sertulariidae (epifaunal assemblage A). *O. bidentata* commonly occurs throughout UK waters and is typical of sandy sediments attaching to shells. Sertulariidae encompass a suite of commonly occurring hydroid species found on a variety of surfaces and which can tolerate sediment influences such as sand scour. Both species are regarded as characteristic epifauna of the Outer Thames Estuary REC grab sample dataset.

The principal epifaunal assemblage, in terms of spatial coverage across the Outer Thames Estuary REC however, is epifaunal assemblage B1. It is strongly associated with mixed slightly muddy sand and gravel sediments, the surfaces of the larger particles present being utilised as attachment sites. The hydroids Sertulariidae are consistent components but are rarely associated with any other epifaunal species. Where they do occur, sea anemones, Actiniaria and sea squirts *Molgula manhattensis* are found together with the Sertulariidae and form discrete sub-types of this assemblage (epifaunal assemblages B2 and C). The other species of sea squirt present, *Dendrodoa grossularia*, forms an additional small discrete assemblage (epifaunal assemblage D).

There is a strong correspondence between the mixed muddy sandy gravel sediment type and a richer and more diverse assemblage (E). This is characterised by a variety of hydroids such as *Clytia hemisphaerica*, Haleciidae, *Sertularella gaudichaudi* and *Hydrallmania falcata*, together with barnacles *Verruca stroemia*, sea squirts (Class Ascidiacea), the bryozoans *Scrupocellaria scruposa* and *Bicellariella ciliata* and sea anemones (Order Actiniaria).

Current data suggest the presence of several variants of **SS.SSa.IFiSa.ScupHyd** describing *Sertularia cupressina* and *Hydrallmania falcata* on tide-swept sublittoral sand with cobbles or pebbles. The prominent hydroids of the biotope are tolerant to levels of sand scour and temporary inundation which might reduce the diversity and abundance of other epifaunal species. It probably exists as a mosaic with other biotope types such as **CR.HCR.XFa.Mol** as indicated by conspicuous *Molgula manhattensis* in some areas i.e. epifaunal assemblages C and B2,

The **XFa.Mol** biotope is noted as commonly occurring as an overlay on soft rock (Connor *et al.,* 2004) and species associated with the **SfR** complex, such as *Barnea candida,* are expected to be found in close proximity. This supports the observed correlation between this epifaunal assemblage and the outcropping of clay at site 45.

Analysis of the seabed photography (Appendices A and C) offers an additional interpretation of the distribution and character of the epibenthic assemblages present. Figure 4.38 presents the distribution of epibenthic assemblages and associated sediment types identified from the seabed photography. Multiple classifications at some of the sample sites relates to replicate photographs and reflects the local variability. Note the high proportion of unsuccessful images from inshore waters. This may be a function of the high turbidity levels associated with the plumes of suspended sediment inputs from local estuaries along the coast in this region.

The mixed muddy sandy and gravel sites were found to be highly variable in terms of their epifaunal assemblages and many of these substrates supported various combinations of mixed hydroid and bryozoan turfs with the keel worm *Pomatoceros* spp. together with the green sea urchin *Psammechinus miliaris* and the common starfish *Asterias rubens*. Further taxonomic definition of the hydroids and bryozoans is often difficult from seabed images which usually require microscopic analysis to determine species identities. However, a number of species have been identified from the seabed photography and include the soft coral (dead man's fingers) *Alcyonium digitatum*, the foliose bryozoan *Flustra foliacea* and the hydroids *Abietinaria abietina* and *Nemertesia* spp.

From the evidence of the seabed photography the epifaunal biotopes in mixed sediment areas are probably better represented as mosaics of robust hydroid and bryozoan turfs interspersed with **SS.SCS.CCS.PomB** describing *Pomatoceros* spp. with barnacles and bryozoan crusts on unstable circalittoral cobles and pebbles. The diversity of biotopes for these sediment types might be quite high as a result of a number of niche biotopes representing highly localised spatial and temporal variations in exposure, scour and substrate stability.

Sand sediments, on the other hand, supported little colonial sessile epifauna due to the lack of attachment sites and instability of the sediments. Hermit crabs (Family Paguridae) were commonly recorded over the sandy sediments.

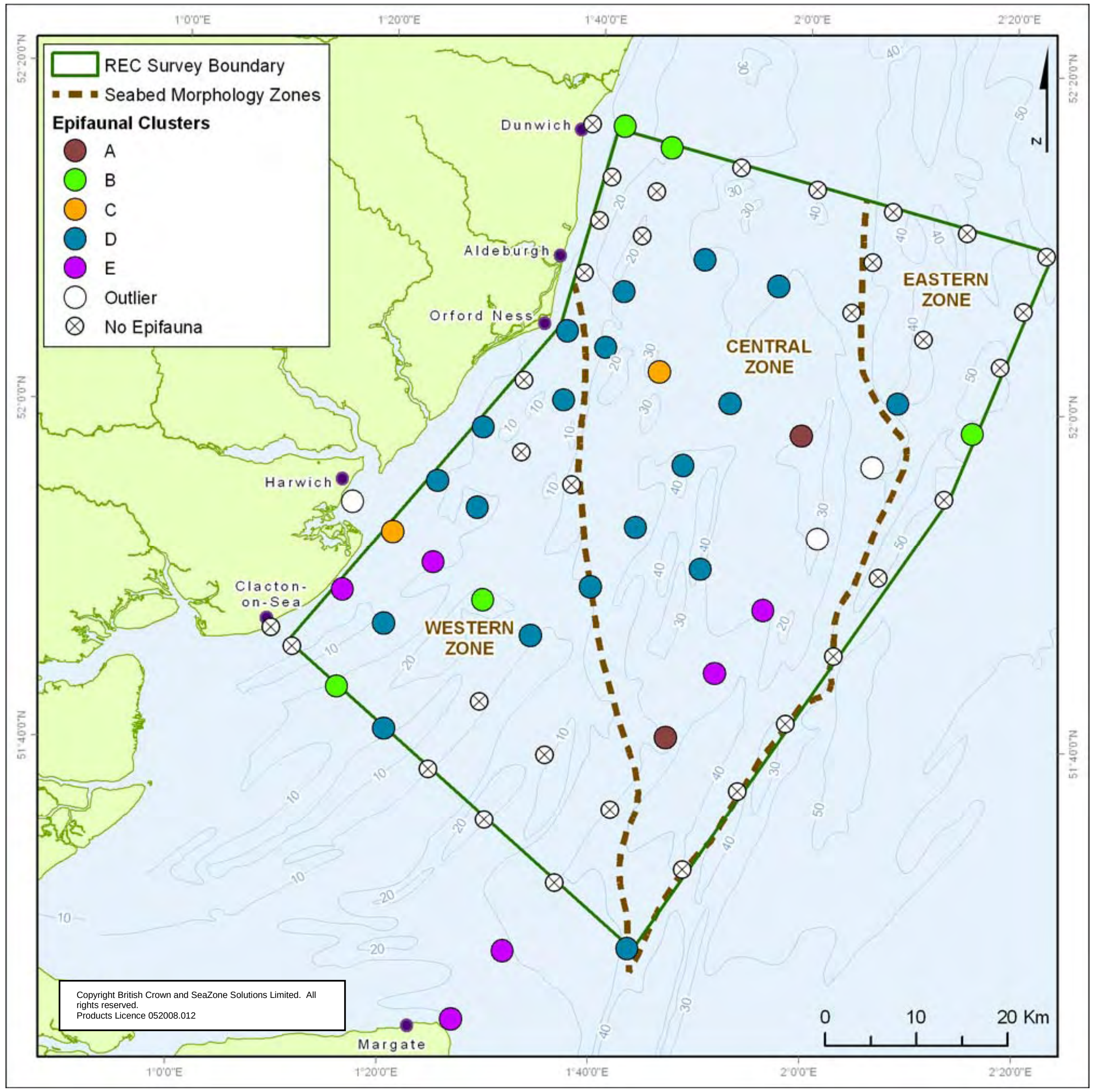

Figure 4.37: Distribution of epifaunal clusters from the Outer Thames Estuary REC grab samples.

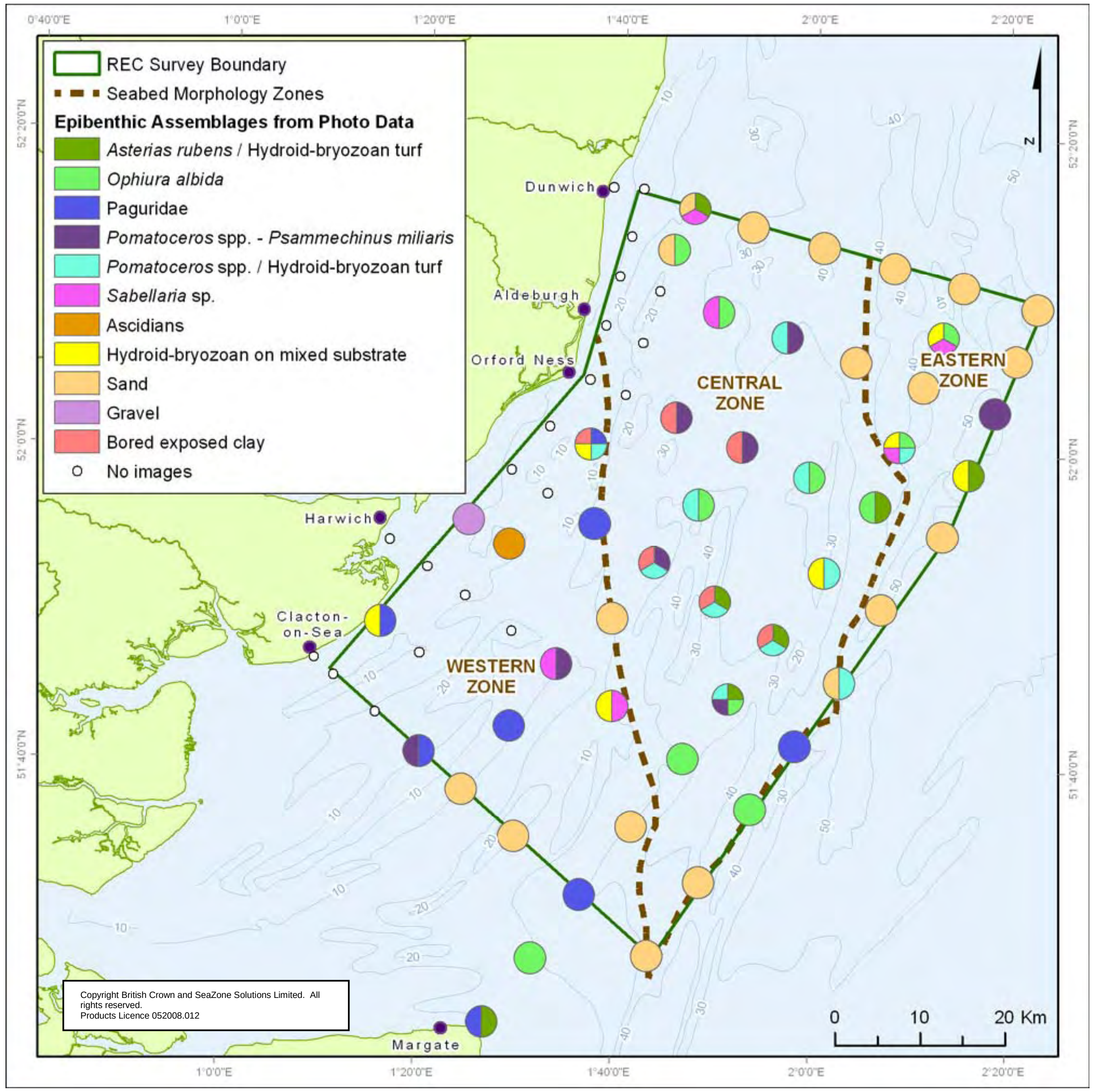

Figure 4.38: Distribution of epifaunal assemblages from the Outer Thames Estuary REC photo data.

A particular advantage of seabed photography is the characterisation of certain harder substrate types where grab sampling is generally inefficient, such as at sites 31 and 42. The seabed images have shown that these exposed bedrock mud substrates support a sparse epifauna but can support dense populations of the boring piddock *Barnea candida*. The relative paucity of colonial sessile epifauna may be a result of the soft nature of the substratum which is generally unsuitable for attachment for these types of organisms although *Molgula manhattensis* appears to have some association with this substrate type within the Outer Thames Estuary REC. Other epifauna found in these areas include *Verruca stroemia*, *Pomatoceros lamarcki* and *Alcyonium digitatum* and relate to surficial gravel veneers overlying the clay substrate. Grab sampling showed that these areas are associated with comparatively high species richness, diversity and abundance. This may relate to the high complexity of the substrate and surficial mixed gravelly sediments which offer a range of niche habitats for macrofauna together with some inherent stability associated with the compacted clay (Figure 4.39).

The seabed photography has also identified a discrete patch of potential *Sabellaria* reef at image site 18 (Figure 4.40). Further assessment of this feature is given in Section 5. Despite the plan view provided by the camera, some impression of elevation above the seabed is given whilst replicate photographs show the density and extent of this feature over the local scale. Associated side scan sonar data indicate the potential extent of this feature across the seabed. Given the nature conservation importance of this feature (see Section 5.3) further ground truthing of the acoustic data to assess and map potential *Sabellaria spinulosa* reef within the Outer Thames Estuary REC is warranted.

4.4 Epibenthos

An alternative definition of the epibenthic communities is achievable through the use of the data derived from the 2 m beam trawls. These datasets are considered to be more useful than the grab samples in describing low density sessile epifaunal assemblages within the Outer Thames Estuary REC study area as well as assemblages of larger mobile benthos. This is because they are able to sample larger areas of seabed so that there is a greater opportunity to encounter features that only occur rarely or infrequently. The mobile nature of the trawl gear is also able to capture information concerning the distribution of faster moving animals such as shrimps, crabs and bottom dwelling fish. Appendix C presents a species list for the 2 m beam trawl samples.

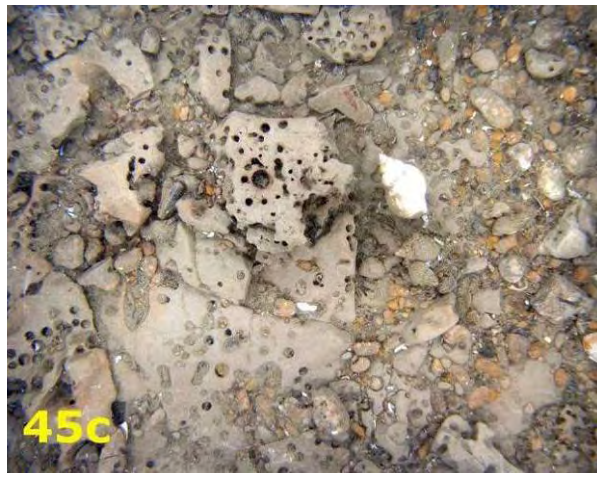

Figure 4.39: Seabed photograph showing bedrock clay outcrops bored by paddocks at site 45.

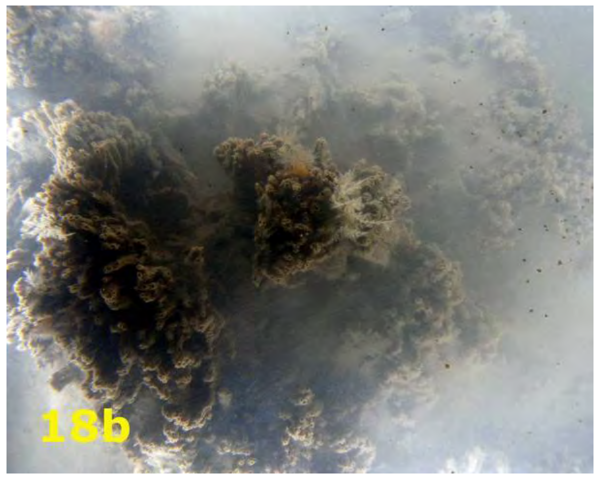

Figure 4.40: Seabed photograph showing potential *Sabellaria spinulosa* reef at site 18.

The 2 m beam trawls identified a total of 29 species of sessile epifauna, ten of which were not recorded by the grab sampling. The most frequently encountered epifaunal species in the trawls was the sea chervil *Alcyonidium diaphanum* rather than the hydroids Sertulariidae as indicated by the grab data. This is a species of erect bryozoan which attaches to stones and rocks and can grow in dense colonies on the sea floor throughout many parts of the Outer Thames Estuary. Oyster fishermen in the Thames Estuary often observe dense seasonal growths of this species which interferes with fishing gears on the seabed and reduces fishing efficiency. Porter *et al.*, (2002) reported that *A. diaphanum* is common within UK coastal waters and is widely distributed throughout the southern North Sea. A comparison of the current data with that from the wider UK waters suggested that some of the largest amounts of *A. diaphanum* are found in the Outer Thames Estuary region (Porter *et al.*, 2002).

The hydroid *Obelia bidentata* was also commonly found in the trawls followed by members of the Sertulariidae family matching observations made of the grab data. Other species, however, occurred occasionally or infrequently. The foliose bryozoan *Flustra foliacea* was found in 4 of 20 trawl samples whilst dead man's fingers *Alcyonium digitatum* and the hydroids *Halecium halecium* and *Nemertesia ramosa* only occurred in two of the samples highlighting the patchy distribution of these species.

4.4.1 Analysis of the Sessile Epifauna in the 2 m Beam Trawls

Figure 4.41 identifies key species in terms of their frequency of occurrence and shows the importance of *A. diaphanum*. Most of the *A. diaphanum* was collected at trawl sample site T23 which is located within the shallow waters close inshore at Harwich (Figure 4.42). The weight of material caught here was 22 kg and accounted for 87% of the total amount of *A. diaphanum* recorded. Clearly, conditions at this inshore location are particularly favourable for the development of dense growths of this species but the gravelly sand substrate identified here by the grab sampling is inconsistent with the rock, stones and pebble substrates normally associated with this species. It is possible that these coarser sediment types exist sporadically within the locale but this was not reflected by the single grab data.

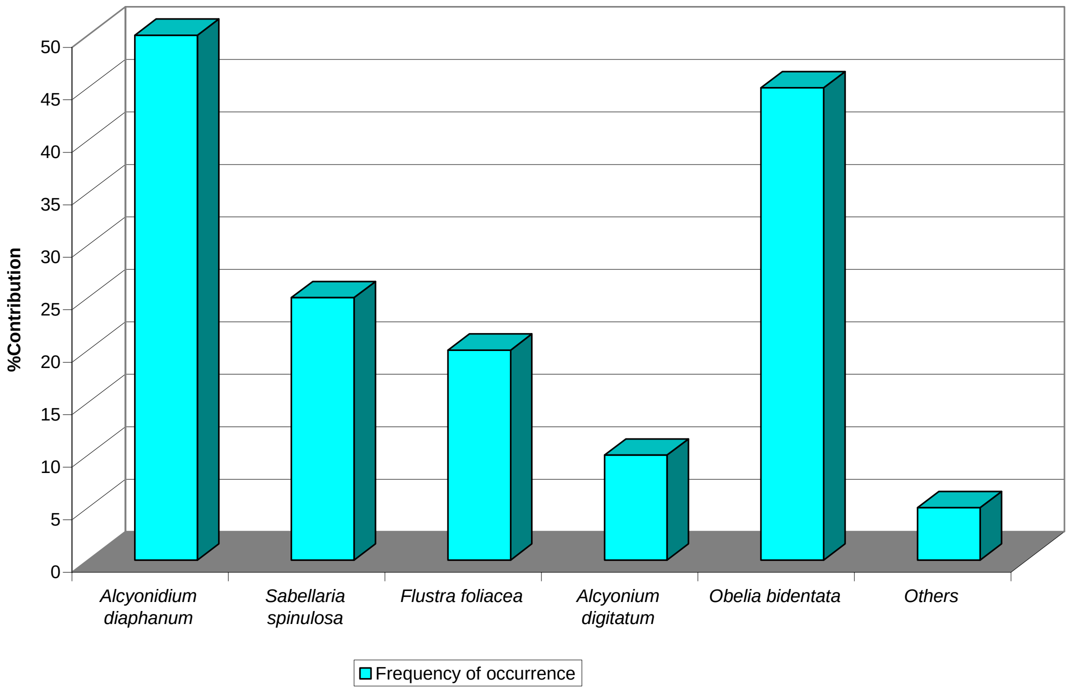

Figure 4.41: Relative frequencies of occurrence of key sessile species caught in the 2 m beam trawls.

Smaller quantities of *A. diaphanum* occur at offshore locations along the eastern edge of the survey array and also to the south of the study area and offshore of the Thanet coastline. Interestingly it is absent from both beam trawl and grab samples collected from northern areas of the Outer Thames Estuary REC area which might reflect the paucity of coarser sediments for attachment of this species and the general mobility of the sediments.

The weight data also reveal the relative importance of encrustations of the Ross worm *Sabellaria spinulosa* and provides evidence as to the further distribution of this feature throughout the Outer Thames Estuary REC area. During the trawl survey the greatest weights of *S. spinulosa* encrustations were found at trawls T7, T41 and T54 (Figure 4.43 and Figure 4.44) with smaller quantities found at trawl locations T29 and T63. Whilst trawl data give no impression on patchiness of *Sabellaria* assemblages, the material recovered suggests the presence of erect encrusting tubes with elevations of several centimetres.

Figure 4.42: Detail of the contents of the 2 m beam trawl sample collected at trawl tow T23 near Harwich showing large quantities of *Alcyonidium diaphanum*.

Other important sessile epibenthic components of the trawls were the erect bryozoan *Flustra foliacea* and the hydroid *Obelia bidentata.* Although conspicuous in terms of their frequency of occurrence in the trawls, these species are relatively small and therefore contribute little to the overall weight of sessile epibenthos.

Cluster analysis based on sessile epifaunal weight in the 2 m beam trawl samples (Appendix C) and subsequent overlay of the groups onto the beam trawl sampling array shows a dominant *Alcyonidium diaphanum* / *Flustra foliacea* assemblage across much of the southern and central areas of the survey array (Figure 4.44).

Other epifaunal species which emerged as characterising a group of sites, although not occurring in any great biomass, were the hydroids *Obelia bidentata* and *Hydrallmania falcata*. Sites within this group occurred in the northern portions of the study area. A subset of sites within this group were characterised by high abundances of *Sabellaria spinulosa* (Figure 4.44).

Two sites (T17 and T32) emerged as outliers primarily as a result of the reduced sessile epifauna caught within these trawls. One further site (sample T9) was of interest. Although this did not separate in the PRIMER analysis, it was characterised by large quantities of the green seaweed, *Enteromorpha* spp. (Figure 4.45).

Figure 4.43: Details of trawl sample T41 showing encrustations of *Sabellaria spinulosa*.

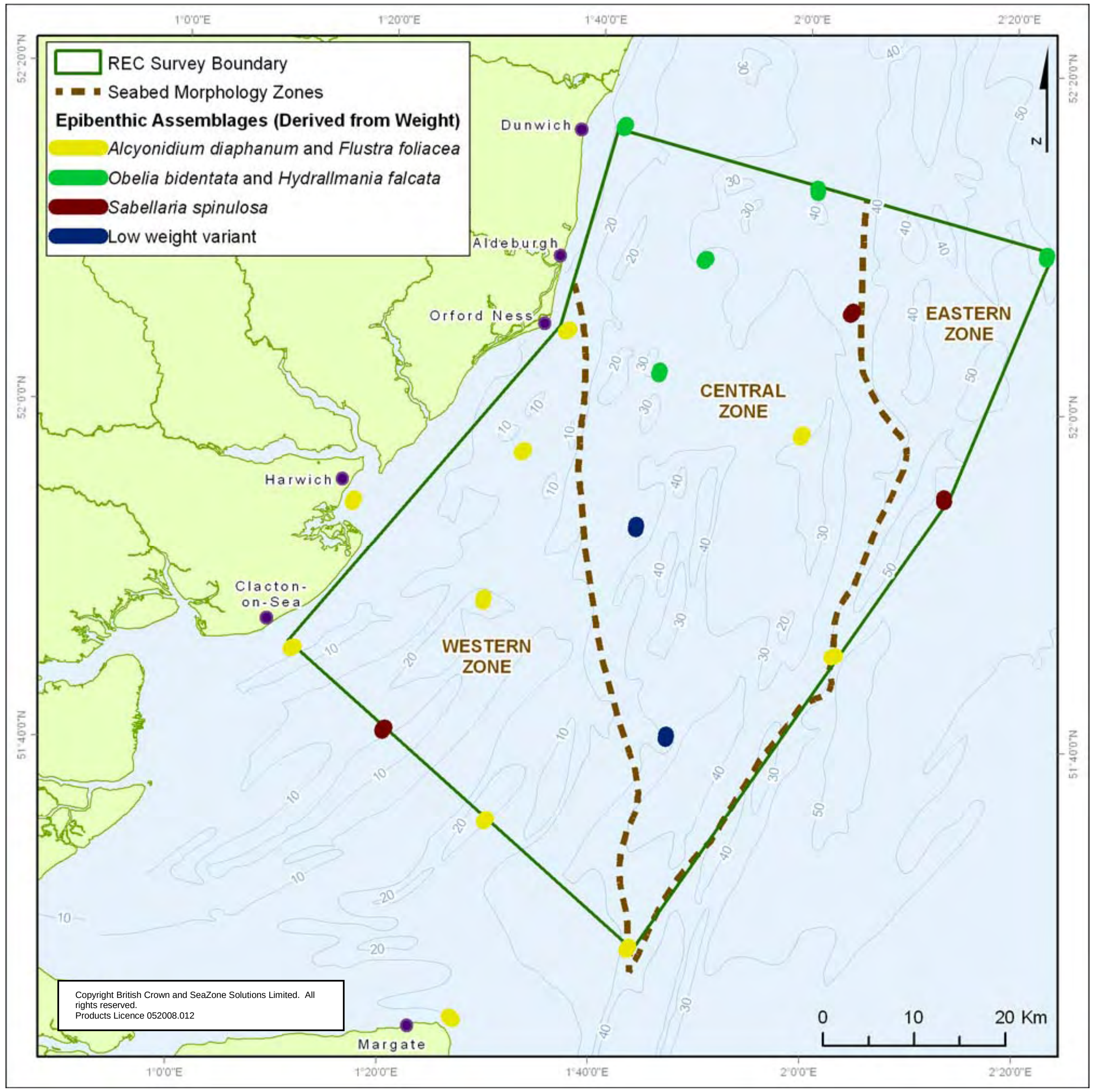

Figure 4.44: Epibenthic assemblages (weight data) in the Outer Thames Estuary REC area derived from the trawl data.

4.4.2 The Mobile Epibenthos

A range of mobile epibenthic species were also caught within the 2 m beam trawl samples. In total the trawl survey recorded 124 larger, mobile species, 72 of which were not recorded in the grabs. Table 4.6 presents a rank of the top 20 most abundant enumerated species found. Among the most numerous species caught with the beam trawls are the brown shrimps, *Crangon allmani* and *C. crangon* with the pink shrimp *Pandalus montagui*, together with brittlestars *Ophiura albida* and *O. ophiura*, the green sea urchin *Psammechinus miliaris*, the flying crab *Liocarcinus holsatus*, sole *Solea solea* and juvenile gobies *Pomatoschistus* spp.

Species that occurred widely throughout the region include both brown and pink shrimps and the green sea urchin together with the common starfish *Asterias rubens*, bib *Trisopterus luscus*, the small spider crab *Macropodia rostrata*, cuttlefish *Sepiola atlantica* and hermit crab *Pagurus bernhardus*.

A total of 28 species of fish were recorded in the trawls. Juvenile gobies *Pomatoschistus* spp. were by far the most numerous fish found and accounted for 57% of the total number of individuals recorded. Sole were also relatively numerous, contributing to 7% of the total number of individuals followed bib (3%). However, in terms of weight, sole was the largest contributor, accounting for 50% of the total weight of fish caught. Thornback ray *Raja clavata* and lesser spotted dogfish *Scyliorhyunus canicula* were secondarily important in this respect accounting for 13% and 11% of the overall weight of fish respectively. Bib and whiting contributed 8% and 5% respectively. Figure 4.46 and Figure 4.47 summarise important species of fish in terms of contributions to total numbers of individuals and total weight.

Figure 4.45: Detail of Trawl sample T9 showing quantities of the green seaweed *Enteromorpha* spp. with sole *Solea solea*.

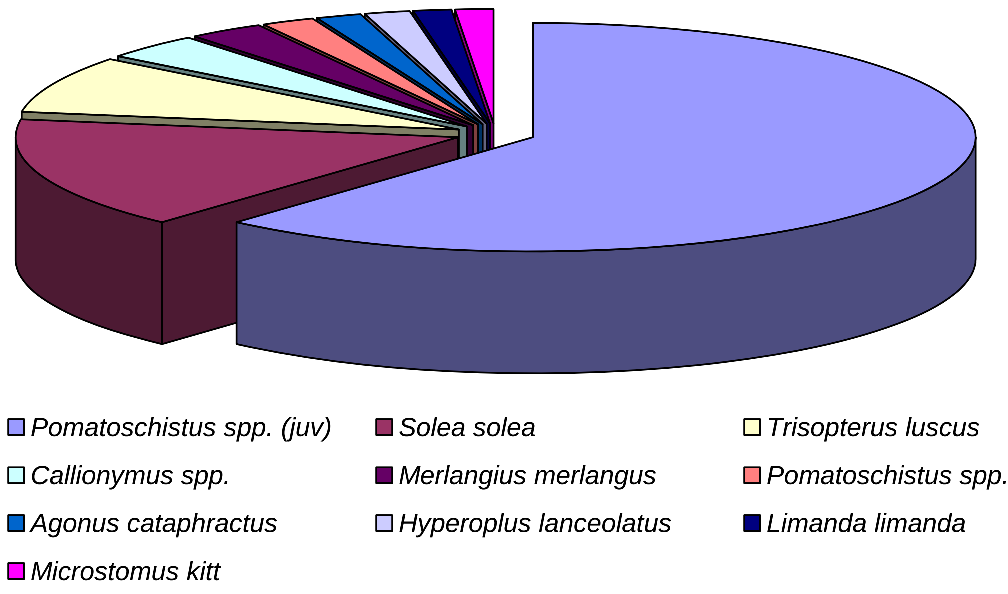

Figure 4.46: Relative contributions of species of fish to the total number of individuals caught in the 2 m beam trawls (species contributing to >1% are shown).

Species	Type of organism	Total Abundance	% frequency of occurrence (n=20)
Crangon allmanni	Brown shrimp	3,260	85
Ophiura albida	Brittlestar	2,695	55
Pandalina brevirostris	Shrimp	1,359	35
Psammechinus miliaris	Green sea urchin	1,291	75
Pandalus montagui	Pink shrimp	1,274	80
Pomatoschistus spp.	Gobies	1,006	85
Ophiura ophiura	Brittlestar	496	35
Crangon crangon	Brown shrimp	478	40
Liocarcinus holsatus	Flying crab	417	95
Solea solea	Sole	256	70
Philocheras bispinosus	Shrimp	152	20
Asterias rubens	Common starfish	150	85
Processa canaliculata	Shrimp	143	30
Trisopterus luscus	Bib	132	75
Balanus crenatus	Barnacle	126	10
Philocheras trispinosus	Shrimp	92	25
Carcinus maenas	Shore crab	83	15
Macropodia rostrata	Spider crab	78	70
Sepiola atlantica	Cuttlefish	70	60
Pagurus bernhardus	Hermit crab	68	75

Table 4.6: Top 20 most abundant species caught within the 2 m beam trawl samples.

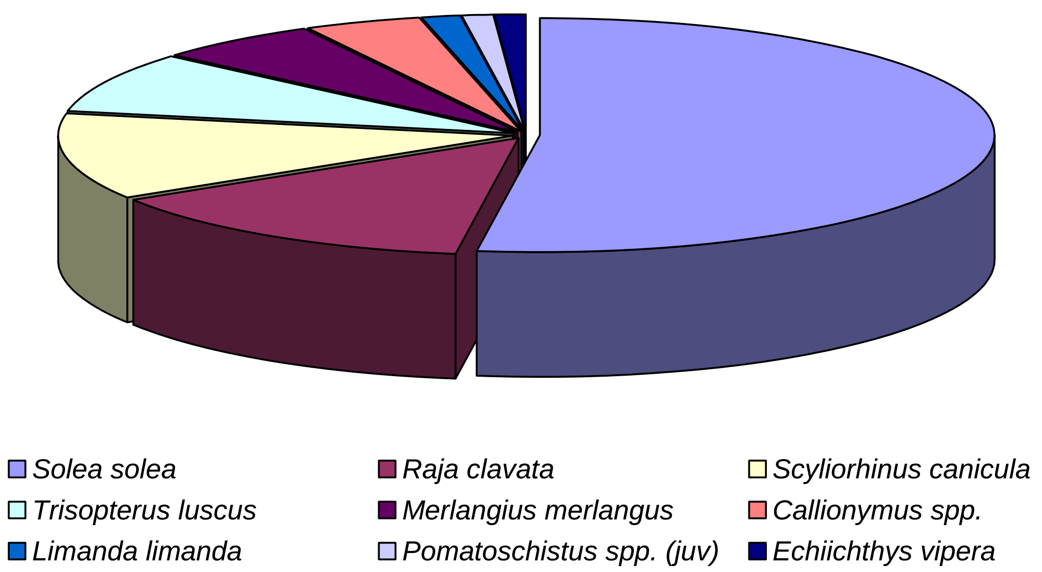

Figure 4.47: Relative contributions of species of fish to overall weight of fish caught in the 2 m beam trawls (species contributing to >1% are shown).

Beam Trawl Group A		Beam Trawl Group B		Beam Trawl Group C	
Samples T01, T07, T41, T63		Samples T45, T54		Samples T03, T05, T09, T17, T20, T23, T29, T32, T34, T43, T47, T56, T66, T69	
Species	Mean Abundance	Species	Mean Abundance	Species	Mean Abundance
Pomatoschistus spp.(juv)	36	*Pandalus montagui*	530	*Crangon allmanni*	214.5
Asterias rubens	8.75	*Pandalina brevirostris*	639	*Ophiura albida*	175.36
Loligo vulgaris	7.5			*Pomatoschistus* spp. (juv)	47.29
Liocarcinus holsatus	7			*Liocarcinus holsatus*	24.93
Callionymus spp.	4			*Psammechinus miliaris*	89.07
Psammechinus miliaris	5			*Crangon crangon*	34.14
Sepiola atlantica	3.75			*Solea solea*	18.21
				Trisopterus luscus	6.5
				Pandalus montagui	14.64
				Asterias rubens	7.14

Table 4.7: Summary of mobile epibenthic species within each trawl sample group. Species are ranked according to their contribution to the internal group similarity following SIMPER analysis (Untransformed data).

4.4.3 Analysis of the Mobile Epibenthos

Multivariate sample sorting (Appendix C) grouped the mobile epibenthos data into three assemblages, A, B and C. Table 4.7 presents those species that are characteristic of each assemblage. Figure 4.48 illustrates the distribution of representative samples throughout the Outer Thames Estuary REC. Figure 4.49, Figure 4.50 and Figure 4.51 show example photographs of each trawl grouping.

The vast majority of the mobile epibenthic assemblages were represented by cluster C. Given its widespread distribution it would appear to be the characteristic community of mobile epibenthic species for the Outer Thames Estuary REC. It was typified by brown and pink shrimps, bib, sole, echinoderms and crabs that are common to the shallow waters of the southern North Sea and which are considered characteristic of the region (see Section 2.5). Samples representing this cluster showed no specific distribution pattern and did not appear to relate to any specific sediment type or habitat preference. Indeed, samples were dispersed widely throughout the study site including the inshore shallow muddy sand sediments and the deeper water disturbed sands further offshore.

Clusters A and B possibly represent variants of the primary epibenthic assemblage depending upon the relative abundances of shrimps, in particular *Pandalina brevirostris*, *Pandalus montagui* and Crangonidae. High abundances of these species were found within the samples comprising cluster B whilst mean numbers were comparatively low in Cluster A. This might indicate the aggregating behaviour of shrimps and non-uniform distribution across the study area.

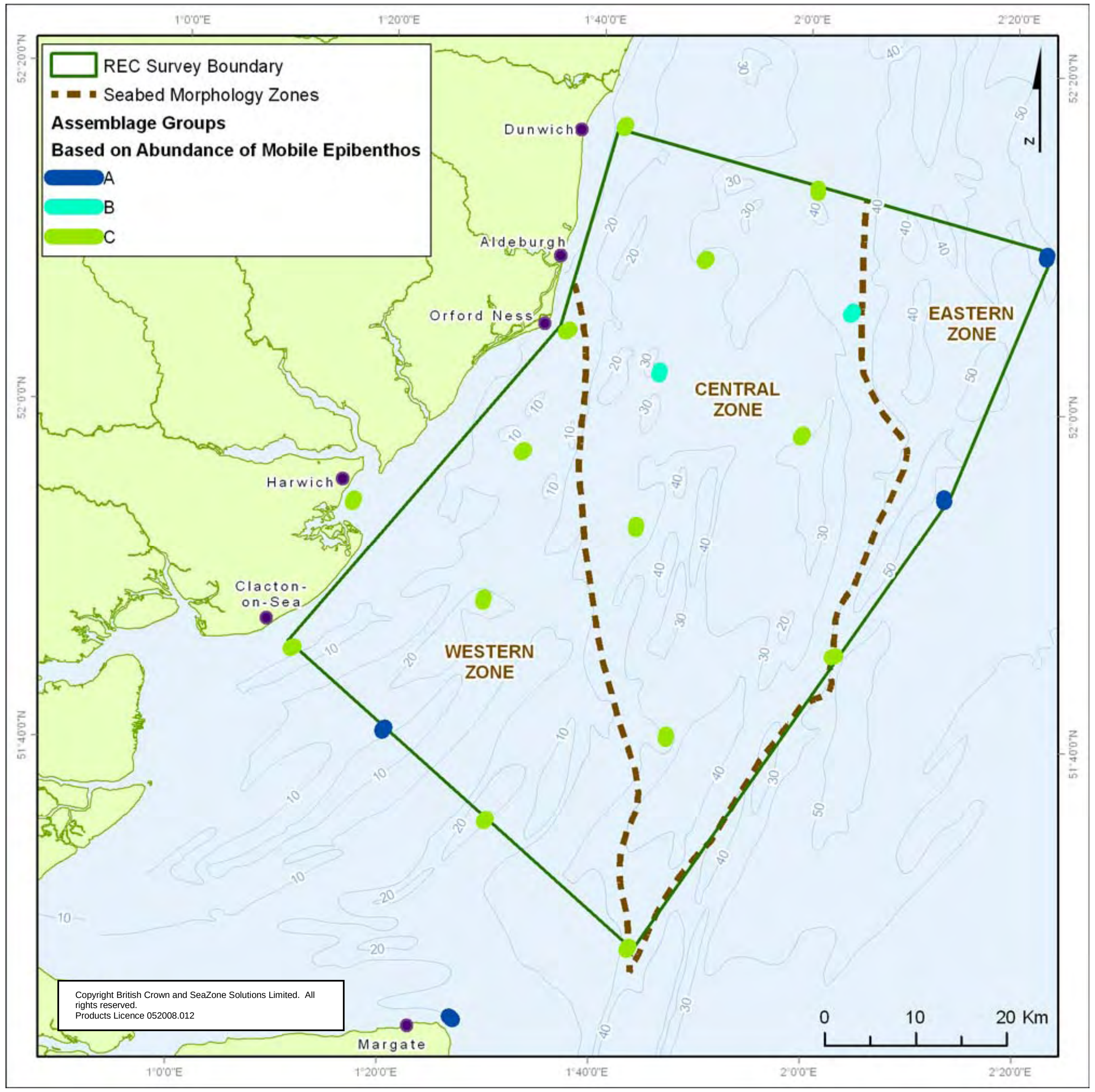

Figure 4.48: Epibenthic Assemblages within the Outer Thames Estuary REC region, calculated on abundance of mobile epibenthos.

Figure 4.49: Example photographs of 2m beam trawl samples belonging to Group A.

Figure 4.50: Example photographs of 2m beam trawl samples belonging to Group B.

Figure 4.51: Example photographs of 2m beam trawl samples belonging to Group C.

4.5 Species-Environment Relationships

As discussed in Section 2.5 the influence of environmental factors such as seabed thermal stability, sediment type, depth, food type and food availability has long been recognised as having important influences on the structuring of benthic communities in the North Sea. At the scale of the current Outer Thames Estuary REC study area it is unlikely that there will be any appreciable variations in seabed temperatures but both the bathymetry data and geological interpretations presented in Section 2.2 show variations in both depth and sediment types across the site together with variations on a larger scale as morphological zones. This section investigates the environmental gradients that have been measured as part of the Outer Thames Estuary REC process and relates these to the observed variations in the characteristics of the habitats and associated biological communities.

Sediment type in particular has a strong influence on the structuring of marine benthic communities (e.g. Hayward & Ryland, 1995) and gradients in sediment types relate to typical and predictable continua of community variation. Complex sediments, such as coarse grained and mixed sand and gravels offer a number of different micro-niches for exploitation by benthic animals. The surfaces of gravel particles, for example, can provide suitable attachment sites for a number of different types of encrusting and attaching epifauna, such as hydroids, bryozoans and barnacles whilst cryptic fauna, such as scale worms, may refuge and forage under gravel and pebbles. The finer sediment components provide burrowing habitat for a variety of sediment dwelling worms, echinoderms and crustaceans. Simpler sediment habitats such as the comparatively homogeneous shallow water sands associated with the sand banks often support a reduced macrofauna relative to more heterogeneous sediment types. Sessile epifauna, for example, will not be present where there is an absence of suitable stable surfaces for attachment whilst the continual erosion of fine sediment particles from mobile sand habitats can reduce food availability for deposit feeding animals.

Depth variations can have important relationships with gradations in substrate stability and food availability so that this factor can also have important consequences for macrobenthos. Sediments within deeper water areas for example can be less influenced by disturbances due to wave action at the surface and are thus more stable or more predictably influenced than those in shallower water areas. Also, deeper waters can reduce the amount of light that reaches the seabed thus limiting the growth of benthic diatoms on sand grains and precluding these as a food source for “sand-licking” sediment macrofauna (Wieking and Krönke, 2005). Consequently, the macrofaunal assemblages in deeper water areas may comprise a higher proportion of species that can utilise surface and sub-surface organic deposits compared to shallow water assemblages.

A simple assessment of the potential influences of sediment type on macrofauna within the Outer Thames Estuary REC area is shown in Figure 4.52, Figure 4.53 and Figure 4.54. These present the mean faunal richness, diversity and biomass values for each Folk sediment classification as derived from the Hamon grab data. Clearly, there is a relationship between sediment classification and the value of these biological indices. In general the finer grained sand and mud sediments, including slightly gravel sandy mud, slightly gravelly sand, sandy mud and sand, support comparatively low richness, diversity and biomass values. In contrast, the more complex coarser grained sediment types, such as the sandy gravel, gravelly mud, muddy sandy gravel and cobble substrates were associated with the greatest richness, diversity and biomass values. This would be expected given the greater availability of micro-niches offered by varied, coarser grained sediments.

Relationships between macrobenthos and sediment habitats have already been explored in Section 4.3 and by the overlay of multivariate sample groupings onto the geological interpretation. Whilst the epibenthos appears to be largely homogeneous across the site with little correspondence with sediment types, there is clear evidence of close relationships between infaunal communities and benthic habitats. In particular the overlay of sample clusters onto the seabed sediment map reveals the close relationships between typical groups of sand fauna, such as *Nephtys cirrosa*, *Ophelia borealis*, *Gastrosaccus spinifer* and *Bathyporeia elegans* with the locations of the major shallow water sandbank features. Furthermore, the presence of comparable macrofauna at the deeper water bedform field to the north and east highlights the degree of consistency in community response to the availability of this sediment habitat type despite the differences in depth.

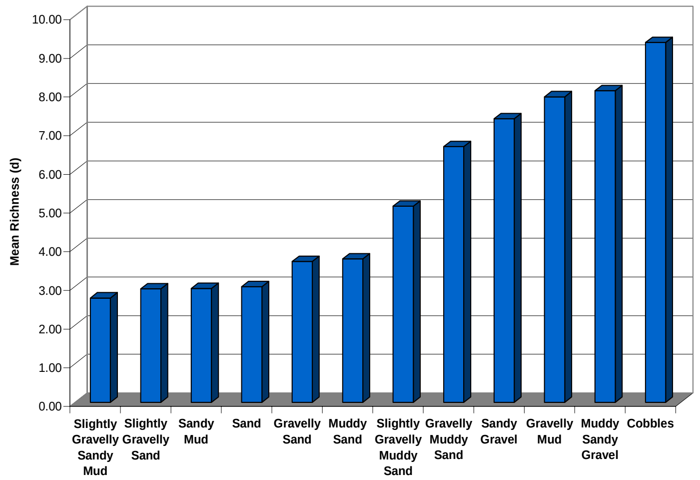

Figure 4.52: Relationships between Folk sediment classification and macrofaunal richness.

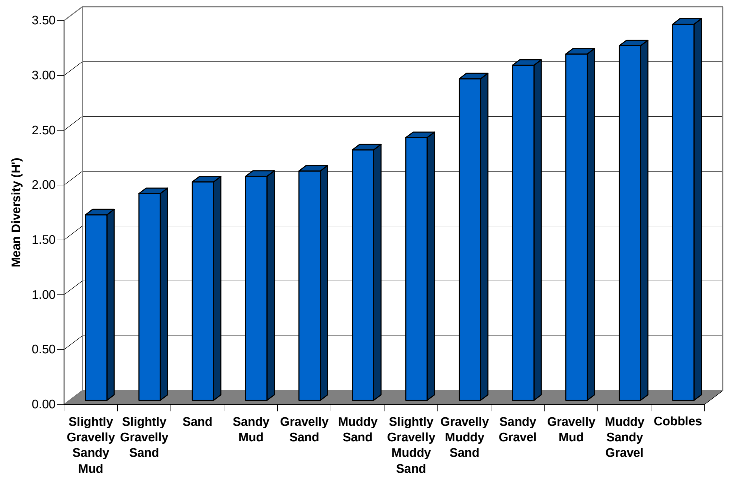

Figure 4.53: Relationships between Folk sediment classification and macrofaunal diversity.

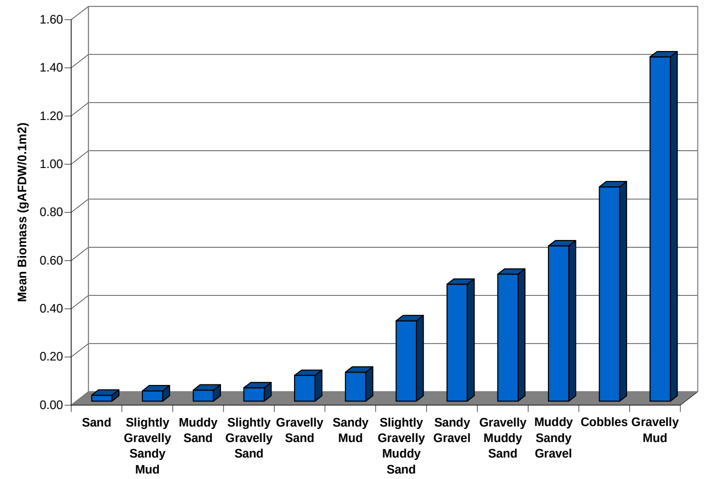

Figure 4.54: Relationships between Folk sediment classification and biomass.

Equally, there is a good overall correlation between the mixed sand and gravel sediments within central areas of the study area and the richer and more diverse community characterised by *Sabellaria spinulosa*, *Ampelisca spinipes*, *Lumbrineris gracilis* and *Notomastus* spp.. Muddier sediments fringing the Essex and Suffolk coasts are also closely associated by a typical suite of muddy sand fauna including *Nephtys hombergii*, *Nucula nucleus*, *Lagis koreni* and *Abra alba*. Less obvious, however, is the relationships between the variant sub-communities and sediment types. Comparison of the fractional sediment data presented in Table 4.4 for example shows very little sediment differences between sub-clusters B1 and B2 and yet two distinct communities have been clearly identified suggesting other factors may also be instrumental in the structuring of benthic communities in these areas.

Whilst this overlay technique illustrates some apparent relationships between substrate type and macrofaunal distribution, this was not entirely supported by the results of a BIOENV analysis of the grab data (Table 4.8).

A number of environmental variables were input into the BIOENV routine including a range of sediment components, sediment diversity and depth. Sediment diversity was the single variable that best explained macrofaunal distribution followed by sediment sorting although the correlation coefficients were low and inconclusive. Depth was particularly poorly correlated as a single variable. Correlations are slightly improved with the addition of a number of other variables including sediment sorting, % coarse sand, % silt/clay and sediment diversity. However the correlation between benthic communities and sediment types and depths was not strong. It is therefore possible that there are additional factors that influence macrobenthic distribution. These may include sediment instability, estuarine inputs and anthropogenic activities and may operate singly or in combination.

Variables	Correlation coefficient (r)
Single Variable	
Sediment diversity	0.303
Sediment sorting coefficient	0.279
Depth (m)	0.135
Multiple Variables	
Sorting, % coarse gravel, % coarse sand, % silt/clay, sediment diversity	0.383
Sorting, % coarse gravel, % silt/clay, sediment diversity, depth (m)	0.381
Sorting, % coarse gravel, % fine sand, %silt/clay, sediment diversity	0.374
Sorting, % coarse gravel, % coarse sand, sediment diversity, depth (m)	0.372

Table 4.8: Results of the BIOENV analysis using enumerated data, the environmental variables were normalised and included sorting % composition of the main sediment components and depth (m).

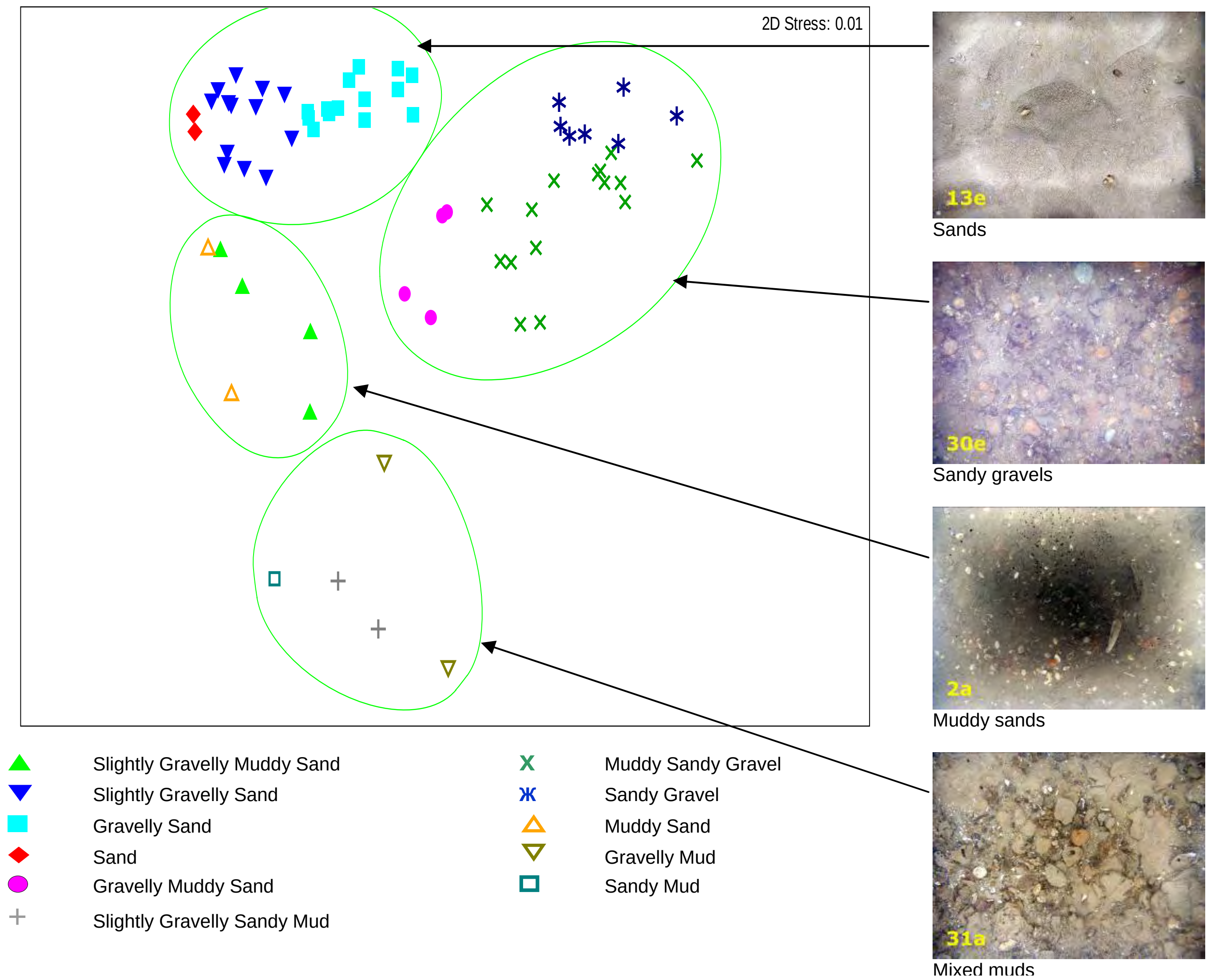

Figure 4.55: MDS ordination of particle size distribution data (% gravel, % sand, % silt) (Euclidean distance) overlaid with Folk sediment classifications and clusters denoting four generic sediment descriptions. Clusters were created by PRIMER at a selected Euclidean distance value.

Given the low correlation between the physical and biological environment at the community level it is perhaps worth investigating species level relationships with sediment types. A simple way to achieve this is by matching species densities to sediment types. In this way any species habitat preferences can be established. The process can be further simplified by aggregating the Folk sediment classifications into a more convenient number of generic sediment descriptions. In this instance, the sediment particle size data have been clustered into four generic substrate types (Sands, Sandy Gravels, Muddy Sands and Mixed Muds) as shown in the MDS ordination in Figure 4.55.

Overlay of the abundances of selected species onto the generic sediment clusters (Figure 4.56) demonstrates that *Notomastus* spp., *Abra alba* and *Nephtys hombergii* has no apparent preference for any sediment habitat type. These species were ubiquitous across all the sediment clusters. Other species, however appear to avoid muddy sediments and are therefore generally restricted to the mixed sand and gravel sediment groupings where fines levels were typically low. *Sabellaria spinulosa* for example is mostly associated with the sandy gravel sediments with some high abundances found in the sandy and muddy sand habitats. Other species were more selective still with their environmental conditions. *Ampelisca spinipes* for example was only found in the mixed sands and gravels whereas *Ophelia borealis* and *Nephtys cirrosa* were almost exclusive to the cleaner sand sediments.

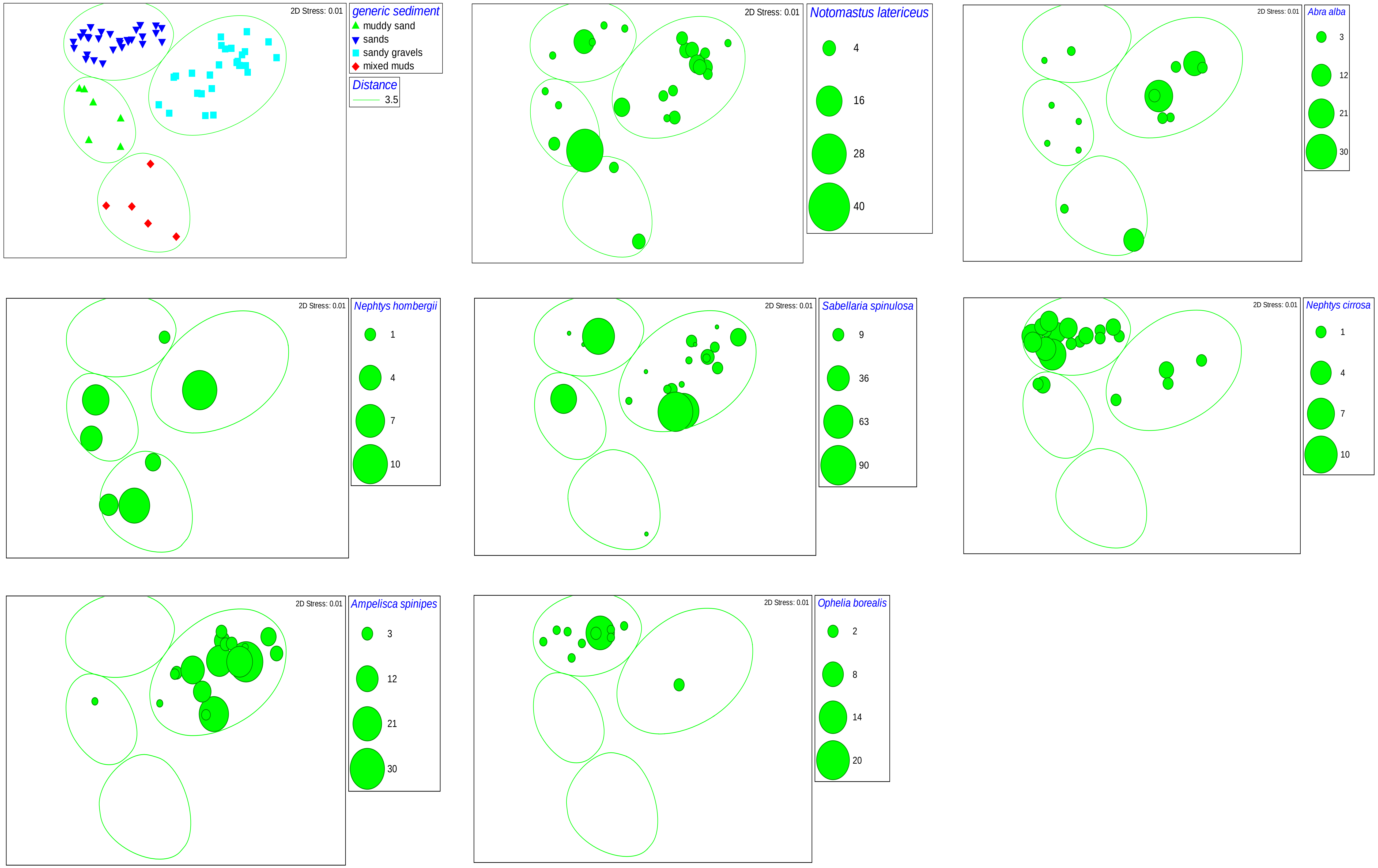

Figure 4.56: MDS ordinations of sediment particle size data overlaid with bubbles proportional in size to the relative species abundances (numbers per 0.1 m^2).

4.6 Regional Environmental Assessment Data

This section provides a brief account of the Outer Thames Marine Aggregate Regional Environmental Assessment (MAREA) benthic grab and trawl data, provided courtesy of Thames Estuary Dredging Association (TEDA), for the purposes of enhancing the current characterisation. Further use of MAREA benthic data is made in Section 5 to refine the boundaries of habitats and biotope complexes and to increase the level of confidence of inferred seabed habitat classifications. A comprehensive analysis and assessment of the MAREA datasets will be made within the Outer Thames Estuary Regional Environmental Assessment.

MAREA benthic field data was collected in August 2008. Corresponding MALSF (REC) survey data was collected almost a year earlier in September 2007. The locations of the MAREA samples, including both 0.1 m^2 Hamon grab and 2m beam trawl samples, relative to the Outer Thames Estuary REC survey array is shown in Figure 4.57. In total, 126 grab samples and 16 beam trawl samples were collected during the MAREA survey. The seabed sampling effort was focused around dredging licence and application areas for the purpose of effectively assessing any impacts aggregate extraction might have on the benthic environment. PRIMER analyses of the MAREA benthic data are provided in Appendix C, in addition to those produced for the Outer Thames Estuary REC data.

4.6.1 Sediment Data

Sub-samples collected from Hamon grabs during the MAREA survey were analysed for particle size distribution analysis and for sediment classification via the Folk classification system. Ten different Folk sediment classifications were identified as summarised in Figure 4.58.

No one sediment type dominated the MAREA survey area although mixed gravelly sediments were particularly well represented. This would be expected given that the sampling effort was concentrated at and around the aggregate licences and aggregate application areas, where there is naturally a greater coarser sediment (gravel aggregate) resource. Sand and mud sediments were less well represented and reflect the comparatively reduced sampling effort along the inshore coastal fringe areas and offshore areas around the periphery of the Outer Thames Estuary REC study area.

4.6.2 Macrofaunal data

Following rationalisation (see Section 4.1.1 for procedure) a total of 380 taxa were identified from the grab samples. These included 320 solitary countable fauna, such as polychaetes, crabs, amphipods, molluscs and echinoderms and 60 non-countable colonial sessile fauna such as hydroids and bryozoans.

The higher total taxa variety recorded on this occasion, compared to the Outer Thames Estuary REC study, is likely to be a result of the greater number of samples collected.

With respect to conspicuous taxa, there was a good degree of correspondence with the Outer Thames Estuary REC data and other, historic, survey data. In particular, *Abra alba*, *Lagis koreni*, *Spiophanes bombyx*, *Ampelisca spinipes*, *Sabellaria spinulosa*, *Pisidia longicornis*, *Lumbrineris gracilis*, *Photis longicaudata*, *Molgula manhattensis*, *Ophiura albida*, *Amphipholis squamata*, *Pomatoceros* spp. and *Notomastus* spp. were commonly found in high abundance during both the Outer Thames Estuary REC and MAREA surveys.

The greatest single species abundance was however attributed to the amphipod *Ampelisca diadema*. The total number of this species recorded within MAREA was 9,627 individuals although this was attributed to a particularly high density at station 83 (9,063 individuals / 0.1 m^2). High densities of the bivalve *Abra alba* (391 individuals / 0.1 m^2) and the amphipod *Photis longicaudata* (251 individuals / 0.1 m^2) were also noted at this location. The associated sediment was classified as a muddy sandy gravel.

High densities of *Ampelisca diadema* in silty gravel and cobble sediments have previously been identified in Sandown Bay (Southern Science Ltd., 1996). Here they constituted an '*Ampelisca* reef' and were described as consolidated silt deposits forming a muddy reef which is maintained by the amphipod *A. diadema*. This species constructs tubes within the fine sediment, consolidating the silts and possibly causing further accumulation of sediment. It was noted that in Sandown Bay, the *Ampelisca* reefs were frequently located near a bedrock feature including mudstone outcrops. *Ampelisca* 'mats' have also been found in Swanage Bay in association with maerl beds (www.seasearch.co.uk) and forming extensive patches within muddy gravel substrates.

Seabed photography collected at station 83 in the Outer Thames MAREA study area was inconclusive as to the characteristics of the benthic habitat but associated seabed video showed extensive areas of muddy gravels with dense *Ampelisca diadema* tubes. These areas had well defined vertical edges and appeared to be raised up above the surrounding sandy gravel seabed by some tens of centimetres. These conditions compare with those described for the *Ampelisca* reef habitat in Sandown Bay and Swanage Bay. Further discussion on the potential *Ampelisca* reef at station 83 is given in Section 5.

4.6.3 Comparisons with REC Data

Eleven MAREA sample stations coincided with those visited during the Outer Thames Estuary REC. While no sediment data was recovered from the REC survey site 45, the remaining ten sample pairs provided an opportunity for comparison and validation of sediment and community data between the two survey occasions. Table 4.9 compares biological and sediment characteristics for each of the paired samples and demonstrates that apart from a few differences there was an overall close correspondence between the Outer Thames Estuary REC and MAREA datasets in terms of species numbers, abundance and sediment descriptions.

Although a few inconsistencies are apparent, a cluster analysis of the faunal data from these ten pairs of samples (Figure 4.59) illustrates that community composition was broadly comparable between the Outer Thames Estuary REC and MAREA surveys. For instance, sample 73 collected as part of the MAREA survey was found to have higher numbers of species and individuals compared to its counterpart REC sample (sample 21A) but was, nevertheless, grouped on the sample sorting Dendrogram (Appendix C), suggesting an overall comparable community structure. Likewise sample 79 collected during the MAREA programme contained a higher total abundance of taxa than its corresponding REC sample (sample 69A). In terms of community structure however, the two samples were very closely related.

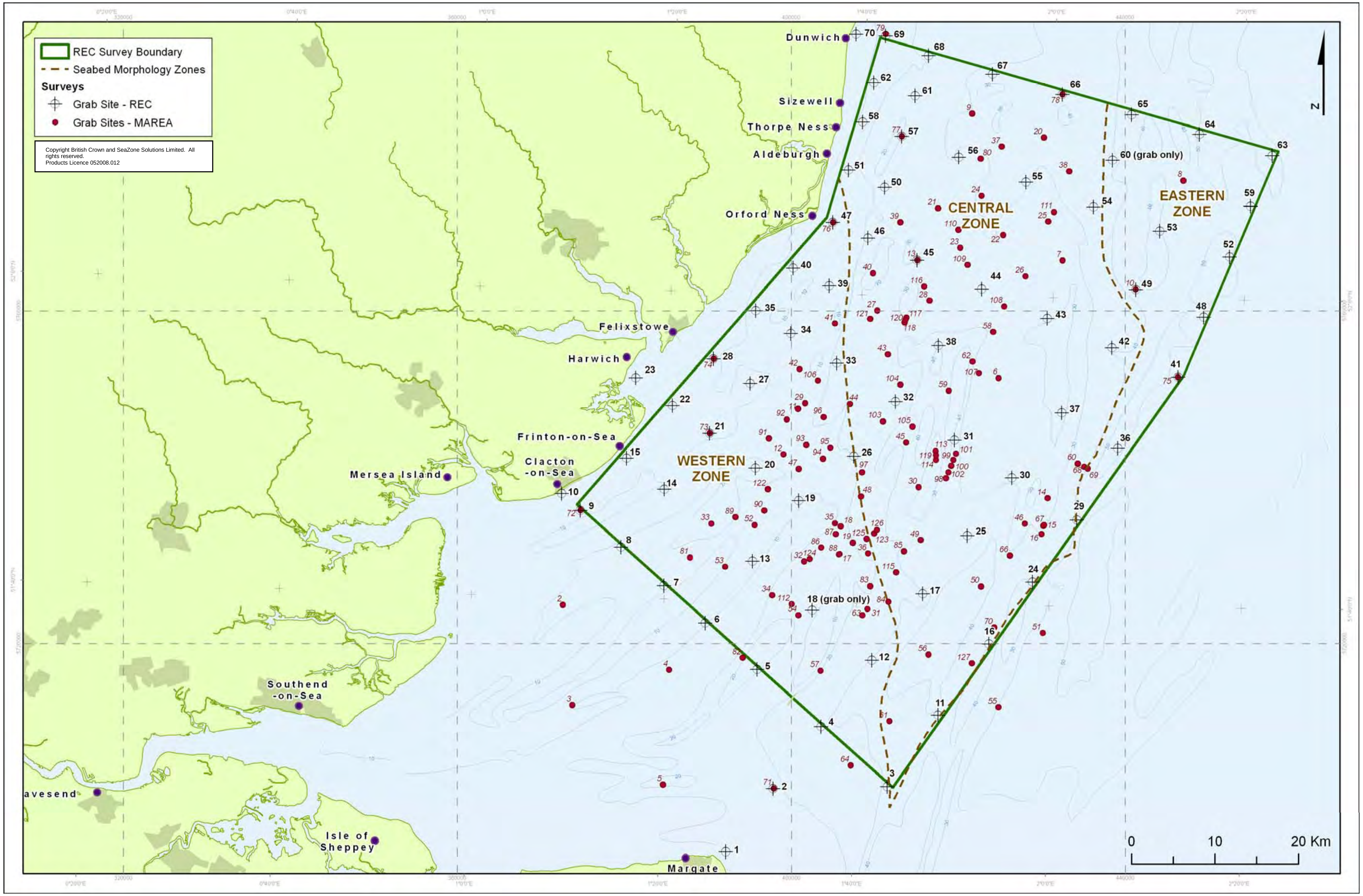

Figure 4.57: Combined Outer Thames Estuary REC and Marine Aggregate Regional Environmental Assessment Hamon grab sample array.

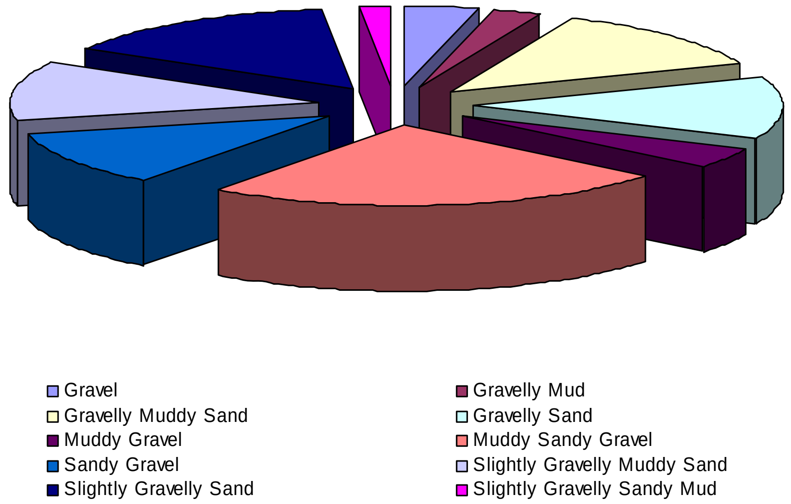

Figure 4.58: Proportional summary of the Folk sediment classifications identified from the TEDA MAREA data.

MAREA Data (August 2008)				Corresponding MALSF Outer Thames Estuary REC Data (September 2007)			
Sample	No. of Individuals (per 0.1 m^2)	No. of Species (per 0.1 m^2)	Folk Sediment Classification	Sample	No. of Individuals (per 0.1 m^2)	No. of Species (per 0.1 m^2)	Folk Sediment Classification
71	478	49	Slightly Gravelly Muddy Sand	**02A**	507	52	Slightly Gravelly Muddy Sand
72	18	9	Slightly Gravelly Muddy Sand	**09A**	22	10	Slightly Gravelly Sandy Mud
73	1,039	72	Muddy Sandy Gravel	**21A**	212	37	Muddy Sandy Gravel
74	223	34	Muddy Sandy Gravel	**28A**	22	13	Gravelly Mud
75	19	11	Slightly Gravelly Sand	**41A**	14	9	Slightly Gravelly Sand
76	33	25	Sandy Gravel	**47A**	32	16	Muddy Sandy Gravel
77	11	5	Slightly Gravelly Muddy Sand	**57A**	12	7	Sand
78	29	15	Slightly Gravelly Sand	**66A**	8	8	Gravelly Sand
79	88	30	Gravelly Muddy Sand	**69A**	166	20	Muddy Sandy Gravel
10	33	20	Sandy Gravel	**49A**	289	16	No PSD sample

Table 4.9: Comparison of the number of individuals and species identified from the MAREA sample data and the corresponding Outer Thames Estuary REC data.

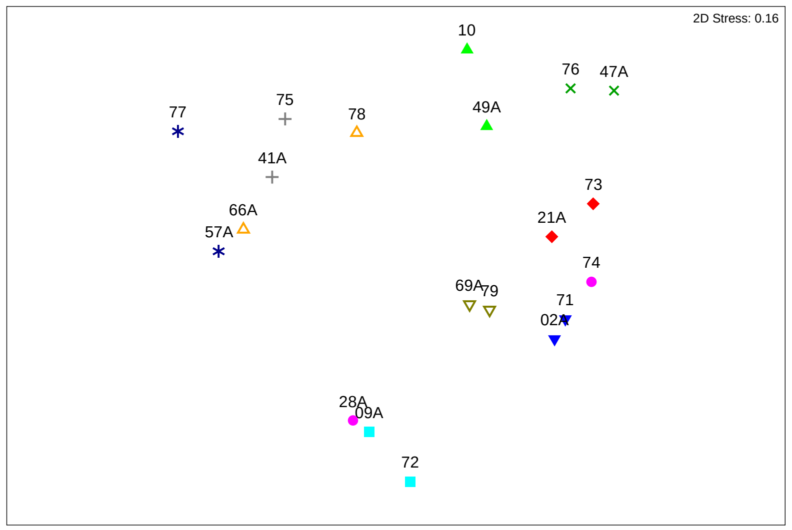

Figure 4.59: MDS plot demonstrating the relative similarities between ten paired samples collected during the Outer Thames Estuary REC and MAREA surveys (enumerated faunal data square root transformed).

Large differences in community structures were apparent for samples 77 & 57A and 78 & 66A, relating to the disproportionate effect of species differences for impoverished datasets. Both of these pairs of samples contained comparatively low numbers of species and numbers of individuals, such that any differences between the samples in the PRIMER analysis will be larger compared to the equivalent differences between samples within a group of richer and more diverse samples.

There is evidence, however, of a change of habitat and community structure inshore and close to the outflow of the rivers Stour and Orwell. This is reflected by the wide separation between REC samples 28A and its corresponding MAREA sample (sample 74). The seabed varied from a gravelly mud in 2007 to muddy sandy gravel in 2008. The fauna appears to have undergone a considerable change from an impoverished *Nepthys caeca*, *Aphelochaeta marioni* and Tubificid community indicative of variable salinity conditions to a more diverse *Ampelisca* spp., *Abra alba* and *Lagis koreni* community, indicative of a fully marine environment.

4.6.4 Macrofaunal Assemblages

The MAREA enumerated macrofaunal data (excluding non-enumerated colonial epifaunal data) were subject to cluster analysis and MDS (Appendix C). This revealed 4 main groupings (Groups C, D, F and G). Table 4.10 gives a summary of the main biological and sediment characteristics for each of the main groupings. This includes a summary of a SIMPER analysis to identify those species contributing most to the internal group similarity as well as summary sediment data.

Three smaller outlier groups comprising just one or two samples were also formed following this analysis (Groups A, B and E). Figure 4.60 shows the distribution of all macrofaunal sample groups across the study area.

Group C

Group C was the largest grouping of MAREA samples comprising 68 samples. This group encompassed a wide variety of sediment types collected from across the study area. Consequently no clear spatial pattern was evident although the habitats were mostly related to coarse and mixed sediment substrates. Conspicuous species in terms of contributions to the internal group similarity and frequency of occurrence included the polychaetes *Ampharete lindstroemi* and *Lagis koreni* together with the bivalve *Abra alba*, the amphipod *Ampelisca spinipes* and the long-clawed porcelain crab *Pisidia longicornis*. Species and sediment attributes were comparable to those encompassed within the Outer Thames Estuary REC Groups A and B, which were characterised by the finer grained muddy sand biotopes **SS.SSa.CMuSa.AalbNuc** and **SS.SMu.CSaMu.LkorPpel** and coarser circalittoral sediment biotopes (**SCS**) including **SS.SCS.CCS.MedLumVen**. High densities of the amphipods *Ampelisca diadema* with *Photis longicaudata* fit the **SS.SMu.ISaMu.AmpPlon** biotope as exemplified at station 83. Seabed video shows that a few locations within this grouping comprised exposed London clay bedrock relating to the soft rock biotope classification **CR.MCR.SfR**. Although the clay bedrock was clearly bored, no boring bivalves, such as *Barnea candida* which typified these areas during the Outer Thames Estuary REC data analyses, were found in the MAREA grab samples. They were, however, found in two of the MAREA beam trawl samples.

This large grouping was further sub-divided into two smaller sub-groups (sub-groups C1 and C2) based on the sample partitioning evident in the dendrogram (Appendix C). A further SIMPER analysis showed that the samples were partitioned principally as a result of differences in the abundances of *L. koreni*, *Spiophanes bombyx*, *Saxicavella jeffreysi*, *A. alba*, *P. longicornis* and *A. spinipes*. The larger of the sub-groups, sub-group C1 comprised 53 samples and was characterised by *Lumbrineris gracilis*, *P. longicornis*, *Caulleriella alata*, *Glycera lapidum*, *A. spinipes*, *A. lindstroemi* and *Notomastus* spp. These species and the associated sediment types relate to circalittoral coarse sediment biotopes (**CCS**) and mixed sediment biotopes (**CMx**) and correspond with the comparatively rich and diverse faunal Group B found following analysis of the Outer Thames Estuary REC data.

	Macrofaunal Group C	Macrofaunal Group D	Macrofaunal Group F	Macrofaunal Group G
No. of Samples	68	17	23	13
Species contributing most to the internal group similarity	*Ampharete lindstroemi* *Abra alba* *Ampelisca spinipes* *Spiophanes bombyx* *Lumbrineris gracilis* *Pomatoceros* spp. *Pisidia longicornis* NEMERTEA *Ophiura albida* *Lagis koreni*	*Glycera lapidum* *Lumbrineris gracilis* *Echinocyamus pusillus* *Balanus crenatus* *Sabellaria spinulosa*	*Nephtys cirrosa* *Ophelia borealis*	*Glycera lapidum* *Polycirrus* spp. *Spisula solida* NEMERTEA *Glycera oxycephala* *Gastrosaccus spinifer* *Nephtys cirrosa* *Notomastus* spp.
Species ranked on % frequency of occurrence	*Pisidia longicornis* *Ampelisca spinipes* *Abra alba* *Lagis koreni* NEMERTEA *Mediomastus fragilis* *Caulleriella alata* *Ampharete lindstroemi* *Ophiura albida* *Amphipholis squamata*	*Glycera lapidum* *Aonides paucibranchiata* NEMERTEA *Lumbrineris gracilis* *Sabellaria spinulosa* *Notomastus* spp.	*Nephtys cirrosa* *Ophelia borealis* *Spiophanes bombyx* *Bathyporeia elegans*	*Glycera lapidum* *Polycirrus* spp. *Glycera oxycephala* *Spisula solida* NEMERTEA *Gastrosaccus spinifer* *Notomastus* spp. *Nephtys cirrosa*
Average % Gravel	34.59	41.15	12.56	15.50
Average % Sand	48.02	49.12	80.26	82.67
Average % Mud	17.39	9.73	7.18	1.83
Associated Sediment Classifications	Slightly Gravelly Sandy Mud Slightly Gravelly Sand Slightly Gravelly Muddy Sand Sandy Gravel Muddy Sandy Gravel Muddy Gravel Gravelly Sand Gravelly Muddy Sand Gravelly Mud Gravel	Sandy Gravel Muddy Sandy Gravel Gravelly Sand Gravelly Muddy Sand	Slightly Gravelly Muddy Sand Gravelly Sand Gravelly Muddy Sand Gravel	Slightly Gravelly Sand Sandy Gravel Gravelly Sand Gravelly Muddy Sand Gravel

Table 4.10: Summary of the biological and sediment characteristics for each major MAREA macrofaunal sample groups.

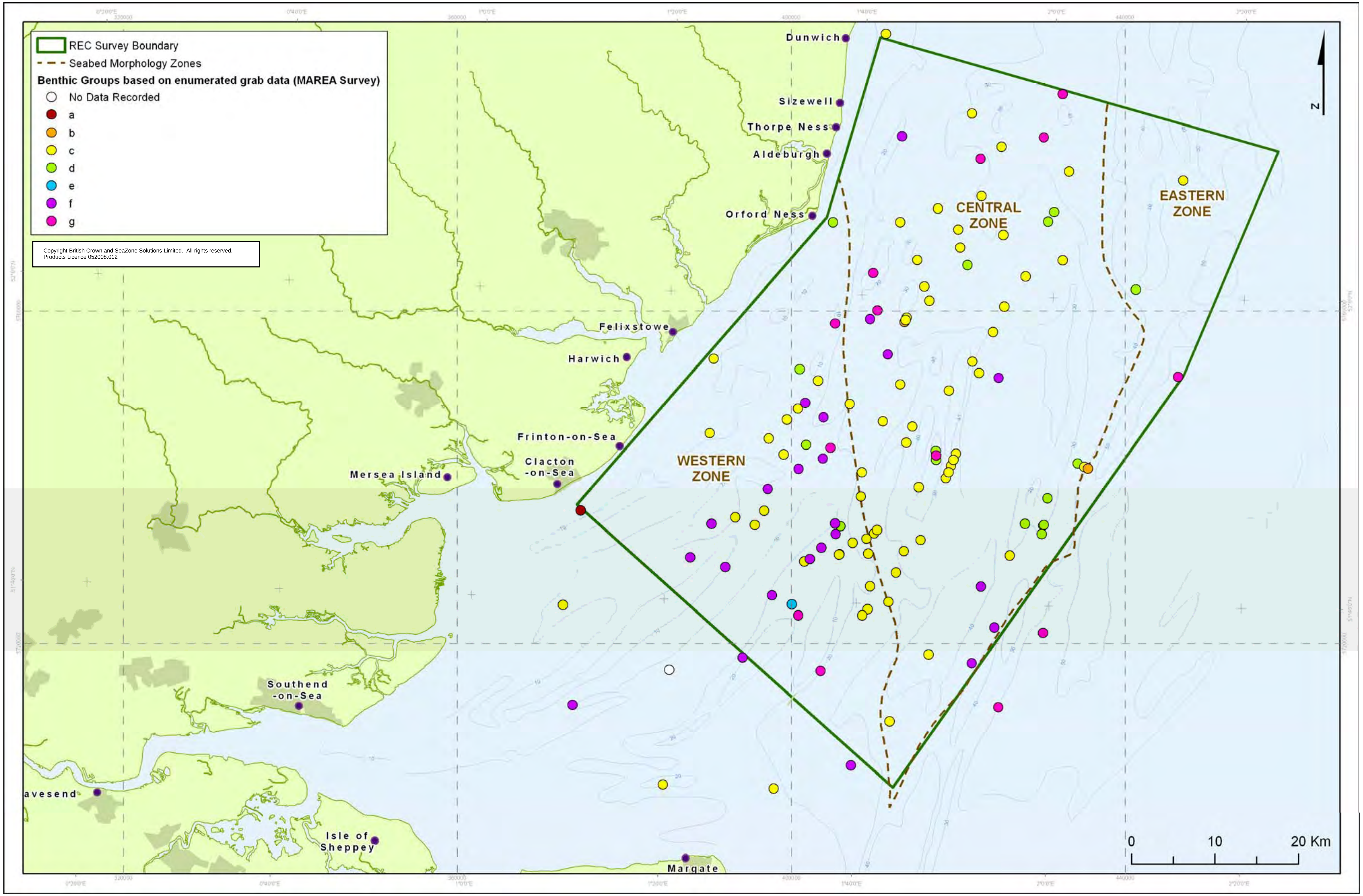

Figure 4.60: Distribution of macrofaunal groups based on enumerated grab sample data derived from the MAREA survey.

These types of biotopes dominated central areas of the outer Thames study area where coarser sand and gravels and mixed muddy gravels were found to occur.

The smaller of the two sub-groups (sub-group C2) encompassed sediments containing a higher proportion of mud. Typical species, therefore, included those that are indicative of finer grained muddy sand and mixed muddy sediments such as *A. alba*, *S. bombyx* and *Mysella bidentata*. This sub-grouping related to the circalittoral muddy sand biotopes (**CMuSa**) found mostly along inshore areas and at the base of some of the sand banks during the REC but which also occurred, albeit with a more patchy distribution throughout the study area, as identified by the MAREA data.

Groups D & G

Both of these faunal groupings were comparatively impoverished, compared to Group C and were characterised by *Glycera lapidum*, *Notomastus* spp. and nemerteans. It is likely that both groups represent areas of sand and sandy gravels given the range of characteristic species descriptions. The relative paucity of species also suggests a degree of sediment disturbance.

Group D is likely to represent areas of coarser sandy gravel sediment material as indicated by the presence of the barnacle *Balanus crenatus* and *Sabellaria spinulosa* which encrust onto larger gravel particles. Group G on the other hand may reflect patches of finer grained sand habitats as indicated by the presence of typical, fine sand species *Nepthys cirrosa* and the mysid shrimp *Gastrosaccus spinifer*. Both groups relate to the **SCS** (sublittoral coarse sediment) biotopes and are likely to represent impoverished variants of **SS.SCS.CCS.MedLumVen** and **SS.SCS.CCS.Pkef**. Shallow water areas subject to sediment disturbance through wave action may support the biotope **SS.SCS.ICS.Glap**.

Group F

This group corresponded very well with the Outer Thames Estuary REC faunal Group C (see Table 4.4). It was closely associated with the homogenous fine sand sediments of the main sand bank features to the south of the study area and supported a typical mobile sand fauna including *Nepthys cirrosa*, *Bathyporeia elegans* and *Ophelia borealis*.

In this instance the MAREA data supported the findings of the Outer Thames Estuary REC with respect to the classification of the fine sand habitats associated with the sand banks. Biotopes related to the **IFiSa** (infralittoral fine sand) family of biotopes and included **SS.SSa.IFiSa.IMoSa** and **SS.SSa.IFiSa.NcirBat** as noted during the REC study.

Outlier groupings

Three small outlier groups, each comprising just one or two samples, were also revealed following the multivariate analysis of MAREA faunal data. Group A only comprised one sample of muddy sandy gravel (sample 73). This was collected to the south and west of the study area and corresponded to sample 21 of the Outer Thames Estuary REC survey array. Sediment attributes matched a **SS.SCS.CCS** (coarse sublittoral sediment) biotope complex, comparable to Group B2 identified in the area from the REC data. The sample was relatively diverse (72 species) but supported a community comparable to that found during the REC survey, as evidenced by the grouping of samples presented in Figure 4.59. The MAREA sample did, however contain a particularly high number of the tunicate *Molgula manhattensis*. A total of 458 individuals / 0.1 m^2 of this species were found here. Although infrequently recorded in grab samples from both the REC and MAREA studies *M. manhattensis* does appear to be a characteristic feature of shallow inshore water areas on mixed muddy coarse sediments. During the Outer Thames Estuary REC study, comparatively dense populations were found at stations 1 and 22 (101 and 252 individuals / 0.1 m^2 respectively). The faunal component may relate to the epifaunal biotope **CR.HCR.XFa.Mol** as identified at other stations within the general vicinity during the Outer Thames Estuary REC study.

Interestingly sample 73 also contained relatively high numbers of *Sabellaria spinulosa* (239 individuals / 0.1 m^2) suggesting an underlying **SspiMx** biotope at this location. However, this density of animals falls short of that normally associated with biogenic *Sabellaria spinulosa* reef (600 to several thousand per grab sample, Holt *et al*., 1998). Seabed photography was not possible at this location due to the high turbidity of the water and so the presence of *Sabellaria spinulosa* reef features is not confirmed. Deck photographs of samples obtained during the Outer Thames Estuary REC survey suggested that potential reef was not found at this location.

Group B contained two samples characterised by an impoverished fauna including *Ophiura albida* and *Lagis koreni*. The associated sediments were highly mixed and included gravelly muddy sand and muddy sandy gravel. One sample within this group was collected offshore in deeper water whilst the other was collected within an actively dredged area.

The final grouping, Group E, comprised just one sample of sand and supported just two individuals of *Spiophanes bombyx* and one individual of *Spio decorata*, *Travisia forbesii*, *Synchelidium maculatum* and *Bathyporeia elegans*. It was collected between Long Sand and Kentish Knock sandbanks to the south of the study area and may therefore represent an example of impoverished inter-bank benthic conditions associated with surficial mobile fine sand sediments.

4.6.5 Colonial sessile epifauna identified from grab samples

Colonial sessile epifauna were not enumerated within the MAREA dataset but were assigned a presence value as per the Outer Thames Estuary REC analyses. Assessments as to the relative abundances of epifauna are therefore not possible, however comparison of the frequencies of occurrence of colonial species can be made. Commonly occurring colonial sessile epifauna found during the MAREA survey included the hydroids *Sertularia* spp., *Obelia dichotoma* and *O. bidentata* and the bryozoans *Conopeum reticulum*, *Electra pilosa*, and *Schizomavella auriculata*. These species were found within 25% or more of the grab samples collected.

Multivariate cluster analysis of the presence / absence data revealed six main colonial sessile epifaunal groups as summarised in Table 4.11.

Epifaunal Group	No. of Samples	Species Identified from Grab Samples
1	24	*Conopeum reticulum*, *Electra pilosa*, *Obelia* spp.
2	21	*Aspidelectra melolontha* *Conopeum reticulum*
3	13	*Sertularia* spp. *Clytia hemisphaerica*
4	11	*Escharella immersa*, *Schizomavella auriculata*, *Disporella hispida*, *Clytia hemisphaerica*, *Conopeum reticulum*, *Sertularia* spp.
5	17	*Sertularia* spp., *Schizomavella auriculata*
6	6	*Conopeum reticulum*

Table 4.11: Colonial sessile epifaunal groups identified from the MAREA survey grab samples.

None of the groupings exhibited any particular distribution pattern although the richest and most diverse assemblage (Group 4) together with the *Sertularia* spp and *Schizomavella auriculata* group (Group 5) tended to occur over the coarser, mixed sediments within the centre of the array where surficial sediments were sparse. Group 2, in contrast, tended to occur towards the south of the study area and over the coarser sediments between the main sandbanks. The *Obelia* spp, group (Group 1) was widely distributed throughout the study area and included sand dominated areas. Here, these hydroid species attached to fragments of broken shell, small stones and gravel particles, as also revealed by the Outer Thames Estuary REC.

4.6.6 2 m Beam Trawl Data

A total of sixteen 2 m scientific beam trawls were collected during the MAREA survey. Catches were comparable to those of the Outer Thames Estuary REC survey and were characterised by the species originally listed in Table 4.6. These included brown and pink shrimps *Crangon allmani*, *C. crangon*, *Pandalus montagui* and *Pandalina brevirostris*, the brittlestar *Ophiura albida*, gobies *Pomatoschistus* spp., the green urchin *Psammechinus miliaris*, flying crab *Liocarcinus holsatus* and bib *Trisopterus luscus*. Commercial species such as sole *Solea solea* and dab *Limanda limanda* were also frequently recorded.

Cluster analysis (Appendix C) identified two main epibenthic assemblages, Groups C and E and three smaller groups (Groups A, B and D) comprising just one or two samples.

The largest group was Group E and incorporated 8 trawl samples. In terms of its conspicuous taxa, this group was comparable to the dominant REC epibenthic assemblage. Characteristic species included the brown shrimps *Crangon crangon*, *C. allmanni* and *Philoceras trispinosus* together with *Pomatoschistus* spp. *P. miliaris*, the hermit crab *Pagurus bernhardus*, *L. holsatus*, the mysid shrimp *Schistomysis kervillei* and *P. montagui*.

Group C comprised 4 samples and appeared to be a variant of Group E, in which the brown shrimps *C. crangon* and *C. allmani* were recorded in low abundance. Characteristic species included *P. bernhardus*, *P. trispinosus*, *T. luscus*, *Pomatoschistus* spp. and *L. holsatus*.

Group A contained 2 samples and was characterised by comparatively high numbers of the urchin *P. miliaris* and the shrimp, *P. brevirostris*. Groups B and D comprised just one sample each and were characterized by comparatively high numbers of *C. crangon* and *L. holsatus* and by *P. miliaris*, *C. allmani*, *O. albida* and *Balanomorpha* (barnacles) respectively.

4.7 Marine Mammals

A brief overview of marine mammals in the Outer Thames Estuary is given here. The complimentary Outer Thames Estuary MAREA project (ERM, in preparation) will provide a more comprehensive baseline in this respect.

Marine mammals inhabiting UK waters comprise cetaceans (whales, dolphins and porpoises) and pinnipeds (true seals and eared seals). Assessing the distribution of marine mammals throughout the southern North Sea identifies eight marine mammal species that occur regularly over large areas of the North Sea. These include:

- Mysticetes (baleen whales): Minke whale (*Balaenoptera acutorostrata*),
- Odontocetes (toothed whales): Harbour porpoise (*Phocoena phocoena*); bottlenose dolphin (*Tursiops truncatus*) (Figure 4.61); white-beaked dolphin (*Lagenorhynchus albirostris*); Atlantic white-sided dolphin (*Lagenorhynchus actus*) and killer whale (*Orcinus orca*) and
- Pinnipeds: Grey seal (*Halichoerus grypus*) and harbour seal (*Phoca vitulina*) (Figure 4.62),

Other occasional visitors to the southern North Sea include the following. However, sightings for these species are relatively rare:

- Odontocetes: Sperm whale (*Physeter macrocephalus*), long-finned pilot whale (*Globicephala melas*) and short-beaked common dolphin (*Delphinus delphis*).

4.7.1 Data Availability and Information Sources

To provide an overview of the marine mammals occurring in the southern North Sea and utilizing the Outer Thames Estuary REC study area, data has been acquired from the following sources:

- Small Cetacean Assessment for the North Sea (SCANS & SCANS II). The SCANS survey that took place in June to July 1994 provides quantitative information for the most abundant cetacean species and provides a robust sampling methodology. The SCANS II project re-evaluates the distribution of small cetaceans in the North Sea based on 2005 and 2006 survey data.
- Atlas of Cetacean Distribution in north-west European waters (Reid *et al*., 2003); combined compatible effort-related data from the SCANS survey, the JNCC's European Sea Bird at Sea team (ESAS), and data held by the Sea Watch Foundation to produce the Atlas of Cetacean distribution in north-west European waters. This dataset includes data from throughout the year and is standardised to account for observer effort.
- Background information on marine mammals relevant to Strategic Environmental Assessments 2 and 3; The report was prepared by scientists from the Sea Mammal Research Unit, Gatty Marine Laboratory, University of St Andrews and describes the distribution and abundance of these mammals and their ecological importance within the SEA 3 area.

Site specific data sources:

- Greater Gabbard Offshore Wind Ltd Marine Mammal and Bird Survey (2004-2005). Marine mammal surveys were undertaken monthly (as weather conditions permitted) commencing in April 2004, until July 2005. Each survey covered approximately 238 km and followed standard transects set at 1.8 nm intervals running approximately perpendicular to the coast.
- London Array Bird Survey (2002-2004). For the London array the data were not acquired with normal visual cetacean survey method, but were acquired during the aerial bird surveys conducted January 2002- June 2004.
- Thames Marine Mammal Sightings Survey (2004–2007). Data held by Zoological Society London (ZSL) and provided in Kowalik *et al*., (2008) are shore based 'non-expert' opportunistic sightings, therefore they can be less relevant than offshore survey and not as systematic or robust.

Table 4.12 provides a summary of the marine mammal species observed from the site specific surveys.

Figure 4.61: Bottlenose Dolphin *Tursiops truncatus*.

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Species of Marine Mammal	Outer Thames Estuary	Inner Thames Estuary	
	Greater Gabbard	London Array	ZSL
Harbour Porpoise (*Phocoena phocoena*)	166	298	184
Bottlenose dolphin (*Tursiops truncatus*)		4	57
Grey Seal (*Halichoerus grypus*)	6	2	86
Harbour Seal (*Phoca vitulina*)	2		169
Seal (unknown)	1		179
Porpoise/Dolphin	1		1
Porpoise/Pilot Whale			1
Pilot Whale			1
Northern Bottlenose whale (dead)			1
Minke whale (dead)			1

Table 4.12: Summary of marine mammal species observed from site specific surveys.

4.7.2 Marine Mammals in the Outer Thames Estuary REC Study Area

Considering the above information, it is possible that any of the eight species previously recorded as live sightings could occur within the Outer Thames Estuary REC study area as occasional visitors; but it is apparent from the combined data provided by Reid *et al.*, (2003) and site specific surveys, that the species; harbour porpoise (*Phocoena phocoena*), bottlenose dolphin (*Tursiops truncatus*), harbour seal (*Phoca vitulina*) and the grey seal (*Halichoerus grypus*) are more common visitors and are most likely to be encountered within the study area.

4.7.3 Cetacean Distribution in the Outer Thames Estuary REC Study Area

Only two species of cetacean (out of a UK total of 27) are present throughout the year or recorded annually within the Outer Thames Estuary REC study area (Evans, 1998).

Harbour Porpoise (Phocoena phocoena) Ecology and Distribution.

The harbour porpoise *Phocoena phocoena* is the smallest and most numerous marine mammal in north-western European shelf waters making it the most frequently sighted cetacean species in the North Sea and the most common cetacean sighted in the study area. Although species are occasionally sighted offshore, individuals are more common near the coast particularly in late summer/autumn (Reid *et al*., 2003). It has been reported that the diet of the harbour porpoise comprises a wide variety of small fish species including small gadoids, sandeels and gobies (Hammond *et al*., 2002).

Harbour porpoise were by far the most commonly encountered marine mammal during the period April 2004 – July 2005 surveys with 166 individuals encountered in total (GGOWL, 2005). The vast majority of harbour porpoise sightings were of single individuals; however, up to six individuals were seen at any one time, on occasions. It was noted that the average group size was 1.39 harbour porpoise and the average encounter rate (unadjusted for sea state) was 0.04 harbour porpoise individuals per km of survey.

The results from both boat survey and aerial survey data from the London Array are consistent with the results from the Greater Gabbard surveys with a total of 298 individual sighted and an average of 0.047 harbour porpoise individuals per km of survey. This supports the statement that the Harbour porpoise is the most numerous marine mammal within the Outer Thames Estuary REC study area.

Bottlenose Dolphins (Tursiops truncatus) Ecology and Distribution

Bottlenose dolphins *Tursiops truncatus* (Figure 4.61) are observed occasionally on all coasts of the UK. The bottlenose dolphin is the only other cetacean sighted in site specific surveys in the Outer Thames Estuary REC area, but has been reported historically near shore in most months, particularly between April and August (Evans, 1998). The bottlenose is known to feed on a wide variety of benthic and pelagic fish (both solitary and schooling species) in addition to cephalopods and shellfish (Reid *et al*., 2003).

Other Cetaceans

The white-beaked dolphin *Lagenorynchus albirostris* occurs rarely in the southern North Sea (Evans, 1998). Although not sighted in recent site specific studies of the Outer Thames Estuary region, historic strandings data, report 65 white beaked strandings across the wider south east coastal region including the coastline of Outer Thames Estuary (Canning *et al*., 2008) suggesting that this species may be an occasional visitor within the study area.

A northern bottlenose whale *Hyperoodon ampullatus* entered the Outer Thames Estuary for three days during January 2006 before dying. A variety of other cetacean species (including bottlenose whale, sperm whale, Atlantic white-sided dolphin, minke whale, fin whale) occasionally strand along the English southern North Sea coast. and other cetaceans to be stranded on the east coast of the UK (Deaville *et al*. 2007; Kowalik *et al*., 2008), suggesting that this species may also occasionally occur within the study area.

4.7.4 Pinniped Distribution in the Outer Thames Estuary REC Study Area

Grey (Halichoerus grypus) and Harbour Seal (Phoca vitulina) Ecology and Distribution

There are two resident species of seal in British coastal waters, the grey seal *Halichoerus grypus* and harbour seal *Phoca vitulina*.

The harbour seal (Figure 4.62) is the smaller of the two pinniped species and feeds on a wide variety of prey including sandeels, whitefish, herring, flatfish, octopus and squid, with their diet varying seasonally from region to region (Jones *et al*., 2004). It is reported that the largest group of harbour seals in the study area can be found on the haul out site located on Foulness Sands and Buxey Sands at the mouth of the River Crouch (Duck, 1998).

Although grey seals do not regularly breed or haul out in the region, very small numbers are occasionally seen, with the closest regular haul-out sites located at Horsey, Norfolk, Scroby Sands, Norfolk and St. Margaret's at Cliffe, Kent (Duck, 1998; SCOS, 2007). Grey seal diet also varies seasonally and from region to region, but consists of sandeels, gadoids and flatfish, in that order of importance (Jones *et al*., 2004).

Only individual pinnipeds were sighted during the Greater Gabbard surveys, these consisted of two harbour seal sightings, six grey seal sightings and one unidentified seal species. The average encounter rate (both seal species combined, including one unidentified individual) was 0.002 individuals per km of survey.

Figure 4.62: Harbour seal *Phoca vitulina.*

(© Ryan Bushby)

4.8 Ornithology

The varied coastline adjacent to the Outer Thames Estuary REC study area supports a variety of important marine habitats and internationally and nationally important numbers of bird species. These areas have been afforded conservation protection as Special Protection Areas (SPAs) under the Birds Directive (79/409/EEC) and/or as Ramsar sites under the Ramsar Convention (1971).

4.8.1 Marine Bird Species within the Outer Thames Estuary REC Study area

Thirty three species of marine birds occur within the wider area of the southern North Sea region (Jones *et al*., 2004). Away from inshore waters, these birds may feed, roost or fly over most areas of open sea in low numbers (Jones *et al*., 2004). However, it is difficult to assess which species and to what extent they utilise the Outer Thames Estuary REC study area as they are unevenly distributed both geographically and in time (Stone *et al*., 1995). A more detailed description of bird species occurring within the study area will be given in the TEDA Outer Thames Estuary MAREA project (ERM, in preparation). Distributions of birds for the wider Outer Thames Estuary area are presented by BERR (2007).

Literature from adjacent coastal designations and previous studies within the southern North Sea region (Jones *et al*., 2004; Stone *et al*., 1995) suggest that five Annex I species are known to utilise the study area. These are:

- Red-throated diver (*Gavia stellata*) (Figure 4.63)
- Black-throated diver (*Gavia arctica*) (Figure 4.64)
- Sandwich tern (*Sterna sandvicensis*)
- Common tern (*Sterna hirundo*) (Figure 4.65) and
- Little tern (*Sterna albifrons*)

Red-throated (Gavia stellata) and black-throated divers (Gavia arctica)

These two species belong to the family of divers (Gaviidae), and are known to breed in the UK. Both species mentioned are migratory, breeding on freshwater lakes and pools but moving to the sea coast in winter (www.rspb.org.uk). During baseline surveys for the London Array Environmental Impact Assessment (EIA), developers identified a previously unknown internationally important population of wintering red-throated diver using the proposed site, and within the wider estuary as a whole (including the Outer Thames Estuary REC study area). It is thought that this newly identified population has more than doubled previous wintering red-throated diver population estimates for the UK.

Sandwich tern (Sterna sandvicensis), Common tern (Sterna hirundo) and Little tern (Sterna albifrons)

These species are small to medium birds belonging to the group known as 'sea' terns however they are not always strictly marine. All three species of tern mentioned are migratory, often seen outside their breeding areas in spring and autumn, but absent from Europe in winter (www.rspb.org.uk).

Figure 4.63: Red-throated diver *Gavia stellata.*

(© Pascal Aleixandre)

Figure 4.64: Black-throated diver *Gavia arctica.*

(© Curtis Carley)

4.8.2 Future Designations

Following the baseline surveys for the London Array Environmental Impact Assessment (EIA) a revised wintering population estimate for red-throated divers around Great Britain was compiled (O'Brien *et al*., 2008). This study utilised data primarily from line transect surveys by aircraft (conducted during 2001 to 2006), supplemented with county bird records and Wetland Bird Survey (WeBS) counts (both from 1995 to 2005). Population estimates were calculated of all data collected within January and February of each year and these were summed to give a revised wintering population estimate.

Wintering red-throated divers were found to be unevenly distributed with a total of 17,116 individuals estimated to winter around Great Britain. By far the greatest numbers were found off south-east and east Britain within the Greater Thames region. An estimated 10,149 were located between Flamborough Head, Yorkshire, and Dungeness, Kent equalling 59.3% of the overall estimated population for Great Britain (O'Brien *et al.*, 2008). This more accurate estimate will help with the process of identifying inshore SPAs for this species during the non-breeding season.

Natural England and the Joint Nature Conservation Committee have recently advised Defra of two areas as suitable for selection as SPAs, including the Thames Special Protection Area (SPA) for red throated divers. The current anticipated date for Defra to submit the new SPAs to the EC is August 2010.

Figure 4.65: Common tern *Sterna hirundo.*

(© Andreas Trepte)

4.9 Commercial Fisheries

Commerical fisheries activities within UK nearshore waters are managed and regulated by Sea Fisheries Committees (SFCs) through a series of local byelaws. These byelaws can be made to regulate the types and sizes of fishing gears used, establish temporal seasonal restrictions on certain activities and set minimum landing sizes for fish and shellfish. They can also restrict activities for the protection of nature conservation.

Sea fisheries districts currently extend six miles offshore from coastal baselines. In June 2006, the Department for Environment, Food and Rural Affairs (Defra) announced that the powers of sea fisheries committees would be modernised in the forthcoming Marine Bill. This will include the replacement of Sea Fisheries Committees with Inshore Fisheries and Conservation Authorities (IFCAs) with a greater extension of the marine nature conservation remit.

The Outer Thames Estuary REC coincides with the jurisdictions of two SFCs. These are the Kent and Essex SFC and the Eastern Sea Fisheries Joint Committee. The boundary between the two districts is the River Stour.

The fleet typically comprises fishing vessels of <10 m in length and which usually fish on a day basis. Vessels leave local harbours and return within the same day rather than spending protracted periods at sea. Consequently, much of the local commercial effort is undertaken within six to twelve nautical miles from home ports and launching beaches although some of the larger vessels i.e. crab viviers, trawlers and fast modern vessels can operate further offshore.

A review of the UK coastal fisheries (Walmsley & Pawson, 2007) describes the seasonal nature of the commercial activity within the general region. The range of mobile and fixed gear types that are used throughout the year reflect the availability of the different target species. Sole is a principal target species for netters and trawlers during the warmer months from spring onwards with plaice, rays, dab and flounder taken as by-catch. Many vessels are reliant on the seasonal sole catches. Both fixed and drifted gill nets are also employed for bass between spring and autumn (Figure 4.66). Longlines deployed from small beach vessels pursue sole, skate, bass and mullet through to the autumn. Occasionally the long liners will set pots inshore on their way to their longlining grounds further away. In summer a small number of fast modern vessels from local harbours will travel to favoured wreck sites or areas of overfalls for commercial angling using rod and lines for cod and bass. This activity has become popular as a result of the availability of live sandeels as bait.

During winter, fishing effort may decline due to inclement weather conditions or switch to inshore and estuarine grounds where greater shelter may be found. Drift nets are used during winter months in pursuit of herring and sprat and also for winter cod and whiting. The winter cod net fishery has declined in recent years (Walmsley & Pawson, 2007). Sprat and herring are also taken in trawls during winter months and pair trawling for sprat occurs from November to February when they appear inshore. There is a discrete herring stock that spawns in spring in the northern part of the Thames Estuary and where strict fishing restrictions are imposed. This is joined seasonally by the main North Sea stock when it enters the southern part of the estuary and which is targeted by trawling.

Pots for crab and lobster are generally set during spring through to late autumn whilst pots for whelks may be set all year round. Pots may be laid up to 30 miles offshore. Lobsters are usually taken from coarse hard grounds closer inshore whilst the clean sandy gravels further offshore are fished for brown crab.

The Outer Thames Estuary REC is intensively trawled by beam and otter trawlers. There are a number of local trawlers operating from some of the larger ports within and adjacent to the study area as well as various visiting trawlers. Typical catches include plaice, sole, turbot, rays, dabs, cod and whiting. Local beam trawlers also target brown shrimp from May to November and are occasionally joined by other beam trawlers from King's Lynn. Otter and pair trawlers also pursue sprat and herring during the winter. Pair trawlers may also take small quantities of smelt and whitebait during the spring and summer.

Sheltered waters within local estuaries are fished for eels and shrimps using eel fyke nets and trawling and are also used for the cultivation of oysters. A number of the oyster beds are covered by Several Orders. Smaller vessels (<10 m) use otter and beam trawls for sole during summer and autumn in the estuaries and switch to nets and lines cod and whiting during colder winter months. Dredges or rakes are sometimes used in the Thames Estuary to collect white weed *Sertularia cupressina* which is dried and sold for decorative purposes. The Thames Estuary also supports a highly productive cockle fishery which is subject to strict management and regulation under the Thames Cockle Fishery Order (1994)

The close proximity to London and other urban centres means that access to the coast is relatively easy for anglers. This means that there is a considerable amount of recreational angling activity within the region both from the shore and from private angling boats. Walmsley & Pawson (2007) suggest that recreational catches may constitute a significant part of the total landings of some species, particularly cod and bass, within the 12 mile zone. Most common species caught by recreational anglers include bass, thornback ray, smooth hound, grey mullet, cod and whiting.

Figure 4.66: Deployment of gill nets.

5. Integrated Assessment of Habitats and Biotopes

5.1 Morphological Zones

Section 2.2 identified three distinct zones characterised by differing seabed configurations and sediments. These correspond to a western sediment rich zone, a central sediment poor zone and an eastern, deeper water, sediment rich dune field. Significance testing between these three zones using the ANOSIM routine (Clarke & Warwick, 2001) showed no differences in benthic communities between the western and central zones but highlighted significant community variation between the central sediment poor zone and the eastern deep-water dune field. This finding, in combination with the conclusion drawn in Section 4, that sediment type alone appears to have limited influence on the structuring of benthic communities, suggests that morphological processes may be of greater importance in this regard.

A summary comparison of taxa between the Central and Eastern Zones is presented in Table 5.1 and follows a SIMPER analysis of combined infauna and epifauna from grab samples (presence / absence data was used, hence the values represent the percentage frequency of occurrence rather than abundance). Taxa are ranked according to their relative contribution to the overall dissimilarity between the two groupings. A two dimensional MDS ordination plot (Figure 5.1) further illustrates the community partitioning between the central sediment poor and eastern dune field groupings. The R value denotes the ANOSIM statistic for the pairwise test which, whilst low, was nonetheless interpreted as significant (P<0.05).

Table 5.1 indicates that whilst there was little variation with regard to species identities there were differences in the mean frequencies of occurrence of certain taxa between the two groupings. Species common to the eastern dune field included the mysid shrimp *Gastrosaccus spinifer* and the white cat worm *Nephtys cirrosa*. These species are typical of regularly disturbed sandy conditions and thus would be expected to be prominent in areas of sand dunes.

Species	Sediment Poor – Central zone	Dune Field – Eastern Zone
Notomastus spp.	58%	20%
Nephtys spp.	58%	53%
Nephtys cirrosa	33%	40%
OPHIUROIDEA	58%	13%
Abra alba	42%	0%
Gastrosaccus spinifer	13%	40%
Ophiura albida	46%	20%
Sabellaria spinulosa	5%	13%
NEMERTEA	54%	20%
Lagis koreni	46%	13%
Lumbrineris gracilis	54%	7%

Table 5.1: Summary of SIMPER analysis comparing mean frequencies of occurrence of species between different geo-morphological zones.

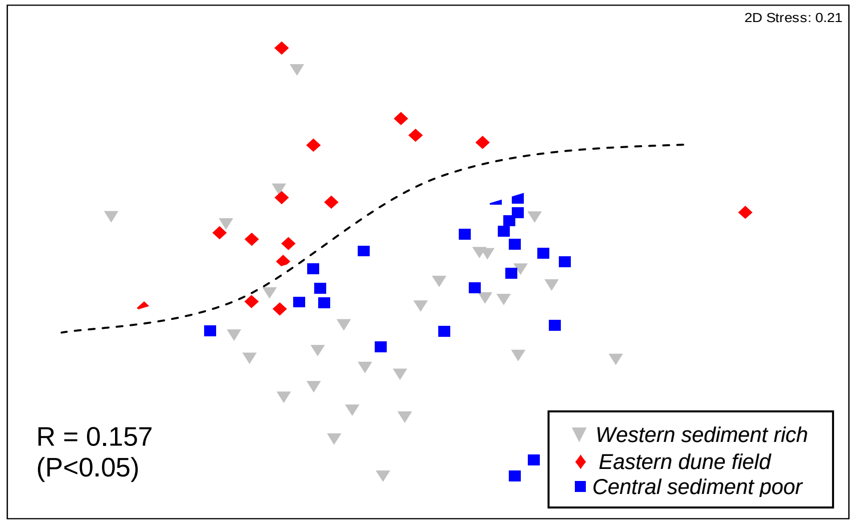


Figure 5.1: MDS plot highlighting separation of the central sediment poor sites and the sites in the eastern dune field area.

The dune areas are subject to a high, but uniform, level of sediment instability. The central sediment poor zone was characterised by taxa which are associated with mixed substrates, such as the polychaetes *Notomastus* spp., *Lumbrineris gracilis* and *Lagis koreni,* the bivalve *Abra alba* and brittlestars from the family Ophiuroidea. The fauna typical of sands were noted less often.

5.2 Palaeochannel Fauna

Palaeochannels are often associated with thick layers of clean gravel. As a result the palaeochannels are particularly attractive to the marine aggregate industry for their high quality resource. To determine if a difference could be identified between the fauna associated with the sediments above the palaeochannel areas and the sediments surrounding them, an ANOSIM test was undertaken. The test results are shown in Figure 5.2 and show no difference between the palaeochannel areas and the surrounding seabed deposits within the (sediment poor) Central Zone of the study area (p>0.05). This indicates that no distinct faunal assemblages occur in the Outer Thames Estuary REC area that might be particularly impacted by dredging.

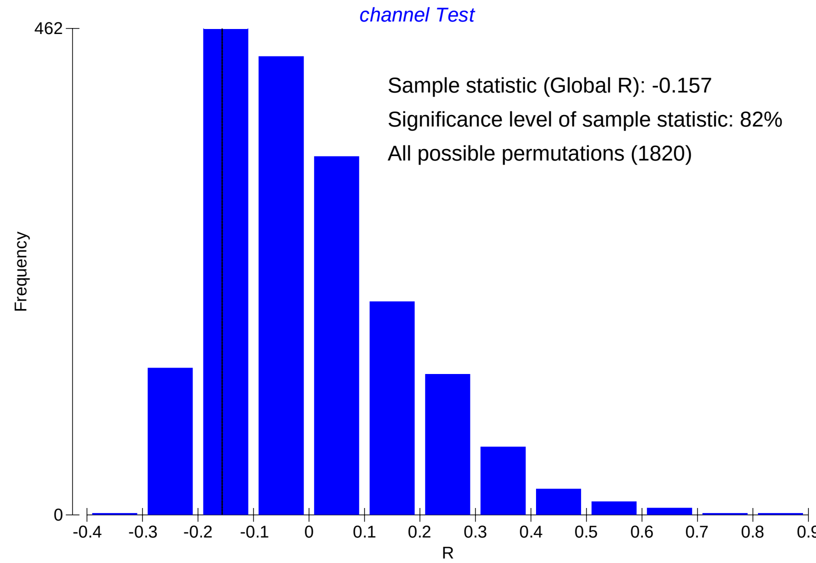


Figure 5.2: Results of the ANOSIM test for differences in faunal assemblages between palaeochannel areas and the surrounding seabed.

However, the spatial frequency of seabed sampling was not sufficient to provide a statistically robust or detailed analysis of these differences and only a few data points were relevant. Consequently, the ANOSIM test was restricted to the area within the centre of the sample array where overlying sand sediments were found to be sparse and palaeochannel substrata were closer to the seabed. Stations to the south and west of the region support recent sand deposits, represented by the various linear sandbank features. Palaeochannels in this region underlie these more recent sediments, and are unlikely to influence the composition of surficial sediments and associated fauna. Outer Thames Estuary samples submitted to the test included samples 17, 25, 30 – 32, 37, 38, 42 – 45, 50, 51, 54, and 55 – 57 with samples 17, 30, 42 and 43 selected as representing palaeochannel areas. Further sampling could improve this assessment.

Sandbanks which are slightly covered by sea water all the time	Reefs
Sandbanks are elevated, elongated, rounded or irregular topographic features, permanently submerged and predominantly surrounded by deeper water. They consist mainly of sandy sediments, but larger grain sizes, including boulders and cobbles, or smaller grain sizes including mud may also be present on a sandbank. Banks where sandy sediments occur in a layer over hard substrata are classed as sandbanks if the associated biota are dependent on the sand rather than on the underlying hard substrata. “Slightly covered by sea water all the time” means that above a sandbank the water depth is seldom more than 20 m below chart datum. Sandbanks can, however, extend beneath 20 m below chart datum. It can, therefore, be appropriate to include in designations such areas where they are part of the feature and host its biological assemblages. Typical animals include invertebrate and demersal fish communities of sandy sublittoral (e.g. polychaete worms, crustacea, anthozoans, burrowing bivalves and echinoderms, sandeels, dragonets, gobies, lesser weever fish, plaice and dab).	Reefs can be either biogenic concretions or of geogenic origin. They are hard compact substrata on solid and soft bottoms, which arise from the sea floor in the sublittoral and littoral zone. Reefs may support a zonation of benthic communities of algae and animal species as well as concretions and corallogenic concretions. “Hard compact substrata” are: rocks (including soft rock, e.g. chalk), boulders and cobbles (generally >64 mm in diameter). “Biogenic concretions” are defined as: concretions, encrustations, corallogenic concretions and bivalve mussel beds originating from dead or living animals, i.e. biogenic hard bottoms which supply habitats for epibiotic species. “Geogenic origin” means: reefs formed by non biogenic substrata. “Arise from the sea floor" means: the reef is topographically distinct from the surrounding seafloor.

Table 5.2: Summary of definitions of Annex I EC Habitat Directive habitats recorded within the Outer Thames Estuary REC.

5.3 Features of Conservation Interest

5.3.1 Habitats

Data collected for the Outer Thames Estuary REC area indicates the presence of two potential Annex I habitats as defined within the EU Habitats Directive (92/43/EEC). These include ‘reefs’ and ‘sandbanks which are slightly covered by seawater all the time’.

These features are among the habitats for which additional SACs may be designated as part of the UK’s commitment to the Natura network of SACs. Natural England and the Joint Nature Conservation Committee are currently consulting, on behalf of Defra, on additional sites for SAC designation, and evidence of reefs and sandbanks identified by the Outer Thames Estuary REC may assist in the process of defining potential Annex I habitats for SAC inclusion. Defra is anticipated to submit details of these new SACs to the EC by August 2010. Guidance on the EU definitions that have been attributed to these habitat types are provided in EU CEC (2007) and are summarised in Table 5.2.

A subdivision occurs with respect to the reef features identified in the Outer Thames Estuary region; geogenic reef and biogenic *Sabellaria spinulosa* reef. Compared with the areas previously defined as potential Annex I habitats in Figure 2.32, there is potential for additional reef features identified from the REC and MAREA data, though the spatial and temporal stability of these features are not clear and further observations are required to understand if such reefs are ephemeral features. The sandbank features identified from the REC and MAREA data are comparable with those predefined as potential Annex I habitats in Figure 2.32.

5.3.2 ‘Geogenic Reefs’ within the Outer Thames Estuary

Outcrops of bedrock composed off compacted clay have been found at various locations within the Outer Thames Estuary REC and may include features which fall within the definition for geogenic reef under the Annex I ‘reef’ definition. Good examples were found at stations 31 and 45 where seabed photography recorded clay bedrock exposures heavily bored by the white piddock *Barnea candida.*

Attaching epifauna are sparse; a typical feature of soft rock habitats which are generally unsuitable for the attachment of colonial sessile animals. However the soft coral *Alcyonium digitatum* and the ascidian *Molgula manhattensis* were found, probably attached to associated gravel and cobbles. Figure 5.3 shows a series of replicate photographs at station 31, with a good example of a clay bedrock outcrop. All photographs were collected over a distance of approximately 80 m indicating the potential spatial extent of the feature.

Examples of exposed clay bedrock were also identified at a number of other stations (30, 32, 38 and 44), although these are overlain with veneers of mixed muddy gravels of a few centimetres thickness. The overlying sediments supported various epifaunal assemblages including the keel worm *Pomatoceros spp.* and the barnacle *Verruca stroemia* with sparse bryozoan and hydrozoan turfs.

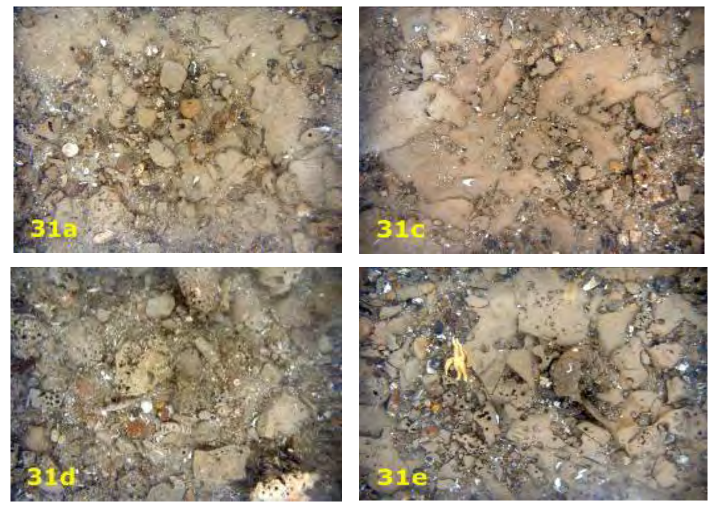


Figure 5.3: Replicate seabed photographs taken at station 31 showing exposed compacted clay. Photographs were taken along a transect of approximately 80 m distance (Replicate 31b not shown).

Despite the limited fauna directly associated with the compacted clay substrate, species data suggest that the outcrop areas were associated with some of the greatest species richness, diversity and biomass values recorded in the area. This highlights the possible regional importance of these habitats as well as their potential international significance as Annex I reef. High values for the various ecological indices may relate to the relative variability of the seabed sediment, especially in areas where there are mixed sediment veneers overlying the soft bedrock substrata resulting in greater availability of niche habitats for cryptic fauna. Conspicuous taxa were drawn from a variety of taxonomic groups including the polychaetes; *Sabellaria spinulosa, Lumbrineris gracilis* and *Harmothoe* spp; the amphipod crustacean *Photis longicornis;* the boring bivalve *Barnea candida;* the ascidian *Molgula manhattensis;* the echinoderm *Amphipholis squamata* and anemones*.*

Classification of a biotope for this group proved difficult because of the wide variety of sediments and associated faunal assemblages. Consequently a broad **SS.SCS.CCS** (Coarse Circalittoral Sediment) provided the best match based on grab data with further refinement using seabed imagery to classify outcroppings of clay as **CR.MCR.SfR** (Soft rock communities).

5.3.3 'Biogenic Reefs' within the Outer Thames Estuary

Encrustations of *Sabellaria spinulosa* tubes found at station 18, have the potential to constitute biogenic reef under the Annex I 'reef' definition. Accurate assessment of *S. spinulosa* reef is presently difficult and the subject of much current debate. Hendrick & Foster-Smith (2006) and Gubbay (2007) offer some assistance in describing condition status and provide criteria in relation to patchiness, extent and elevation, against which these features may be scored. Gubbay (2007) draws upon the previous criteria suggested by Hendrick & Foster-Smith (2006) of large extent and elevation from the seabed as defining *S.spinulosa* reef in its simplest form and within the context of the EU Habitats Directive. Gubbay also indicates that regardless of extent, patchiness appears to be a feature of reefs and therefore 100% coverage should not be expected in an area defined as *S. spinulosa* reef. A derived series of values were established for patchiness (as % cover) and elevation (as height above seabed), for use in combination, to determine whether a particular area might qualify as reef and to confer a greater level of confidence on the classification.

Emu Ltd (2008) further developed this assessment as a result of a consideration of practical field constraints relating to data acquisition; using side scan sonar, low visibility video imaging and grab sampling in areas suspected of supporting *S.spinulosa* reef. The use of a variety of appropriate techniques enabled sufficient data to be acquired for the determination of elevation, patchiness, consolidation and density characteristics for aggregations of *S. spinulosa*. These were then used to classify areas of *S. spinulosa* as 'moribund loose tubes', 'crusts', 'clumps', 'potential reef' or 'absent' as summarised in Table 5.3. Features classified as potential reef could then be tested against the criteria laid out by Hendrick & Foster-Smith (2006) and Gubbay (2007).

The data indicate that the *S. spinulosa* assemblage at station 18 could constitute reef, based on extent and elevation. The images (Figure 5.4) taken along an 80 m transect highlight the extent of potential *S. spinulosa* reef. The photographs indicate a possible elevation of potential reef of tens of centimetres but further assessment, through the employment of additional camera surveys providing oblique views, would better reveal the elevation of these encrustations. No grab sampling was undertaken at this location and so densities of the live *S.spinulosa* worm could not be determined.

Sabellaria spinulosa aggregation	Description
Moribund loose tubes	Loose tubes not attached to the seabed.
Crusts	Low lying tubes.
Clumps	Nodules of reef <10 cm in diameter.
Potential reef	Continuous (not clumped) erect *Sabellaria* sp. tubes with height >2 cm.

Table 5.3: Categories of *Sabellaria spinulosa* aggregations used to define areas of potential biogenic reefs.

In contrast to the elevated aggregations of *Sabellaria* at station 18, the more typical growth form was low growing isolated clumps, as demonstrated Figure 5.5. This illustrates assemblages of *S. spinulosa* at image station 60 and is highly representative of the nature of the *Sabellaria* assemblages found within the REC study area. Only two of the replicate images contained *S.* clumps highlighting the sporadic nature of this feature. Other examples of the typical low growing and patchy *S. spinulosa* aggregations are presented in Appendix C.

The majority of *S. spinulosa* found within the Outer Thames Estuary REC would therefore be classified as clumps and consequently are unlikely to constitute biogenic reef under the Annex I 'reef' definition. The appearance of aggregations of *S. spinulosa* in all five replicates at image station 18 however, suggests a more consistent and extensive feature worthy of further field investigation to more fully assess its condition and extent.

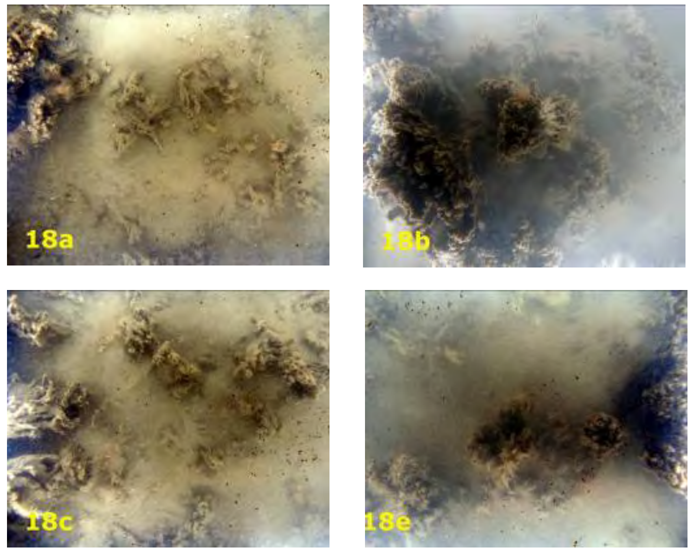


Figure 5.4: Replicate seabed photographs taken at image station 18 illustrating the consistent appearance of aggregations of *Sabellaria spinulosa* tubes. Photographs were taken along a transect of approximately 80 m distance (Replicate 18d not shown).

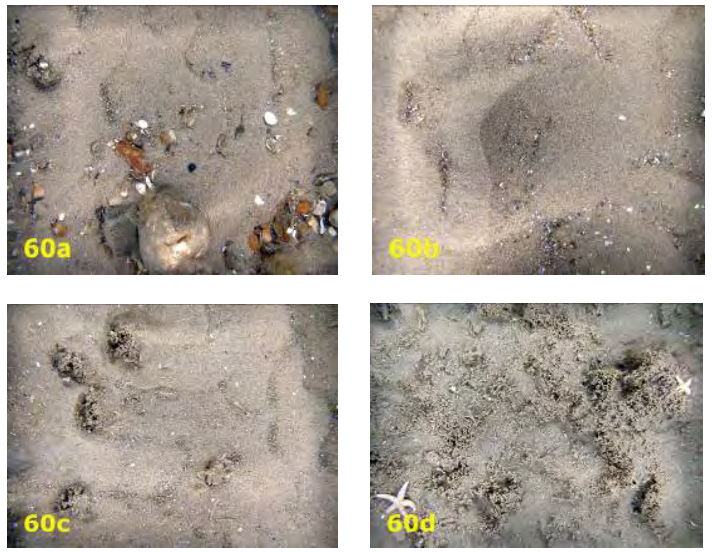


Figure 5.5: Replicate seabed photographs taken at image station 60, demonstrating the locally patchy distribution of aggregations of *Sabellaria spinulosa* tubes. Photographs were taken along a transect of approximately 80 m distance. (Replicate 60e is not shown).

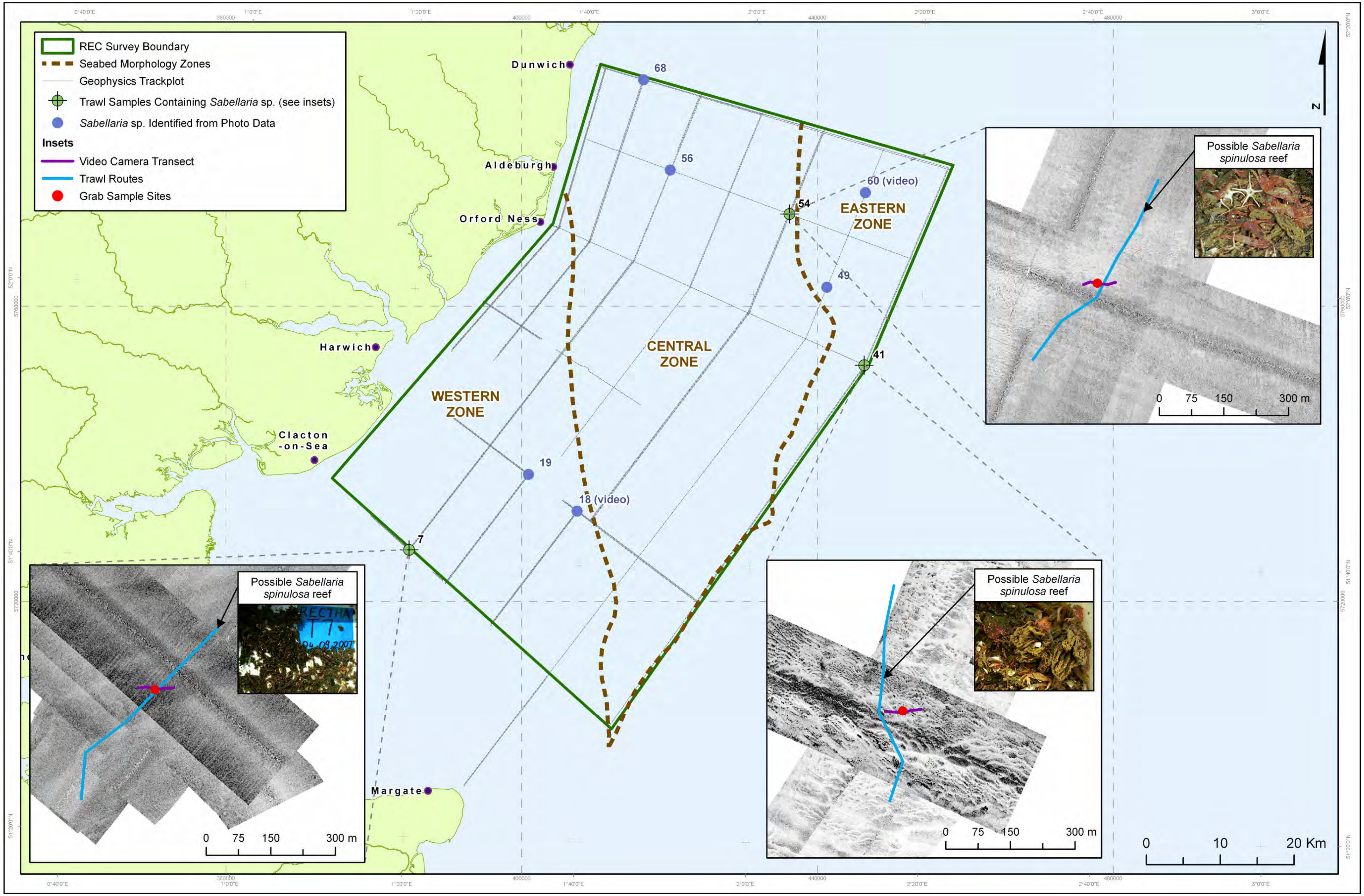


Figure 5.6: Side scan sonar data with the path of the 2 m beam trawl, the seabed camera transects and grab samples indicating potential areas of *Sabellaria spinulosa* reef at stations 7, 41 and 54.

Biotopes associated with loose *S. spinulosa* aggregations include **SS.SBR.PoR.SspiMx** describing biogenic *Sabellaria* reefs on mixed sediment. However, the majority of the current examples are clearly impoverished variants and do not support the abundances of *S. spinulosa* and high macrofaunal diversity which are normally associated with biogenic *S. spinulosa* reefs. Overlying epifaunal biotopes include **CR.HCR.XFa**, comprising mixed faunal turf communities of hydrozoans and bryozoans in combination with the biotope **SS.SCS.CCS.PomB** describing a relatively impoverished community characterised by *Pomatoceros* spp. with barnacles and bryozoa.

Chunks of *S. spinulosa* tube agglomerations, several centimetres in length were also found in three of the beam trawls samples collected at stations 7, 41 and 54. Whilst it is normally difficult to pin-point the locations of seabed features that have been sampled by beam trawls, the acquisition of side scan sonar data provides opportunity to review seabed textures along the path of each 2 m beam trawl tow for any typical signatures that might indicate potential reef.

Figure 5.6 presents details of side scan sonar data with the path of the 2 m beam trawls, the seabed camera transects and grab samples at stations 7, 41 and 54, used to identify possible areas of *S.spinulosa* reef. These areas provide combined data, including groundtruthing of the side scan sonar, to contribute to the mapping of potential *S. spinulosa* reef and for the further determination of Annex I reef features in the Outer Thames Estuary REC.

Station 7 is interpreted as coarse sandy gravel sediment with high reflectivity backscatter and overlaid with patches of finer sand within an inter-bank or trough area between Sunk Sand and Gunfleet Sand and located to the south west of the study area. Station 41 shows that the sample was retrieved from an area of low reflectivity interpreted as fine to medium sand however surrounding areas show strong reflectance which would suggest areas of gravels. Larger bedforms may also be present (i.e. small to medium dunes orientated mostly east-west). Station 54 represents a range of sediments from coarse sand and gravels to mud as shown by the variety of acoustic reflectance and supported by the results of the PSD analysis.

5.3.4 *Ampelisca* Reefs

Seabed video at station 83 located to the south of the survey area and east of Kentish Knock sandbank show that the dense *Ampelisca diadema* population appear to be consolidating fine muds which accrete as successive layers raising the community above the ambient seabed level. Seabed consolidation in this way also appears to have promoted species diversity allowing colonisation by species less tolerant to seabed disturbances. Grab sampling identified comparatively high species diversity (73 species). Characteristic species included *A. diadema* with *Abra alba* and *Photis longicaudata.* The associated sediment was classified as circalittoral muddy sandy gravel. The depth of water was 22 m. The best match was with the Marine Habitat Classification **SS.SMu.ISaMu.AmpPlon** although this is likely to be a deeper water and coarser sediment variant.

Although not currently recognised as such, it is possible that *Ampelisca* reefs fulfil the criteria for biogenic reef. Holt *et al.* (1998) define biogenic reefs as '*solid massive structures which are created by accumulations of organisms, usually rising from the seabed, or at least forming a substantial, discrete community or habitat which is very different from the surrounding seabed'*. They go on to describe biogenic reefs as being '*composed almost entirely of the reef building organisms and its tubes or shells, or it may to some degree be composed of sediments bound together by the organism'*. The observations made during the 2008 TEDA MAREA survey fit this definition. They may deviate from the EU definition (Table 5.2) however, as they are not concretions or hard compact substrata. Nevertheless, *Ampelisca* reefs do fulfil the functions of biogenic reef in that they support a community which is different to that of the surrounding seabed, they consolidate the substrata and they promote species diversity. Clearly there is an argument for the consideration of *Ampelisca* reefs within the definition of biogenic reef and further studies to characterise these features are warranted.

5.3.5 'Sandbanks which are slightly covered by seawater all of the time'

This study has identified the typical physical and biological characteristics of the local sandbanks. These provide shallow, clean and moderately well-sorted to well-sorted fine-medium sand-gravel substrates with a low fines content (<1%). These support a comparatively impoverished macrofauna typified by burrowing polychaete worms, shrimps, amphipods and sandeels (*Ammodytes* spp.).

Sandbanks are typically large features and their boundaries, according to the Annex I criteria, can often be delineated with good quality bathymetry data. In very shallow sloping areas, slope analysis may be used to differentiate between the flanks of the sandbank and the surrounding inter-bank areas. Klein (2006) suggests methods for modelling slopes and proposes some criteria to define this within the context of the EC Habitats Directive, including inclination and degree of slope. Slope analysis (Figure 5.7) shows clear delineation of the main sandbank to the south of the study area, at Long Sand and Sunk Sand for example, suggesting that slope analysis may assist the demarcation of Annex I sandbank features in the Outer Thames Estuary region.

Side scan sonar coupled with grab sample and photography ground truth data identified inter-bank seabed areas as comprising coarse gravel substrate. This sediment type often occupies the deeper water trough areas between the sandbanks throughout the study area and contrasted with the homogenous finer sand sediments forming the sandbanks themselves. The boundary between the two sediment types is very abrupt as demonstrated by side scan sonar (Figure 5.8) and therefore is an additional tool for the demarcation of Annex I sandbanks habitats in the Outer Thames Estuary region.

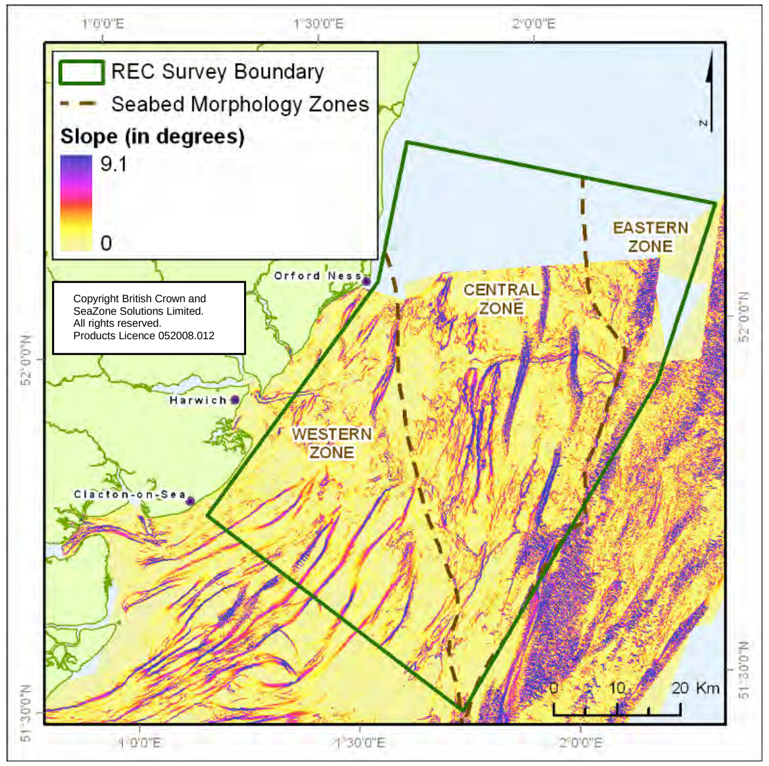


Figure 5.7: Slope analysis showing the margins of the sandbanks clearly delineated with slopes of 5 – 9º.

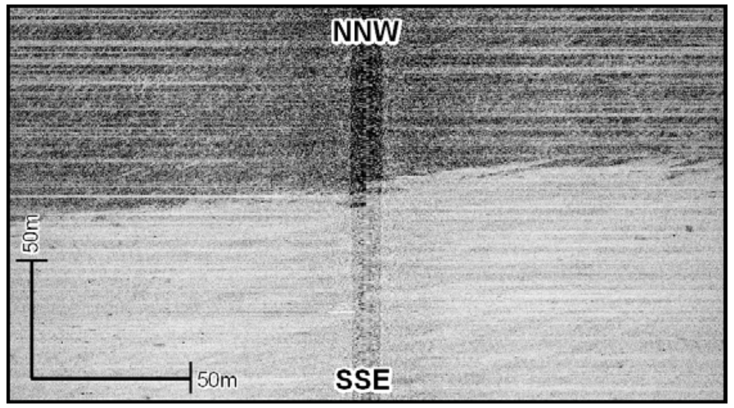


Figure 5.8: Detail of side scan sonar data showing the abrupt boundary between the fine sand sediments of the sandbank (lighter shading) and the coarser sediments occupying deeper water trough areas (darker shading).

Elliott *et al.* (1998) explained that mobile sandbanks are typically characterised by strong current flows and that the speed of the water and erosion and depositional rates are important in maintaining the integrity of these features. Tidal streams and wave action affect sediment transport and erosion, which in turn affects grain size and sorting. The concentration of silt and clay is typically low as a result of the continual winnowing and erosion of finer sediment particles from the substrate.

Macrofaunal richness and diversity associated with mobile sandbanks is generally less than that of the surrounding seabed areas because of the physical stresses present within the constantly mobile sand substratum. Species present include robust polychaetes, amphipods and molluscs which are adapted to unstable substrata, with the capacity to rapidly re-burrow following temporary displacement. Mobile epifauna include mysid shrimps, crabs and fishes, particularly sandeels.

Biotopes associated with areas of sandbanks include **SS.SSa.IFiSa.IMoSa** (very low diversity mobile sands), and **SS.SSa.IFiSa.NcirBat** describing impoverished mobile fine sand with typical sand fauna *Nepthys cirrosa* and *Bathyporeia* spp. Because of the general absence of larger stable sediment particles, colonial sessile epifauna are absent or present in low abundances attached to shell fragments, e.g. the hydroid *Obelia bidentata.* Consequently, sessile epifaunal biotopes generally do not occur over sandbanks although trawling during this study did identify small quantities of the bryozoan *Alcyonidium diaphanum* in the vicinity.

Numerous distinct sandbanks in shallow water of less than 20 m exist within the study area including the large sandbanks to the south of the study region, as mentioned above, together with a number of other linear sandbanks at Inner and Outer Gabbard, The Galloper, Shipwash, Bawdsey Bank and Aldeburgh Napes (see Figure 2.10). In these respects, the sandbanks fit the EC criteria for Annex I sandbanks (CEC, 2007).

Sampling with the grabs, trawls and seabed camera did not coincide with the crests of the sandbanks and so assessment of faunal communities at these locations was not possible. However, a small number of grab and beam trawl samples and associated seabed images were taken close to the base of some of the banks and along their flanks. These samples identified clean, homogenous fine sands supporting an impoverished macrofauna of typical sand fauna such as *Bathyporeia* spp. and *Nepthys cirrosa* and matching the **IMoSa** and **NcirBat** biotope classifications normally associated with sandbanks and other mobile sandy habitats. Conspicuous mobile epibenthos included sole *Solea solea*, bib *Trisopterus luscus,* juvenile gobies *Pomatoschistus* spp.(juv), hermit crabs and brown shrimps *Crangon allmani* and *C. crangon.* Whilst these assemblages were distinct from the coarse and mixed sediment habitats they were indistinguishable from other sandy habitats in the study area including the deeper water dune field to the north and east. Grab sampling also showed patches of deeper water muddy sand sediment on the flanks or at the base of some of the sandbanks supporting the bivalves *Abra alb*a and *Nucula nucleus* (**SS.SSa.CMuSa.AalbNuc**). These discrete muddy sand habitats possibly represent areas of local deposition.

In summary, the shallow water sandbanks identified in this study and highlighted in Figure 2.10 support a range of infauna, fish and shrimps typical of shallow water sandy habitats. Deeper water areas are more muddy and host bivalves typical of muddy sand sediments in places. The banks themselves are clearly distinguishable using acoustic techniques and match the morphological characteristic of the EC interpretation of Annex I ‘sandbanks which are slightly covered by seawater all of the time’.

5.4 Species and Biotopes

In addition to the Annex I habitat types, a number of species and biotopes of potential nature conservation importance have also been recorded within the Outer Thames Estuary REC. These include UK Biodiversity Action Plan (BAP) species and candidate Nationally Important Marine Features (cNIMF) (Hiscock *et al*., 2006). Table 5.4 presents a list of these features, as identified from the Outer Thames Estuary REC survey and the TEDA MAREA survey. Consequently, the Outer Thames Estuary REC is of value to regional BAPs and also to Natural England and the Joint Nature Conservation Committee in the process of establishing a network of Marine Protection Areas (MPAs) by 2012.

Features	Common Name	Designation
Ammodytes marinus	Lesser sandeel	UK BAP priority species
Barnea candida	White piddock	cNIMF species.
CMx biotope	Circalittoral mixed sediment	cNIMF biotope
Gadus morhua	Cod	UK BAP priority species
MedLumVen biotope	*Mediomastus fragilis*, *Lumbrineris* spp. and venerid bivalves in circalittoral coarse sand or gravel.	cNIMF biotope
Merlangius merlangus	Whiting	UK BAP priority species and cNIMF species
Ostrea edulis	Native oyster	UK BAP priority species
Pleuronectes platessa	Plaice	UK BAP priority species
Solea solea	Sole	UK BAP priority species.
SS.SBR.PoR.SspiMx biotope	*Sabellaria spinulosa* reefs	UK BAP priority habitat
SS.SCS.CCS biotope	Sublittoral sands and gravels	UK BAP priority habitat

Table 5.4: Summary of species and biotopes of potential UK nature conservation interest recorded within the Outer Thames Estuary REC study area.

5.4.1 Features of Ecological Interest

The 'Inner Gabbard Deeps' represent a series of unusual seabed features characterised by steep-sided narrow channels with maximum bottom depths of approximately 57 m. Section 3 provides a full description of these features and discusses their possible formation.

It is possible that specialist communities exist in the areas of the Inner Gabbard Deeps in response to the steep seabed gradients and the greater water depths, together with any localised scouring or depositional influences. Although no sampling was undertaken in these areas, stations 31 and 38 were sampled close to the slopes and some MAREA samples were collected to the south of one of the 'Deeps'. This limited sampling showed the presence of exposed compacted clay confirming the erosion of the 'Deeps' features into clay bedrock (Section 3). Further targeted survey using seabed imagery and grab sampling would provide data to assess the habitat community characteristics associated with the 'Deeps' including any particular sensitivities or natural heritage interests.

5.5 Biotope Summaries

In 1987, the Joint Nature Conservation Committee (JNCC) commenced the Marine Nature Conservation Review (MNCR) initiative. This sought to identify and classify the range of marine seabed habitats and their associated faunal communities, collectively termed biotopes that occur within UK and Irish waters. Since this time the Marine Habitat Classification has been further developed with successive iterations being made to accommodate continued expansion and refinement of biotopes as new survey data became available. This has culminated in the most up to date version developed in 2004 and which is in current use today (Connor *et al.*, 2004). Appendix C provides a complete list of habitats and biotopes as defined in the Marine Habitat Classification for guidance.

In general, biotopes encompass a specific set of environmental conditions, such as depth, substrate type and exposure together with the species that characterise those conditions. They provide a convenient ecological unit for classification and mapping of ecological resources and are particularly useful for the dissemination of spatial ecological information to inform management decision making.

This section presents a detailed synthesis of the surface geological and biological information for the purposes of constructing high definition biotope maps for the Outer Thames Estuary REC. Biotope summaries are presented at the end of this section and highlight the biological and physical attributes of the identified biotopes based on individual sample data.

All data strands have been used in the assignment of biotopes including Hamon grab derived macrofauna and particle size data, seabed photography and 2 m beam trawl data. The grab samples provide detailed point data to enable the classification of habitat types as defined by the physical influences and seabed types and also provides the biological information necessary for higher level biotope definition. The seabed photography and trawl data provide confirmatory information concerning seabed types and allow assessment and classification of overlying epifaunal biotopes, where these occur. Expert judgement was used to match survey data to the Marine Habitat Classificaiton for the derivation of biotope codes.

This approach to biotope classification differs from the community classification employed in Section 4, which generated a series of generic biotopes for the region based on grouped biological and geological data. Whilst useful for initial biotope assessment of large areas of seabed, the process of sample grouping using a group average method tends to result in the loss of information for less frequently occurring species, which means this approach often fails to fully capture the complexity of biotopes present. In order to address this, each individual sample has been assigned a biotope classification so that the complete range of biotopes present is represented.

Three habitat and biotope maps have been produced showing the distributions of habitats and biotopes at high, mid and low levels of classification. In each instance the classifications were initially overlaid onto the geological interpretation and bathymetry data so that an iterative assessment of the potential relationships with surface geology and geomorphological processes could be undertaken. This approach was adopted to enable meaningful habitat and biotope boundaries to be established which relate to the underlying physical conditions and which allow confident extrapolation of classifications in areas where little or no survey data exist. Boundaries between many of the seabed types and associated communities are naturally indistinct and so some overlap tends to occur. In all three of the following maps the bathymetry data is included as the base data layer to demonstrate the use of morphological boundaries to map the habitats and biotopes.

MAREA survey data has also been used to refine the boundaries of the habitat and biotope complexes and confirm the classifications made on the basis of the Outer Thames Estuary REC data.

5.5.1 Habitat Complexes

The distribution of habitat complexes, which encompass the basic physical habitat types present, is shown in Figure 5.9. This shows the dominance of subtidal sands (**SS.SSa**) around peripheral areas of the Outer Thames Estuary REC. These sediments closely correspond with the eastern and western geomorphological zones and the sand deposits associated with the deeper water dune field and the areas of sandbanks. On the basis of this observed relationship, the smaller sandbanks, for which there are no sampling records, such as the Galloper, Greater Gabbard and Bawdsey Banks have also been assigned this classification. Further justification for the classification of the former two banks is provided by the findings of a site specific survey relating to the proposed Greater Gabbard offshore wind farm. This found a typical mobile sand habitat associated with these features, consistent with the **SS.SSa** habitat complex.

MAREA data shows that subtidal sands overlap with other classifications. This is likely to be a result of the presence of transient sands and small bed forms in mixed sediment and coarse sediment areas.

Subtidal mixed sediment (**SS.SMx**) forms the other major habitat complex within central areas of the Outer Thames Estuary REC. It occurs primarily within the central, sediment poor zone and is clearly not associated with the main sandbanks or deeper water dune field suggesting a broad boundary between these two habitat complexes.

Subtidal coarse sediments (**SS.SCS**) form smaller isolated groups throughout the study area and appear to be associated with areas between the main sandbanks. It is possible that this is a more extensive inter-bank habitat complex than that indicated in Figure 5.9 but there is little or no physical evidence to support spatial distribution at present. MAREA data shows the presence of coarse sediments within mixed sediment areas suggesting the natural heterogeneity in seabed habitat types present throughout the study area.

There is a small and discrete grouping of subtidal mud habitat (**SS.SMu**) found within the shallow, inshore waters, adjacent the Rivers Stour, Orwell and Deben.

Circalittoral rock (**CR.MCR**) and subtidal biogenic reef (**SS.SBR**) classifications describe the geogenic (clay bedrock outcrop) and the potential *Sabellaria spinulosa* reefs respectively. The scale and density of the remote sensing and sampling surveys do not allow for the mapping of these features and will require full coverage acoustic survey with higher intensity ground truthing to determine their spatial extents. However, given the association of outcroppings of clay with the areas of 'Deeps' together with supporting MAREA seabed video data, some predictions as to the distribution of potential geogenic reef have been made.

The habitat complexes and the symbology corresponding with Figure 5.9 are described in Table 5.5.

High-level biotopes may be broadly correlated with the recent UKSeaMap marine landscapes classifications (Connor *et al.*, 2006). These draw upon a variety of benthic and water column environmental datasets, including sediment types, depth, turbidity and tidal current flow to enable broad-scale mapping for the purposes of assisting policy making and seabed resource management. The outputs of the UKSeaMap project indicate that the Outer Thames Estuary REC encompasses a number of different marine landscape types including shallow sand plain, shallow coarse sediment plains under both moderate and strong tidal current stress, and shallow mixed sediment plain under moderate tidal current stress. These terms broadly relate to the sand and coarse mixed sediment habitats identified above and, therefore, support the classifications made at the this level of biotope interpretation. The identification of additional mud and potential reef habitats in the current study reflects the finer spatial scale over which the Outer Thames Estuary REC study has been conducted.

Symbol	Habitat Complex	Habitat Type
(grey)	**CR.MCR**	Moderate energy circalittoral rock
(light green)	**SS.SBR**	Sublittoral biogenic reefs on sediment
(pink)	**SS.SCS**	Sublittoral coarse sediment
(light blue)	**SS.SMu**	Sublittoral cohesive mud and sandy mud
(orange)	**SS.SMx**	Sublittoral mixed sediment
(pale yellow)	**SS.SSa**	Sublittoral sands and muddy sands

Table 5.5: High-level habitat complexes in the Outer Thames Estuary REC study area with symbology relating to Figure 5.9.

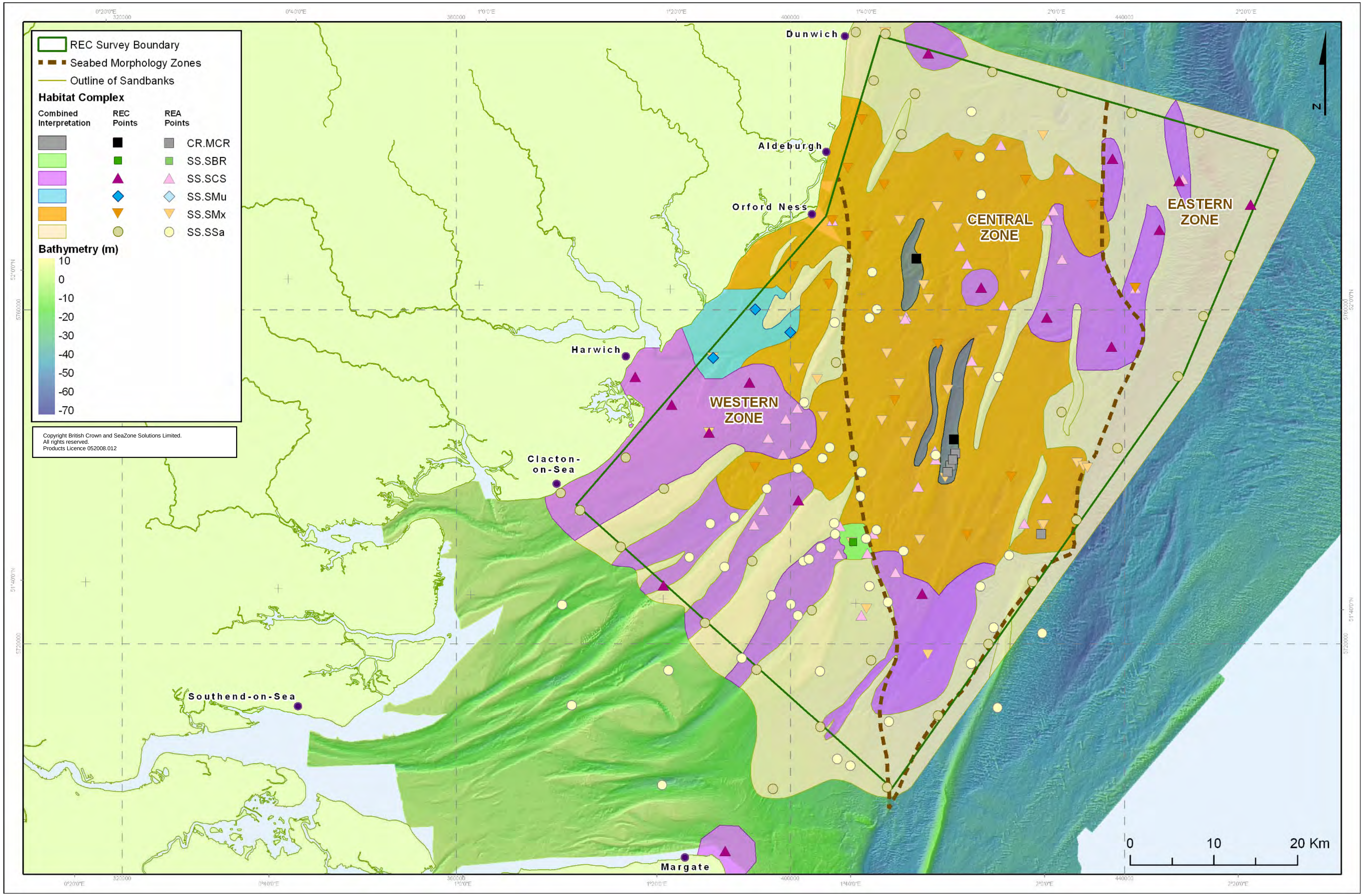


Figure 5.9: Distribution of high-level habitats (habitat complex) in the Outer Thames Estuary REC study area based on Outer Thames Estuary REC and TEDA MAREA survey data.

5.5.2 Biotope Complexes

The distribution of biotope complexes, which introduce a further level of habitat division according to sediment type and other physical factors such as depth, is presented in Figure 5.10.

Sublittoral sands were divided into shallow water fine sands (**SS.SSa.IFiSa**), corresponding to the sandbanks in the south and west of the study area together with isolated areas of muddy sands (**SS.SSa.IMuSa** and **SS.SSa.CMuSa**) probably representing local depositional areas in shallow (infralittoral) and deep water (circalittoral) respectively. The muddy sand habitats correspond with the mud sediments identified by the geological interpretation, which suggests suitable boundaries with adjacent biotope complexes. However, the demarcation between infralittoral and circalittoral muddy sand biotopes remains less certain.

Further definition of the subtidal sands located along the eastern and northern periphery of the survey area and corresponding to the deeper water dune field was not possible. This was because the sediments and depth correspond to a relatively coarse mobile sand within the circalittoral zone for which no suitable biotope complex description exists. The closest description is the fine sand complex, **SS.SSa.IFiSa**, associated with the shallow water sandbanks. These sediments, therefore, remain classified as **SS.SSa**.

Mid-level definition of the classifications did not produce any further division of the circalittoral coarse and mixed sediments (**SS.SCS.CCS** and **SS.SMx.CMx** respectively) with the exception of the shallow inshore sample collected at station 28 located close to Harwich. This coarse sediment habitat was classified as **SS.SCS.ICS** (infralittoral coarse sediment).

The small subtidal mud grouping was divided into a sandy mud sediment biotope (**SS.SMu.ISaMu**) and a sandy muddy sediment influenced by variable salinity (**SS.SMu.SMuVS**), the latter reflecting possible local estuarine influences.

The potential reef features were further interpreted as soft rock reef (**CR.MCR.SfR**) and polychaete reef (**SS.SBR.PoR**).

The biotope complexes and the symbology corresponding with Figure 5.10 are described in Table 5.6.

Symbol	Biotope Complex	Biotope Complex Type
	CR.MCR.SfR	Circalittoral, moderately exposed soft rock
	SS.SBR.PoR	Polychaete worm reef on sublittoral sediment
	SS.SCS.CCS	Circalittoral coarse sediment
	SS.SCS.ICS	Infralittoral coarse sediment
	SS.SMu.ISaMu	Infralittoral sandy mud
	SS.SMu.SMuVS	Sublittoral mud in variable salinity
	SS.SMx.CMx	Circalittoral mixed sediment
	SS.SSa	Sublittoral sands and muddy sands
	SS.SSa.CMuSa	Circalittoral muddy sand
	SS.SSa.IFiSa	Infralittoral fine sand
	SS.SSa.IMuSa	Infralittoral muddy sand

Table 5.6: Mid-level biotope complexes in the Outer Thames Estuary REC study area with symbology relating to Figure 5.10.

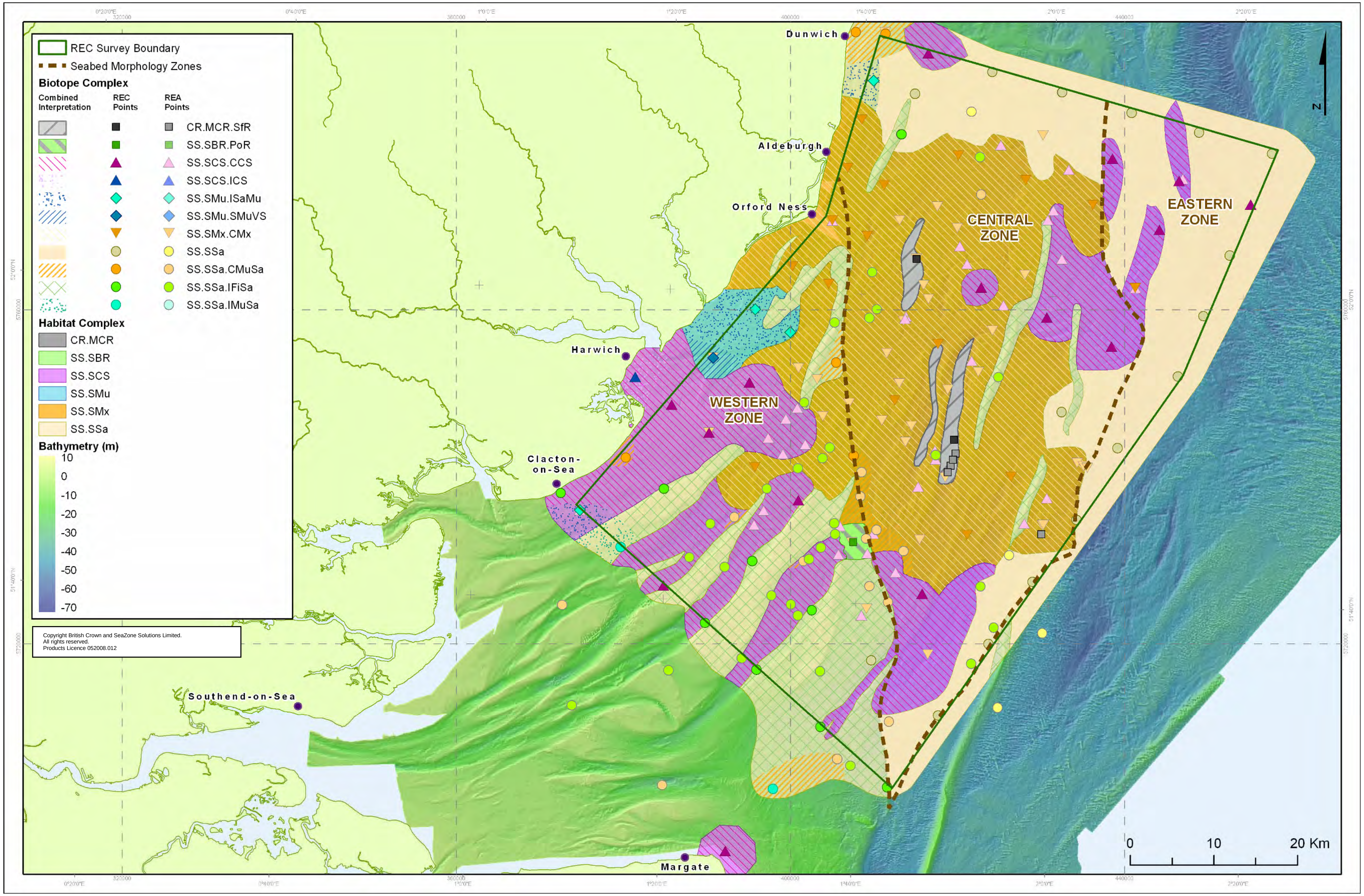


Figure 5.10: Mid-level habitat classifications (biotope complex) of the Outer Thames Estuary REC study area based on Outer Thames Estuary REC and TEDA MAREA survey data.

5.5.3 Biotopes

The distribution of detailed level biotopes incorporating species information derived from the grabs and seabed photography is presented in Figure 5.11. This map differs from the two previous maps as it incorporates an overlay of epifaunal biotopes. Trawl data have also been considered here to help inform the classification of overlying epifaunal biotopes.

This map is based almost entirely on the Outer Thames Estuary REC data but uses MAREA data to identify additional sites supporting important geogenic reef areas, **CR.MCR.SfR.Pid** and *Ampelisca* reef, **SS.SMu.ISaMu.AmpPlon**.

Table 5.7 presents a list of the infaunal biotopes classified from the Outer Thames Estuary REC data and the symbology corresponding with the high-level biotope classification presented in Figure 5.11. Similarly, Table 5.8 presents a list of the epifaunal biotopes and corresponding symbology for Figure 5.11.

There is currently a general dichotomy within the Marine Habitat Classification, broadly separating infaunal biotopes from epifaunal biotopes. This is largely a result of the differences in sampling methods and data treatments (i.e. the availability of either enumerated or semi or non-quantitative data). As a result, it has been necessary in some instances to assign both an infaunal biotope, based on grab sample data, and an 'overlying' epifaunal biotope, based on the seabed photography and trawl data to fully explain the benthic habitats and communities present. Further development of the Marine Habitat Classification and derivation of biotopes which unify both infaunal and epifaunal components of offshore mixed coarse substrates is warranted. The biotope summaries are, therefore, based on the infaunal data with associated epifaunal biotopes described under the principal infaunal classifications.

Symbol	Biotope Code	Biotope Type
■	**CR.MCR.SfR.Pid**	Piddocks with a sparse associated fauna in sublittoral very soft chalk or clay.
□	**SS.SBR.PoR.SspiMx**	*Sabellaria spinulosa* on stable circalittoral mixed sediment.
△	**SS.SCS.CCS**	Circalittoral coarse sediment.
▲	**SS.SCS.CCS** and **SS.SBR.PoR.SspiMx**	Circalittoral coarse sediment (with *Sabellaria spinulosa* on stable circalittoral mixed sediment).
▲	**SS.SCS.CCS.MedLumVen**	*Mediomastus fragilis, Lumbrineris* spp. and venerid bivalves.
△	**SS.SCS.ICS.SLan**	Dense *Lanice conchilega* and other polychaetes in tide swept infralittoral sand and mixed gravelly sand.
◇	**SS.SMu.ISaMu**	Infralittoral sandy mud.
◆	**SS.SMu.ISaMu.AmpPlon**	*Ampelisca* spp., *Photis longicaudata* and other tube-building amphipods and polychaetes in infralittoral sandy mud.
◆	**SS.SMu.ISaMu.NhomMac**	Infralittoral sandy mud (with *Nepthys homergii* and *Macoma balthica*).
◆	**SS.SMu.SMuVS.AphTubi**	*Aphelochaeta marioni* and *Tubificoides* spp. in variable salinity infralittoral mud.
▽	**SS.SMx.CMx**	Circalittoral mixed sediment.
▼	**SS.SMx.CMx** and **SS.SCS.CCS.MedLumVen**	Circalittoral mixed sediment (with *Mediomastus fragilis, Lumbrineris* spp. and venerid bivalves).
▼	**SS.SMx.CMx** and **SS.SBR.PoR.SspiMx**	Circalittoral mixed sediment (with *Sabellaria spinulosa* on stable circalittoral mixed sediment).
○	**SS.SSa**	Sublittoral sands and muddy sands.
●	**SS.SSa** and **SS.SBR.PoR.SspiMx**	Sublittoral sands and muddy sands (with *Sabellaria spinulosa* on stable circalittoral mixed sediment).
●	**SS.SSa.CMuSa.AalbNuc**	*Abra alba* and *Nucula nitidosa* in circalittoral muddy sand or slightly mixed sediment.
●	**SS.SSa.IFiSa.IMoSa**	Infralittoral mobile clean sand with sparse fauna.
●	**SS.SSa.IFiSa.NcirBat**	*Nephtys cirrosa* and *Bathyporeia* spp. in infralittoral sand.
○	**SS.SSa.IMuSa**	Infralittoral muddy sand.
●	**SS.SSa.IMuSa.FfabMag**	*Fabulina fabula* and *Magelona mirabilis* with venerid bivalves and amphipods in infralittoral compacted fine muddy sand.

Table 5.7: List of infaunal biotopes presented in Figure 5.11, classified from the Outer Thames Estuary REC data.

Symbol	Biotope Code	Biotope Type
○	**CR.HCR.XFa** and **SS.SCS.CCS.PomB**	Mixed faunal turf communities (with *Pomatoceros triqueter* with barnacles and bryozoan crusts on unstable circalittoral cobbles and pebbles
○	**CR.HCR.XFa.Mol**	*Molgula manhattensis* with a hydroid and bryozoan turf on tide-swept moderately wave-exposed circalittoral rock.
○	**CR.HCR.XFa.SpNemAdia**	Sparse sponges, *Nemertesia* spp. and *Alcyonidium diaphanum* on circalittoral mixed substrata.
○	**CR.HCR.XFa**	Mixed faunal turf communities.
○	**SS.SCS.CCS.PomB**	*Pomatoceros triqueter* with barnacles and bryozoan crusts on unstable circalittoral cobbles and pebbles.

Table 5.8: List of overlying epifaunal biotopes presented in Figure 5.11, classified from the Outer Thames Estuary REC data.

The extents of each of the biotopes are inferred from the observed relationships between respective 'parent' biotope and habitat complexes and the geomorphological and seabed geological features. Some boundaries, however, remain uncertain since the spatial extent and temporal stability of biotope characteristics are unclear. Higher intensity data acquisition over smaller spatial scales is required to allow their extents to be resolved more accurately. It is likely that boundaries between many of the mixed sediment biotopes are naturally indistinct and that seabed types and associated communities exist along environmental gradients of different types; such as tidal stress linked with associated scouring and seabed stability; response to estuarine influences as well as anthropogenic activities. Furthermore, there is evidence in this study that a number of characteristic species of mixed muddy sand and gravel sediments exhibit little habitat preference within the range of physical conditions present. As a consequence there may be considerable overlap of species between related biotope and habitat complexes. At the biotope level, therefore, discrete boundaries may not exist or may be difficult to discern, with the resulting description based on matrices of biotopes.

In total, 16 infaunal biotopes and 4 epifaunal biotopes were classified. The principal physical and biological characteristics are reviewed in the following biotope summaries *.

* The biotope summary tables presented on pages 108 to 119 refer to biotopes that can occur in combination with other biotopes in the Outer Thames Estuary region. Consequently, some summary tables display more than one of the symbols presented in Table 5.7 and Figure 5.11.
Where biotopes are characterised by just one seabed sediment sample, the resulting sediment distribution bar graphs do not display error bars.

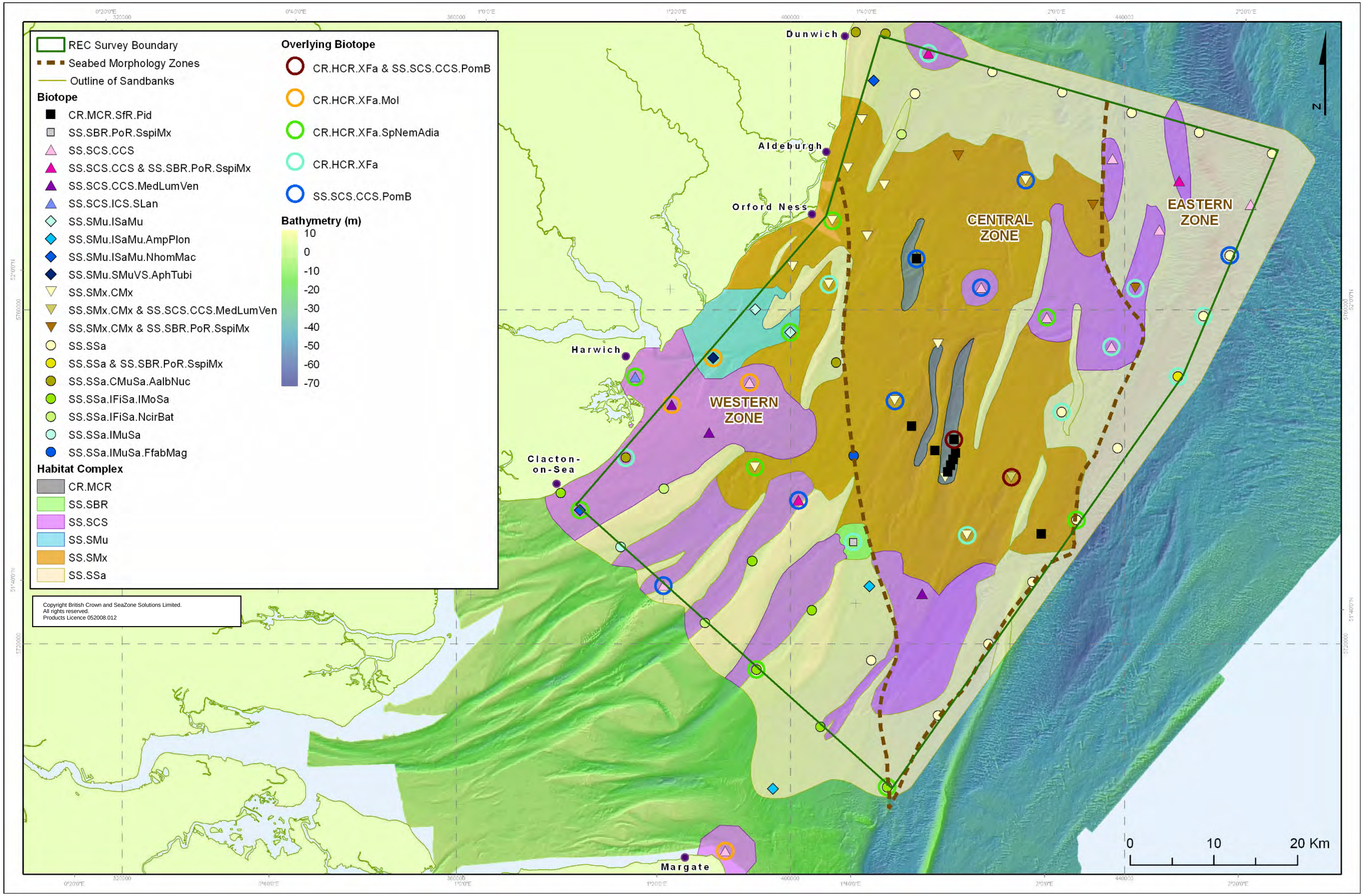


Figure 5.11: Low-level biotope classification in the Outer Thames Estuary REC study area based on Outer Thames Estuary REC survey data.

CR.MCR.SfR.Pid

Piddocks with a sparse associated fauna in sublittoral very soft chalk or clay
(Examples of this biotope found at REC Sample Sites 31 and 45)

Biotope description

This biotope was associated with outcrops of compacted clay with little or no overlying sediment veneers. Soft rock is generally unsuitable for the settlement of sessile epifauna so that these do not generally occur in large abundances within this biotope. However, the tunicate *Molgula manhattensis* and the soft coral *Alcyonium digitatum* were found at station 45 where surficial sediments were comparatively thicker giving rise to an overlying **XFa.Mol** biotope. The barnacle *Verruca stroemia*, keel worm *Pomatoceros lamarcki* and the long-clawed porcelain crab *Pisidia longicornis* were particularly conspicuous in grab samples suggesting a further **PomB** biotope as an overlay. Prominent infauna included the boring bivalve *Barnea candida* and polychaetes *Sabellaria spinulosa, Lumbrineris gracilis* and *Harmothoe* spp.

Characterising species within the Outer Thames Estuary REC

Sabellaria spinulosa	*Barnea candida*
Verruca stroemia	*Pisidia longicornis*

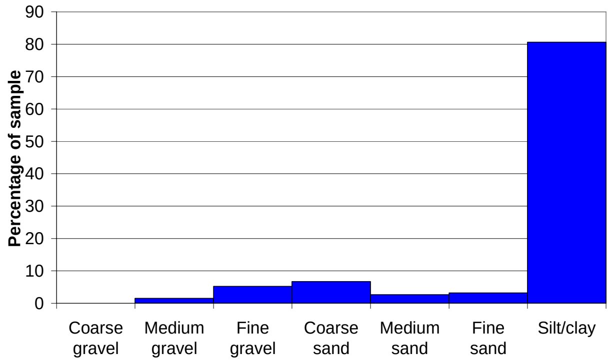
Seabed photographs showing bored compacted clay overlain in places with a thin veneer of medium and coarse gravel. Epifauna were typically sparse and included the *Verruca stroemia* and *Molgula* whilst larger stones supported *Alcyonium digitatum* (illustrated).

Sediment description

Particle size distribution data are unrepresentative for this habitat type and do not reflect the hard nature of the seabed with the silt/clay fraction effectively compacted.

Visual assessment

Bored bedrock (compacted clay) with patches of mixed pebbles and gravel with occasional cobbles. The clay substrata is generally bare with no attaching species but *Verruca stroemia, Pomatoceros* spp. and *Psammechinus miliaris* are frequently recorded on surficial gravel sediments.

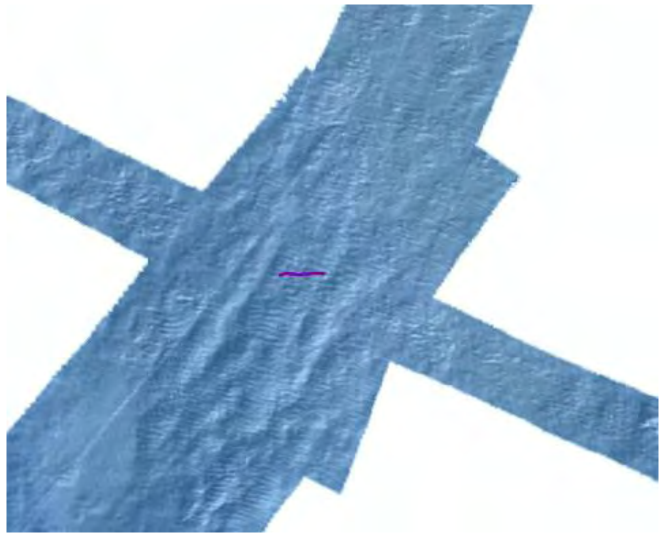


Site 31 only. No sediment data recovered for Sample 45.

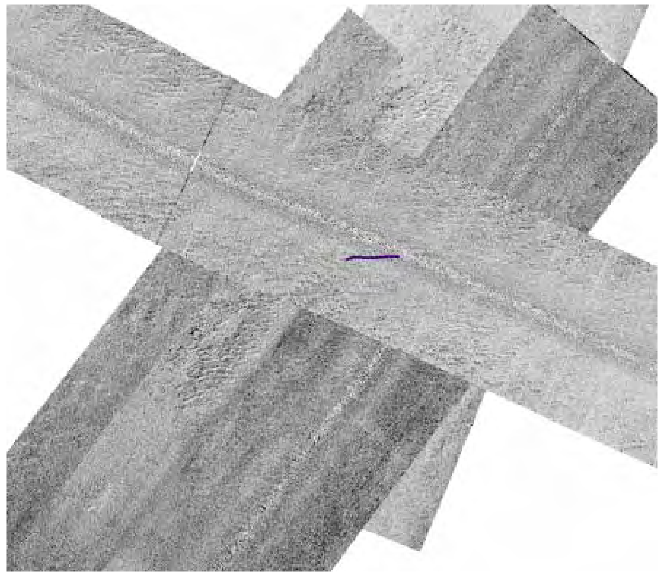
Overlying epifaunal biotopes

SS.SCS.CCS.PomB - *Pomatoceros triqueter* with barnacles and bryozoan crusts on unstable circalittoral cobbles and pebbles. Occurs on patches of mixed muddy gravel veneers overlying the compacted clay sediments. The biotope found may represent a biological variant on the Marine Habitat Classification as a result of the dominance of *P. lamarcki* and *Verruca stroemia.*
CR.HCR.XFa.Mol – The ascidian *Molgula manhattensis* and mixed bryozoan and hydroid turf on sediment influence circalittoral rock. This biotope is usually associated with turbid, shallow water conditions and often occurs on soft rock. Its distribution therefore may be indicative of additional areas of exposed compacted clay.

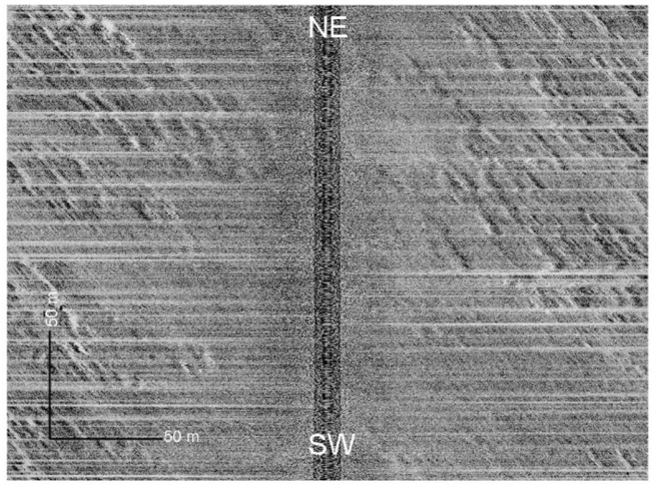
Other characterising species – *Pomatoceros* spp., *Alcyonium digitatum, Psammechinus miliaris, Asterias rubens,* Paguridae, *Buccinum undatum,* Actiniaria, *Pandalina brevirostris, Pandalus montagui, Microstomus kitt.*



Multibeam image shows a slightly irregular seabed with NE-SW trending low ridges with smaller E-W trending bedforms in between. Water depth is around 27 m.



Side scan sonar image shows camera transect located in an area of moderate reflectivity interpreted as gravelly lag sediments and bedrock exposures with dispersed sands and localised E-W oriented sand bedforms.



Detailed side scan sonar image of medium to high reflectivity seabed interpreted as gravelly lag sediments overlying partially exposed bedrock, with localised sands located in the troughs.

SS.SBR.PoR.SspiMx

***Sabellaria spinulosa* on stable circalittoral mixed sediment**

(Examples of this biotope found at REC Sample Sites 19, 41, 49, 54, 56 and 68, and at Image Stations 18 and 60)

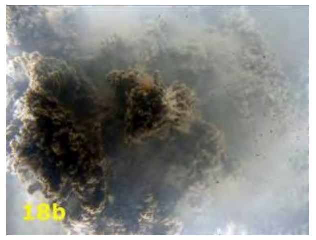
Biotope description

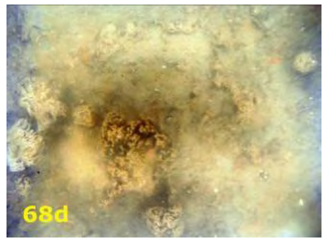
Coherent and extensive *Sabellaria spinulosa* growths were recorded at image station 18. This may be regarded as potential reef on the basis of elevation, patchiness and extent characteristics and further survey in this area would be helpful for assessment purposes. Seabed photography have identified a number of other areas of circalittoral coarse and mixed sediments supporting growths of *Sabellaria spinulosa*, although the data supported the presence of isolated and patchily distributed clumps (example image station 60). These clumps are not regarded as potential reef but are nonetheless assigned the **SspiMx** classification as this is the best match with the Marine Habitat Classification for *Sabellaria spinulosa* on mixed sediments.

Trawls collected at stations 7, 41 and 54 also contained encrustations of *Sabellaria spinulosa* tubes with apparent elevations of several centimetres, further indicating the presence of potential reefs along the respective trawl tow paths.

Characterising species within the Outer Thames Estuary REC

Sabellaria spinulosa
Spiophanes bombyx
Eulalia ornate
Abludomelita obtusata
Photis longicaudata
Lagis koreni
Echinocyamus pusillus
Lumbrineris gracilis
ACTINIARIA
Ophiura albida
NEMERTEA





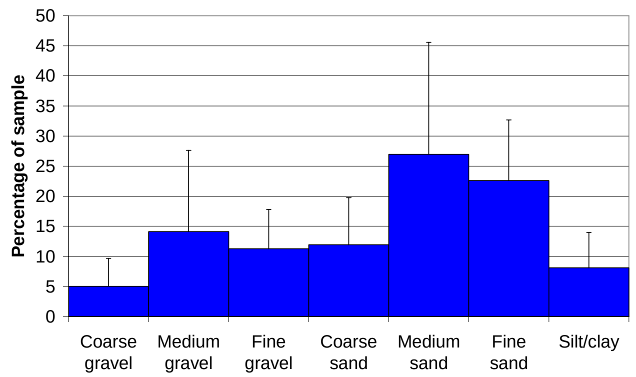
Seabed photographs showing potential *Sabellaria spinulosa* reef at image station 18b. Also shown are the more typical isolated clumps (examples 68d and 60d).

Sediment descriptions

Gravelly sand, sandy gravel, muddy sandy gravel and gravelly muddy sand.

Visual assessment

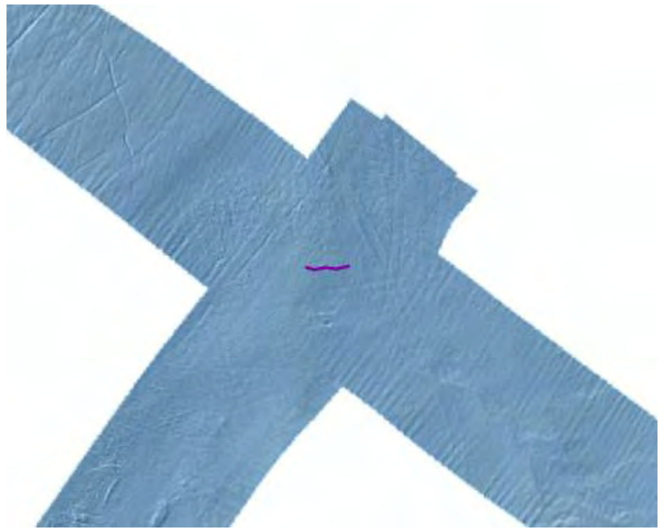
Substrates associated with this biotope are highly variable. Gravel is the major sediment component at stations 18 and 19 whilst sand dominated at the remainder of stations with smaller quantities of fine to medium gravel.



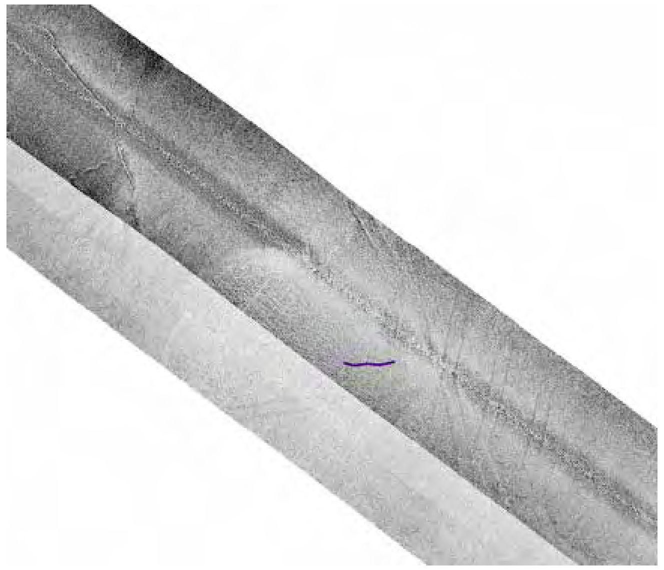
Overlying epifaunal biotopes

SS.SCS.CCS.PomB - *Pomatoceros triqueter* with barnacles and bryozoan crusts on unstable circalittoral cobbles and pebbles. This biotope occurs on patches of mixed muddy gravel veneers as a mosaic with assemblages of *Sabellaria spinulosa.* The biotope found may represent a biological variant on the Marine Habitat Classification as a result of the dominance of *P. lamarcki* and *Verruca stroemia.*
CR.HCR.XFa – Mixed faunal turf communities although typical sponge species were sparse or absent from the Outer Thames Estuary REC. The other associated epifauna are generally sparse due to the current exposed conditions and associated sediment scouring effects.

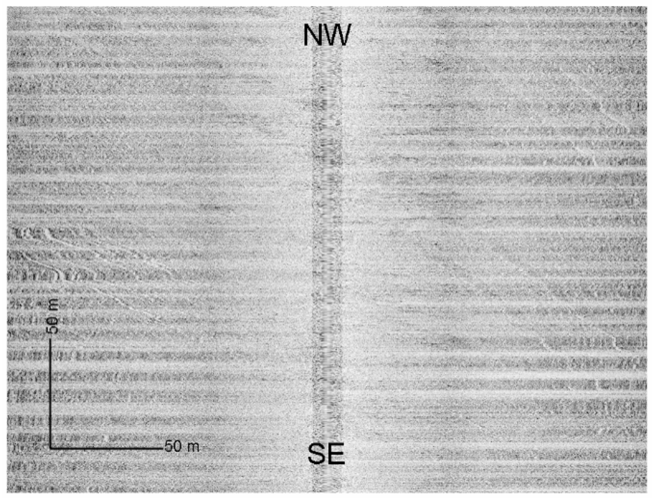
Other conspicuous fauna – *Asterias rubens, Ophiura albida,* Actiniaria*, Verruca stroemia,* Paguridae*, Pomatoceros* spp.*, Psammechinus miliaris.*



Multibeam image of a flat seabed with small NE-SW trending bedforms and occasional trawl marks on seabed. Water depth is around 23 m.



Side scan sonar image showing camera transect along low-moderate reflectivity interpreted as slightly gravelly sediments with trawl marks in the east. Higher reflectivity backscatter (more gravelly sediments) are visible towards the north and west.



Side scan sonar image of the sample location shows a moderate reflectivity seabed with localised areas of higher backscatter, interpreted as a gravelly seabed. Trawling and small bedforms (sand streaks and small dunes) are present.

SS.SCS.CCS and SS.SCS.CCS.MedLumVen

Circalittoral coarse sediment (with *Mediomastus, Lumbrineris* and venerid bivalves)

(Examples of SS.SCS.CCS biotope found at REC Sample Sites 01, 07, 17, 19, 21, 22, 27, 42, 43, 44, 53, 59, 60, 68 and Image Station 60)

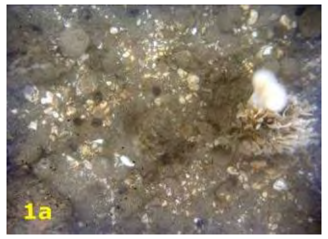
(Examples with MedLumVen biotope found at REC Sample Sites 17, 21, 22 and 30)

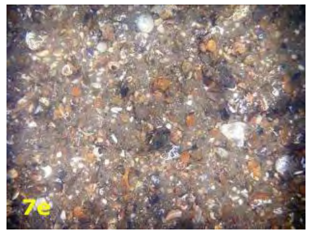
Biotope description

Patches of seabed comprising coarse sediments were attributed the **CCS** biotope classification. It has been used to classify those areas for which greater definition was not possible due to the apparent paucity of species or absence of a suitable species match with the Marine Habitat Classification. The species found in grab samples at stations 17, 21, 22 and 30 however were found to match the **MedLumVen** classification although the typical venerid bivalves were present in low abundance or were absent. Although a better defined biotope, **MedLumVen** is regarded as very broad and appears to represent a wide variety of sub biotopes

Characterising species within the Outer Thames Estuary REC

Molgula manhattensis	*Sabellaria spinulosa*	*Pomatoceros lamarcki*
Amphipholis squamata	Mytilidae	*Lumbrineris gracilis*
ASCIDIACEA	*Phoronis* spp.	*Ampelisca spinipes*
Photis longicaudata	*Ophiura albida*	*Pisidia longicornis*





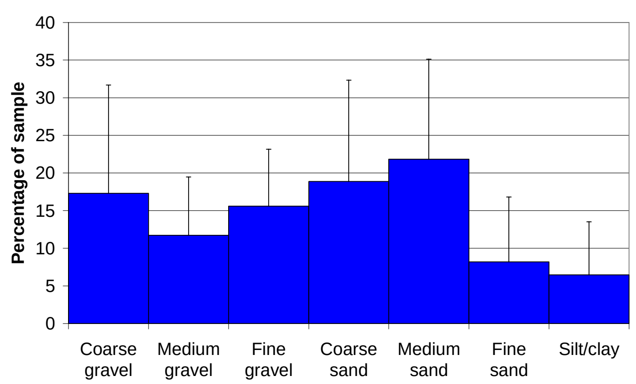
Seabed photographs illustrating the range of coarse sand and gravel sediments present which in some instances provide suitable for colonisation by colonial sessile epifauna such as the soft coral *Alcyonium digitatum* and *Flustra foliacea*.

Sediment description

Muddy sandy gravel, sandy gravel, gravelly sand, gravelly muddy sand

Visual assessment

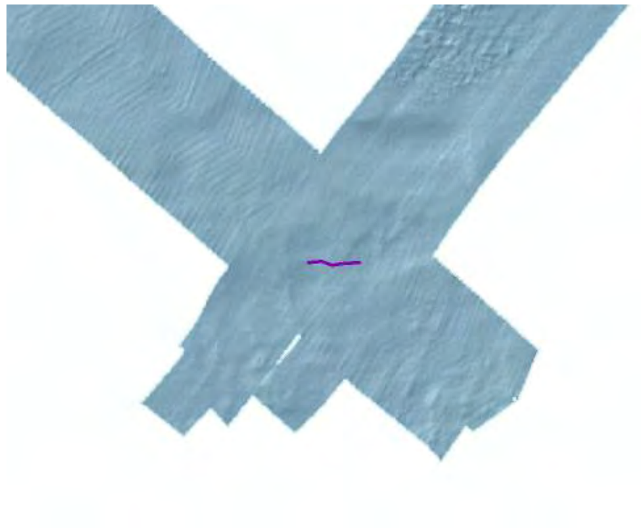
Pebbles and gravel dominate sediments to the south and within the centre of the REC area supporting hydroids, bryozoans and the soft coral *A. digitatum.* Sediments become more sandy with increasing distance north and east and lack a conspicuous epifauna.



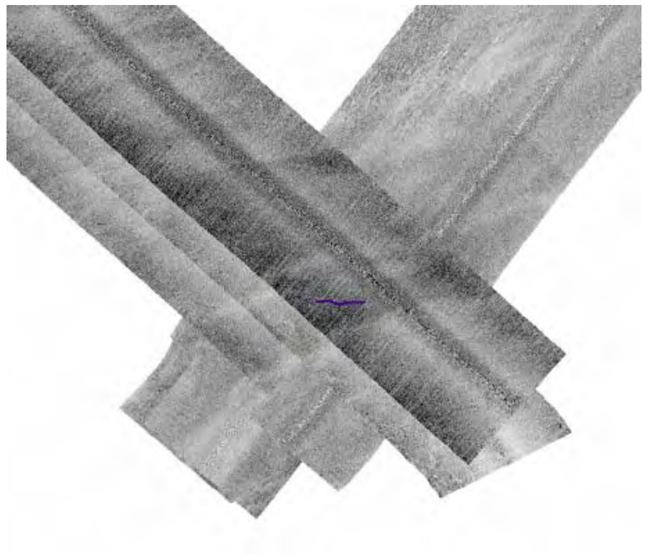
Overlying epifaunal biotopes

SS.SCS.CCS.PomB - *Pomatoceros triqueter* with barnacles and bryozoan crusts on unstable circalittoral cobbles and pebbles. The biotope found may represent a biological variant on the Marine Habitat Classification as a result of the dominance of *P. lamarcki* and *Verruca stroemia.*
CR.HCR.XFa – Mixed faunal turf communities although typical sponge species were sparse or absent from the Thames REC. The other associated epifauna are generally sparse due to the current exposed conditions and associated sediment scouring effects.
CR.HCR.XFa.Mol – The ascidian *Molgula manhattensis* and mixed bryozoan and hydroid turf on sediment influence circalittoral rock. This biotope is usually associated with turbid, shallow water conditions and often occurs on soft rock. Its distribution therefore may be indicative of additional areas of exposed compacted clay.

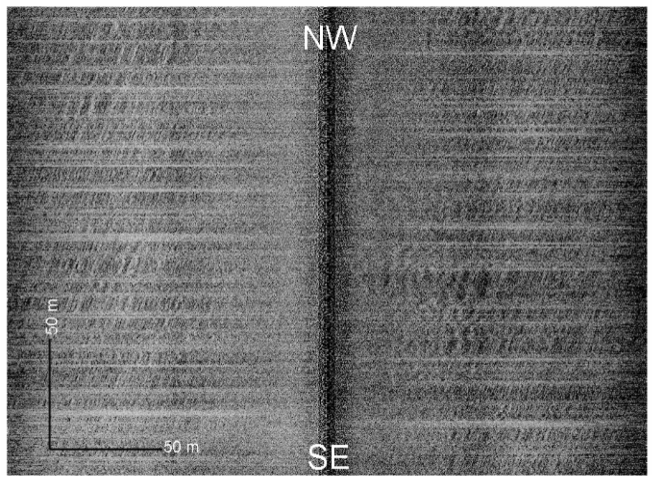
Other conspicuous fauna – *Alcyonium digitatum, Asterias rubens, Ophiura albida,* Actiniaria, Paguridae, *Pomatoceros* spp.*, Psammechinus miliaris, Nemertesia* spp.*, Macropodia* spp.



Multibeam bathymetry shows a slightly irregular seabed at the camera transect location which becomes rough towards the north-east. Water depth is around 13 m.



Side scan sonar image shows a high reflectivity seabed near the camera transect location, indicating gravelly sediments. Lower reflectivity sand patches are present to the north and south.



Side scan sonar image of high reflectivity, locally irregular seabed interpreted as uniform gravelly sediments.

SS.SMx.CMx

Circalittoral mixed sediment

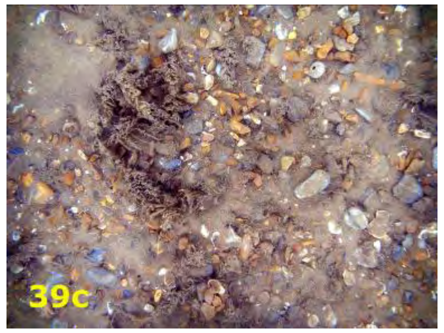
(Examples of this biotope found at REC Sample Sites 20, 25, 30, 32, 38, 39, 40, 46, 47, 49, 50, 51, 54, 55, 56 and 58)

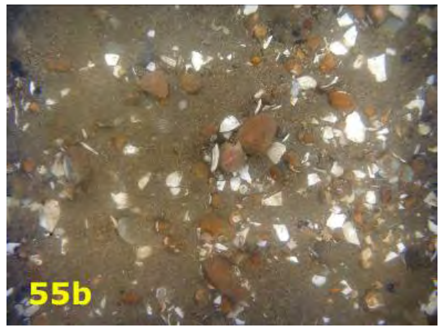
Biotope description

Well mixed muddy, sandy gravel sediments occupying central and shallow near-shore areas within the Outer Thames Estuary REC. This broad biotope encompasses a variety of the generic biotopes previously described including **SS.SSa.CMuSa.AalbNuc, SS.SCS.CCS, SS.SCS.CCS.MedLumVen** and **SS.SSa.CMuSa.**

Characterising species within the Outer Thames Estuary REC

Lagis koreni	*Notomastus* spp.	*Lumbrineris gracilis*
Spiophanes bombyx	*Lanice conchilega*	*Sabellaria spinulosa*
Ampelisca spinipes	*Sarcodictyon roseum*	*Scalibregma inflatum*
Abra alba	*Ophiura albida*	





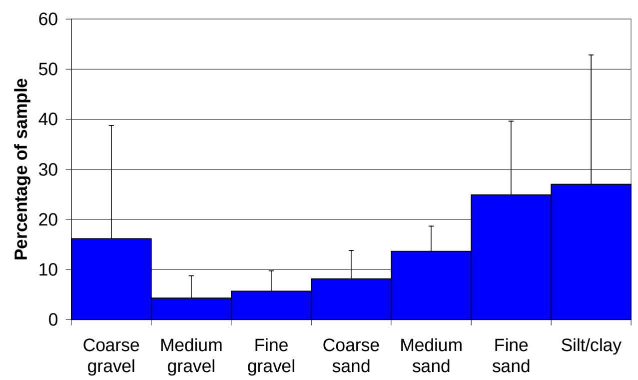
Seabed photographs showing mixed muddy gravels and shell gravels

Sediment descriptions

Muddy sandy gravel, gravelly muddy sand, sandy mud.

Visual assessment

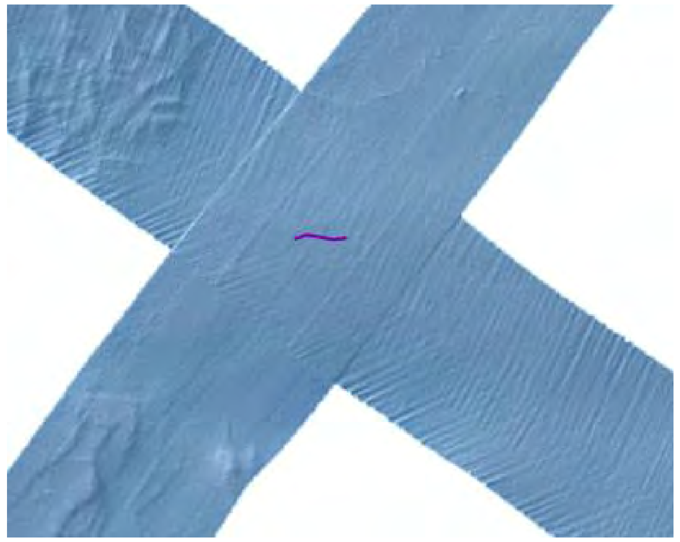
The sediments are characterised by muddy sands overlain with gravel. The foliose bryozoan *Flustra foliacea* colonises the larger, more stable gravel particles.



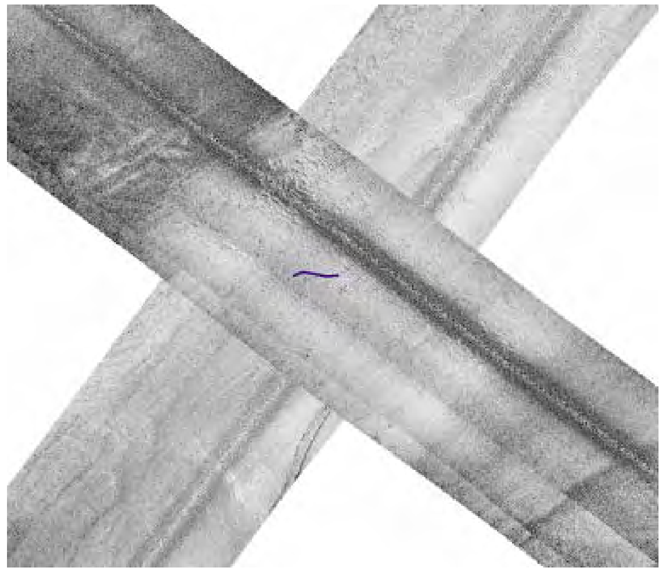
Overlying epifaunal biotopes

SS.SCS.CCS.PomB - *Pomatoceros triqueter* with barnacles and bryozoan crusts on unstable circalittoral cobbles and pebbles. The biotope found may represent a biological variant on the Marine Habitat Classification as a result of the dominance of *P. lamarcki* and *Verruca stroemia*.
CR.HCR.XFa – Mixed faunal turf communities although typical sponge species were sparse or absent from the Thames REC. The other associated epifauna are generally sparse due to the current exposed conditions and associated sediment scouring effects.
CR.HCR.XFa.Mol – The ascidian *Molgula manhattensis* and mixed bryozoan and hydroid turf on sediment influence circalittoral rock. This biotope is usually associated with turbid, shallow water conditions and often occurs on soft rock. Its distribution therefore may be indicative of additional areas of exposed compacted clay.
CR.HCR.XFa.SpNemAdia – Sparse sponges, *Nemertesia* spp. and *Alcyonidium diaphanum* on circalittoral mixed substrata. Identified from trawl samples.

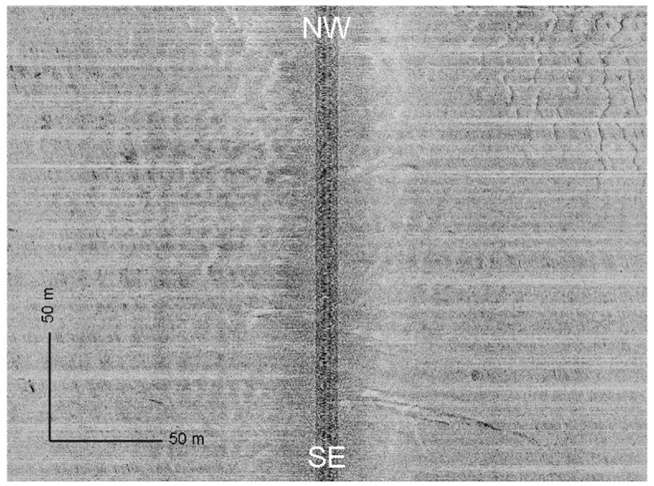
Other conspicuous fauna – *Crangon allmani, C. crangon, Alcyonium diaphanum, Flustra foliacea, Ophiura albida, Psammechinus miliaris, Pomatoschistus* spp.*, Solea solea, Sertularia* spp.



Multibeam image shows a flat seabed becoming significantly more irregular towards the south and north-west. Camera transect lies at around 23 m depth.



Side scan sonar image shows a predominantly low reflectivity seabed at the transect location, indicating sand dominated sediments with localised small dunes. A higher reflectivity seabed to the NW and SE suggests a more gravelly seabed.



Side scan sonar image showing a low-moderate seabed reflectivity interpreted to be sands or gravelly sands. Small dunes and trawling tracks are present.

SS.SSa

Sublittoral sands and muddy sands

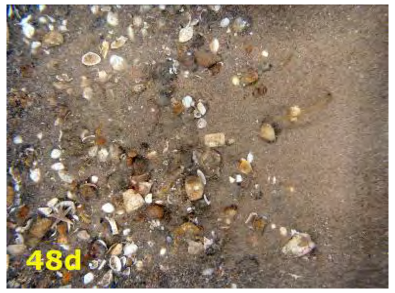
(Examples of this biotope found at REC Sample Sites 11, 12, 16, 24, 29, 36, 37, 41, 48, 52, 61, 63, 64, 65, 66 and 67)

Biotope description

This is a broad classification which captures sand and slightly gravelly sand sediment habitats supporting a particularly impoverished macrofauna. There is a high degree of correspondence between this biotope and the deeper water sand dune field which fringes the Outer Thames Estuary REC area along its northern and easternmost boundaries.

Characterising species within the Outer Thames Estuary REC

Gastrosaccus spinifer
Urothoe brevicornis
Nephtys cirrosa
Ophiura albida
Abludomelita obtusata
OPHIUROIDEA
Notomastus spp.



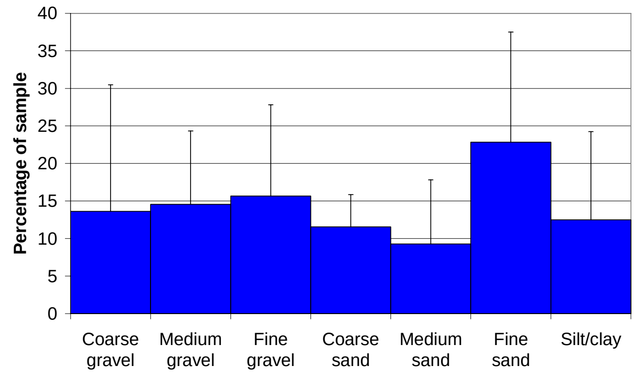
Example seabed photographs showing predominately sand sediments. These are largely homogenous habitats with occasional patches of gravel and shell and infrequent cobbles providing some local variation.

Sediment descriptions

Muddy sandy gravel, sandy gravel, slightly gravelly muddy sand.

Visual assessment

The sediments are dominated by the gravel and pebble fractions with levels of gravel decreasing relative to increased sand towards the north. The amounts of pebbles are largely consistent throughout the Outer Thames Estuary REC, although grab data suggests decreased coarse sediment material and a higher fine sediment component closer inshore.

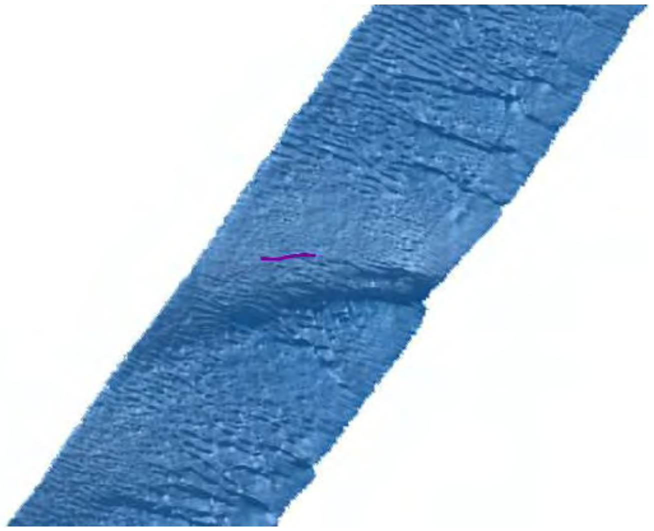


Overlying epifaunal biotopes

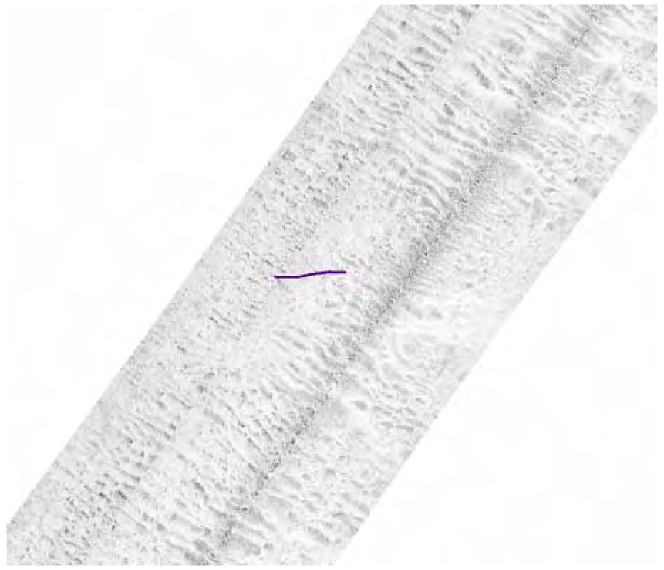
Epifaunal biotopes are impoverished and sporadically distributed throughout the range of the **SSa** biotope being largely confined to gravel and occasional cobble particles. Small growths of hydroids and *Alcyonidium diaphanum* occur infrequently within the sand and indicate the possible presence of coarser substrates below a thin sand veneer. The hydroid *Obelia bidentata* attaches to shell fragments. Although sparsely distributed and poorly represented the following epifaunal biotopes may be associated with the **SSa** classification;

SS.SCS.CCS.PomB - *Pomatoceros triqueter* with barnacles and bryozoan crusts on unstable circalittoral cobbles and pebbles.
CR.HCR.XFa – Mixed faunal turf communities
CR.HCR.XFa.SpNemAdia – Sparse sponges, *Nemertesia* spp. and *Alcyonidium diaphanum* on circalittoral mixed substrata.

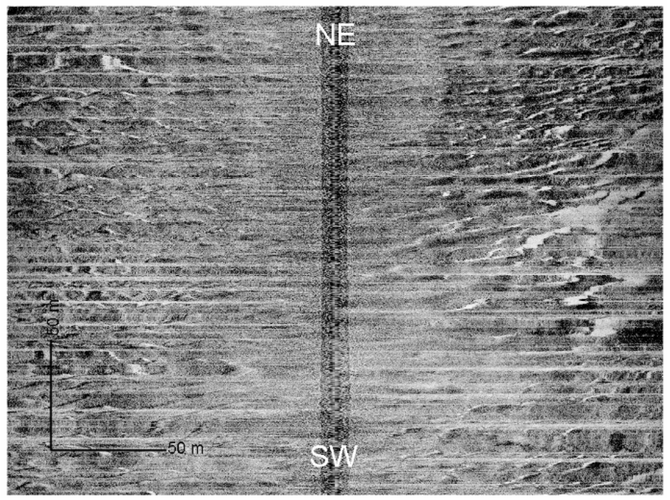
Other conspicuous fauna – *Crangon allmani, Ophiura albida, Hydrallmania falcata, Obelia bidentata, Echiichthys vipera*



Multibeam image shows an irregular, rough seabed with a distinct ENE-WSW trending large submarine dune, with smaller WNW-ESE trending dunes superimposed either side of the crest. Water depth is around 32 m.



Side scan sonar image shows a low reflectivity seabed with ridges oriented approximately NW-SE, interpreted as sand dunes possibly with gravelly sediments locally exposed in the troughs.



Side scan sonar image shows a moderate reflectivity, locally ridged seabed suggesting sandy and gravelly sediments. The gravelly sediments lie in the troughs between the sand patches and bedforms (dunes).

SS.SSa.CMuSa.AalbNuc

***Abra alba* and *Nucula nitidosa* in circalittoral muddy sand or slightly mixed sediment**
(Examples of this biotope found at REC Sample Sites 15, 33, 69 and 70)

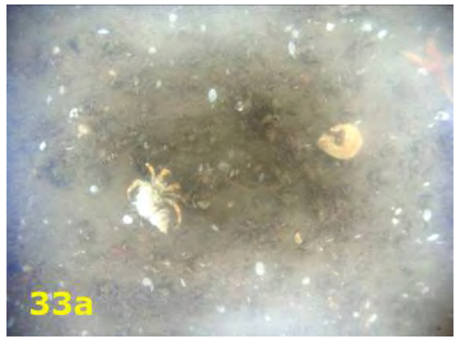
Biotope description

This biotope is represented by four samples collected mainly from inshore locations. Samples 69 and 70 form a small discrete cluster to the far north-west of the area.

Characterising species within the Outer Thames Estuary REC

Spiophanes bombyx
Nucula nucleus
Abra nitida
Lagis koreni
Abra alba
Sabellaria spinulosa
Ophiura albida
Unciola crenatipalma
Nephtys hombergii

Spiophanes bombyx



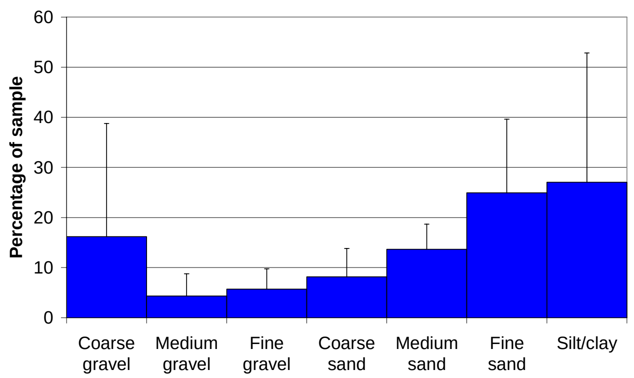
Example seabed photographs showing mixed muddy sediments overlain with gravel, slightly shelly gravel and occasional cobbles. *Flustra foliacea* colonises the larger sediment particles.

Sediment descriptions

Muddy sandy gravel, gravelly muddy sand, sandy mud.

Visual assessment

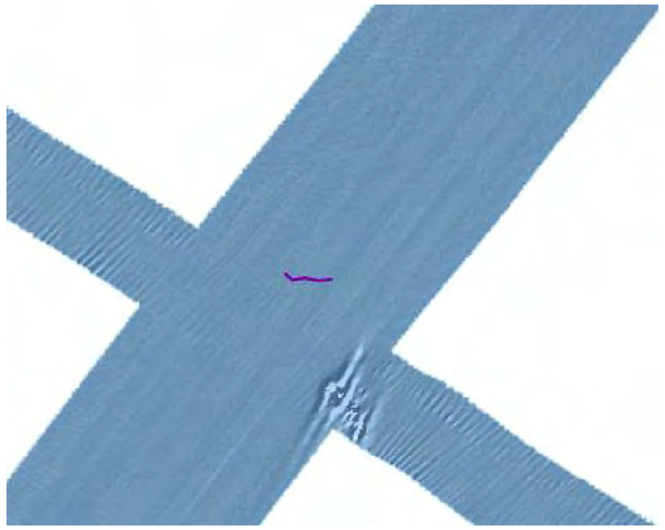
The sediments are characterised by muddy sands overlain with gravel. The foliose bryozoan *Flustra foliacea* colonises the larger, more stable gravel particles.



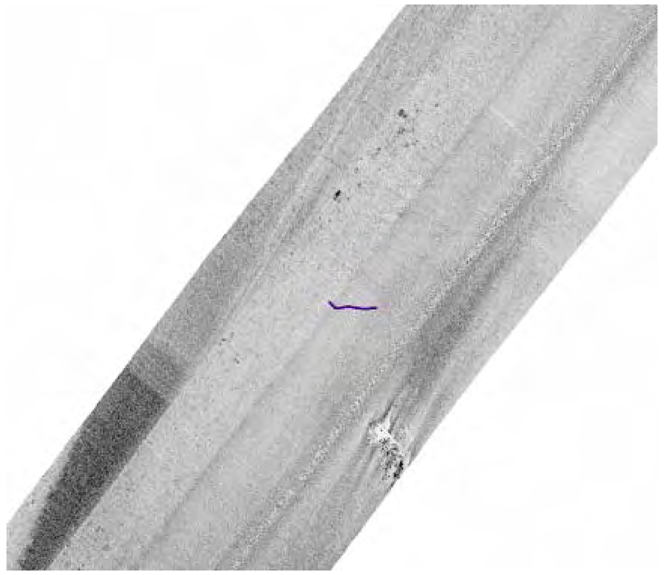
Overlying epifaunal biotopes

CR.HCR.XFa – Mixed faunal turf communities confined to cobbles where they occur.

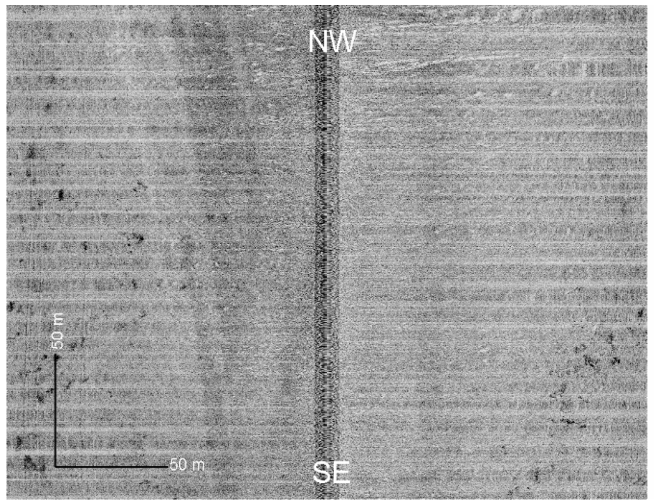
Other conspicuous fauna – *Ophiura albida, Flustra foliacea,* Paguridae, *Pomatoceros* spp.



Multibeam shows a very uniform and flat, featureless seabed. Water depth is around 22 m.



Side scan sonar shows a moderate reflectivity, slightly irregular seabed.



Side scan sonar shows moderate, speckled reflectivity interpreted to be gravelly sediments with patches of cobbles in places.

SS.SSa.IMuSa and SS.SSa.IMuSa.FfabMag

Infralittoral muddy sand and *Fabulina fabula* and *Magelona mirabilis* with venerid bivalves and amphipods in infralittoral compacted fine muddy sand.
(Example of SS.SSa.IMuSa biotope found at REC Sample Site 8. Example of SS.SSa.IMuSa.FfabMag biotope found at REC Sample Site 26)

Biotope description

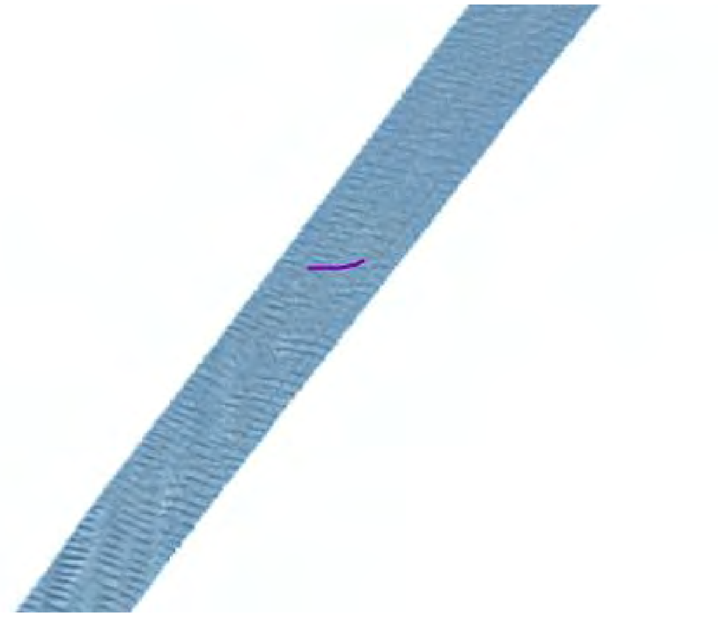
The **SS.SSa.IMuSa** biotope (Infralittoral muddy sands) was identified at Sample Site 8.

Represented by only one sample (Sample Site 26), the **SS.SSa.IMuSa.FfabMag** biotope is a highly impoverished variant compared to the Marine Habitat Classification and may actually fit better with one of the fine sand biotopes such as **IMoSa** or **NcirBa**t for example. The characterising species however match the **FfabMag** classification although abundances of all taxa were extremely low. Consequently the assignment of this biotope is tentative and should be treated with caution.

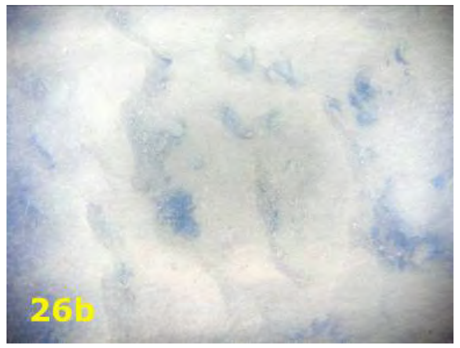
Characterising species within the Outer Thames Estuary REC

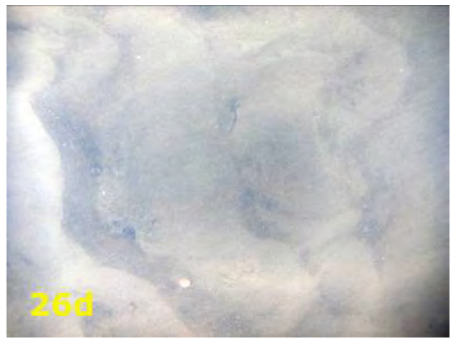
Magelona johnstoni
Fabulina fabula
Nephtys cirrosa
Notomastus spp.
Sertulariidae
Hydrallmania falcata
Syllidae
Eusyllis blomstrandi
Photis longicaudata
PELECYPODA

Nepthys cirrosa



Multibeam image of small and medium size dune field, oriented ENE-WSW. Water depth is around 19 m.





Seabed photographs showing a slightly rippled fine sand substrate at station 26. Floc material accumulates within the troughs between the ripples

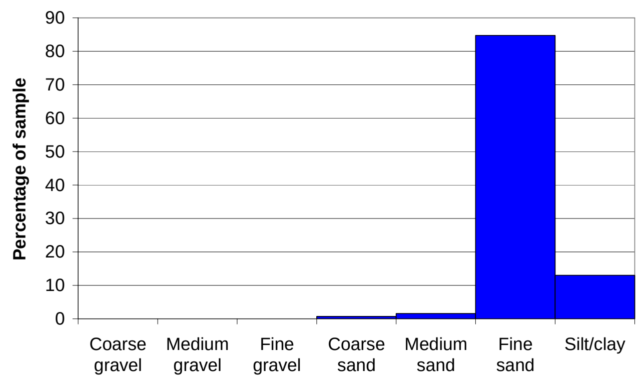
Large scale side scan sonar not available

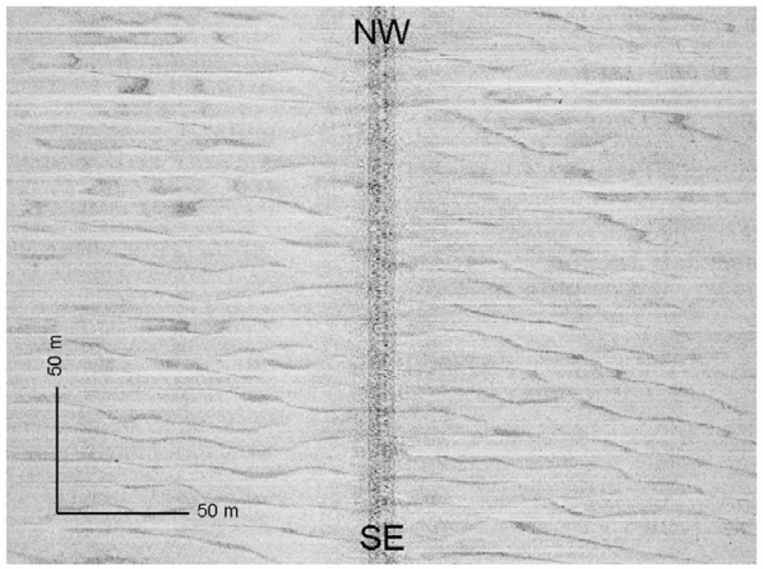
Sediment descriptions

Muddy sand

Visual assessment

Fine sand with no conspicuous epifauna.





Side scan sonar image showing a low reflectivity, ridged seabed interpreted as a sand seabed with abundant bedforms - small ENE-WSW trending dunes.

Overlying epifaunal biotopes

None associated with this biotope.

SS.SSa.IFiSa.IMoSa

Infralittoral mobile clean sand with sparse fauna

(Examples of this biotope found at REC Sample Sites 03, 04, 05, 10, 13 and 18)

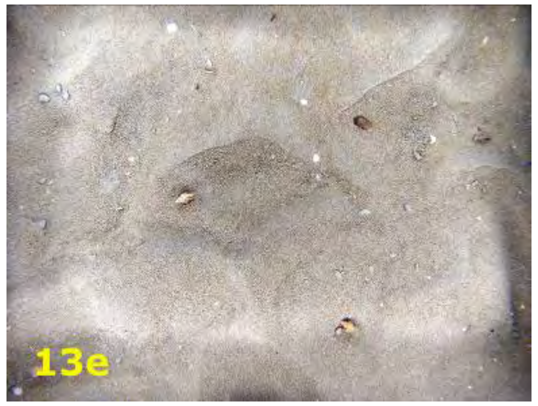
Biotope description

This biotope comprises fine sand which is overlain in places with small patches of gravel. The associated macrofauna is particularly impoverished and is characterised by range of typical sand fauna. Samples representing this biotope correspond with the locations of the major sandbank units to the south of the Outer Thames Estuary REC and match the typical shallow water disturbed sand habitat normally associated with this classification. The paucity of species is a result of the mobility of the sediment. In areas of comparative shelter, this biotope may grade into **NcirBat.**

Characterising species within the Outer Thames Estuary REC

Ophelia borealis
Nephtys cirrosa
Magelona johnstoni
Gastrosaccus spinifer
Synchelidium maculatum
Crangon crangon

Crangon crangon

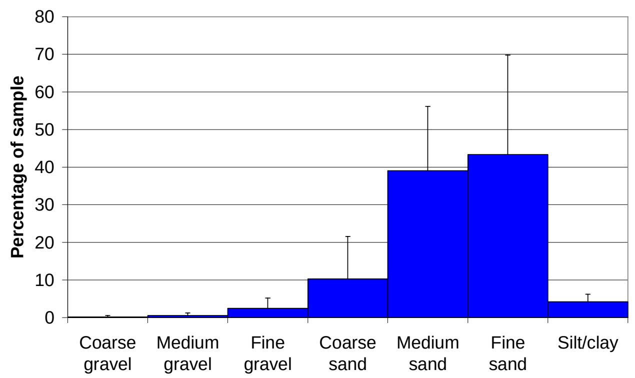


Sediment descriptions

Slightly gravelly sand, gravelly sand.

Visual assessment

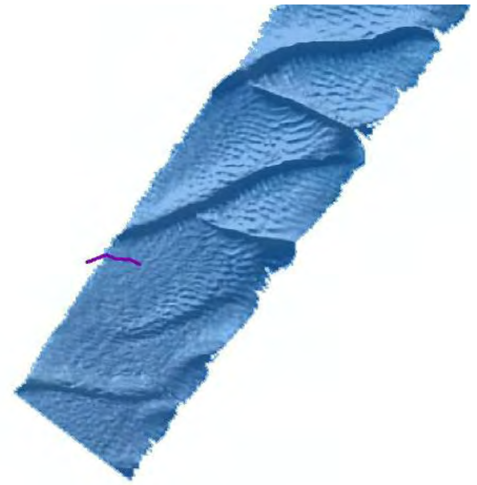
Sediments are dominant by fine sand with no conspicuous epifauna.



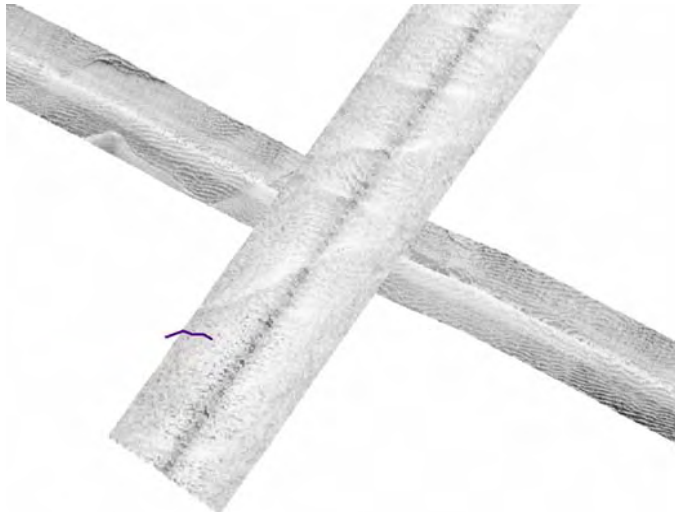
Overlying epifaunal biotopes

CR.HCR.XFa.SpNemAdia – Sparse sponges, *Nemertesia spp*. and *Alcyonidium diaphanum* on circalittoral mixed substrata. Impoverished variant and highly localised occurring on patches of gravel where present.

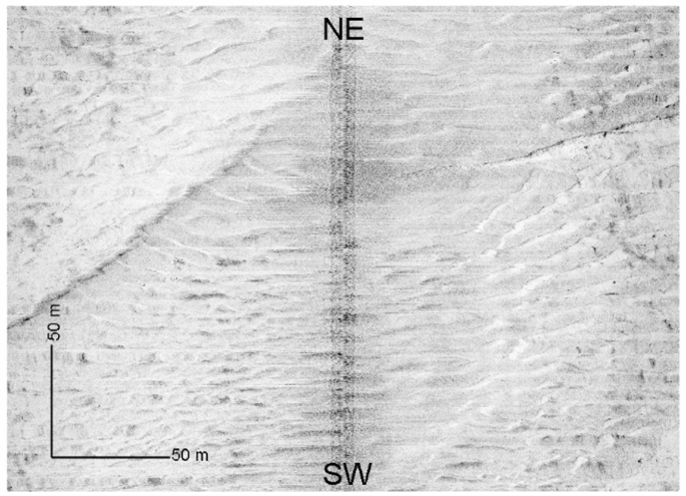
Other conspicuous fauna –*Obelia bidentata,* Paguridae, *Crangon allmani, C. crangon, Pandalus montagui, Philoceras* spp., *Alcyonidium diaphanum, Pomatoschistus* spp. (juv.)



Multibeam image showing large dunes with NE-SW and NW-SE trending crests and smaller dunes superimposed. Water depth is around 33 m.



Side scan sonar image shows a low reflectivity seabed and large dune field interpreted to be composed of mobile sands.overlying gravelly sediments locally exposed in the troughs.



Side scan sonar image of a low reflectivity seabed composed of E-W oriented large sand dunes with smaller dunes superimposed. In places the small dunes lie perpendicular to the large dune crests.

SS.SSa.IFiSa.NcirBat

***Nephtys cirrosa* and *Bathyporeia* spp. in infralittoral sand**

(Examples of this biotope found at REC Sample Sites 06, 14 and 57)

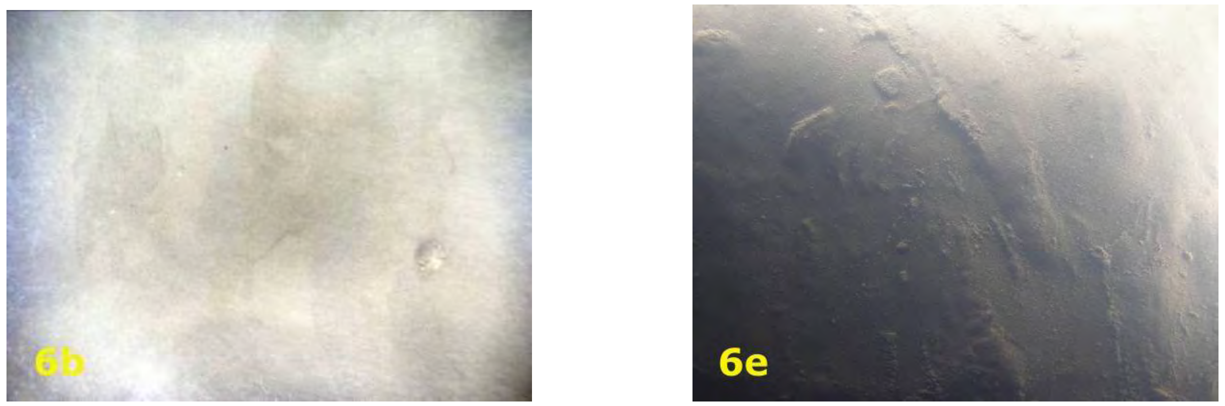
Biotope description

This is a variant of the **IMoSa** biotope reflecting fine sands subjected to comparatively reduced mobility although sediment disturbance is still a key influencing factor. The samples representing **NcirBat** coincide with the slopes of some of the main sandbanks suggesting that these areas are subject to relatively less seabed disturbance compared to other sand habitats in the Outer Thames Estuary REC.

Characterising species within the Outer Thames Estuary REC

Bathyporeia elegans
Nephtys cirrosa
Pontocrates altamarinus

Bathyporeia elegans



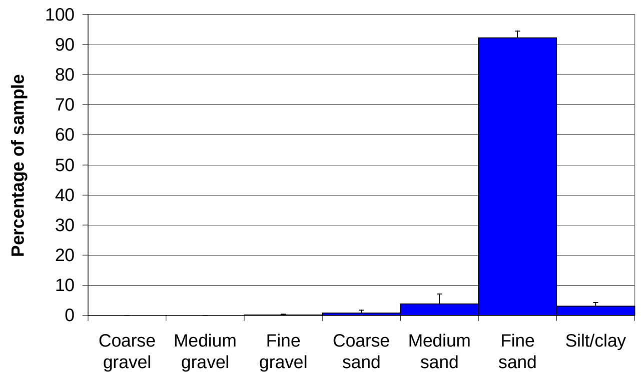
Seabed photographs showing homogeneous, clean fine sand at site 6.

Sediment descriptions

Well sorted clean fine sand.

Visual assessment

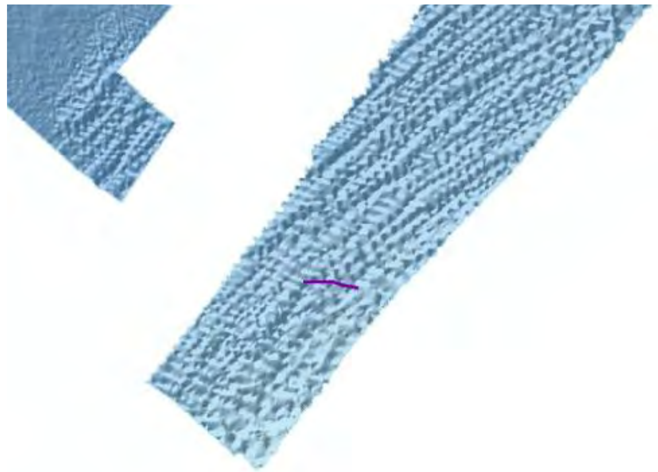
Homogeneous clean fine sand with no conspicuous epifauna excepting an occasional *Pagurus* spp.



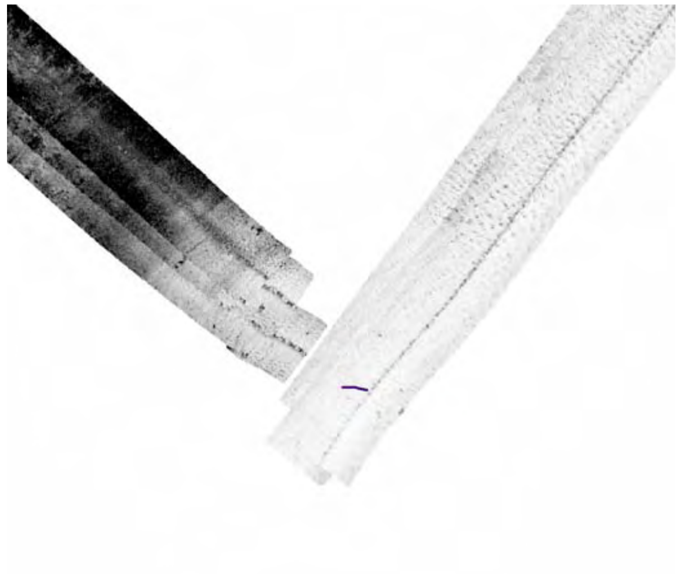
Overlying epifaunal biotopes

None associated with this biotope

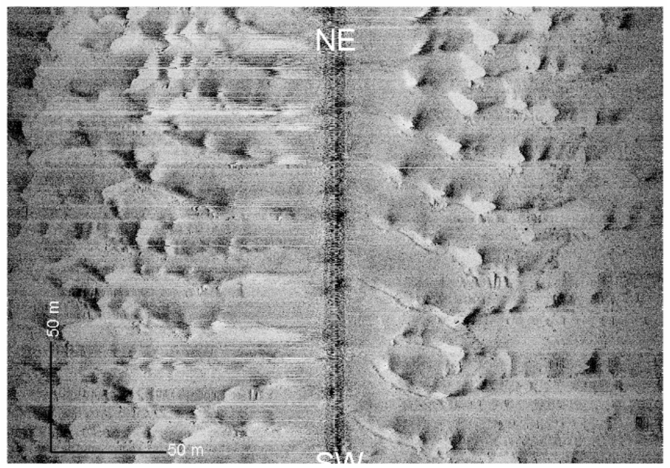
Other conspicuous fauna – Paguridae.



Multibeam image of a highly irregular seabed with NE-SW oriented bedforms. Water depth is around 15 m.



Side scan sonar image of the transect located in area of low reflectivity seabed interpreted to be sand, with very high reflectivity seabed to the NW interpreted to be gravels possibly overlying bedrock.



Side scan sonar image of a low reflectivity seabed interpreted as a small dune system composed of mobile sands.

SS.SMu.ISaMu and SS.SMu.ISaMu.NhomMac

Infralittoral sandy mud (with *Nepthys homergii* and *Macoma balthica*)

(Examples of SS.SMu.ISaMu biotope found at REC Sample Sites 09, 34, 35 and 62. Examples with NhomMac found at REC Sample Sites 09 and 62)

Biotope description

The ISaMu biotope was found at two adjacent inshore stations (34 & 35) forming a discrete cluster. Despite the presence of *Lagis koreni* this lower definition classification was selected in preference over **LkorPpel** because of the apparent absence of *Abra alba*. Two shallow water, near-shore muddy sand stations were assigned the **NhomMac** extension. Despite having similarities with the biotope **AalbNuc, NhomMac** is found in shallower, more muddy areas and therefore represents a better fit in terms of physical habitat characteristics. **NhomMac** may occur in small patches or swathes in shallow waters parallel to the shore or in shallow near-shore depressions or trenches where finer material collects e.g. off the Suffolk coast (Connor *et al*., 2004). The characteristic bivalve *Macoma balthica* is lacking from the Outer Thames Estuary REC.

Characterising species within the Outer Thames Estuary REC

Nucula nucleus
Lagis koreni
Nephtys hombergii

Lagis koreni

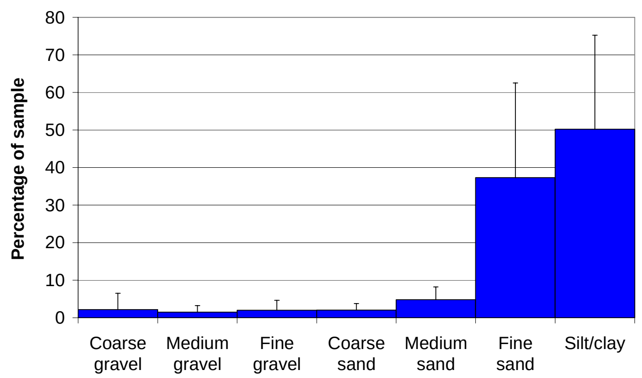
Deck photographs showing a soft sand and mud deposit from the shallow near-shore areas as sampled by the grab and the contents of the corresponding 2 m beam trawl sample including *Solea solea, Trisopterus luscus* and Crangonidae.

Sediment descriptions

Muddy sand, slightly gravelly sandy mud, gravelly muddy sand.

Visual assessment

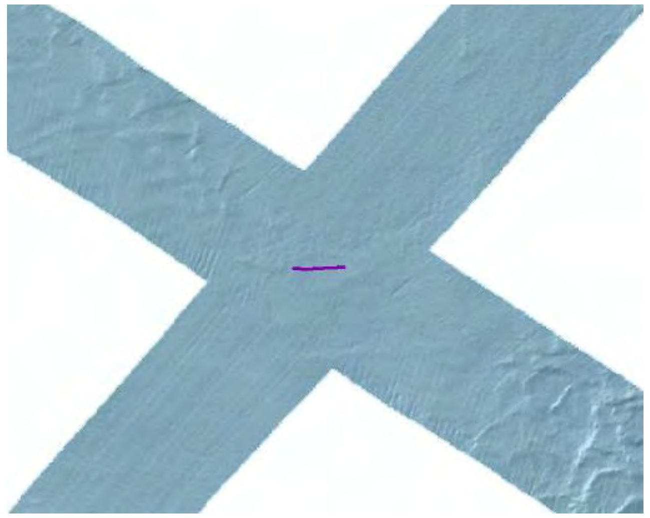
No seabed photography available



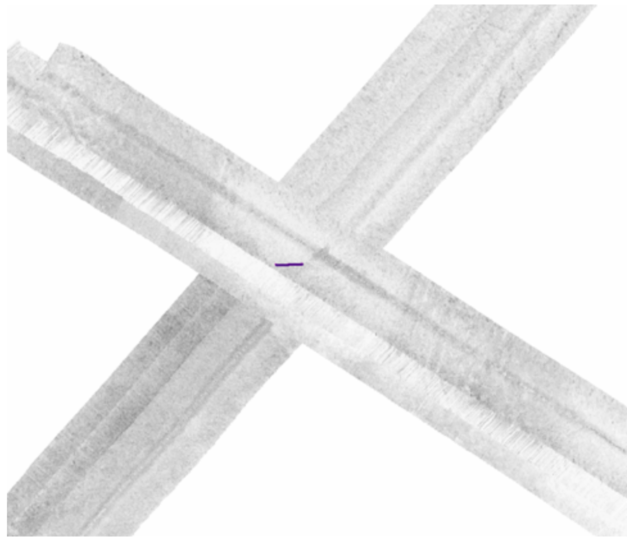
Overlying epifaunal biotopes

CR.HCR.XFa.SpNemAdia – Sparse sponges, *Nemertesia* spp. and *Alcyonidium diaphanum* on circalittoral mixed substrata. Impoverished variant and highly localised occurring on patches of gravel where present.

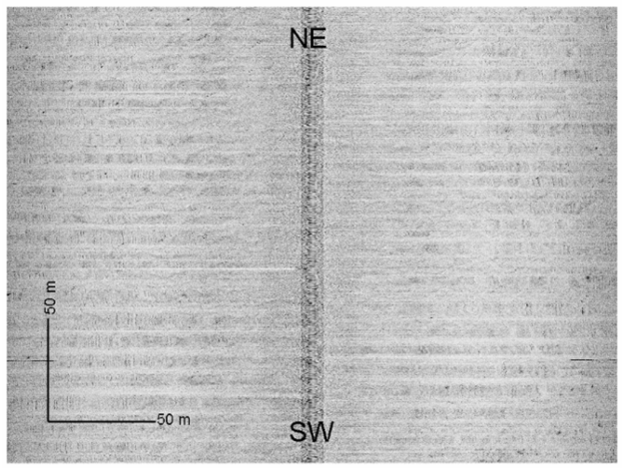
Other conspicuous fauna – *Enteromorpha* spp., (identified from trawl sampling at station 9), *Crangon crangon, Macropodia rostrata, Liocarcinus holsatus, Alcyonidium diaphanum*.



Multibeam image of a featureless, flat seabed at the camera transect location. Water depth is around 12 m.



Side scan sonar image of a low reflectivity seabed in the area of the camera transect, interpreted to be composed of sandy sediments.



Side scan sonar image of a slightly irregular low reflectivity seabed, interpreted to be composed of sandy sediments.

SS.SMu.SMuVS.AphTubi

Aphelochaeta marioni and *Tubificoides* spp. in variable salinity infralittoral mud
(Example of this biotope found at REC Sample Site 28)

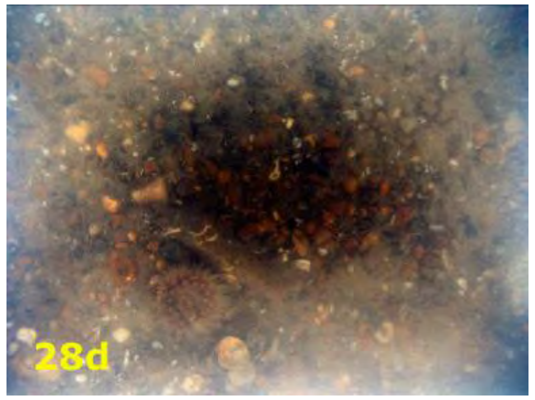
Biotope description

Found close inshore within a shallow water muddy sediment habitat. The classification indicates possible influences of variable salinity which may reflect the local estuarine inputs.

Characterising species within the Outer Thames Estuary REC

Nephtys spp.
Aphelochaeta marioni
Tubificidae
Nephtys hombergii
Notomastus spp.
Abra nitida
Molgula manhattensis

Molgula manhattensis



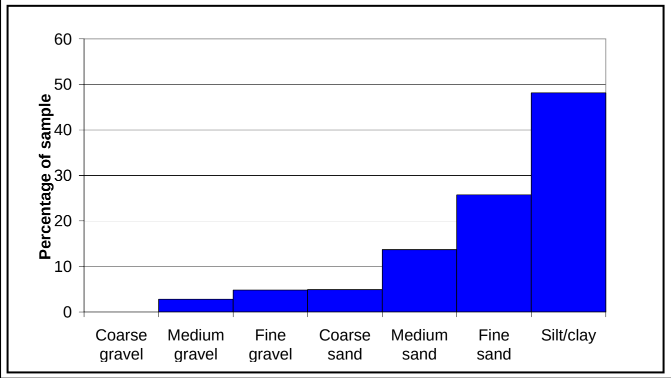
Deck and seabed photographs illustrating the near-shore sandy mud sediment overlaid with medium and fine gravel. The Dahlia anemone *Urticina felina* is present in the seabed photograph.

Sediment descriptions

Gravelly mud.

Visual assessment

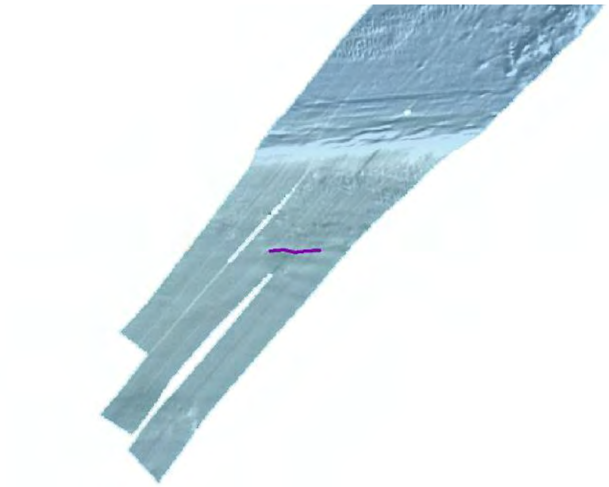
Sandy mud overlain with a thin veneer of medium and fine gravel.



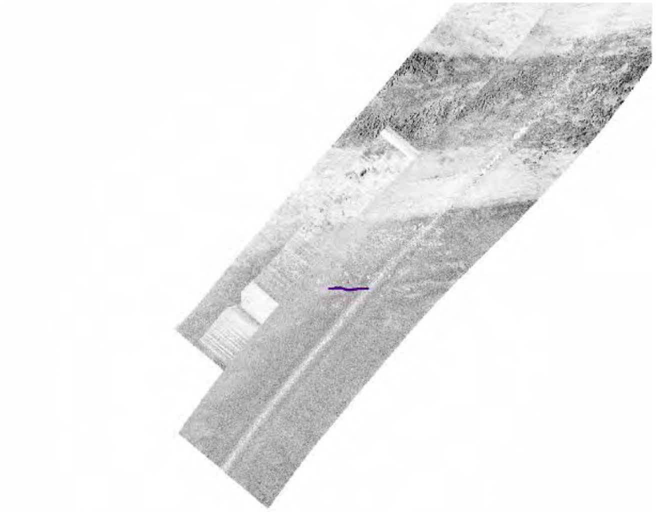
Overlying epifaunal biotopes

CR.HCR.XFa.Mol – The ascidian (as shown in top right picture above) and mixed bryozoan and hydroid turf on sediment influence circalittoral rock. This biotope is usually associated with turbid, shallow water conditions and often occurs on soft rock. Its distribution may be indicative of additional areas of exposed compacted clay.

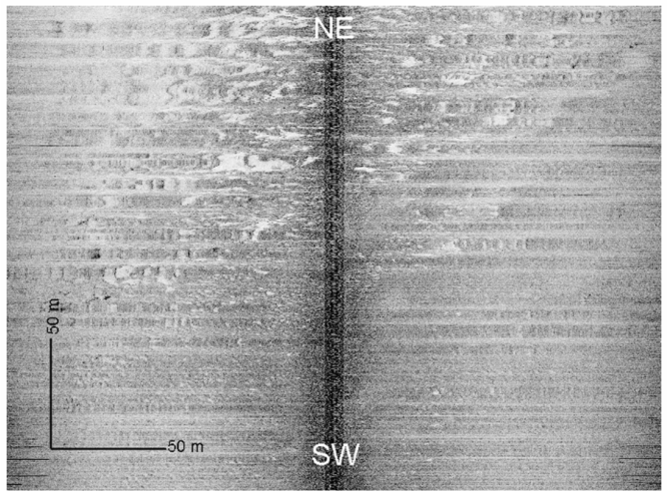
Other conspicuous fauna – *Pomatoceros* spp., *Urticina felina.*



Multibeam image of the flat, low relief seabed at the transect location, becoming increasingly irregular towards the north. Water depth is around 8 m.



Side scan sonar image shows the camera transect lying in an area of medium-high reflectivity, interpreted to be composed of gravelly sediments. Immediately to the north an E-W trending band of low reflectivity is interpreted to be composed of sandy sediment.



Side scan sonar image of a patchy seabed, generally high reflectivity seabed, interpreted to be composed of gravelly sediments with patches of sands.

SS.SCS.ICS.SLan

Dense *Lanice conchilega* and other polychaetes in tide swept infralittoral sand (Example of this biotope found at REC Sample Site 23)

Biotope description

This biotope has a limited distribution within the Outer Thames Estuary REC represented by only one sample collected inshore towards Harwich. It may be depth limited locally as it typically occurs in shallower (infralittoral) waters although equally it may be under-represented within the widely disperse sampling array. It has previously been found in close association with sandbanks and *Sabellaria spinulosa* reefs offshore of the Wash and north Norfolk coasts and may exhibit a similar distribution within the Outer Thames Estuary REC area.

Characterising species within the Outer Thames Estuary REC

Lanice conchilega
Spiophanes bombyx
Magelona johnstoni
Nepthys cirrosa
Nepthys homergi
Amphilochus neopolitanus

Lanice conchilega

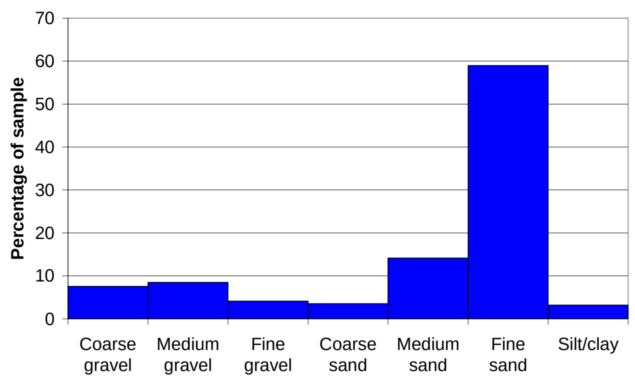
Deck photographs showing a predominately sand sediment with small amounts of gravel and quantities of the sandy *Lanice conchilega* tubes. Also shown is the contents of a 2 m beam trawl sample collected at this station. This shows large quantities of the fleshy bryozoan *Alcyonidium diaphanum* and indicates the presence of coarser sediment material nearby onto which this species attaches.

Sediment descriptions

Gravelly sand

Visual assessment

No seabed photography.



Overlying epifaunal biotopes

CR.HCR.XFa.SpNemAdia – Identified from the trawl sample taken at station 23 and containing, quantities of *Alcyonidium diaphanum* with *Flustra foliacea* and *Nemertesia* spp. The coarse substrate type normally associated with epifaunal biotope conflicts with the generally sandier sediment associated with the **SLan.** It is possible that **SLan** exists as patches and is interspersed amongst coarser sediment types at this location.

Other conspicuous fauna – *Alcyonidium diaphanum, Flustra foliacea, Crangon allmani, Carcinus maenus, Pomatoschistus* spp. (juv).

SS.SMu.ISaMu.AmpPlon

***Ampelisca* spp., *Photis longicaudata* and other tube-building amphipods and polychaetes in infralittoral sandy mud (Example of this biotope found at REC Sample Site 2)**

Biotope description

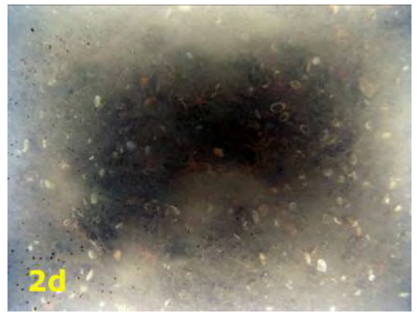
Represented by one sample suggesting an isolated occurrence within the Outer Thames Estuary REC. The biotope here may be a temporal variant on the **AalbNuc** biotope and has already been classified as such during the assignment of generic biotopes of groupings of samples However, the relatively high densities of tube building polychaetes and amphipods together with the low abundances of *Abra alba* and *Nucula* spp. compared to other locations within the Outer Thames Estuary REC, suggested that **AmpPlon** would be a better match on this occasion.

This classification was also assigned to a dense population of *Ampelisca diadema* with *Abra alba* and *Photis longicaudata* identified during the TEDA MAREA survey and representing an area of *Ampelisca* reef.

Characterising species within the Outer Thames Estuary REC

Photis longicaudata
Euclymene spp.
Spiophanes bombyx
Sabellaria spinulosa
Lanice conchilega
Maldanidae
Owenia fusiformis
OPHIUROIDEA
Ampharete finmarchica
Nephtys spp.

Photis longicaudata



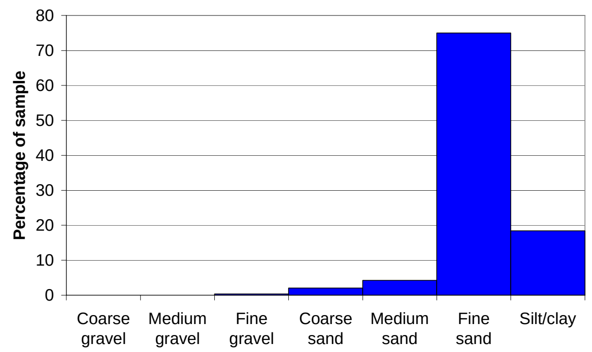
Seabed photographs showing sandy mud seabed with broken shell fragments and the brittlestar *Ophiura albida.*

Sediment descriptions

Gravelly mud.

Visual assessment

Sandy mud overlain with fine broken shell gravel.



Overlying epifaunal biotopes

None associated with this biotope

Other conspicuous fauna – *Ophiura albida*

6. Conclusions and Recommendations

Context

The Outer Thames Estuary Regional Environmental Characterisation (REC) provides an environmental reference statement defining marine and seabed conditions within the study area. Prior to this study, regional environmental assessment of the Outer Thames Estuary was based upon dispersed data acquired over several decades. The Marine Aggregate Levy Sustainability Fund (MALSF) has provided the opportunity to acquire and interpret an integrated physical and biological dataset for the first time in this region. The dataset was acquired along geophysical survey transects spaced 10 – 20 km apart and grab samples were recovered at the intersection of survey lines.

The Outer Thames Estuary REC provides a unique, robust scientific basis to define the regional marine environment, outlining the character of seabed conditions within the study area. This will permit informed, confident and consistent decision-making and consequently the Outer Thames Estuary REC will be of value to all stakeholders including government, marine industry, planners and environmentalists. The knowledge will contribute to the protection of the marine environment, promote the sustainable management of the seabed and focus future development investment.

The Outer Thames Estuary REC develops the approach initially adopted in the previous marine aggregate regional characterisation studies but also makes a comprehensive assessment of the heritage issues which have been integrated with the Quaternary geology where necessary. The characterisation process has reviewed the physical conditions in the area, for example tides, currents, seabed geology and seabed sediment transport. The heritage assessment has been combined with the interpretation of the Quaternary geology to produce an integrated assessment, whilst the wreck and other modern archaeology are treated separately. Analysis of the benthic infauna and epifauna communities has been combined with an evaluation of their associated physical conditions to produce a habitat and biotope assessment. The characterisation process also highlights regional environmental sensitivities, for example sites of potential conservation, fisheries or heritage significance, as well as informing marine spatial planning.

Geology and Heritage

Conclusions

The seabed consists of three distinct morphological zones which reflect the dominance of erosional and deposition processes in each zone. The Western Zone is dominated by a large coast-parallel sandbank system resulting in a depositional morphology. The sandbanks are composed of well sorted fine-medium grained sand whilst sandy gravels lie on the seabed in the troughs between the banks. The Central Zone consists of a sediment-starved bedrock platform forming an erosional morphology which is typically overlain by a discontinuous, thin, gravelly lag deposit, dispersed sandy bedforms and isolated sandbanks. Two parallel, north-south trending troughs, the Inner Gabbard Deeps, have been eroded into the bedrock in this zone. The seabed in the Eastern Zone consists of an extensive sand dune field. In general there is a net seabed sediment transport to the south across the area.

The seabed in the Outer Thames Estuary mainly comprises a thin, superficial, layer of mobile and immobile sediments overlying exposures of Quaternary, Cenozoic and Cretaceous sediments. Ten enclosed deeps are identified and interpreted as being formed at the margin of the Elsterian-Anglian glacial maximum ice limit, which is now proposed to lie 50 – 100 km farther south than previously thought. The stratigraphic relationship of these features with the major east-west river system (the Thames-Medway) that cuts across the Outer Thames Estuary REC area suggests this channel must have been incised prior to this glaciations (OIS 12: c. 450 kaBP). Further, the spatial correlation of this channel system with terrestrial river terrace gravels on the Essex coast suggests it may have been formed as early as Cromerian Complex II (OIS 18: c. 720 kaBP). The southern edge of the Outer Thames Estuary REC area crosses the northern margin of the post-Elsterian/Anglian Thames-Medway river courses as they migrate southwards and separate to become the modern Thames and Medway systems. Again through spatial correlation with the terrestrial record c. 40 m thick sections of river channel infill sediments have been identified, which may hold a record of 450,000 years of sedimentation.

The interpretation of the Quaternary succession represents a significant step forward in our understanding of the character of both the geological and heritage record of the Outer Thames Estuary. The identification of an extensive relic landscape dating back to the early Middle Pleistocene as well as a potential sedimentary channel fill record dating back 450,000 years has great significance to our understanding of the Quaternary of the North-west European continental shelf of both local and regional geological significance.

Similarly, the identification of a large palaeo-land surface (1,500 km^2) and channel system dating to 720,000 BP onwards, in close proximity to the earliest known occupation sites in Britain, is highly significant for our understanding of the early occupation of the British Isles. It represents a resource that has the potential to inform us about the nature and rate of environmental change, as well as potentially preserving actual archaeological material and sites. Consequently, this area should become a focus for intensive higher resolution investigation, to try and establish the true archaeological potential of this area.

Analysis of the extant wreck record and associated sites of maritime activity and infrastructure, from the Roman period to the present, clearly identifies the maritime archaeological significance of the Outer Thames Estuary. Identification of seven new sites has been possible, although it was beyond the remit of this project to provide a full description of these targets the data will be made available to the NMR and appropriate SMR's. Given the relatively small percentage of the area surveyed this represents only a small insight into the full maritime potential of the area and there is thus high potential for further discoveries.

Recommendations

The results of the Outer Thames Estuary REC have revealed a complicated and potentially highly significant geological and heritage record. Recommendations include:

1. Any geophysical or core/grab sample data gathered within this region be made available to the geological/archaeological community.
2. Focussed investigations are planned to assess the findings of this study, for example high resolution profiling and core samples to be recovered from key locations.

3. A full review of additional geophysical and in particular core data from BGS and industrial archives be undertaken, with the specific intention of identifying the need for additional targeted study.
4. That a new approach to the submerged heritage be developed in this area and monitoring plans should now reflect the significance of the findings of this study.

Ecology and Habitats

Conclusions

Analysis of the Outer Thames Estuary REC grab sample data revealed three principal macrobenthic assemblages. The largest assemblage, in terms of representative numbers of samples, was associated with the mixed muddy sandy gravels within central areas of the sample array and was characterised by a rich and diverse macrofauna including the Ross worm *Sabellaria spinulosa*, the polychaetes *Lumbrineris gracilis*, *Notomastus* spp., *Lagis koreni* and *Ophiura albida* and amphipod *Ampelisca spinipes*,. This assemblage was divided into three sub-groups in the basis of the relative abundances of the characterising species. The sub-groups included an *Ampelisca spinipes / Lagis koreni* assemblage, a *Sabellaria spinulosa* assemblage and a comparatively impoverished *Notomastus* spp. assemblage.

Clean sand sediments dominated large areas along the southern and eastern extents of the study area and supported a typically impoverished sand fauna including the white catworm *Nephtys cirrosa*, the mysid shrimp *Gastosaccus spinifer* and the polychaete *Ophelia borealis*. These habitats related to areas of sandbanks to the south and the deeper water dune fields to the north and east.

Muddy sand sediments were found predominantly along inshore areas and were characterised by the polychaetes *Nephtys hombergii*, *Spiophanes bombyx*, *Notomastus* spp. and *Lagis koreni*, the nut shell *Nucula nucleus* and bivalve *Abra alba*. Species assemblages close to the outflows of the Rivers Stour, Orwell and Deben were indicative of variable salinity conditions.

Colonial sessile epifauna were associated with the mixed and coarse sediments within the central areas of the array. Typical assemblages included mixed hydroid and bryozoan turfs together with the keel worm *Pomatoceros* spp., common starfish *Asterias rubens*, brittlestars *Ophiura albida* and the green sea urchin *Psammechinus miliaris*. Shallow inshore locations supported considerable amounts of the fleshy bryozoan *Alcyonidium diaphanum* and quantities of green algae *Enteromorpha* spp. The larger and more mobile components of the epibenthos were dominated by various shrimps *Pandalus montagui*, *Pandalina brevirostris*, *Crangon crangon* and *C. allmani*, Gobies *Pomatoschistus* spp., flying crab *Liocarcinus holsatus* and sole *Solea solea*.

The macrofaunal benthic assemblages in the Outer Thames Estuary REC demonstrate an apparent relationship with two principal components of the benthic habitat; overall sediment character and seabed morphology. In terms of individual environmental variables, sediment and depth corresponded relatively poorly with the observed benthic infaunal distribution. Of the three morphological zones identified, two clearly support distinct benthic communities. The region is also subject to a range of other physical influences which have affected the benthic faunal composition. These include seabed sediment mobility, for example the impoverished clean sand habitats associated with the sandbanks and deeper water dune fields; estuarine inputs, with muddy shallow water habitats, near to the inputs of the Rivers Stour, Orwell and Deben; as well as anthropogenic activities as evidenced by seabed marks from demersal fishing on side scan sonar and swath bathymetry data.

The generic communities described above were created on the basis of the principal infaunal groupings derived from PRIMER analysis. These were further refined to determine biotopes based on individual site attributes, including integration of seabed photography, 2 m beam trawls and grab samples. The data were mapped at different levels of biotope complexity such that correspondence with seabed character could be achieved allowing biotope extents to be determined. In total 16 infaunal and 5 epifaunal biotopes were identified including two potential Annex I habitats. One area was found to support potential biogenic reef **SS.SBR.PoR.SspiMx** and two areas supported potential geogenic reef **CR.MCR.SfR.Pid**. The geogenic reef habitat in particular was noted in the vicinity of the unusual seabed features referred to as the Inner Gabbard Deeps. Incorporation of Marine Aggregate Regional Environmental Assessment (MAREA) data identified areas of potential biogenic *Ampelisca diadema* reef **SS.SMu.ISaMu.AmpPlon**.

Comparatively rich and diverse shallow water muddy sand and sandy mud community biotopes e.g. **SS.SSa.CMuSa.AalbNuc** and **SS.SCS.ICS.SLan** were predominant within a narrow fringe along the Essex and Suffolk coasts, with areas under estuarine influences classified as **SS.SMuVS.AphTubi**. Central areas supported a range of mixed sediment and coarse sediment biotopes based on the **SS.SMx.CMx** biotope complex and **SS.SCS.CCS.MedLumVen**. Clean, mobile and faunistically impoverished sand biotopes dominated peripheral areas of the Outer Thames Estuary REC and coincided with the main sand banks to the south and west, including **SS.SSa.IFiSa.IMoSa** and **SS.SSa.IFiSa.NcirBat**. The deeper water dune fields to the east supported the biotope complex **SS.SSa**, with no further definition of this area possible within the current Marine Habitat Classification biotopes descriptions.

Recommendations

Potential geogenic and biogenic reefs as defined under EC Habitats Directive Annex I 'reef' have been recorded within the Outer Thames Estuary REC, though their extent and temporal stability is uncertain. Given their potential natural heritage importance further survey to characterise and map the spatial extents of these features is warranted. Investigative surveys will be informed by existing acoustic records with any data gaps filled by full coverage side scan sonar and multibeam swath survey. Ground truthing will involve remote high intensity seabed imagery and deployment of small grabs to acquire extent and community information, in agreement with Natural England. The developed assessment methodology for *Sabellaria spinulosa* will ensure consistency of classification with other potential reef areas in the southern North Sea (Emu Ltd., 2008). Geogenic clay outcrops may require novel survey techniques for effective sampling and assessment of compositional diversity such as diver observation, diver coring and box coring.

Although outside of the EU definition of biogenic reef, the *Ampelisca diadema* reef is worthy of further study to characterise its extent and associated biological and physical conditions. Little is currently known of this feature and further study using scientific divers and seabed photography would enhance our knowledge as well as advancing its status as an important natural heritage feature.

Classification of detailed biotopes within the Outer Thames Estuary REC region is difficult on such a broad scale, with uncertainties associated with the local variability of the defining physical and biological characteristics. Further surveying at a more intense spatial scale would be of benefit in order to determine their spatial extent and temporal stability, particularly those associated with potential geogenic and biogenic reef features.

The ‘Deeps’ represent unusual seabed features and an ecological survey is recommended to determine the presence of any associated specialist benthic communities. The steep slopes and deeper areas represent regionally rare habitats and have potential to support distinct assemblages reflecting localised scouring and depositional effects.

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Appendices

Technical data and information utilised during the compilation of the Outer Thames Estuary Regional Environmental Characterisation is included in the attached CD. A summary of its contents is as follows:

Appendix A – Introduction and Regional Setting

A.1. - MALSF 2007 Survey Operations Report.

Appendix B – Geology and Heritage

B.1. - National Monuments Record and UK Hydrographic Office wrecks data and analyses.

Appendix C – Ecology, Habitats and Biotopes

C.1. - List of enumerated species obtained from the Outer Thames Estuary REC grab samples.

C.2. - Results of biomass analyses of the Outer Thames Estuary REC grab samples.

C.3. - PRIMER analyses of fauna obtained from the Outer Thames Estuary REC grab samples.

C.4. - PRIMER analyses of epibenthic fauna determined using the Outer Thames Estuary REC seabed photography.

C.5. - List of enumerated species obtained from the Outer Thames Estuary REC 2 m beam trawls.

C.6. - PRIMER analyses of epibenthic fauna determined using the Outer Thames Estuary REC 2 m beam trawl weight data.

C.7. - PRIMER analyses of epibenthic fauna determined using the Outer Thames Estuary REC 2 m beam trawl mobile epibenthos data.

C.8. - PRIMER analyses of fauna obtained from the TEDA MAREA grab samples.

C.9. - PRIMER analyses of fauna obtained from the TEDA MAREA 2 m beam trawl data.

C.10. - Seabed photographs at stations supporting aggregations of *Sabellaria spinulosa*.

C.11. - Marine Habitat Classifications.

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