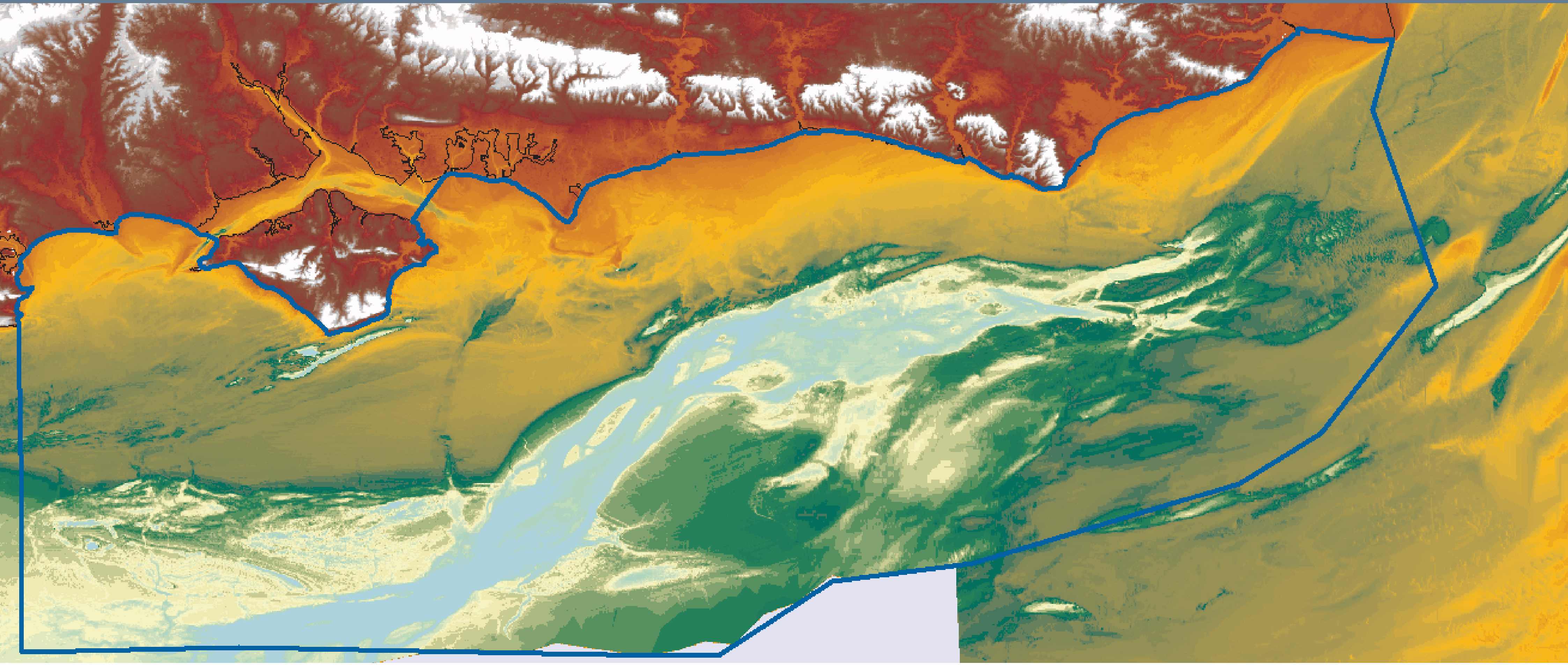
The MALSF synthesis study in the central and eastern English Channel



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Marine Aggregate Levy Sustainability Fund MALSF

The MALSF synthesis study in the central and eastern English Channel

Marine Aggregate Levy Sustainability Fund (MALSF)

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This report is available at www.alsf-mepf.org.uk. The South Coast REC report (James *et al.,* 2010) and the Eastern English Channel Marine Habitat Map (EECMHM) report (James *et al.,* 2007) are also available at www.alsf-mepf.org.uk
MEPF data is available from www.marinealsf.org.uk

Cover: Onshore and offshore morphology (see figures 44a and 44b for explanation).

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

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

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

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

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Biological line drawings

Sara Marzialetti

Introduction

The need for effective stewardship of the marine environment through integrated management, balancing the requirements for development and exploitation with nature conservation and legislation, has been widely recognised. However, implementing such a strategy requires a significant knowledge of the nature of the sea bed. Acquiring such knowledge in the central and eastern English Channel (Figure 1) has been a focus of the Marine Aggregate Levy Sustainability Fund (MALSF) since 2005. The MALSF has funded a series of surveys to acquire high resolution data and its subsequent interpretation, along with other data, using a multi-disciplinary approach including geologists, biologists and archaeologists. This has produced a great deal of beneficial cooperation and interaction between these disciplines and enhanced the quality of the interpretations and results.

This report presents a **synthesis** and summary of the results and outputs of these previous studies aimed at a wider public audience in an accessible and relatively simple format, complementing the published scientific reports and datasets that have been produced. The synthesis study has been led by the British Geological Survey with Marine Ecological Surveys Ltd, Cefas, Wessex Archaeology and Sussex Sea Fisheries District Committee as partners in the study.

This synthesis report has as its core two regional environmental characterisation (REC) studies, the Eastern English Channel Marine Habitat Map (EECMHM) (James *et al*, 2007) and the South Coast REC (James *et al*, 2010). Although these REC studies overlap (Figure 2), when looked at in the context of UK waters in the central and eastern English Channel, there were two significant gaps in coverage. The first

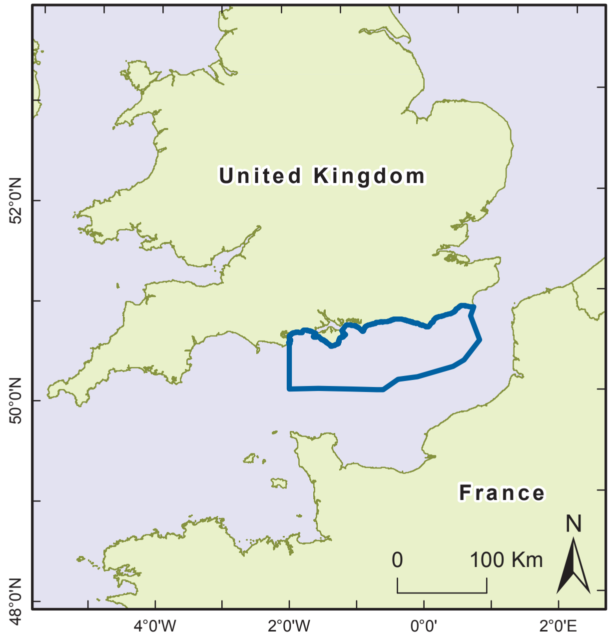

Figure 1 Location of synthesis study area.

is in the northeast of the study area along the nearshore strip from around Beachy Head to Dungeness, and the second in the southwest up to the median line with French waters. However the latter has recently been the subject of a survey and report by Defra funded project ME1102 (Coggan *et al.*, 2009). These gaps have been incorporated in the synthesis study to provide complete coverage and interpretations in this part of UK waters from Poole Bay in the west to Dungeness in the east. The total area covered by the synthesis study is 12 755 km^2.

The principal objectives for the EECMHM and South Coast RECs and this synthesis study include geological interpretations to characterise the rock and sediments, ecological interpretations of the marine biology, and integrating the geology and biology to provide maps of sea bed habitat. Archaeological objectives include characterising and mapping wrecks and objects on the sea bed, and also characterising the potential of the area to contain submerged sites of prehistoric occupation (Arnott *et al*, 2010).

The amalgamated data from these two REC studies plus further data in the two new areas has been re-assessed to provide a harmonised interpretation for the whole synthesis study area. The synthesis study has also enabled a new analysis of the biological and geological characteristics of the study area and the production of a new biotope interpretation and map, based on a modified EUNIS classification.

The report has been broken down in to a number of themes and within these themes there are individual sections. The sections are designed to stand alone and can be read in isolation. There are six themes in total and they are distinguished graphically by different colour fills for their section headings. The six themes are:-

Regional setting

Provides a perspective for the synthesis study area within the whole English Channel in terms of sea bed morphology, geology, sediments, hydrodynamics and biology.

The remaining five themes are all primarily focused on describing the synthesis study area.

Human uses and activities

A wide range of activities take place within the study area. This includes long-standing commercial activity such as fishing, marine aggregates and disposals at sea, and newer commercial enterprises like proposed wind farm development. The recreational pastimes of angling and diving are also covered. Marine conservation is currently an important driver for marine research and current areas designated for conservation purposes both onshore and offshore are described.

Surveys and sampling

This describes the survey programmes undertaken for the MALSF since 2005, the methods that were deployed and the locations of the sample and geophysical data that were acquired. There are also graphics illustrating how the survey equipment was used and some examples of the results.

Geology

Covers the geological perspective, from ancient rocks of solid geology, through the glacial cycles of the Quaternary period, to the modern present day sediments on the sea bed. Includes sections on bedforms such as sand banks and sand wave fields and also describes the interesting occurrence of channel systems in the study area.

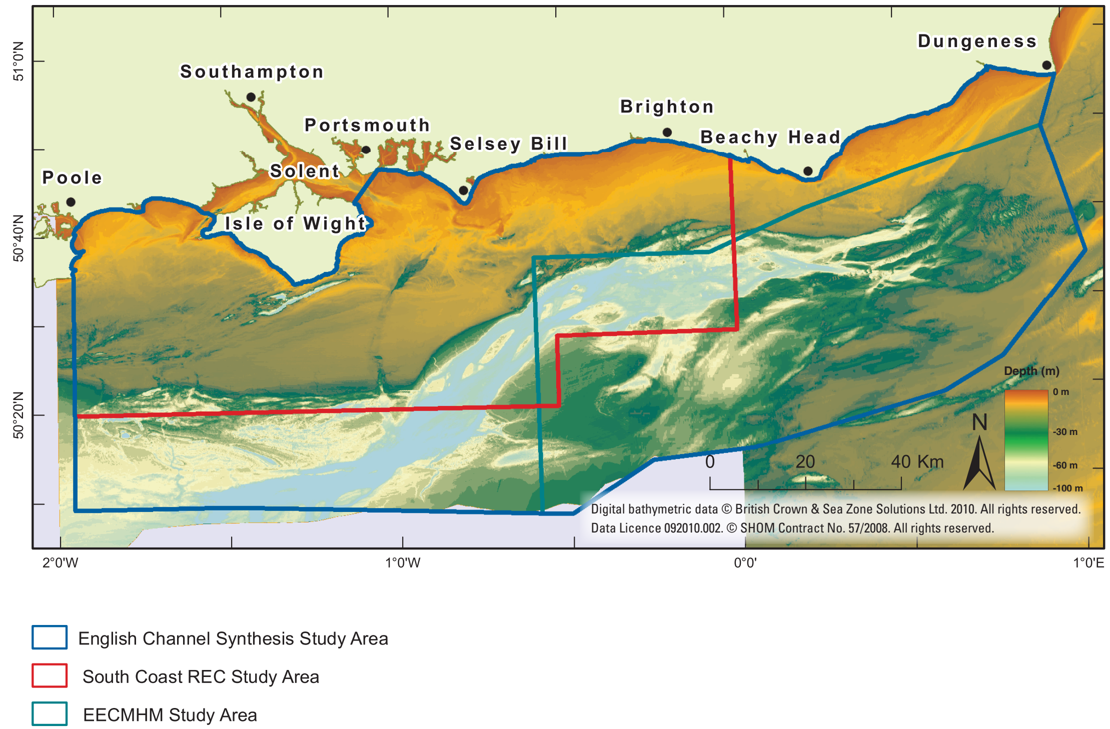

Figure 2 Location of synthesis study area in central and eastern English Channel.

Biology and habitats

Includes both study area-wide results and interpretations along with insights into more focussed aspects such as interesting or significant species. Provides comprehensive coverage with the production of a new EUNIS based habitat model for the whole study area plus a comparison of this model with other models that have been produced in the English Channel. The distribution of some benthic or bottom living animals are described in terms of the communities they form on the sea bed. Possible habitat designations under European legislation are also covered.

Archaeology

Begins with analysis of how humans may have lived within the study area during the last 500 000 years by comparison with evidence available on land for human occupation. Followed by a maritime archaeology section including a history of shipping in the area, which stretches back to the Bronze Age, and charting all known wrecks and obstructions. Concludes with a look at the 20th century phenomenon of aircraft wrecks on the sea bed.

English Channel

Physical setting

The synthesis study area covers most of the northeast quarter of the English Channel (Figure 4). The study area does not sit in isolation. It is part of the whole English Channel system which has evolved from its geological origins which can be traced over 550 million years to the sea and sea bed we have today. Under the influence of modern present-day conditions the Channel continues to evolve and change. It is essential therefore to understand, for the English Channel, what influences and controls present day geological, biological and archaeological conditions.

The English Channel is a shallow sea, with most of it in water depths of <100 m (Figure 4). It is about 160 km wide in the west between Cornwall and Brittany and gradually narrows eastward to a width of 35 km in the Dover Strait. The east to west extent of the Channel is about 500 km.

Figure 3 The law of superposition states that in any undisturbed sequence of rocks or sediments deposited in layers, the oldest layer is at the bottom and the youngest layer is on top.

The morphology of the sea bed in the English Channel, particularly in its western half, is dominated by a very low-angled to virtually flat surface with much of the sea bed lying at a depth of 60–70 m. It rises gradually to the east and reaches a depth of >40 m in the Dover Strait.

A notable sea bed feature is a prominent break of slope around the 50–60 m depth contour. In the west, this break of slope occurs close to the coasts of Cornwall and Brittany producing a very narrow coastal platform with relatively deep water close to the coast. To the east, although the coastal platform generally becomes wider, there is a contrast between the English and French coast. On the English side the coastal platform is relatively narrow whilst on the French side, west of the Cotentin Peninsula and from the Baie de Seine to Cap Gris Nez, it is much wider and loses the distinctive break of slope.

The erosion of the sea bed planation surface may have been initiated about 5 million years ago. Subsequently, a number of significant processes and events have occurred, in particular those associated with global climatic change during the Quaternary period (Figure 54), creating glacial and interglacial cycles with sea level rise and fall which produced a variety of environments across the English Channel including rivers, estuaries and marine with phases of sea bed erosion and deposition of sediments.

Hurd Deep is one of the most prominent erosional features in the English Channel (Figure 4). It is a narrow linear deep about 150 km long just north of the Channel Islands where it reaches a maximum depth of 172 m.

The Northern Palaeovalley is a significant open channel system southeast of the Isle of Wight with much of its floor around a depth

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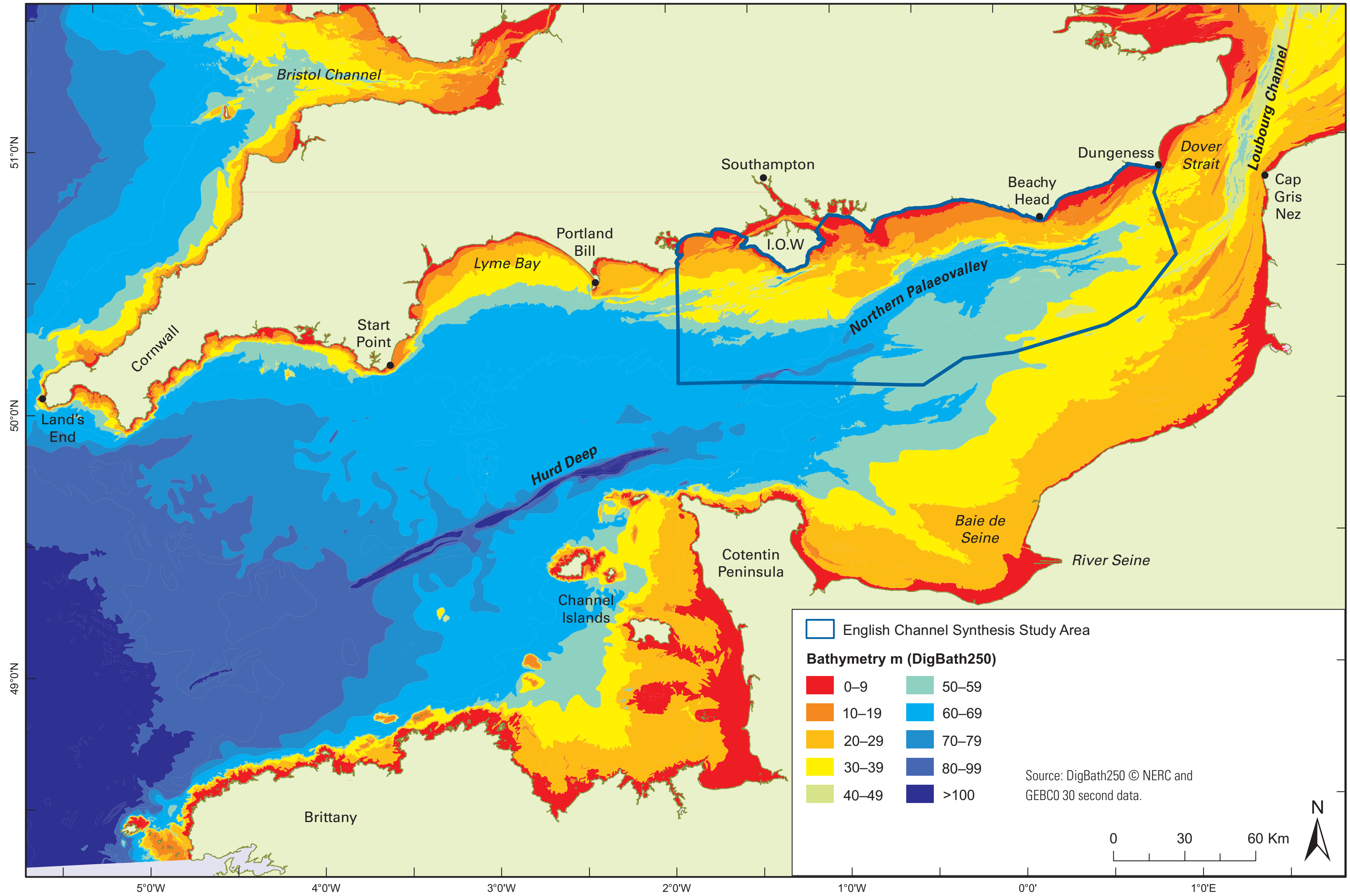


Figure 4 Regional bathymetry of the English Channel.

of 60 to 80 m. The northern margin of the Palaeovalley is backed by a narrow, shallow coastal platform with depths of <30 m, which runs along much of the coastal fringe of the English coast. The Northern Palaeovalley has a number of tributary channels, both open and filled with sediment.

As well as open channel systems, the eastern English Channel has an extensive network of channels filled with sediment (Figure 56).

There are at least eleven sand banks in the east near the Dover Strait created by the deposition of sand on the sea bed under modern conditions in the last 5 000 years. These are significant linear features, up to 30 km in length, and can rise over 40 m above the surrounding sea bed. There are also two large sand banks up to 40 km long on the margin of the Northern Palaeovalley. There are numerous smaller banks close to shore at various localities along the English and French coast particularly around headlands and islands. Some of the sand banks are surrounded by sand wave fields with some sand waves >10 m high.

The major morphological features such as the deeps and sand banks are relatively well-defined, but growing evidence from high resolution geophysical surveys (Figure 40a & b) has improved our knowledge of smaller bedforms such as sand waves and megaripples. This high resolution data also resolves small rock outcrops on the sea bed and enables mapping of the sea bed in much greater detail, especially where the sediment is very thin and there are rock outcrops on the sea bed. This type of rocky terrain is a common form of sea bed in the English Channel. (Figure 7).

Geology

A basic geological concept is the law of superposition which states that in any undisturbed sequence of rocks or sediments deposited in layers, the oldest layer is at the bottom and the youngest layer is on top, each layer being older than the one above it (Figure 3). This also holds true for undisturbed biological and archaeological deposits.

The offshore geology of the English Channel comprises three major and distinctive elements. These three elements can be ordered by the law of superposition, with the youngest at the top, they are:-

- Sea bed sediments
- Quaternary sediments
- Solid geology — bedrock

However, in reality, the geology found at the sea bed may not follow this simple three-fold layering. For example, bedrock can occur at the sea bed with no covering layers of Quaternary sediment or sea bed sediment. The latter two elements may have been eroded or simply not been deposited. Similarly, sea bed sediments can be found in some places directly lying on bedrock.

Bedrock in the English Channel is generally older than 32 million years (Figure 5) and there followed a long period of time before the onset of the Quaternary period which began about 2.6 million years ago (Mya), although evidence for Quaternary sediments older than 0.5 million years in the English Channel are meagre.

There is also a distinction between the bedrock and Quaternary sediments in their character and form. The age and length of time since bedrock was deposited has allowed them to be compressed and hardened into dense, cemented, solidified masses i.e. rock. Because of their relative youth, the Quaternary sediments have not had time to go through this rock forming process. They are loose, uncemented grains of mud, sand and gravel.

Another distinction is the relative impact of tectonic activity. This is particularly marked in its effect on bedrock in some areas, with large scale folding and faulting and disruption of bedding (Figure 51). Within the Quaternary, the only major tectonic activity that has been proposed is simple horizontal uplift (Westaway *et al*, 2006) that has led to the formation and preservation of river terraces and raised beaches onshore.

The English Channel includes a diverse and distinctive solid geology which outcrops or lies immediately beneath the sea bed over a relatively large proportion of the Channel. The oldest rocks are Pre-Cambrian (>542 Mya), whilst the youngest at about 32 million years old are from the Tertiary (Figure 5 & 50).

The region has a long history of tectonic movement with evidence for a number of episodes of uplift and subsidence with associated faulting and folding since the Carboniferous, over 300 Mya. Subsequent episodes have tended to align along a roughly east-west structural trend with reactivation of movement along pre-existing major fault lines. The last major tectonic episode is associated with the Alpine Orogeny during the Tertiary Miocene epoch, over 20 Mya. The present day evidence of these tectonic events is regional scale structures such as the Tertiary filled Hampshire–Dieppe Basin, the Purbeck–Wight Monocline and the Central English Channel Monocline (Figure 52a).

Upper Jurassic rocks lie within the Weald-Artois Anticlinoreum, which crosses the Dover Strait, and also Dorset which has the World Heritage site of Jurassic rocks known as the Jurassic Coast. To the west in the English Channel, chalk is very extensive and lies within east-west trending structures, and older Permo-Triassic and Devonian rocks sit alongside the chalk.

The rocks ranging in age from the Ordovician to the Tertiary in the English Channel not only hold within their layers the evidence for the type of sediments and rock that were deposited, but also the fossils of

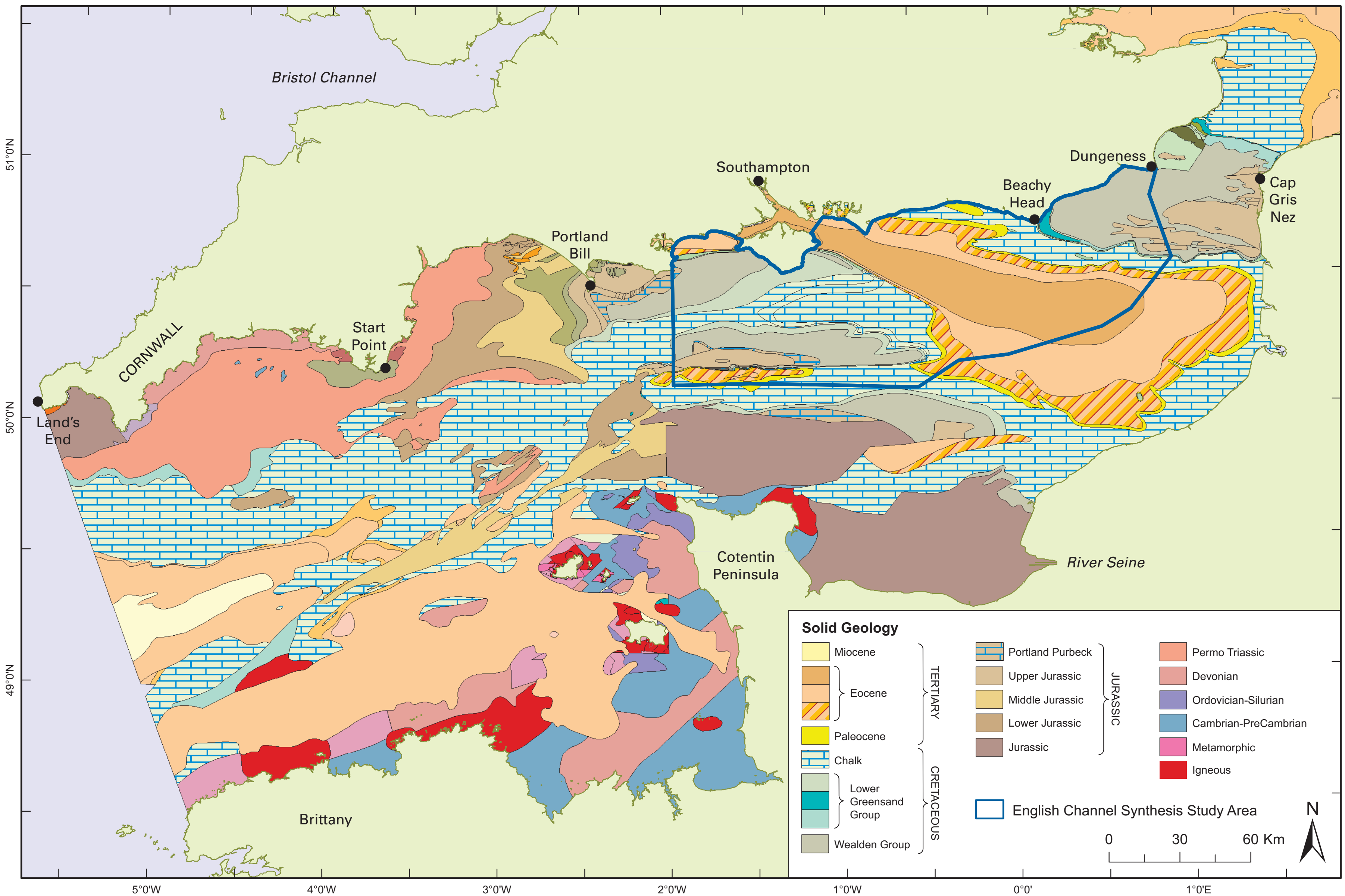


Figure 5 Offshore solid geology in the English Channel — (after BGS DigRock250 © NERC and BRGM (1974)).

the animals and plants that were alive during these periods. Most of the animals and plants that live today in the English Channel can trace their ancestry and origin back in geological time (Figure 6). For example, sea urchins can trace their evolution back to the Middle Ordovician ~470 Mya, and fish were first noted swimming in Devonian seas 350–400 Mya.

There have been numerous glacial cycles during the Quaternary (Figure 54) but there is no evidence from glacial deposits to show that glacial ice reached into the English Channel. However, the English Channel has been affected by the major changes in sea level associated with the cycles of glacials and interglacials.

During periods of low sea level in the Early to Middle Quaternary, extensive east to west river systems flowing from English and French sources developed in the English Channel (Gibbard and Lautridou, 2003). The Thames and the Rhine also became a part of the channel system with the opening of the Dover Strait in the middle Quaternary (Gibbard, 1988, 1995). Both open and infilled channels and deeps have been formed within the system (Figure 56) (Dingwall, 1975, Smith, 1985, Antoine *et al*, 2003, Gupta *et al*, 2007). River sediments will dominate the infill of these channel systems although some marine sediment may be present as a consequence of sea level rise.

Sea bed sediments can overlie and cover both Quaternary sediments and Solid Geology outcrops. They comprise immobile and mobile sediment lying at the sea bed surface. The sediments can

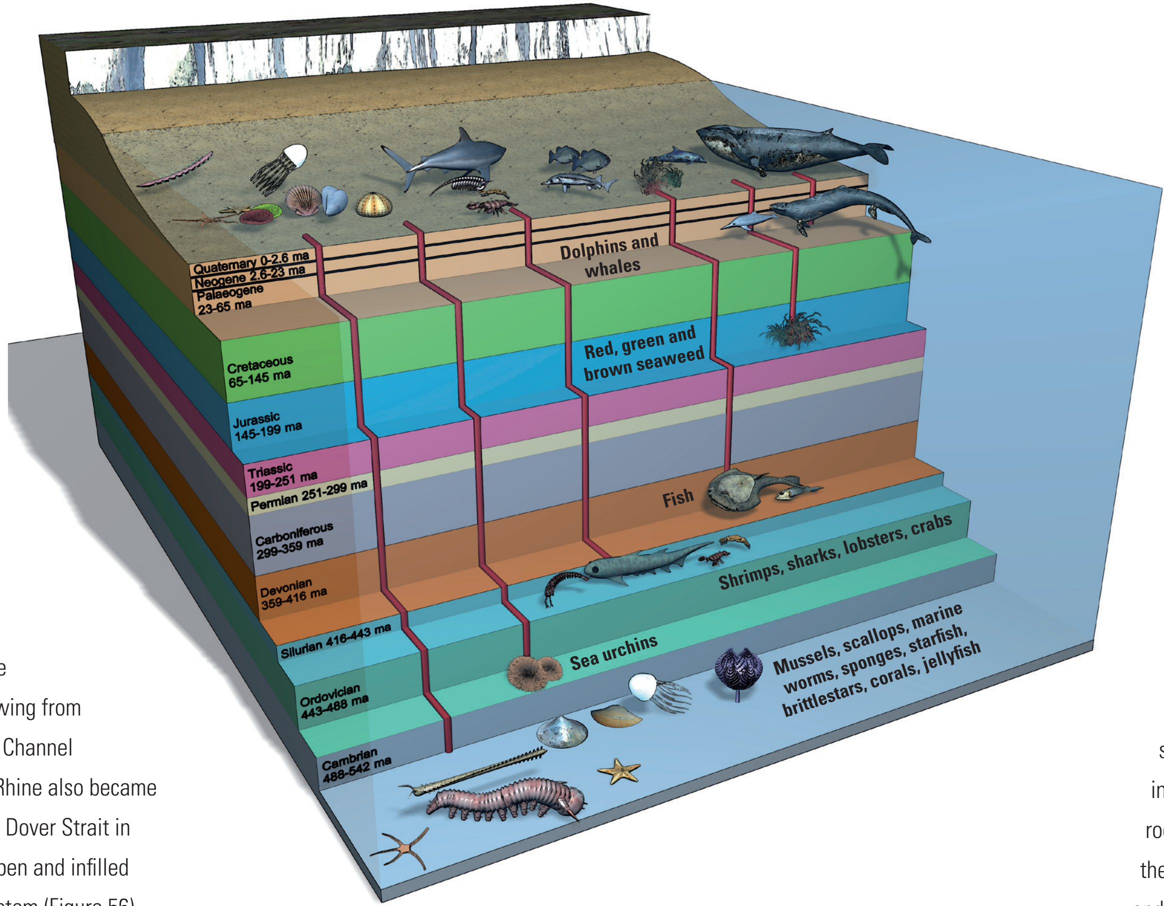


Figure 6 Geological ancestries of animals and plants in the present day English Channel.

consist of mud, sand and gravel, with the gravel ranging in size from pebble and cobble to boulder. Figure 7 is a map of sea bed character for the English Channel based on a six-fold division of sediments and rock:-

- Muddy sediment
- Sandy sediment
- Mixed sediment
- Coarse sediment
- Rock and thin sediment
- Rock

Coarse sediment is the most extensive form of sea bed cover and dominates the western and central areas. Sand is confined to some of the bays along the English and French coast with the most significant occurrences associated with the sand banks in the east and the Dover Strait. Rock and thin sediment is mapped extensively in the northern part of the Channel east of Portland Bill past the Isle of Wight to Beachy Head and also south of Dungeness. It is likely that further investigation will extend the area mapped as rock and thin sediment further south towards the Baie de Seine and Cotentin Peninsula and also to the west in some areas currently mapped as coarse sediment.

The nature and form of the underlying geology, and modern and long-term hydrodynamic processes control the character of the sea bed sediments in the English Channel. Where rock is at or close to the sea bed much of the gravel is likely to be derived from the underlying bedrock. The relatively strong currents in the area (Figure 8) have winnowed fine sandy sediment from the sea bed surface.

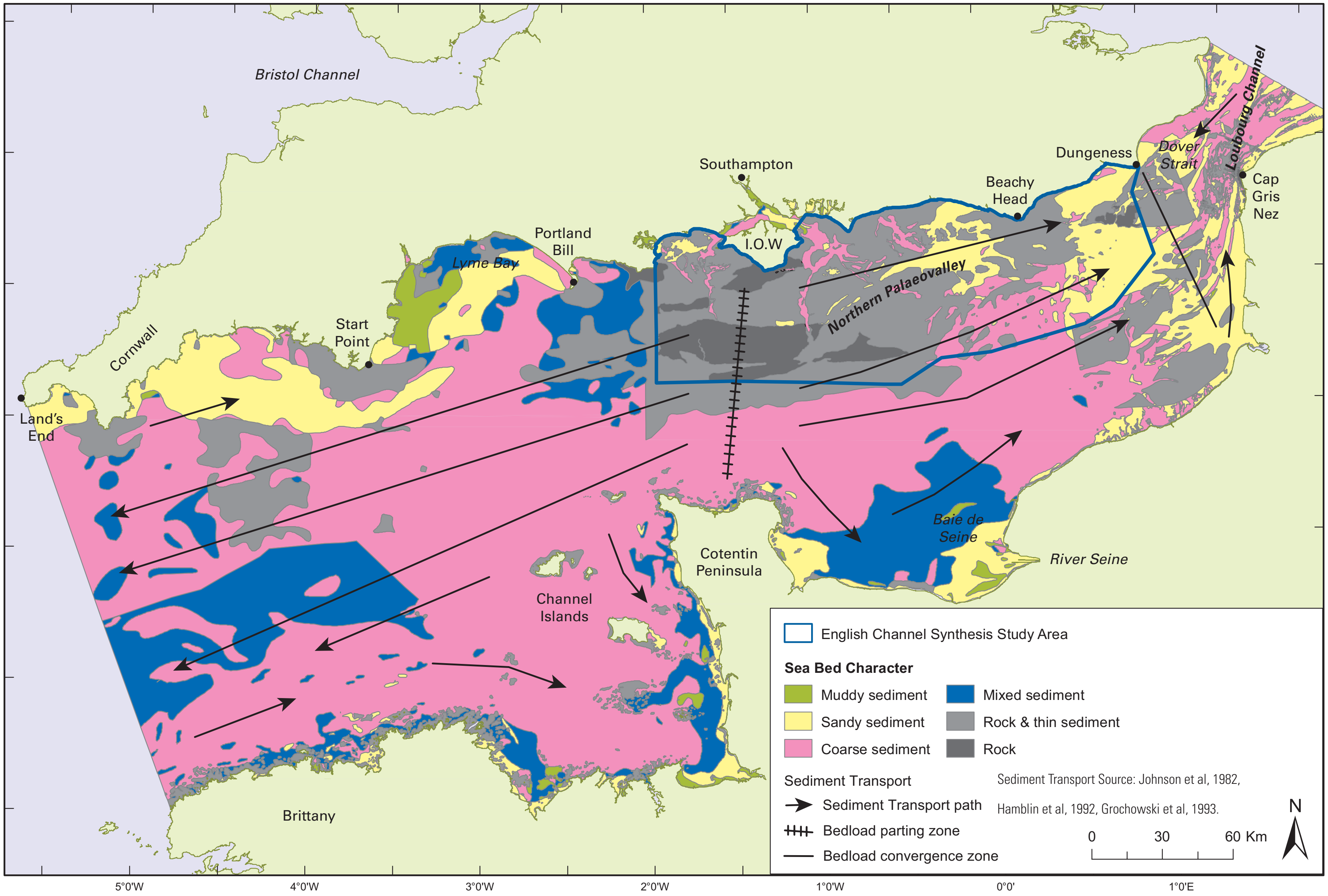


Figure 7 Draft map of sea bed character and sediment transport pathways in the English Channel — (subject to amendment. After synthesis study data, BGS data © NERC and EMODNET).

Hydrodynamics

We know from the character of the sea bed that the sea itself has an impact on the sediments and rocks, by moving sediment in some areas, depositing them elsewhere or simply by eroding and removing rock. Tides move up and down the Channel virtually twice a day with the ebb and flood. The tidal wave takes about 6.5 hours to travel from Land's End to the Dover Strait. Tidal current speed varies from <0.5 metres per second (ms^{-1}) to >3.0 ms^{-1}. Low tidal current speeds occur predominantly along the coastal margins but offshore from Dungeness there is an area of relatively low current speeds that extends out into the centre of the English Channel.

The highest tidal current speeds are in some of the narrows around the Channel Islands. This area of relatively high current speed area extends as a zone across the English Channel from the Cotentin Peninsula to the Isle of Wight. To the east and west of this zone the tidal current speeds diminish and only increase again further east in the narrows of the Dover Strait, with values in part >2.0 ms^{-1}.

Figure 8 is a modelled distribution of sea bed stress in the English Channel. Sea bed stress is a function of the interaction of tidal current velocity, water depth and bottom roughness and is a measure of the force exerted on the sea bed by water passing over it. The distribution seen in Figure 8 mirror the values for tidal current velocities. There is a correlation between the distribution and grain size of sea bed sediment, and sea bed stress. The relatively high sea bed stress zone across the English Channel between the Isle of Wight and Cotentin Peninsula is associated with a rock and gravel sea bed which has been swept of fine sediment. The lower bed stress levels in the east and coastal bays are associated with deposition of sand and fine sediment.

Weather systems also have some effect on the sea bed particularly at the coast and in shallow water depths. The English Channel is open

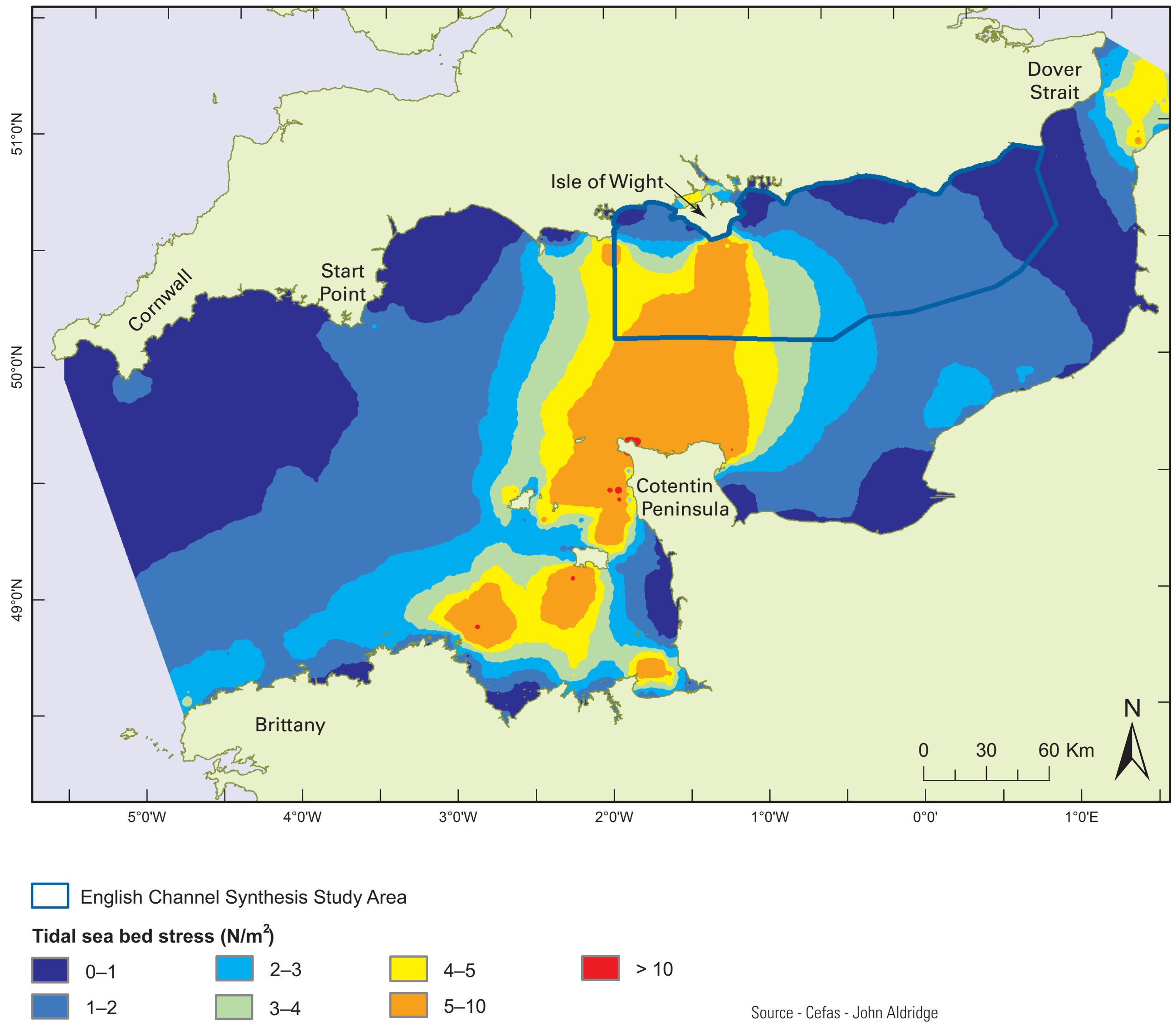


Figure 8 Sea bed stress in the English Channel.

to the Atlantic Ocean in the southwest with dominant southwesterly weather systems producing strong wind, wave and swell conditions in the Channel. Tidal currents are the dominant factor in controlling sediment transport in water depths deeper than average wave base. Wave base is the maximum water depth where the motion of waves may cause movement in the water column, and in the English Channel this is generally <20 m. It is only during large storm events when waves may have some impact on sediment transport at greater depths further out in the Channel.

Sedimentation processes

Hydrodynamic forces affect how sediments are eroded and deposited both over the long-term, measured in decades and hundreds of years, and the short-term, measured in lunar tidal cycles or daily storm events. The evidence for long-term effects is the development of large bedforms such as sand banks or the maintenance of a swept gravelly or rocky sea floor. The evidence for short-term effects are small bedforms such as megaripples on the flanks of sand banks or the flattening of sand bank tops after a storm event.

From the evidence of numerical modelling and the physical proof of sediment movement from sand bedforms seen on geophysical records (Grochowski *et al*., 1993; Hamblin *et al*., 1992; Johnson *et al*., 1982), major sediment bedload parting and accumulation zones have been identified within the English Channel as well as the pathways of sediment associated with these zones (Figure 7).

There is a correlation between sediment transport pathways and bed sheer stress in the English Channel (Figure 8). The decreasing bed sheer stress gradient from the central English Channel to the eastern English Channel is associated with a net sediment transport from west to east. The high bed sheer stress zone in the central English Channel between the Isle of Wight and Cotentin Peninsula acts as a bedload parting with velocities and sheer stresses high enough to entrain sand and fine sediment and create a swept sea floor dominated by rock and coarse gravel lag sediment. This entrained fine sediment is swept out of the bedload parting zone down the sediment transport pathway to the east and west.

The eastern sediment pathway leads to a sediment convergence zone south of Dungeness associated with an area of relatively low tidal current velocity and sea bed stress. It is an area of sediment accumulation characterised by a number of sand banks, some over 20 km in length, and up to several kilometres wide.

The flanks of sand banks are commonly covered by sand waves and associated megaripples. These smaller bedforms can extend from the sand banks and create extensive sand wave fields such as the Greater Bassurelle Sands (Figure 72).

Flood tides dominate the west to east transport pathway in the eastern English Channel towards the bedload convergence zone south of Dungeness. Ebb tides are dominant in the sediment pathway to the west of the bedload parting zone south of the Isle of Wight.

Modern input of sediment to the English Channel is minimal. The management of rivers and coastal protection has affected the natural supply of sediment to the sea. There is also unlikely to be a significant volume of sediment to be derived from the erosion of the *in-situ* sea bed. To all intents and purposes the sediment budget of the English Channel is in virtual equilibrium. It will require a major regional event such as a change in climate to disrupt this state.

West-east biological trends

To understand the distribution of habitats and species within the synthesis study area it is important to appreciate that it is part of the wider Channel ecosystem as a whole, and understand how the environmental characteristics of that wider ecosystem influence and shape the physical environment of the study area. In the marine ecosystem, environmental factors such as temperature, salinity, depth and substrate type all influence the distribution of organisms in much the same way that temperature, altitude, rainfall and ground type influence the distribution of species on land.

The English Channel is a sleeve-shaped sea (hence the French name 'la Manche' — 'the sleeve'), deep and wide at the western 'shoulder' end, becoming narrower and shallower towards the eastern 'cuff' end. There is a net flow of water along the Channel from west to east, emptying into the southern North Sea (Holme, 1961). Most of the water originates from distinct water masses lying in different areas and depths in the west, and these become mixed as they progress up the Channel into shallower areas (Holme, 1961). Waters in the west are generally warmer than those in the east, with an annual temperature range of six degrees Celsius in the west (10°C in winter, 16°C in summer), but about 10 degrees in the east (6°C in winter, 16°C in summer) (Holme, 1961, Stanford and Pitcher, 2004).

Two further temperature patterns occur. The first arises because the mid-channel water moves faster up the Channel than the coastal water, causing a tongue of western water to extend into the east such that in winter (February), mid-channel water off Dungeness is about 0.75°C warmer than inshore, while in summer (August), it is 0.75°C cooler. The second seasonal pattern is in the temperature of water at the sea bed (bottom temperature). In the winter there is complete vertical mixing of water throughout the Channel, so surface and bottom temperatures are equal. But in the summer, as the sun warms the surface waters, they become less dense and start to 'float' on the colder bottom water. In the deeper regions to the west this results in a seasonal 'thermocline',

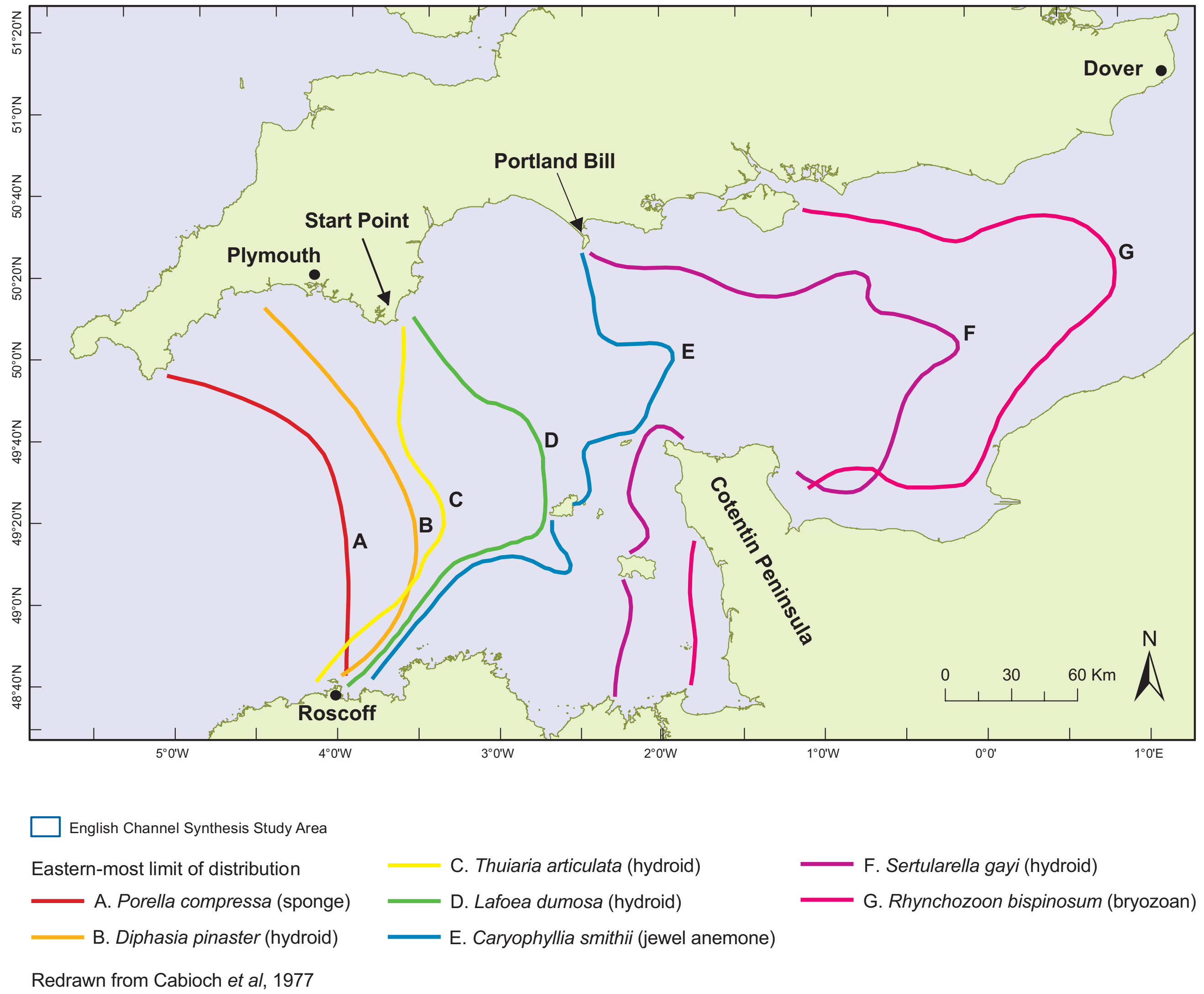


Figure 9 Cabioch's map showing the eastern-most ingress up the English Channel of species whose distribution he considered as primarily influenced by climatic conditions ('Distribution climatiques').

a thermal stratification of the water column at around 40 to 50 m water depth, with the warmer water on top and the colder water underneath. In the far west, beyond Cornwall, the temperature difference between surface and bottom waters is around 5°C, but this reduces moving east so that due south of Start Point the difference is only around 1°C in the mid-Channel and finally disappears altogether in the eastern Channel as the stronger tidal streams and shallower water (Holme 1961) keeps the water column mixed. It follows that there is a considerable west-east temperature gradient (cooler to warmer) on the sea bed in summer, but not in winter.

The spatial and temporal nature of these thermal regimes is important as different faunal species have different tolerances to temperature minima, maxima and rates of change. Fauna that are sensitive to a large seasonal temperature change and/or cold winter temperatures will tend not to spread into the eastern Channel. Those with more tolerance might be found in mid-Channel in the east, but not in coastal waters, and those with high tolerance might be found across the whole of the English Channel. This influence of temperature (climate) was recognised both by Norman Holme and Louis Cabioch who studied the composition of benthic communities and distribution of indicator species in the Channel in the mid-20th Century, Holme being based in Plymouth and Cabioch in Roscoff. Both recognised a strong longitudinal cline and some latitudinal variations between the northern coast of France and the south coast of England (Holme, 1961, 1966; Cabioch 1968; Cabioch *et al*, 1977). Both pieces of work also recognised that there was a depth effect, with western species penetrating farther up the channel in the deeper mid-Channel water than they did in the shallower coastal waters (Figure 9).

A second environmental factor that has major influence on the distribution of species and the composition of benthic communities i.e. those living in or on the sea bed, is the type of substrate at the sea bed e.g. rock, gravel, sand, mud and mixed substrates (Figure 7). The association between certain types of fauna and certain types of substrate has long been recognised (Sanders, 1958; Gray, 1974; Snelgrove and Butman, 1994) and is based on the fact that different life-forms such as sponges, anemones, worms, shrimps, crabs, snails, bivalves, starfish, urchins etc have different body forms, different ways of feeding and different needs for shelter, so their individual 'life-traits' make them better suited to live in or on a particular type or range of substrates. Hence we usually find worms living in soft sediments that they can burrow through, while seaweed is found mostly on rock because it needs to attach to a hard, solid surface.

So, certain types of organism are characteristic of certain types of substrates, but these substrates are not evenly distributed throughout the English Channel (Figure 7). Instead, there is a broad-scale pattern to their distribution that is linked to a number of factors including the morphology of the sea bed and the hydrodynamics of the Channel (Figure 8). Hydrodynamics are significant because the flow and strength of tidal currents impacts directly on the sea bed. In the same way that the wind blows fine sand but not cobbles along a beach, so tidal currents tend to 'sort' sediment particles along the sea bed, according to their overall size or mass. When fast-moving water flows over the sea bed it picks up the lighter particles, like sand and mud, and carries them away in suspension, and may roll some larger particles, like granules and bits of gravel along the sea bed. As the speed of the current reduces, so it begins to drop or leave behind the particles it has been carrying, starting with the coarser, heavier bits of gravel and finishing with the lighter, dusty bits of silt. In this way, over the last few thousands of years, some of the sediments on the surface of the sea bed in the English Channel have been transported and 'sorted' (see sedimentation processes - page 10).

Current speed can also directly influence the distribution of certain organisms, especially the filter feeders like sponges and some tube-building worms; the more water that passes them the more food they can capture. Many attached life-forms cannot tolerate frequent disturbance so are usually restricted to the more stable substrates such as cobbles and boulders that are not regularly overturned by tidal currents. In contrast, other taxa are active burrowers, feeding on organic material within the substrate, so they are well adapted to survive in highly mobile sediments. Between these two extremes is a range of other habits (lifestyles), like surface-deposit feeding bivalves that bury in the sea bed sediment but can tolerate periodic disturbance because they can quickly re-bury themselves. It is therefore clear that the physical and environmental properties of the sea bed at any particular location will have a tremendous influence in determining the range of organisms that can live there.

In conclusion, the environmental conditions of climate (temperature), substrate and current speed (energy) that exist across the Channel have a strong influence on the variety and distribution of habitats, biotopes and species. The western and eastern parts of the Channel are fundamentally different in their particular set and range of environmental conditions and so can be seen as distinct, though not separate or independent, regional ecosystems. Within the eastern Channel there is a marked gradient of physical habitat conditions from west to east and this will undoubtedly have a major influence on the distribution of biotope classes within the study area.

Marine aggregate

Sand and gravel used as aggregate is an important resource for building and construction from paving a garden path to the structure of an Olympic complex. It is essential to maintaining and improving the country's physical infrastructure. Sand and gravel aggregate found on land has been excavated for many hundreds of years but significantly since the Second World War the sea bed has also provided sand and gravel as marine aggregate. Now about 20% of total sand and gravel used in England and Wales (Highley *et al*, 2007) is dredged from the sea bed. Marine aggregate accounts for about 32% of the total aggregate supplied to London and the South East and about 70% of total UK production of marine sand and gravel is landed in these two areas. In 2009 total marine aggregate production in England and Wales was 20.19 million tonnes (Mt), of which 6.09 Mt (30.2%) was produced in the synthesis study area (www.thecrownestate.co.uk/dredge_areas_statistics).

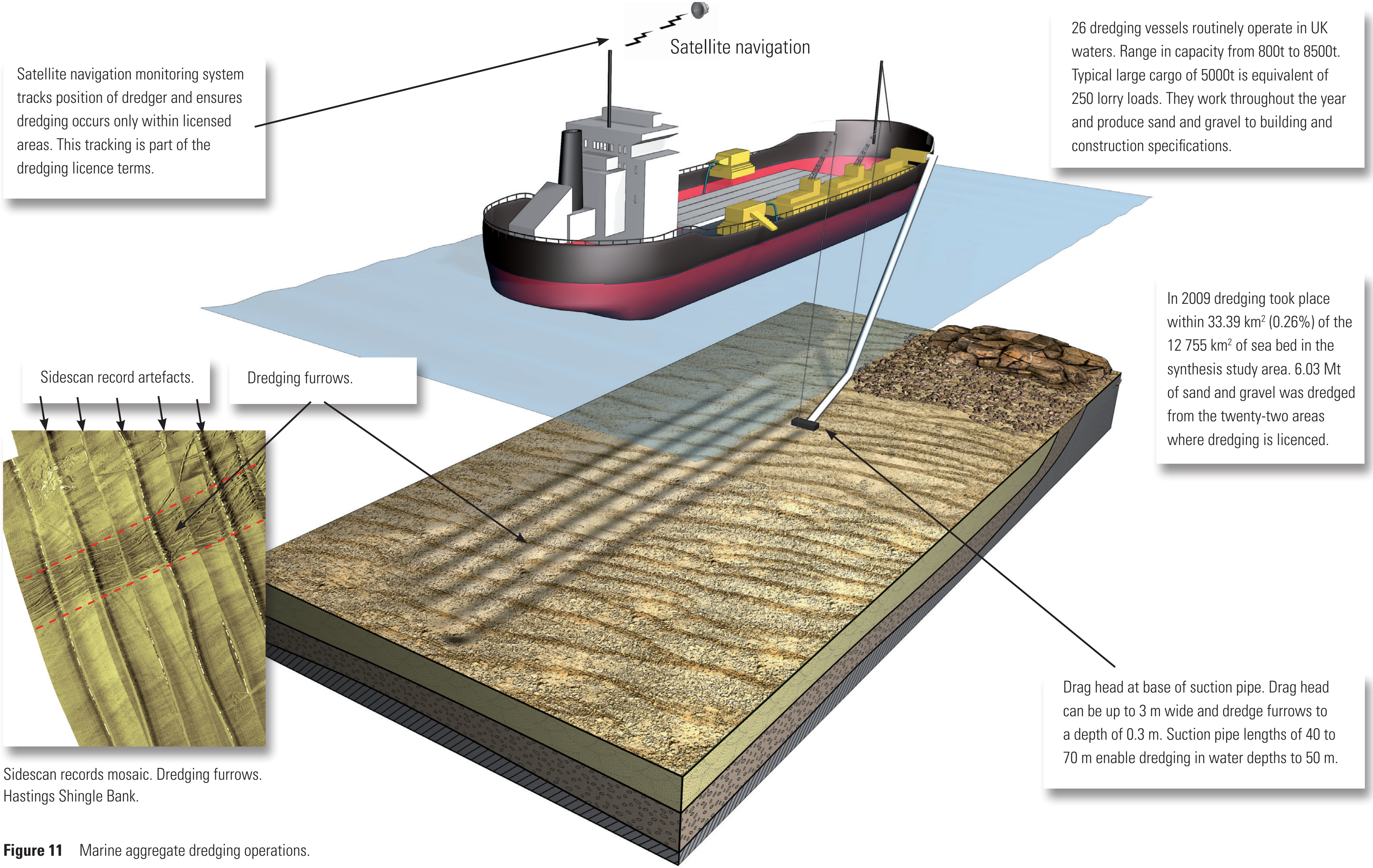
The Crown Estate owns the rights to all minerals, except for oil and gas, from the UK's sea bed, this includes sand and gravel. The licensing and dredging for marine aggregate is managed by The Crown Estate in consultation with other regulatory bodies. Monitoring of dredging is also undertaken by the Crown Estate, including satellite tracking of dredger position (Figure 11).

Figure 10 Beach nourishment with marine dredged sand and gravel — Hayling Island © Westminster Dredging.

Aggregate dredging is permitted at twenty two designated licensed dredging areas within the synthesis area (Figure 12). The licence areas east and west of the Isle of Wight, plus the Owers and Hastings Shingle Bank have been exploited for a relatively long time and it was realised that new sources of marine aggregate had to be found. The search that followed pinpointed an area of sand and gravel further offshore and in deeper water and this led to the development of a new region, the East English Channel (Figure 12). Dredging began here in 2006 and by 2009 it was providing more than 50% of the marine aggregate dredged in the synthesis study area.

The licensed dredging areas are located where there is sand and gravel of suitable quality and in sufficient quantity to enable the dredging of marine aggregate over an economic period of time. Other factors have to be accounted for including cost of dredging and transport, legislation, environmental issues, fisheries, conservation and shipping, but the availability of aggregate is the paramount reason for the location of dredging areas, they would obviously not be located in areas where there are no economic deposits of sand and gravel.

The majority of the licensed areas are associated with ancient river channel systems, which have been infilled with sand and gravel (Figure 13 and 66). A few areas west of the Isle of Wight appear to be widespread relatively thin sheets of sand and gravel or linked with sand banks. Although not currently licensed, gravel from Shingle Bank at the western entrance of the Solent (Figure 72) has been dredged in the past for beach nourishment in Christchurch Bay. Beach nourishment, which is used to maintain beaches as a natural form of sea defence, has also been undertaken at Bournemouth and Hayling Island (Figure 10). 0.28 Mt of marine sand and gravel was dredged for beach nourishment in the synthesis study area in 2009.



Sidescan records mosaic. Dredging furrows. Hastings Shingle Bank.

Figure 11 Marine aggregate dredging operations.

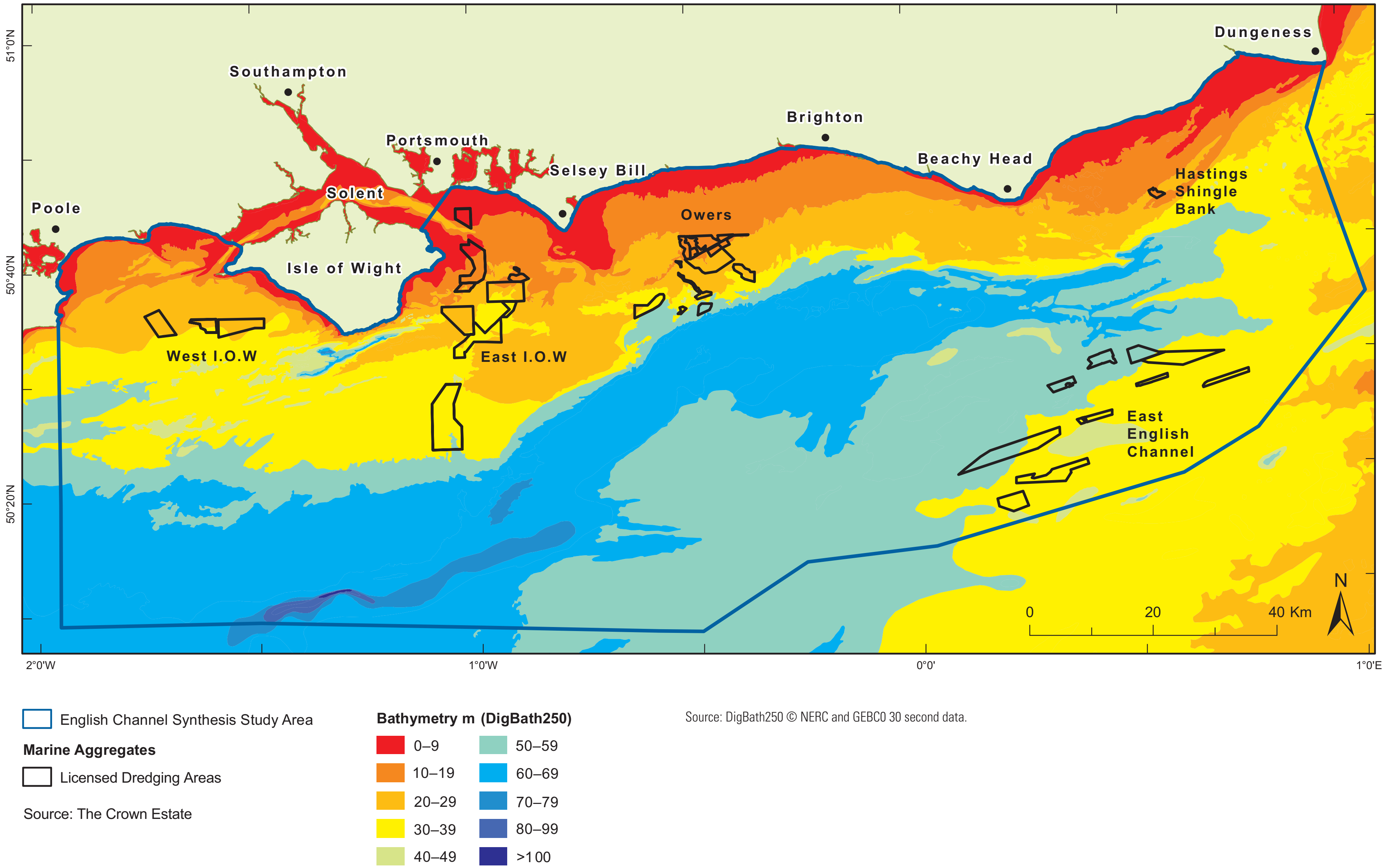


Figure 12 Licensed dredging areas.

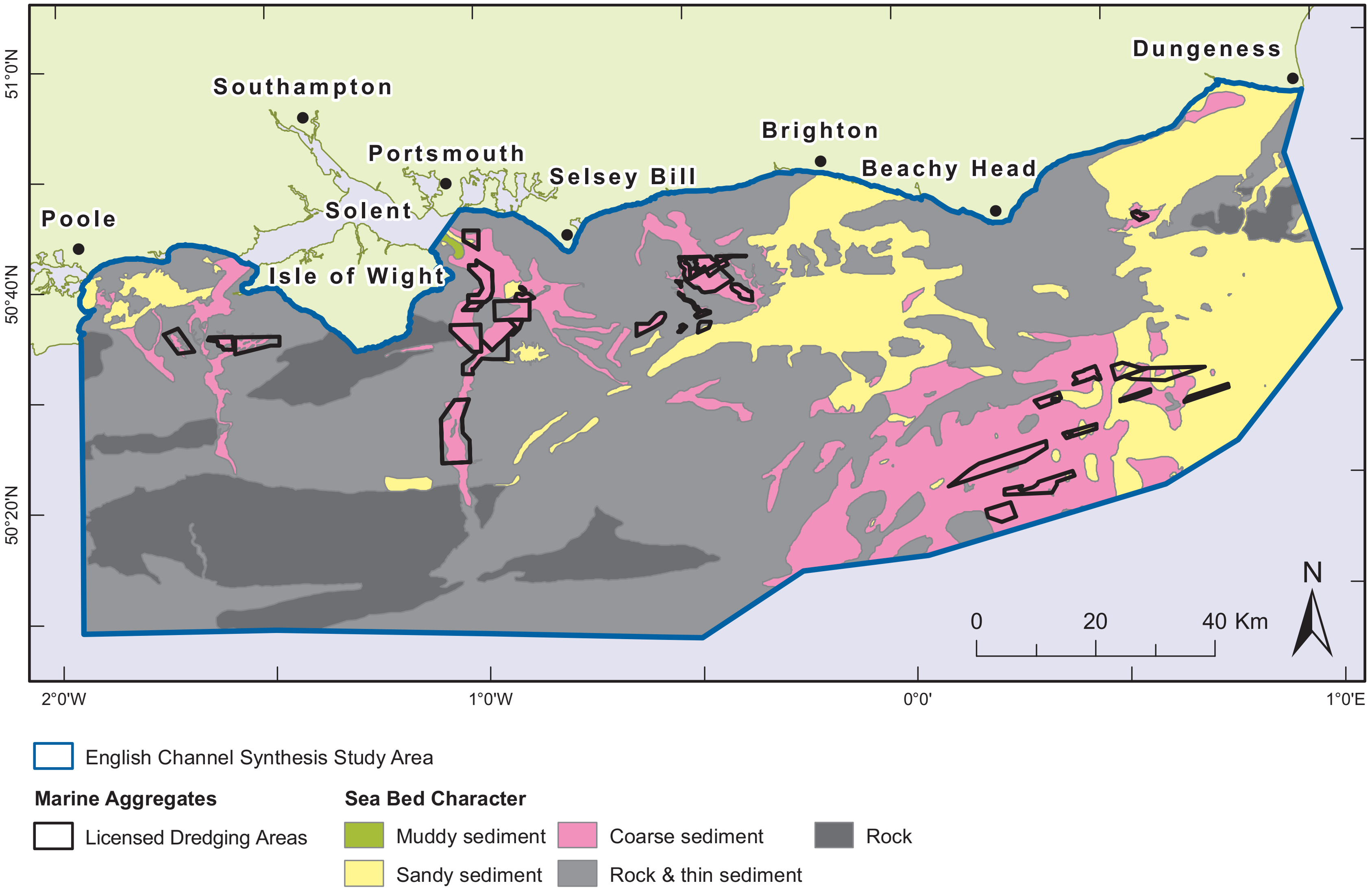


Figure 13 Licensed dredging areas and sea bed character.

Windfarms

As with aggregate extraction, any use of the UK sea bed for construction must be licensed by The Crown Estate. In January 2010, the government announced the go-ahead for nine new offshore windfarm zones, making it one of the biggest infrastructure projects for wind energy in the world, with the potential to deliver 32 GigaWatts of energy, about one quarter of the UK's electricity needs (source: Crown Estate). At the earliest, construction is likely to begin in 2014. Prior to that, the companies who have successfully bid to develop each zone are required to undertake environmental and engineering surveys as part of their application for a license to build. The Crown Estate will be working in partnership with the successful companies during this pre-construction phase, but the companies will operate independently of the Crown Estate if they gain consent for construction.

Zone & Name	6. Rampion	7. W. Isle of Wight
Developer	E.On	Eneco
Area (sq km)	270	726
Output (MW)	665	900
No. of Turbines	95–185	180–300
Distance offshore (km)	19.8	21.4
Construction start	2014	2016
Full operation	2016	2018
Homes powered	371 834	503 234
Projected cost (£m)	?	300

Table 1 Summary data for the two Round-3 windfarm development zones in the synthesis study area (Source: 4C Offshore Ltd).

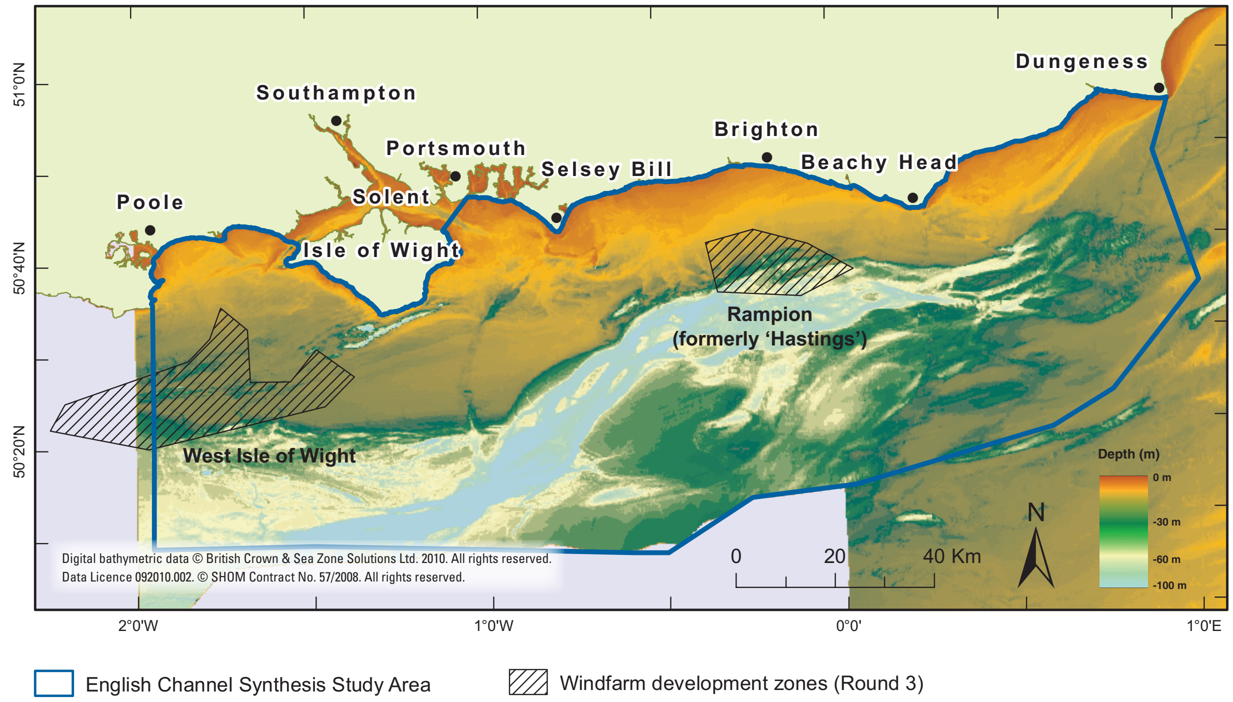


Figure 14 Windfarm development zones.

Two of the development zones are associated with the synthesis study area and are known respectively as 'West Isle of Wight' and 'Rampion' (Figure 14), The latter was previously referred to as the 'Hastings' development zone, but as the agreed final location is off the western coast of Sussex and not near Hastings, the name has recently been changed to Rampion, the name of the county flower of Sussex. The energy companies who were successful in their bids to develop these new zones were Eneco for the West Isle of Wight and E.On for Rampion. A summary for each site is provided in Table 1.

E.On completed a Scoping Report for the Rampion site in September 2010, in response to which the Infrastructure Planning Commission (IPC) has produced a Scoping Opinion in October 2010. Offshore geophysical surveys have been conducted at the West Isle of Wight site.

Disposals at sea

The Crown Estate licenses certain areas of the sea bed for disposal of materials. Within the synthesis study area there are fifteen of these sites (Figure 16), ten are currently open and five are closed. The closed sites include an old World War II munitions dump in the vicinity of St Catherine's Deep, just south of the Isle of Wight, and one of the open sites, off Newhaven, is licensed solely for 'burials at sea'.

The other sites are principally used for disposing of material from dredging operations, for example, where dredgers are used to maintain navigation channels or to dig into the beach or river banks to make new port facilities. Such activities are strictly controlled and the amount of material disposed of at each site is recorded. The various types of waste materials are explained below. Table 2 shows what types of materials are disposed of at which sites, and Figures 17, 18 and 19 show graphs summarising the deposits made at the open sites during the period 2000 to 2008.

Note that this data has been updated from that reported in the South Coast REC report because database query errors made at that time caused some significant over-reporting of the amount of materials concerned.

Figure 15 Maintenance dredging at Sovereign Harbour, Eastbourne, March 2010. Material disposed at Eastbourne site.

Types of material

Although colloquially referred to as 'dredge material', not all the materials deposited on the sea bed are directly related to dredging. The various types of material are as follows:

Capital Dredgings (CD). This is material that has either been dredged for the first time, such as during the construction of a new port or marina, or is from areas that have not been dredged in the last 10 years.

Maintenance Dredgings (MD). This is material considered to originate from natural siltation processes (i.e. mud or sand) removed from areas such as ports, marinas and navigation channels in order to maintain access and function (Figure 15). It only applies to material from areas that have been dredged within the last 10 years.

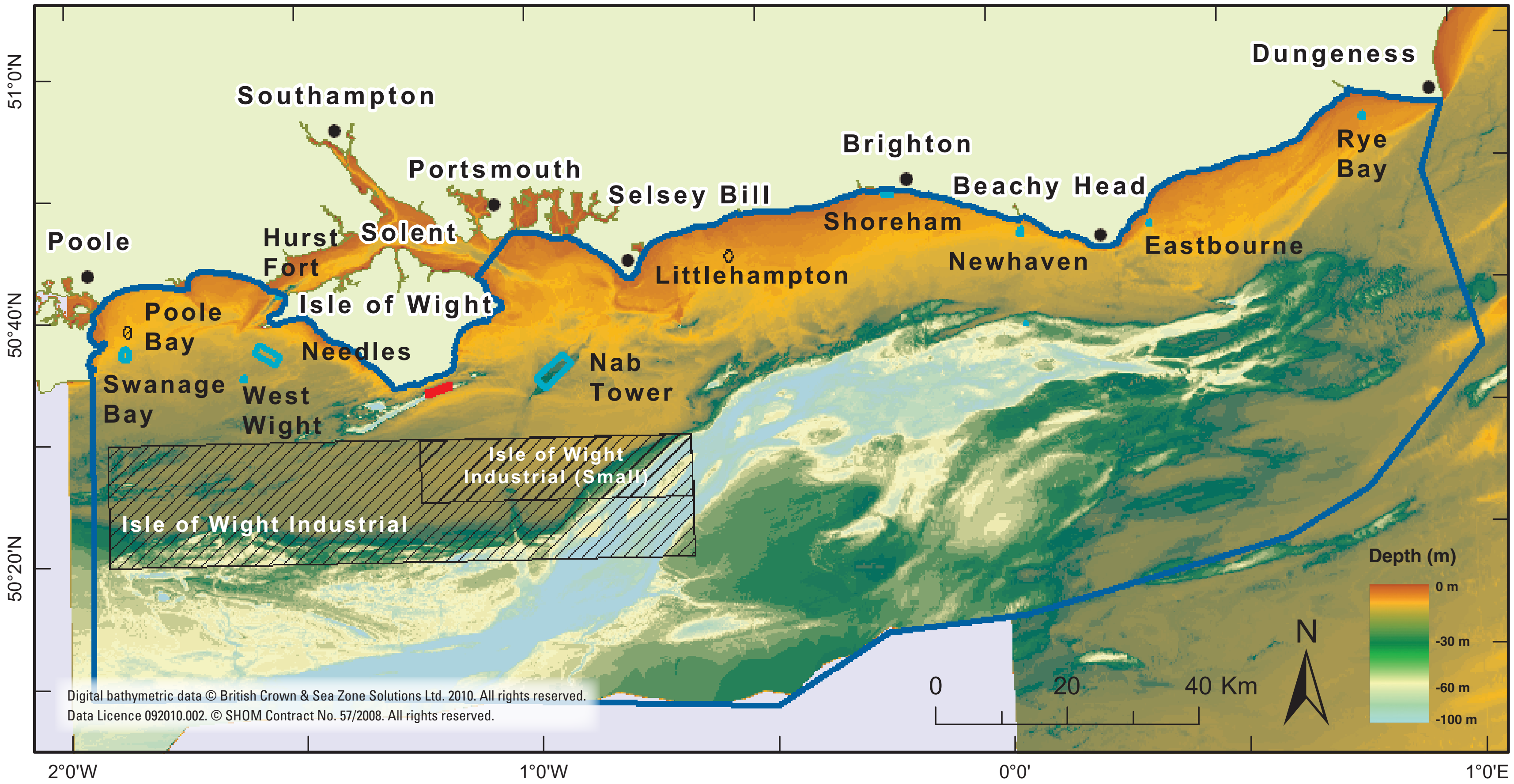
Re-deposited Dredgings (RD). This is material that originates from dredging trials, or sometimes from aggregate dredging where the material brought on board is not the right type or grade of aggregate, so it is deposited back on the sea bed.

Sediment (SE). This is the unwanted, finer material washed from aggregate cargos which is not of commercial value and so is returned to sea.

Aqueous Organics (AO) and **Aqueous Solids (AS).** This is liquid industrial waste, which used to be disposed of at sea. This practice is reported to have stopped at the end of 1992 (info. from MFA website).

Drilling Muds (DM). These are the various types of lubricating mud used in drilling rigs or directional drilling operations related to the installation of coastal pipelines.

Sewage Sludge (SS). This is material derived from sewage plants. The practice of dumping this material at sea was phased out during 1998 (info. from MFA website).



Source:

The information on disposal sites has been provided by Cefas' Regulatory Assessment Team and was sourced from the Marine Consents Management System (MCMS), which is now run by the Marine Management Organisation (MMO) who deal with applications for disposal under the regulations Food and Environmental Protection Act (FEPA) regulations.

Figure 16 Sites licensed for disposals at sea.

Site name	Year Closed	Type of material							
		AO	AS	CD	DM	MD	RD	SE	SS
Swanage Bay				x	x	x		x	
West Wight							x		
Needles				x		x			
Hurst Fort				x		x		x	
Nab Tower		x		x	x	x		x	x
Shoreham				x		x		x	
Newhaven				X		X			
Eastbourne				X		X			
Rye Bay				X		X			
Poole Bay	2002					x			
IoW Industrial	1998		x						
IoW Industrial (small)	1998		x						
Littlehampton	1998					x			

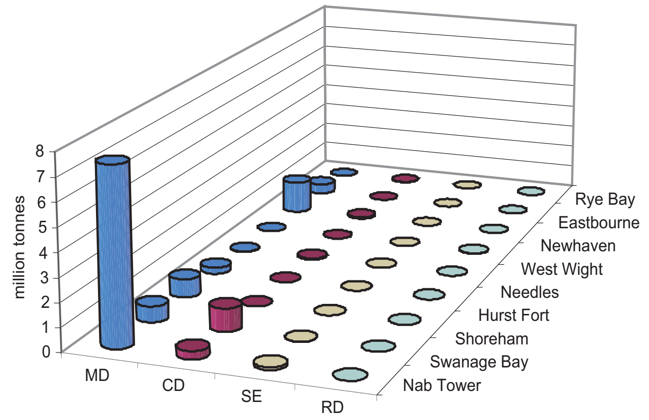


Figure 18 Amount of each type of material deposited at each site during the period 2000–2008.

Table 2 Type of dredge materials received by the 10 licensed disposal sites recorded in the synthesis area, with year of closure (where appropriate). AO = Aqueous Organics, AS = Aqueous Solids, CD = Capital Dredgings, DM = Drilling Muds, MD = Maintenance Dredgings, RD = Re-deposited Dredgings, SE = Sediment, SS = Sewage Sludge.

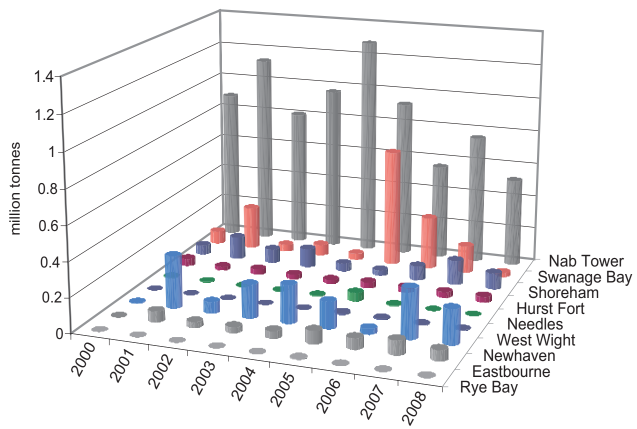


Figure 17 Total amount of dredged material deposited each year at each site.

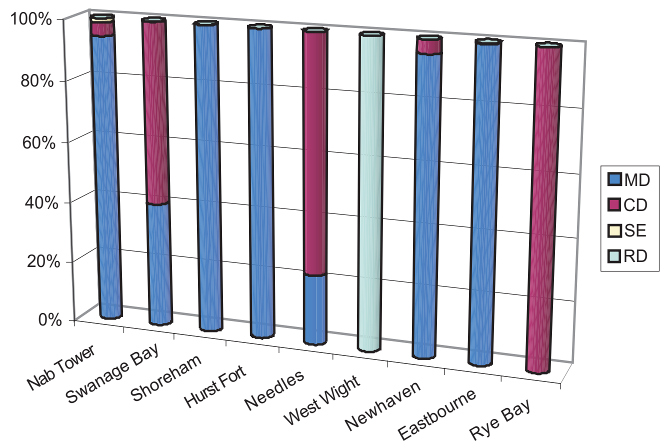


Figure 19 Proportion of each material at each site during the period 2000–2008.

Fisheries

Most fishing boats that operate in the study area are less than 10 m in length (Table 4) and operate inshore, usually within six nautical miles (nm) of the coast. These boats land their catch daily. Most of this fleet is multi-purpose, operating throughout the year in pursuit of whichever stock, and/or quota, is available. For example, sole are mainly fished in the spring and autumn, bass are targeted in the summer and autumn, and cod in the winter.

These smaller inshore vessels use a variety of static and mobile gears. Nearshore gill, trammel and entangling net fishing takes place widely in the study area. Other fishing methods which are deployed nearshore include stern trawling, beam trawling, pair trawling, drift netting, and scallop and oyster dredging. There is also an important fishery potting for brown crab and lobster along the Dorset, Hampshire and Sussex coastline.

Outside of six nm an internationally significant beam trawling fleet operates. These vessels mainly target sole, plaice and other flatfish. In particular, large UK, Belgian and French vessels operate beyond the six nm limit to the east of Selsey Bill. In the centre of the eastern English Channel, scallop beds are dredged by large scallop boats from England and Scotland (Figure 20).

Figure 20 Scallop dredges and catch on fishing vessel © Sussex Sea Fisheries Committee (SSFC).

Data provided by the Marine Management Organisation (MMO) for 2008 gives an indication of the value of the landings by ICES areas and sub-rectangles within the study area (Table 3). The highest value per ton sub-rectangle ICES areas are 30E9 and 29E9 in the east of the study area where a number of intensive fishing methods, including scallop dredging and beam trawling, take place (Figure 21).

The study area is significant for commercial fisheries: 538 vessels (Sussex and Southern Sea Fisheries Committee (SFC) data) out of total UK fleet of 2 915 vessels (MMO data, 2009) are based within the area. The number of vessels based in the study area, by length, is presented in Table 4. Because the majority of this fleet is under 10 m in length they are not likely to routinely fish on grounds outside of the study area. However, it is difficult to calculate the exact number of active vessels because other UK and international fishing vessels operate in the study area.

Fisheries management

Fisheries in the European Union (EU) are managed through the Common Fisheries Policy (CFP). In territorial waters (0–12 nm), management responsibility is divided between the European Community (policy formulation) and the Member State (policy implementation). Management is delivered through a mixture of technical conservation measures including minimum mesh sizes and catch composition and Total Allowable Catches (TACs). In UK territorial waters, the UK can augment the EU system of management through the introduction of their own rules as long as they do not contravene basic principles and existing CFP measures.

Within the region, the right to access fisheries resources reflects previous concessions; these now exist by way of derogation from the

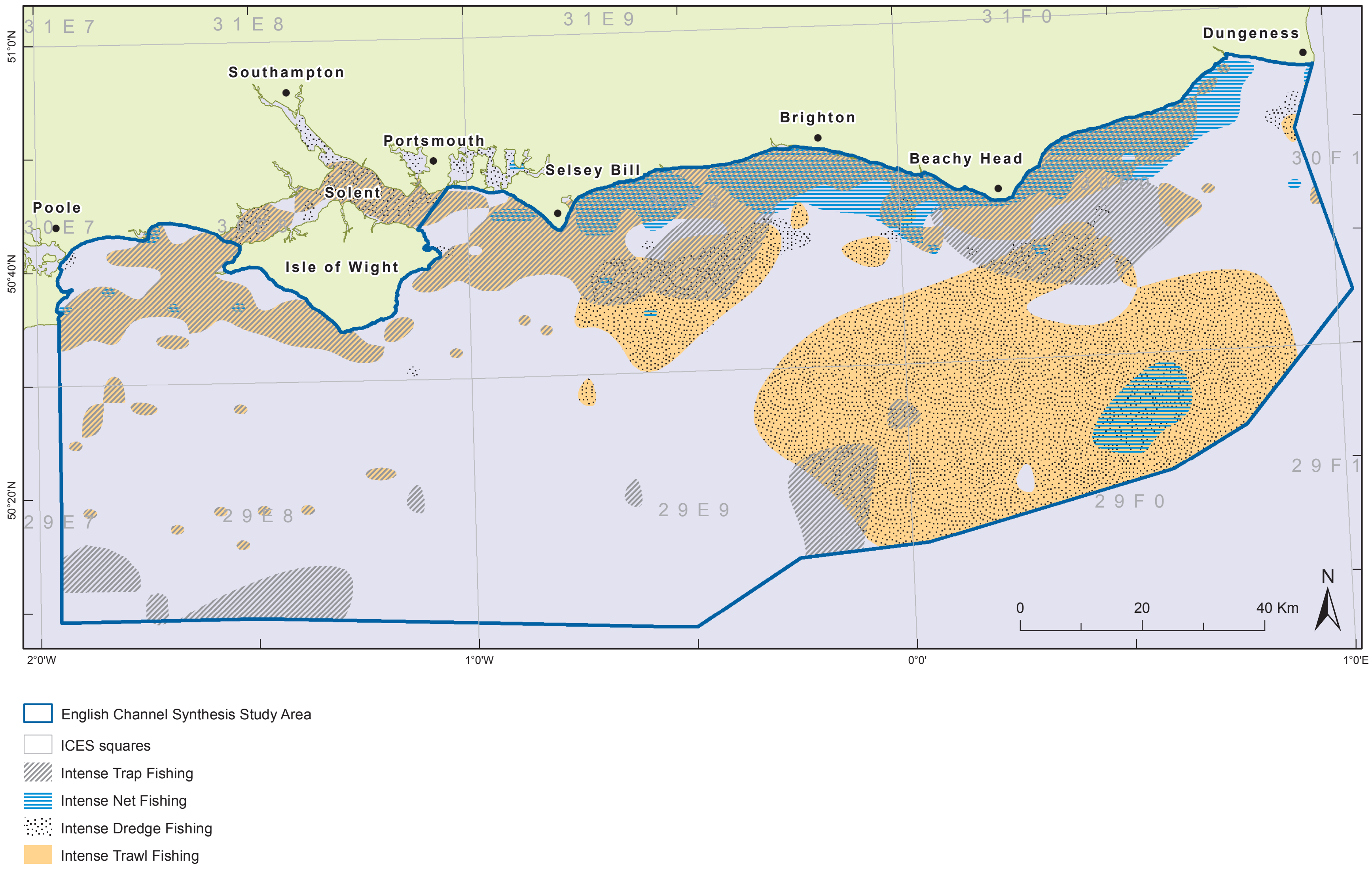


Figure 21 Distribution of fishing activity within the synthesis study area. Source: created from composite data derived from SSFC & MMO 'sightings' and data derived from the Vessel Monitoring Systems (VMS) carried aboard all fishing vessels which are greater than 15 m in length. The methodology and data source is described in Vanstaen and Silva (2010). Data provided by CEFAS. Note: whilst this figure is not a definitive representation of fishing in the study area it is indicative of the areas which are fished intensively.

	Weight	
ICES	(Tons)	Value (£)
30 E 8	998	1 616 569
29 E 8	5	12 915
30 E 9	3 983	5 352 498
29 E 9	690	1 543 677

Table 3 Weight and total value of fisheries landings, by ICES sub-rectangle, for 2008. Source MMO year 2008 data.

principle of a common policy. In the 0–6 nm zone, British registered vessels have exclusive right of access. In the 6–12 nm zone, British and French registered craft can fish all species, and east of Selsey Bill, Belgium vessels have rights to catch demersal fish. In areas outside these zones, fishing rights are limited to EU vessels which have access to the relevant quotas and will be subject to conservation measures.

From 2011, inshore fisheries in England will be managed by the Inshore Fisheries and Conservation Authorities (IFCAs), with the Marine Management Organisation (MMO) administering the national regulations which augment and implement the CFP throughout the region. The synthesis study area will fall within the jurisdiction of three IFCAs: Kent & Essex, Sussex and Southern.

Fish stocks in the synthesis area

The International Council for the Exploration of the Sea (ICES) and CEFAS have assessed a number of the fish stocks within the area; these assessments are mostly limited to stocks for which a EU TAC is set. Many of the most important fisheries within the synthesis study area are not subject to a TAC, for example, the fisheries for scallop, whelk and bass.

Stocks which straddle or are contained within the study area, and which are assessed, include the cod and sole stocks. The cod stock within the area is recorded as suffering reduced reproductive capacity and as being harvested sustainably. The sole stock in the area has full reproductive capacity but is at risk of being harvested unsustainably.

For most other species, an absence of defined reference points means that the state of the stock has not been, and often cannot be, evaluated. Catch per unit effort (C.P.U.E.) data coupled with length, age and maturity data is used in these fisheries to understand their condition, for example, it is apparent that production of young bass and recruitment to the bass fishery has been relatively high over the last ten years or so.

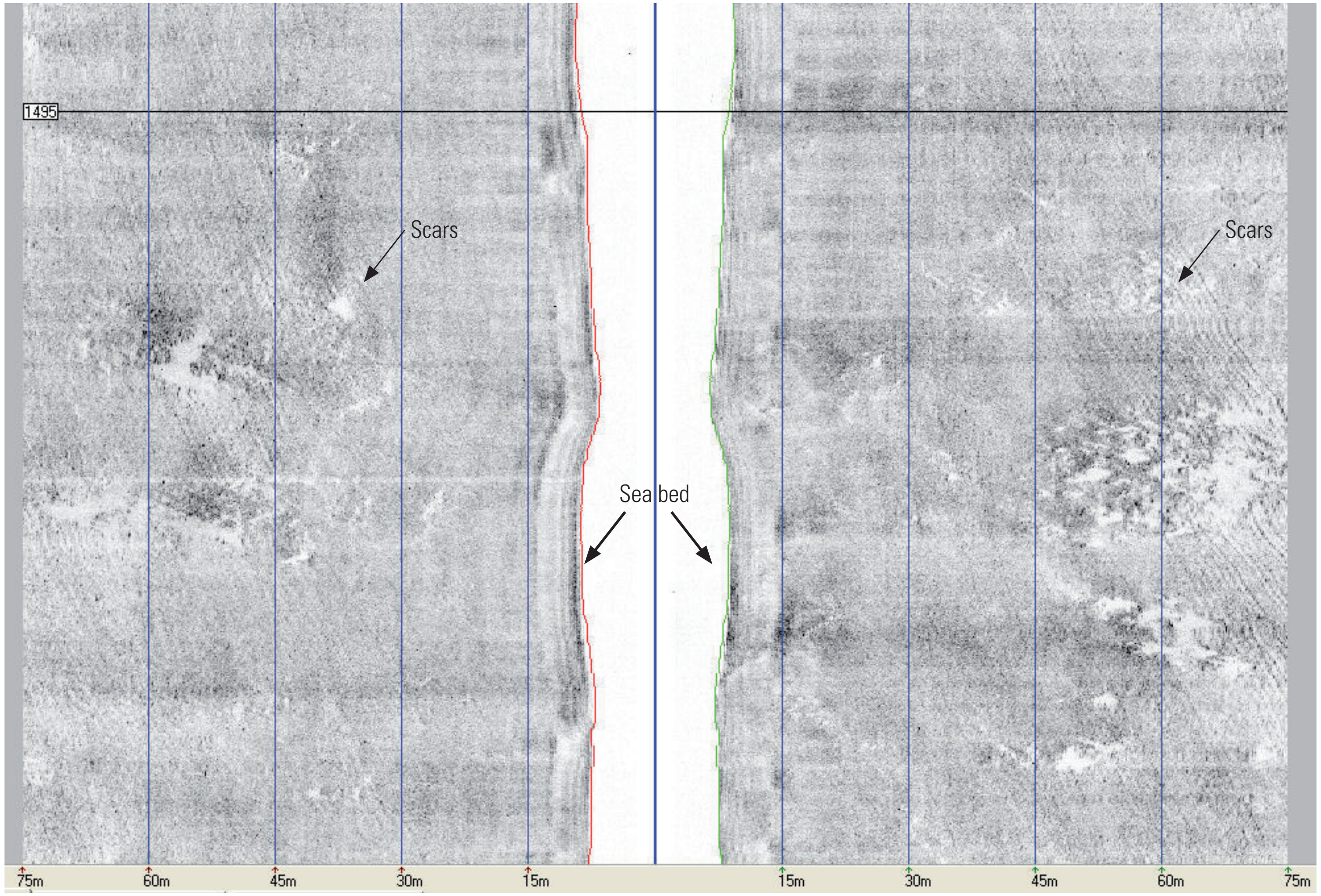


Figure 22 Sidescan sonar record of parallel lines of scallop dredging scars on the sea bed.

Vessel length	Dorset	Hampshire (exc. I-O-W)	Isle of Wight	Sussex	Total
≤10 m	94	94	36	273	497
>10 m	6	11	2	22	41
Total	**100**	**105**	**38**	**295**	**538**

Table 4 Number of UK fishing vessels for the synthesis region. Source Southern and Sussex SFC 2010 data.

Fishing gears and their operation

Mobile demersal fishing gear towed across the sea bed will have an impact on the sea bed which is likely to influence the biological communities in the region. The scale of influence varies throughout the region depending on the nature and scale of fishing, and the sediment type present. The environmental impact of fishing with mobile gear ranges from high levels of bycatch (Hall and Mainprize, 2005), reduced benthic community biomass and productivity (Hiddink *et al.*, 2006), reduced benthic species richness (Collie *et al.*, 2000) and direct physical impacts on habitats (Kaiser *et al.*, 2002). Whilst the impacts of static gear on benthic systems are relatively little studied, some damage can result to attached benthic species (Johnson, 2002). However, the 'footprint' of the individual fishing operations may be less than mobile gear.

To the south of Dungeness, where intense scallop dredging takes place, sonar images show striated patterns on the sea bed (Figure 22). These are probably caused by the penetration of the spring-loaded tooth bars which are used on scallop dredges to agitate scallops *(Pecten maximus)* from the sea bed into dredge bags.

Figure 23 Inshore fishing boat hauling a trammel net off East Sussex © SSFC.

Figure 24 Beam trawler © SSFC.

Angling

Figure 25 Angling charter boat © SSFC.

Figure 26 Black bream © Sean Clark.

Figure 27 Fishing Match — Shoreham Harbour © Sean Clark.

Recreational sea angling is carried out around much of the UK coast (Figure 25 and 26), but had received little attention until its profile was raised by a number of Government reports (Defra, 2009). These tended to look at the economic value and social importance of recreational fishing, both in the UK (Cabtree and Willis, 2004) and at the EU level (Pawson *et al*, 2006).

The synthesis study area includes waters that are nationally significant for recreational sea angling, mainly because of:-

- the proximity of large human populations
- the diversity of sea bed features and habitats
- the variety of fish species in the area
- the easy access provided by numerous sheltered moorings.

Onshore recreational angling occurs all along the coastline; piers, marinas and harbour walls are usually busy with anglers throughout the year (Figure 27). The open beaches and the many closed bays and estuaries are all important areas for recreational sea anglers. The diversity of these nearshore habitats produces a wide range of fish species that are prized by sea anglers.

Offshore, the area contains 'marks' that are nationally recognised as offering a unique angling experience. These include, but are not limited to, two areas in the eastern Solent. The first is known as 'Utopia' which is famed for tope fishing, and the second is the 'Overfalls', which is good for bass angling. Another popular site is the bream nesting area near 'Kingmere', offshore from Littlehampton, Sussex.

Until very recently, there had been no concerted effort to map angling activity, probably because there has been a recognised lack of formal information available (Defra 2009). While there are numerous books available informing anglers about good coastal fishing spots, or offshore 'marks', they give no indication of how many anglers actually use these sites. The situation is now changing, especially in the eastern English Channel, as the Balanced Seas project has just undertaken such an angling survey.

Balanced Seas is one of four regional projects funded by the Government that work in partnership with local people who have an interest in the marine environment. Their purpose is to identify and recommend Marine Conservation Zones for inshore and

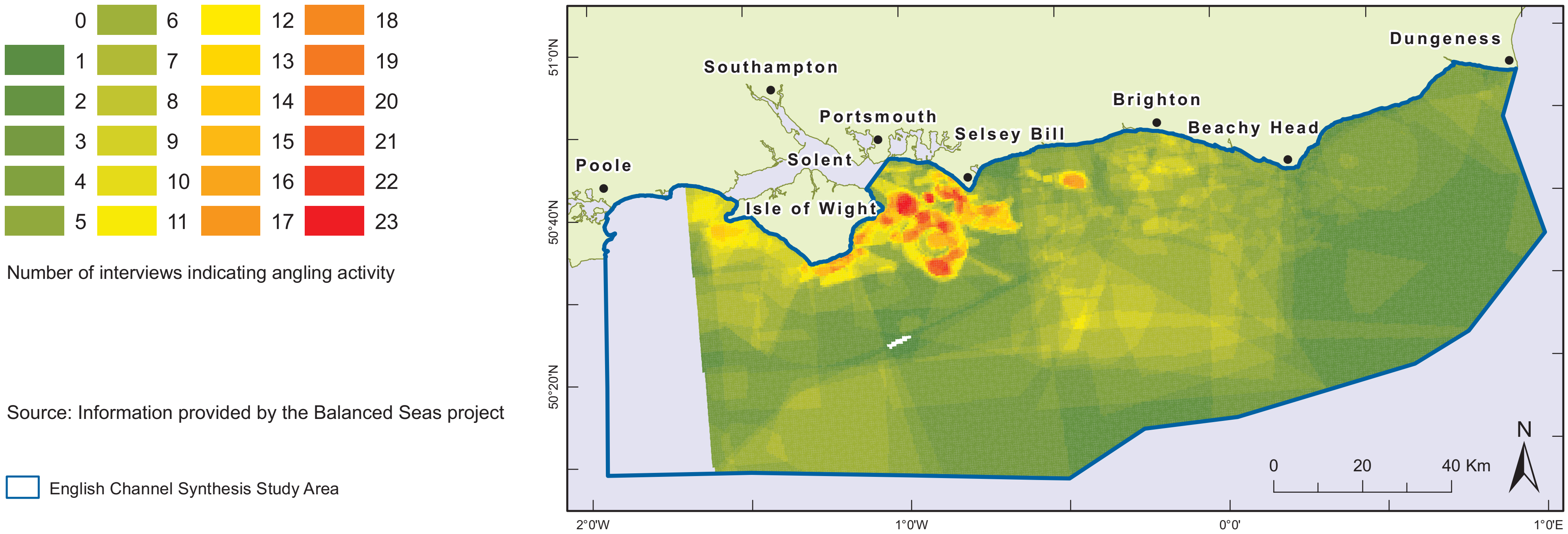


Figure 28 Draft map of sea-angling effort, based on stakeholder interviews.

offshore waters. The Balanced Seas project covers the area from the Hampshire–Dorset border, just west of the Isle of Wight, to the river Deben, on the east coast of England, just north of Felixstowe.

Their angling survey involved face to face interviews with recreational sea angling clubs, both shore- and boat- based, and with tackle shops and charter boat operators. Project Liaison Officers travelled to meet with a chosen representative of a club, or the owner of a shop or vessel, and take them through a questionnaire, 'StakMap', designed to tease out the information needed to capture the social and economic activity that was going on in their area. In addition to the questionnaire, stakeholders helped to map their activities using a purpose built GIS programme by highlighting their regular fishing grounds and 'marks' both on the coast and out to sea. For each of the areas they identified, information was collected on how many people used it, how often, and at what time of year. Charter boats also gave estimates of the importance of certain areas by estimating what proportion of their total vessel earnings came from working in that area. When this mapping information has been combined with all the other information collected at the interviews, an accurate and up-to-date picture of the social and economic use of the southeast will have been established, and this information will be used to help develop the conservation plans for the region.

This collection of information from stakeholders has only just finished (October 2010). The data is now being analysed and will be reported soon. The Balanced Seas project has kindly supplied a first draft map indicating angling effort for the part of their area that covers the synthesis study area (Figure 28). This shows relative fishing effort, in terms of the number of interviews, that indicated activity was taking place in a particular area. The most popular areas are immediately clear. Later versions of this map may include more 'hot spots' as more of the interview data is analysed. The reader is directed to the Balanced Seas project website (http://www.balancedseas.org/) for updated information and maps.

Diving and dive sites

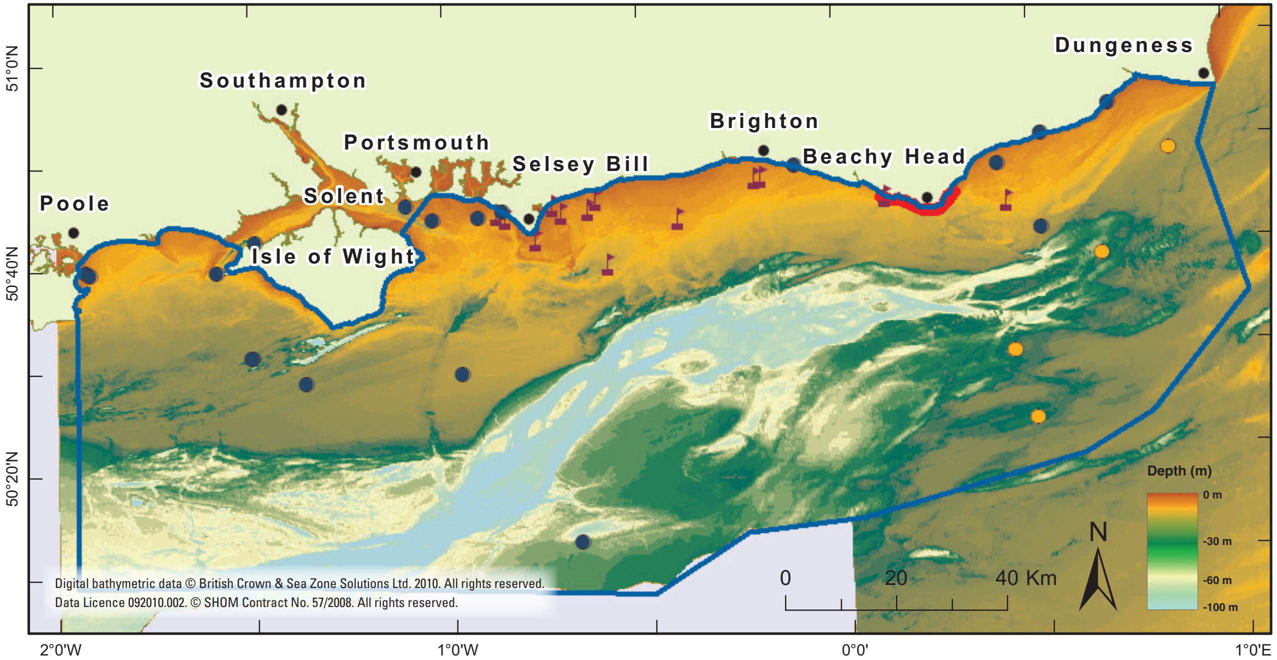


Figure 29 Location of dive sites.

The eastern English Channel is a very popular area for recreational diving with over 20 British Sub-Aqua Club (BSAC) dive clubs along the coastline as well as many popular dive sites. The coastal waters are home to numerous areas of outstanding biological and geological interest that are particularly important dive sites (Figure 29). Unique or unusual geological features such as the Mixon Hole off Selsey Bill and sublittoral chalk exposures at Worthing are particularly distinctive habitats. These habitats, many of which have a very limited distribution in the UK, support a very high diversity of marine life and interesting communities, and are of particular interest to divers and underwater photographers.

The synthesis study area is also home to a number of nationally important shipwrecks, designated under the Protection of Wrecks Act (PWA) (1973), which also serve as a major draw for divers (Figure 30). For example, the wreck of the HMS/m *A1*, discovered by divers in 1989, represents the remains of the first truly British designed and built submarine (Figure 141) and attracts divers from all over the country. There are many other wrecks in the area, not designated under PWA but nonetheless of historical interest, such as the wreckage of the World War II Mulberry Harbour Units, between Bognor Regis and Worthing, that are regularly used by recreational divers.

Figure 30 Diver on wreck © Geoff Mayhill.

Nature conservation sites

The waters of the English Channel contain a number of protected sites which are of national and international importance for nature conservation. In the UK, there are several types of protected area, each driven by different legislation and conservation priorities. Those which apply to the marine and coastal environment are summarised in Table 5.

The Joint Nature Conservation Committee (JNCC) has overall responsibility for the delivery of the UK's conservation responsibilities and, as such, has a duty to designate Special Areas of Conservation (SACs), Special Protection Areas (SPAs) and Sites of Special Scientific Interest (SSSIs) where specified threatened habitats and species occur.

As a signatory of the Ramsar Convention (1971), the UK government is also obliged to designate wetlands of international significance as Ramsar sites. Other nationally and locally important marine resources are protected through designations such as Marine Nature Reserves (MNR), National Nature Reserves (NNR), and marine Sites of Nature Conservation Importance (mSNCI).

Areas protected under existing conservation designations will form the basis of an 'ecologically coherent network of Marine Protected Areas (MPAs)' which is due to be in place by 2012. The network will be supplemented by a number of new MPAs called Marine Conservation Zones (MCZs) designated under the Marine and Coastal Access Act (2009). MCZs in the English Channel will be delivered through the Balanced Seas Project (www.balancedseas.org), one of four regional projects set up to deliver these new MCZs.

Designation	Abbreviation	Legislation	Importance	Focus of protection
Special Areas of Conservation	SAC	European Habitiats Directive (92/43/EEC)	European	Habitats and species (as listed under Annex I and Annex II of the Directive
Special Protection Areas	SPA	European Wild Birds Directive (79/409/EEC)	European	Birds and habitats used by birds (bird species specified in Annex I of the Directive
Ramsar sites	Ramsar	Covention on Wetlands of International Importance (1971)	International	Wetlands utilised by birds
Sites of Special Scientific Interest	SSSI	Wildlife and Countryside Act (1981)	National	Species, habitats and geological features of national importance
National Nature Reserves	NNRs	Wildlife and Countryside Act (1981)	National	Best UK examples of SSSIs - species, habitats and geological features of national importance
Marine Nature Reserves	MNR	Wildlife and Countryside Act (1981)	National	Marine flora and fauna and geological/physiographical features of special interest (e.g. Lundy Island) – to be replaced by MCZs
Marine Conservation Zones	MCZ	The Marine and Coastal Access Bill (2010)	National	Nationally important marine wildlife, habitats, geology and geomorphology. The focus will extend to include the full range of UK marine wildlife not just those considered rare or threatened
Marine Sites of Nature Conservation Importance	mSNCI	N/A	Local	Non-statutory locally valued wildlife sites
Voluntary Marine Conservation Area	VMCA	N/A	Local	Areas of coastline which are of particular wildlife and scientific value that enjoy a level of voluntary protection. These are often extensions of statutory, terrestrial or coastal designations

Table 5 Summary of marine and coastal conservation designations in the UK.

A relatively large number of protected sites have been designated for nature conservation in the English Channel reflecting the ecological and environmental diversity present in this area (Natural England, 2009a, b, c). The significance of these habitats and species is reflected in the multiple designations applied to many of the sites.

The overwhelming majority of protected sites in this area are either coastal or fully terrestrial with protection focussed on seabirds. There are however three internationally important marine areas which overlap with the boundary of the study site, as illustrated in Figure 31. The conservation focus of these sites is presented in more detail in the following pages.

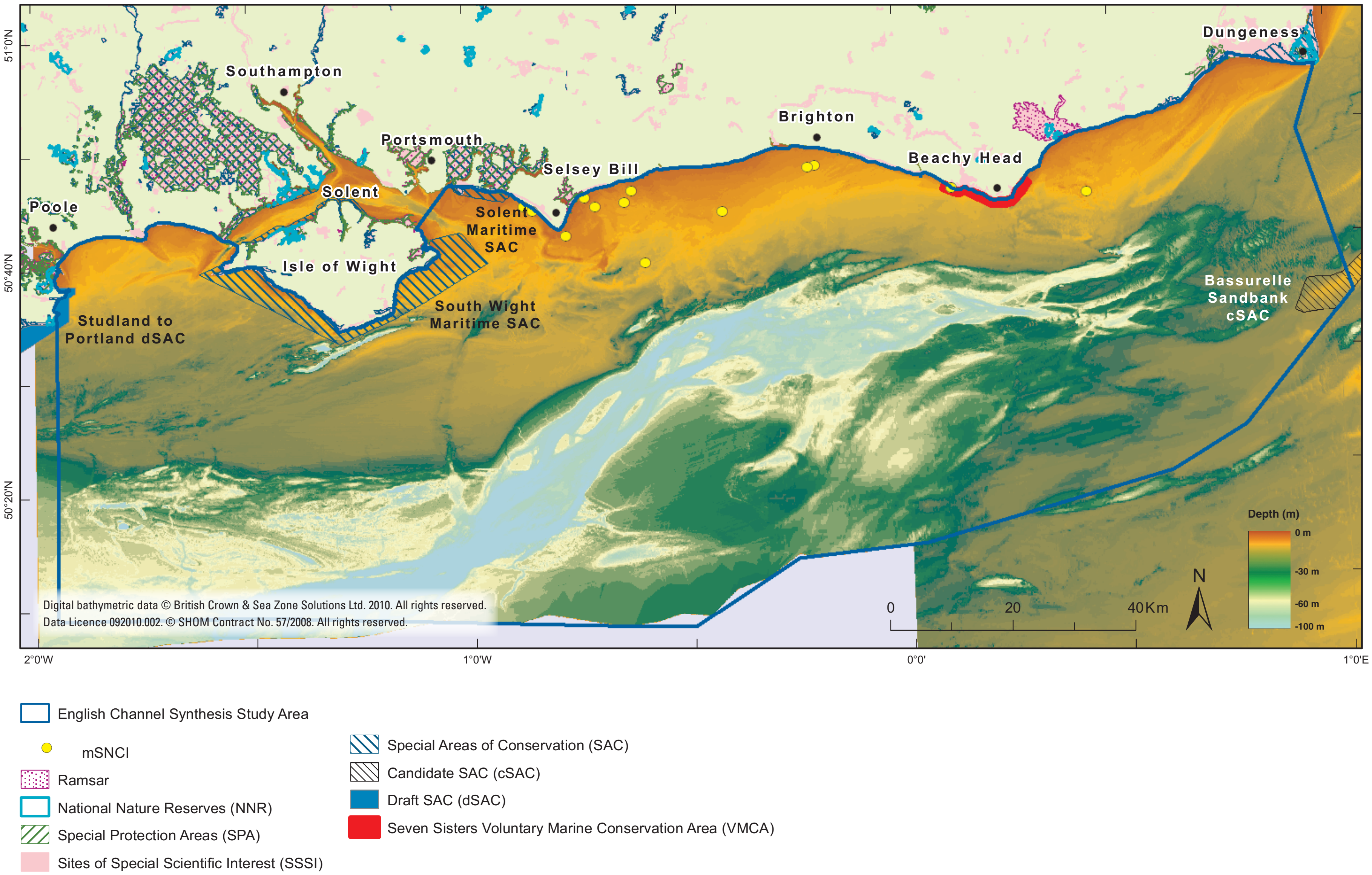


Figure 31 Marine and coastal conservation designated sites.

South Wight Maritime SAC

Area: 19 863 Hectares — 198.63 km^2

Qualifying Features: Geogenic Reefs, Sea Caves and Cliffs

A variety of geogenic reef features are present within the South Wight Maritime SAC, the most significant of which are the chalk reefs and exposures which support diverse assemblages across the subtidal and intertidal zones. Other geogenic reefs present in this area include boulder reefs and hard rock reefs.

High energy waves around the coast of the Isle of Wight have had a profound impact on the coastline, carving sea caves into the island's cliffs. These are the only example of subtidal chalk sea caves in the UK and are highly significant since they support a unique suite of species. The cliffs themselves are also a qualifying feature of the South Wight Maritime SAC because they support a diverse mosaic of plant life.

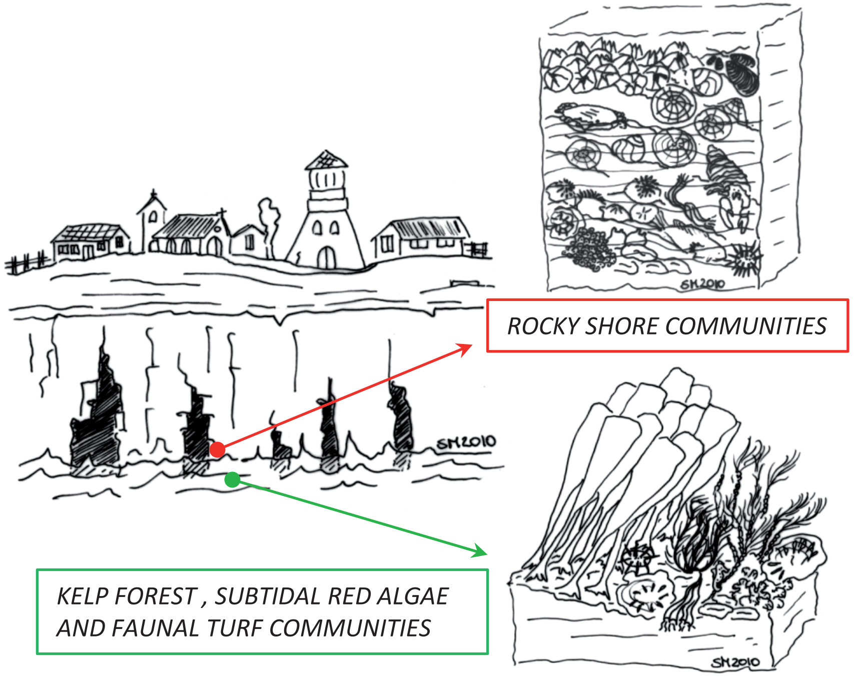


Figure 32 Sea caves and the types of marine fauna they support.

Solent Maritime SAC

Area: 11 325 Hectares — 113.25 km^2

Qualifying Features: Estuaries, Cordgrass swards, Atlantic Salt Meadows

Secondary Features: Sandbanks

Figure 33 Aerial view of Langstone and Chichester harbour © UKP/Getmapping Licence No. UKP2006/01.

The Solent and its inlets are considered to be unique in Europe because they are subject to four, rather than two, tides each day giving rise to a complex matrix of marine and estuarine habitats. A total of four bar-built and four coastal plain estuaries are present as well as extensive sand and mud flats which support important seagrass *(Zostera)* beds. The Solent Maritime SAC is the only site containing the smooth cordgrass, *Spartina alterniflora*, in the UK. It is also one of only two UK sites containing significant expanses of small cord grass, *Spartina maritima*.

The Solent Maritime SAC contains the second-largest aggregation of Atlantic salt meadows in southwest England. This feature is particularly notable as it is ungrazed and includes rather unusual transitions from freshwater reed swamps, alluvial woodland and coastal grassland. Highly rare sponges identified in the Yar estuary, and biogenic reefs formed by the ross worm, *Sabellaria spinulosa*, are also included as qualifying features in this SAC.

Studland to Portland dSAC

Area: 33 177 Hectares — 331.77 km²

Qualifying Features: Geogenic and Biogenic Reefs

Numerous geogenic and biogenic reef features have been identified within the Studland to Portland dSAC. The geogenic reefs which have been identified as qualifying features include a series of limestone and other rock ledges, limestone blocks known as 'sea bed caves', chalk bedrock, boulders and cobbles. These geological features have been found to support a range of sponges, the ross coral *Pentapora foliacea*, and colonies of the pink sea fan *Eunicella verrucosa*. Biogenic reef features have also been identified in this area including beds formed by the edible mussel *Mytilus edulis*, sand reefs formed by the ross worm, *Sabellaria spinulosa*, *Ampelisca* mats and brittle star beds.

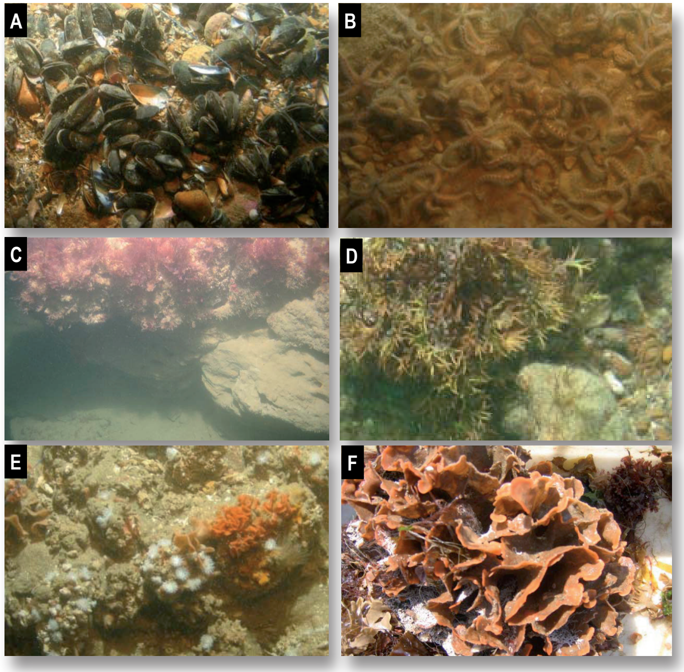


Figure 34 Examples of reef features protected by the Studland to Portland SAC. A) Mussel beds, B) Brittle star beds, C) Boulder formations, D) Rocky reef, E) Sponge reef F) *Pentapora foliacea*.

Bassurelle Sandbank cSAC

Area: 6 709 Hectares — 67.09 km²

Qualifying Feature: Sandbanks

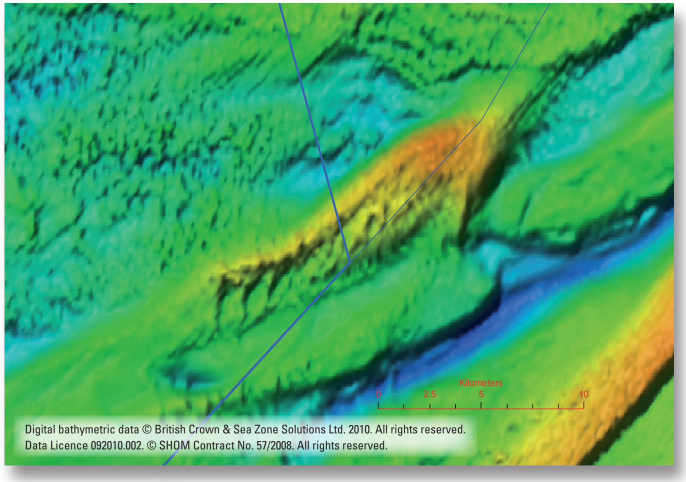


Figure 35 Bathymetric image of the Bassurelle Bank.

The Bassurelle Sandbank lies within a much larger area of sand but is distinct because of the thickness of sediment (up to 25 m thick). The bank supports an impoverished infaunal community characterised by polychaete worms and bivalves including the razor clam *Ensis* spp.. However, the bank also supports a number of fish species including the sandeels *Ammodytes tobianus* and *Hyperoplus lanceolatus* (Figure 36), which form a critical component in the diet of larger fish and seabirds.

Figure 36 The sandeel *Hyperoplus lanceolatus*. © seasurvey.co.uk

Surveys and sampling

The nature and character of the sea bed is the focus of investigation for marine habitat studies. This includes the animals and plants that live on or just beneath the sea bed and the physical character of the sea bed: Is it sandy, gravelly, muddy or rocky? Is it flat, steep, undulating or rough? Does it have deep areas and shallow areas, submerged valleys, ridges, channels and cliffs? Are currents strong enough in sandy areas to fashion sand waves and sand banks? These are just some of the questions which a survey programme should be designed to answer as well as some of the most important questions: Is there a relationship between animals and plants and the physical character of the sea bed? Do some animals and plants prefer to live on some types of sea bed and not others?

Many of these features can be quite small like an individual sand wave a few metres high or a black bream fish nest a couple of metres square, others like submerged valleys and sand banks can be tens of kilometres long. How can we survey both large and small features over an area as extensive as that covered by the synthesis study, which is 12 755 km^2? The short answer is that it would be prohibitively expensive and time consuming to survey all the small metre scale features but the larger features can mostly be identified with a bathymetric dataset that has become available in the last few years (James *et al,* 2008). This is UK Hydrographic Office data provided through SeaZone Solutions as a 25 m bathymetric grid from which a sea bed morphology model can be produced (Figure 44a and 44b). The model allows a survey programme to be designed to investigate the large features and some of the small features that form within them.

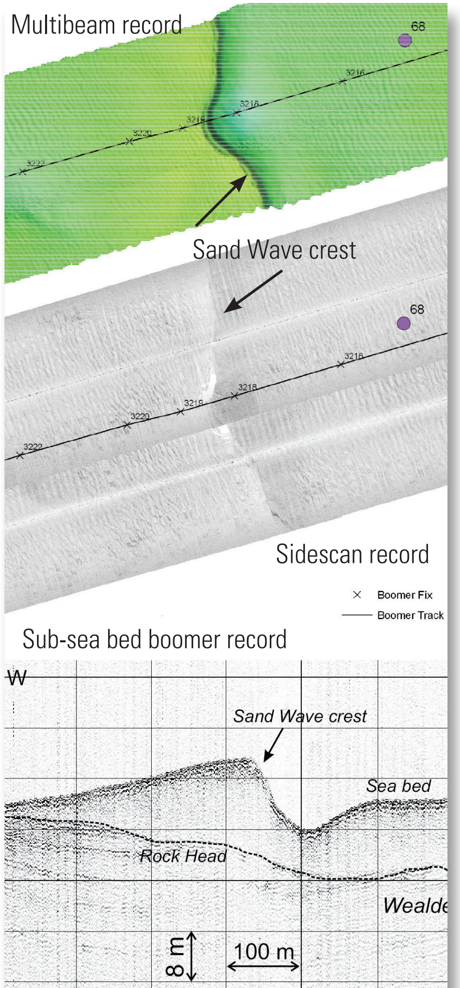


Figure 37 Multibeam, sidescan sonar and boomer records.

The survey programme is designed around two principal methodologies, the first is remote and does not directly sample the sea bed and is based on geophysical survey techniques which are illustrated and described in Figure 40a and 40b. They are:-

- Multibeam echo sounder (MBES)
- Sidescan sonar
- Boomer sub-bottom profiler

The second methodology is based on direct sampling and visualisation of the sea bed. These direct techniques are known as ground truthing and are illustrated and described in Figure 41a and 41b. They are:-

- Hamon grab
- Clamshell grab
- Beam trawl
- Drop camera
- Camera sledge

The aim of survey programmes for marine habitat studies is to provide an integrated biological, geological and geophysical dataset whose individual elements are complementary, with each adding value to the whole and gaining value from each other. This dataset would then be used for a comprehensive analysis and interpretation of the marine habitat of the study area.

The geophysical surveys funded by the MALSF for the Eastern English Channel Marine Habitat Map study (James *et al* 2007) and the South Coast REC (James *et al* 2010) were undertaken to assess the topography and morphology of the sea bed, establish its texture and character, and delineate the underlying geology and thickness of the superficial sediments. This was fundamental to provide the physical and regional framework on which to develop the biological sampling programme and the interpretation of sea bed habitats.

A 'corridor approach' was adopted to maximize the coverage of the area within the allocated budget for the study. The survey strategy was devised to acquire three parallel lines with sidescan sonar and multibeam deployed simultaneously, aiming to provide a sea bed swath width of up to 500 m for each corridor, and to acquire sub-sea bed profile data with a surface tow boomer along the centre line of each corridor. The grid of corridors run in two principal directions, west-east and north-south and were designed to cross the major geological and geomorphological features present in the survey area (Figure 39).

With a large area to cover, the rationale for sea bed sampling has to be selective. It is reasonable that sea bed sampling should only take place within the geophysical corridors, as the co-location of physical and biological information maximises the power of the survey to describe, differentiate and delineate sea bed habitats. As the geophysical survey is based on a grid-design, it was logical to place one ground-truth sampling station at each of the grid crossing points to ensure full spatial coverage. The placing of further sampling stations was decided following detailed scrutiny of the sidescan and multibeam records. Sites were selected to provide ground truthing information for geophysically distinct areas which were related to changes in sediment or rock type. Sites were also chosen to help interpret bedforms such as sand waves and sand banks. Resources were not sufficient to allow all direct techniques to be used at every sampling station. The number of stations occupied by the various equipment types used in the synthesis study interpretation is shown in Table 6.

Figure 38 Camera sledge and drop camera sea bed photographs (scale bar–20 cm).

Station equipment type	Number of stations
Hamon grab	562
Clamshell grab	79
Beam trawl	215
Drop camera	649
Camera sledge	194
Grabs used for particle size analysis	2363

Table 6 Sample station equipment type statistics.

The MALSF funded 5128 line kilometres of geophysical survey in the synthesis area including a survey in March 2010 in the Beachy Head — Dungeness area which produced boomer sub-bottom profiler and sidescan sonar data (Smart *et al,* 2010). As well as the MALSF funded geophysical surveys a number of other geophysical surveys provided by the British Geological Survey, Cefas, South Coast Regional Environmental Assessment, Cemex, Hanson Marine and Tarmac Marine have been used in the interpretation of the synthesis area. These are estimated to have been around 2500 line kilometres. The full coverage of geophysical data is shown in Figure 39. These organisations plus Westminster Dredging and Britannia Aggregates also provided sample data, some of which are included in samples used for particle size analysis (PSA) (Figure 42). The location of the 429 sample stations used in the assessment of biotopes are shown in Figure 43.

The survey data and reports funded by the MALSF for the EECMHM (James et al, 2007), South Coast REC (James et al, 2010) and synthesis study (Smart et al, 2010) are available from MALSF Marine GIS www.marinealsf.org.uk.

Marine Aggregate Levy Sustainability Fund MALSF

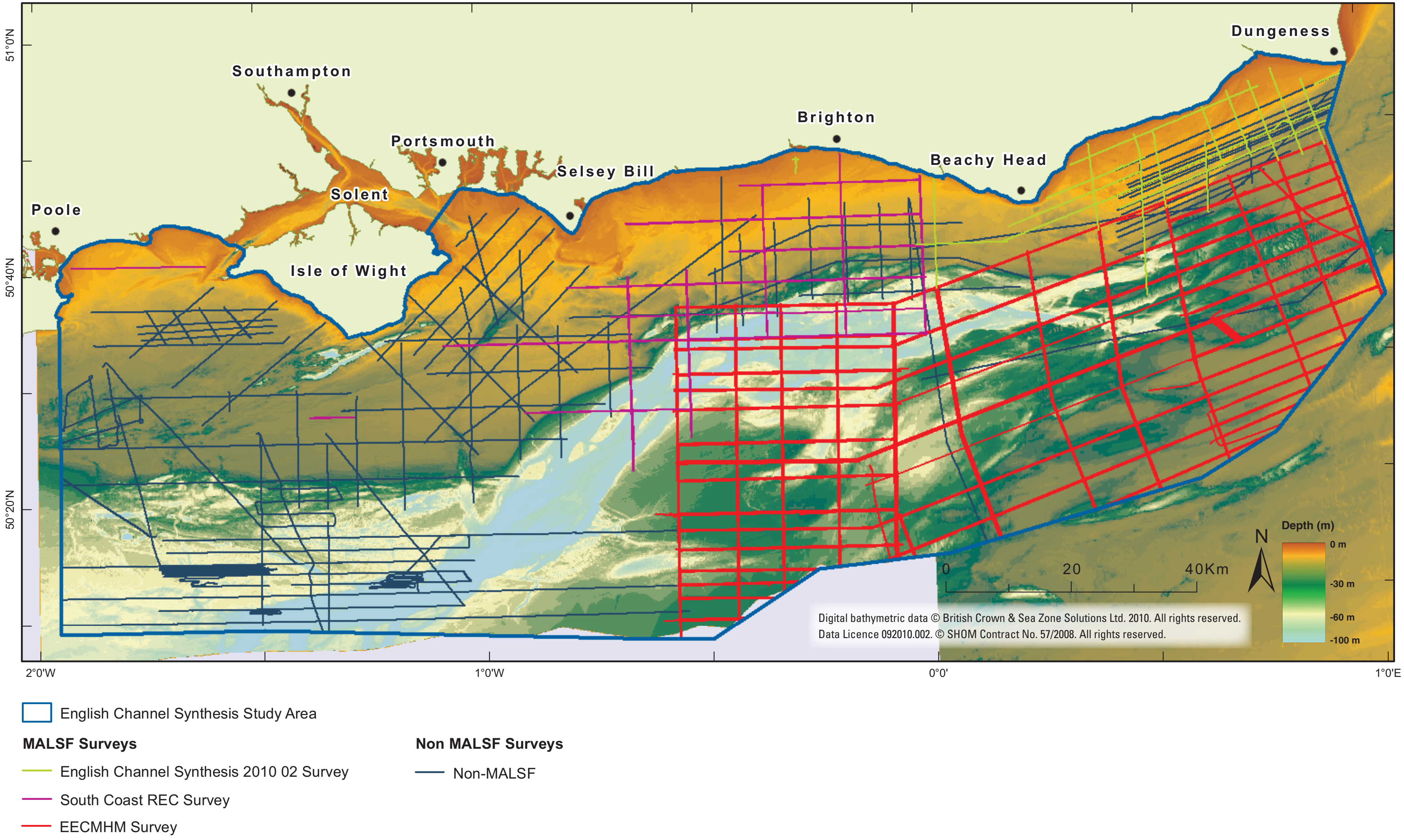


Figure 39 Geophysical survey lines.

Geophysical survey techniques

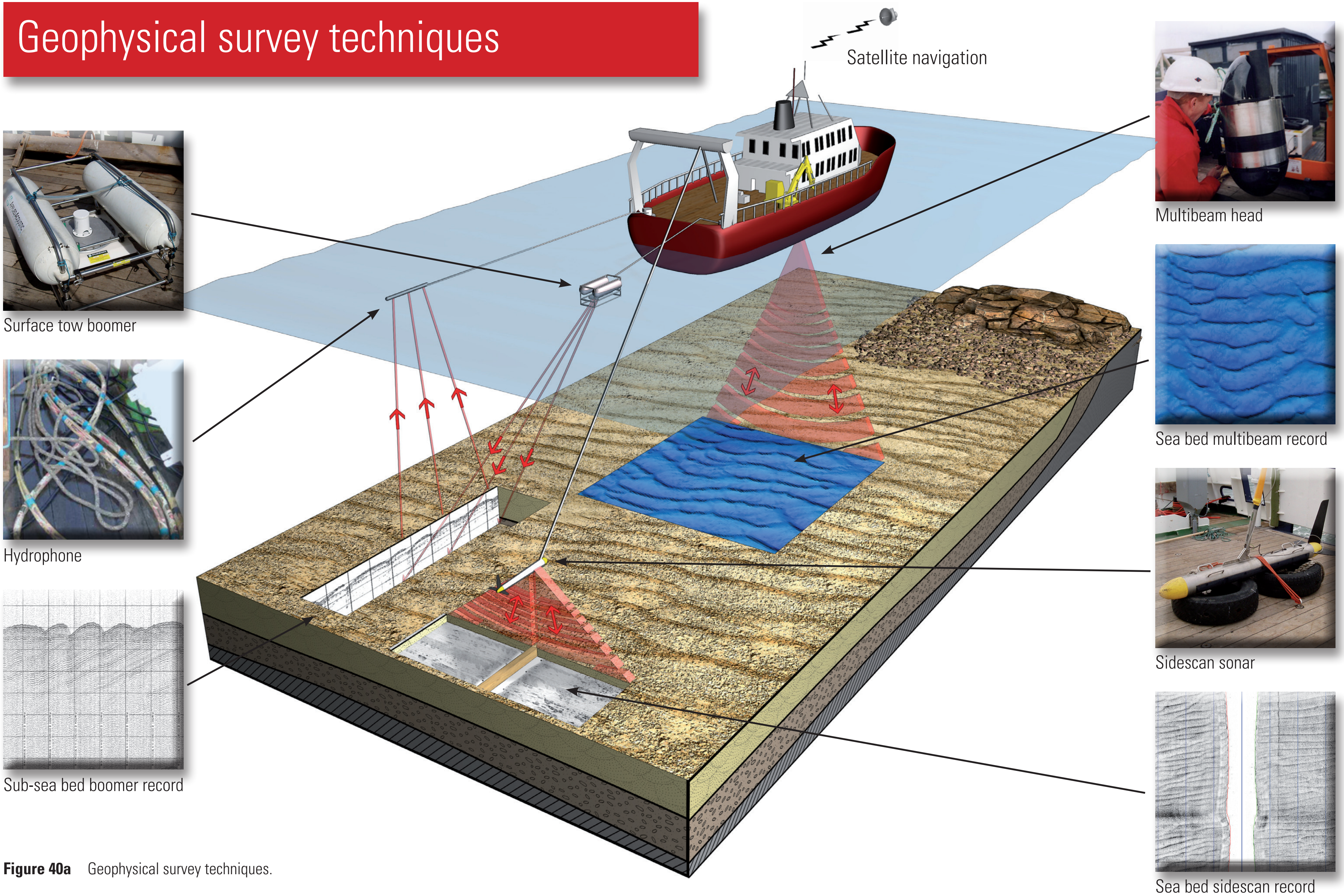


Figure 40a Geophysical survey techniques.

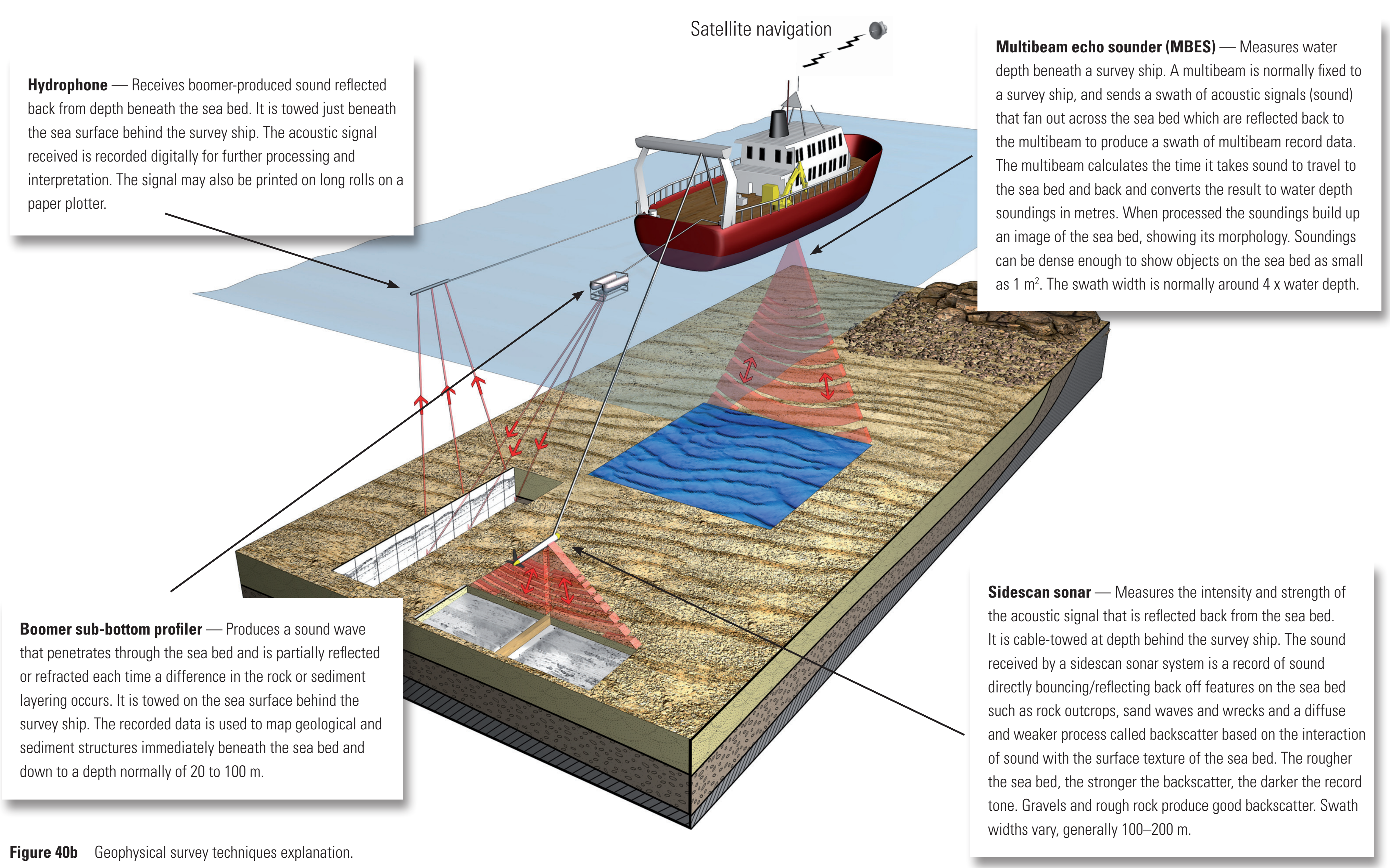


Figure 40b Geophysical survey techniques explanation.

Sampling survey techniques

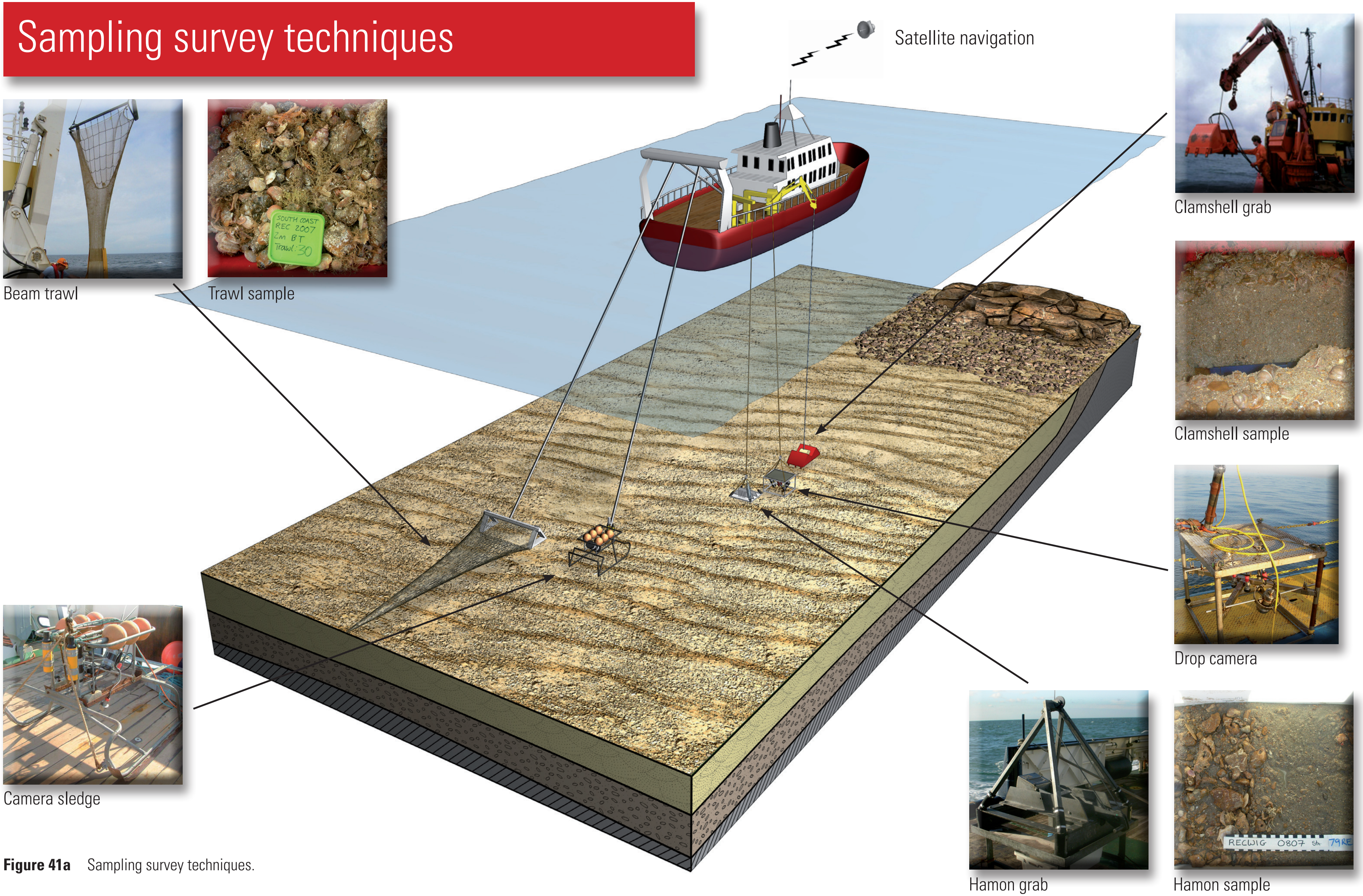
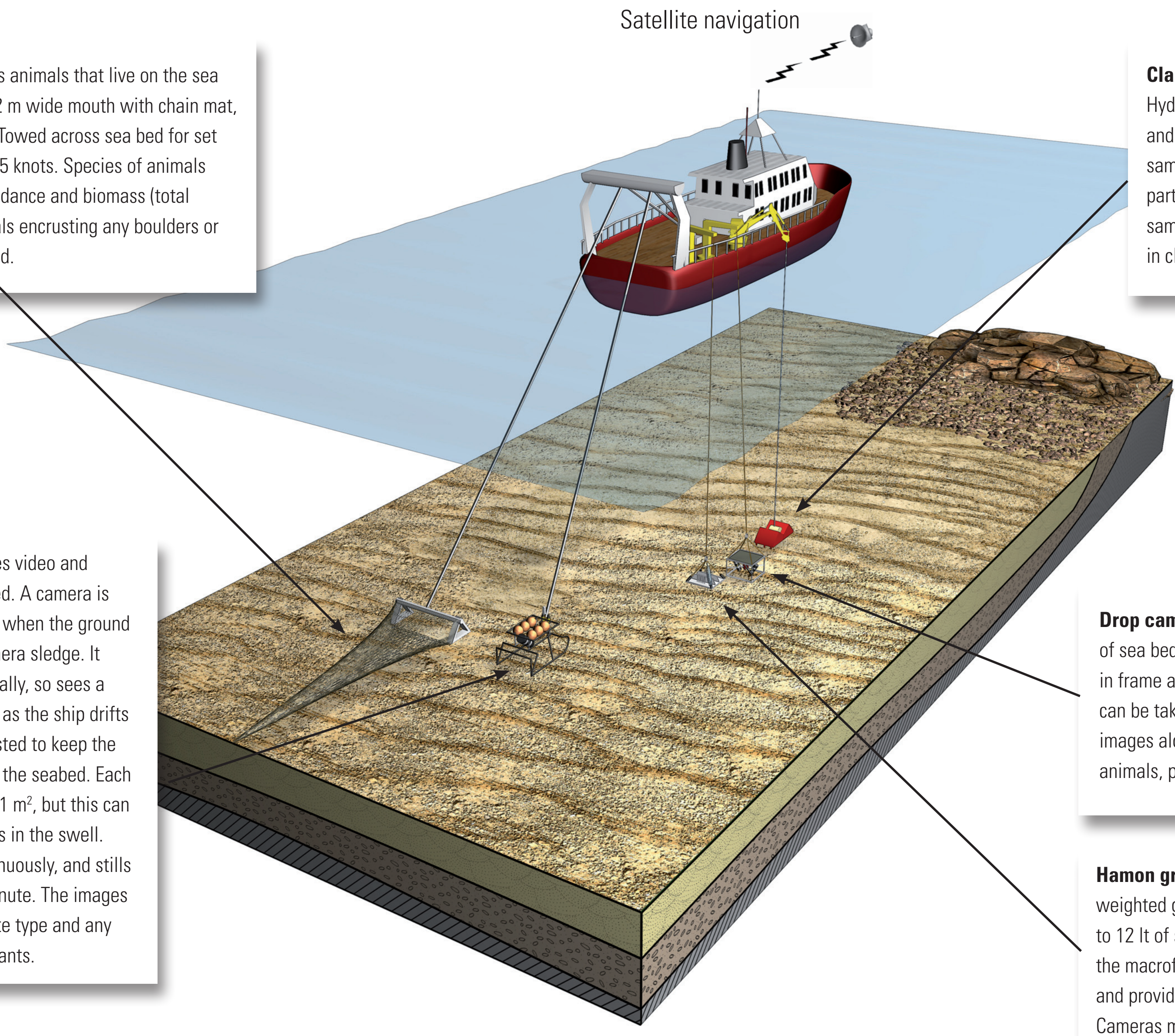


Figure 41a Sampling survey techniques.

Beam trawl — Collects animals that live on the sea bed surface (epifauna). 2 m wide mouth with chain mat, and 5 mm mesh at end. Towed across sea bed for set time e.g. 5 minutes at 1.5 knots. Species of animals identified and their abundance and biomass (total weight) recorded. Animals encrusting any boulders or cobbles are also recorded.

Clamshell grab — Samples sea bed sediment. Hydraulic powered grab covers 0.5 m^2 of sea bed and samples up to 340 lt of sediment. Collected samples used for aggregate assessment and particle size analysis (PSA). Also collects rock samples where rock is soft enough to be excavated in clamshell jaws.



Camera sledge — Takes video and still images of the sea bed. A camera is mounted in a drop-frame when the ground is too rough to use a camera sledge. It is usually mounted vertically, so sees a plan-view of the sea bed as the ship drifts along. The winch is adjusted to keep the camera frame just above the seabed. Each image generally covers ~1 m^2, but this can change as the ship moves in the swell. The video is left on continuously, and stills are taken about every minute. The images are assessed for substrate type and any identifiable animals or plants.

Drop camera — Takes digital photographic still images of sea bed surface. Still camera normally held vertically in frame and each image generally covers ~1 m^2. Images can be taken at a specific location or as a series of images along a line. Images assessed for identifiable animals, plants and type of sediment and rock.

Hamon grab — Samples sea bed sediment. Gravity weighted grab covers 0.1 m^2 of sea bed and samples up to 12 lt of sediment. Collected samples used to assess the macrofauna retained on sieves with 1 mm mesh and provide particle size analysis (PSA) of the sediment. Cameras may be attached to the grab for sea bed photography at grab sample station.

Figure 41b Sampling survey techniques explanation.

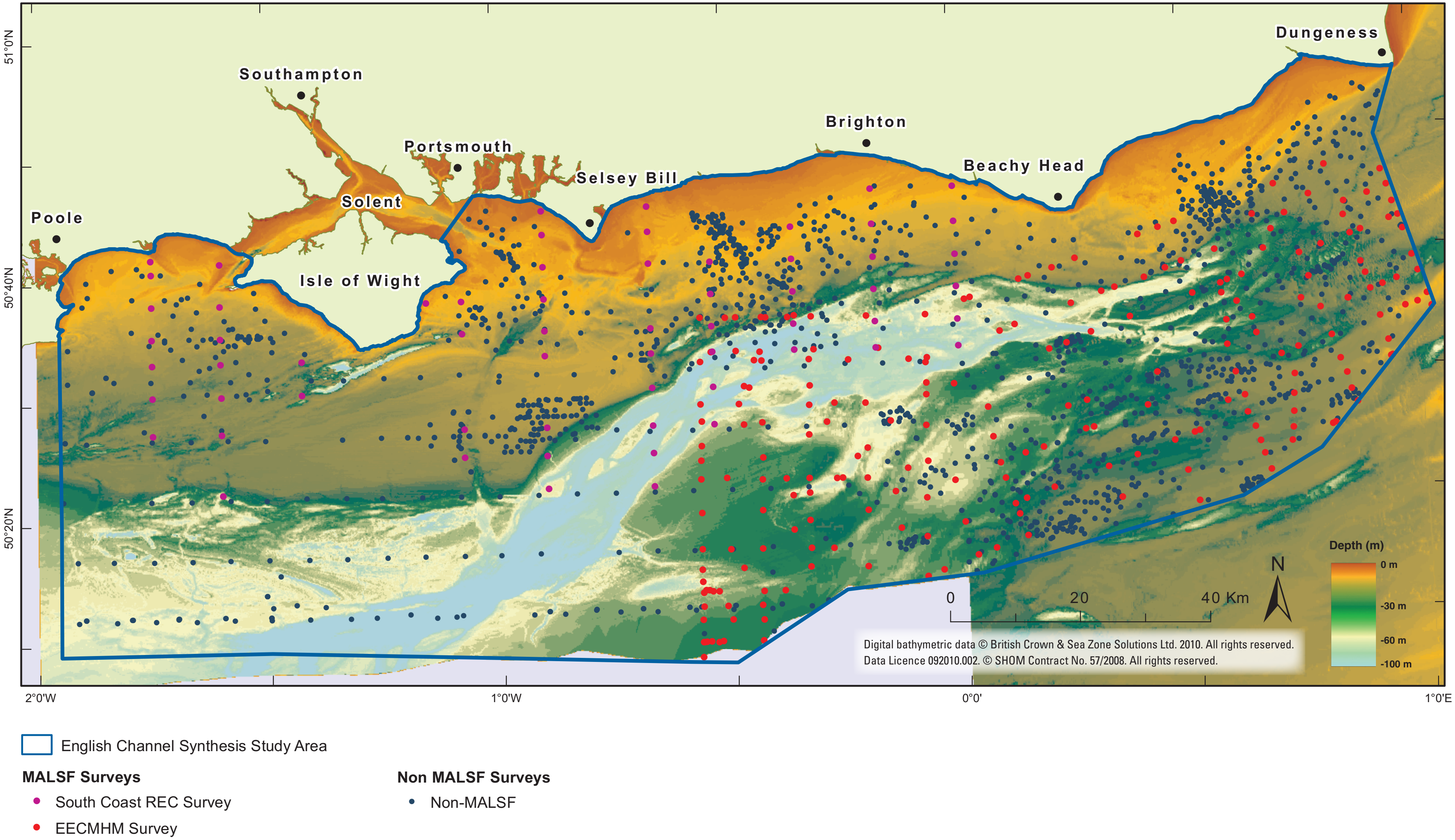
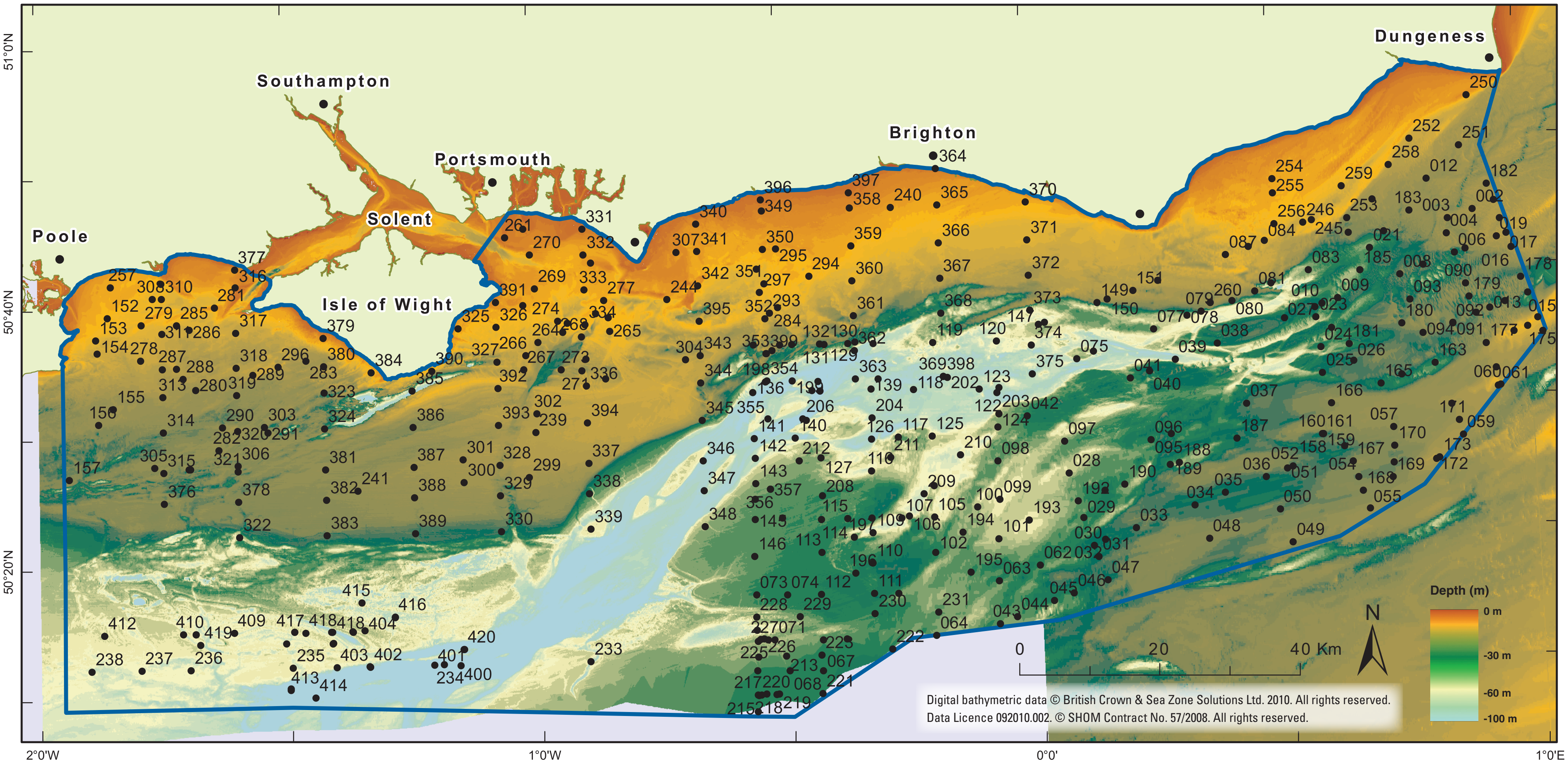


Figure 42 Sample stations with particle size analysis (PSA) data.



English Channel Synthesis Study Area

• English Channel Synthesis Biotope Analysis Stations

Figure 43 Sample stations used for synthesis study biotope analysis. (See pages 74–102.)

Onshore and offshore morphology

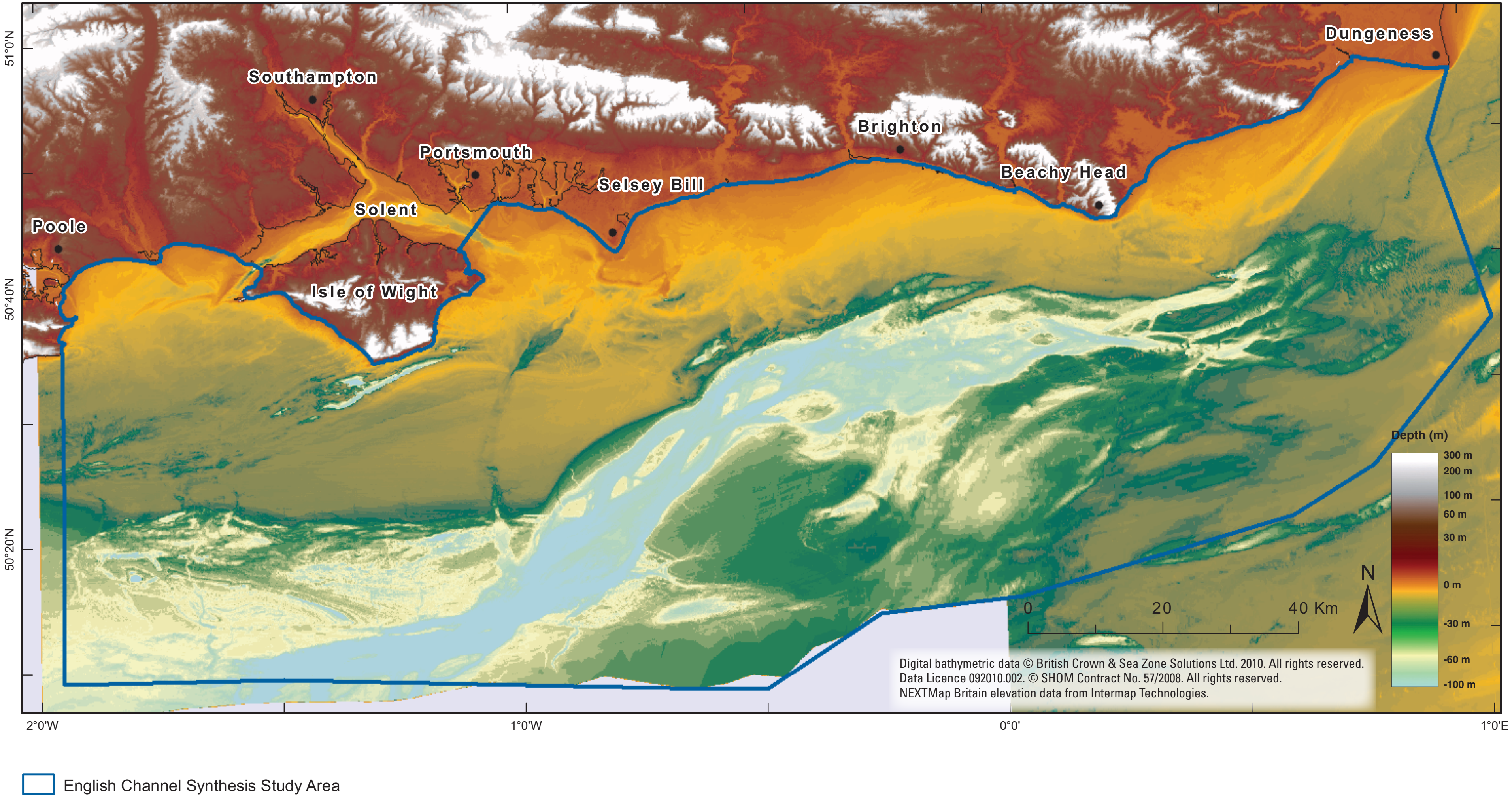


Figure 44a Onshore and offshore morphology.

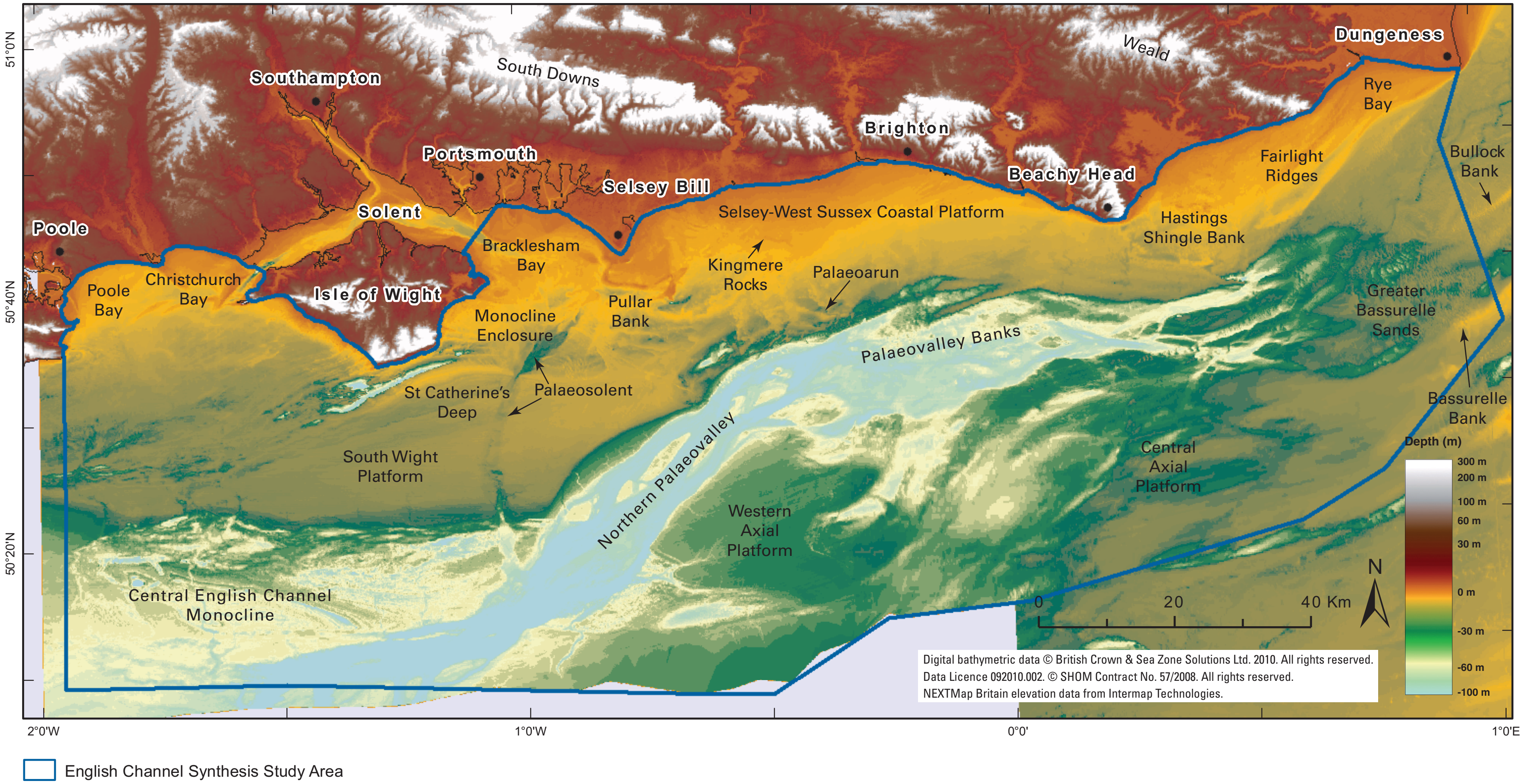


Figure 44b Onshore and offshore morphology with named physical and geographical features.

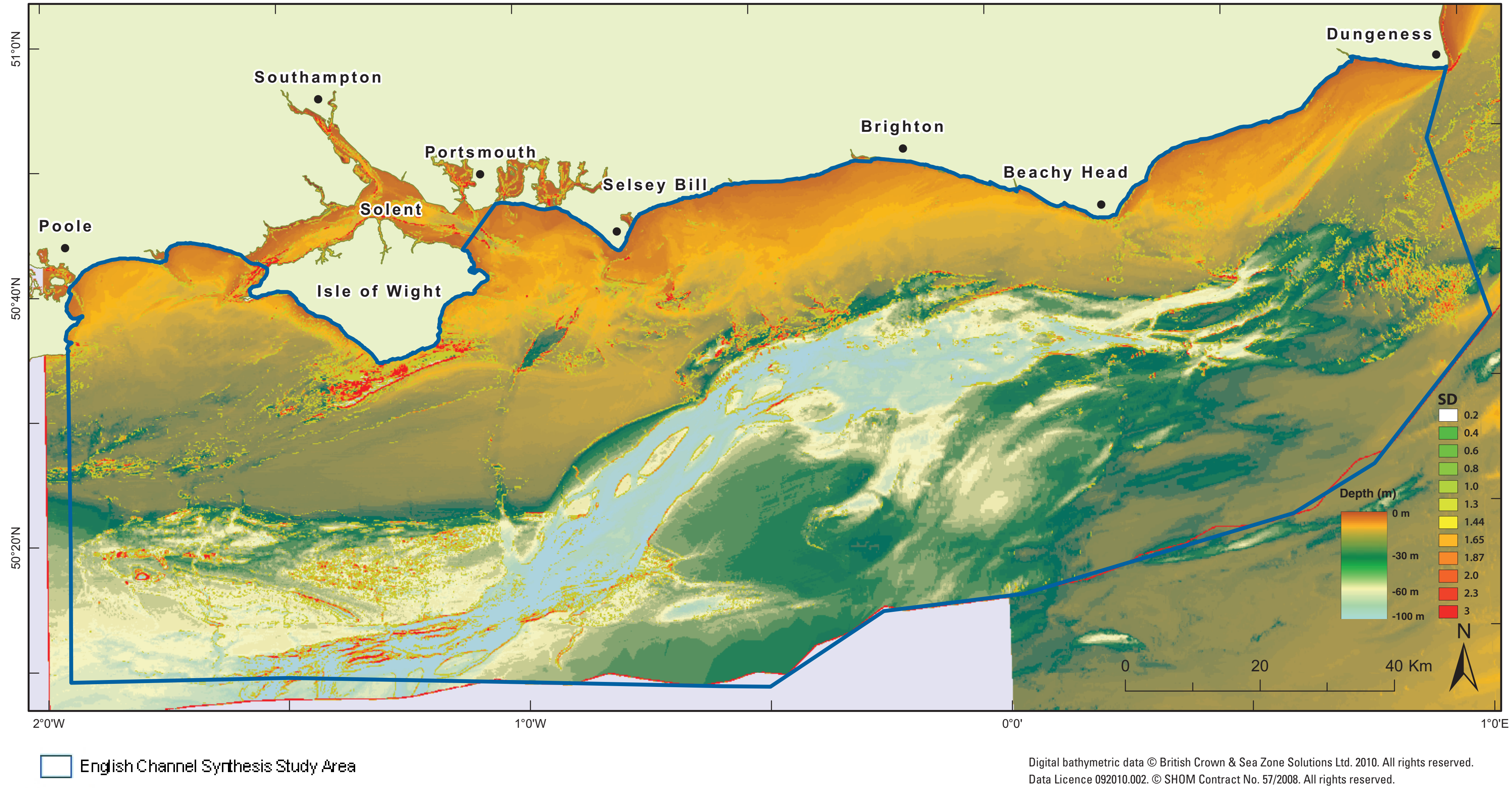


Figure 45 Sea bed roughness and morphology.

The roughness image was computed by running a 7 pixel by 7 pixel neighbourhood filter (Figure 94) over the morphology model and calculating the focal standard deviation. The calculation produces a measure of the deviation of the centre pixel in the filter compared to the surrounding values as measured by the 7 by 7 area. Areas with a low standard deviation (SD) are areas of relative low 'roughness', and, conversely, high standard deviation values represent relatively high 'roughness.

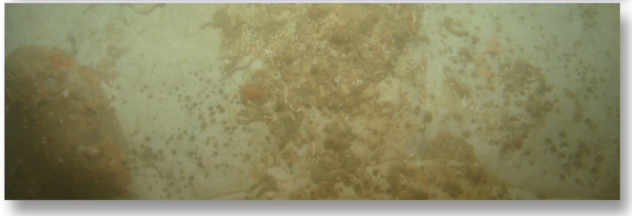
Solid geology — bedrock

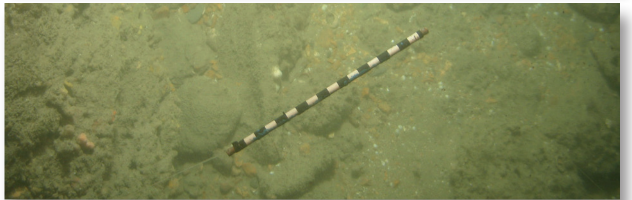
Both solid geology and bedrock are terms which conjure up the thought of physical properties such as hard, strong, dense, unyielding, a good foundation, and this is what the solid geology of the synthesis study area provides: a 'rock-solid' foundation on which loose sediment of mud, sand and gravel can lie or alternatively, where sediment is missing, and bedrock is the substrate exposed at the sea bed, a foundation for the sea itself. This 'rock-solidness' stems from the fact that bedrock in the study area ranges in age from the Tertiary to the Upper Jurassic a period that spanned 32 to 155 million years ago (Mya). During this period of time these rocks were deposited, compressed, folded and faulted and changed from loose sediment laid down in various Jurassic, Cretaceous and Tertiary seas, lagoons, estuaries and rivers into the solid geology we see today (Figure 50 and 51).

The bedrock of solid geology underlies the whole synthesis study area (Figure 52a and 52b), however, it is only in those areas of sea bed where rock or rock and thin sediment is found and exposed at the sea bed (Figure 66) such as the South Wight Platform, Central English Channel Monocline, Western Axial Platform, Monocline Enclosure east of the Isle of Wight, and offshore of Selsey Bill and Beachy Head (Figure 74) where the form, nature and lithology of the bedrock will impact on the character of the sea bed. In other parts of the study area, mobile sea bed sediment and thick Quaternary sediment provide the substrate for the sea bed surface.

Where rock is exposed at the sea bed, whether in small patches only a few metres across or extensive areas measured in tens of square kilometres, its character will have a great influence on the type of animals and plants that are able to survive or thrive on these rocky substrates. These influential rock characteristics include lithology i.e. what the grains of rock are made of and their size. Is it a fine grained soft mudstone which can be bored by burrowing animals such as piddocks *(Barnea candida)*, or is it a hard dense sandstone or conglomerate with cemented gravel which form an unyielding surface for burrowing animals but may be an ideal habitat for surface growing animals such as tube worms (Serpulidae).

Another influential rock characteristic is bedding. Beds of rock are formed by the layering of sediment, one on top of the other when they were deposited in their original environment millions of years ago (Figure 3), The thickness of the layers and their lithology is controlled by a number of factors but primarily when and where they were deposited. For example, the Upper Jurassic Kimmeridge Clay was deposited in a shallow sea close to land, it has numerous layers of hard dolomite and soft mudstone which reflect the changes in climate, sea level and depths found in this shallow sea and the varying input of sediment from the nearby landmass. The numerous beds of hard dolomite and soft mudstone can be seen today on the sea bed in the Central English Channel Monocline where the sea has etched out long linear scarps and hollows in the folded hard and soft beds of Kimmeridge Clay. These scarps and hollows provide niche habitats for animals such as crabs and 'dead men's fingers' *(Alcyonium digitatum)*. Bedding of relatively hard and soft rock is also a characteristic of the Cretaceous Wealden and some of the Tertiary formations. Bedding is not a characteristic of





Figures *(top to bottom)*

46 Chalk cliff at Beachy Head

47 Chalk bedrock exposed at sea bed

48 Wealden rocks at Fairlight, Rye Bay

49 Wealden bedrock exposed at sea bed (scale bar 20 cm).

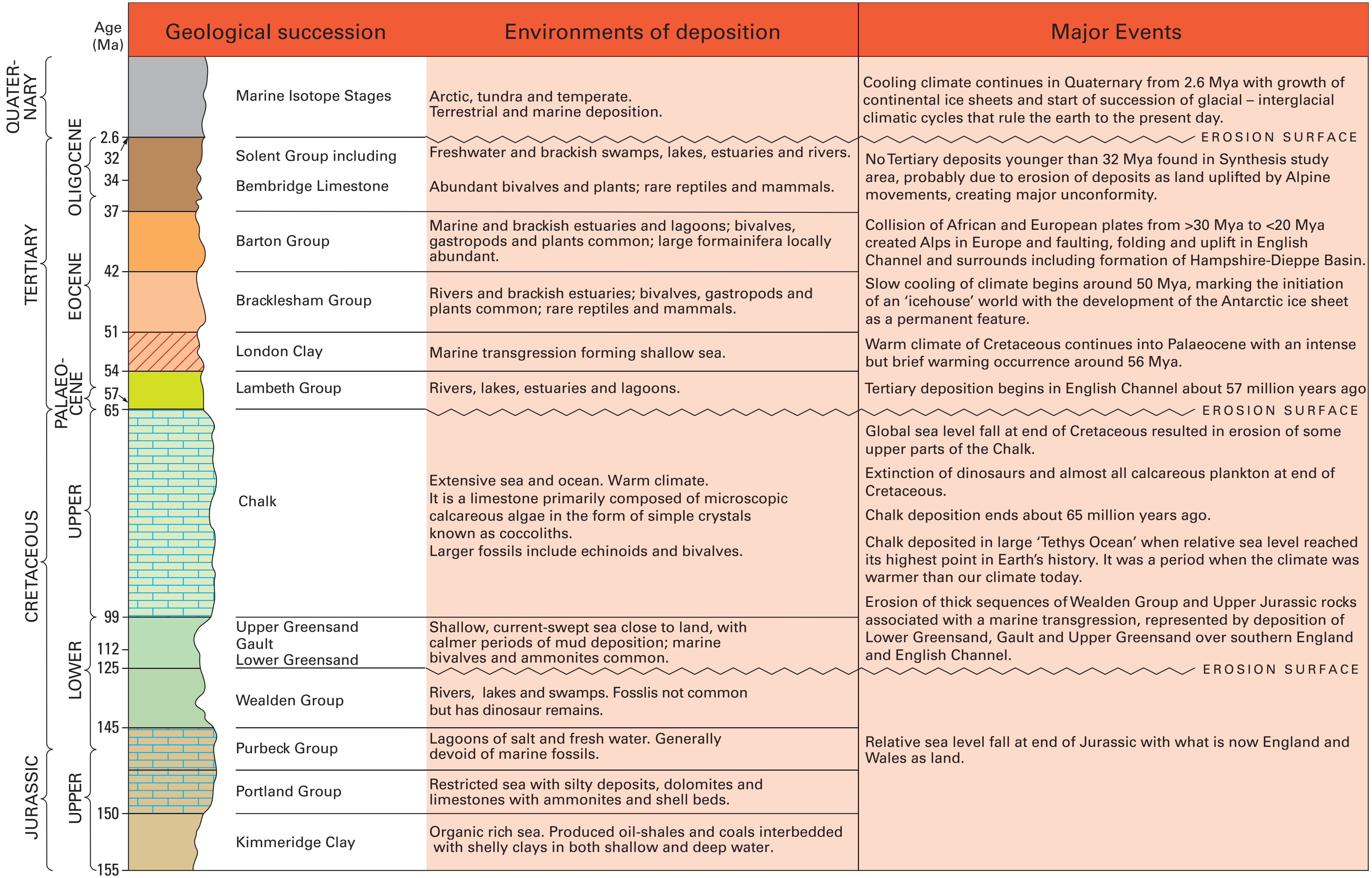
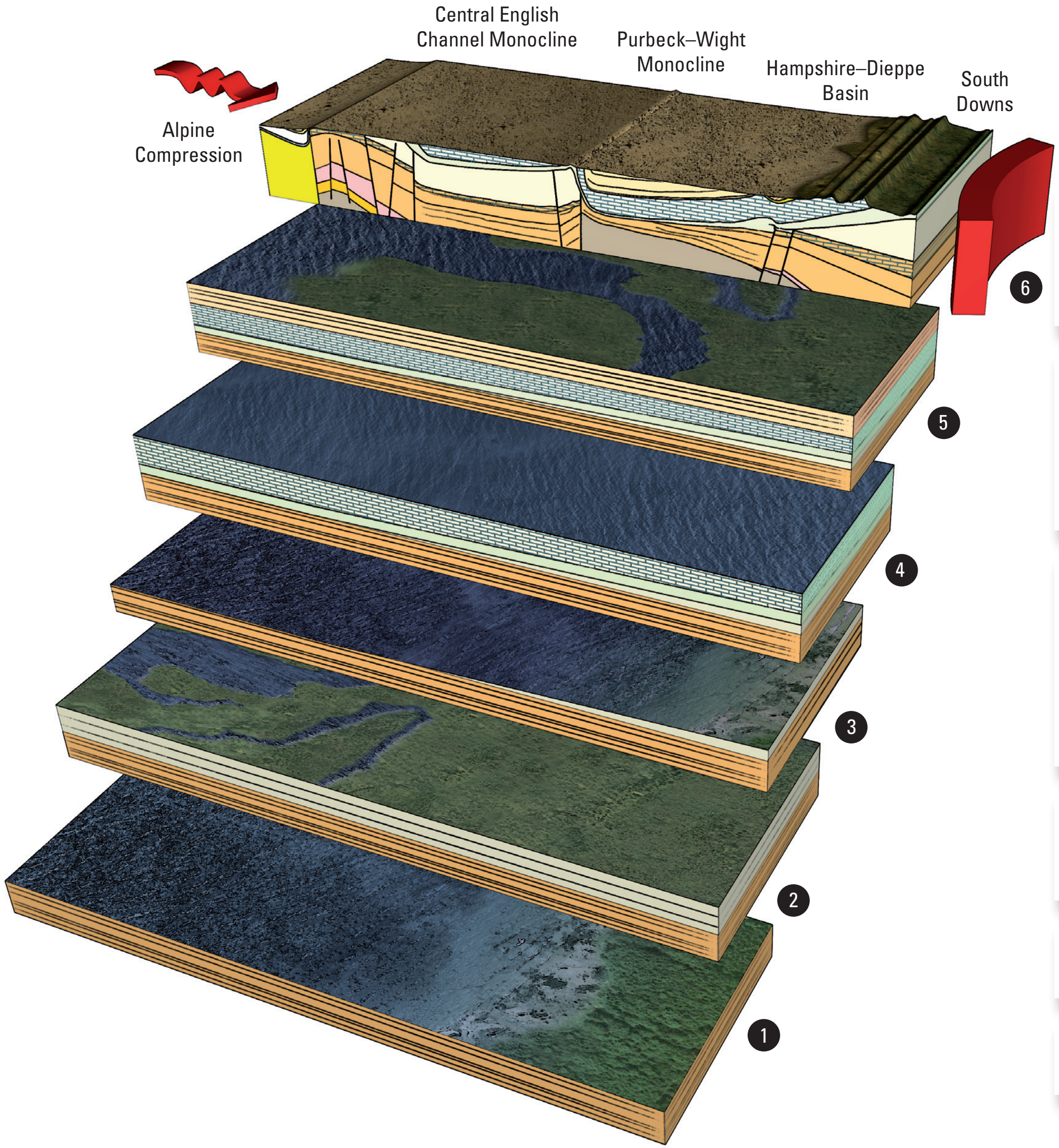


Figure 50 Geological timescale and stratigraphy with environments of deposition and major events.



6 ~20–30 million years ago
Collision of African and European plates creates mountains in Alps — effects felt in English Channel with rocks compressed and folded and forming structural features such as the Hampshire Dieppe Basin, Purbeck–Wight Monocline and Central English Channel Monocline.

5 32 to 57 million years ago
Tertiary sediments deposited in marginal coastal and marine environments, including shallow seas, estuaries, rivers and lakes.
Global sea level fall at end of Cretaceous resulted in erosion of some upper parts of Chalk creating a major unconformity at base of Tertiary deposits.

4 65 to 99 million years ago
Chalk deposited in extensive warm tropical sea, which may have covered whole of England and Wales.
99 to ~120 million years ago
Greensand and Gault formed in shallow seas and coastal environments associated with marine trangression.

3 ~125 million years ago
Sea level rise begins with marine transgression, and significant erosion of underlying Wealden and Upper Jurassic rocks creating a major unconformity.

2 125 to 145 million years ago
Wealden deposits formed in rivers, swamps and lakes.

1 145 to 155 million years ago
Upper Jurassic seas and lagoons. Sea level falls at end of Jurassic.

Figure 51 Simple chronology of solid geology development in synthesis study area.

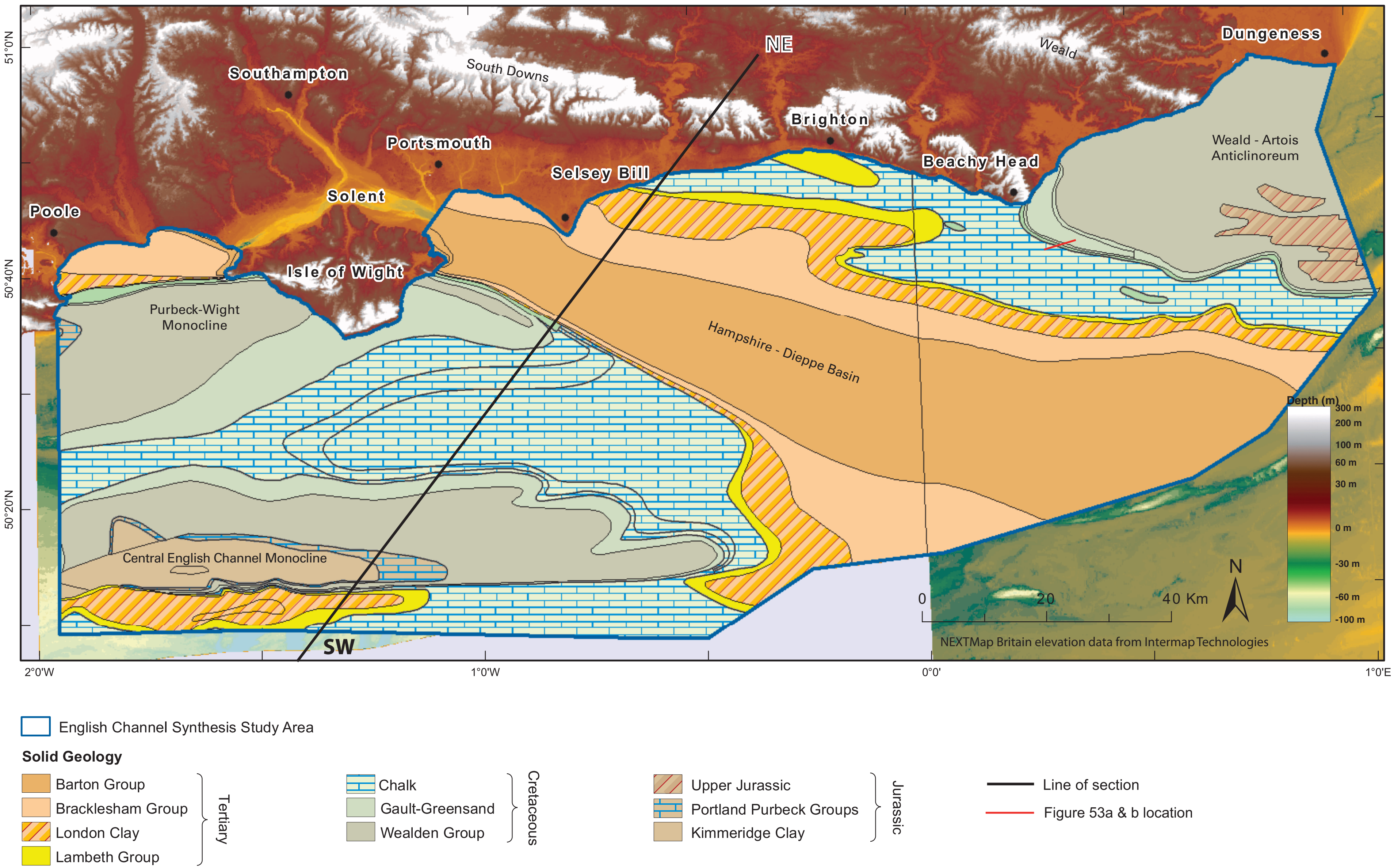


Figure 52a Solid geology © NERC (Solid geology only shown for synthesis study area. Onshore shows morphology).

Marine Aggregate Levy Sustainability Fund MALSF

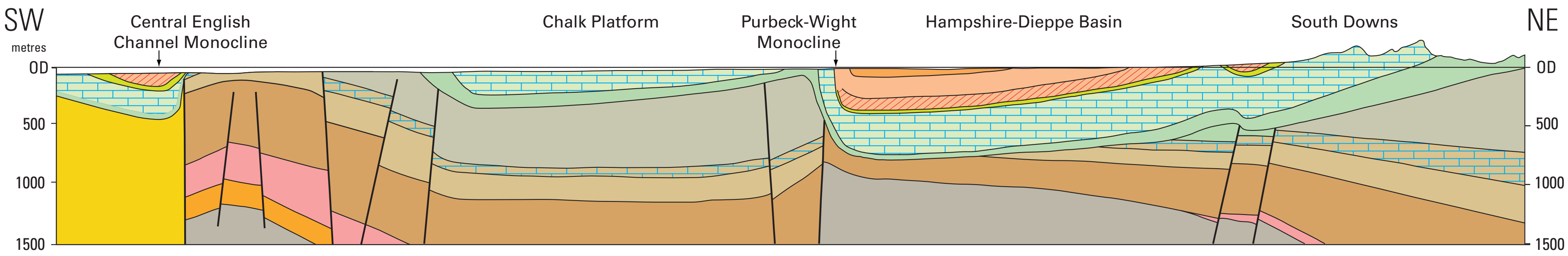


Figure 52b NE–SW schematic solid geology cross section © NERC.

the Cretaceous chalk. It was laid down primarily in a warm deep ocean, which was relatively undisturbed, and its source of sediment did not change greatly over time, allowing thick and massive deposits of chalk to be formed (Figure 46).

The solid geology rocks are formed of three principal sequences (Hamblin *et al*, 1992; BGS 1988 & 1995; Insole *et al.*, 1998; Hopson, 2009). The oldest are Upper Jurassic in age formed 155 Million years ago to ~145 My ago, and include the Kimmeridge Clay, Portland and Purbeck Groups. They are found at three distinct localities: firstly, a small area around Durlston Head south of Poole Bay which is at the eastern end of the World Heritage Jurassic Coast (www.jurassiccoast.com); secondly, associated with the distinctive folds and faults of the Central English Channel Monocline in the southwest of the study area; and thirdly, in the core of the Weald-Artois Anticlinoreum, another folded and faulted zone in the far east of the study area which extends across the English Channel to France.

The Upper Jurassic rocks are overlain by Cretaceous rocks, which includes the chalk, one of the most distinctive and famous rocks in the English Channel (Figure 46 & 47). Beneath the Chalk are the Greensand, Gault, and Wealden Group. These Cretaceous rocks dominate much of the south and west of the study area below the Isle of Wight, and also occur in the north along the Selsey–West Sussex Coastal Platform and then extensively off Beachy Head and further east in the Weald-Artois Anticlinoreum (Figure 48 & 49). Since their deposition 65 to 99 Mya these Cretaceous rocks have undergone structural uplift and folding, which have created east-west trending anticlines and synclines (Figure 51 and 52b). Some of these major structures have formed large distinctive morphological features on the sea bed including the Monocline Enclosure east of the Isle of Wight, the South Wight Platform and the Central English Channel Monocline and within these are numerous small morphological features like scarps and hollows which have been etched by erosion on the sea bed, mimicking the lines of the deeper folds and faults.

The third principal sequence is formed of rocks of Tertiary age, which lie uncomformably on the Cretaceous chalk. The unconformity represents a hiatus in time during which there was some uplift and erosion of the chalk prior to the deposition of the Lambeth Group sediments as a thin basal conglomerate when the first episode of Tertiary sedimentation began 57 Mya and subsequently overlain by grey and red muds. These were followed over a period of around 25 million years by the deposition of successive Tertiary formations including London Clay, Bracklesham, Barton and Solent Group, in shallow seas, estuaries, lagoons, swamps and rivers across what is now the English Channel and southern England. These Tertiary rocks predominantly comprise a mix of relatively thick sand, silt, and mud with some gravel, and subordinate occurrences of limestone and more esoteric rocks like lignite, which is a poor quality coal.

The Tertiary rocks are found within the NW–SE trending Hampshire-Dieppe Basin which runs from Poole and Christchurch Bay in the west across the northern half of the Isle of Wight and Selsey Bill then eastwards to cover most of the southeast quarter of the study area (Figure 52a). There is also a smaller occurrence of Tertiary rocks including London Clay on the southern limb of the Central English Channel Monocline.

The tectonic movements which created the Hampshire-Dieppe Basin began in the latest Cretaceous or earliest Tertiary and continued intermittently in the Eocene. These movements affected Tertiary sedimentation and the structure of the underlying Cretaceous and Jurassic rocks. These tectonic movements were associated with the compressional forces which were building the Alpine mountain chain on continental Europe; these came to a culmination in the Oligocene to early Miocene 20 Mya, possibly 10 million years after the deposition of the youngest Tertiary rocks in the study area (Figure 51). This Alpine event was significant in that it included the final formation of two monoclines, the Purbeck–Wight Monocline (also known as the Wight-Bray and Isle of Wight monocline) which runs across Poole Bay, Christchurch Bay, through the Isle of Wight and out eastward to beyond to the Northern Palaeovalley, and secondly, the Central English Channel Monocline.

Of the three principal solid geology sequences the Tertiary within the Hampshire Dieppe Basin has the most extensive cover of sediment and the least exposure as rock or rock and thin sediment at the sea bed. A consequence perhaps of the relative softness of the Tertiary rocks, compared to Cretaceous and Jurassic rocks and their preferential erosion by rivers in the English Channel during the Quaternary, and infilling with a cover of Quaternary sediment.

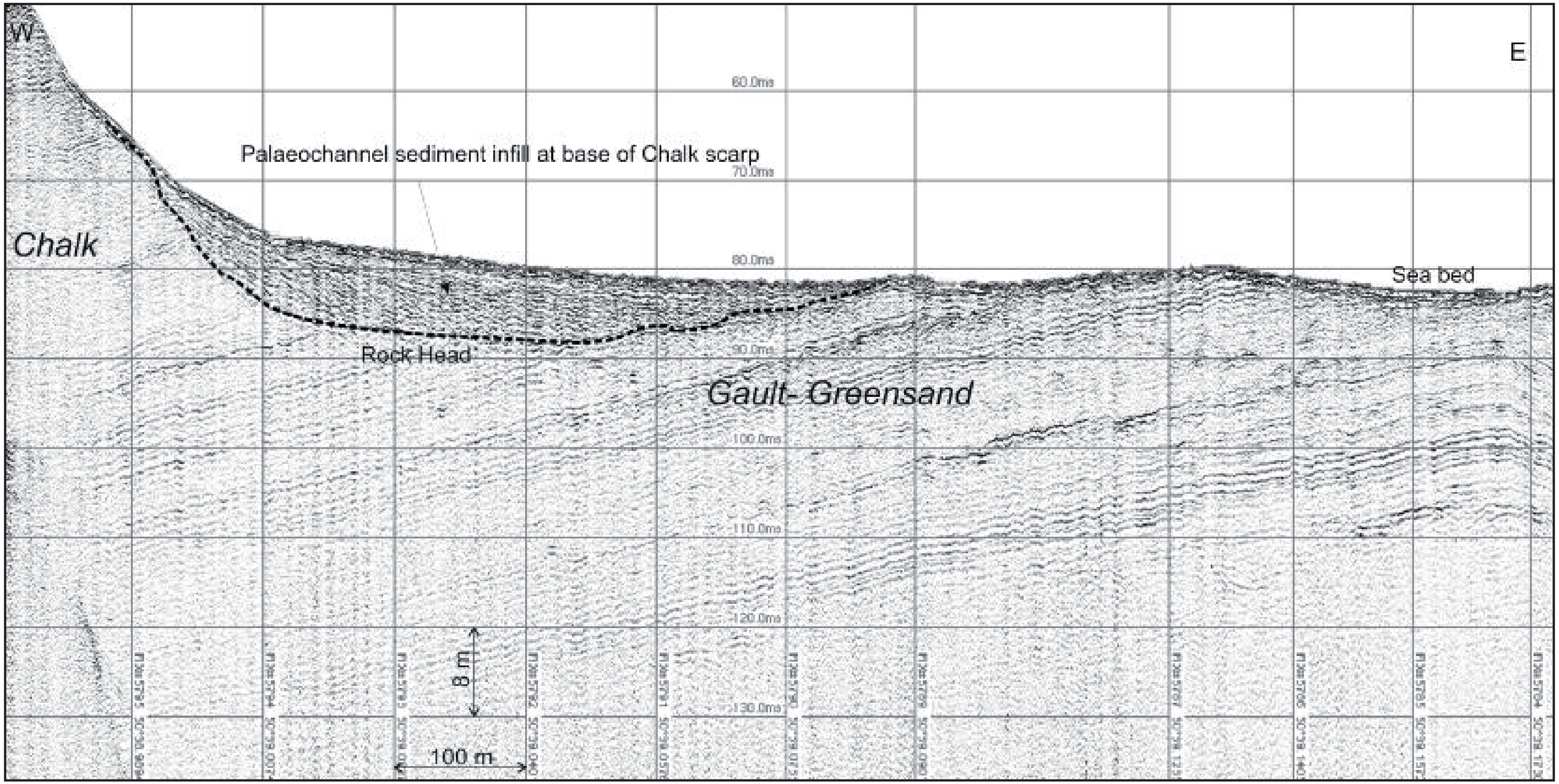


Figure 53a Boomer sub-bottom profile record showing a palaeochannel infilled with Quaternary sediment eroded into relatively soft Gault and Greensand rocks at the base of a cliff-like chalk scarp. (See Figure 52a for location.)

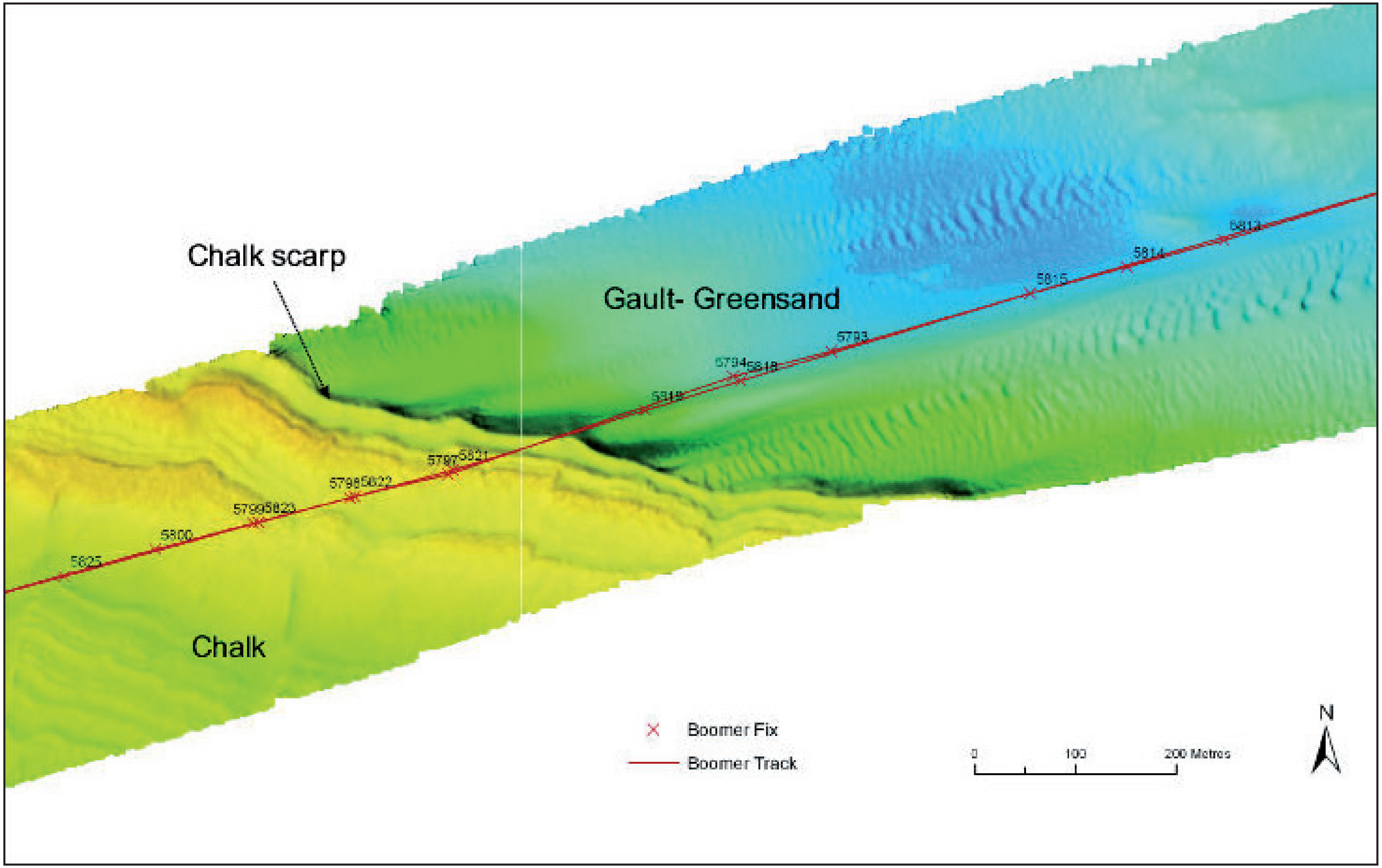


Figure 53b Multibeam record of sea bed showing the boundary between the chalk and Gault and Greensand rocks. The chalk scarp is up to 25 m high with numerous parallel scarps up to a metre high to the west. The main scarp is the offshore extension of the chalk which forms the cliff at Beachy Head. Parallel trains of sand waves and megaripples stream to the northeast away from the scarp. (See Figure 52a for location.)

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Quaternary sediment

The onset of the Quaternary Period around 2.6 Mya marks a point where the cooling of global climate, which began in the Tertiary, was intensified with the start of a succession of glacial — interglacial climatic cycles. Over 50 such cycles have been identified throughout the Quaternary (Figure 54), (Walker & Lowe, 2007). In 2011 we are experiencing an interglacial with its characteristic relatively warm global temperatures and high sea levels. These climate cycles are believed to be primarily driven by astronomical controls including variations in the Earth's orbit and axis, which changes the way the earth orbits the sun and in turn affect the length of the seasons during a year, and the amount of solar radiation received by the earth. These are known as Milankovitch cycles.

A significant change associated with these climate cycles is the variation in global sea level, with falls of over 100 m during glacial maximums, as water is locked up and frozen in polar ice caps and large continental ice sheets. Currently much of the sea bed of the English Channel is in water depths shallower than 100 m and means that most of the English Channel would have been land during the maximum of the last glacial around 21 000 years ago (MIS 2) with the coastline out in the Southwest Approaches. A land based English Channel area is likely to have been the case in previous glacials with sea level rising and falling with successive climate cycles.

Evidence in the synthesis study area

Paradoxically, even though we have an excellent history of climate cycles throughout the Quaternary from the oxygen isotope record based on sediment deposited in the deep oceans, the evidence of these cycles within the synthesis study area as deposits of Quaternary age sediment is probably restricted to the last 0.5 Ma, back to MIS 13 (Figure 54). The physical evidence is restricted to those areas where sediment is >1 m thick which only accounts for about 33.6% of the synthesis area i.e. under the areas of coarse, sandy and muddy sediment shown in Figure 66, with the thickest and best sequences preserved in channel systems (see pages 53–57) (Figure 56). Unfortunately we do not currently have any dates for when these thicker sequences were deposited which would enable us to compare the age of these deposits with the global oxygen isotope record.

So, why are relatively old Quaternary sediment poorly preserved in the synthesis study area? One of the main reasons is that each cycle of sea level rise and fall, tends to erode and recycle the deposits of each previous cycle, destroying the evidence from past cycles. It's like the annual cycle of harvesting and ploughing a field, it destroys each year's plant growth, not allowing it to decompose and form a layer in the soil as a record of the year's passing.

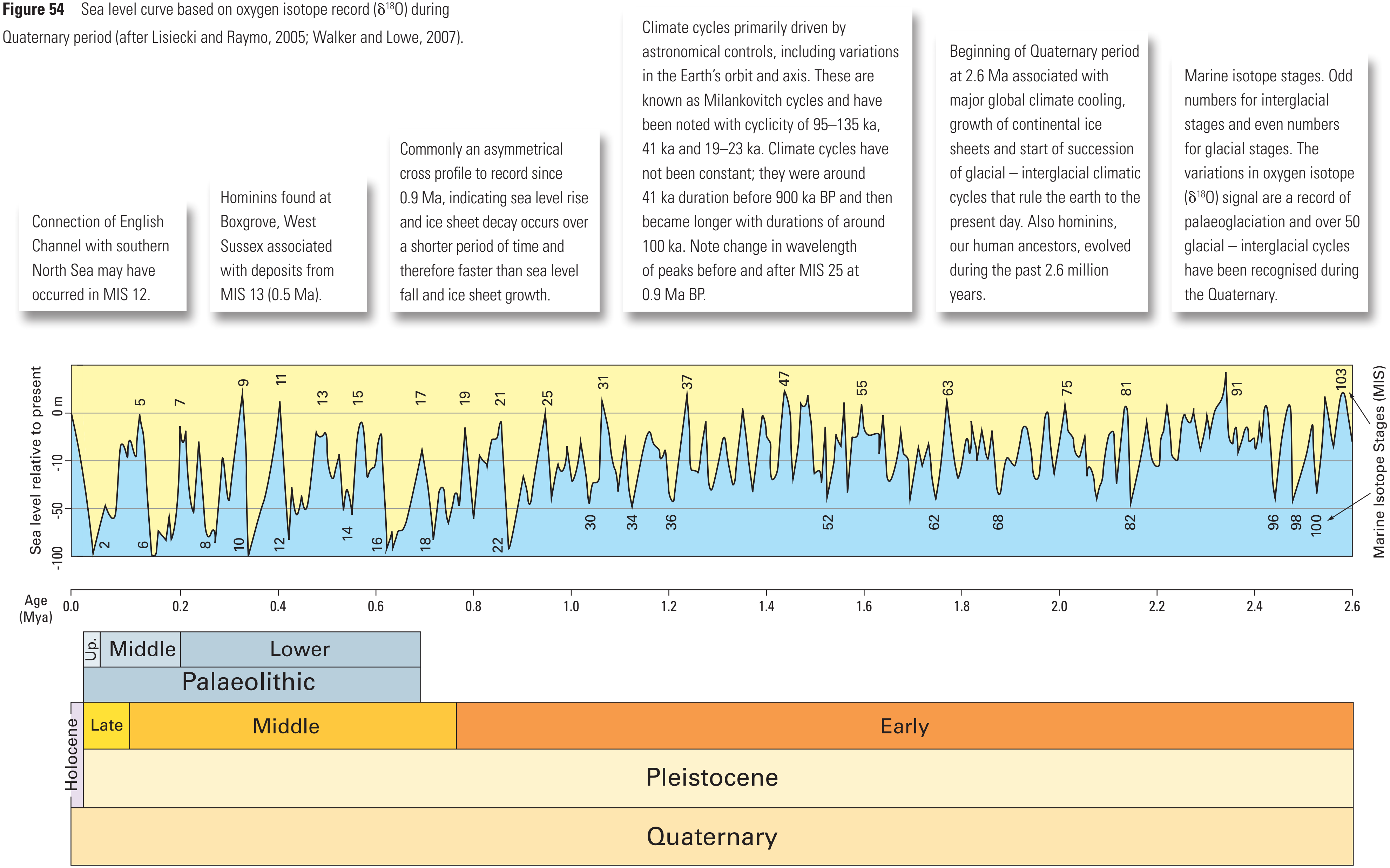
Glaciations are significant events and leave strong direct evidence of their passing, like moraines in East Anglia and U-shaped valleys in the Pennines. There is no evidence that ice sheets associated with the major glaciations that occurred in the British Isles have reached the English Channel. Certainly the ice sheets that crossed England in the glaciations since MIS 12 stopped north of the Thames (Figure 126).

This lack of preservation of older Quaternary sediment can also be traced back in to the Tertiary. No Tertiary rocks younger than 32 Mya are preserved in the synthesis study area. This is a very long period with missing physical evidence in terms of deposits of rock and sediment. During this long period, tectonic activity between 30 Mya and 20 Mya associated with Alpine mountain building (Figure 50 and 51) is estimated to have uplifted the landmass by about 1500 m (Simpson, *et al.,* 1989). Since then erosion has probably stripped off 1500 m of rock and sediment.

Uplift has been on going through the Quaternary, although not associated with Alpine tectonism. Westaway (2006) has calculated that the area has been uplifted by ~150 m since around 3.5 Mya. This uplift has enabled the preservation of terraces onshore particularly in the rivers north of the Solent and the oldest of these terraces has been modelled by Westaway (op cit) to around 1.2 Mya. Unfortunately there is no evidence for Quaternary sediments in the synthesis study area which can be correlated with these onshore terrace deposits.

The other principal Quaternary deposits that are preserved onshore are marine raised beach deposits, of which there are at least four within the West Sussex Coastal Plain (Figure 125) (Bates *et al.,* 1997; 2000; 2010; Briant *et al.,* 2009). These onshore terraces and marine deposits have provided a considerable wealth of archaeological material and evidence of human occupation. These are described further in pages 120–132.

Figure 54 Sea level curve based on oxygen isotope record ($\delta^{18}O$) during Quaternary period (after Lisiecki and Raymo, 2005; Walker and Lowe, 2007).



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Channel systems

The thickest and most extensive deposits of Quaternary sediment in the study area lie within a series of channels, which have been eroded into the underlying bedrock of solid geology. The channels are part of an extensive channel system within the eastern English Channel (Figure 56), which have been cut by rivers flowing across the floor of the English Channel during periods of low sea level in glacial cycles during the Quaternary (Figure 54). The south flowing channels in the north of the synthesis study area have sources in English rivers, but these are only tributaries to the large east-west flowing channel systems in the rest of the Channel floor, which can be traced to continental European sources, particularly French rivers such as the Somme and Seine and other European rivers such as the Rhine through the Dover Strait and southern North Sea (Figure 56).

There are two principal forms of channel in the synthesis study area (Figure 55a and b).

- Infilled channels with significant deposits of sediment. These can be single infilled channels surrounded by rock substrate, or a series of infilled channels connected by sediment over their margins as terraces or sheets of sediment
- Open channels with little or no sediment infill

The infilled channels are best developed in two areas.

The first are associated with rivers that have flown off the English landmass. These include some very minor channels running south from Poole and Christchurch Bay (Velegrakis *et al*., 1999), but more significant are the Solent and Palaeosolent (Dyer, 1975), and the

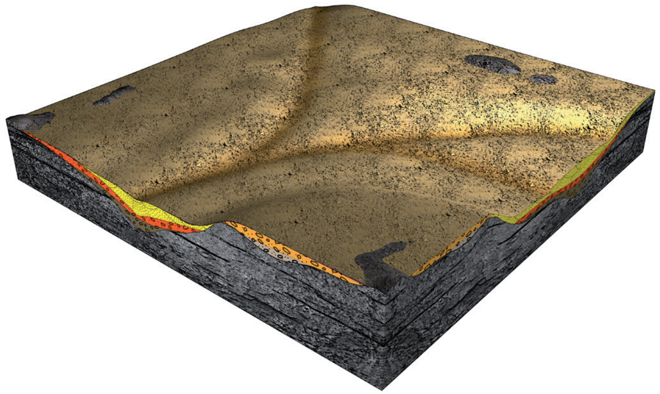

Figure 55a Infilled channel.

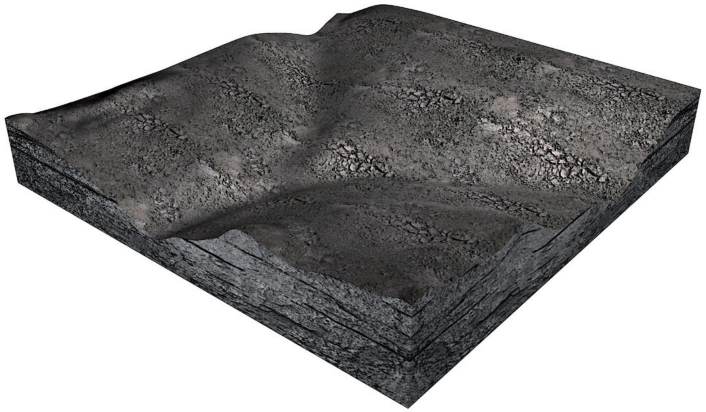

Figure 55b Open channel.

Arun/Palaeoarun (Bellamy, 1995; Gupta *et al*, 2004) (Figure 74) which crosses the Selsey–West Sussex coastal platform (Figure 44b). Apart from the Solent, north of the Isle of Wight, these channels are relatively narrow and generally isolated within a surrounding rock based sea bed. The catchments of these rivers are relatively short and also have limited tributaries. The east-west structural grain of the landscape onshore with high ground such as the South Downs and Weald (Figure 44a & b) has blocked the development of long north-south flowing rivers on the scale of the Thames, Trent or Severn flowing in to the English Channel. These south flowing English based river systems have not left extensive areas of channel filled sediment across the study area, although their deposits are significant enough to have been exploited for marine aggregate east and west of the Isle of Wight and at the Owers (Figure 12 & 13).

The directions in which these English based rivers have flowed have been considerably affected by the structure of the underlying solid geology. The rivers that now flow into Poole and Christchurch Bays originally flowed west to east through the Solent (Velegrakis *et al*, 1999) parallel to the west-east chalk outcrop, which formed a barrier to the south. Intriguingly to the east of the Isle of Wight the course of the Palaeosolent river turns through 90 degrees across the line of the chalk outcrop at the sea bed and heads south across the Monocline Enclosure directly towards the Northern Palaeovalley. Why this turn when it should have been easier to continue parallel to the line of the chalk on the north side of the Monocline Enclosure? A possible explanation lies in the fact that hundreds of metres of Tertiary rocks

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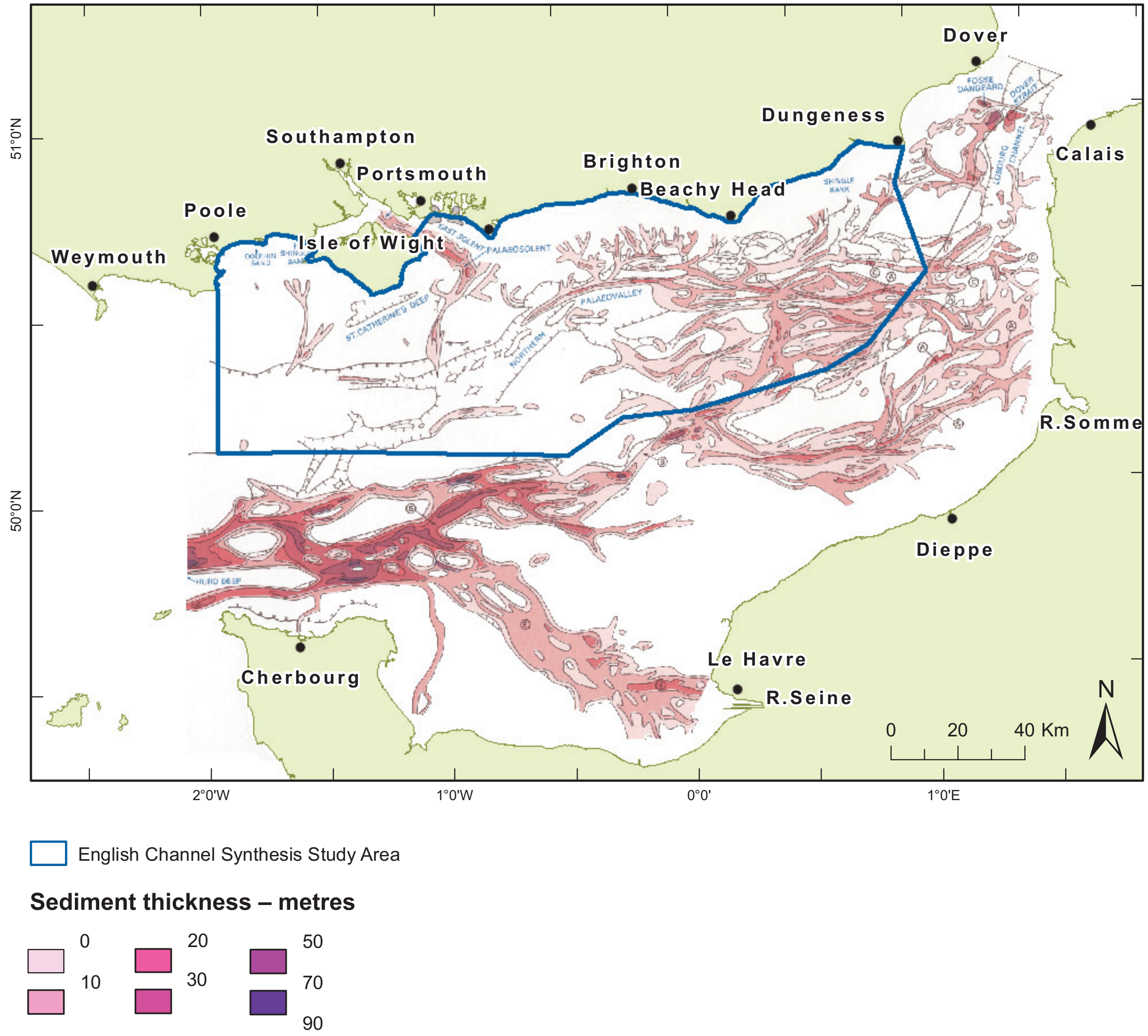


Figure 56 Channel systems and palaeovalleys in the central and eastern English Channel © NERC (From Hamblin et al, 1992).

once covered the whole English Channel. Rivers would have flowed across these Tertiary rocks and eroded down until they eventually reached the chalk, but continued to follow the courses they began in the Tertiary taking no account of the underlying chalk based structure. Another explanation is that the Palaeosolent exploited a weakness in the chalk at this point in the monocline, possibly a fault or relatively softer rock and preferentially eroded through the weakness. The course of the Palaeoarun on the Selsey – West Sussex Platform is similarly structurally controlled in its southern half. Just before it enters the Northern Palaeovalley through a narrow gorge its course is diverted eastwards by the dip slope of tilted Tertiary rock.

The second and most significant area comprises a series of infilled channels beneath the Central Axial Platform in the southeast of the synthesis study area (Figure 74). These channels are part of the major east-west flowing system in the centre of the English Channel with river sources from the east and southeast. They can include sediment over 25 m thick but are covered by a sheet of coarse and sandy sediment so that each individual channel is poorly seen at the sea bed. They are best identified and traced using boomer sub-bottom profiler data (James *et al*, 2007).

This boomer data seems to indicate that the main channels beneath the Central Axial Platform flowed to the southwest and not into the Northern Palaeovalley as implied in Figure 56, which shows the channel system having a significant extension into the Northern Palaeovalley. Figure 57 is an example of a boomer profile across a section of one of the main channels indicating how the palaeochannels have been filled by successive phases of sediment deposition and some erosion where sediment has been cut out before being covered by new sediment. The profile is a typical example of a section of sediment filled river channel in this area.

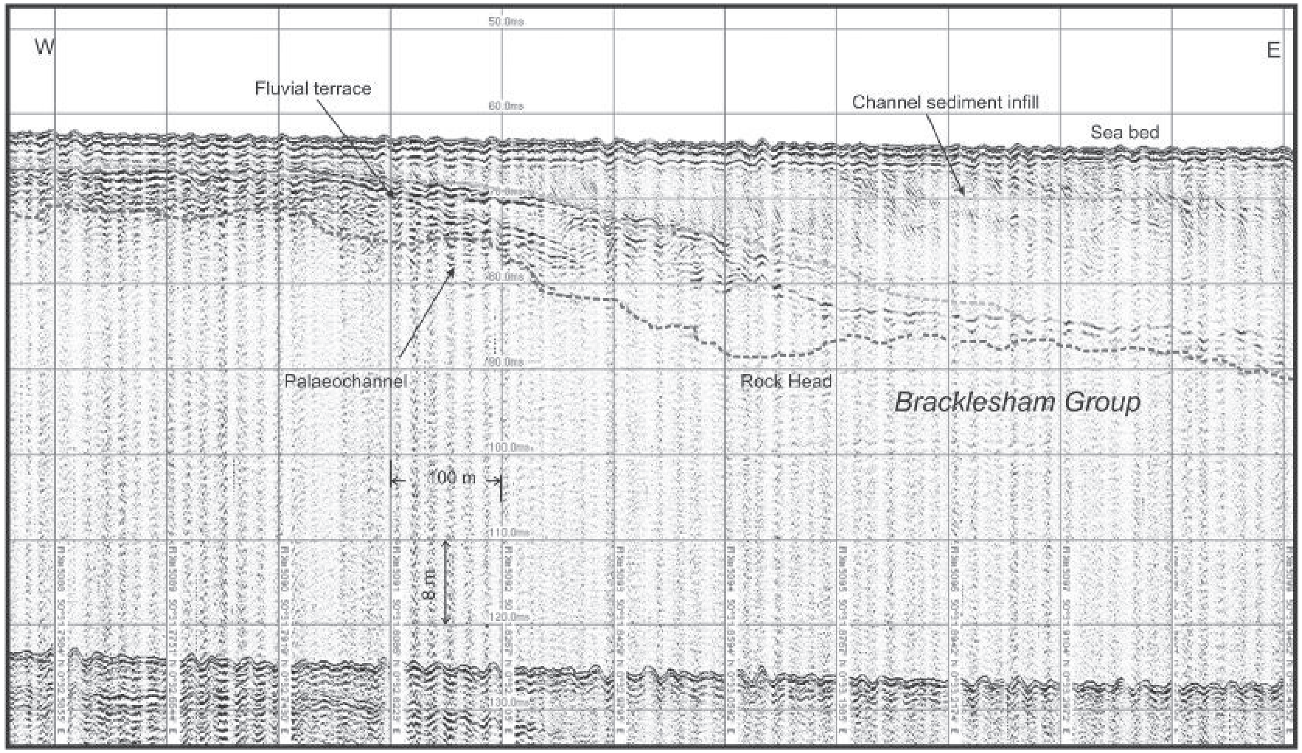


Figure 57 Boomer profile across infilled channel.

When the location of these channels beneath the Central Axial Platform are compared with the solid geology of the synthesis study area (Figure 52a) it's apparent they are mainly located on Tertiary rocks within the line of the Hampshire-Dieppe Basin. They appear to have cut down preferentially into the relatively softer Tertiary clay, mud and sand rather than the harder chalk of the Western Axial Platform, and Jurassic rocks in the core of the Weald-Artois Anticlinoreum to the east.

Although these infilled channels are distinctive features they are eclipsed, certainly as visibly distinctive sea bed features by the open channel system of the Northern Palaeovalley (Figure 44a, 44b & 58). It is not only a significant physical feature in the synthesis study area, but it's scale makes it one of the most significant features in the English Channel.

The Northern Palaeovalley has a particularly well-defined margin on its northern side and an upper break of slope at a depth of 25 to 30 m with the valley floor generally at depths of 55 to 75 m. The total length of the Palaeovalley is around 160 km. Its eastern half is relatively wide, from 16 to 20 km compared to the western half, which varies in width from 8 to 16 km. There is a distinct narrowing of the valley between these two halves at an 8 km wide pinch point, which marks the location where the steeply dipping Purbeck-Wight monocline trends NW–SE across the Palaeovalley. The monocline forms the boundary between relatively soft Tertiary rocks to the east and more resistant Cretaceous chalk to the west. Hence the wider Palaeovalley to the east in less resistant Tertiary rocks and the funnelling of the valley through the pinch point at the monocline. Underlying rock structures have also controlled the line of the northern margin of the Palaeovalley in its eastern half, with the southern limb of a relatively steeply dipping E–W trending anticline forming a natural barrier to the northward migration of the Palaeovalley.

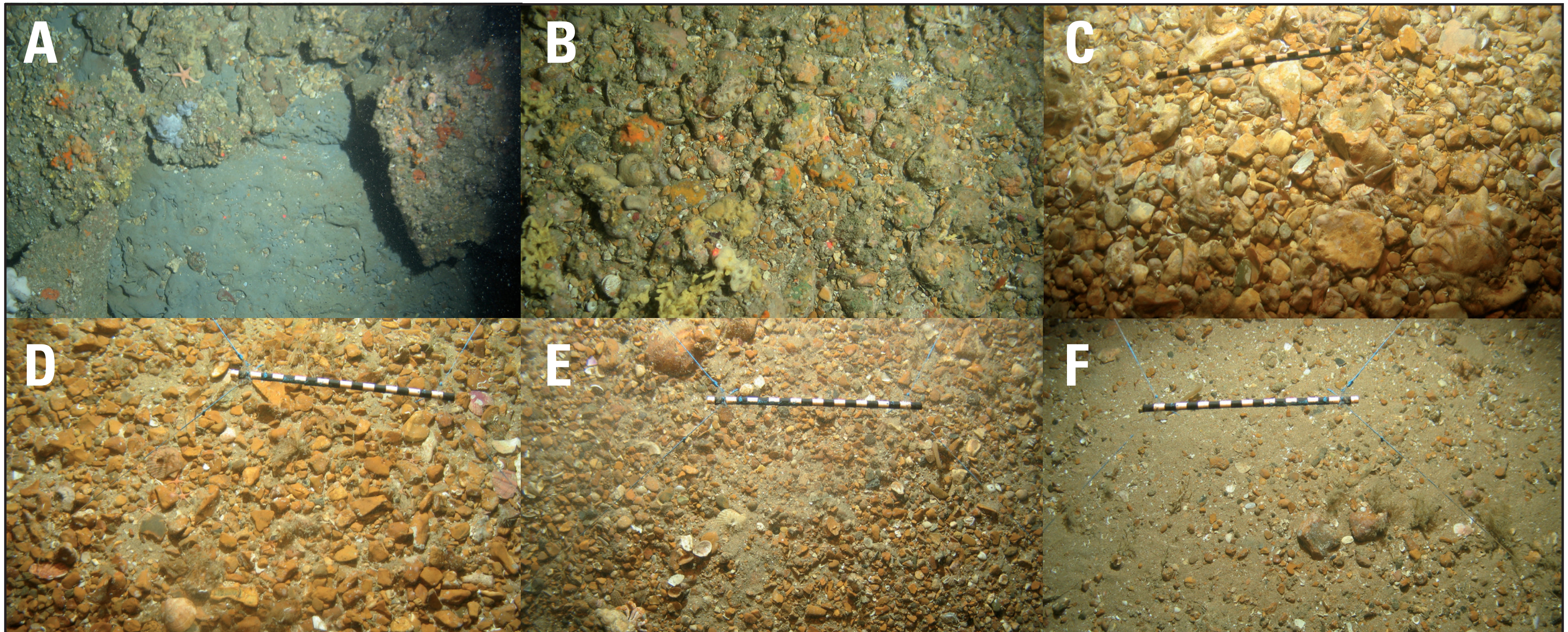
In the west the Palaeovalley floor is characterised by well-developed channels, some of which are incised in the narrows between bars. The Palaeovalley has acted as a conduit for the eastward migration of sand associated with net sediment transport in an easterly direction. The floor is sandy gravel, which is relatively well sorted but becomes progressively sandier to the east and eventually becomes dominantly gravelly sand with megaripples and some isolated sand waves. However, much of the floor, particularly in the west, is underlain by rock or rock with only a thin layer of sediment above (see box page 56).

The bars in the Palaeovalley floor have relatively steep sides generally 10 m high, some up to 20 m high. These can be up to 10 km long and from 0.8 to ~ 2 km wide. The limited seismic profiler evidence suggests that these bars are cored with rock and that any sediment cover is a thin veneer.

A terrace feature runs along the northern margin of the Palaeovalley for about 25 km west of the monocline pinch point. At its widest point its extent is about 4.5 km and thins out at its northern and southern limits. The surface of the terrace is marked by a significant number of meandering channels up to 300 m wide and incised to depths of up to 4.5 m. These flow over the front of the terrace and feed into the main Palaeovalley channel. The form of this terrace and the rock cored bars within the main channel suggest that the Palaeovalley has undergone at least two major phases of erosion and incision within this area with the possibility of a significant hiatus between the two phases.

The sea bed has numerous tributary open channel systems which can be seen on the sea bed morphology model (Figures 44a & 44b) but the most significant is the Northern Palaeovalley.

The English Channel has only been open to the North Sea since the Anglian Glaciation (MIS 12) (Hamblin *et al*, 1992; Gibbard, 1988, 1995; Toucanne *et al.*, 2009). Prior to MIS 12 it would have been a large embayment during high interglacial sea levels with a very different oceanographic and marine environment to the post MIS 12 interglacials which are likely to be more erosive and less depositional in the study area, similar to the present day. Further work is required to piece together the timing of the cutting and infilling of the channel systems. It is obvious that it is a complex picture involving a number of glacial/interglacial cycles with rivers eroding these channels and depositing sediment within them. An alternative theory has been put forward by Smith (1985) and Gupta et al (2007) that some, if not all of these channel systems, are associated with a catastrophic outburst of ponded water from the North Sea through a breach in the Dover Strait.



Sea bed images **A-F** cover a 100 km long west-east stretch of the floor of the Northern Palaeovalley from the rocky Central English Channel Monocline (**A+B**) to sands (**F**) near the Northern Palaeovalley Banks (Figure 44b). **A** shows grey mudstone, probably London Clay, with animal borings in its surface, overlain by broken blocks of a cemented 'concrete like' sediment skin. **B** has a cemented, immobile surface of pebbles, possibly forming a 'concrete like' skin on rock?. **A** and **B** are in water depths of 70 to 90 m. **C** and **D** are located near the pinch point (Figure 58) and indicate the channel floor has changed eastwards to cleaner, uncemented cobbles and pebbles. This cleaner and relatively mobile sea bed sediment becomes gradually finer to the east with well sorted pebbles in **E** and sandier sediment in **F**. **A** to **F** are in water depths of 50 to 65 m. (Scale bar - 20 cm. **A/B** ~40 cm across).

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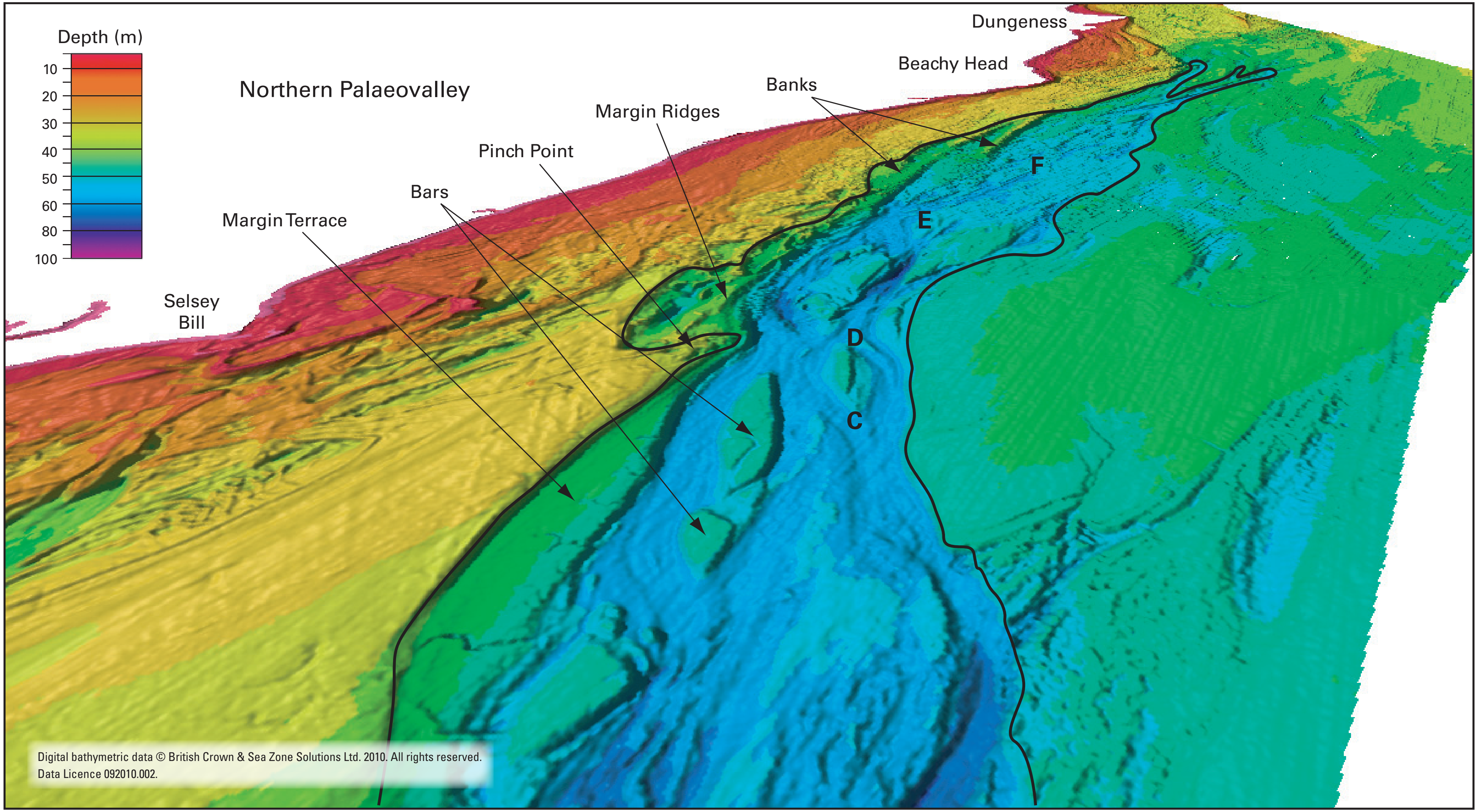

Figure 58 Northern Palaeovalley morphology oblique view to the east (C to F - sea bed image locations - see box on page 56).

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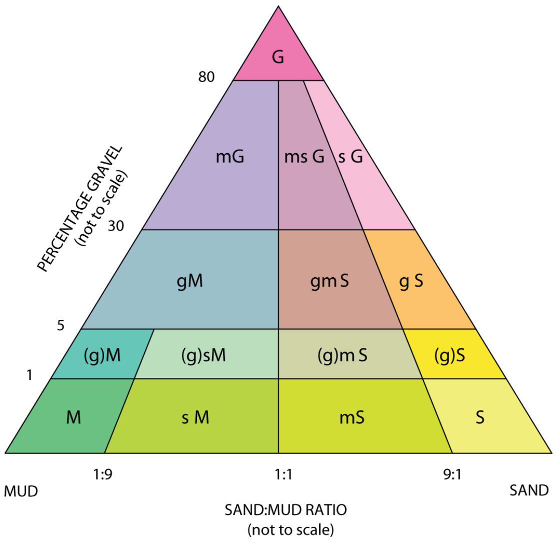
Sea bed sediment



M .... Mud
sM .... Sandy mud
(g)M .... Slightly gravelly mud
(g)sM .... Slightly gravelly sandy mud
gM .... Gravelly mud
S .... Sand
mS .... Muddy sand
(g)S .... Slightly gravelly sand
(g)mS .... Slightly gravelly muddy sand
gmS .... Gravelly muddy sand
gS .... Gravelly sand
G .... Gravel
mG .... Muddy gravel
msG .... Muddy sandy gravel
sG .... Sandy gravel

English Channel Synthesis Study Area

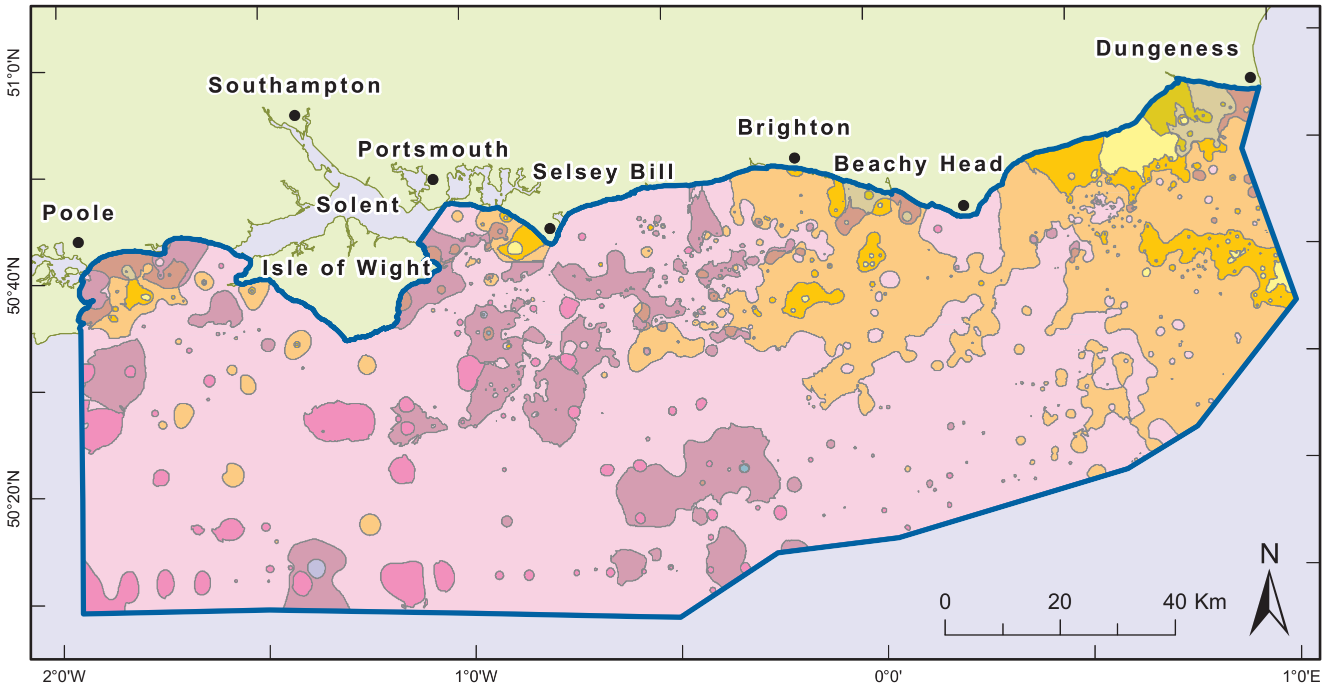


Figure 59 Modelled distribution of sea bed sediment based on Folk classification system (Folk, 1954).

Modelled Folk sediment distribution

The distribution of sea bed sediments across the synthesis study area shown in Figure 59 is a computer generated model based on the Folk classification system (Folk, 1954) where each sample has been classified by grain size using the relative proportions of gravel, sand and mud. The particle size analysis (PSA) of 2 363 grab samples was used in the model (Figure 42).

The modelled Folk sediment distribution covers the whole synthesis study area. However, it should be noted that virtually no account is taken in the sea bed sediment model of evidence from multibeam, sidescan, sub-bottom or sea bed photography data. For example, outcrops of rock are not shown in the model. It is therefore important that the modelled sea bed sediment map is read in conjunction with the sea bed character interpretation (Figure 66), bedforms (Figure 72), sediment parameters

(Figure 60–61) and the biotope model (Figure 81). All are complementary and together provide a comprehensive understanding of the sedimentary character of the sea bed.

Across the synthesis study area the main features of the model are a western half dominated by the coarse members of the Folk system particularly sandy gravel with muddy sandy gravel and some gravel. The only significant areas with sandy sediments such as gravelly sand and slightly gravelly sand in this western half are within bays west of Selsey Bill and west of the Isle of Wight. In the latter the sandy sediments are associated with sand banks at Dolphin Bank, Dolphin Sand and Hook Sand (Figure 72).

Although sandy gravel extends in to the eastern half of the study area it is mainly confined to the southern segment and eventually peters out to gravelly sand, which is the dominant sediment type in the Greater Bassurelle Sands in the east. Sands are found on and around the Bassurelle Sand Bank in the far southeast and also close to the coast near Dungeness where it is associated with some muddy sands.

The extensive areas of rock and thin sediment seen in the sea bed character interpretation (Figure 66) are associated with the coarser end members of sandy gravel, muddy sandy gravel and gravel in the west. However, in the east beyond the Greater Bassurelle Sands where rock and thin sediment is exposed, the occurrences of thin sediment are dominated by sandy sediment.

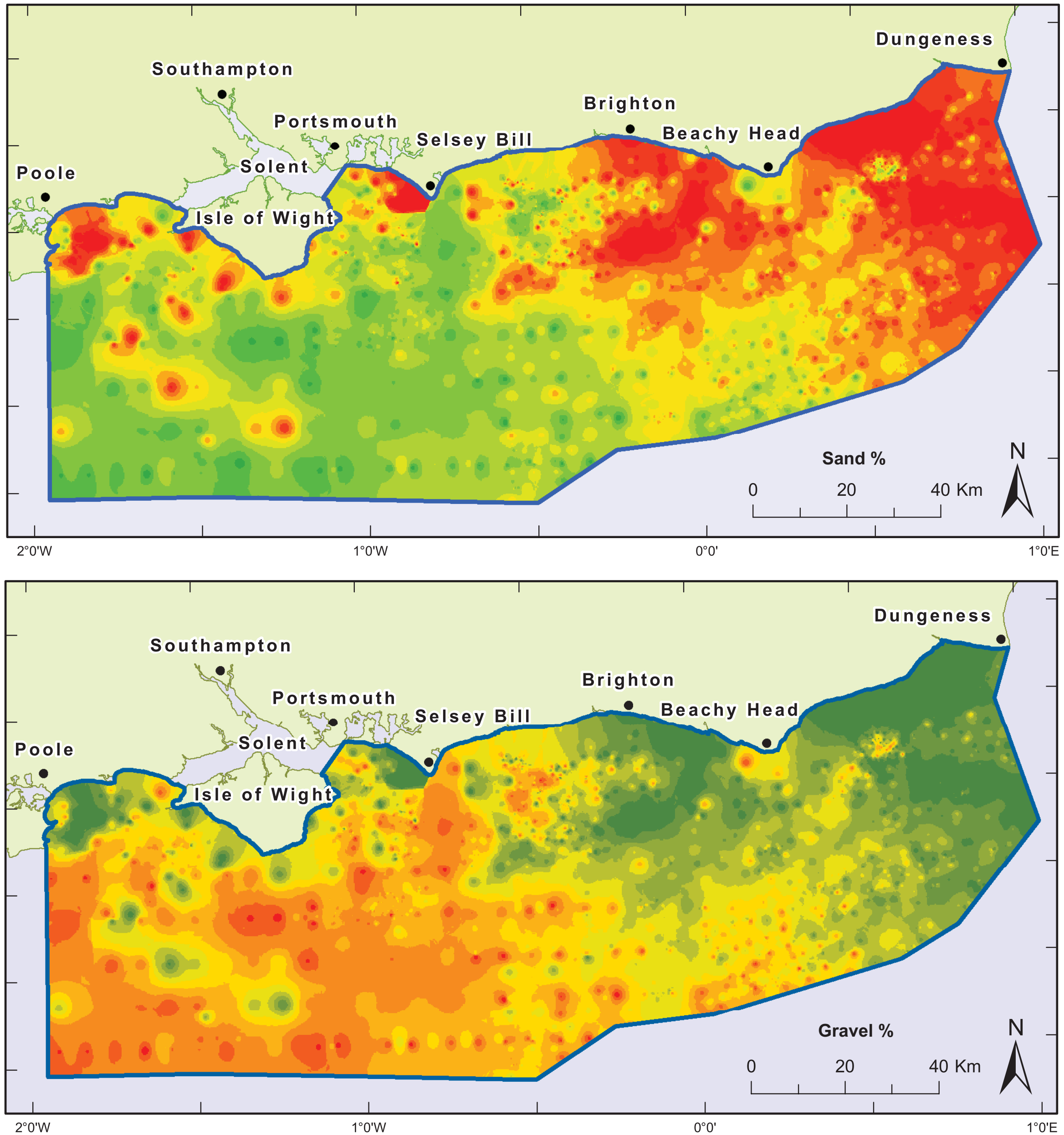


Figure 60 Modelled distributions of sand (top) and gravel (bottom).

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Modelled gravel, sand and mud distribution

The PSA data in the 2363 samples has also provided statistics on the percentage of sand, gravel and mud in each sample. These percentages have been modelled for each sediment type and the results are shown in Figure 60 and 61. Apart from the higher percentages of sand in the bays west and east of the Isle of Wight, the western half of the synthesis study area has >50% gravel with most of the eastern half having >50% sand. The models show an eastward trend of decreasing grain size across the study area reflected in the decreasing gravel percentage and increasing sand percentage.

The eastward fining and sorting trend reflect the strong currents moving sediment away from the area of relatively high sea bed stress south of the Isle of Wight (Figure 8) and the poorer sorting of sediment in this area south of the Isle of Wight with a winnowed sea bed surface of pebbles, cobbles, boulders and rock (see West–east changes section pages 105–106).

The percentage of mud found in grab samples over much of the study area is <5% (Figure 61), however there are patches where mud is >10%, with a maximum recorded value of 60%. The muddy patches are most extensive in inner Poole Bay, inner Christchurch Bay, nearshore off the east and northeast of the Isle of Wight, east of Brighton and in Rye Bay west of Dungeness.

Some of these occurrences are likely to be due to sheltered areas in bays and behind headlands where mud can settle on the sea bed. However, some occurrences are on rock outcrop and thin sediment underlain by London Clay, Bracklesham Group, Barton Group and Wealden Group clays and silts, many of these rocks have a muddy component which could be sampled by a grab. A number of patches of >25% mud may be the product of dredged material dumped in disposal sites (Figure 16) such as the Nab Tower, Rye Bay and Needles.

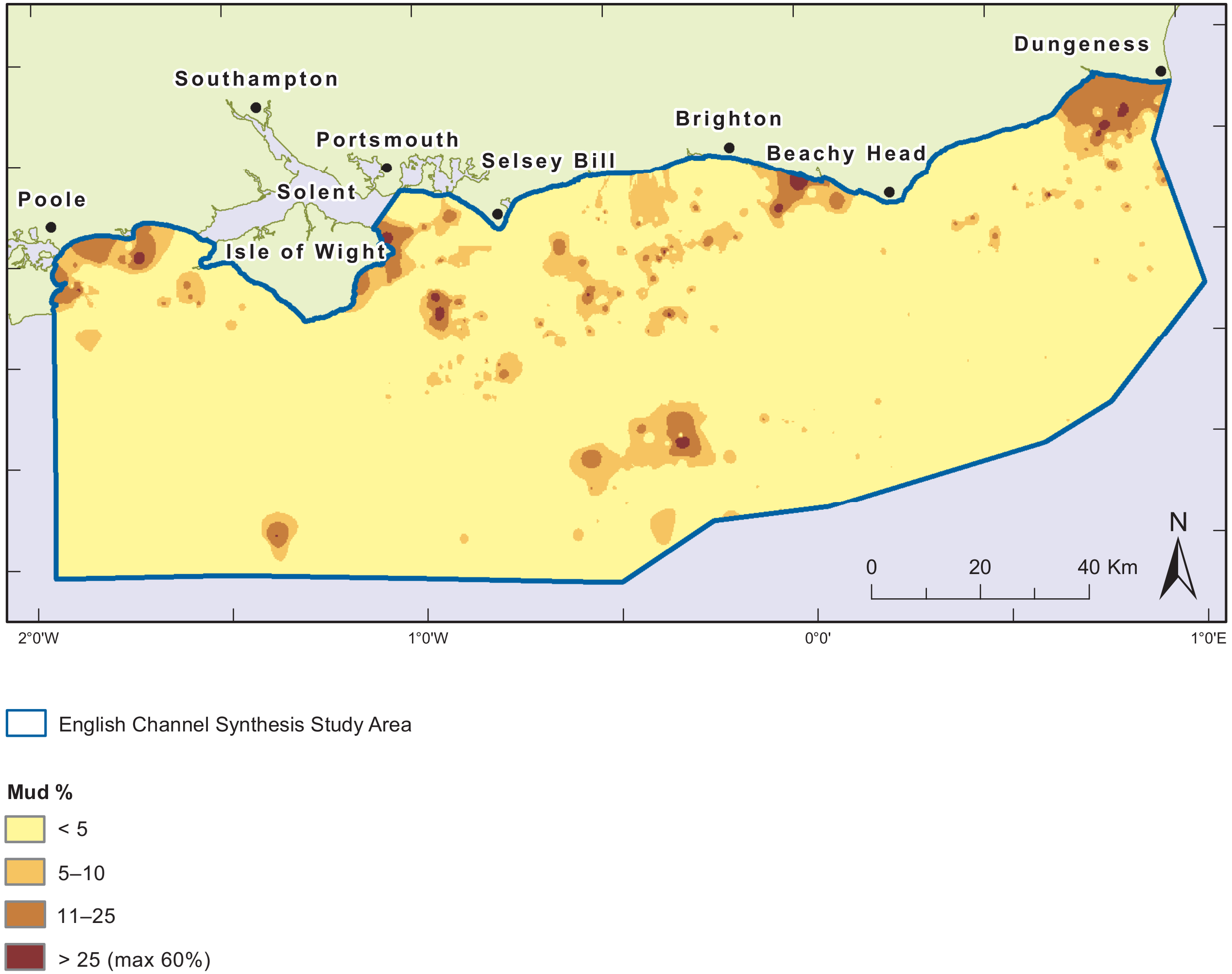

Figure 61 Modelled distribution of mud.

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Sea bed character

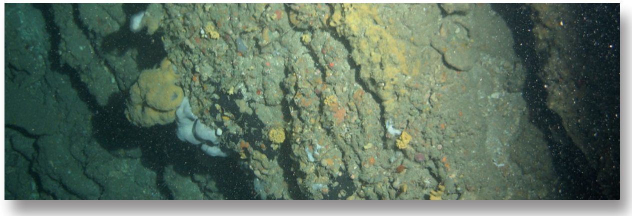
The present character of the sea bed is the result of both ancient and modern events and processes. The ancient are those that happened before 10 000 years ago and their drivers are on a global or continental scale. They include those major events and processes that controlled and produced the nature and form of the substrate that occurs at and beneath the sea bed.

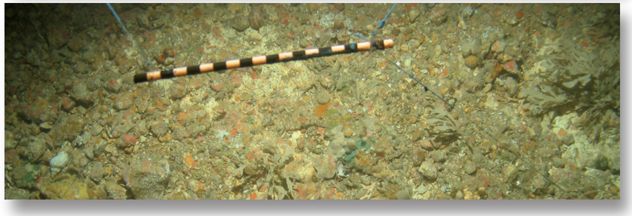
The most significant ancient events and processes are:-

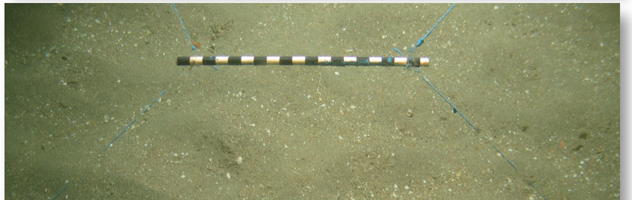
- Glacial and interglacial cycles during the 2.6 million years of the Quaternary Period (Figure 54) that eroded channel systems in the study area, which are now either open or infilled with thick sediment (see pages 53–57). These cycles also produced repeated marine transgressions (sea level rise) and regressions (sea level fall) across the English Channel, which cumulatively have gradually planed down the sea bed surface compared to the adjacent upstanding and undulating landmass of southern England (Fugyre 44a & 44b)
- Folding and faulting of older Upper Jurassic to Tertiary rocks producing strong morphological linear features (Figure 50 & 51), such as scarps and depressions which are etched on the sea bed surface by the different erosion rates of hard and soft rocks.

Modern events and processes include:-

- The marine transgression which swept eastwards across the English Channel as sea level rose from depths >100 m after the last glacial maximum 21 000 years ago, eroding, reworking and transporting sediment along its path.
- Marine tides and currents over the last 5000 years since sea level attained its modern day level. The impact of tides and currents during this period has been significant in terms of erosion, transport and deposition of sediment and the fashioning of sand bedforms, lag gravel and swept rock outcrop. Their influence continues in the present day.







Figures ***(top to bottom)***

62 Rock at sea bed.

63 Rock and thin sediment at sea bed.

64 Coarse sediment at sea bed.

65 Sandy sediment at sea bed.

The sea bed has been mapped (Figure 66) with a five-fold classification of sea bed character:-

- Muddy sediment
- Sandy sediment
- Coarse sediment
- Rock and thin sediment
- Rock

The interpretation of sea bed character (SBC) is primarily based on an integrated analysis of data provided by the sea bed morphology model, roughness model, multibeam, sidescan sonar, boomer sub bottom profiler, sediment sampling, video and still photo imagery.

The sea bed character interpretation has also been completed in conjunction with the modelled sea bed sediment map (Figure 59). Both interpretations are complementary and should be read in tandem to gain a fuller understanding of the character of the sea bed. For example, the coarse sediment classification in the SBC interpretation primarily includes Folk sediment categories with >30% gravel (Figure 64) and the sandy sediment classification primarily includes Folk sediment categories with >70% sand (Figure 65). A fuller explanation of the sea bed character interpretation methodology can be found in James *et al* 2007 and 2010.

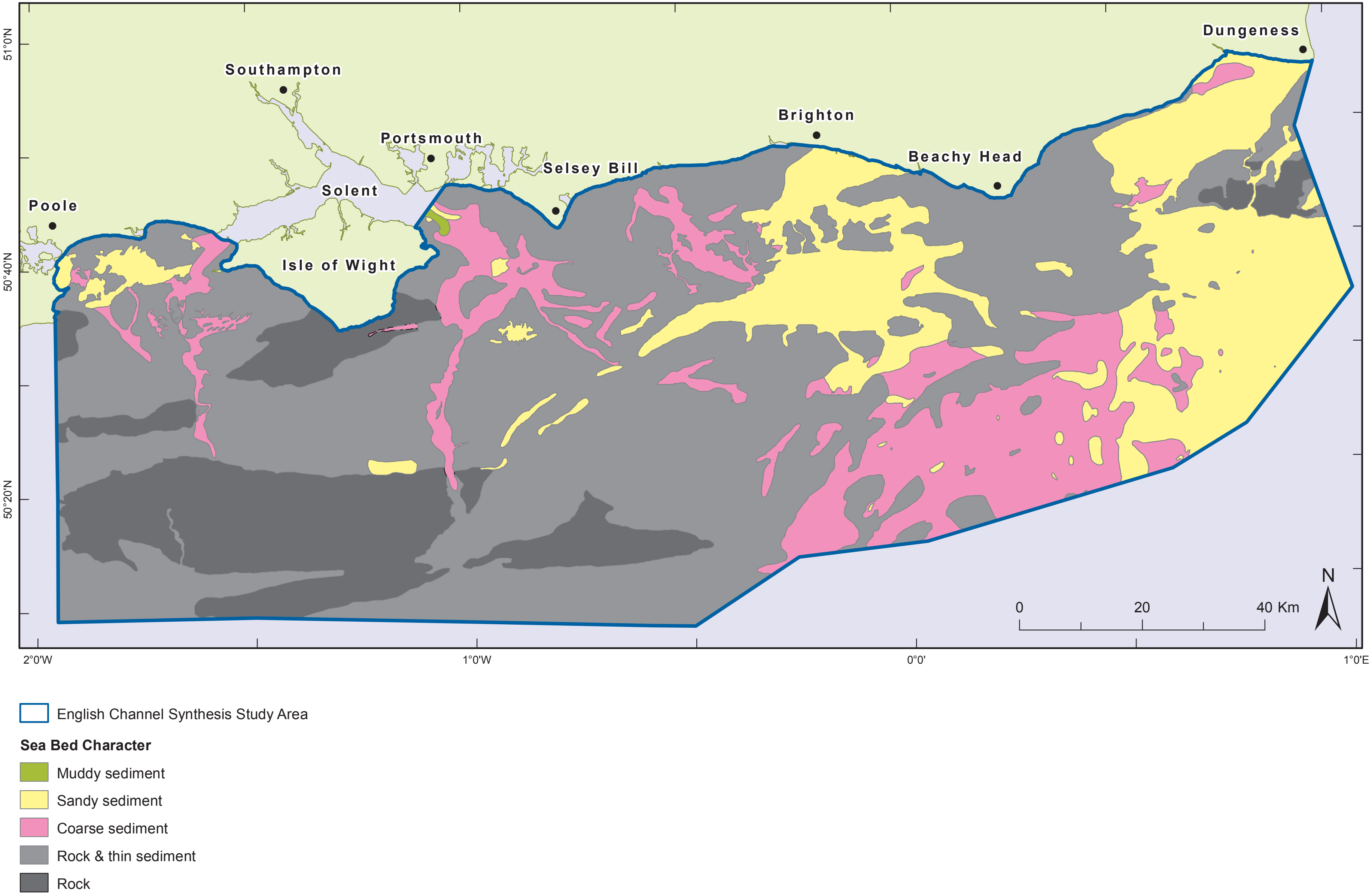


Figure 66 Sea bed character.

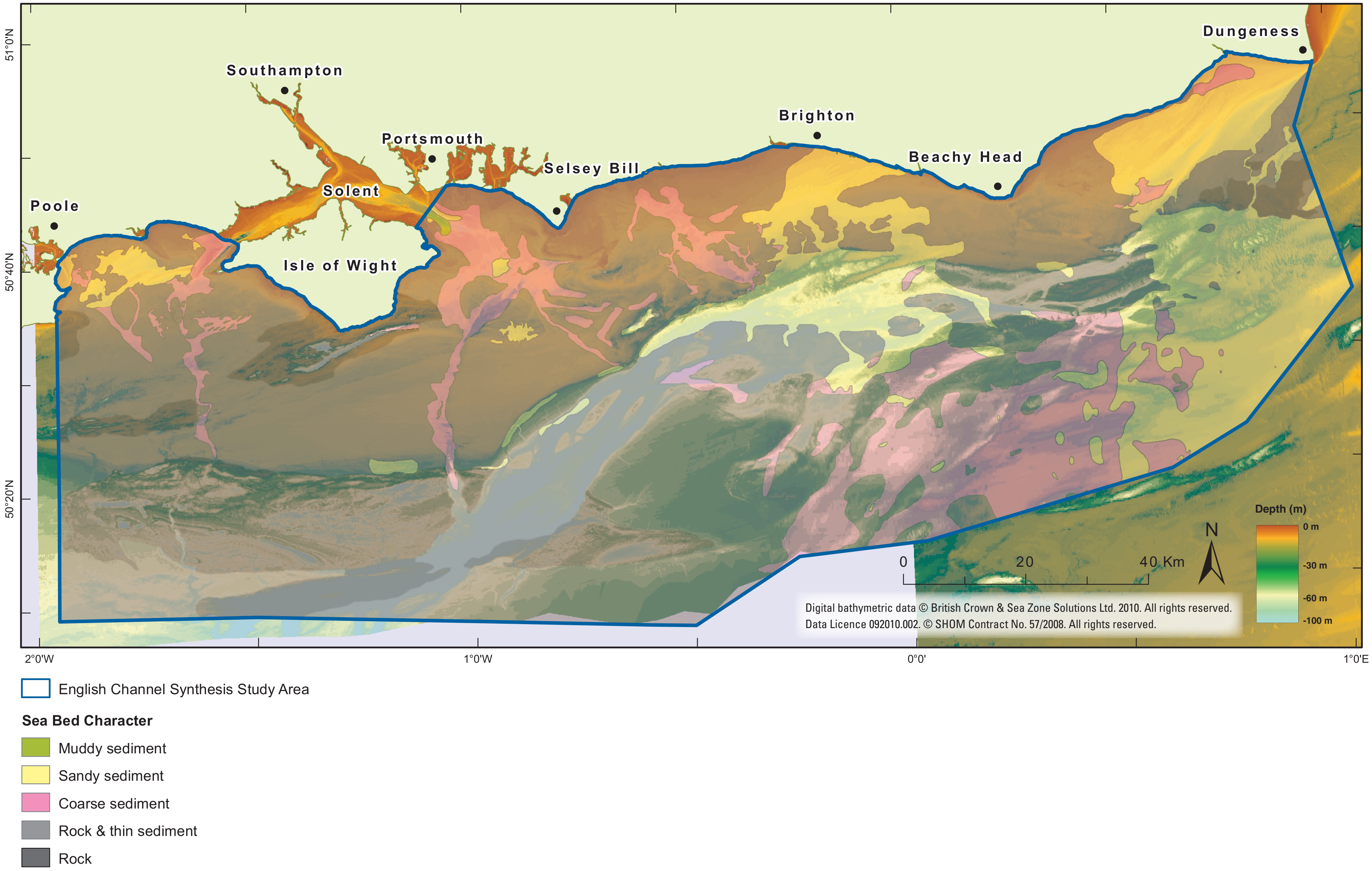


Figure 67 Sea bed character draped on sea bed morphology model.

Figure 68a Sea bed in rock and thin sediment in EECMHM sample station 74 transect. (Scale bar divisions 1 cm).

Rock and thin sediment denotes those areas where sediment is thin and less than a metre or so thick with numerous patches and windows of bedrock exposed at the sea bed (Figure 63). Where bedrock is exposed at the sea bed it was usually possible to distinguish rock structures and bedding on the sea bed morphology model, multibeam and sidescan data and to confirm these sea bed structures with corresponding boomer sub-bottom profiler record, and sea bed photography (Figure 62 to 65). However, the boomer data commonly indicated a more extensive outcrop of bedrock at or virtually at the sea bed than apparent from the multibeam or sidescan. The comparison indicated a difference in the resolution of rock features picked at the sea bed by the three geophysical methods (Figure 69 & 68a and b). Using boomer records the areas where rock is shown to be at or within a metre or so of the surface was mapped as rock and thin sediment and reproduced in the sea bed character map. For those areas where rock and thin sediment is mapped in the SBC interpretation, the modelled sediment category of any thin sediment in these areas can be seen on the sea bed sediment map (Figure 59).

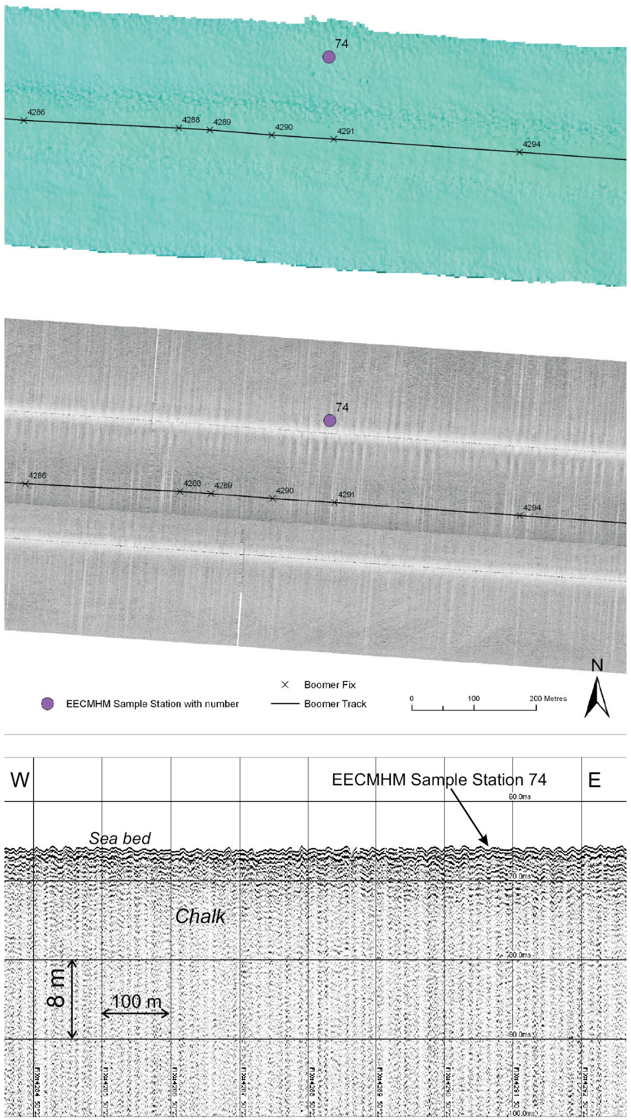


Figure 69 ***(From top to bottom)*** Multibeam, sidescan sonar and boomer profile images of rock and thin sediment on chalk bedrock in Western Axial Platform.

Figure 68b Sea bed in rock and thin sediment in EECMHM sample station 74 transect. (Scale bar divisions 1 cm).

The rock category has been reproduced by superimposing the roughness model over the original rock and thin sediment interpretation and where the roughness model has high values this is interpreted as an indication of rock exposed at the sea bed as scarps and positive outcrops. Those areas with extensive and dense high values of roughness were then mapped as areas with rock exposed at the sea bed (Figure 45 & 75) although it should be noted that sediment can also occur in these mapped rock areas.

Extent

The synthesis study area covers approximately 12 755 km^2. Rock and thin sediment is the most common form of sea bed character lying over 6718 km^2 (53%) of the study area (Figure 66 & 67). The area mapped as rock extends over 1762 km^2 (14%), which is comparable to the area of coarse sediment coverage at 1821 km^2 (14%). Sandy sediment is a little more extensive and spread over 2446 km^2 (19%). With only a coverage of 8 km^2 (0.1%) muddy sediment is not a significant element of the sea bed in the study area.

Rock

The six mapped areas of rock are predominantly associated with localities where the underlying solid geology (Figure 52a & 52b) has been folded and faulted to form scarps and depressions which are etched on the sea bed surface (Figure 62). They are most common south and west of the Isle of Wight particularly in areas underlain by the Central English Channel Monocline, and structures associated with the Purbeck-Wight Monocline such as St Catherine's Deep and the Monocline Enclosure (Figure 44b). The one locality of rock mapped in the east of the study area is underlain by steeply dipping rocks in the Weald–Artois Anticlinoreum.

Rock and thin sediment

Rock and thin sediment provides extensive cover across the sea bed for much of the western half of the study area. The dominance of rock based substrate in this western half is only broken by relatively small areas of sandy and coarse sediment. In the east, rock and thin sediment is subordinate to coarse and sandy sediment although it has a significant presence on the Selsey — West Sussex Platform around and south of Beachy Head, which extends into deeper waters north of the Central Axial Platform. Here rock and thin sediment forms ridges between the sediment filled channels which underlie the Central Axial Platform. In the deeper water south of Dungeness rock and thin sediment forms an extensive platform with a number of small open dendritic channels etched in its surface.

The roughness map (Figure 75) indicates there are extensive areas of relatively smooth rock and thin sediment sea bed such as within the South Wight Platform, Western Axial Platform and some of the Selsey — West Sussex Coastal Platform. These relatively smooth areas are generally underlain by relatively flat lying solid geology — bedrock (Figure 63). However, the roughness map also indicates areas where scarps, ridges and high points are significant and where rock outcrops are likely to be exposed at the sea bed within the rock and thin sediment areas. These include the channel margins and bars of the Northern Palaeovalley, the banks and ridges around and southeast of Selsey Bill, the ridges west of the Palaeoarun, and the ridges and highs south and east of Beachy Head.

Coarse sediment

The significant deposits of coarse sediment are principally associated with channel systems which have been cut into the underlying bedrock. The most extensive occurrence lies beneath the Central Axial Platform in the southeast of the study area and is linked with a major channel system in the English Channel (Figure 56). The other principal coarse sediment deposits lie within and south of Poole and Christchurch Bay, the Solent and Palaeosolent east of the Isle of Wight, and the Palaeoarun system which crosses the Selsey — West Sussex Coastal Platform. Although relatively small, Hastings Shingle Bank is an important coarse sediment area east of Beachy Head. Further east in Rye Bay a patch of coarse sediment has been mapped based on sidescan sonar, and the possibility that rock eroded from Wealden cliffs on the west side of Rye Bay may be the source for this occurrence of coarse sediment.

Sandy sediment

Sandy sediment is very extensive in the eastern quarter of the study area. Here there are two separate and distinct occurrences. The Greater Bassurelle Sands lying in deeper water in the southeast and sands in shallower coastal waters in the northeast associated with the Fairlight Ridges and extending in to Rye Bay. The Greater Bassurelle Sands are the most extensive and becomes progressively sandier in content to the east (Figure 60) with the western tip of the Bassurelle Sand Bank in the southeast corner. The sand of the Fairlight Ridges lies in the lee of the chalk coastal platform which extends offshore for almost 20 km southeast of Beachy Head. The eastern side of the sand is bounded by the headland of Dungeness and in this outer area of Rye Bay some of the sands have a slightly muddy content (Figure 59).

The other extensive area of sand in the study area is associated with the eastern end of the Northern Palaeovalley where sand has been pressed against the northern margin of the Palaeovalley with the formation of two large banks and associated sand wave field and sand sheets. This area of sand is linked northwards to sand which extends across the Selsey — West Sussex Coastal Platform to the coast east of Brighton.

In the western half of the study area sand occurrences are relatively minor with the most significant occurring in Poole and Christchurch Bay, and small sand wave fields at the Overfalls and Nab Hole east of the Isle of Wight (Figure 72). Elsewhere in the areas covered by rock and thin sediment there will be isolated patches of sand.

Muddy sediment

The only notable evidence of muddy sediment is a small area at the entrance to the East Solent near the sand bank of Horsetail Bank (Figure 72). The interpretation is based on sample station data although tidal currents may be high enough to maintain mud in suspension in this channel and sampling may have been affected by maintenance dredging in the vicinity. The lack of muddy sediment across the study area is mainly due to strong currents which prevent muddy sediment from settling. Also, there appears to have been very little input of muddy sediment in to the English Channel since the last glaciation, so there may not have been a great deal of mud in the system.

Bedforms

We have modelled the sea bed in terms of the sea bed sediments which lie on its surface (Figure 59) and provided a further element in describing the character of the sea bed (Figure 66). However there is a further dimension which can be added to how we describe the nature of the sea bed, and this dimension is the fashioning of sediment, predominantly sand, by the movement of sea water into bedforms such as ripples and other sandy waveforms.

A walk along a sandy beach will provide examples of how the surface of the beach can be fashioned and formed of different types and sizes of ripples and waveforms (Figure 70). A sandy beach is a restless surface with ripples coming and going with each rise and fall of the tide, and probably even greater changes after storms and between the seasons. The sea bed across the synthesis study area is also a restless surface with the twice daily ebb and flood tidal currents moving mobile sandy sediment back and fore with the added help of wave action in shallow waters.

With the interpretation of high resolution geophysical survey data (Figure 40a & b) we can identify areas of the sea bed where sediment has been fashioned into ripples, megaripples and sand waves and these can be seen down to a resolution of a metre. Photographs and videos of the sea bed help us to identify ripples only a few centimetres across (Figure 71). These can form a hierarchy of waveforms with ripples superimposed on megaripples up to a metre high, and megaripples superimposed on sand waves which may exceed ten metres in height (Figure 73). In areas where there are widespread deposits of sand, extensive fields of megaripples and sand waves can develop if the current conditions are favourable. These fields can be many hundreds of square kilometres in area such as the Greater Bassurelle Sands. Conversely in areas of rocky sea bed where there is little sandy sediment but the tidal conditions are favourable, isolated individual sand waves or narrow trains and patches of megaripples can form. However the largest sandy bedforms in the hierarchy are sand banks and these are commonly covered by ripples, megaripples and sand waves. Sand banks can be tens of metres high and tens of kilometres long. They are relatively numerous in the eastern English Channel with a series of sand banks leading up to the Dover Strait and one of these, the Bassurelle Bank encroaches into the southeast corner of the synthesis study area.

The dominance of rock, and rock and thin sediment plus the areas of coarse sediment means that the study area has a limited extent of major sandy bedforms (Figure 72) although sand streaks, sand patches, sand ribbons, megaripple trains and isolated sand waves do occur on

Figure 70 Sand ripples on beach. Ripple wavelength ~10 cm, height ~2 cm © NERC.

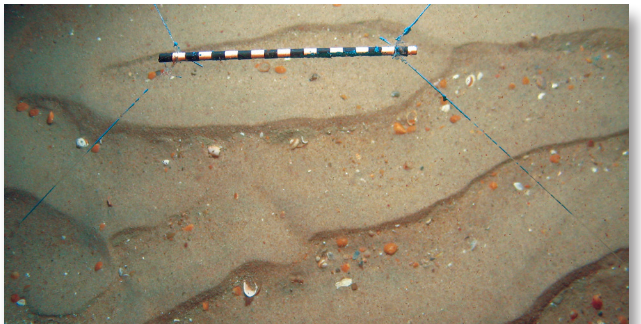


Figure 71 Sand ripples on sea bed. (Scale bar — 20 cm long).

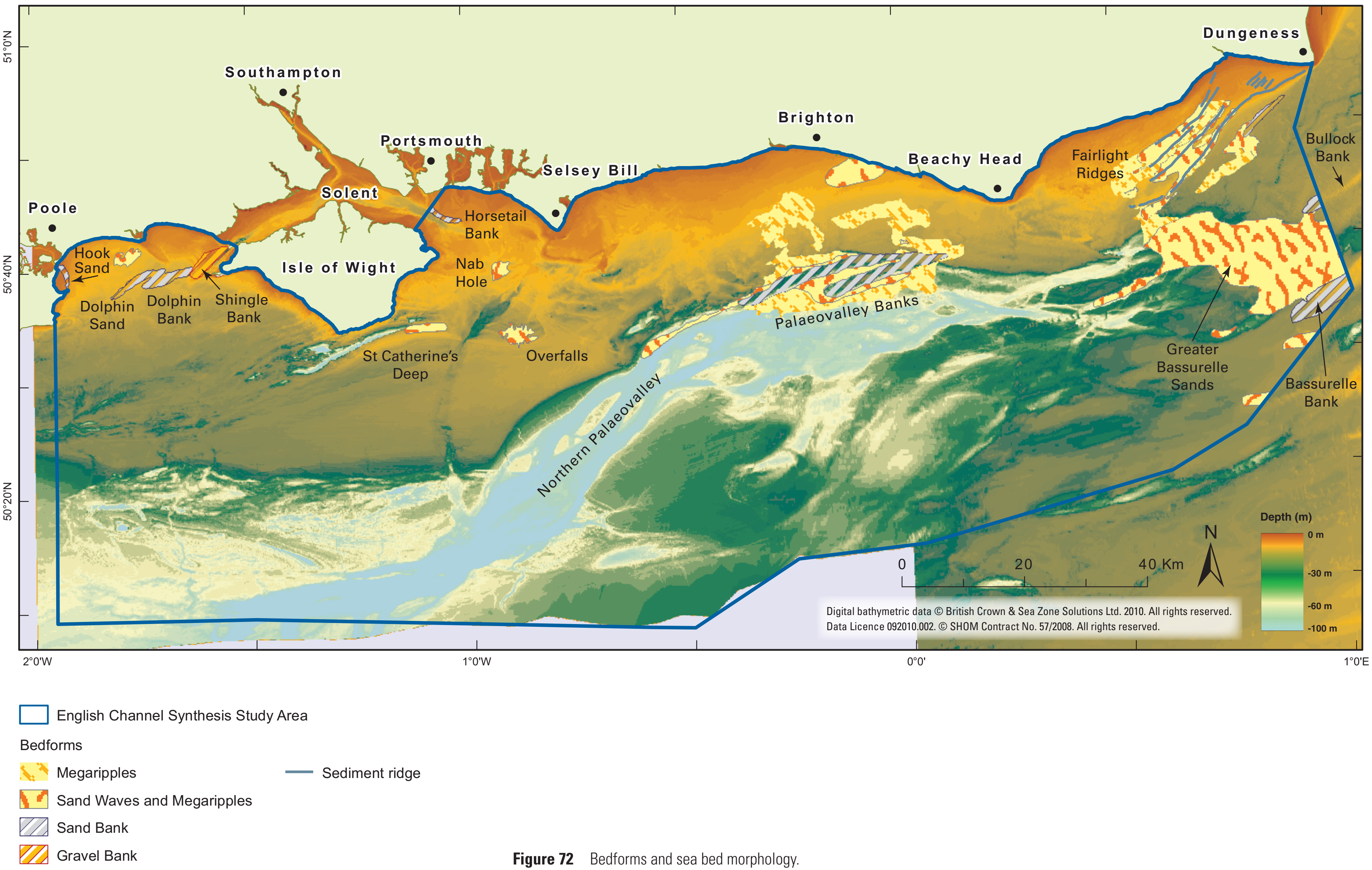


Figure 72 Bedforms and sea bed morphology.

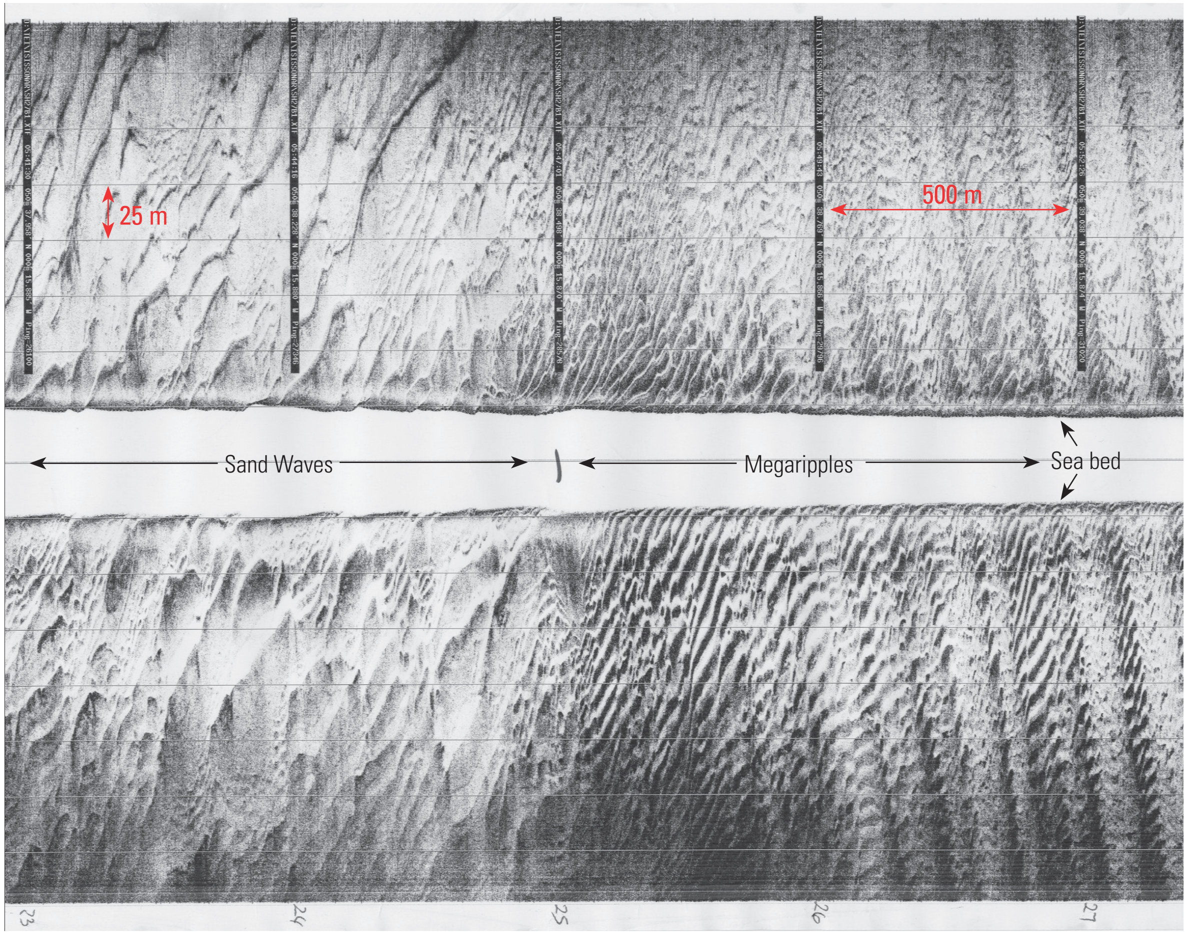


Figure 73 Sidescan sonar record of megaripples on right half of record and sand waves on left half of record. Note megaripples on shallow (stoss) slopes of sand waves which are over 3 m high and have an asymmetrical cross profile on the sea bed.

these rocky substrates. The area south of the Isle of Wight including the South Wight Platform and the Central English Channel Monocline is an area of relatively strong tidal currents and high values of tidal sea bed stress (Figure 8). This has contributed to the creation of a sea bed with a winnowed lag surface of rock and thin coarse sediment with fine sediment being driven to the east away from this bedload parting zone (Figure 7).

There has been a long term process in the central and eastern English Channel of fine and sandy sediment being swept by tidal currents, and to some extent wave action, to the north and east, with the shallower coastal margins and eastern sand wave fields and banks acting as sinks and conduits for these sediments (James *et al.*, 2007). The sand banks, sand ridges and sand wave fields in the east of the synthesis study area are within this English Channel sediment conduit and sink system.

The bedforms in the synthesis study area have been divided and mapped as five categories (Figure 72 & 74):-

- Megaripples
- Sand waves and megaripples
- Sand banks
- Sediment ridges
- Gravel banks

We have noted that the western half of the study area is dominated by a rock based sea bed with some coarse sediment associated with channel systems. The major bedforms that occur here are the three sand banks and one gravel bank within Poole and Christchurch Bay. The smallest of these sand banks is Hook Sand in the east of Poole Bay. It is <4 km long and has an asymmetric cross profile with a steeper west facing lee slope up to 5 m high. The sand banks of Dolphin Sand and Dolphin Bank are aligned in a slightly offset en-echelon form, virtually east-west across 14 km of the bays. They also have an asymmetrical cross profile with steep south facing lee slopes up to 14 m high. There appears to be a small sand wave field on the inshore side of these banks.

Shingle Bank at the western entrance to the Solent (Figure 72) is the only gravel bank that has been mapped in the western half of the study area. It is about 7 km long and is the ultimate sink for gravel produced by the eastward longshore transport of sediment around Christchurch Bay. Further candidates as gravel banks are in the east at Hastings Shingle Bank just east of Beachy Head (Figure 74), and a small area in the shallow inner part of Rye Bay near Dungeness.

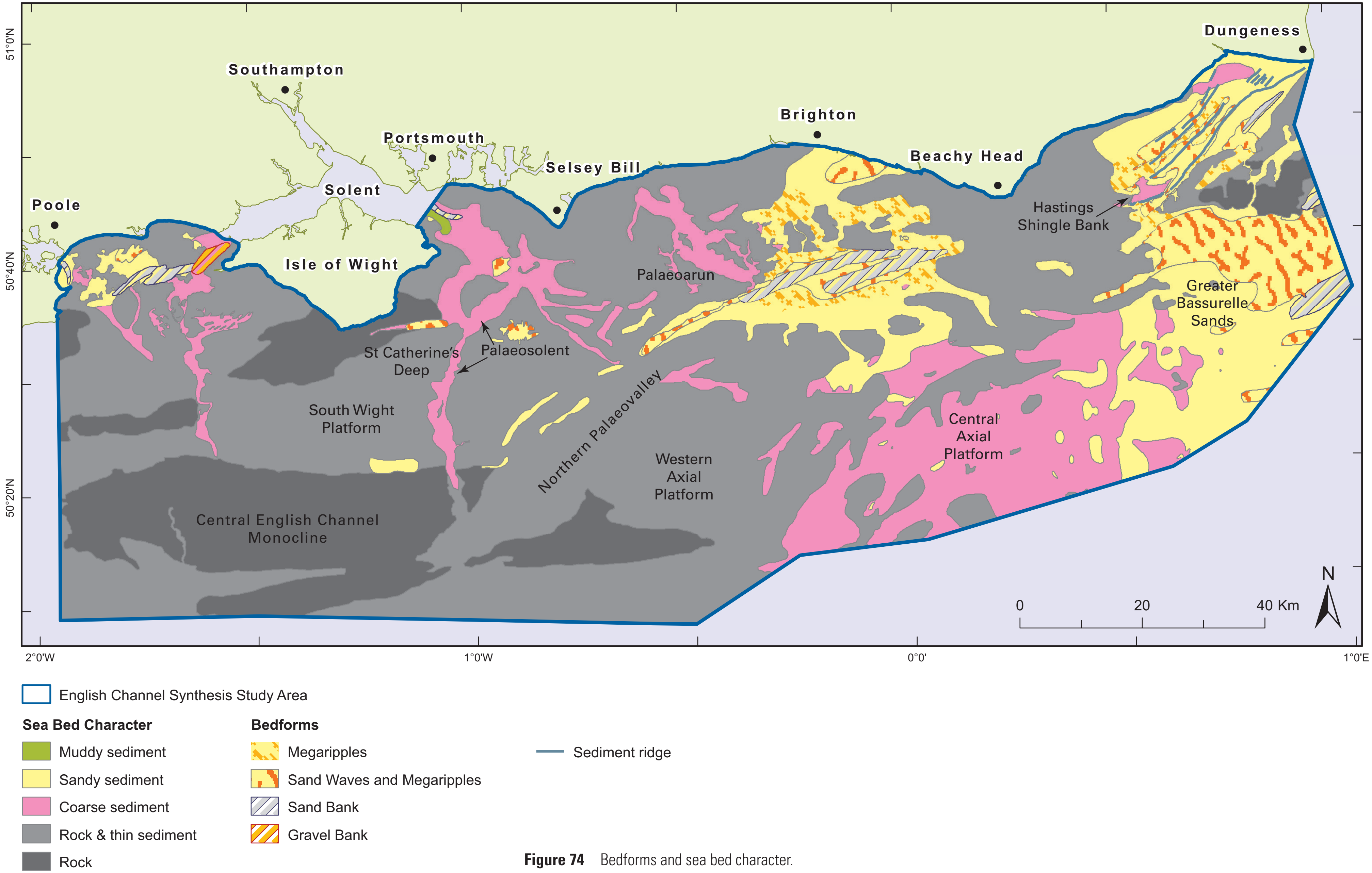


Figure 74 Bedforms and sea bed character.

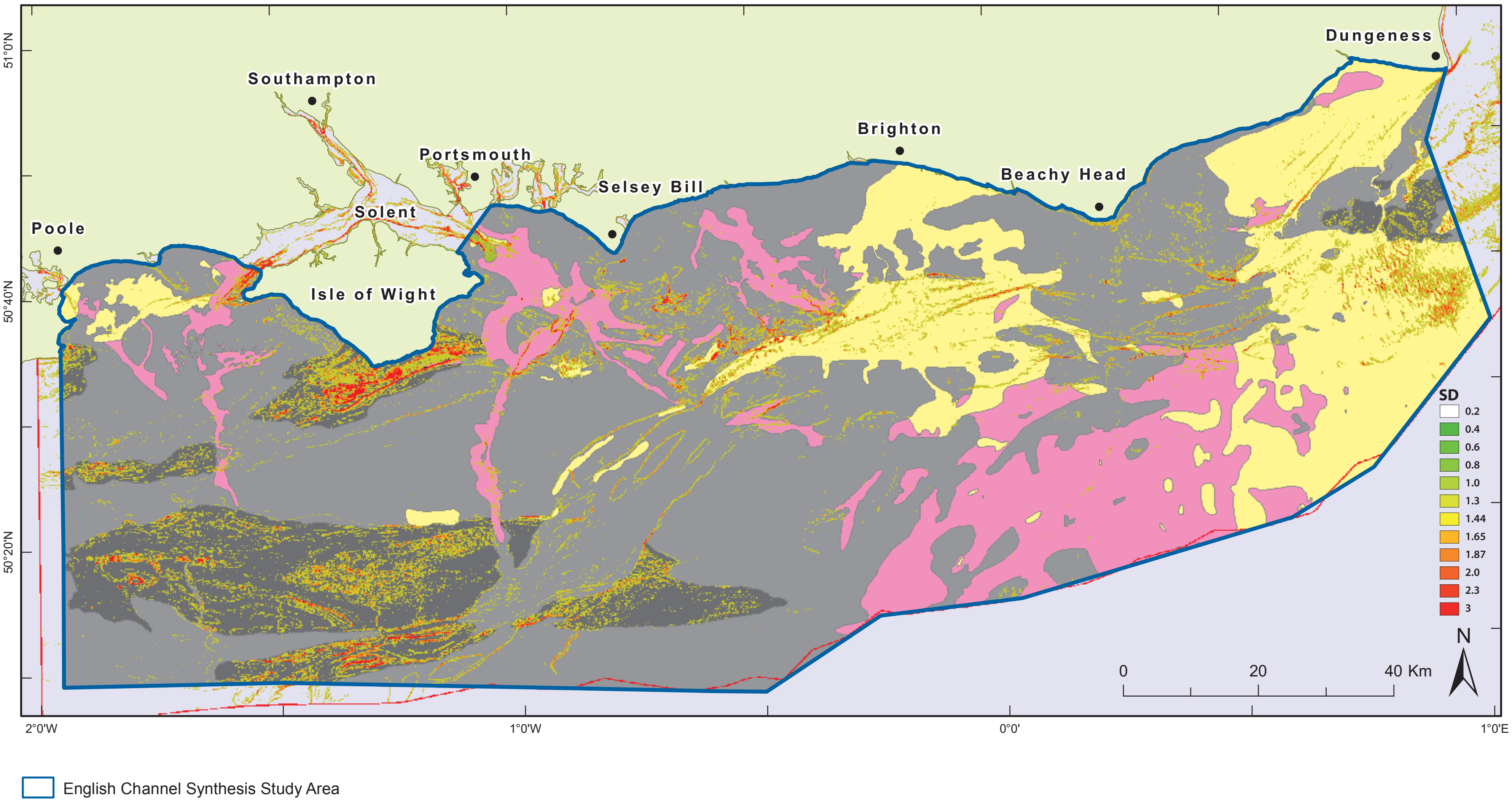


Figure 75 Sea bed roughness model and sea bed character.

The roughness model was computed by running a 7 pixel by 7 pixel neighbourhood filter (Figure 94) over the morphology model and calculating the focal standard deviation. The calculation produces a measure of the deviation of the centre pixel in the filter compared to the surrounding values as measured by the 7 by 7 area. Areas with a low standard deviation (SD) are areas of relative low 'roughness', and, conversely, high standard deviation values represent relatively high 'roughness.

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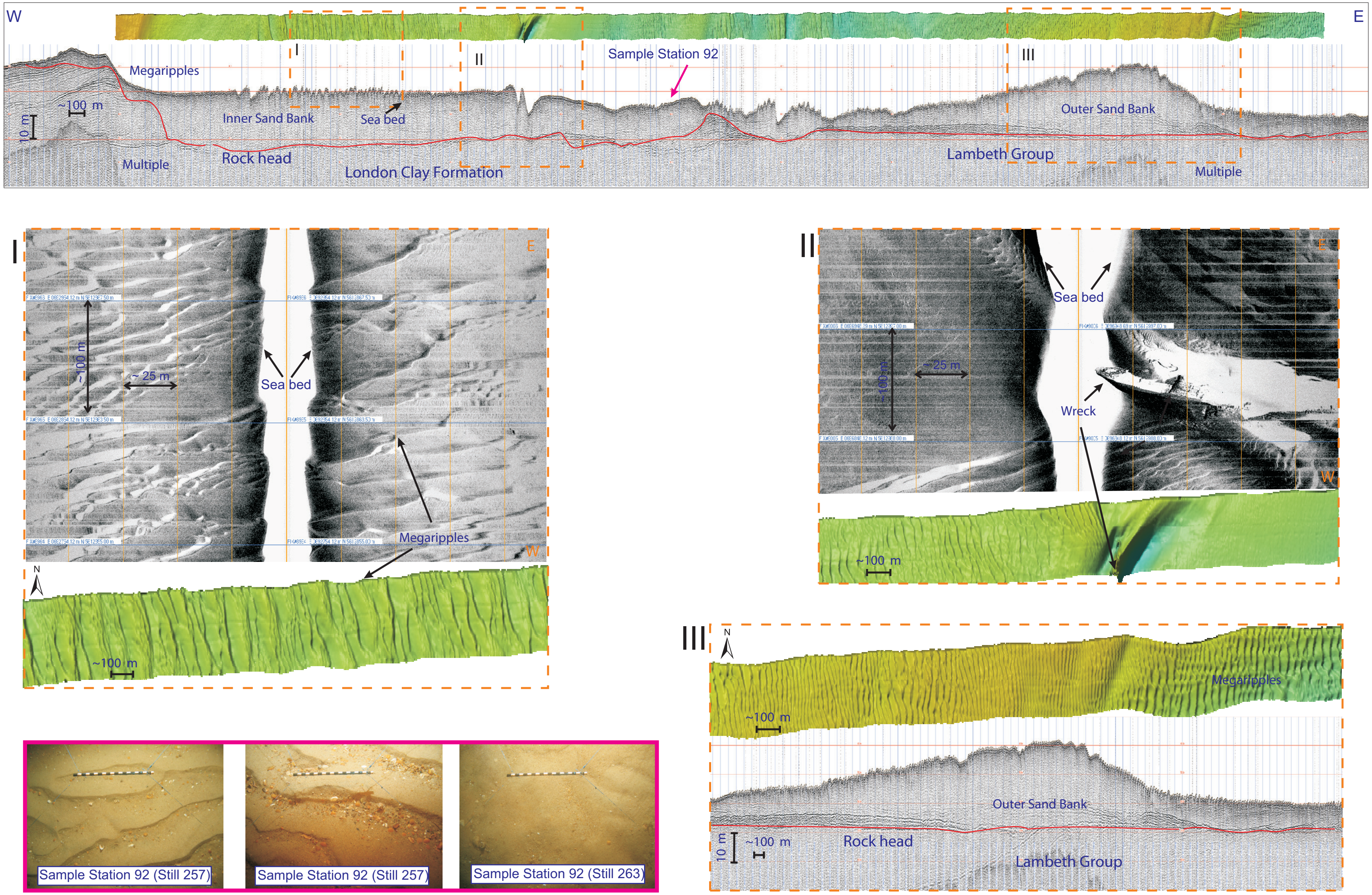

Figure 76 West–east sub-bottom profile across Northern Palaeovalley Banks with multibeam and sidescan sonar records of megaripples and sand waves on the sand banks. Sea bed images of ripples at South Coast REC sample station 92 (see James *et al*, 2010).

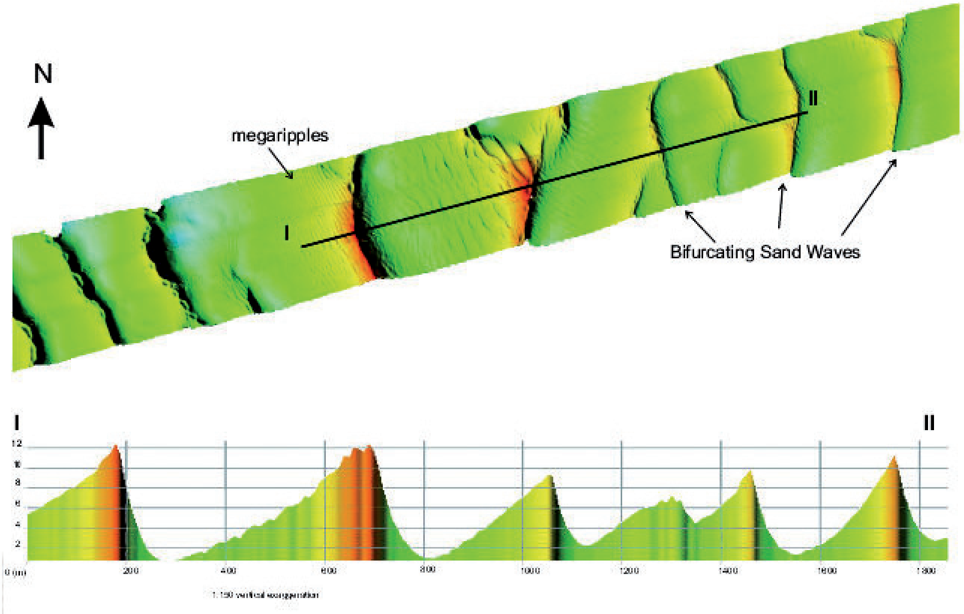

Figure 77 Multibeam record and cross profile of sand waves in the Greater Bassurelle Sands.

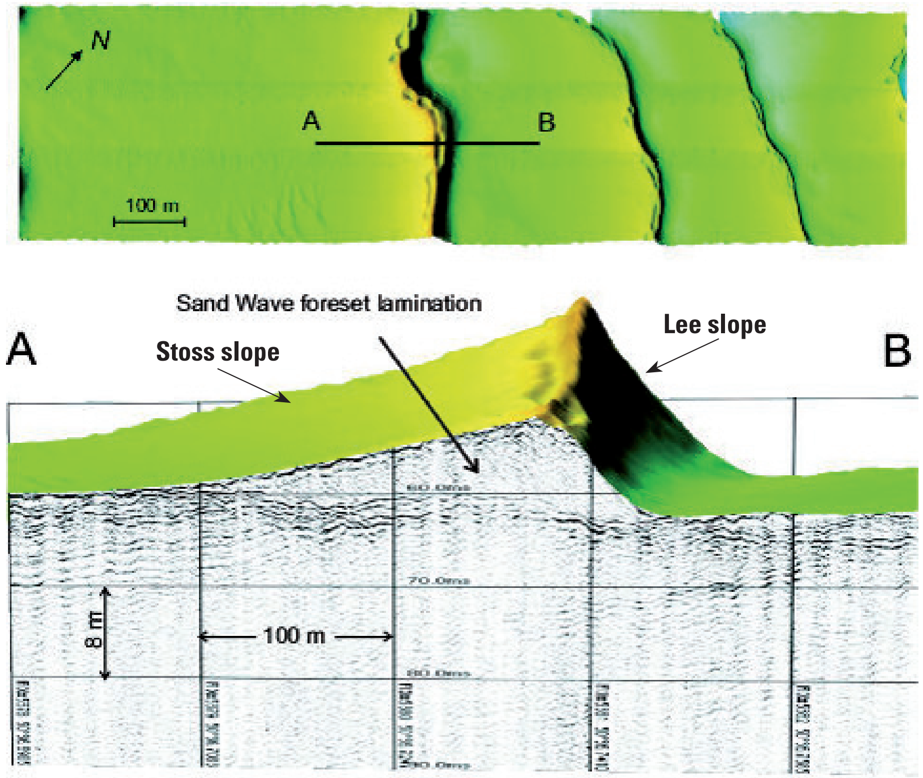

Figure 78 Multibeam record and sub-bottom profile record of sand waves in the Greater Bassurelle Sands. The foreset laminations are evidence of the sand wave growing as sand is moved by currents up its shallow long (stoss) slope and deposited down its shorter steep (lee) slope.

The only other notable bedforms in the western half lie just to the east of the Isle of Wight where three relatively small sand wave fields occur. The first of these is a linear field of sand waves at the eastern entrance to St Catherine's Deep which are constrained between two rock ridges to the north and south. The second is a sand wave field called the Overfalls (Tingley *et al.*, 2006), which lies within the Monocline Enclosure (Figure 44b and 72) just east of the Palaeosolent. It covers an area of 5 km by 3 km and the nine mapped sand waves are up to 3 km long with crests at depths around 25 m. They are symmetrical or asymmetrical with a steep east facing lee slope. The third is within Nab Hole, a small depression just south of Bracklesham Bay in the east Solent, where a small sand wave field has formed with ~3 m high east facing sand waves.

Some small linear trains of megaripples and sand waves have been noted along the northern margin of the Northern Palaeovalley southeast of the Palaeosolent and these are evidence of the regional eastward transport of sand in this area. Tracing this sediment transport path further east along the Northern Palaeovalley we come across a significant area of megaripples and sand wave fields, which cover much

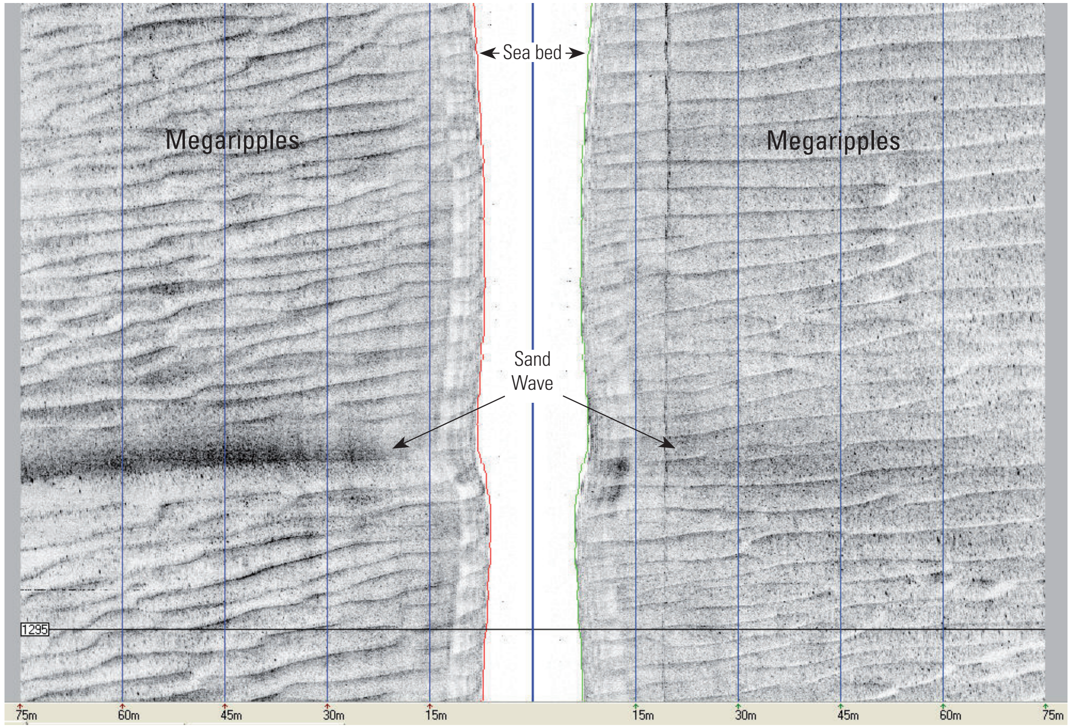

Figure 79 Sidescan sonar record of a single sand wave 2–3 m high on one of the Fairlight Ridges with dense pattern of associated megaripples.

of the floor of the eastern end of the Northern Palaeovalley and extend up on to the Selsey — West Sussex Platform towards Brighton. At the heart of this extensive area of sand are the Northern Palaeovalley Banks (James *et al*, 2010). These are two large linear sand banks (Figure 76) The outer bank is well developed with a single virtually straight crest line over 16 km long, which is attached at its eastern end to the coastal platform. The inner bank is about 28 km long but is not continuous through its entire length. In common with the outer bank its eastern end is attached to the coastal platform. The sand banks and their associated sand waves are well displayed by high values of roughness seen in Figure 75 with the line of the banks picked out against the yellow sandy sediment background.

The Greater Bassurelle Sands in the southeast of the study area is an extensive area of sandy sediment which includes a large field of sand waves covering an area of 329 km^2. This is shown on Figure 75 as an area with high values of roughness with a NW–SE grain parallel to the crest lines of the sand waves. The sand waves are dominantly asymmetrical in cross profile (Figure 77) with east and northeast facing steeper lee slopes, Asymmetrical sand waves can be an indicator of net sand transport in the facing direction of the lee slope. The sand waves in the Greater Bassurelle Sands therefore imply that net sediment transport is to the east. The internal structure of the sand waves with east facing foresets is evidence of the growth of the sand waves in height and volume to the east as a long term process (Figure 78). The sand waves vary in height from 1.5 to 12 m and their wavelengths range from 200 to 1300 m.

About 7 km of the western end of the Bassurelle Sand Bank impinges into the southeast corner of the study area and it extends for a further 17 km to the northeast. It has a maximum height of ~15 m and is ~2.5 km wide. It has well developed megaripples and sand waves up to 2.5 m high on its flanks and crest. The NE-SW trend of the sand bank crest is virtually parallel to the strongly linear tidal currents in the area.

The sandy nearshore area between Hastings Shingle Bank and Dungeness is notable for a number of linear sediment ridges which run sub-parallel to the coast and are from <10 to 30 km in length. Collectively, for the purpose of this study, these ridges have been named the Fairlight Ridges after the adjacent Fairlight cliffs which lie on the coast behind them. Two of these ridges are named individually on Admiralty charts with the Four Fathoms sand ridge off Hastings and Stephenson Shoal to the southwest of Dungeness Point. The sediment ridges are commonly covered by megaripples and sand waves <2 m high although some can be over 3 m high (Figure 79). They lie in water depths of 5 to 15 m, becoming deeper offshore. Boomer sub-bottom profiler data indicate they are underlain by sediment over 10 m thick and they have developed and grown by advancing offshore to the southeast. They do not extend beyond a line from Hastings Shingle Bank to the tip of Dungeness. Both these fixed points control their extent as strong currents further offshore do not allow these ridges to advance by further deposition of sand. These sediment ridges are another sink of sediment in the eastern English Channel with their growth possibly allied to the development of Dungeness (Dix *et al*, 1998).

EUNIS habitat model

Model development and problems with mapping

Within the past decade there have been considerable advances in the way we make maps of sea bed habitats. One of these advances has been to standardise the way in which marine habitats are classified, so everyone calls the same habitat by the same name. This work began in the UK with a national programme called the Marine Nature Conservation Review (MNCR) which developed the Marine Habitat Classification for Britain and Ireland (Connor *et al*, 2004). This has now been adopted and further developed at the European level to provide a single classification system that is applicable across the whole of Europe. The agreed classification is part of the European Nature Information System, commonly known as 'EUNIS' (Davies & Moss, 2004; see also the EUNIS website at http://eunis.eea.europa.eu/habitats-code-browser.jsp?expand=A#level_A and the MNCR classification at the JNCC website http://www.jncc.gov.uk/marine/biotopes/hierarchy.aspx].

Figure 80 A parachute jump over rocky mountains, but is the ground really all rocky? (© Or Hiltch).

Throughout Europe all major sea bed habitat mapping projects now use the EUNIS classification system, which has many advantages in standardising the way in which information is analysed and presented. The EUNIS classification system is hierarchical, which means it is a series of steps with each new step providing a more detailed description, similar to the taxonomic system that we use to name animals and plants. For example a simple hierarchy for naming humans is:-

- Animals
  - Vertebrates
    - Mammals
      - Primates
        - Hominids
          - Humans

In a similar way, the EUNIS hierarchy for naming a seaweed biotope found on an exposed shoreline at low tide is:-

- Marine habitats
  - Infralittoral rock
    - Moderate energy infralittoral rock
      - Kelp and red seaweeds

Each step in the system is called a level, so in the example above, the kelp biotope occurs at EUNIS level 4. The term 'habitat' is commonly used when referring to the upper levels of the classification (1, 2 & 3) that describe physical characteristics (e.g. substrate type), while the term 'biotope' tends to be used for the lower levels of the classification (4, 5 & 6) that include information on the animals and plants that form distinct and recognisable communities. This system is very useful, but like all efforts to describe the world in simple terms, it is not perfect; and that can lead to some problems when making habitat maps.

The South Coast REC study, which preceded this synthesis study, found it necessary to propose some new EUNIS biotope classes as it recorded distinct biotopes that were not described in the current version of EUNIS (James *et al.*, 2010). The EUNIS scheme is periodically updated to accommodate new biotopes, and new versions have been published in 2006 and 2008.

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The South Coast REC study also reported a relatively poor match between the broadscale EUNIS Level 3 modelled map that it generated and the biotope classes that it assigned on the basis of grab and underwater camera samples taken at an array of sampling sites. In many cases, the difference between the modelled map and the observations were quite fundamental, for example in some places the model predicted a rock habitat but the grab and video samples showed a sediment habitat. This discrepancy was partly a scale issue and partly a classification issue. At EUNIS Level 3, which is appropriate for broad, regional scale mapping, habitats are classified by high level descriptors such as 'high energy rock' or 'circalittoral coarse sediment' but this does not allow any finer-scale variability to be described, such as significant patches of sediment that overlies bedrock, or patchy outcrops of rock in an otherwise sediment dominated substrate.

This scale problem can be more easily understood by considering an analogy, that of making a parachute jump over rocky mountains (Figure 80). When sky-divers looked down from the aeroplane they would see 'rocky mountains', but when they arrived on the ground they might land on soil or sand, but not rock.

So the pilot of the plane would draw the area as rock, but the sky-divers would draw the spot where they landed as soil or sand. The question is, who is right? And the answer is that they are both right, because the fine scale observations made by the sky-divers when they landed can exist within the broader-scale map made by the pilot. In precisely the same way, it is possible to find sand, mud or gravel in a grab taken from a point on the sea bed where a more general, high-level EUNIS modelled map classifies the area as rock.

A potential solution

The classification issue arises because the EUNIS system only allows a limited number of substrate descriptors to be used at Level 3 in the

EUNIS Level	'EUNIS Code'	EUNIS Name	'MNCR-style Code'
1	A	Marine Habitats	
2	A3	Infralittoral Rock and other hard substrata	IR
3	A3.1	High energy Infralittoral Rock	IR.HIR
3	A3.2	Moderate energy Infralittoral Rock	IR.MIR
3	A3.3	Low energy Infralittoral Rock	IR.LIR
3	A3.7	Features of Infralittoral Rock	IR.FIR
3	(A3.8)	High energy Infralittoral Rock and thin Sediment	IR.HIRthS
3	(A3.9)	Moderate energy Infralittoral Rock and thin Sediment	IR.MIRthS
3	(A3.A)	Low energy Infralittoral Rock and thin Sediment	IR.LIRthS
2	A4	Circalittorlal rock and other hard substrata	CR
3	A4.1	High energy Circalittoral Rock	CR.HCR
3	A4.2	Moderate energy Circalittoral Rock	CR.MCR
3	A4.3	Low energy Circalittoral Rock	CR.LCR
3	A4.7	Features of Circalittoral Rock	CR.FCR
3	(A4.8)	High energy Circalittoral Rock and thin Sediment	CR.HCRthS
3	(A4.9)	Moderate energy Circalitttoral Rock and thin Sediment	CR.MCRthS
3	(A4.A)	Low energy Circalitttoral Rock and thin Sediment	CR.LCRthS
2	(A4D)	Deep Circalittorlal rock and other hard substrata	DCR
3	(A4D.1)	High energy Deep Circalittoral Rock	DCR.HDCR
3	(A4D.2)	Moderate energy Deep Circalittoral Rock	DCR.MDCR
3	(A4D.3)	Low energy Deep Circalittoral Rock	DCR.LDCR
3	(A4D.8)	High energy Deep Circalittoral Rock and thin Sediment	DCR.HDCRthS
3	(A4D.9)	Moderate energy Deep Circalittoral Rock and thin Sediment	DCR.MDCRthS
3	(A4D.A)	Low energy Deep Circalittoral Rock and thin Sediment	DCR.LDCRthS
2	A5	Sublittoral Sediment	SS
3	A5.1	Sublittoral Coarse sediment	SS.SCS
3	A5.2	Sublittoral Sand	SS.SSa
3	A5.3	Sublittoral Mud	SS.SMu
3	A5.4	Sublittoral Mixed sediment	SS.SMx
3	A5.5	Sublittoral Macrophyte-dominated sediment	SS.SMp
3	A5.6	Sublittoral Biogenic Reefs	SS.SBR

Table 7 Extract of the modified EUNIS habitat classification developed by the synthesis project, showing Levels 1, 2 & 3 only. Brackets indicate biotope classes that do not yet exist in the official EUNIS listing.

EUNIS Level	EUNIS Code	EUNIS Name	'MNCR'-style Code'
3	(A3.8)	High energy Infralittoral Rock and thin Sediment	IR.HIRthS
4	(A3.81)	+ thin Coarse sediment	IR.HIRthS.Cs
4	(A3.82)	+ thin Sandy sediment	IR.HIRthS.Sa
4	(A3.83)	+ thin Muddy sediment	IR.HIRthS.Mu
4	(A3.84)	+ thin Mixed sediment	IR.HIRthS.Mx
3	(A3.9)	Moderate energy Infralittoral Rock and thin Sediment	IR.MIRthS
4	(A3.91)	+ thin Coarse sediment	IR.MIRthS.Cs
4	(A3.92)	+ thin Sandy sediment	IR.MIRthS.Sa
4	(A3.93)	+ thin Muddy sediment	IR.MIRthS.Mu
4	(A3.94)	+ thin Mixed sediment	IR.MIRthS.Mx
3	(A3.A)	Low energy Infralittoral Rock and thin Sediment	IR.LIRthS
4	(A3.A1)	+ thin Coarse sediment	IR.LIRthS.Cs
4	(A3.A2)	+ thin Sandy sediment	IR.LIRthS.Sa
4	(A3.A3)	+ thin Muddy sediment	IR.LIRthS.Mu
4	(A3.A4)	+ thin Mixed sediment	IR.LIRthS.Mx

Table 8 Expansion of a section of the EUNIS hierarchy dealing with the Rock and thin Sediment class, to illustrate how the superficial sediments are discriminated at EUNIS Level 4. (+ sign indicates position of Level 3 description).

classification, namely rock or sediment (sand, mud, coarse or mixed sediments). It does not cater for areas where both elements occur, that is where there is rock and a thin covering of sediment. To overcome this problem, the synthesis study proposes the introduction of 'rock and thin sediment' (abbreviated to RthS) as a new substrate category in the EUNIS classification. This acts as a transitional class between the existing pure-rock and pure-sediment habitats and reflects the reality of what has been observed extensively at many locations across the eastern English Channel, where the physical habitat and the benthic community exhibit characteristics of both rock and sediment biotopes. Previously, these areas have been treated as biotope 'mosaics', but it has proved unworkable to use this approach in mapping due to the complexity of representing multiple biotope classes at a single point location or in a single mapped polygon. The advantage of the new rock and thin sediment class is that it allows the coexistence of rock and sediment at the same location, so the mosaic itself can be represented by a single biotope class, providing greater clarity to the resulting map that makes it easier to interpret and apply to marine spatial planning.

Accordingly, for this study a series of rock and thin-sediment (RthS) classes has been introduced at EUNIS Level 3, as shown in Table 7. The new classes have been placed within the existing EUNIS Level 2 classes for Infralittoral Rock (A3) and Circalittoral Rock (A4), and they have been assigned alpha-numeric codes that are not yet used in the 'official' EUNIS classification. Some appropriate MNCR-style codes have also been developed, as many people find these abbreviated codes more meaningful than the strictly alpha-numeric EUNIS codes. The different superficial substrate types (sand, mud, coarse and mixed sediments) are introduced at EUNIS level 4 as illustrated in Table 8.

In applying this revised classification, we have employed the existing EUNIS rock classes A3.1, A3.2, A3.3 strictly to identify areas where rock outcrops at the sea bed, either as reefs or ridges or bare expanses of rock. The new rock and thin sediment classes have been applied where rock occurs near the surface of the sea bed but it is typically covered with <0.5-1 metres of sediment (in the form of mud, sand or gravel, or mixtures of these). In these circumstances the biological communities include fauna characteristic of both sediment and hard substrate habitats. We have reserved the use of the existing EUNIS sediment classes, A5.1, A5.2, A5.3 & A5.4 for areas where there is >0.5-1 metres of sediment. In these circumstances, infaunal taxa dominate the biological community, and there is comparatively little epifauna.

One further modification has been made to the EUNIS classification system to facilitate the modelling process, as the current hierarchy is inconsistent in the way it deals with the biological zones, namely the infralittoral, circalittoral and deep circalittoral classes. The infralittoral is the zone where there is sufficient light to support algal growth; commonly called the photic zone, it ranges from the sea surface down to about 10 to 30 metres, depending on the turbidity of the water. The circalittoral zone lies beneath this, being the area of sea bed that has low or no light, but is still disturbed by wave action, so the communities there are tolerant to this disturbance. The deep circalittoral lies below the circalittoral and is a region where the sea bed is not disturbed by wave action. As a consequence, more fragile organisms can become established, such as delicate sponges, so some of the deep circalittoral communities can be quite intolerant to physical disturbance. The inconsistency in the present EUNIS system is that the infralittoral and circalittoral zones are introduced at Level 2 for rock habitats, but the deep circalittoral zone is only introduced at Level 4. This is both illogical and inconsistent.

This anomaly has significant consequences for modelled EUNIS maps, especially those made at EUNIS Level 3 which is commonly used for broadscale regional habitat mapping. Such maps show infralittoral and circalittoral rock, but cannot display deep circalittoral rock habitats. Consequently, for this project, the deep circalittoral zone has been introduced at Level 2 for rock habitats, the same level at which the Infralittoral and circalittoral zones are introduced (see Table 7). The Level 2 code 'A4D' has been used for the deep circalittoral, the D

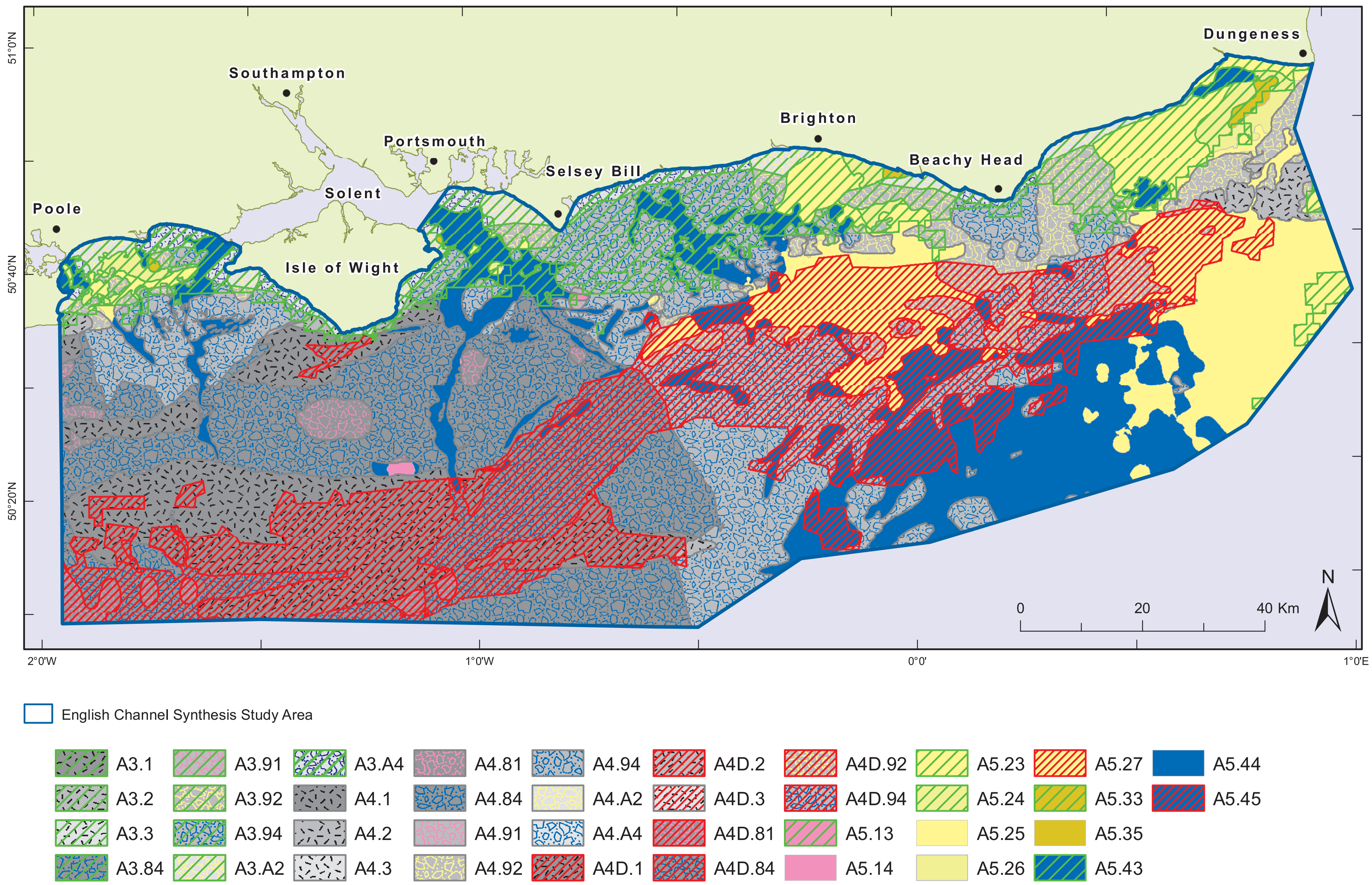

Figure 81 Modelled habitat map for the synthesis study area, displayed at EUNIS Level 4. See Appendix 1 for an explanation of the EUNIS codes. See text for an explanation of the symbology.

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representing 'deep'. Note that the new 'rock and thin sediment' classes also occur within the deep circalittoral zone (e.g. A4D.8 = high energy, deep circalittoral rock and thin sediment).

The consequence of the zonal anomaly is not so acute for sediment biotopes, as they tend to be dominated by fauna that live within the sediment, rather than on the substrate surface, so the composition of these communities is much less influenced if at all by light or wave disturbance. However it still has an effect on modelled maps as the deep circalittoral sediments can only be shown if the map uses EUNIS Level 4 or more.

EUNIS Level 4 modelled map

The modelled map for this project (Figure 81) has been produced at EUNIS Level 4, allowing full display of the infralittoral, circalittoral and deep circalittoral zones for all substrate types. The biological zones are indicated in the maps' symbology, using a green over-hatching for all infralittoral biotopes and a red over-hatching for all deep circalittoral biotopes. The lower limit of the infralittoral zone is defined as the depth at which light levels fall to 1% of surface irradiance (Hiscock & Mitchell, 1980, Chapman, 1987), and has been modelled following the methodology described by Coggan and Diesing (2009). The upper limit of the deep circalittoral is the depth at which waves no longer disturb the sea bed, and this has been determined using the same maximum wave-base model used in the first version of the UK SeaMap (Connor *et al.*, 2006) applied to the sea bed morphology model used in this study (Figure 44a & 44b).

The symbology used in the map polygons is intended to be logical and informative (Table 9) and is explained below. Any grey colour indicates rock of some sort, any yellow indicates sand, any green indicates mud, any magenta indicates coarse sediment and any blue indicates mixed sediment.

Substrate	Colour
Rock [R]	grey
Sand [Sa]	yellow
Mud [Mu]	green
Coarse [C]	magenta
Mixed [Mx]	blue

Table 9 Polygon-fill colours used to indicate substrate types in modelled map.

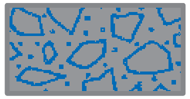
	High energy, Circalittoral Rock (A4.1 = CR.HCR)
	Low energy, Circalittoral Rock and thin Sandy sediment (A4.A2 = CR.LCRthS.Sa)
	Moderate energy Circalittoral Rock and thin Coarse sediment (A4.91 = CR.MCRthS.Cs)
	High energy Circalittoral Rock and thin Mixed sediment (A4.84 = CR.HCRthS.Mx)

Table 10 Examples of symbology used for the exposed rock and rock-and-thin-sediment classes.

The symbology used for rocky substrate has a grey background and uses the appropriate colour for the foreground ornamentation, as shown in Table 10. Variations in the shade used for the grey background indicate different exposure levels; dark shade = high energy, mid shade = moderate energy, light shade = low energy.

Interpretation of the EUNIS level 4 map

The modelled map (Figure 81) shows very clearly the three biological zones, with the infralittoral fringing the coast and the deep circalittoral further offshore. The infralittoral extends well out to sea, as much as 20 km from the coast in some places, highlighting the shallow waters that overlie the coastal platform which stretches from Selsey Bill to Dungeness. Some offshore areas in the extreme southeast of the study area are also in the infralittoral zone, and these are associated with shallow waters (<20 m deep) above the Bassurelle and Bullock sand banks (Figure 72).

Deep circalittoral habitats are mostly associated with the Northern Palaeovalley, which reaches depths over 100 m in the south west but gradually shallows and broadens towards the east. Some deep circalittoral habitats occur very close to shore just south of the Isle of Wight in the area known as 'St Catherine's Deep', which is over 70 m deep in places.

Across the study area there is a distinct change in substrate type from west to east which confers a distinct longitudinal change in habitat type. Outcropping rock (A4.1) occurs in the south west, supporting reef-like habitats, but the major part of the western and central area is dominated by rock and thin mixed sediment (A4.84 and A4.94) which is characterised by the presence of scour-tolerant epifauna and interstitial infauna. Sediment habitats dominate the eastern part of the study area, reflecting an accumulation of sand and gravel. Mixed sediment (A5.44) is associated with the complex system of sand and gravel-filled palaeochannels on the Selsey–West Sussex coastal platform and also with other channel systems notably to the west and east of the Isle of Wight (Figure 66). Further to the east this grades into sand habitats where a few thousand years of natural sediment transport has deposited the smaller, lighter particles around a bedload convergence zone (Figure 7). Moving inshore, a significant area of exposed bedrock occurs due south of Dungeness, covered in part by thin sheets of mobile sand. Closer to shore, in the lee of Dungeness Point, lies one of the few muddy habitats (A5.33 & A5.35) that occur in the area.

Moving east to west along the coast the sandy areas of Rye Bay and Fairlight Ridges (Figure 72 & 74) contains coarse sediment patches close inshore and also further offshore to the west, at Hastings Shingle Bank. This gives way to rocky habitats associated with the chalk cliffs of Beachy Head, the influence of which reaches quite far out to sea in an area of rock and thin mixed sediment (A3.A4 & A4.94). Rock and thin sand (A3.A2) extends along the immediate shoreline either side of Beachy Head, as far as 30 km to east and 15 km to the west.

Off Brighton, the sand is thick enough to be mapped as a sediment habitat (A5.23), but further west this grades into mixed sediment over rock (A3.94 & A3.A4) and then into mixed sediment proper (A5.43 & A5.44) as the deposits become thicker when associated with the relict channel systems of the Palaeoarun and the Palaeosolent, to the east of the Isle of Wight (Figure 74). These areas are the focus of much of the marine aggregate dredging activity that occurs in this area (Figure 13).

Selsey Bill has rock and thin mixed sediment to the east, but thin sandy sediment to the west. This alternation between thin sand and thin mixed sediment continues around the south coast of the Isle of Wight, save for the southern-most coast which shelves steeply into St Catherine's Deep, giving a rapid change from infralittoral rock reef (A3.2 & A3.3), to circalittoral (A4.1) and deep circalittoral rock (A4D.1).

Further channel systems exist to the west of the Isle of Wight, in Poole and Christchurch Bays, but the sea bed here is very diverse, with rock and thin sand or thin mixed sediment over much of the area, surrounding a central, thicker sand sheet including Dolphin Sand and Dolphin Bank (Figure 72). These sands have a muddy area (A5.33) to their northeast. A large sand bank, Hook Sand, features on the approaches to Poole Harbour, and south of this the rock and thin sand of western Poole Bay gives way to outcropping rock (A3.2 & A3.3) off Swanage.

Across the whole study area there is a notable west-east trend in 'exposure' or' energy status' of the habitats, the high energy of the south west reducing to moderate energy in the central and eastern areas. The same trend occurs moving south to north, with high energy offshore reducing to low energy immediately adjacent to the coast. See pages 103–106 for details on these west-east and coast-offshore trends.

Biotope assignments for sample stations

The synthesis study has re-analysed grab and video data collected from 429 ground-truth sample stations in the study area (Figure 43), and has used that analysis as the basis for assigning a biotope class to each sample location. The assignments were made at EUNIS levels 4 or 5 depending on the level of detail available in the data. Several infaunal community assemblages were recognised as a result of a cluster analysis of grab sample data from 374 locations and these were used to define four 'functional biological communities' (FBCs) at EUNIS Level 5, and finer-scale variants of those communities at EUNIS Level 6. The EUNIS classification is poorly developed for offshore sediment habitats, so it was considered more appropriate to use this opportunity to describe new biotope classes, based on the analysis of actual samples, than to force our observations into existing but poorly fitting EUNIS biotope classes which were developed from a data set in which the deeper and more offshore locations were poorly represented. Details of the composition and distribution of these 'functional biological communities' are given in pages 94–102.

For stations on hard ground, where no grab samples were obtained, a biotope assignment has been made on the basis of the analysis of sea bed videos and photographs, following the same methodology used in the previous, site-specific reports within the synthesis study area (James *et al.*, 2007, Coggan *et al.*, 2009 and James *et al.*, 2010). This analysis allowed biotopes to be identified at EUNIS levels 4 to 6. Ten of the existing EUNIS rock biotope classes were identified, but as four of these existed in both the circalittoral and deep circalittoral zones, four new EUNIS codes were generated to specifically identify their occurrence in the deep circalittoral zone.

A complete list of the EUNIS biotopes assigned in the course of this study is given in Appendix 1, along with descriptions and MNCR-style code. A summary list is presented here in Table 11 giving the number of sample stations to which each biotope was assigned (total 429 stations).

A map with symbols showing the biotopes assigned at each sample station is presented in Figure 82. Different parts of the symbols are used to provide information about different aspects of the habitat and its associated community. The shape of the symbol identifies the biological community. Symbol shapes used for the 'functional biological communities' that occurred in the sediment and 'rock and thin sediment' habitats are given in Table 12, along with an MNCR-style code. These communities occur across multiple EUNIS Level 4 classes, as seen in Table 11. Symbols used for rock biotopes are given in Table 13, and here the symbol orientation has been used to indicate a sub-biotope.

The border colour of the symbol is used to identify the substrate type (Table 14). Border colours have been selected to contrast with the fill colours used for sediments and substrates in the EUNIS model, so they show up when the two are superimposed (Figure 83).

The fill colour of the symbols is used to identify the specific sediment or substrate type (Table 15). The shade of the fill colour becomes deeper to reflect deeper biological zones.

EUNIS	MNCR style code	Number of Stations
A3.215	IR.MIR.KR.XFoR	2
(A3.912)	IR.MIRthS.Cs.BAscTbPo	3
(A3.921)	IR.MIRthS.Sa.PoBivAm	12
(A3.922)	IR.MIRthS.Sa.BAscTbPo	1
(A3.923)	IR.MIRthS.Sa.Cre	1
(A3.941)	IR.MIRthS.Mx.PoBivAm	3
(A3.942)	IR.MIRthS.Mx.BAscTbPo	9
(A3.943)	IR.MIRthS.Mx.Cre	2
(A3.A21)	IR.LIRthS.Sa.PoBivAm	2
(A3.A23)	IR.LIRthS.Sa.Cre	1
(A3.A42)	IR.LIRthS.Mx.BAscTbPo	2
(A3.A43)	IR.LIRthS.Mx.Cre	1
A4.11	CR.HCR.FaT	2
A4.111	CR.HCR.FaT.BalTub	1
A4.12	CR.HCR.DpSp	3
A4.131	CR.HCR.XFa.ByErSp	3
A4.134	CR.HCR.XFa.FluCoAs	16
A4.213	CR.MCR.EcCr.UrtScr	1
A4.214	CR.MCR.EcCr.FaAlCr	11
A4.22	CR.MCR.CSab	1
A4.241	CR.MCR.CMus.Cmyt	1
(A4.811)	CR.HCRthS.Cs.PoBivAm	1
(A4.812)	CR.HCRthS.Cs.BAscTbPo	6
(A4.821)	CR.HCRthS.Sa.PoBivAm	4
(A4.824)	CR.HCRthS.Sa.CvCru	7
(A4.841)	CR.HCRthS.Mx.PoBivAm	2
(A4.842)	CR.HCRthS.Mx.BAscTbPo	15
(A4.844)	CR.HCRthS.Mx.CvCru	7
(A4.912)	CR.MCRthS.Cs.BAscTbPo	2
(A4.921)	CR.MCRthS.Sa.PoBivAm	11
(A4.922)	CR.MCRthS.Sa.BAscTbPo	1
(A4.924)	CR.MCRthS.Sa.CvCru	1
(A4.931)	CR.MCRthS.Mu.PoBivAm	1
(A4.941)	CR.MCRthS.Mx.PoBivAm	12
(A4.942)	CR.MCRthS.Mx.BAscTbPo	33
(A4.944)	CR.MCRthS.Mx.CvCru	8
(A4D.111)	DCR.HDCR.FaT.BalTub(Sp)	1
(A4D.12)	DCR.HDCR.DpSp	4
(A4D.131)	DCR.HDCR.XFa.ByErSp	1
(A4D.134)	DCR.HDCR.XFa.FluCoAs(Sp)	3

EUNIS	MNCR style code	Number of Stations
(A4D.811)	DCR.HDCRthS.Cs.PoBivAm	1
(A4D.812)	DCR.HDCRthS.Cs.BAscTbPo	3
(A4D.822)	DCR.HDCRthS.Sa.BAscTbPo	2
(A4D.841)	DCR.HDCRthS.Mx.PoBivAm	2
(A4D.842)	DCR.HDCRthS.Mx.BAscTbPo	6
(A4D.844)	DCR.HDCRthS.Mx.CvCru	2
(A4D.911)	DCR.MDCRthS.Cs.PoBivAm	1
(A4D.921)	DCR.MDCRthS.Sa.PoBivAm	15
(A4D.941)	DCR.MDCRthS.Mx.PoBivAm	13
(A4D.942)	DCR.MDCRthS.Mx.BAscTbPo	13
(A4D.944)	DCR.MDCRthS.Mx.CvCru	6
A5.13(B)	SS.SCS.ICS.PoBivAm	1
A5.13(C)	SS.SCS.ICS.BAscTbPo	6
A5.14(7)	SS.SCS.CCS.PoBivAm	1
A5.14(8)	SS.SCS.CCS.BAscTbPo	1
A5.23(7)	SS.SSa.IFiSa.PoBivAm	15
A5.23(8)	SS.SSa.IFiSa.BAscTbPo	1
A5.24(7)	SS.SSa.IMuSa.PoBivAm	2
A5.24(8)	SS.SSa.IMuSa.Cre	1
A5.25	SS.SSa.CFiSa	1
A5.25(4)	SS.SSa.CFiSa.PoBivAm	23
A5.25(5)	SS.SSa.CFiSa.BAscTbPo	12
A5.25(6)	SS.SSa.CFiSa.CvCru	1
A5.26(3)	SS.SSa.CMuSa.PoBivAm	1
A5.27(4)	SS.SSa.DCSa.PoBivAm	19
A5.27(5)	SS.SSa.DCSa.BAscTbPo	3
A5.33(7)	SS.SMu.ISaMu.PoBivAm	2
A5.43(6)	SS.SMx.IMx.PoBivAm	6
A5.43(7)	SS.SMx.IMx.BAscTbPo	3
A5.43(8)	SS.SMx.IMx.Cre	2
A5.44	SS.SMx.CMx	3
A5.44(7)	SS.SMx.CMx.PoBivAm	11
A5.44(8)	SS.SMx.CMx.BAscTbPo	26
A5.44(9)	SS.SMx.CMx.Cre	3
A5.45(2)	SS.SMx.DCMx.PoBivAm	8
A5.45(3)	SS.SMx.DCMx.BAscTbPo	12
A5.45(4)	SS.SMx.DCMx.CvCru	1
A5.521	SS.SMp.KSwSS.LsacR	2

Table 11 List of EUNIS biotopes assigned to 429 sample stations considered in the synthesis study, with MNCR style biotope code and the number of stations to which each biotope was assigned.

Community Type	MNCR-style code	Symbol
Interstitial polychaetes with burrowing bivalves and amphipods	PoBivAm	Triangle
Barnacles, ascidians and tube worms	BAscTbPo	Square
Crepidula beds	Cre	Circle
Crevice dwelling crustacean community	CvCru	Pentagon

Table 12 Sample station symbol shapes used for functional biological communities determined from grab sample analysis.

EUNIS	MNCR code	Shape	Up/ Down
A3.215	IR.MIR.KR.XFoR	Circle	
A4.11	CR.HCR.FaT	Triangle	up
A4.111	CR.HCR.FaT.BalTub	Triangle	down
A4.12	CR.HCR.DpSp	Square	
A4.131	CR.HCR.XFa.ByErSp	Pentagon	up
A4.134	CR.HCR.XFa.FluCoAs	Pentagon	down
A4.213	CR.MCR.EcCr.UrtScr	Star	up
A4.214	CR.MCR.EcCr.FaAlCr	Star	down
A4.22	CR.MCR.Csab	Octagon	
A4.241	CR.MCR.CMus.Cmyt	Rounded Square	
(A4D.111)	DCR.HDCR.FaT.BalTub(Sp)	Triangle	down
(A4D.12)	DCR.HDCR.DpSp	Square	
(A4D.131)	DCR.HDCR.XFa.ByErSp	Pentagon	up
(A4D.134)	DCR.HDCR.XFa.FluCoAs(Sp)	Pentagon	down
A5.521	SS.SMp.KSwSS.LsacR	Cross	

Table 13 Sample station symbol shapes used for rock biotopes.

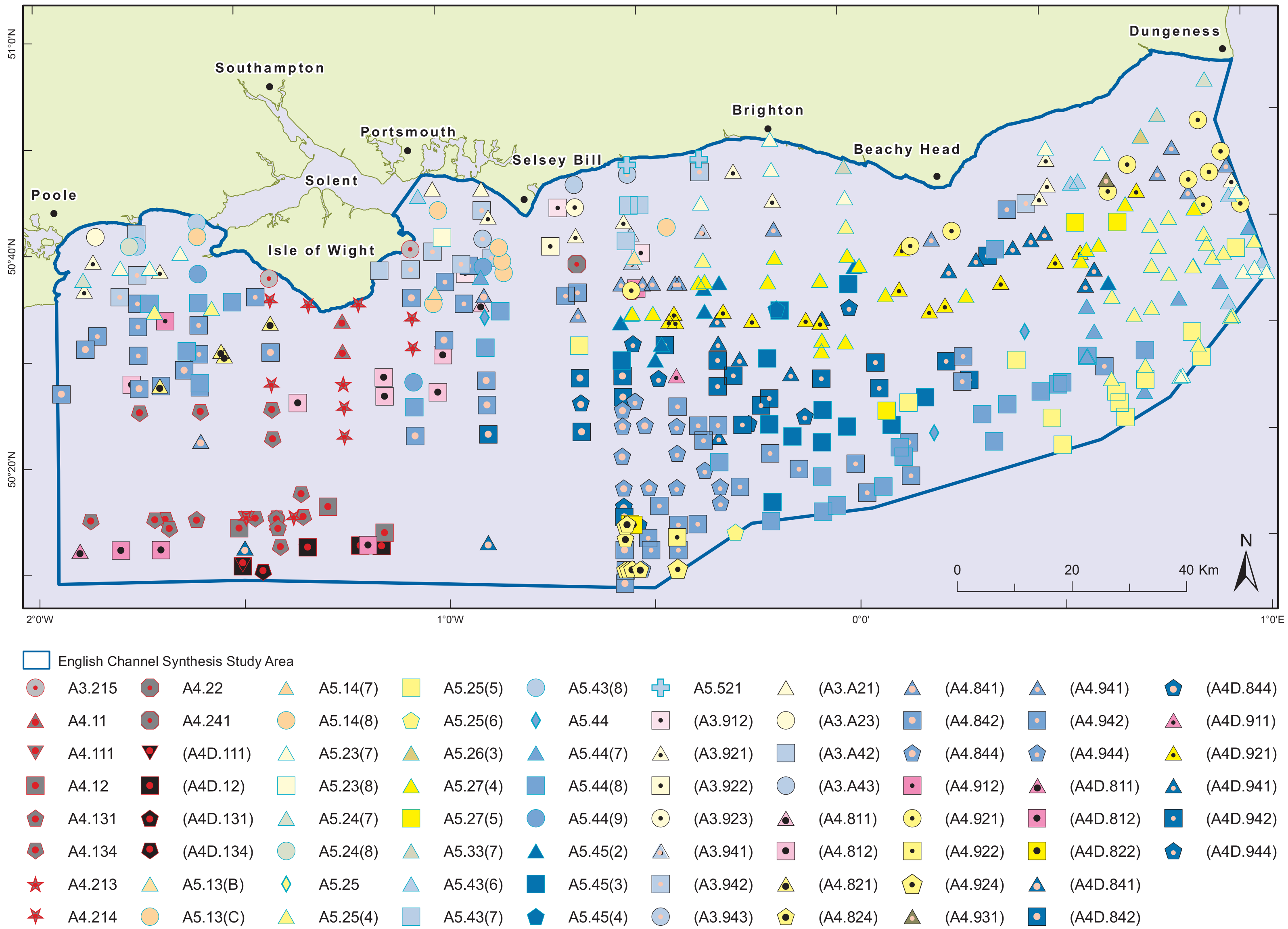


Figure 82 EUNIS biotope classes at Levels 4 and 5 assigned to 429 ground-truth sample stations. See Appendix 1 for an explanation of the EUNIS codes. See text for an explanation of the symbology. See Figure 43 for sample station numbers.

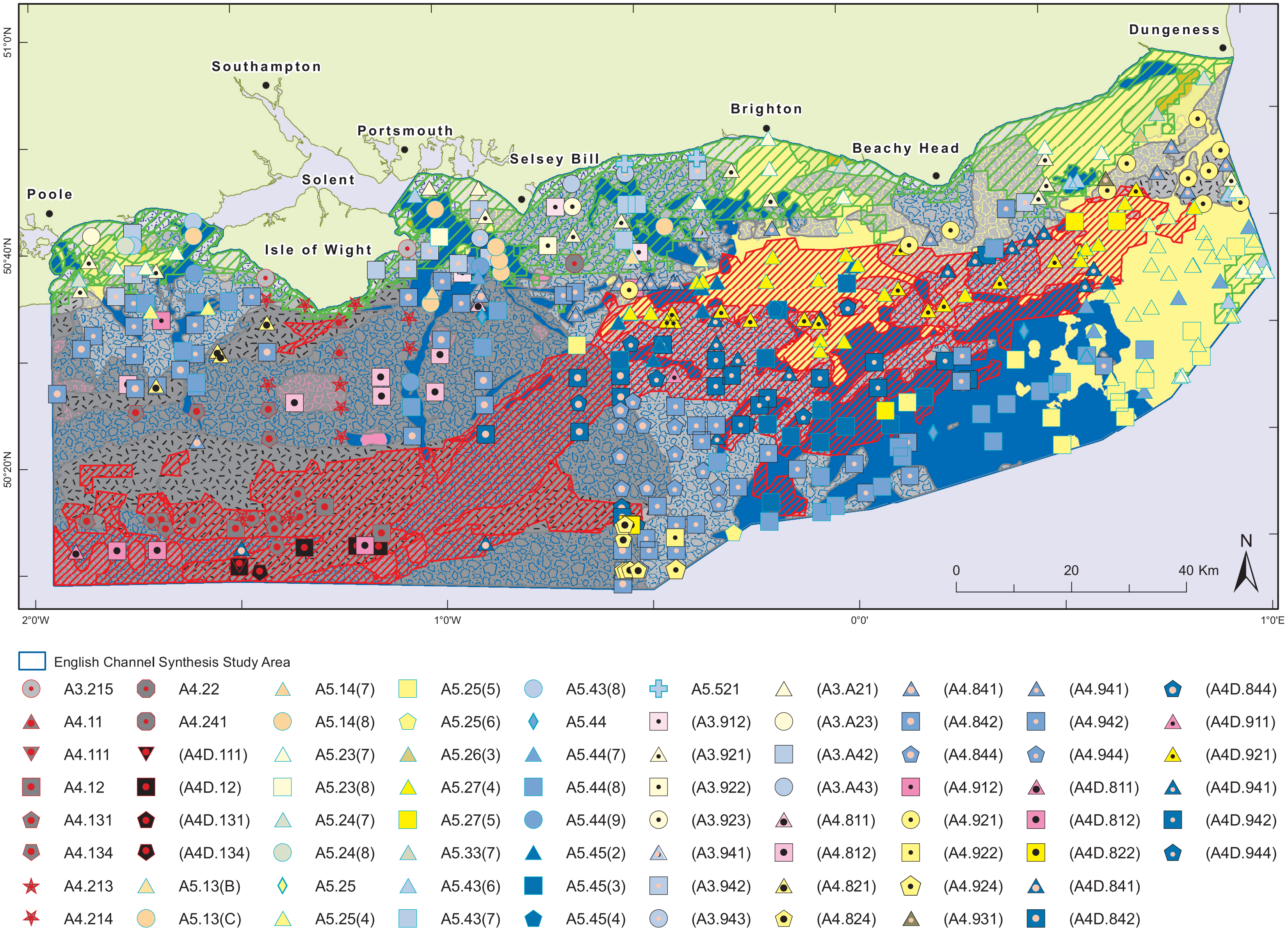


Figure 83 Sample station biotopes overlaid on the EUNIS biotope model. Symbology as in Figures 81 and 82.

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Finally, the energy status of the habitat is indicated by the size of the spot in the centre of the symbol (Table 16). The colour of the spot is not indicative of anything, but is selected to contrast with the background colour. The EUNIS classification system only assigns energy levels to rock habitats, not sediment habitats. We have also applied it to the new rock and thin sediment habitats.

Sampling stations in the southwest of the study area were predominantly rock habitats although grab samples were obtained from a few stations. In the more offshore areas, the rock communities were characterised by sponges and the foliose bryozoan *Flustra foliacea* (A4.12, A4D.12, A4.131 & A 4.134), but on moving inshore to the chalk based South Wight Platform (Figure 44b) these sponge communities gave way to encrusting fauna with associated echinoderms, mostly brittlestars (A4.213 & A4.214), and faunal 'turf' communities (A4.11). One isolated rock habitat was located about 10 km south east of Selsey Bill and was characterised by the mussel *Mytilus edulis* (A4.241). Kelp and red seaweed communities were only found adjacent to the shore, both to the west and east of the Isle of Wight (A3.215) and in the cobble & pebble substrates between Brighton and Selsey Bill (A5.521).

Two functional biological communities dominate the substrates over the rest of the study area, namely the interstitial polychaetes, burrowing bivalves and amphipod community (PoBiAm) represented by a triangular symbol, and the barnacle, ascidian and tube worm community (BAscTbPo) represented by a square symbol. The PoBiAm community occurs mostly on/in sands (yellow fill to symbols) while the BAscTbPo community occurs mostly on mixed sediment (blue fill) but was also present in both sandy and coarse sediment (yellow and magenta fill). These communities do not show a great affinity to any particular biological zone, as they occurred in the infralittoral, circalittoral and deep circalittoral. The crevice dwelling crustacean community (pentagonal symbol) was restricted to an area southeast of the Northern Palaeovalley named the Westen Axial Platform (Figure 44b) in the EECMHM study (James *et al.*, 2007), where the community occurred on both mixed and sandy substrates. The *crepidula* community (circular symbol) tended to occur in the shallower, more nearshore areas, and was found on sandy, muddy and mixed sediments.

Substrate	Border colour
Rock	RED
Rock& thin sediment	BLACK
Sediment	CYAN

Table 14 Sample station symbol border colours used to identify substrate type.

	Colour	Infra-litto-ral	Circa-littoral	'Deep Circalittoral'
'Coarse Sand [CsSa]'	Orange			
'Fine Sand [FiSa]'	Yellow			
'Muddy Sand [MuSa]'	Olive			
'Mud or Sandy Mud [Mu, SaMu]'	Green			
'Coarse [Cs]'	Magenta			
'Mixed [Mx]'	Blue			
'Rock [R]'	Grey			

Table 15 Sample station symbol fill colours.

Energy level	Spot size
High	large
Moderate	small
Low	none

Table 16 Spot size in centre of sample station symbols, indicating energy status.

Comparing observed with modelled biotopes

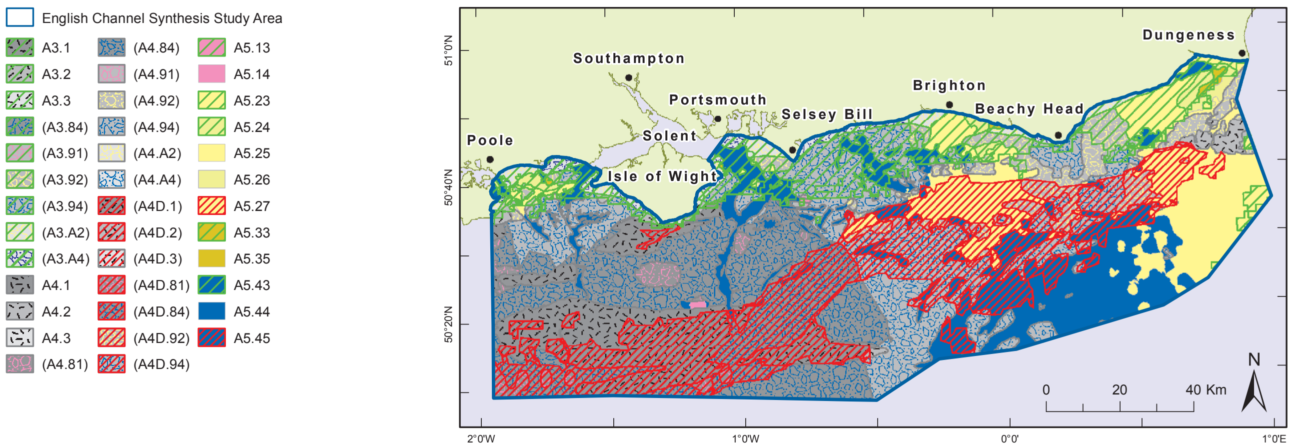
The accuracy of this projects' EUNIS level 4 modelled map can be assessed by overlaying it with the biotope classes assigned at the sample station locations, as shown in Figure 83. There is a high degree of correspondence between the model and the observations especially for the sand and mixed sediment biotopes, as demonstrated by the blue symbols overlaying blue (or grey and blue) polygons and the yellow symbols overlaying yellow (or grey and yellow) polygons. Some discrepancies occur, but this is to be expected when comparing finescale point samples with broadscale classified maps. The most notable discrepancy is seen in the west, where some pink symbols representing coarse sediment overlay rock (grey + black) or rock and thin mixed substrates (grey + blue). This suggests there is a degree of local variability in the thin sediment substrates that is not captured by the broadscale EUNIS level 4 modelled map.

Comparison among EUNIS models

It is instructive to compare the modelled EUNIS map developed by this study with the outputs of the recent UKSeaMap2010 project which modelled habitat distribution using new data from the Defra 'data-layers' projects MB0102 (Brown, 2009) and MB0103 (Gafeira *et al.* 2010).

Figure 84 compares the synthesis project map with the EUNIS Level 3 map from UKSeaMap2010. The latter included a data layer for 'rock & hard substrate' and an updated sea bed sediments map (pre-release version), both produced by the BGS. The 'rock & hard substrate' layer mapped areas having hard substrate within 0.5–1 m of the sea bed surface, and this has resulted in substantial areas near the coast being classified as infralittoral rock (A3.1 & A3.2) and further offshore as circalittoral rock (A4.1 & A4.2). The distribution of these rock habitats is broadly similar to the 'rock and thin sediments' areas identified in the synthesis study, but tends to mask areas of exposed bedrock that most closely resemble a classic 'reef' habitat. Indeed some areas have been directly taken from the EECMHM report (James *et al*, 2007) and South Coast REC study (James *et al*, 2010) and reclassified from rock and thin sediment to rock.

A further variance between the two maps is seen in the distribution of sublittoral sediments (A5) which in the UKSeaMap model are prominent on both the west and the east of the study area, but in the synthesis study map are largely confined to the east, the western area being classified as mostly rock and thin sediment, having fauna representative of both rock and sediment habitats. Examination of video material from the South Coast REC and EECMHM project suggests that sediment layers are thin (<1 m) to the southwest of the Isle of Wight and present a significantly different habitat to the thicker sediments in the east of the study area e.g. in the Central Axial Platform.



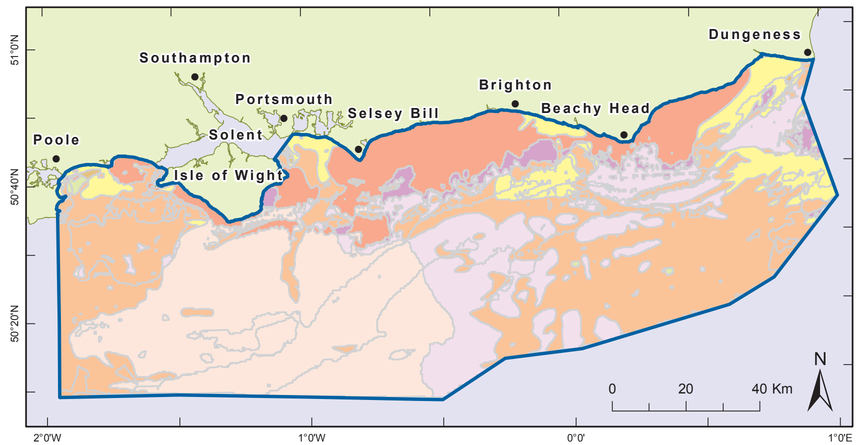


Figure 84 Comparing EUNIS maps from the synthesis study and UKSeaMap2010 projects. Brackets () indicate EUNIS classes created by the synthesis study.

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The root cause of these differences between the modelled maps can be traced to two sources, the first being the limited capacity of seismic survey techniques to discriminate thin layers of sediment from underlying rock, and the second being the structure of the EUNIS classification system, which allows only rock or sediment biotopes and does not sufficiently consider the nature of biotopes that arise where rock and sediment occur in close association.

There is also a notable difference in the dominant sediment type between the two modelled maps, coarse sediment (A5.1) featuring widely in the UKSeaMap, but mixed sediment (A5.4) being predominant in the synthesis study map. This arises because the two projects have used slightly different groupings when simplifying the Folk sediment trigon (James *et al*, 2010) into the four more general sediment classes, namely coarse, sand, mud, and mixed sediments. The grouping selected by the synthesis study shifted some of the Folk classes from the 'coarse sediment' group into the 'mixed sediment' and 'sand' groups, as evidence from grab data indicated both the grain-size spectrum and the fauna found in these samples were not consistent with 'coarse sediment' biotopes. The net result is that there are only very small areas of sublittoral mixed sediment (A5.4) in the UKSeaMap and only very small areas of sublittoral coarse sediments (A5.1) in the synthesis study map.

There is clearly a need to harmonise these different approaches in order to provide uniformity in interpretation and compatibility among the outputs of different studies. The fact that the synthesis study was not content to use the simplified sediment classification developed by the MESH project (MESH 2008) and adopted in the UKSeaMap2010 project suggests that its suitability needs to be reviewed in the light of results and evidence from more recent offshore habitat mapping

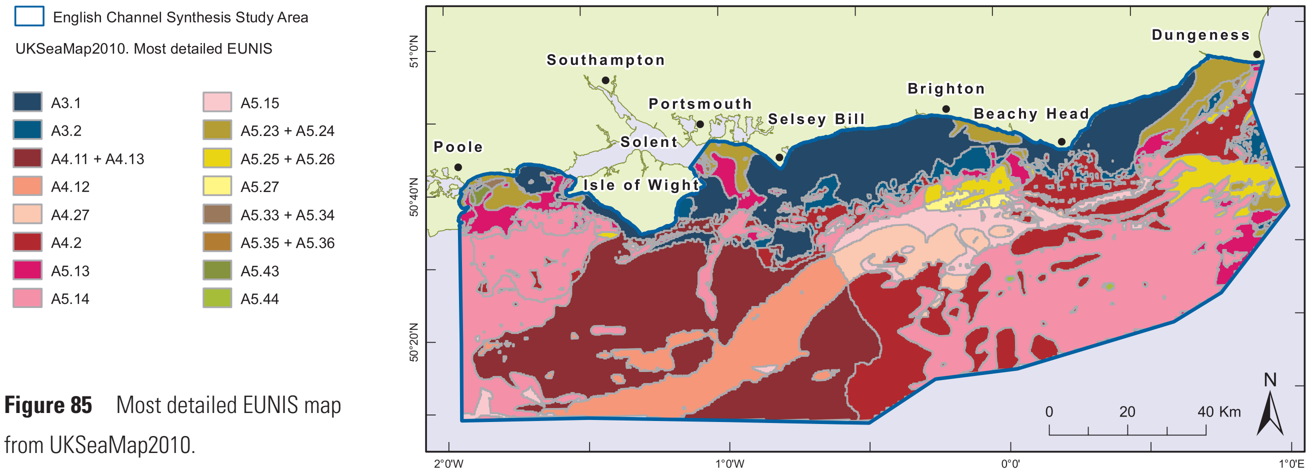

Figure 85 Most detailed EUNIS map from UKSeaMap2010.

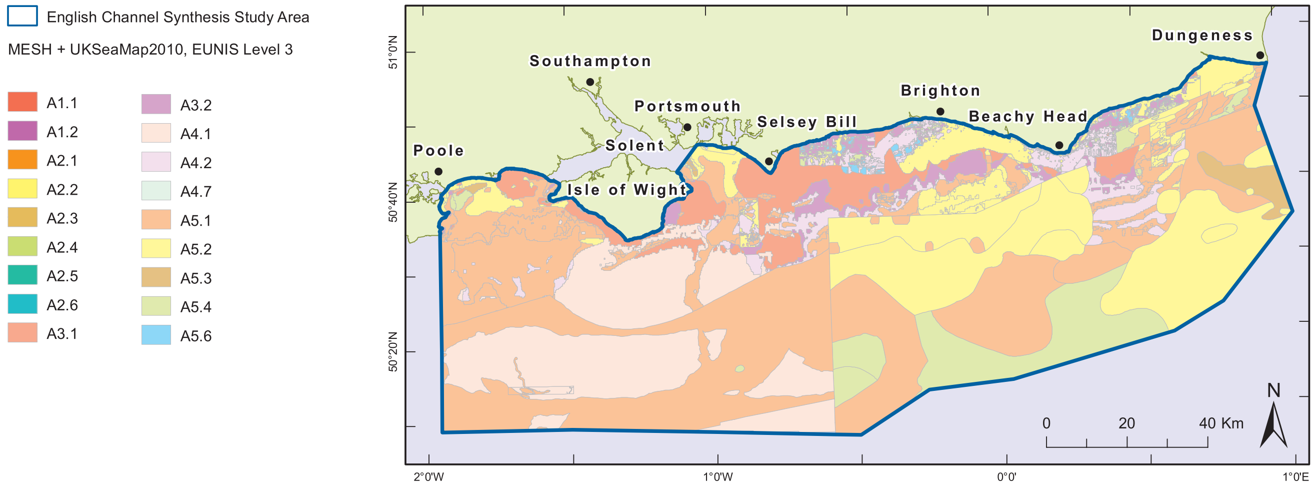

Figure 86 UKSeaMap2010's merger of their new map and the MESH project map, at EUNIS Level 3.

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studies conducted through initiatives such as the MALSF research programme.

Finally, there are some clear differences between the models in spatial resolution; the boundaries of the infralittoral habitat classes being somewhat 'blocky' in appearance in the synthesis study map, but more smoothly defined in the UKSeaMap2010 model. This reflects the more modern data layers for the photic/aphotic boundary that was developed within the MB0102 project (Brown, 2009) and implemented in the UKSeaMap2010, but could not be released during the modelling phase of the synthesis study.

Figure 85 shows a more detailed EUNIS model produced by the UKSeaMap2010 project, showing EUNIS level 4 classes where available, as has been done in the synthesis study map (Fig 84, top). The improved matching between the maps reflects that EUNIS Level 4 separates sublittoral sediment habitats into three biological zones, namely infralittoral, circalittoral and deep circalittoral. It is a quirk of the EUNIS system that the infralittoral-circalittoral split is performed at Level 2 for rock habitats but at Level 4 for sediment habitats; and that the deep circalittoral zone is introduced at Level 4 for both sediment and rock habitats. This is a fundamental flaw in the current EUNIS scheme that diminishes its effectiveness when applied to predictive modelling. The synthesis study has made a logical improvement by intoducing a deep circalittoral class at Level 2 for both rock habitats and 'rock & thin sediment' habitats (A4D.x, the D denoting Deep, see Table 7). This has helped to pick out the southwestern part of the Northern Palaeovalley as high energy, deep circalittoral rock (i.e. A4D.1), which has only two equivalents in the current EUNIS system, namely A4.12 'Sponge communities on deep circalittoral rock', and A4.27 'Faunal communities on deep moderate energy circalittoral rock'; classes that have been assigned to all the deeper parts of the palaeovalley floor in the UKSeaMap (Figure 85).

Another advantage of the synthesis study map is that it performs better in delineating sediment filled channels systems which provide important aggregate resources. It is particularly notable that the channel systems on the Selsey — West Sussex Coastal Platform, which hold important aggregate extraction sites at the Owers (Figure 12 & 13) are missing from the UKSeaMap model (Figure 85). The smaller channel system to the west of the Isle of Wight is also missing.

The final comparison is with a map produced by the UKSeaMap2010 project that combines the MESH EUNIS map with the UKSeaMap2010 model (Figure 86). This was constructed by overlaying the UKSeaMap2010 model with any sections of the MESH map that had a MESH confidence score >58%, indicating that the survey techniques must have used a combination of remote sensing and ground truthing to derive the habitat types. The most striking feature of this map is the sharp discontinuity in EUNIS classes between three large blocks in the map, two below the Isle of Wight and one covering the offshore section of the eastern half of the map. These three blocks represent the study areas of different projects, namely the South Coast REC (James *et al.*, 2010), a Defra funded project mapping reefs in the central Channel (Coggan *et al.*, 2009, Diesing *et al.*, 2009) and the Eastern English Channel Marine Habitat Map (EECMHM) (James *et al.*, 2007). Eradicating this discontinuity is precisely the 'raison d'être' for this synthesis study, which has harmonised and updated the interpretation and habitat class assignments made in the three prior projects.

Other 'blocks' or clusters of classification are notable to the southwest of Brighton and the southeast of Beachy Head, again reflecting areas studied by specific projects that contributed to the MESH map. These were much finer scale studies, covering smaller areas, and hence produced a greater density of mapped polygons, which can be regarded as a 'higher resolution' biotope map. The major problem with applying this mixed MESH & UKSeaMap2010 map is that it appears to be internally inconsistent and confused, as each of the surveys underlying the MESH parts of the map were done at different spatial scales using a different range of sampling techniques. For example, the polygons that MESH used from the EECMHM study are based on analysis of grab sample data (sediment type and benthic infauna) whereas those in the central Channel reef study are based on sonar, video and grab sampling. In comparison, the EUNIS map produced by the synthesis study (Figure 81) is an interpretation of all the availabe data, underpinned by the best available sea bed morphology model, and so is more regionally consistent in its interpretation and in the assignment of habitat classes.

Another significant broad-scale mapping initiative published recently is the output from the CHARM II project (Carpentier *et al.*, 2009). However this approaches mapping from a different perspective, that of resource management, so the maps portray the distribution of individual species of interest, including commercial fish species, rather than mapping habitats and biotopes per se. The CHARM II project uses the term 'Habitat' to refer to the area in which a species lives, rather than to describe a distinct and recognisable community. Consequently, direct comparison of the CHARM II maps and the synthesis map are not possible. The only comparison that can be made is with a map of benthic communities used by the CHARM II project (page 94 in Carpentier *et al.*, 2009 & Figure 87), which presents five different classes, named according to the type of substrate which they characterise. The data on which this map is based has been collected by systematic grid surveys conducted by French researchers using dredge and grab sampling techniques in the 1960s and 1970s. Despite the high sample density, compared to some UK projects, there is limited spatial resolution as broadscale bathymetry data or morphological models are not as readily available in France as they are

English Channel Synthesis Study Area

CHARM II Benthic Communities

- Pebbles
- Coarse heterogeneous sandy gravel
- Fine heterogeneous sandy gravel
- Sand
- Fine sand

Data source:
L. Cabioch *et al.*, (1972-1976)
Roscoff Biological Station.
Numerical analysis by Sanvicente Anorve (1995)

Courtesy of Dr A Foveau, IFREMER

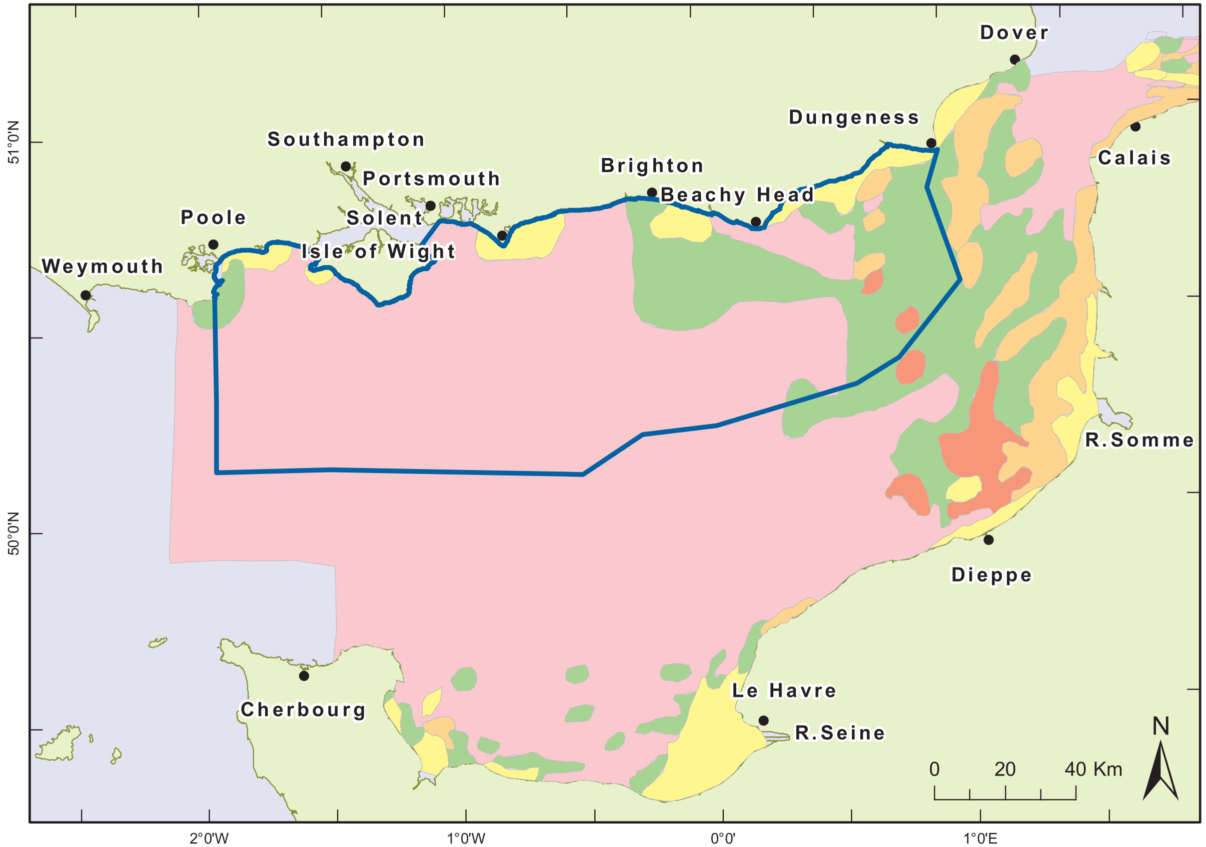

Figure 87 Distribution of benthic community types, based on French legacy data.

in the UK. However, the now familiar pattern of communities associated with coarse sediments in the west and central regions changing to communities of sandy sediments in the east and towards the UK coastline is still evident.

In summary, the synthesis study's modelled EUNIS map appears to have a number of advantages over other recent broadscale mapping outputs that cover this study area, providing a good match to what is actually found 'on the ground'. This is achieved by implementing suggested modifications to the EUNIS classification. However, it remains a habitat map at a regional scale, which can be improved as further data becomes available.

Note

The MALSF has also funded a project (Hooper *et al* 2011), which has used data collected by EMU Ltd in an area of the eastern English Channel, with the aim of developing a representative regional set of biotopes or regional variants of existing biotopes, and produce a methodology for future studies of this type in other areas. To facilitate the biotope mapping process for stakeholders, the project also aimed to develop an interface for determining biotopes from survey data. The project has been undertaken in the same time frame as the synthesis study, and although both have progressed and reported independently they are seen by the MALSF as being complementary projects. See www.marinealsf.org.uk for both published reports.

Reef and sand bank habitats

Reefs and sand banks are considered to be important habitats because they have special qualities that help keep the marine ecosystem healthy and productive. On land, we are familiar with some special habitats like woodlands and wetlands, and the fact that some of these areas are protected for our benefit. For example, natural woodlands can have a particularly rich and diverse range of animals and plants, while marshes and other wetlands can be important as natural flood defences, both inland and around the coast. These are among many of the terrestrial habitats that can be designated for special protection.

In a similar way, rocky reefs and sand banks have been identified as two of the marine habitats that are of conservation importance. The legal requirement for our country to protect a representative proportion of these special habitats was set out in the European Habitats Directive (European Commission, 1992). Annex I of this Directive lists important habitats that must be protected, and Annex II lists important species. Reefs and sand banks are two of the seven marine habitats listed in Annex I.

Figure 88 Example of a sidescan sonar mosaic of the sea bed showing a rock outcrop (darker area) and sand (lighter area). Note the fissures in the rock and the ripples on the sand. The dark, parallel diagonal lines are artefacts of the sidescan sonar processing technique and do not exist on the sea bed. Each of these dark lines represents one pass over the area by the survey vessel. The distance between the lines is about 200 metres.

One of the difficulties that the UK faced in complying with the Habitats Directive was that whilst there is a very large amount of sea bed very little of this had been mapped in any detail. Consequently we did not know where all the reefs and sand banks were and could not reliably estimate how much of our sea bed they covered. Since then, there has been several initiatives aimed at improving these maps and the Joint Nature Conservation Committee (JNCC) has responsibility for compiling all the new data to bring the maps up to date. New information, like the habitat maps produced in this and other studies funded by the MALSF, are important contributions to developing a definitive map for the UK sea bed. In the section below we will compare our map for reef habitats in the synthesis study area with the draft map that the JNCC are working on, but first of all it is important to understand some of the problems that are involved.

Rocky Reefs

To make a map of 'rocky reef' habitats, 'rocky reef' must first be accurately defined to know precisely what it is that should be mapped, but this is actually quite difficult in practice. In simple terms, any area of rock that sticks out of the sea bed can be regarded as a reef, even if it has no life growing on it. So we can map all rock outcrops as reef areas. But what about areas of the sea bed that are covered by boulders and cobbles? These are rocks too and support the same type of animals and plants that are found on rock outcrops, so these can be thought of as stony reefs. But this raises another question; how many stones do you need to make a reef? Is one stone a reef, or do you need ten, or a hundred, or a thousand? And what if you have thin layers of sediment over the bedrock, like sheets of gravel or sand, up to a metre thick, that slowly

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get moved around by the tides and currents? Some of the animals and plants found in such situations are fixed to the underlying rock, whilst others specialise in living in or on the sediments; so does this qualify as a rocky reef habitat or not? Because of these difficulties, the EU published a guidance document where it laid out definitions for each of the seven Annex I Marine Habitats (European Commission, 2007a & b), and this recognises rock outcrops, stony areas (hard substrates) and rock & thin sediment areas as reef habitats (Figure 89).

One technological difficulty that we have to overcome in marine habitat mapping is that we cannot get satellite images of the sea bed in the same way that we can get them for areas on land. This is because satellites use light to take photographs, and light gets reflected from the surface of the sea, so the sea bed cannot usually be seen unless the water is very clear and quite shallow. Instead we have to use ship-based sonar instruments that work on the same basic principle as an echo-sounder, using sound rather than light to detect the sea floor (see pages 32–36). Sound travels very well through water, much better than light, which is one reason why whales and dolphins have very well developed sonar senses that they use for communication and 'echo-location'.

The advanced sonar and seismic instruments used on survey ships can remotely sense the sea bed surface and the underlying structure of the sediments and rocks. Exposed bedrock is hard, giving a very strong echo, so sonar instruments are good at detecting bedrock outcrops (Figure 88).However stones are also good at reflecting sound, therefore areas of the sea bed with a high proportion of boulders or cobbles also appear as 'hard substrate', and cannot easily be distinguished from exposed bedrock. Sandy and muddy sediments tend to absorb sonar pulses, so these give a very weak echo. But where sediments occur in thin layers (<1 metre thick) on top of bedrock, the sound that passes through them is

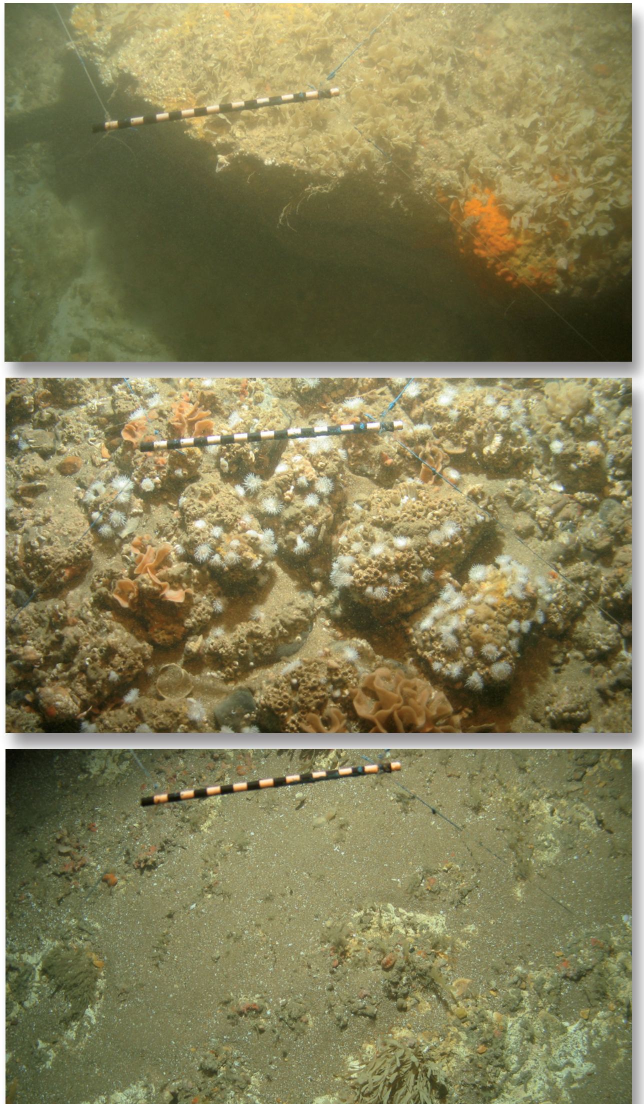

Figure 89 Examples of different types of 'rocky reef'. Rock outcrop (top), stony reef (middle) and rock & thin sediments (bottom). (Scale bar 20 cm)

strongly reflected by the hard underlying rock, so these areas also appear like rock to an acoustic sensor. To solve this problem of discriminating between rock outcrop, stony reef or rock & thin sediment we take small 'ground-truth' samples from these areas of sea bed, using underwater cameras to actually see what is there, or small grabs to collect some of the material lying on the sea bed surface (see pages 37–38).

The practical difficulties that these technical limitations pose on mapping rocky areas are evident when we start comparing the synthesis maps with those that the JNCC are developing. Figure 90 shows the JNCC's draft map for Annex I reefs, overlaid with an outline of the EUNIS habitat classes that are consistent with rock outcrops identified by the synthesis study, that is the existing EUNIS classes A3.1, A3.2, A3.3, A4.1, A4.2, A4.3, and some of the new classes defined by the synthesis study for deep circalittoral rock, namely A4D.1, A4D.2 and A4D.3.

The JNCC's draft map is based on recent work by the British Geological Survey (Gafeira *et al.*, 2010) who produced a modelled map of the distribution of 'rock and hard substrates' for the whole UK continental shelf, based on a re-interpretation of their archive of data from past geophysical surveys using seismic, sonar, coring and grab sampling techniques. The JNCC consider all these areas of rock and hard substrate to be 'Potential Annex I reefs' and can positively map some areas within this as 'Known Annex I Reef' where there is evidence from supporting surveys and ground-truth sampling (e.g. Coggan *et al.*, 2009; Diesing *et al.*, 2009) that show the sea bed at these locations is consistent with the definition of 'reef' given in the EU guidelines.

Figure 90a shows the rock outcrop habitats mapped by the synthesis study, which have a total area of 1 762 sq km. This map confirms three of the 'Known Annex I Reef' areas already identified by the JNCC, but it also shows three new areas that might now be considered as 'Known Annex I Reef' if the supporting evidence from ground-truth sampling is sufficiently robust. It is notable that the new area to the southwest of the Isle of Wight lies largely outside the main 'Potential Annex I Reef' areas mapped by the JNCC. There is also an area of 'Known Annex I Reef' just south of Selsey Bill that does not feature among the 'rock outcrop' outlined by the synthesis study, but this may be a stony area that the JNCC has already confirmed is consistent with the definition of Annex I Reef.

Figure 90b compares the areas mapped by the synthesis study as 'rock & thin sediment' (a total of 6 717 sq km) with the remaining 'Potential Annex I Reef areas' from JNCC's draft resource map. Although there is a lot of commonality, there are some significant differences near the coast. To the west of the Isle of Wight there could be more potential Annex I reef than currently suggested by the BGS 'rock & hard substrate' map, as the synthesis study has mapped much of this area as 'rock & thin sediment'.

Conversely, there are two areas about 20 km west and 20 km east of Beachy Head that are mapped as 'rock & hard substrate' (i.e. Potential Annex I Reef) but are not covered by the synthesis study's class of 'rock & thin sediment'. This means that we consider the sediments in these areas to be relatively thick (>1 m), particularly in the sediment-filled channels, so the sea bed habitats and communities are more likely to be consistent with sediment biotopes than with rock biotopes. It will be interesting to know what experience the local fishermen, anglers and divers have of these specific areas. If they are clearly sediment dominated then they can be added to the class that the JNCC's uses to map areas that are positively identified as 'Not Annex I Reef'.

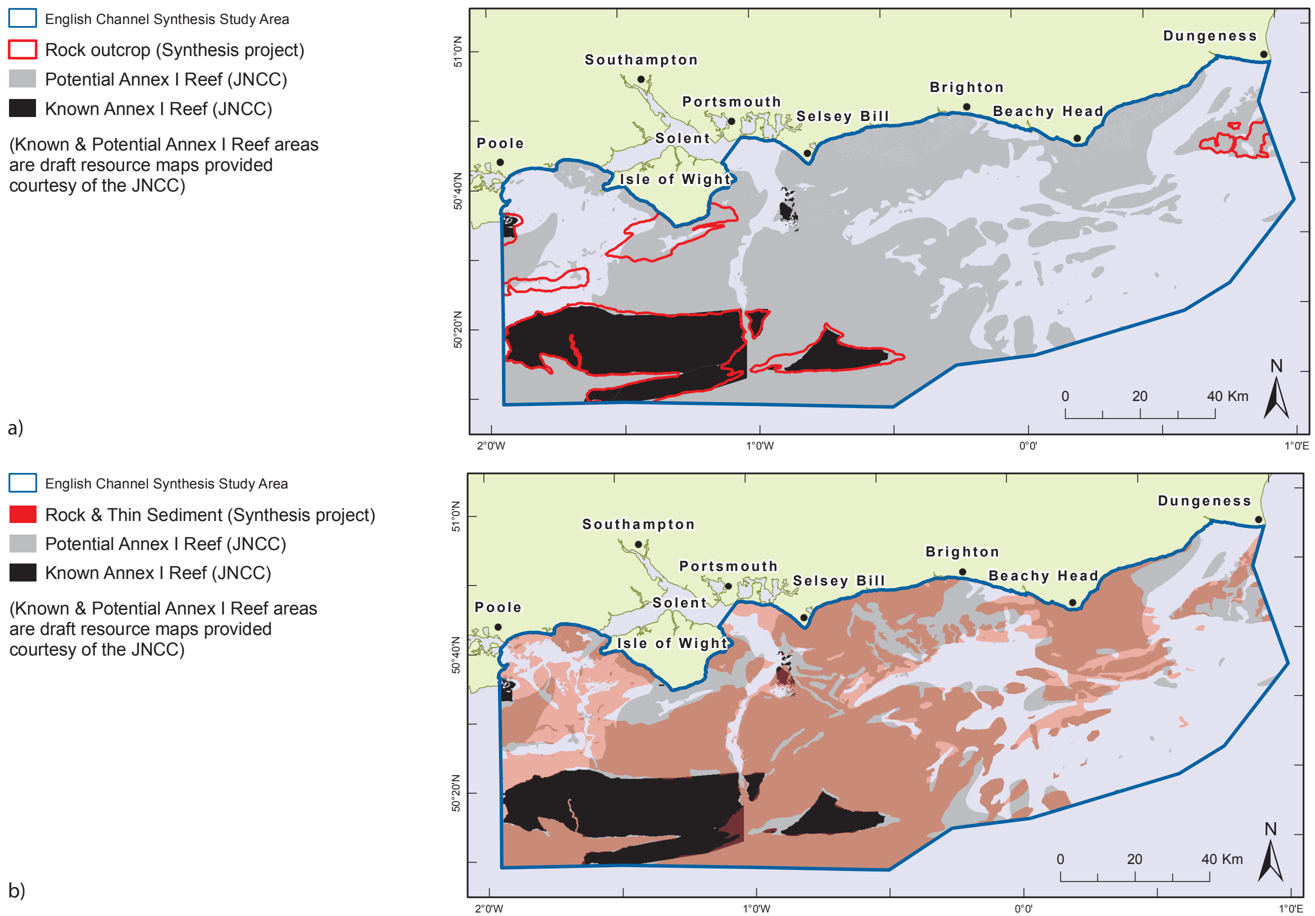

Figure 90a & b Areas of rock and rock and thin sediment mapped by the synthesis study compared with draft JNCC resource maps.

Sand banks

Parts of the sea bed in the synthesis study area are dominated by sand, and this can be fashioned into a variety of bedforms such as megaripples, sand waves and sand banks, depending on the local topography, sediment supply and currents. The location of these various bedforms is shown in Figure 92 and 72.

Sand banks are important habitats for many creatures both as a place to live and a place to feed. They provide a home for burrowing invertebrates such as worms, crabs and shrimps, bivalves and sea urchins, and also for some fish, especially the sandeel (*Ammodytes* spp.). Sandeels are very rich in oil and provide high energy food for other fish (Figure 91) and sea birds. They are commercially fished and used in animal feedstuffs and fertilisers. Until recently, some countries even used them as fuel in their power stations.

Closer inshore, sand banks also provide habitat for eelgrass *(Zostera marina)* and maerl beds (made of free-living coralline algae). These biogenic habitats support a high diversity of species and are fairly rare in the UK, so are considered to be of high conservation value.

Because of the importance of sand banks as marine habitats they are listed under Annex I of the Habitats Directive and may be subject to statutory conservation measures. The Habitats Directive specifically targets shallow water sand banks that are 'slightly covered by seawater all the time'. In practical terms this has been interpreted to mean that their shallowest points are less than 20 m below Chart Datum (BCD).

Figure 91 A whiting hunting sandeels on a sand bank.

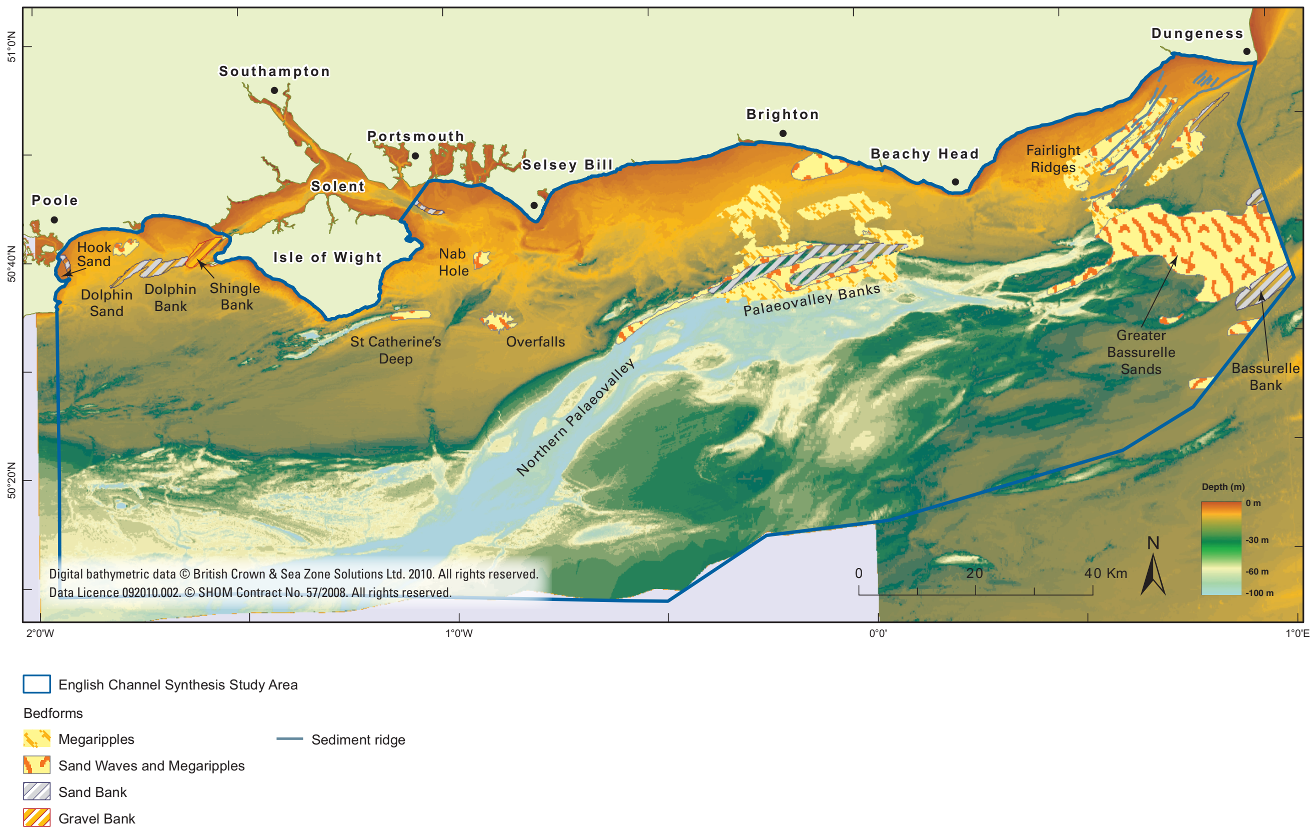

Figure 92 Bedforms and sea bed morphology. (See also figure 72)

Sand banks are mapped at seven locations in the synthesis study area. Three of these are in the shallow coastal waters in the north west of the study area. The first , Hook Sand, extends about 3 km (~2 Nautical Miles (NM)) southeast from Poole Harbour in water that is less than 10 m (BCD). The second extends west from 'The Needles' on the Isle of Wight and has two distinct crests, each about 7 km (~4 NM) long. Nautical charts show the depth here is generally less than 20 m BCD and the crests are 'Dolphin Bank' and 'Dolphin Sand' which shoal to depths of 7.9 and 9.6 m BCD respectively. Adjacent to these and closer to the western mouth of the Solent, there is also a gravel bank Shingle Bank. Parts of this dry out at low tide. The third sand bank lies just south of Portsmouth harbour and is the southern extension of Horse and Dean Sand, known as 'Horse Tail'. The crest is about 5 km (~3 NM) long and has a depth of less than 5 m BCD along its whole length.

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There is a much larger bank system on the margin of the Northern Palaeovalley. This is not named on nautical charts, most likely because it is in deeper water (30 to 50 metres) and does not pose a hazard to navigation. They are named the Northern Palaeovalley Banks (James *et al.* 2010). They extend for around 35 km (~19NM) and have two main crests which are at approximately 30 m BCD for most of their length. (see pages 66–73).

The three remaining sand banks lie in the extreme east of the study area. The first is quite small, about 9 km (~5 NM) long, lying a little way southwest from Dungeness It is not named on nautical charts, but the crest has a depth around 18 m BCD. To the north of this sand bank, in the lee of Dungeness point, lie a series of parallel sand ridges, the Fairlight Ridges, that extend as much as 35 km (19 NM) in a southwest direction. As the sea bed becomes shallower, onshore so the crests of these ridges become shallower, ranging from around 15 to 5 m BDC.

The last two sand banks are the westerly 'tail ends' of the Bullock Bank and the Bassurelle, which are prominent shallow features in mid-channel approaching the Dover Strait. The crest of the Bullock Bank lies just to the east of the synthesis study area and is charted at 14 m BCD. The crest of the Bassurelle extends about 7 km (~4 NM) into the synthesis study area, where it lies at about 14 m BCD, though the shallowest part of the Bassurelle is only 5 km (~3 Nautical Miles) outside the study area and has a charted depth of 7 m BCD.

Six of the seven sand banks mapped by the synthesis study have their crests in water shallower than 20 m BCD and so meet the criteria set out in Annex I of the Habitats Directive. In addition, the sand ridges between Dungeness and Beachy Head would also appear to qualify. However, in the context of the UK as a whole, the sand banks and ridges identified in the synthesis study area are not of 'national importance', as far more extensive areas exist in the southern North Sea, specifically in The Wash, off North Norfolk and on the Dogger Bank. It is therefore likely that the sand banks identified in Figure 72 and 92 will continue to remain available as a potential aggregate resource.

Application of a surface roughness model to help identify potential reefs and sand banks

One problem associated with mapping reef and sand bank areas is that they sometimes occur as distinctly linear features and consequently can be difficult to recognise using modelled sea bed bathymetry (as in Figure 93 top) and difficult to represent in a polygonised map, such as the modelled EUNIS habitat map (Figure 81). As both rocky reefs and sand banks tend to be structures that are elevated above the surrounding sea bed, mapping the 'roughness' of the sea bed has the potential to identify them from their surroundings. Such a roughness model was developed using simple GIS analysis techniques applied to the sea bed bathymetry model, and is presented in Figure 93 (bottom) and Figure 75.

Conceptually, this particular roughness model used a 7 pixel x 7 pixel 'moving window' and calculated the standard deviation of the 49 depth values in that window; each pixel representing 25 sq m of sea bed. If the area was smooth, the 49 depth values would all be similar, giving a low standard deviation (Figure 94, top). If the area was rough, there would be a lot of variation in the 49 depth values, giving a high standard deviation (Figure 94, bottom). Making this calculation for every possible 7 pixel x 7 pixel window in the bathymetry model provided a roughness model for the whole area.

The areas that have been mapped as rocky reef, gravel banks, sand banks and sand wave fields stand out well in the roughness model, but it also reveals many linear features, some of which have not been mapped. Typically, these are ridges in the sea bed and could be attributable to low-lying rock outcrops or sand 'trains', which are narrow but extend for long distances. These long narrow shapes are practically impossible to represent as polygons on the modelled EUNIS modelled maps, because they would be too thin to see. The roughness model could be overlayed on the EUNIS map, but this would only tell us where areas were rough or smooth. Instead, reverting to expert interpretation of the available information, using the roughness model, the bathymetry model and the sea bed character model would help us judge which of the linear features in the roughness model are rock and which are sand. This approach was used to map the sandy Fairlight Ridges near Dungeness in Figure 72 & 92, where they are represented as lines, rather than polygons.

The human eye remains one of the most sophisticated image analysis 'instruments' available and even the layman can begin to interpret the combined image of the roughness model and the bathymetric model (Figure 93 bottom) as well as sea bed character (Figure 75) and tell which areas of roughness are most likely to be rocky reef and which are sand banks or sand wave fields. One of the advantages of using the roughness model is that it is objective and can pick out fine linear features that might be overlooked by a human observer focusing on the broader, regional interpretation.

For example, the roughness model highlights an area about 5 km south of Selsey Bill. On nautical charts this is known as 'The Looe' and is notoriously rocky and hazardous to navigate. The western edge of The Looe is known as 'Boulder Bank' and is less than 1 m BCD. The circumstantial evidence therefore suggests this is a potential rocky reef area, but this would need to be confirmed by ground-truth observations before it can be mapped as such.

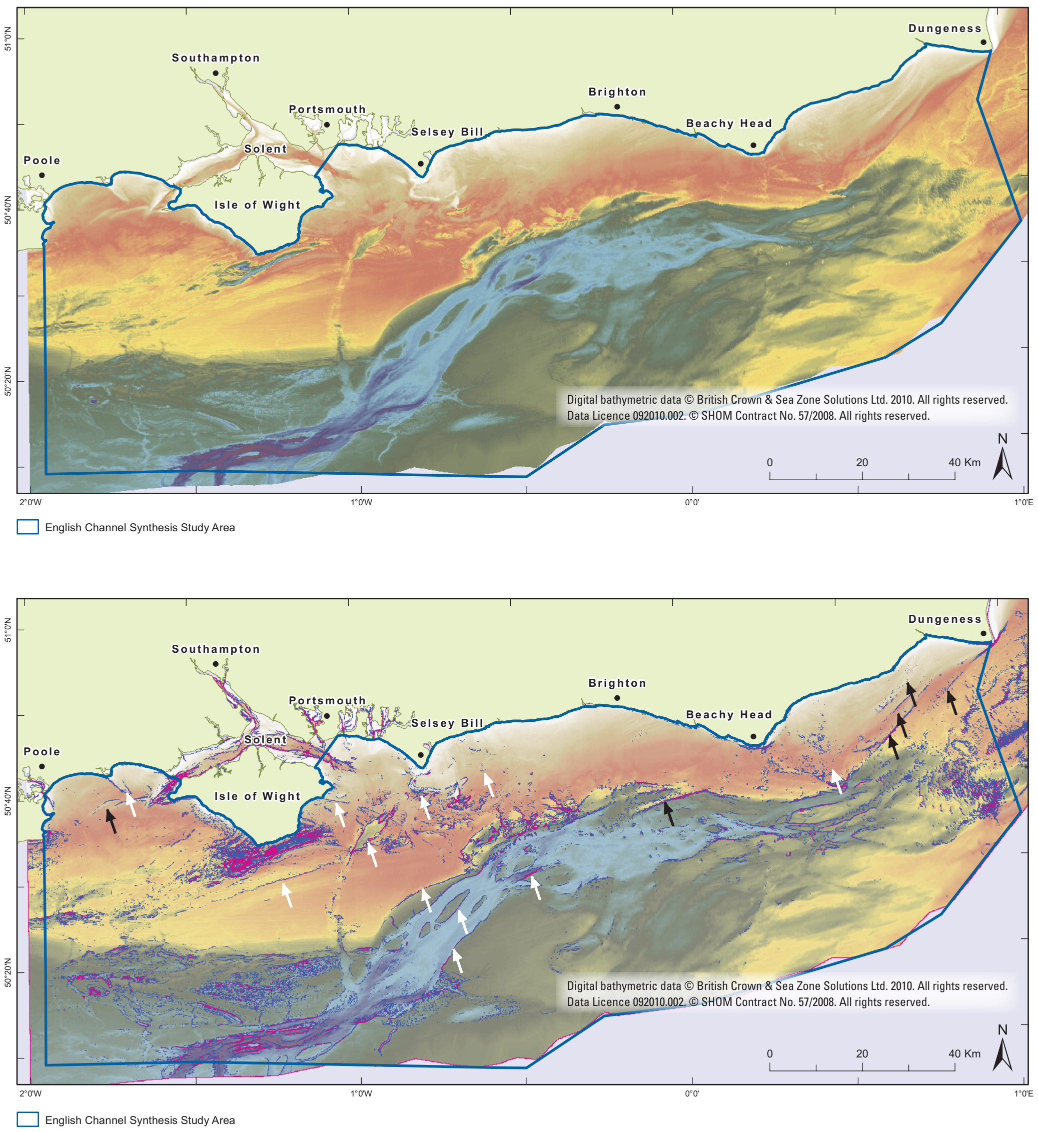


Figure 93 Morphology model (top), and with an overlay showing sea bed surface roughness (purple overlay in bottom image). Arrows highlight linear features; black arrows = potential sandbanks, white arrows = potential rock outcrops.

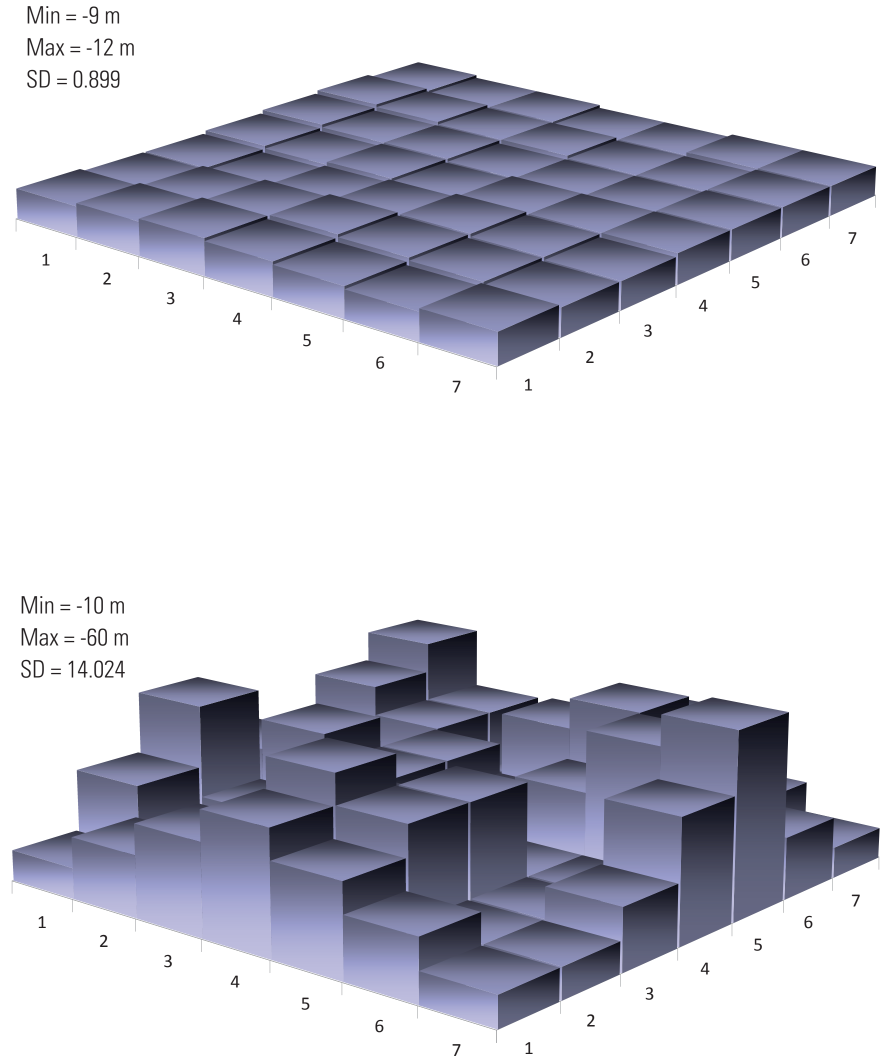


Figure 94 Schematic diagram illustrating method of deriving the sea bed roughness model by calculating the standard deviation (SD) of depth values in a 7 pixel x 7 pixel 'moving window'. Top = smooth seabed, low SD; bottom = rough seabed, high SD.

Functional biological communities

The distribution of benthic or bottom living animals in the marine environment is influenced, in part, by the physical conditions. The type of substrate, whether the sea bed is hard, rocky and immobile or composed of mobile sediments, as well as environmental conditions such as strength of tides and waves, and available light levels, can determine the types of animals that occur. There is however, a large element of chance involved in the presence of many marine benthic species and, consequently, their distribution can be very patchy. This is because the vast majority of marine invertebrates release their larvae into the water column where they are subject to often considerable water currents and may be carried a large distance from their parents. The eventual settlement of new recruits depends on numerous factors including the availability of suitable habitat at the right time either through disturbance or natural mortalities of individuals and the 'right' environmental conditions to enable new arrivals to grow and survive. These chance elements mean that marine communities are usually highly variable in terms of particular species that are present. However, different species may fulfil the same ecological role or function in a community such as 'encrusting filter-feeder' or 'infaunal polychaete'. Thus, communities of animals can be defined in terms of broader functional groupings rather than specific species. For example, where there is available space for encrusting species, barnacles are likely to occur, the most common in the synthesis area being *Balanus crenatus* and *Verruca stroemia*. Thus, at the functional level the presence of any barnacle species is the key to describing the community. It is therefore useful to apply 'functional biological communities' as a tool in the mapping of habitats in an area as large as that covered by the synthesis study.

Biological groups identified using the same standard multivariate analysis (MVA) techniques used by James *et al.*, 2007 and James *et al.*, 2010 were therefore amalgamated where they were characterised by species performing the same function. For example, a community dominated by *Pisidia longicornis*, the crevice-dwelling pea crab, was combined with a community which was dominated by *Galathea*, a crevice-dwelling squat lobster. These communities had many other species or functional components in common but were separated in MVA on the basis of which particular crevice-dwelling crustacean was most abundant. Four broad level functional communities were identified in the synthesis study as shown in Figure 95 and described in pages 95–102.

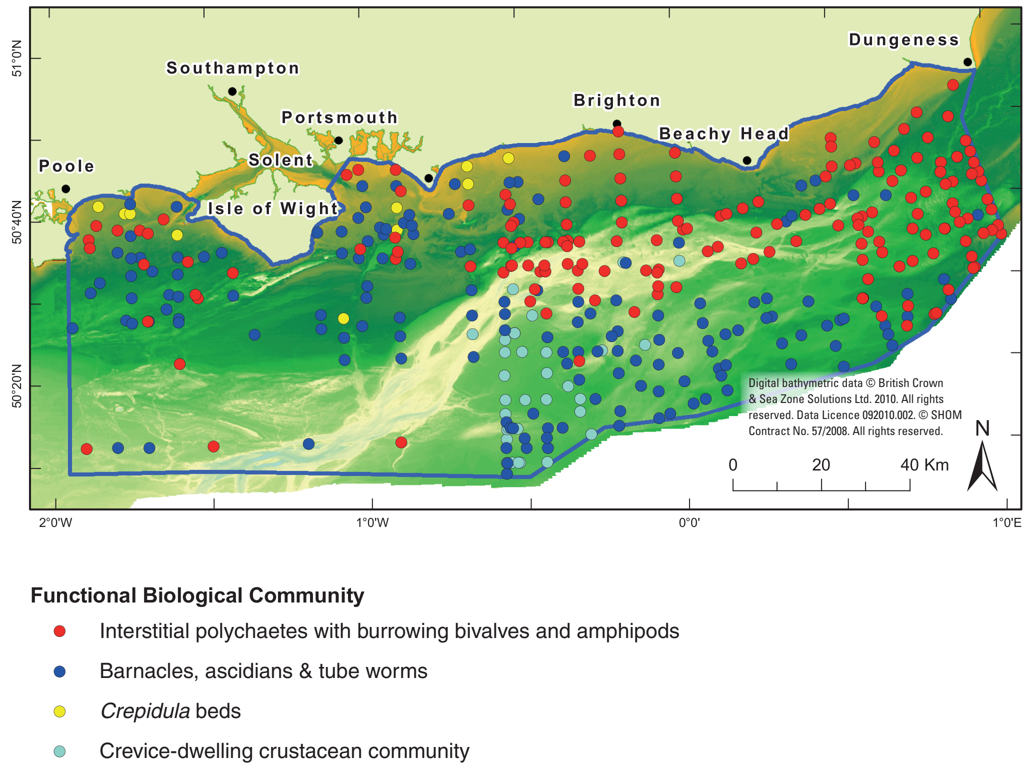
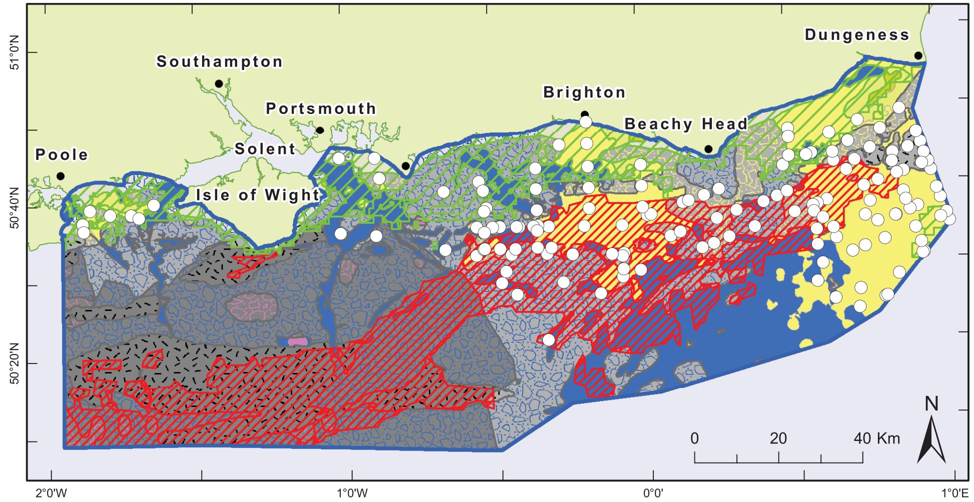


Figure 95 The distribution of functional biological communities at sample stations across the study area. (See Figure 43 for sample station numbers.)

Interstitial polychaetes with burrowing bivalves and amphipods



The distribution of the interstitial polychaetes with burrowing bivalves and amphipods community at sample stations across the study area and the modelled biotopes (EUNIS Level 4) upon which they are found (see Figure 81).

Most of the eastern half of the study area was found to support a community characterised by various species of interstitial polychaete including *Lumbrineris gracilis, Spiophanes, Notomastus latericeus* and *Poecilochaetus serpens*. This community was also characterised by the presence of burrowing bivalves, such as *Goodallia triangularis* and *Mysella bidentata* and burrowing amphipods belonging to the genus *Ampelisca*. The pea urchin *Echinocyamus pusillus* also formed an important component of this community in some areas. All of these species are infaunal, that is they live within the sea bed as opposed to living on its surface. The distribution of this community is therefore limited to areas of sand or sandy mixed sediments, where they are able to burrow and/or move through the sediments. Depth appears to have no influence on the distribution of this community across the study area. However, there is a notable absence of this community across the South Wight Platform indicating that the depth, stability and possibly the composition of sediment deposits may play an influential role in the distribution of this community.

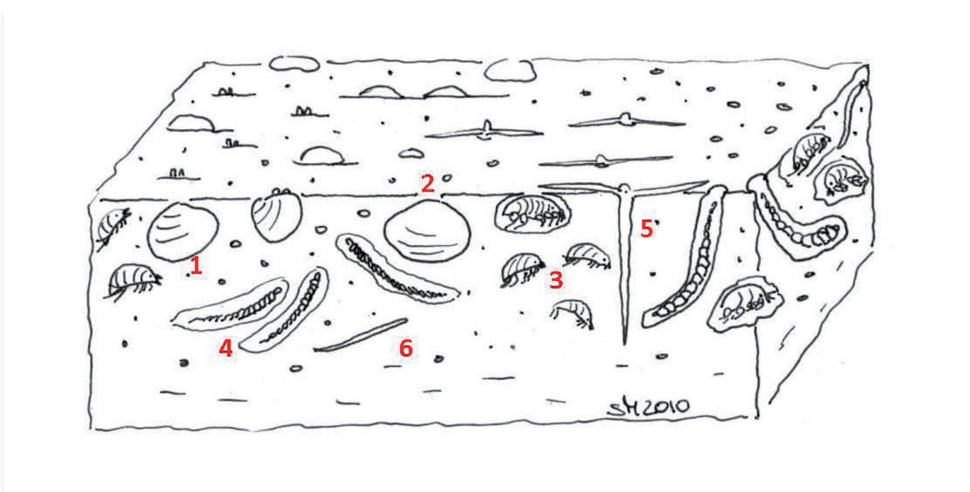
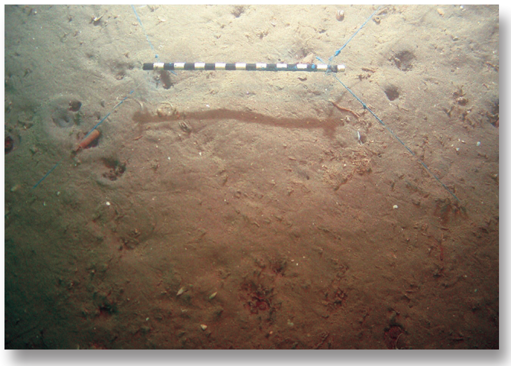
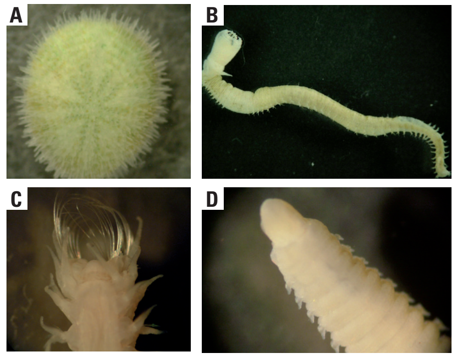


Illustration of the interstitial polychaetes, burrowing bivalves and amphipods community showing the main characterising species and their position in relation to the sea bed: **Bivalves**: 1. *Mysella bidentata* 2.*Goodalia triangularis*, **Amphipods**: 3. *Ampelisca* spp., **Polychaetes**: 4. *Lumbrineris gracilis*, 5. *Spiophanes* spp., 6. *Ophelia borealis* and other small infaunal polychaetes.



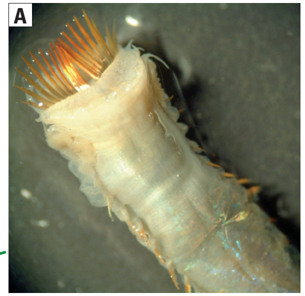
Sea bed image of an interstitial polychaetes, burrowing bivalves and amphipods community at Station 370. (Scale bar 20 cm.)

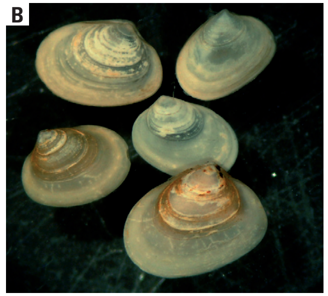


Species typical of the interstitial polychaetes, bivalves and amphipods community: pea urchin A) *Echinocyamus* B) *Glycera lapidum* C) *Poecilochaetus serpens* and D) *Lumbrineris*.

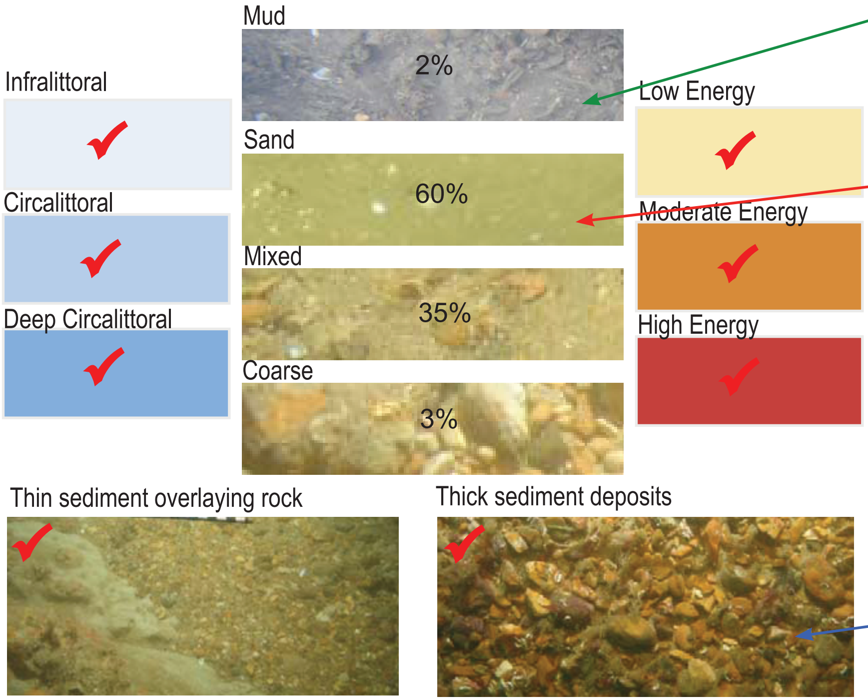
Variation in species composition

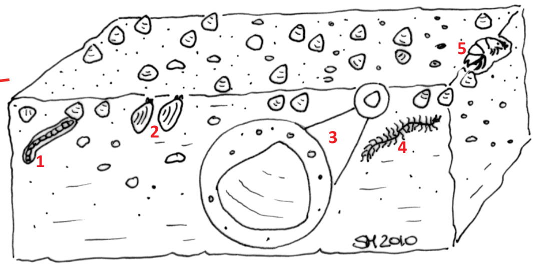
Although this community is characterised by interstitial polychaetes there is considerable variation in the precise species composition across the study area. This variation is also influenced by the composition of the sediment deposits. For example, the polychaete *Lagis koreni* is found in muddier sediment deposits whereas *Glycera lapidum* is more abundant in areas with a higher proportion of gravel. This highlights the need for a predominantly functional description of biological communities at this broad level (EUNIS Level 5). There may also be changes in the relative proportions of the major groups or species within this community. For example, where there are fine sands the bivalve *Goodallia triangularis* may become numerically dominant and in some areas the faunal composition was similar but animals were more sparsely distributed.



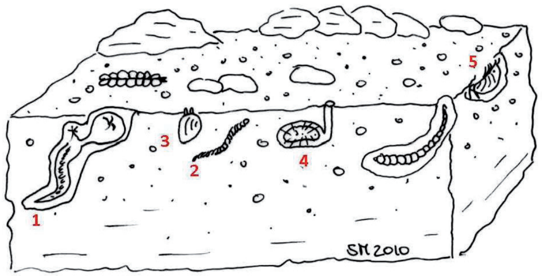


A community dominated by the tubiculous polychaete A) *Lagis koreni* and the bivalve B) *Mysella bidentata* was found in sheltered areas with increased mud.





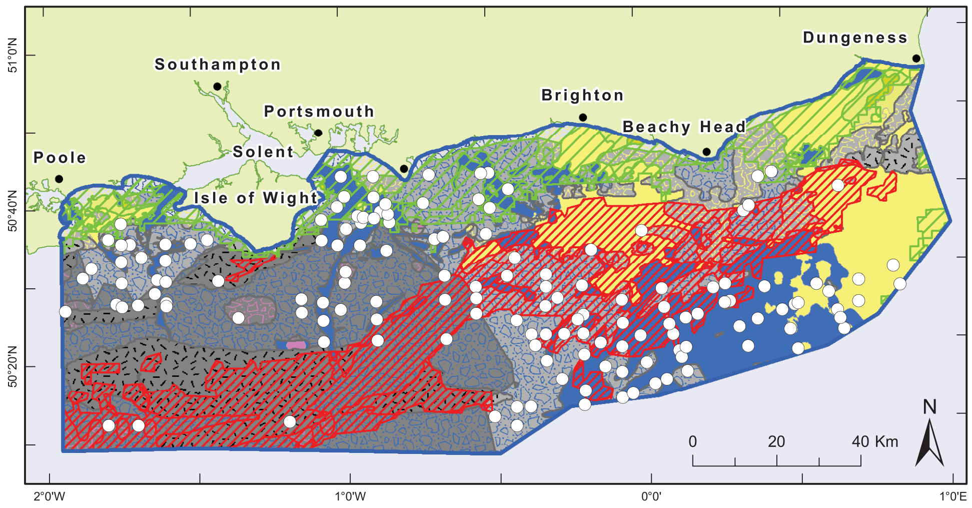
In areas of fine sand the community may be locally dominated by the bivalve 3) *Goodalia triangularis*.



In some sandy and mixed sediment areas the community may be similar in composition but sparsely populated.

Ticked boxes indicate the EUNIS Level 4 categories in which the community is found, and the percentage of samples that fall into each EUNIS sediment classification.

Barnacles, ascidians and tube worms



The distribution of the barnacles, ascidians and tube worms community at sample stations across the study area and the modelled biotopes (EUNIS Level 4) upon which they are found (see Figure 81).

A community dominated by barnacles, ascidians and tube worms is particularly widespread in the synthesis study area. It has been identified in several of the modelled EUNIS Level 4 habitats including shallow infralittoral, and deep circalittoral coarse, mixed and sandy sediments and thin layers of similar sediments overlying bedrock The distribution of this community is largely determined by the presence of stable coarse sediments to which these epifaunal species can attach. Over 80% of the stations at which this community was found were categorised as having mixed or coarse sediment.

Balanus crenatus is the most abundant and widespread barnacle associated with this community although *Verruca stroemia* is also present, albeit in much lower numbers. There were many areas where these two barnacle species were found to co-exist, indicating that there is significant overlap in their environmental requirements. Ascidian sea squirts are also abundant in this community, most notably *Dendrodoa grossularia*, although other ascidians which are more difficult to identify also represent an important component of the community. Two tube worm species were recorded in this community, the keel worm *Pomatoceros lamarcki*, and the Ross worm *Sabellaria spinulosa*. Neither species were present in very high abundance with an average of 5–10 individuals per grab.

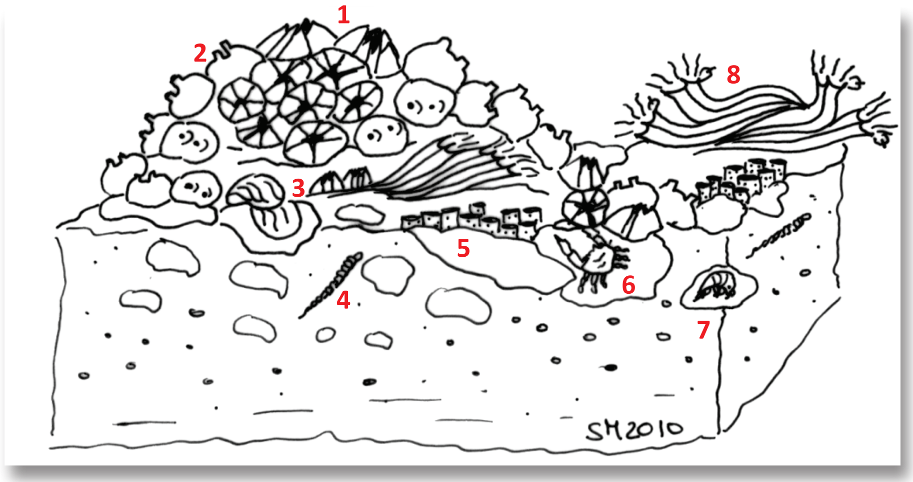
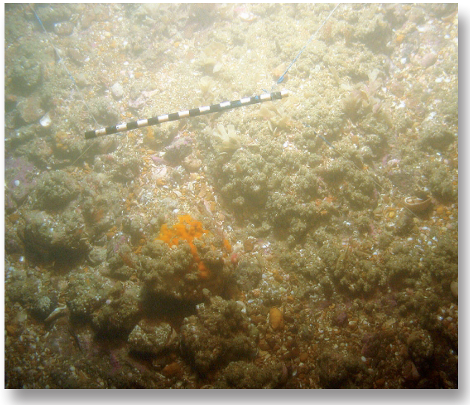
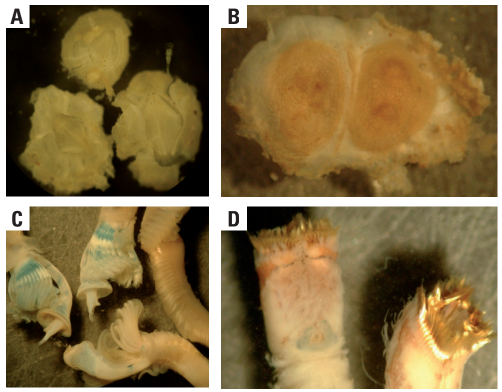


Illustration of the barnacle, ascidian and tube worm community showing typical characterising species and their position in relation to the sea bed 1. *Balanus crenatus* 2. *Dendrodoa grossularia* 3. *Crepidula fornicata* 4. *Lumbrineris gracilis* 5. *Sabellaria spinulosa* 6. *Pisidia longicornis* 7. *Ampelisca spinipes* 8. *Pomatoceros lamarcki.*



Sea bed image of the barnacle, ascidian and tube worm community at Station 326. (Scale bar 20 cm.)

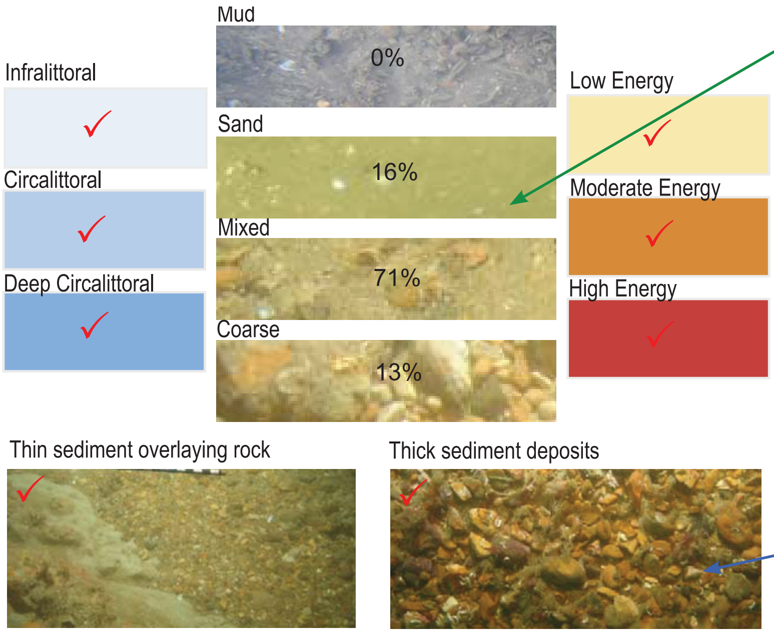


Characteristic fauna of the barnacle, ascidian and tube worm community: A) *Balanus crenatus* B) *Dendrodoa grossularia* C) *Pomatoceros lamarcki* and D) *Sabellaria spinulosa.*

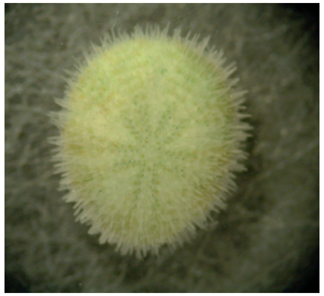
Variation in species composition

The precise species composition of this community will be determined largely by the random recruitment of larvae, meaning that different combinations of species will be present across the area in different abundances. There are, however, several species including barnacles and the tubiculous polychaetes *Sabellaria spinulosa* and *Pomatoceros lamarcki* that will settle preferentially where adults are already present and in these areas high abundance of a single species may persist over a number of years.

There is also an infaunal community within the smaller sediment particles between the gravels and pebbles of mixed and coarse sediments. For example, where there is a high proportion of sand the bivalve *Glycymeris glycymeris* may be common and the pea urchin *Echinocyamus* was also present in high numbers in sandy and mixed sediments. The squat lobster *Galathea* was abundant in some mixed sediments and this assemblage may represent a transition between barnacles, ascidians and tube worms and the crevice-dwelling crustacean community.



Ticked boxes indicate the EUNIS Level 4 categories in which the community is found, and the percentage of samples that fall into each EUNIS sediment classification.

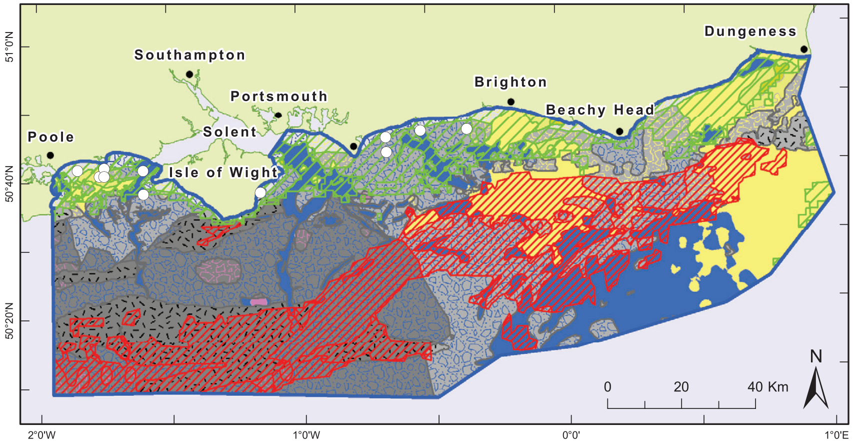


The small pea urchin *Echinocyamus* was common at some stations in sandy or mixed sediments.

At a few stations where the sediments had a higher sand component the infaunal 'dog cockle' *Glycymeris glycymeris* was sometimes present.

In some areas of mixed sediment there were high numbers of the squat lobster *Galathea*. This species tends to live under stones and rocks and in crevices.

Crepidula fornicata beds



The distribution of *Crepidula fornicata* beds at sample stations across the study area and the modelled biotopes (EUNIS Level 4) where they are found (see Figure 81)

The American slipper limpet *Crepidula fornicata* is an introduced species which has become well established in the synthesis study area. This mollusc is a sequential hermaphrodite which forms long-lived stacks of males, females, juveniles and adolescents in transition from male to female. Fertilisation is internal and it has been demonstrated that the eggs of a given female are commonly fertilized by multiple males, mostly found in the mother's stack. This behaviour is thought to contribute significantly to the reproductive success of *C. fornicata*.

Crepidula fornicata beds are limited to the infralittoral and shallow (~ 30m) circalittoral zone and are found in areas with some sand and mud. This sediment preference may in part be due to its utilisation of suspended organic material for food but may also result from accumulated faeces and pseudofaeces where *C. fornicata* is present in high densities. Where *Crepidula* beds develop, their exceptionally high densities physically exclude many other epifaunal species and the alteration of environmental conditions may also exclude others. However, the hard surface of the *C. fornicata* shell can itself form a home for epifaunal species including the tubiculous polychaete, *Pomatoceros lamarcki*, and barnacles as well as encrusting hydroids and bryozoans. Infaunal species which are able to tolerate, or even prefer elevated levels of fine particulate material, are also able to utilise the sediment accretions which develop between the stacks of *C. fornicata*. These include the sand mason worm *Lanice conchilega* and the tubiculous amphipod *Ampelisca*.

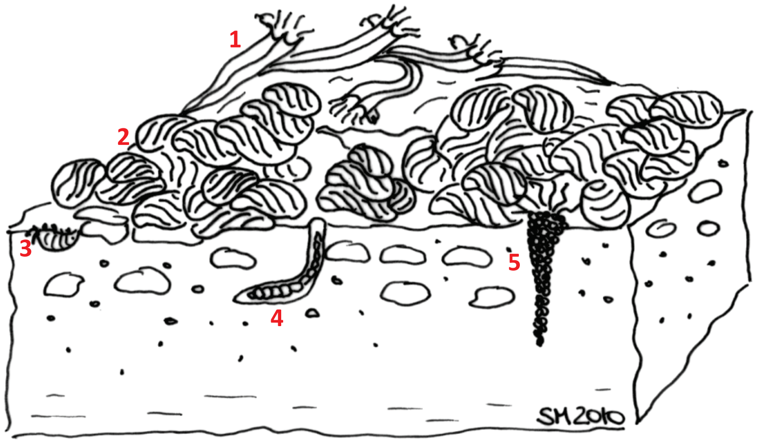
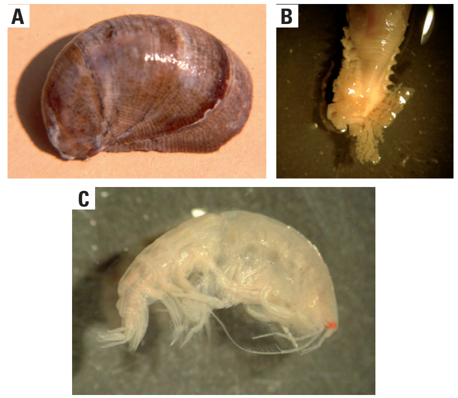


Illustration of *Crepidula fornicata* beds showing the main characterising species and their position in relation to the sea bed 1. *Pomatoceros lamarcki* 2. *Crepidula fornicata* 3. *Ampelisca* spp. 4. *Notomastus latericeus* 5. *Lanice conchilega*.

Sea bed image of a dense *Crepidula fornicata* bed at Station 165. (Scale bar 20 cm.)



Characteristic fauna of *Crepidula fornicata* beds: A) *Crepidula fornicata* B) *Lanice conchilega* C) *Ampelisca* spp.

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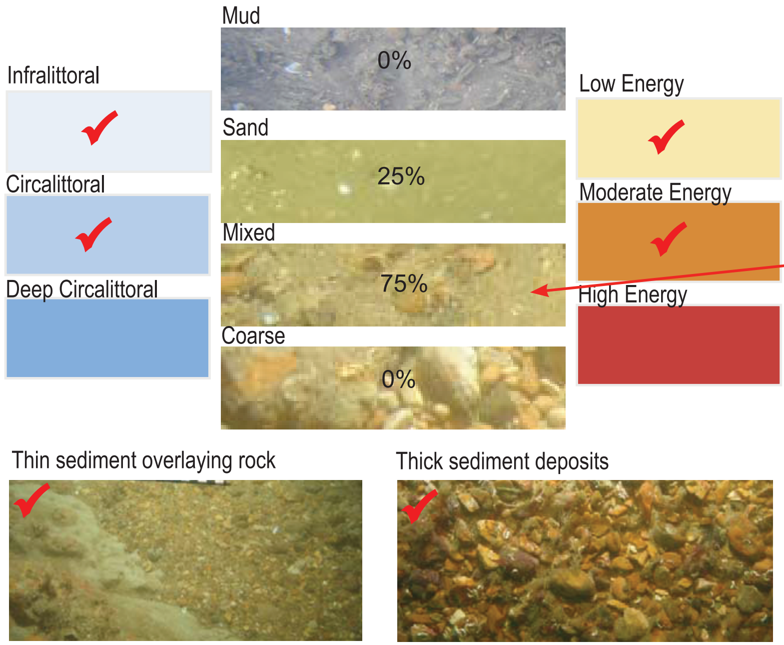
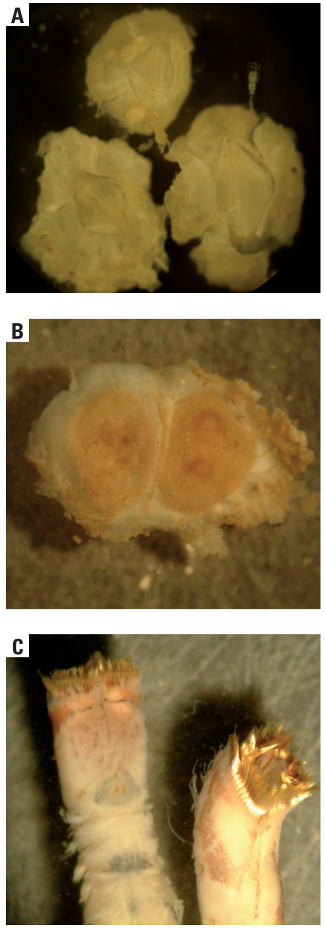
Variation in species composition

Where *Crepidula* occurs in dense beds it generally excludes many other animals and so species variation is not especially high in this functional community. However, in occasional patches of mixed sediment, where *Crepidula* is not present in high abundance, there may be space for the attachment of encrusting species, including the barnacle *Balanus crenatus*, ascidians like *Dendrodoa* and the tube building *Sabellaria spinulosa*. Thus, the distribution of the barnacles, ascidian and tube worm community has probably been limited by the presence of *Crepidula* in some areas.



Ticked boxes indicate the EUNIS Level 4 categories in which the community is found, and the percentage of samples that fall into each EUNIS sediment classification.



Where there are mixed sediments encrusting fauna such as the barnacle A) *Balanus crenatus*, the ascidian B) *Dendrodoa grossularia* and the tube building polychaete C) *Sabellaria spinulosa* may also be found.

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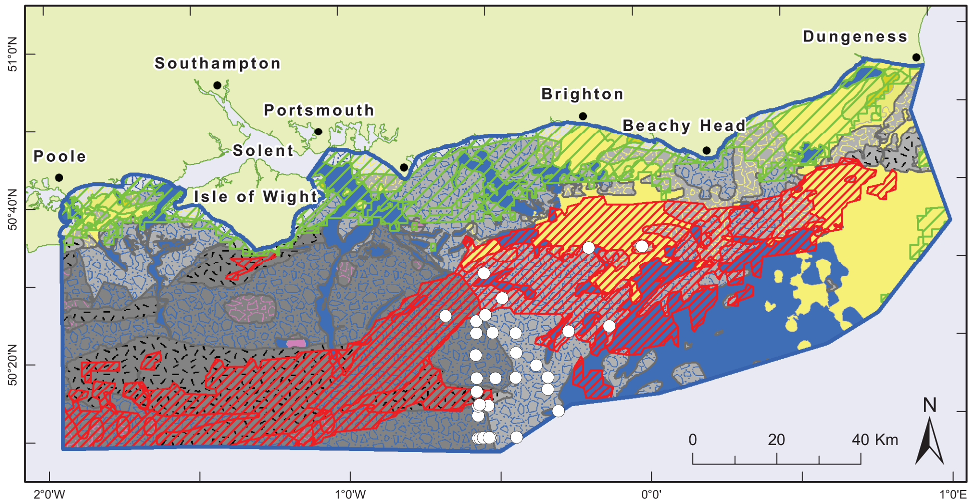
Crevice-dwelling crustacean community



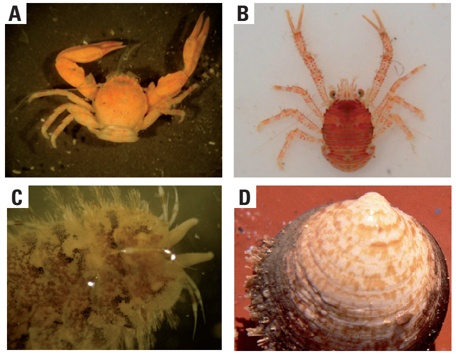
The distribution of the crevice-dwelling crustacean community in sample stations across the study area and the modelled biotopes (EUNIS Level 4) within which they are found (see Figure 81).

A biological community dominated by crevice-dwelling crustaceans was identified in association with circalittoral and deep circalittoral mixed sediments. This community was found on both thick mixed sediment deposits and thin mixed sediment overlying rock indicating that the thickness of sediment deposits is not a limiting factor in the distribution of this community. This community does however seem to be absent from the shallower infralittoral zone.

The main species that are characteristic of this community are the pea crab *Pisidia longicornis* and the squat lobster *Galathea intermedia*. Both of these crustaceans are small in size (<1 cm) and reside in the crevices between sediment particles. It is unsurprising that they are limited to the more heterogeneous sediment deposits of the study area. Other species, which were found to be characteristic of this community include the dog cockle *Glycymeris glycymeris*, a large and long-lived bivalve, and various scale worm species including representatives of the genus *Harmothoe*. Because the habitats in which this community is found contain a significant proportion of gravel, they also support epilithic species including the barnacle *Balanus crenatus* and the tubiculous polychaete *Pomatoceros lamarcki*, albeit in rather low abundances.

Illustration of the crevice dwelling crustacean community showing the main characterising species and their position in relation to the sea bed 1. *Pomatoceros lamarcki* 2. *Balanus crenatus* 3. *Pisidia longicornis* 4. *Glycymeris glycymeris* 5. *Galathea intermedia* 6. *Harmothoe* spp.

Sea bed image of a crevice-dwelling crustacean community at Station 375. (Scale bar 20 cm.)



Characterising fauna of the crevice-dwelling crustacean community: A) *Pisidia longicornis* B) *Galathea intermedia* C) *Harmothoe* spp and D) *Glycymeris glycymeris*.

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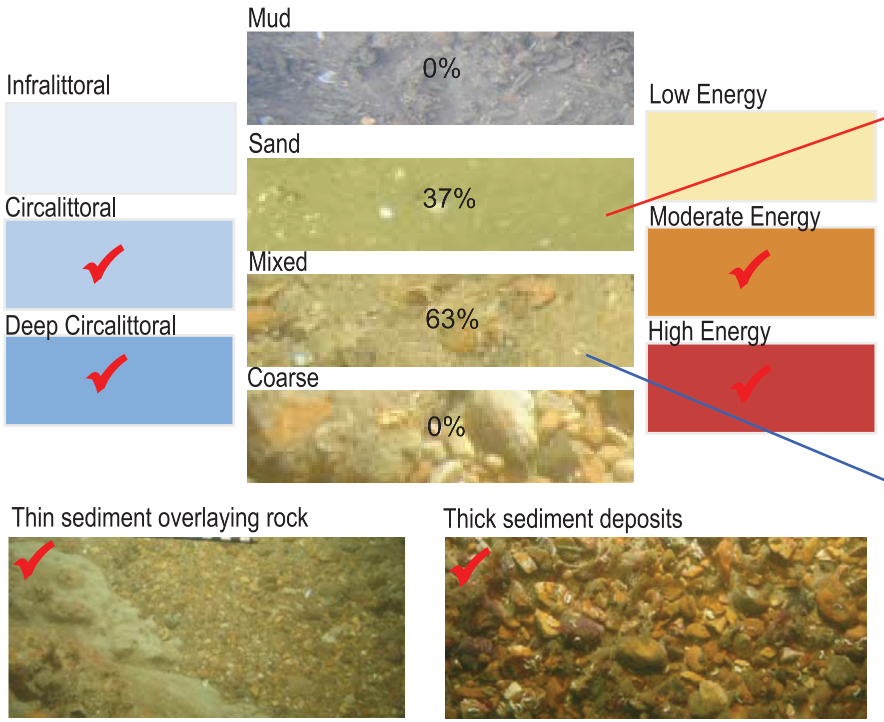
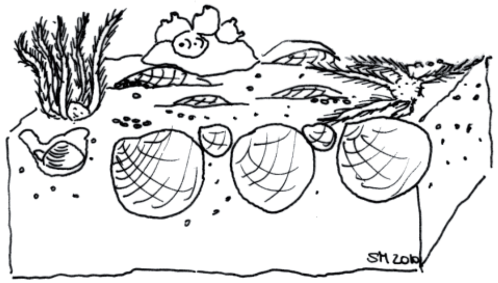
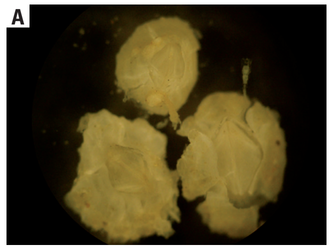
Variation in species composition

Two variants of this community type were identified in the synthesis area which were largely related to the composition of the sediment. In some areas where there was a high component of sand the bivalve *Glycymeris* was found to be locally abundant. Where large sediment particles provide habitat for a range of epifaunal species there may be higher abundances of barnacles, tube worms and ascidians. This may also represent a transitional community between the crevice-dwelling community and the barnacle, ascidian and tube worm community.





Where there is a large sand component the crevice dwelling community may also have high numbers of the bivalve *Glycymeris*.



Where large sediment particles are present there ay be very high abundances of barnacles such as A) *Balanus crenatus* and tube like B) *Pomatoceros*.

Ticked boxes indicate the EUNIS Level 4 categories in which the community is found, and the percentage of samples that fall into each EUNIS sediment classification.

Coast to offshore changes

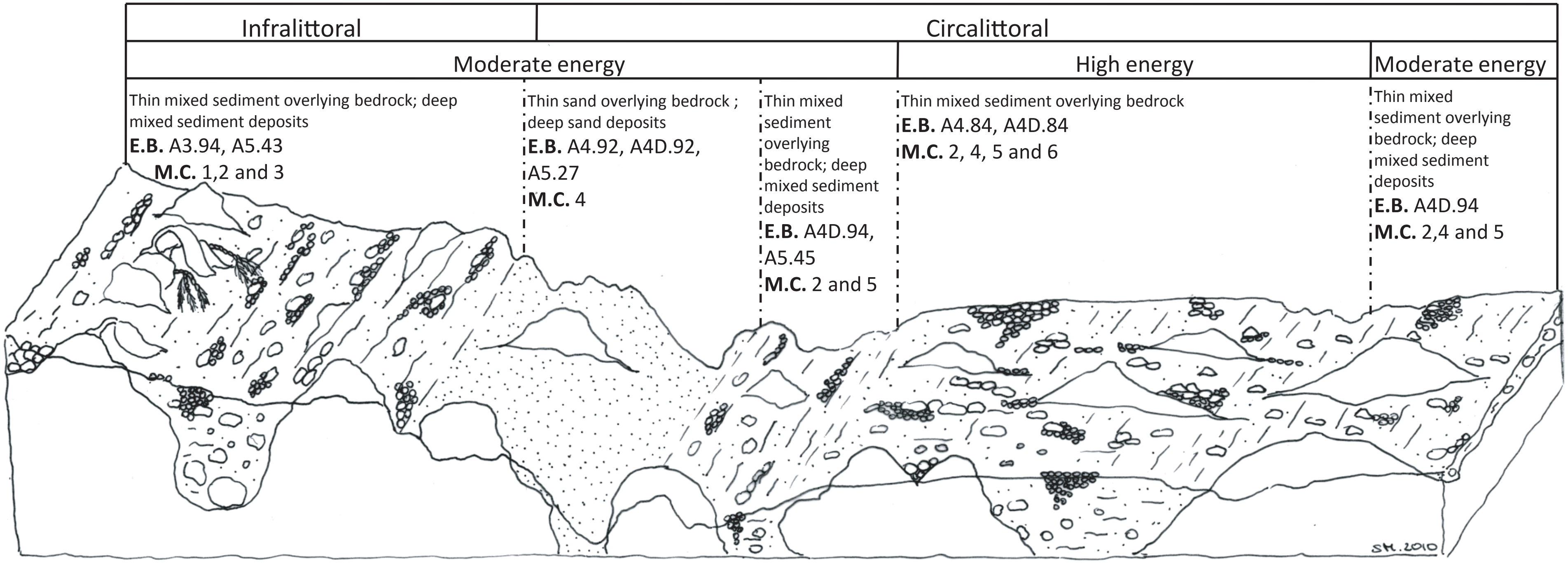
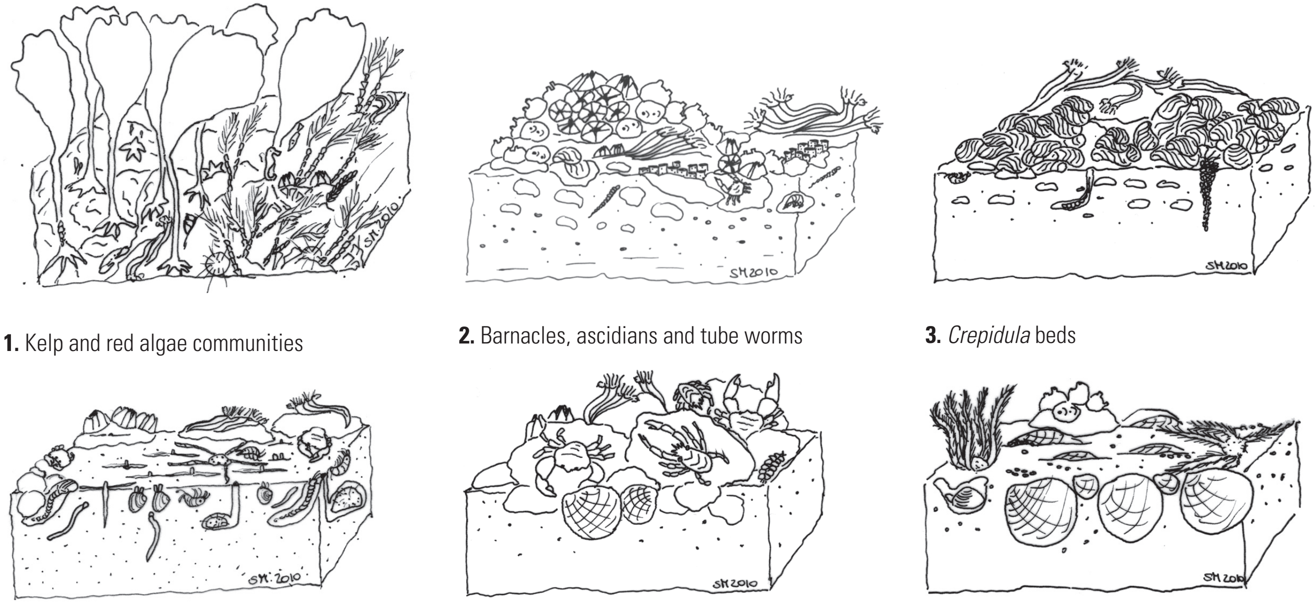


Figure 96a Schematic of onshore to offshore gradient as observed in the synthesis area. E.B. = EUNIS Level 4 biotope codes, M.C. = marine community 1–6.

Marine communities are determined by the physical environment and biological interactions such as predation and competition. From the shore, or infralittoral zone, to the deeper waters of the subtidal or circalittoral habitat there are several distinct physical gradients that play a significant role in the distribution of marine organisms. In particular, the depth of the water, and consequently the amount of light reaching the sea bed and the level of wave action change with distance away from the shore and help shape the biological communities that can occur.

The distribution of marine plants, known as macroalgae or seaweeds, is limited to the 'infralittoral' zone, where there is adequate light for photosynthesis. In very clear coastal waters in the UK macroalgae may be found to a maximum depth of 20 m although more usually they will only be present in shallower waters. In particularly turbid waters, such as in estuaries, marine algae may only be found in less than a metre of water. Seaweeds, such as large brown kelps, have particular adaptations, such as a tall stem or stipe, or gas bladders to hold the plant high in the water column, extending the depth to which plants can survive. Small slow growing red algae may be found in the understorey of kelps and extend to depths beyond the point at which kelps can survive. As the depth of water increases the presence of red algae also diminishes and below about 25 m only animals can survive. Thus, one of the most important coast to offshore biological gradients is a decline in the presence of marine plants.



1. Kelp and red algae communities

2. Barnacles, ascidians and tube worms

3. *Crepidula* beds

4. Interstitial polychaetes and amphipods

5. Crevice dwelling crustacean communities

6. *Glycymeris* communities

Figure 96b Marine communities 1–6 (M.C.).

Wave action and tidal energy may also affect sea bed communities, particularly in the infralittoral zone but also in the shallow subtidal. Wave action may limit the presence of mobile and fragile species, shape the morphology of seaweeds and sort the size and shape of any sediment on the sea bed.

In the synthesis study area, communities of kelp and red algae (Figure 96 a & b) were observed in shallow waters (but not recorded in grab samples) where mixed sediments were present. In areas where wave and tide energy is not too strong seaweeds can attach to large pebbles and cobbles, as well as bedrock. In deeper water where plants are unable to survive, these mixed sediments become colonised by encrusting, predominantly filter feeding animals such as barnacles, ascidians and calcareous tube worms (see page 97–98). These communities often do well where there is sufficient wave and/or tidal energy that brings a supply of food for these animals in the form of suspended particulate matter. There may also be a community of crevice-dwelling fauna such as small crabs and bivalves in these habitats, and these may be more dominant where tide and wave energy is particularly strong (see page 101–102). Where there is a higher component of sand the bivalve *Glycymeris* may also be found (Figure 96a & b).

The depth of the water column may also be a factor determining the distribution of the invasive American slipper limpet *Crepidula fornicata*. In the synthesis area this species forms high density beds (several hundred individuals per 0.1 m^2) but only in areas that are shallower than about 30 m (see page 99–100). The reasons for this are unclear although wave energy may be important in supplying adequate food in the form of particulate matter to this filter feeding mollusc.

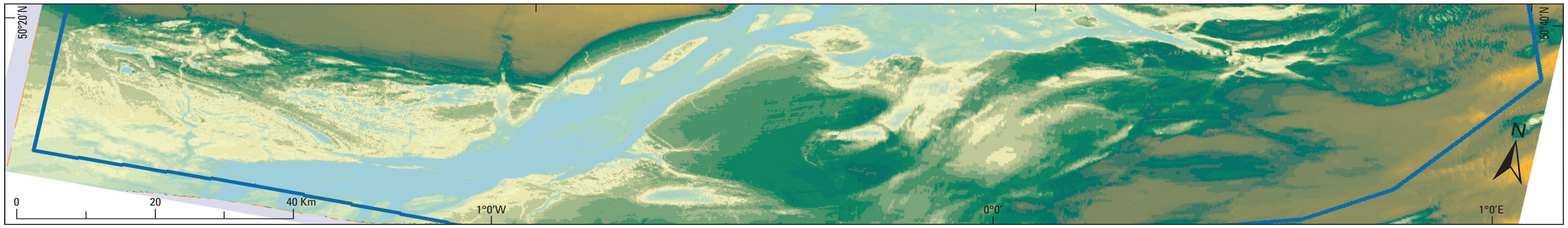
Sea beds where sand deposits are mobilised and fashioned into ripples and sand waves by currents are lacking in coarse sediment as attachment sites for epifauna. Consequently communities are dominated by animals that live within the sediments, such as polychaetes, burrowing bivalves and amphipods, and urchins may also be present (see page 95–96). When sediments are highly mobile only a sparse fauna is likely to be present.

West to east changes

A feature of the synthesis study area is the distinctive change in the character of the sea bed from west to east across the area — a distance of about 215 km. The essential change is from a rock based sea bed in the west to a relatively fine, sand based sea bed in the east. This change is most notable in the deeper southern half of the study area.

What are the factors that have contributed to creating this west-east fining trend? In no particular order the most significant are:-

- The sea bed in the west has extensive areas where rock is exposed at the sea bed, particularly in the area of the Central English Channel Monocline where steeply dipping beds of rock have produced numerous scarps, edges and depressions.
- The area in the west has high bed shear stress (Figure 8) and tidal current speeds, enough to winnow sand and muddy sediment from the sea bed leaving a gravel or rock surface. This western area is also a bed load parting zone (Figure 7) with sand and fine sediment being transported away from this zone, to the east on flood dominant currents and to the west on ebb dominant currents.
- The eastward movement of sediment has been a long-term trend in this part of the English Channel for the last ~5000 years since sea level reached its current level, and has enabled sand to build up in the east in the Greater Bassurelle Sands sand wave field and the Bassurelle Sand Bank and even further east outside the study area.
- The sea bed in the west does not have extensive deposits of Quaternary sediment, whereas the area in the east has relatively thick Quaternary sediment, up to 20 m, lying within channels cut in to bedrock. Therefore rock is not exposed at the sea bed where these channels occur, and the sea bed in the east is dominantly sediment based not rock based.
- The west-east sediment gradient is also mirrored in the biology with animals which can attach themselves to rock and coarse sediment dominant in the west and animals which are adapted to the more mobile environment of the sands in the east, particularly forms which can burrow down in to sediment.



West–East Sea Bed Morphology. (See Figure 44a)

West–East Sea Bed Character. (See Figure 66)

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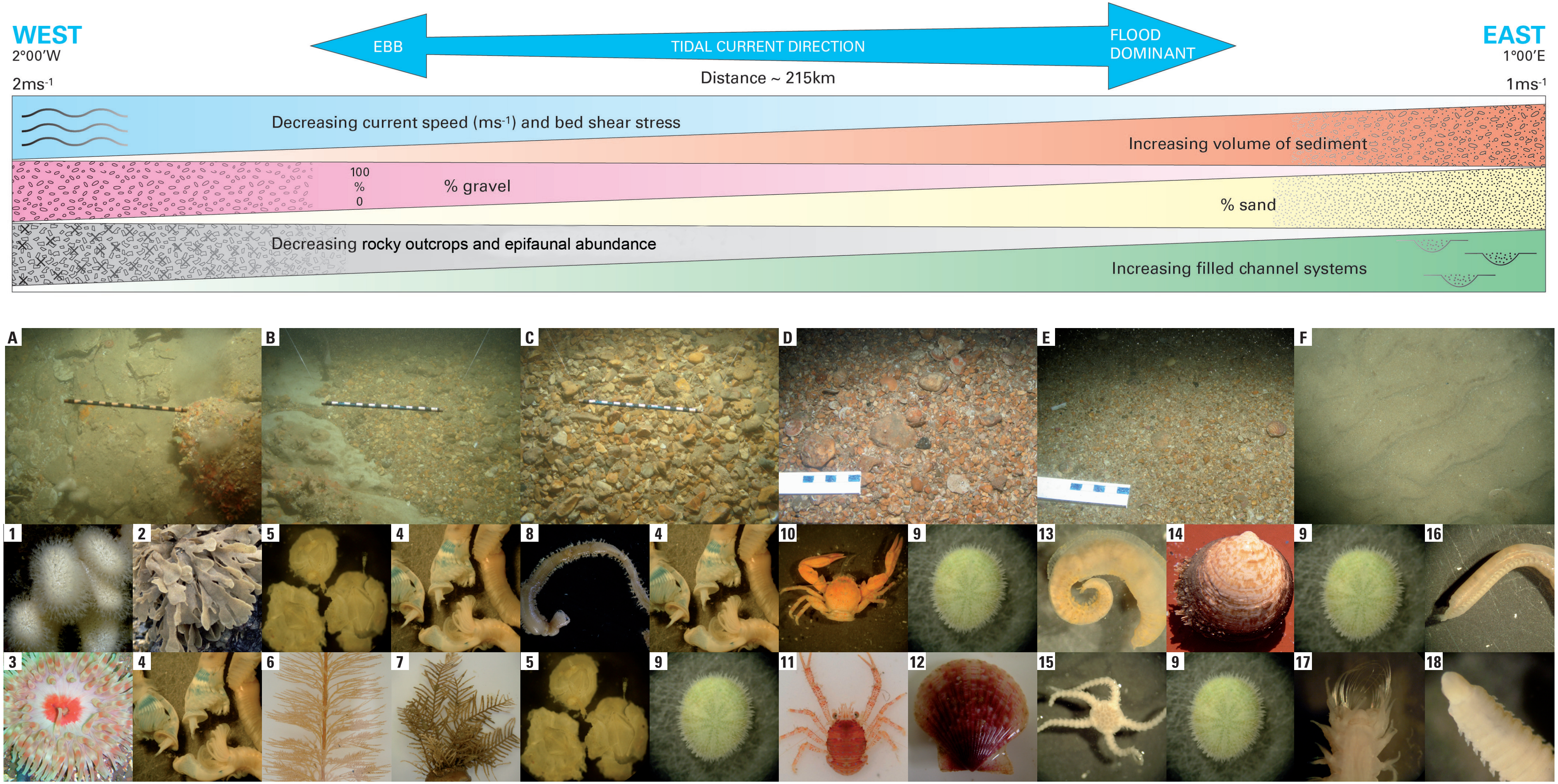


A Rock, **B+C** Rock and thin sediment, **D** Coarse sediment, **E+F** Sandy sediment (Scalebar intervals 1 cm). © www.seasurvey.co.uk, Cefas, Jane Ossman.

1 *Alcyonium digitatum*, 2 *Flustra foliacea*, 3 *Pomatoceros lamarcki*, 4 *Urticina*, 5 *Balanus crenatus*, 6 *Sertularia cupressina*, 7 *Abietinaria abietina*, 8 *Glycera*, 9 *Echinocyamus pusillus*, 10 *Pisidia longicornis*, 11 *Galathea intermedia*, 12 *Aequipecten*, 13 *Scalibregma inflatum*, 14 *Glycymeris*, 15 *Ophiura*, 16 *Ophelia borealis*, 17 *Poecilochaetus serpens*, 18 *Lumbrineris*

Figure 97 Composite of physical and biological characteristics associated with west-east fining trend.

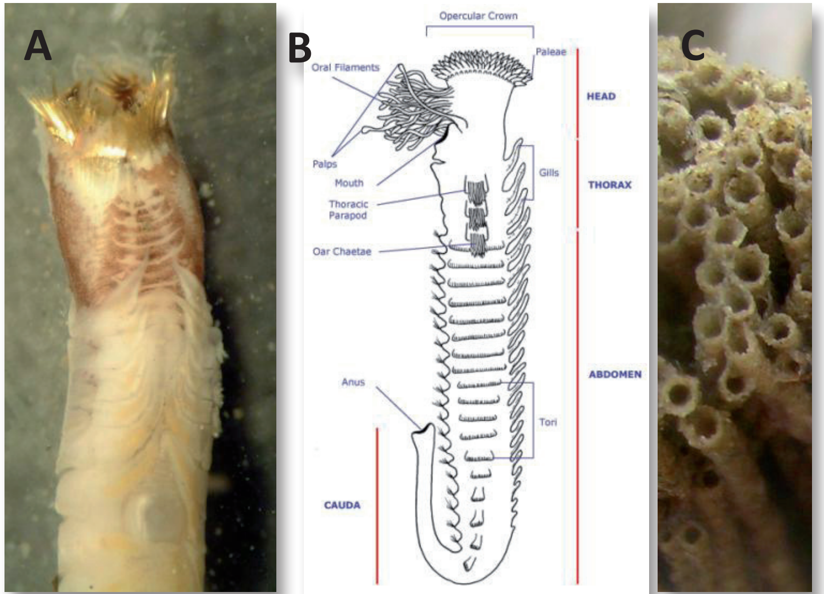
Sabellaria spinulosa

Sabellaria spinulosa is a sedentary marine polychaete worm that lives in a tube it constructs from sand particles (Figure 98). Large tentacle-like structures on the head, called 'palps', are responsible for grabbing sand particles and passing them to the mouth where they are coated in mucus before being added to the tube. *Sabellaria spinulosa* is a filter feeder. Oral filaments on the head of the worm whirl plankton, such as small algae, larvae and particulate matter, towards the mouth.

Sabellaria spinulosa is generally gregarious in nature with the larvae settling preferentially on mature and even degraded structures built by colonies of the same species (Pawlick, 1988; Wilson, 1970). Thus, in areas with a good supply of sand, aggregations, that can range in size from very small clumps to massive structures (Figure 99), can be found. The large aggregations can have a significant impact on the nature of the sea bed by turning large quantities of sand into intricate but disorganised tube colonies that have been compared to reef structures (Foster-Smith, 2003; Hendrick, 2006; Jones, 2000). The formation of these reef-like aggregations can alter and in many cases consolidate the benthic habitat.

It is thought that these reef structures can have a positive impact on local biodiversity by providing a more complex habitat that can be colonised by different types of animals (Figure 100). The hard surfaces of the aggregated tubes provide space for attachment of encrusting fauna whilst old tubes and gaps in the reef provide refugia for crevice-dwelling animals (Figure 101). There may be high numbers of some species such as bivalve molluscs like *Aequipecten opercularis*. In some areas there is a strong association between *Sabellaria spinulosa* reefs and the pink shrimp *Pandalus montagui*, particularly on the east coast of England. In the English Channel there appears to be a stronger association with the crevice-dwelling pea crab *Pisidia longicornis* (Figure 102) and the squat lobster *Galathea intermedia*.

Sabellaria spinulosa is fairly widespread around the UK coast and is most commonly found on coarse sediments with moderate water currents and a good supply of sand (Foster-Smith, 2003). Where *Sabellaria spinulosa* form persistent, topographically distinct reef structures they may be awarded protection under Annex 1 of the EU Habitats Directive because of their potential contribution. Since aggregations most often occur on coarse deposits offshore with a good supply of sand they can be present in areas suitable for aggregate dredging.



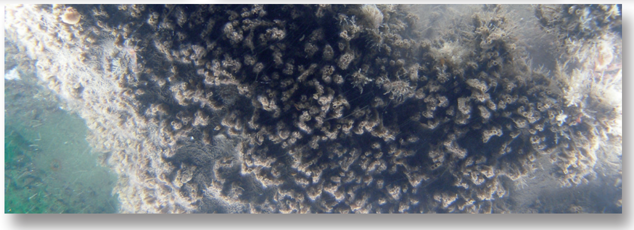


Figure 98 A) Photograph of *Sabellaria spinulosa* specimen removed from its tube; B) illustration of *Sabellaria spinulosa* showing the different body sections and key anatomical features; C) small aggregation of *Sabellaria* tubes.

Figure 99 Sea bed image of extensive *Sabellaria spinulosa* reef aggregation.

Figure 100 Sea bed image of *Sabellaria spinulosa* reef with high numbers of the queen scallop *Aequipecten opercularis*.

Figure 101 Crevice-dwelling crustaceans, *Galathea intermedia* (left) and *Pisidia longicornis* (right), often found in high numbers on *Sabellaria spinulosa* reefs.

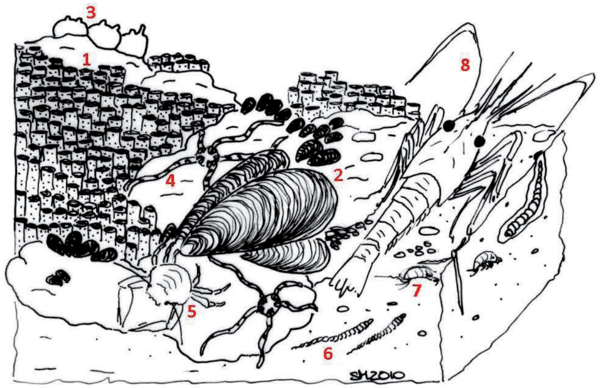


Figure 102 Illustration of *Sabellaria* reef community with 1. *Sabellaria spinulosa*, 2. the common mussel *Mytilus edulis*, 3. sea squirts, 4. brittle stars, 5. the pea crab *Pisidia longicornis*, 6. infaunal polychaetes, 7. amphipods and 8. the pink shrimp *Pandalus* spp.

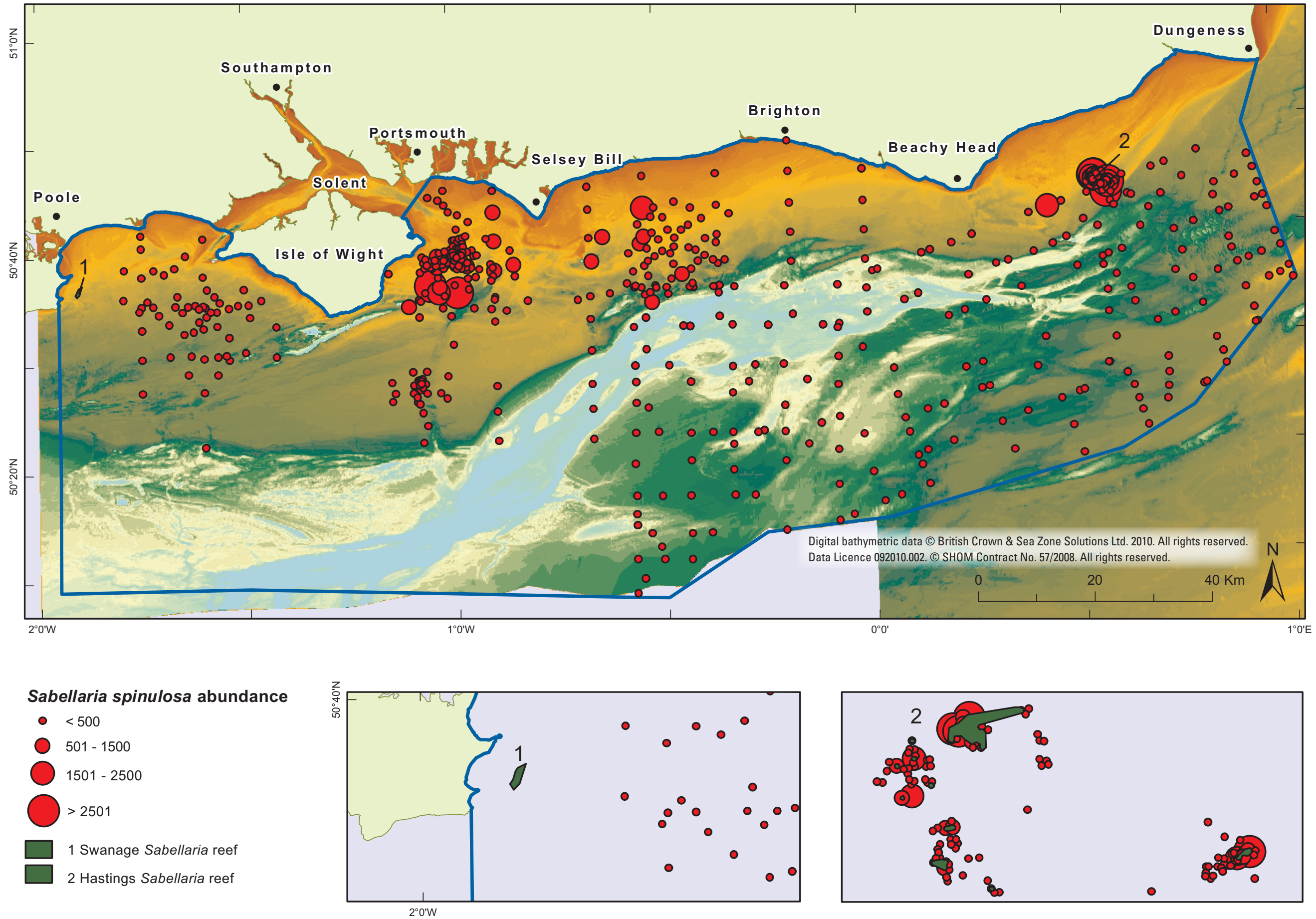


Figure 103 Distribution and abundance of *Sabellaria spinulosa* in the synthesis area and the location and extent of reef systems at Swanage (1) and Hastings (2).

Although *Sabellaria spinulosa* is widespread in the synthesis area the presence of large reef structures is limited to two areas; 1. Swanage and 2. Hastings Shingle Bank (Figure 103). The Hastings reef is the most extensive, at about 1 km^2 in area, although this is considerably smaller than the *Sabellaria spinulosa* reefs in the Wash, on the east coast of the UK where there are many square kilometres of significant aggregations.

Mussels

Blue mussels *(Mytilus edulis)* are filter feeding bivalves which feed on microscopic animals and organic material suspended in the water column (Figure 106). They are gregarious in nature and can form extensive beds which may be up to 6 layers deep. They are commonly found on the lower shore and in shallow estuaries and inlets where they often form extensive beds.There is an important mussel fishery in Poole Harbour.

In the permanently submerged shallow coastal waters of the synthesis study area mussels have been observed to form semi-infaunal beds on sandy, muddy or gravelly substrate, or even quite sandy areas. Mussels are also recorded on subtidal rock such as the chalk platform south of Beachy Head and on mixed substrate of small boulders, cobbles and pebbles.

Mytilus edulis is found in a wide range of exposures, but in order to develop large reef structures considerable water movement is required. Where such conditions prevail mussels can form extensive biogenic reef features where living and dead mussels, sand and mud are all bound together by the mussels' sticky 'beards' of byssal threads.

Figure 104 illustrates the locations where mussels have been recorded within the study area. The mussel beds east of Beachy Head have long been associated with a fishery for plaice *(Pleuronectes platessa)* (Figure 105) and there have been attempts to harvest the mussels for relaying and ongrowing from areas outside 6nm south of Selsey Bill.

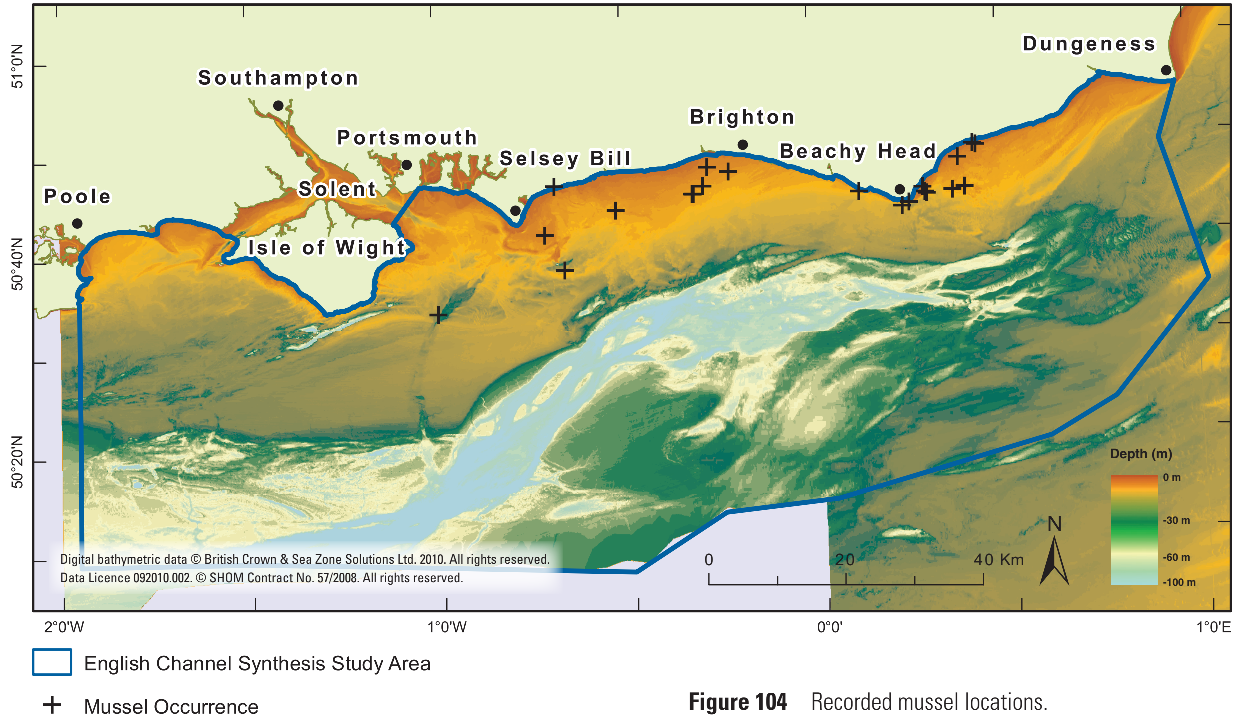


Figure 104 Recorded mussel locations.

On soft sediments mussel reefs form heterogeneous structures; they form complex habitats and are associated with diverse epifaunal species assemblages. *Mytilus edulis* reefs are of conservation value as they are a UKBAP Priority Habitat, on the OSPAR List of Threatened and/or Declining Species and Habitats (Region II — Greater North Sea, and Region III — Celtic Sea) and can also be key features of habitats listed in Annex I of the Habitats Directive.

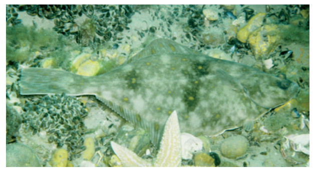


Figure 105 Plaice on Mussel Bed © Sussex Seasearch.

Figure 106 Mussel bed on rock outcrop southeast of Selsey Bill.

Echinoderms

Echinoderms are the largest group, or phyla, of animals to be found solely in the marine environment. Representatives of this group can be found at every ocean depth, from the intertidal to the deep ocean floor and there are fossil records of echinoderms dating back to the Cambrian (~488–542 Mya) (Figure 6) making this one of the most persistent group of marine animals in our seas today.

There are five classes of echinoderm, the starfish, the brittle stars, the sea urchins, the sea cucumbers and the feather stars, all of which were present in the study area. The first four of these classes are fully mobile and keep their mouths face down to the substrate whilst the feather stars, and many of their extinct relatives, attach themselves to the sea floor and have their mouths facing upwards (Figure 107).

The echinoderms are important geologically because their fossilised skeletons are often well preserved in rocks, providing valuable clues to the geological environment of the past. Echinoderms also play a key ecological role in marine ecosystems by regulating the colonisation and growth of other organisms through their grazing activities, releasing nutrients into the ocean during burrowing and as an important prey item for fish and seabirds. Echinoderms are also thought to have encouraged deeper penetration of the sea floor by depleting nutrients, which in turn increased the depth of oxygenation and allowed the development of a more complex burrowing fauna.

The variety of echinoderms identified in the study area is illustrated in Figure 107 and described in more detail in the following pages.

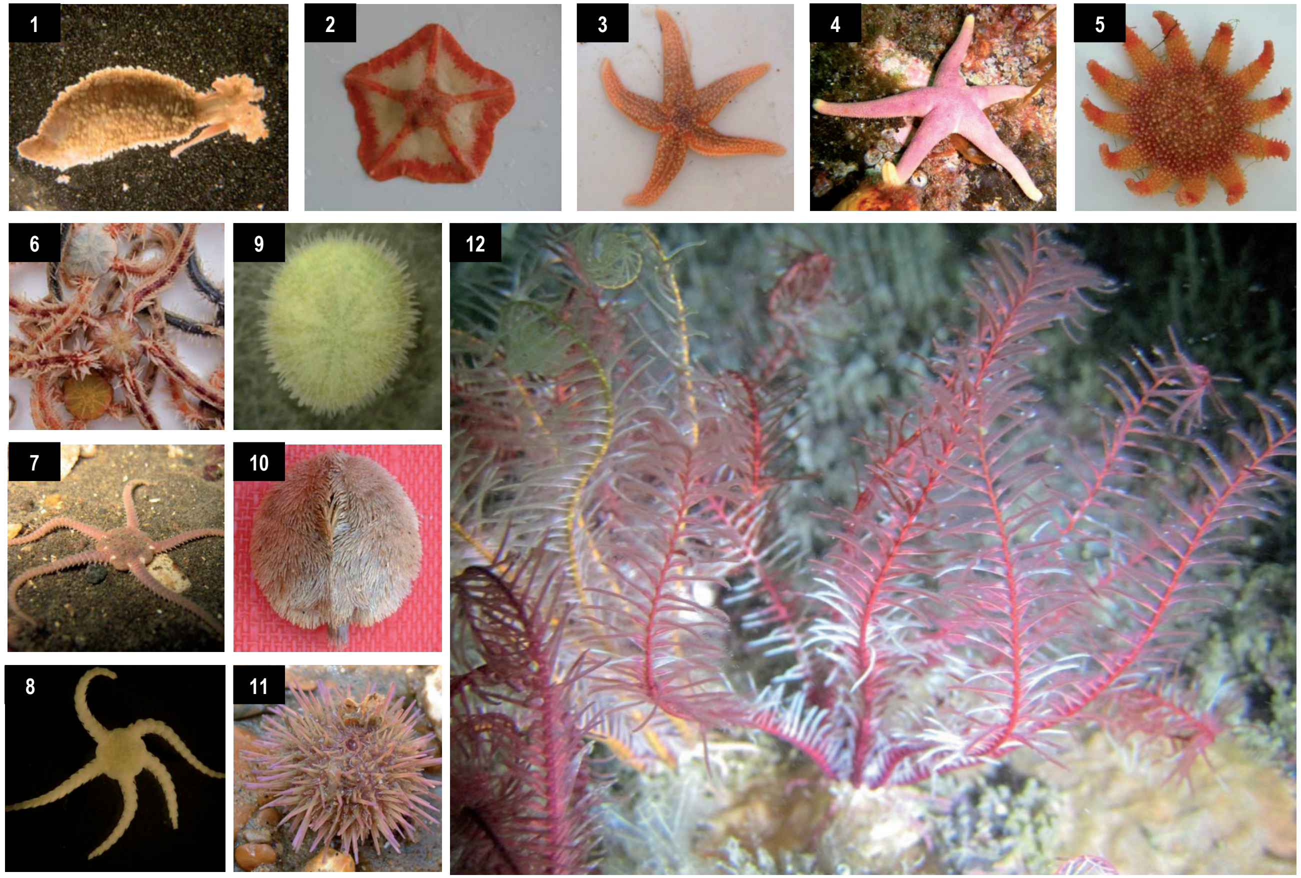


Figure 107 Photographs of echinoderm species found in the study area; 1. *Thyone fusus* (sea cucumber) 2. *Anseropoda placenta* (goose foot starfish) 3. *Asterias rubens* (common starfish) 4. *Henricia oculata* (bloody henry starfish) 5. *Crossaster papossus* (sun star) 6. *Ophiothrix fragilis* (brittle star) 7. *Ophiura ophiura* (brittle star) 8. *Ophiura albida* (brittle star) 9. *Echinocyamus pusillus* (pea urchin) 10. *Echinocardium cordatum* (burrowing heart urchin) 11. *Psasmmechinus miliaris* (common urchin). 12. *Antedon bifida* (rosy feather star). © www.seasurvey.co.uk, Cefas, Anne Bennett.

Sea urchins

The sea urchins, or echinoids, have a rigid skeletal capsule, called a test, made up of closely fitted plates arranged around a globose body. This allows movable spines, operated by internal muscles, to be used alongside their podia in locomotion. Most urchins are herbivores or omnivores grazing on plant and animal material. Regular urchins which are symmetrical and globose, such as *Psammechinus miliaris*, are able to remove encrusting organisms using their complex feeding apparatus called Aristotle's lantern. Some of the irregular urchins such as the heart urchins lack this feeding apparatus and instead use modified tube feet to feed on particles of detritus.

Four species of urchin were identified in the study area, the regular urchin *Psammechinus miliaris*, the tiny pea urchin *Echinocyamus pusillus* and two irregular burrowing heart urchins, *Spatangus purpureus* and *Echinocardium cordatum* (Figure 108). The two burrowing heart urchins were restricted in their distributions to the sandy deposits in the east of the area and were not present in very high densities. *Psammechinus miliaris* and *Echinocyamus pusillus* were much more abundant and were widespread across the east of the study area. (Figure 109).

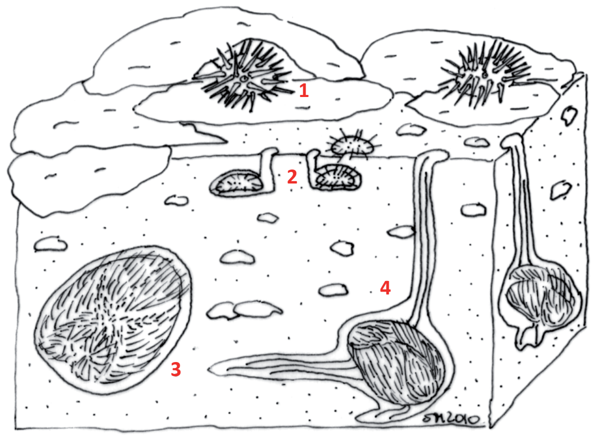


Figure 108 1. *Psammechinus miliaris* 2. *Echinocyamus pusillus* 3. *Spatangus purpureus* 4. *Echinocardium cordatum.*

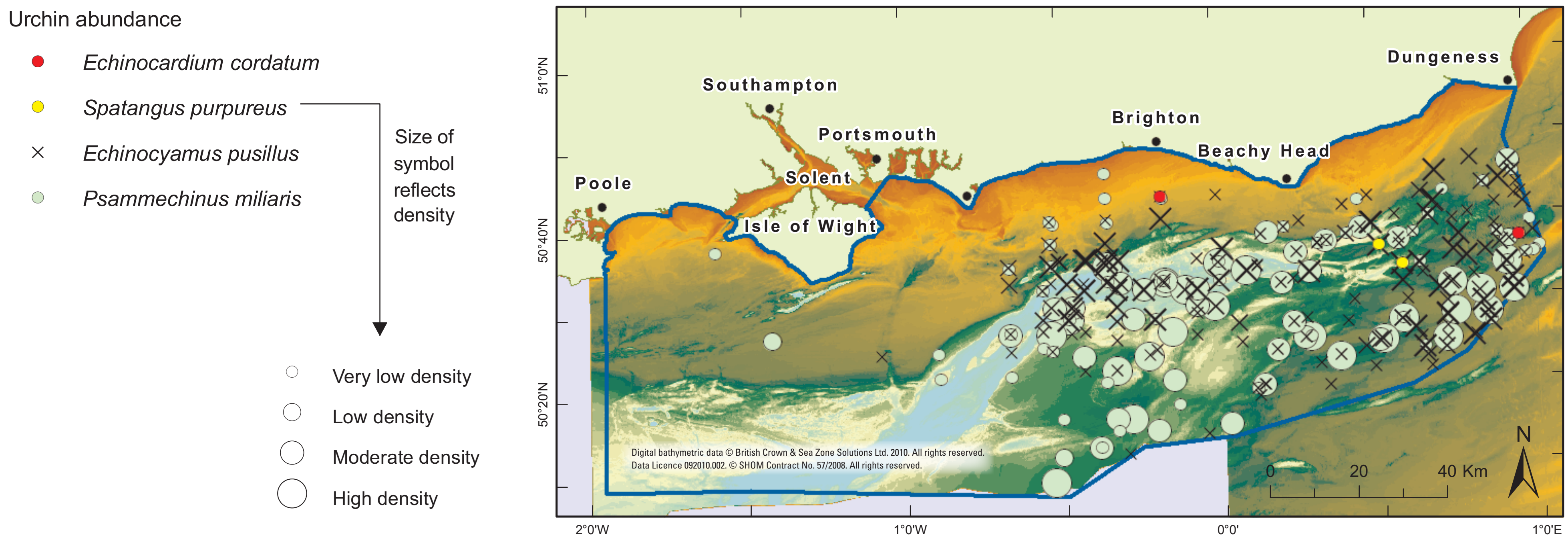


Figure 109 Distribution of sea urchin species across the study area and their approximate densities based on observations in grab, trawl and sea bed imagery samples.

Brittle stars and feather stars

Brittle stars are so called because they are characterised by five very thin and delicate arms radiating from a central disc (Figure 110 & 107–6, 7 & 8). Their mouth lies at the centre of the disc on the underside and is surrounded by jaws. The tube feet are also used in feeding giving rise to a wide range of feeding habits including scavenging, deposit and suspension feeding. Eight species of brittle star were observed across the study area although only three were observed in moderate to high densities. The first of these *Ophiura albida* is a small brittle star. Its arm spines lie almost flat against the arms giving a smooth appearance. *Ophiothrix fragilis* and *Amphiura filiformis* are quite different with raised arm spines giving an almost furry appearance. Both *O. albida* and *O. fragilis* live on the surface of the sea bed whereas *A. filiformis* lives in a burrow underneath the sea floor (Figure 110).

A. filiformis is necessarily limited in its distribution to pockets of fine muddy sediments where it is able to burrow (Figure 111). *O. albida* also appears to be limited by the substrate and is almost entirely absent from areas of rock or rock and thin sediment. *O. fragilis* has the widest distribution across the area and was frequently found at very high densities.

Antedon bifida, the rosy feather star, was also identified in the study area. *Antedon* was limited to the rocky areas to the south of the study area where there were suitable surfaces on which it could cling (Figure 110).

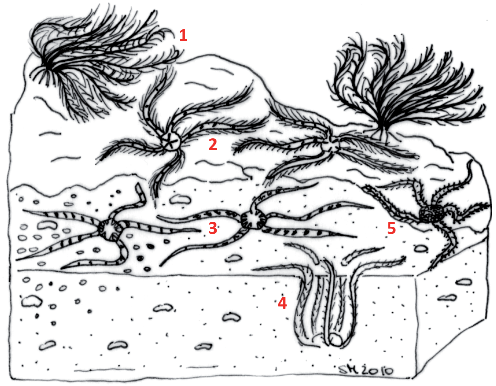


Figure 110 1. *Antedon bifida* 2. *Ophiothrix fragilis* 3. *Ophiura ophiura* 4. *Amphiura filiformis* 5. *Amphiopholis squamata.*

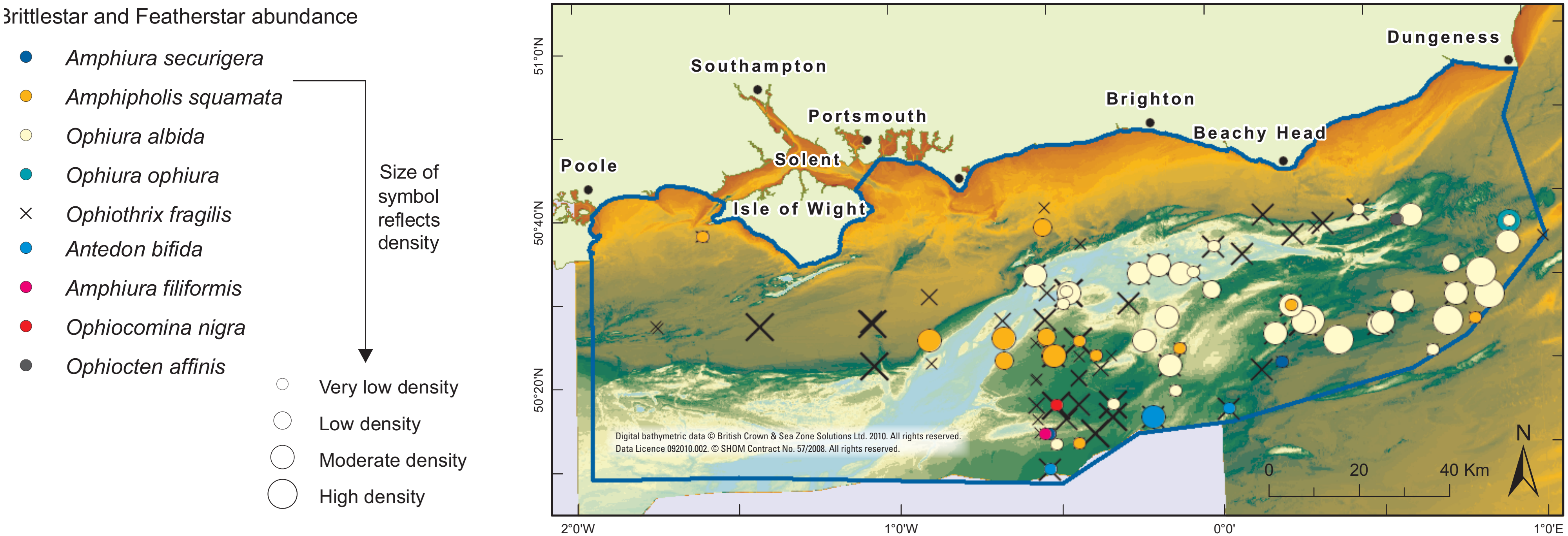


Figure 111 Distribution of brittle star and feather star species across the study area and their approximate densities based on observations in grab, trawl and sea bed imagery samples.

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Starfish and sea cucumbers

Starfish are the echinoderms which people are most familiar with since they are often found on the seashore and are easily identified by the presence of five arms which grade into the central disc. Starfish are much larger and more robust than the brittle stars and many are carnivorous. Four species were identified in the study area, the common starfish *Asterias rubens*, the sun star *Crossaster papposus*, the goose foot starfish *Anseropoda placenta* and the bloody henry starfish *Henricia* spp. All four of these species live on the surface of the sea bed (Figure 112) and feed on other invertebrates with the exception of *Henricia* which is a suspension feeder.

Sea cucumbers or holothurians look quite different to all other echinoderms and could be said to more closely resemble marine worms (Figure 112). The calcareous skeleton of sea cucumbers is much reduced, generally consisting of microscopic plates which in some species such as *Leptosynapta inhaerens* are in the form of anchors and wheels. Sea cucumbers are found buried in sediments, sometimes in U-shaped burrows or attached to stones and rock. Numerous species were recorded across the study area but only *Leptosynapta inhaerens* was found in any significant abundance, associated mostly with sediment deposits in the east of the area (Figure 113).

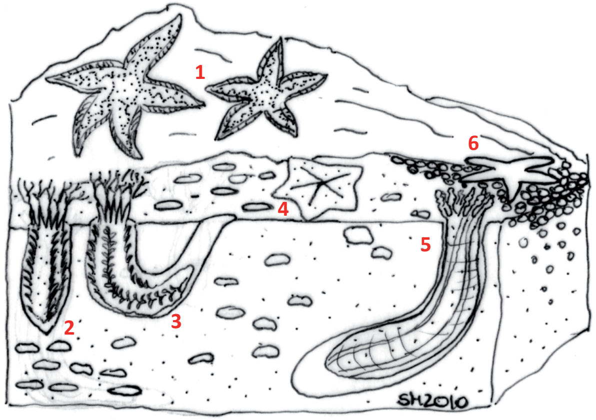


Figure 112 1. *Asterias rubens* 2. *Thyone fusus* 3. *Leptopentacta elongata* 4. *Anseropoda placenta* 5. *Leptosynapta inhaerens* 6. *Henricia oculata.*

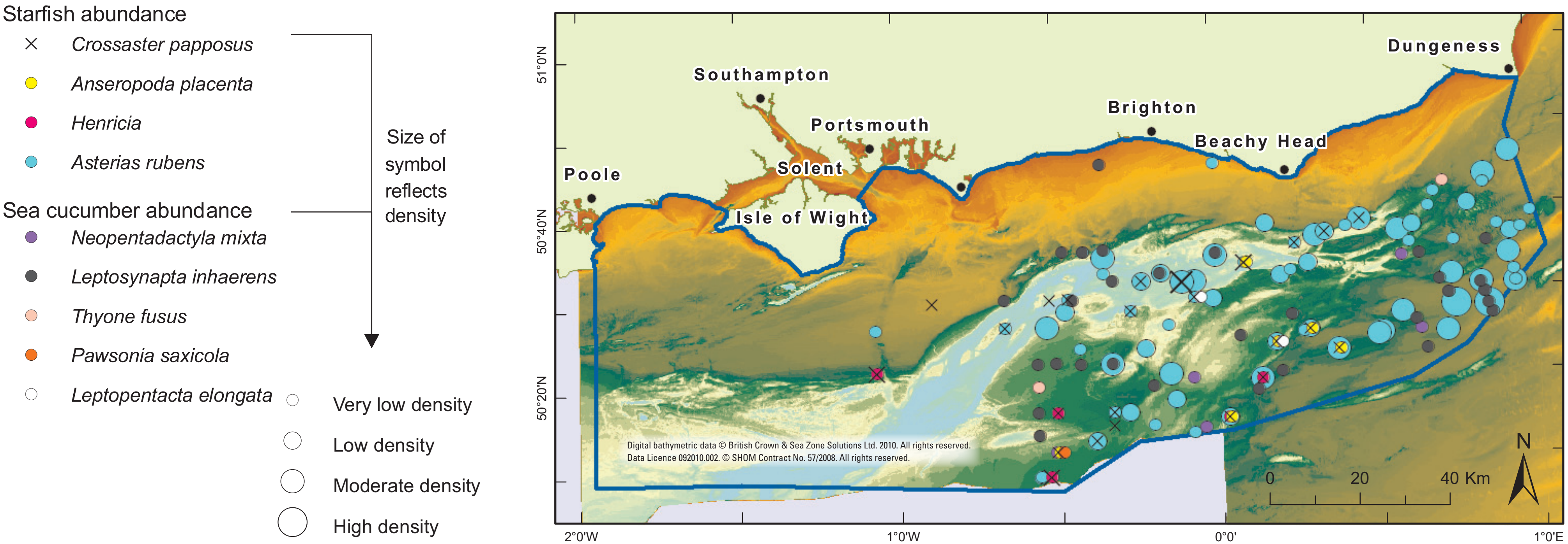


Figure 113 Distribution of starfish and sea cucumber species across the study area and their approximate densities based on observations in grab, trawl and sea bed imagery samples.

Black bream

Black bream *(Spondyliosoma cantharus (L.))*

In spring each year black bream migrate from the wider English Channel, along the 9°C isotherm (Pawson, 1995), to the shallow coastal waters within the synthesis area. Once inshore the bream form spawning congregations. Larger male bream seek specific sea bed sediment types where they 'build' or excavate individual 'nests' (depressions on the sea bed surface) in the hope of attracting a mate (Figure 116).

In the process of building their 'nests' male black bream use their tail to remove the surface layer and expose the bedrock or compacted gravel beneath (Lythgoe and Lythgoe, 1971). In doing so, male black bream may use their nests in intraspecific competition to attract a female.

Sea bed substrates and features which have been identified with bream nest sites include thin sands and gravels, and gravels on bedrock and adjacent to reefs and wrecks. The bedrock they have been noted on includes Chalk and the Tertiary Bracklesham Group.

Bream nest sizes are typically between 1–2 m^2 and 5–30 cm in depth. They create a distinctive group of pitted sea bed features that are clearly discernable on sidescan sonar records. Figure 114 illustrates such groups on a thin sediment on bedrock, with bedrock evident as thin ledges where sea bed is exposed. It is through the use of this technique that the nesting sites in the area have been identified.

Once a female bream has selected a suitable nest she will lay her eggs in a thin layer within the nest; bream eggs are sticky and become strongly attached to the substrate (Figure 117).

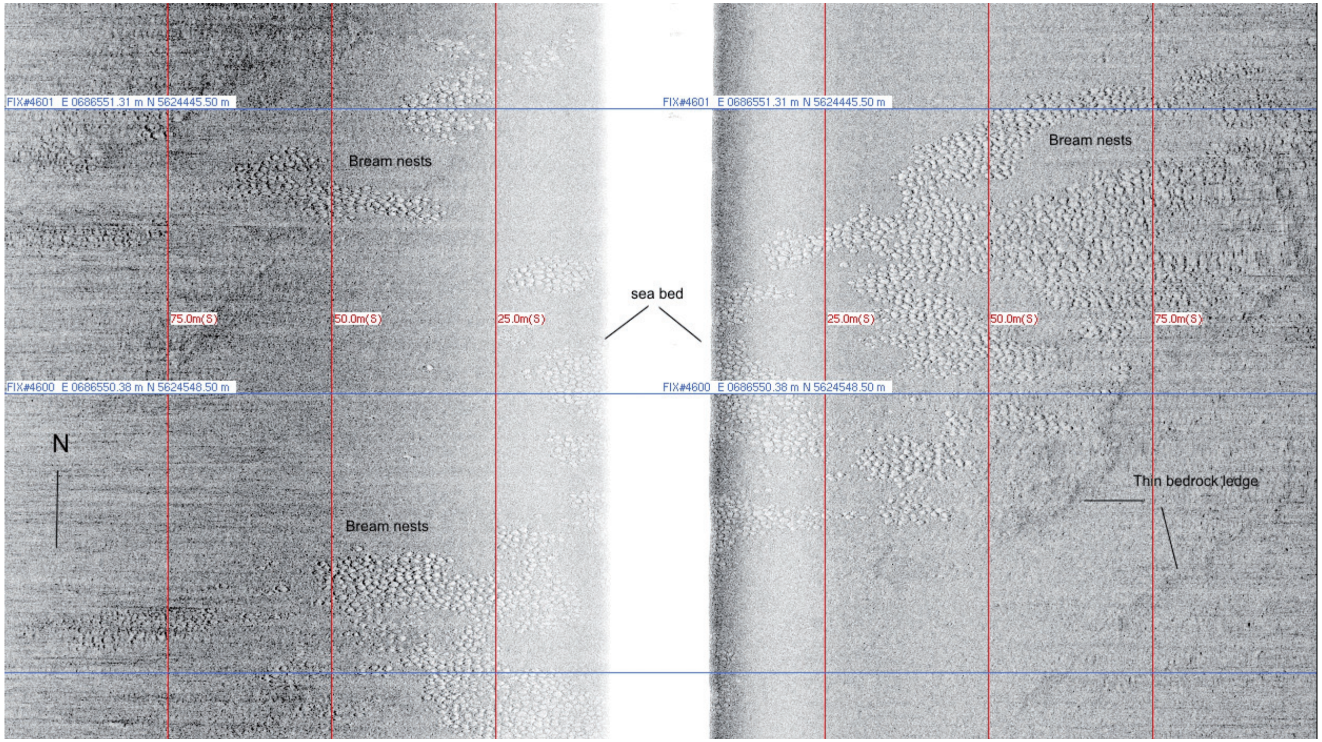


Figure 114 Sidescan sonar record of groups of Black Bream nests on thin sediment on bedrock. Selsey - West Sussex Coastal Platform.

After the female has laid her eggs the male fish will fertilise them and guard them until they hatch to protect them from predators such as crustaceans and to ensure siltation of the nest does not occur. This philopatry does however make the adults susceptible to fisheries exploitation.

The consultancy EMU Ltd. on behalf of two companies who have licenses to extract aggregate from the region have been monitoring an area off Littlehampton, West Sussex, for some years; providing a valuable insight in to the fish's behaviour in the region. The work conducted as part of the South Coast REC (James *et. al.*, 2010) demonstrates the wider importance of the region for bream, and the known spatial distribution of the bream nests. Figure 115 updates this work with further records of known nesting areas.

Unmolested juvenile bream will remain in the vicinity of the nest sites until they are 7–8 cm in length, after which they disperse but remain in the inshore areas for 2–3 years (to reach approximately 20 cm in length) (Pawson, ibid.)

Black bream are protogynous hermaphrodites (Lythgoe. and Lythgoe, op. cit.); at sexual maturity they develop female sexual organs, then as they grow, they become males. When the bream become sexually mature (as females) they recruit into the adult stock and range into the wider English Channel to feed. It is expected that the bream exhibit site fidelity, perhaps returning to the same sites to spawn annually.

Black bream are not subject to ICES stock assessment as they are not classed as a pressure stock for EU fisheries management purposes and no Total Allowable Catch is prescribed. As a non-quota species the fish is fished inshore and offshore in net and trawl fisheries, notably in the synthesis area by pair trawlers. There is currently no legal minimum landing size for black bream under European Union Technical Regulations; as protogynous hermaphrodites such measures can have a counter-productive effect. The vulnerability of the nesting sites means that they are suitable candidates for protection through spatial management measures.

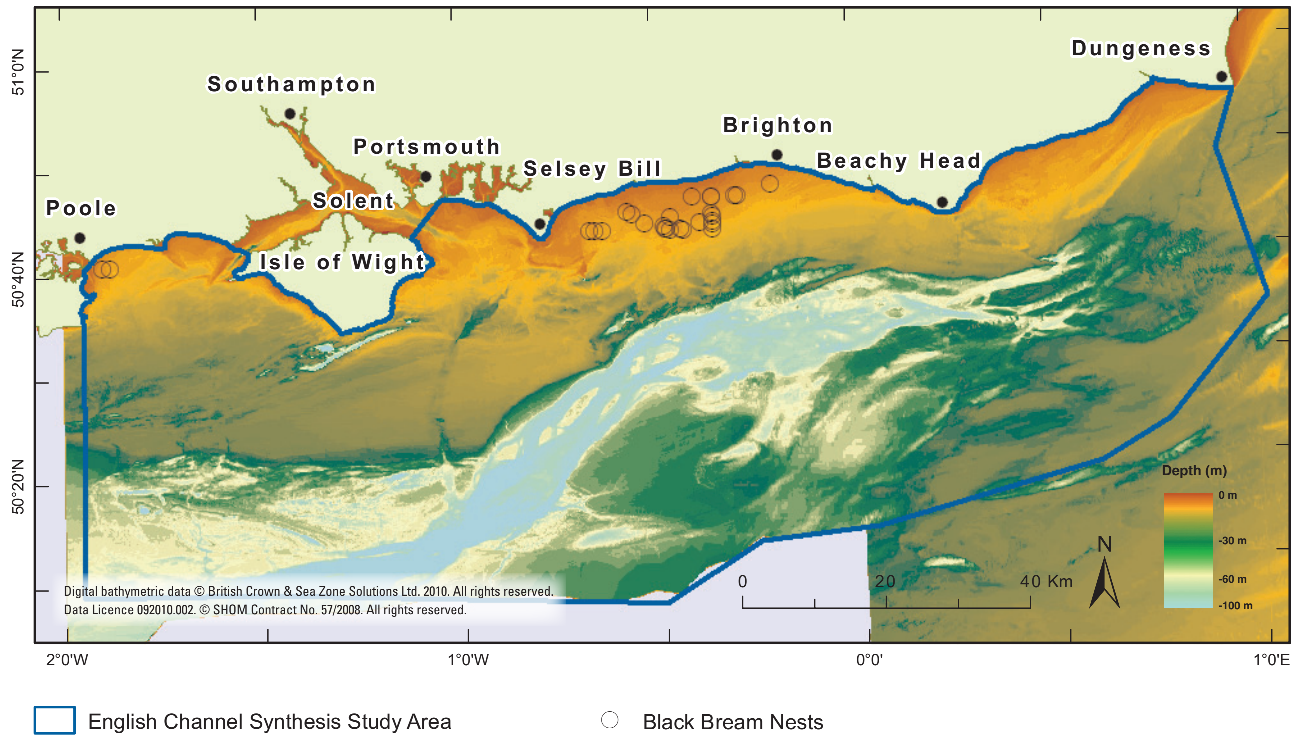


Figure 115 Distribution of black bream nests identified on sidescan sonar records from South Coast REC 2007 Survey. Also includes Sussex Sea Fisheries Committee monitoring area data near Kingmere Rocks — location courtesy of Tarmac Marine and Hanson Marine.

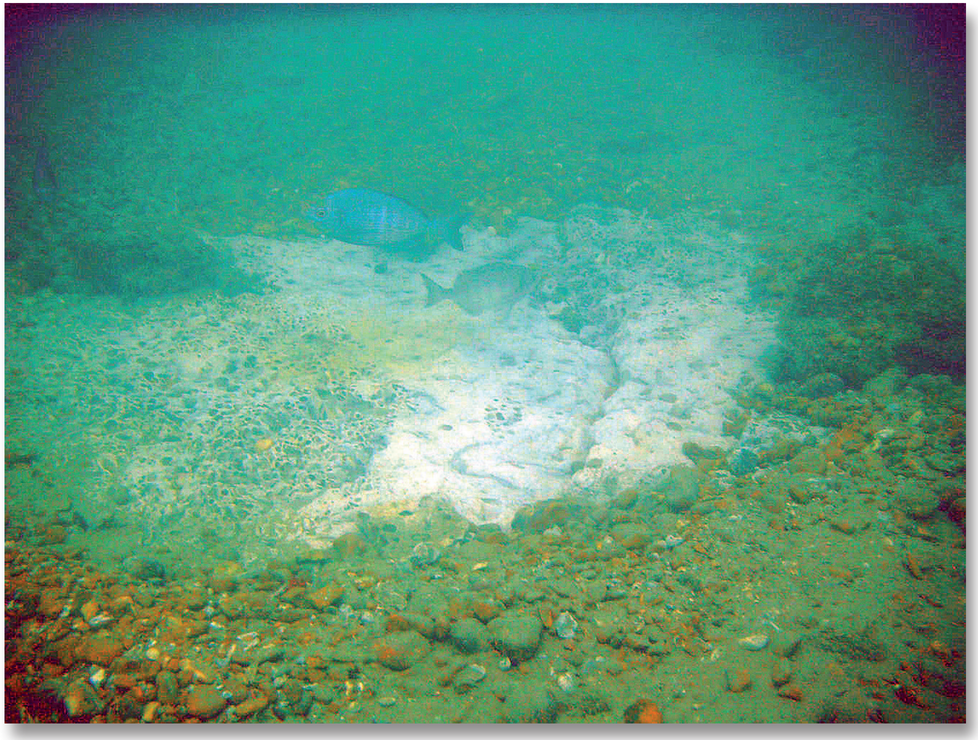


Figure 116 Sea bed photo of Black Bream nest on exposed bedrock surrounded by thin sand and gravel. Note two Black Bream swimming above nest © Alex Holmes.

Figure 117 Sea bed photo of Black Bream eggs in nest on exposed bedrock © Alex Holmes.

Rare and alien species

One of the main objectives of nature conservation is the avoidance of species extinctions. The rarity of species is a key factor determining the risk of extinction, thus identifying the presence of rare species is an important component of conservation management. The Joint Nature Conservation Committee (JNCC) developed criteria for the assessment of the rarity of marine benthic species in 1996 (Sanderson 1996). This identifies Nationally Rare species; those which have been recorded in eight or fewer of the 1546 10 km^2 squares of the Ordnance Survey national grid and Nationally Scarce species; those occurring in nine to fifty-five squares. A number of marine species are also listed in the OSPAR List of Threatened and/or Declining Species and Habitats (OSPAR, 2009) as well as the International Union for Conservation of Nature and Natural Resources (IUCN) Red List of Threatened Species (IUCN, 2010).

Another objective of nature conservation is to control the impacts of introduced species. Thousands of marine animals, plants and algae are transported from their native range to 'new' areas through the transport and discharge of ballast water, as fouling organisms on ships hulls or through aquaculture. Environmental changes also give rise to new introductions, for example climate change is responsible for the extension of the natural range or distribution of numerous species. The term 'alien' is given to non-native species which have established self-maintaining populations in the UK. Where non-native species have not established self-maintaining populations or their origin is not clear they

Figure 118 American slipper limpet *Crepidula fornicata.*

are classified as cryptogenic. This classification is particularly useful as it prevents introduced species from being described as new or rare species. A number of rare and alien species have been identified in grab, trawl and video samples taken across the synthesis study area and these are summarised in Table 17.

Nationally rare species

A number of nationally rare species were identified across the study area, perhaps the most notable being the sea squirt, *Microcosmos claudicans* (Figure 121b), which was recorded in significant numbers in both grab (n=35) and trawl (n=127) samples. The abundances recorded in this area indicate that this could be an important habitat for this species. It is also possible that this species has, until now, been under-described in the UK, possibly because of its preference for coarse substrata which can be difficult to sample. The rare colonial bryozoan, *Hincksina flustroides* was also relatively abundant across the synthesis area, recorded in eleven grab samples and four trawls.

Non-native species

Four established alien species were identified in the synthesis study area (Table 17), the most conspicuous being the American slipper limpet, *Crepidula fornicata* (Figure 118, 120 & 122). *C. fornicata* is perhaps the best-known alien species on British shores, partly because of the detrimental impact this introduction has had on oyster fisheries (Davidson 1976; Key and Davidson 1981). The first occurrence of this species in Europe was in Liverpool Bay in 1872 although these populations have since died out (Eno *et al.*, 1997). The American slipper limpet was subsequently introduced to a number of other locations in association with the American oysters *Crassostrea virginica* (Eno *et al.*, 1997) and *Mercenaria mercenaria* (McMillan, 1938) and is now common throughout Europe.

Crepidula fornicata has become very well established in the synthesis study area, particularly in the area surrounding the Isle of White (Figure 119). The UK distribution of this species has until recently been limited to latitudes <54°N which is reported to be linked to high mortalities during cold winters (Theiltges *et al.*, 2004). Given that winter mortality is such a key factor in the population dynamics of *C. fornicata*, an extension of their northern boundary is unsurprising in the wake of climate change and this species has now been recorded as far north as the Humber (Figure 119) (Pearce *et al.*, In Press).

The American slipper limpet can tolerate a wide range of environmental conditions but is found in higher densities in wave protected areas and in muddy or mixed muddy sediments, as was observed in the west of the study area (de Montaudouin *et al.*, 1999; de Montaudouin *et al.*, 2001). The affinity between *C. fornicata* and muddy sediments may in part be due to its utilisation of suspended material for food but may also be a result of its influence on the substrata. Faeces or pseudofaeces produced by *C. fornicata* accumulate where it is found in high densities significantly altering the nature of the substratum (Barnes *et al.*, 1973).

The introduction of the American slipper limpet is thought to have had a detrimental effect on the native oyster population since it competes for food and space, whilst also depositing fine sediments on them (Utting and Spencer, 1992). The accumulation of fines by this species is also thought to render the substratum unsuitable for the settlement of oyster spat (Barnes *et al.*, 1973). The monitoring and management of the *C. fornicata* population within the synthesis study area should therefore be a high priority for future conservation efforts in this area.

Species	Phylum	Description	Status	Grab Samples		Trawl Samples REC only		Video	
				Records	Abundance	Records	Abundance	Records	Abundance
Crepidula fornicata	Mollusca	American slipper limpet	Alien	55	1863	16	4579	30	
Styela clava	Chordata	The leathery sea squirt	Alien	1	1	3	6	2	
Elminius modestus	Crustacea	Barnacle	Alien	3	20	0	0	NI	
Monocorophium sextonae	Crustacea	Amphipod	Alien	8	32			NR	
Jassa falcata	Crustacea	Tubiculous amphipod	Cryptogenic	1	1	0	0	NR	
Jassa marmorata	Crustacea	Tubiculous amphipod	Cryptogenic	1	3	0	0	NR	
Monocorophium insidiosum	Crustacea	Amphipod	Cryptogenic	0	1	0	0	NR	
Thecacera pennigera	Mollusca	Sea slug	Cryptogenic; Nationally scarce	0	0	1	1	NR	
Rissoides desmaresti	Crustacea	Mantis shrimp	Nationally Scarse	2	2	1	3	NR	
Achaeus cranchii	Crustacea	Cranch's spider crab	Nationally Scarse	2	3	0	0	NR	
Apherusa ovalipes	Crustea	Amphipod	Nationally Scarse	1	1	0	0	NR	
Hartlaubella gelatinosa	Cnidaria	Errect colonial hydroid	Nationally Scarse	1	1	0	0	0	
Mesacmaea mitchelli	Cnidaria	Sea anemone	Nationally Scarse	0	0	0	0	0	
Stelletta grubii	Porifera	Sponge	Nationally Scarse	0	0	0	0	11	
Obelia bidentata	Cnidaria	Errect colonial hydroid	Nationally Rare	3	n/a	0	0	0	
Apherusa clevei	Crustacea	Amphipod	Nationally Rare	2	2	0	0	NR	
Hincksina flustroides	Bryozoa	Errect colonial bryozoan	Nationally Rare	23	n/a	4	Present	0	
Microcosmos claudicans	Chordata	Sea squirt	Nationally Rare	14	35	8	127	0	
Acanthocardia aculeata	Mollusca	Spiny cockle	Nationally Rare	3	11	0	0	NR	
Adreus fascicularis	Porifera	Sponge	Nationally Rare	0	0	0	0	5	
Echinus esculentus	Echinodermata	Edible Sea Urchin	IUCN: Lower risk(LR / nt)	0	0	0	0	1	
Nucella lapillus	Mollusca	Dogwhelk	OSPAR Listed	0	0	1	1	0	
Raja montagui	Chordata	Spotted Ray	OSPAR Listed	0	0	1	1	0	
Dorvillea	Annelida	Marine worm	Not found in UK	2	3	0	0	NR	
Ericthonius brasiliensis	Crustacea	Amhpipod	Not yet recorded	2	17	0	0	NR	
Leucothoe richiardii	Crustacea	Amhpipod	Not yet recorded	1	1	0	0	NR	

Table 17 Rare and alien species identified in grab and video sampling across the synthesis study area, and trawl sampling only in South Coast REC study area.

NR = Not resolvable by video
NI = not identifiable from video/stills alone

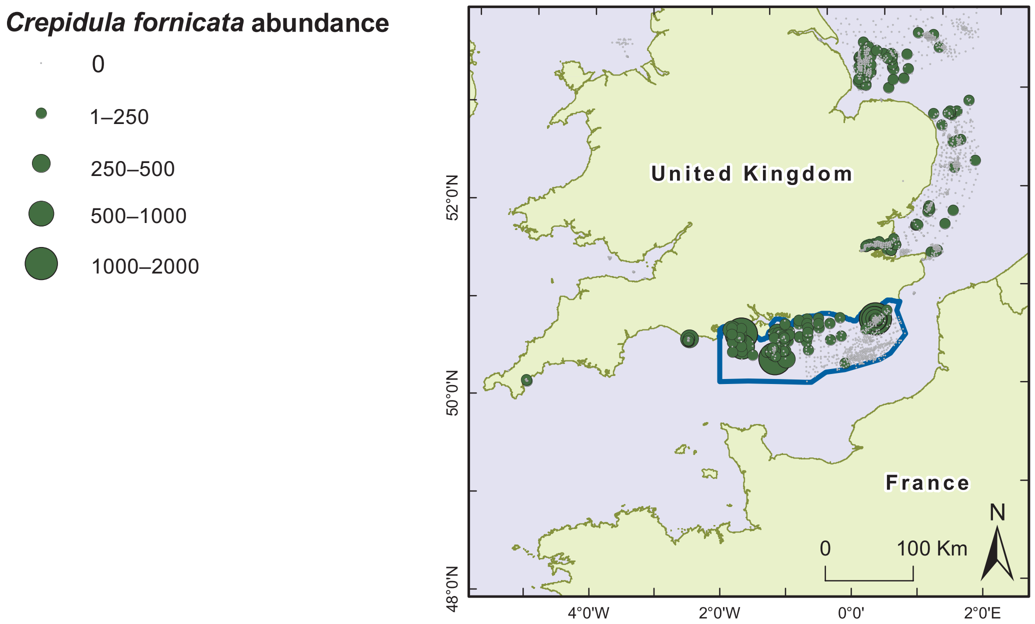


Figure 119 Distribution of *Crepidula fornicata*.

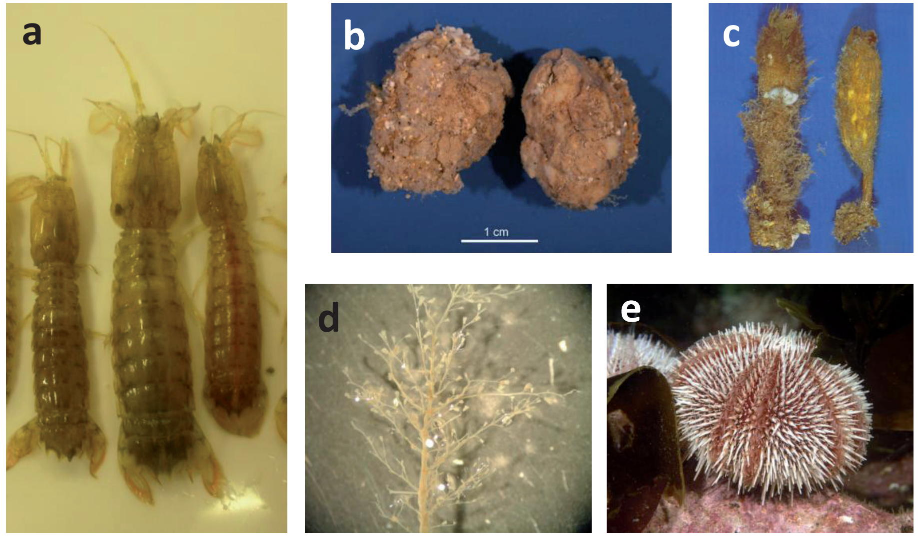


Figure 121 Some rare and alien species found in the synthesis area: a) nationally scarce mantis shrimp *Rissoides desmaresti*, b) nationally rare sea-squirt (ascidian) *Microcosmos claudicans*, c) invasive 'leathery sea squirt' *Styela clava*, d) nationally rare erect hydroid *Obelia bidentata* and e) edible urchin *Echinus esculentus* (IUCN Low risk). Images b) and c) © John Ryland. All other images © www.seasurvey.co.uk.

Figure 120 Sea bed covered with *Crepidula fornicata* and several species of red algae

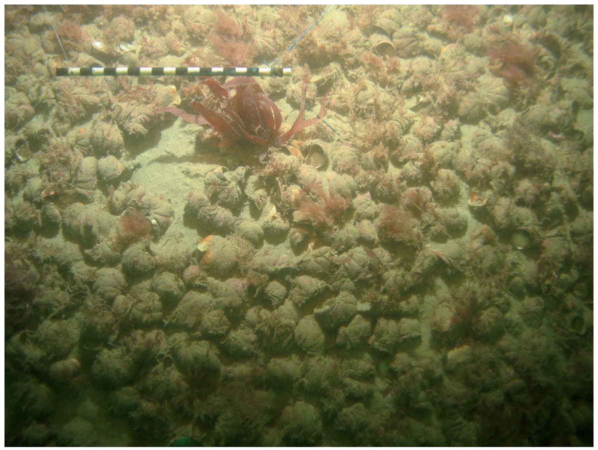


Figure 122 Large clamshell grab sea bed sample crammed full with *Crepidula fornicata*.

Submerged prehistoric landscapes

Sea level change and archaeology

Over the last million years the area now occupied by the English Channel has alternated between dry land and ocean as relative sea level has fallen and risen. One reason for these changes in sea level is climate change. During periods of very cold climate (ice ages or glacials) water is frozen in massive sheets of ice at the poles and in high mountain chains, causing sea level to drop (see pages 51–52). In the warmer periods (interglacials) these ice sheets melt and sea levels rise. During the periods of lowest sea level large parts of the Channel were dry land.

These once-dry lands that now form the sea bed would have been no different to the more familiar lands on either side of them in what are today southern England and the coasts of Brittany, Normandy, Picardy and Pas-de-Calais. Rivers flowed across the land, wind and rain eroded exposed rock and fragile soils. Populations of plants and animals would have lived here, and among these would have been our remote ancestors known as hominins, and later our own species, *Homo sapiens sapiens* (Figure 123).

It is possible to broadly model the landscapes that would have existed at different times and to picture the sorts of environments these early humans would have lived in. Evidence derived from ancient sites that have been preserved on land can give us clues about the sort of places that might have been lived in or used. On this basis we can suggest the sort of places where preserved evidence might survive submerged beneath the sea.

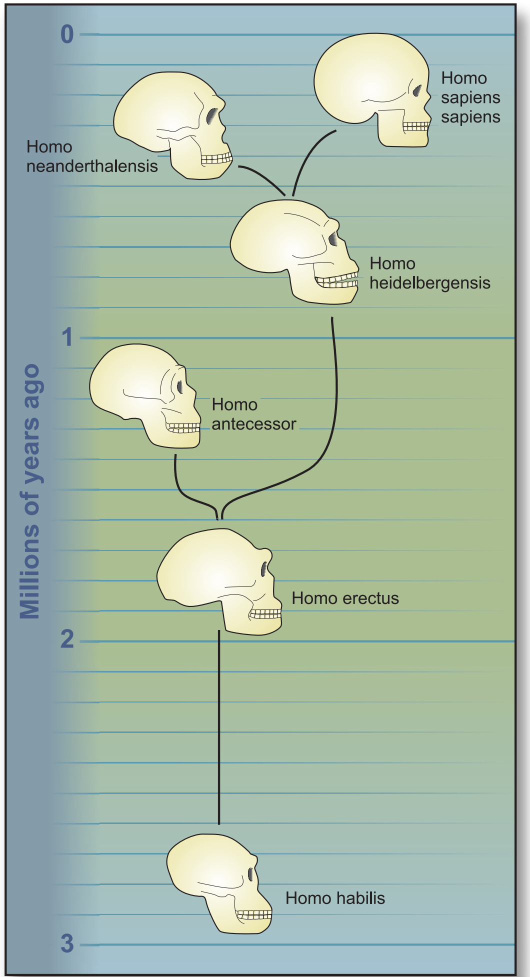


Figure 123 The human family tree.

Complicating factors

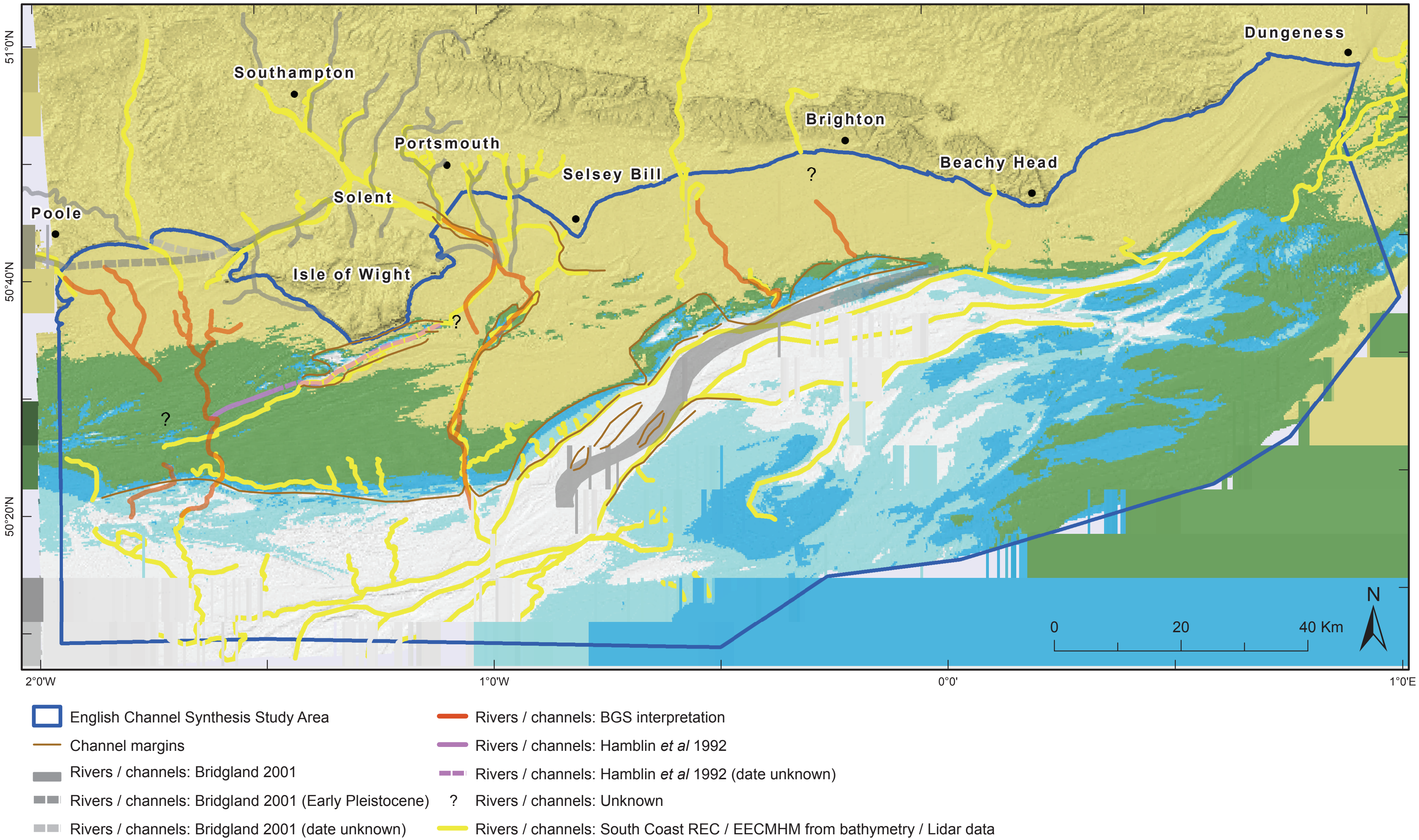
Trying to picture the ancient landscapes of the English Channel is complicated by the different processes that have shaped the current sea bed. We need to take account of the impact these will have had on the landscapes that would have been exposed in the past, and the part they may have played in the destruction or preservation of traces of those ancient landscapes in the present.

Bedrock and uplift

The different geological formations and bedrock types in the region are outlined elsewhere in this book (see pages 44–50). Structurally the region is quite complex, with rocks ranging in age from 32 to 155 million years. These have been subject to uplift, tilting and erosion during these times. Where bedrock is exposed at the sea bed the form and character of the rock may exert some control on the pattern of landforms and how they have responded to different sea depths during periods of higher sea level.

Old rivers

Most of the surviving topography and sedimentation in the study area results from the actions of rivers at times when the area was dry land. Evidence of these old river systems can be seen across the study area where a complicated network of old valleys of different ages lies buried (Figure 124). Many of these valleys form extensions of rivers which still exist on land. Others belong



Digital bathymetric data © British Crown & SeaZone Solutions Ltd. 2007. All rights reserved. Data Licence 052008.012.
Jarvis A., H.I. Reuter, A. Nelson, E. Guevara, 2008, Hole-filled seamless SRTM data V4, International Centre for Tropical Agriculture (CIAT), available from http://srtm.csi.cgiar.org.

Figure 124 Old river systems.

to rivers which no longer exist (the Solent and Channel Rivers for instance).

It is the land surfaces associated with these old valleys that are thought to be the most likely places where prehistoric archaeological sites and objects might survive. Sometimes, the archaeological material has not moved since it was first deposited and remains in what are called primary contexts. More often, artefacts have been moved from their original positions by rivers or the sea and deposited elsewhere in secondary contexts.

The changing shore

One obvious effect of rising and falling sea level is that the coastline moves. The positions of former shores can survive on land as raised beach deposits and old cliff lines. A series of raised beaches survive in Sussex, where sand and gravel beaches lie at the base of cliffs parallel to the present coast (Figure 125).

From the oldest to the youngest these are:-

- Goodwood-Slindon Raised Beach
  Marine Isotope Stage (MIS 13) ~500 000 years ago
- Aldingbourne Raised Beach (MIS 9) ~340 000 years ago
- Brighton–Norton cliff line (MIS 7) ~240 000 years ago

These raised beach deposits can be very important sources of archaeological artefacts and information, as they preserve land surfaces and deposits that have elsewhere been destroyed. For example, the Slindon Beach Formation contains the oldest dated human remains ever discovered in Britain.

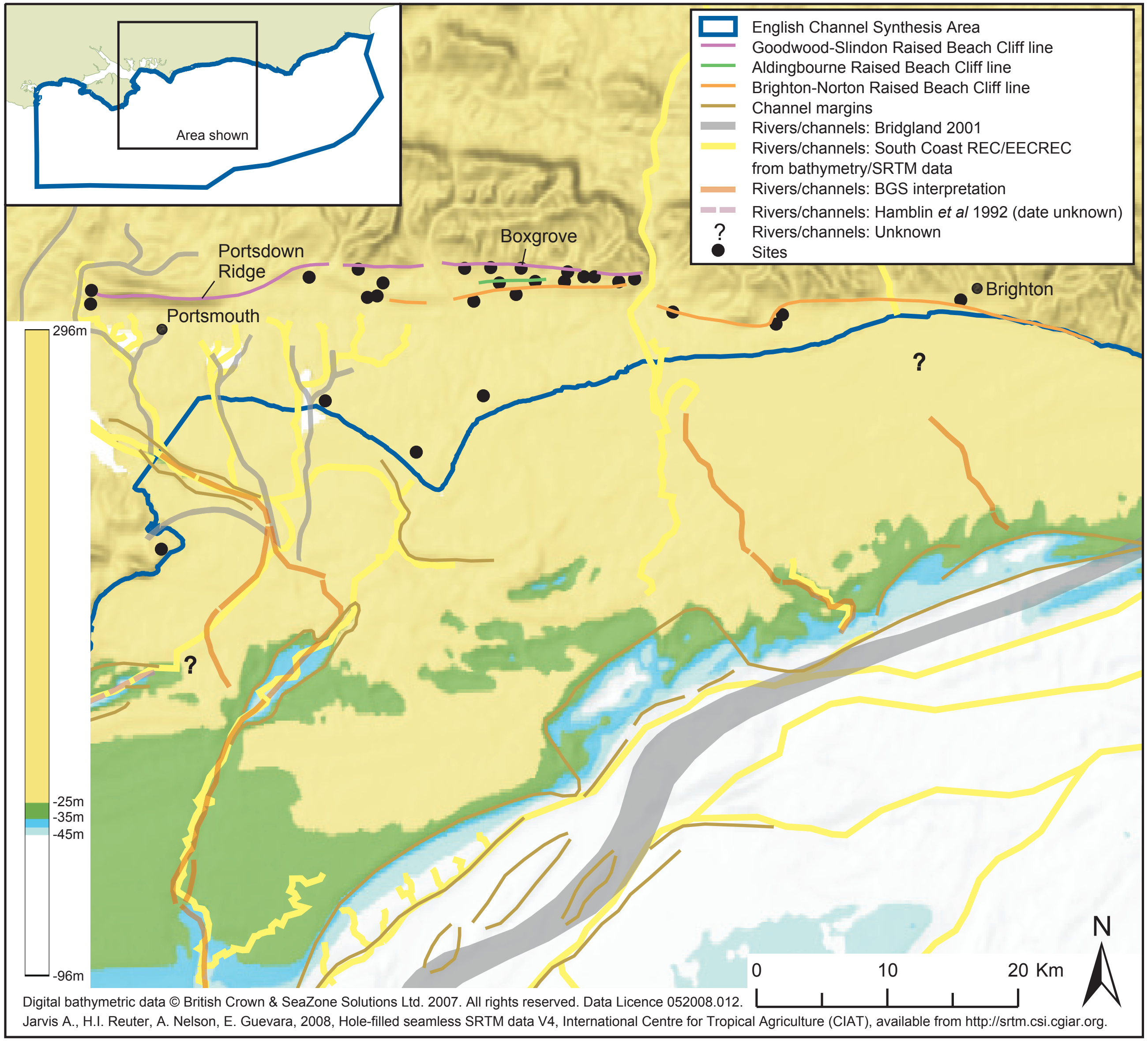


Figure 125 Sussex raised beaches.

Marine Aggregate Levy Sustainability Fund MALSF

Ice ages and the rising seas

During the most recent ice ages sea levels fell to exceptionally low levels leaving what is now southern England and northern France intensely cold and dry and uninhabited by any human populations. The ice sheets did not reach the English Channel (Figure 126), but the whole region was frozen in a periglacial, with permafrost conditions.

Once temperatures finally started to rise the ice sheets began to melt, leading to further rapid changes in sea level.

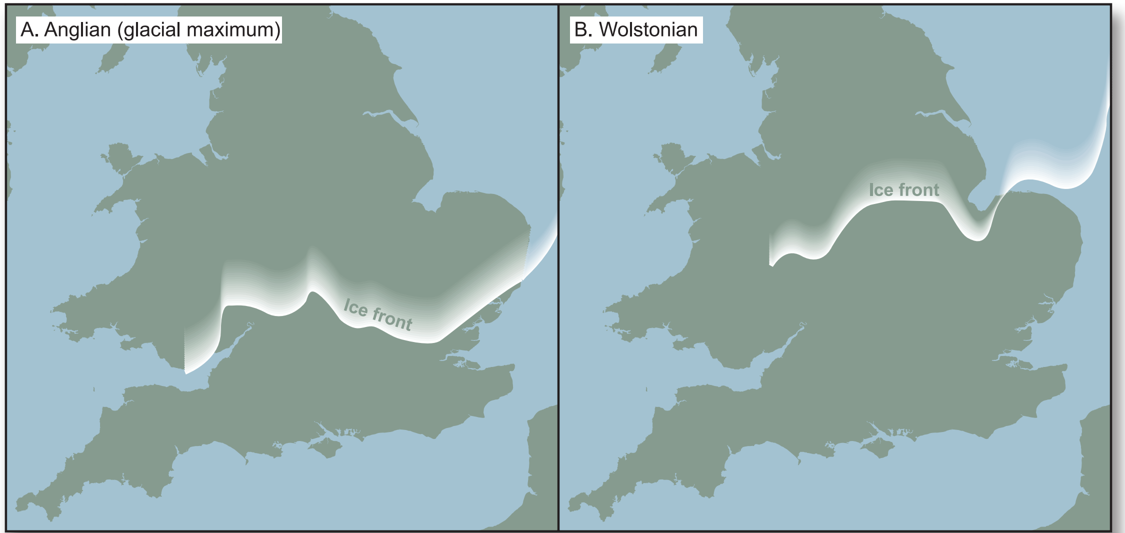


Figure 126 Southern extents of ice sheets in the UK during the most recent ice ages.

Hominins and early humans around the English Channel

Most of the evidence we have for what might lie under the sea comes from the land (Figure 127). Even here, a lot of the material we find — mostly stone tools — tends to be out of context, things of different ages are mixed up together as a result of natural processes and human activities like ploughing. It is only very occasionally that we find material relating to the earliest inhabitants of Britain in undisturbed *in situ* deposits.

Raw materials and tools

The most durable of materials employed by early populations in the study area were stone, most commonly flint although a variety of other materials were also used. The change in type, range and style of manufacture of flint and other stone tools is the main way that archaeologists have worked out a chronological sequence (Figure 128) which holds good for much of northwest Europe, ranging from the earliest of Palaeolithic finds from at least three quarters of a million years ago to the Middle Bronze Age three and a half thousand years ago. Using this chronology even individual tools and the waste material left over from their manufacture can be at least broadly dated.

Most prehistoric finds from the sea bed date from the Palaeolithic or earlier Mesolithic. Later material, after about 10 000 years ago, tends to be in intertidal and near-shore locations as it is younger than the main episodes of Holocene sea-level rise.

Lower Palaeolithic

During the Lower Palaeolithic, before 150 000 BP, a very restricted range of stone tools were used, the most common of which were handaxes (Figure 129). Technological changes can be seen but the dating and sequence is very difficult to define. Suffice it to say that, over a period of perhaps 350 000 years during which earlier forms of hominin (probably *Homo heidelbergensis*) are known to have come and gone from the area around what is now the English Channel, there are very few fixed chronological points.

Middle Palaeolithic

Distinctive types of flint axes known as Mousterian types (Figure 130) are associated with the remains of *Homo neanderthalensis*. Although Neanderthal skeletons have been found very rarely in Britain they are much more commonly encountered in the river valleys of northern France. Distributions of Mousterian tools indicate that Neanderthals must have been present on both sides of the Channel, even if sporadically.

Upper Palaeolithic

Modern humans, *Homo sapiens sapiens* — us, were present in northwest Europe from at least 38 000 BP, and potentially overlapped with *Homo neanderthalensis* by 10 000 years or so. Throughout this period changes in stone tool technology are very obvious, with the abandonment of axes as the tool of choice and a much wider range of small implements being adopted, many made on long narrow blades (Figure 131).

Mesolithic

Mesolithic toolkits continue to be dominated by implements made on blades. Distinctive new types appear, including new forms of

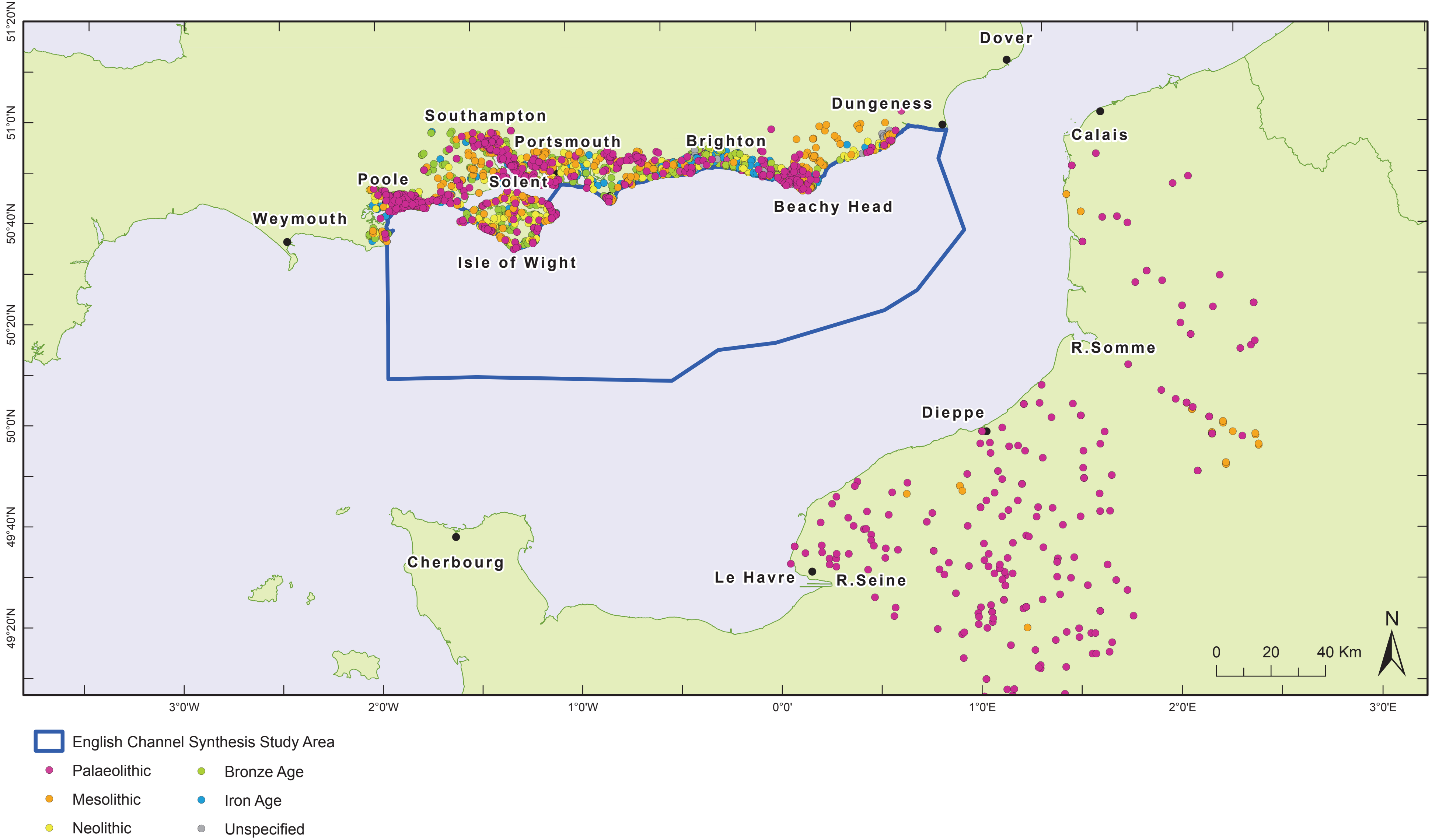


Figure 127 Known prehistoric sites on the English and French coasts. The English data consists of sites from the National Monuments Record. The French data consists only of Palaeolithic and Mesolithic sites and is sourced from Wessex Archaeology (2005).

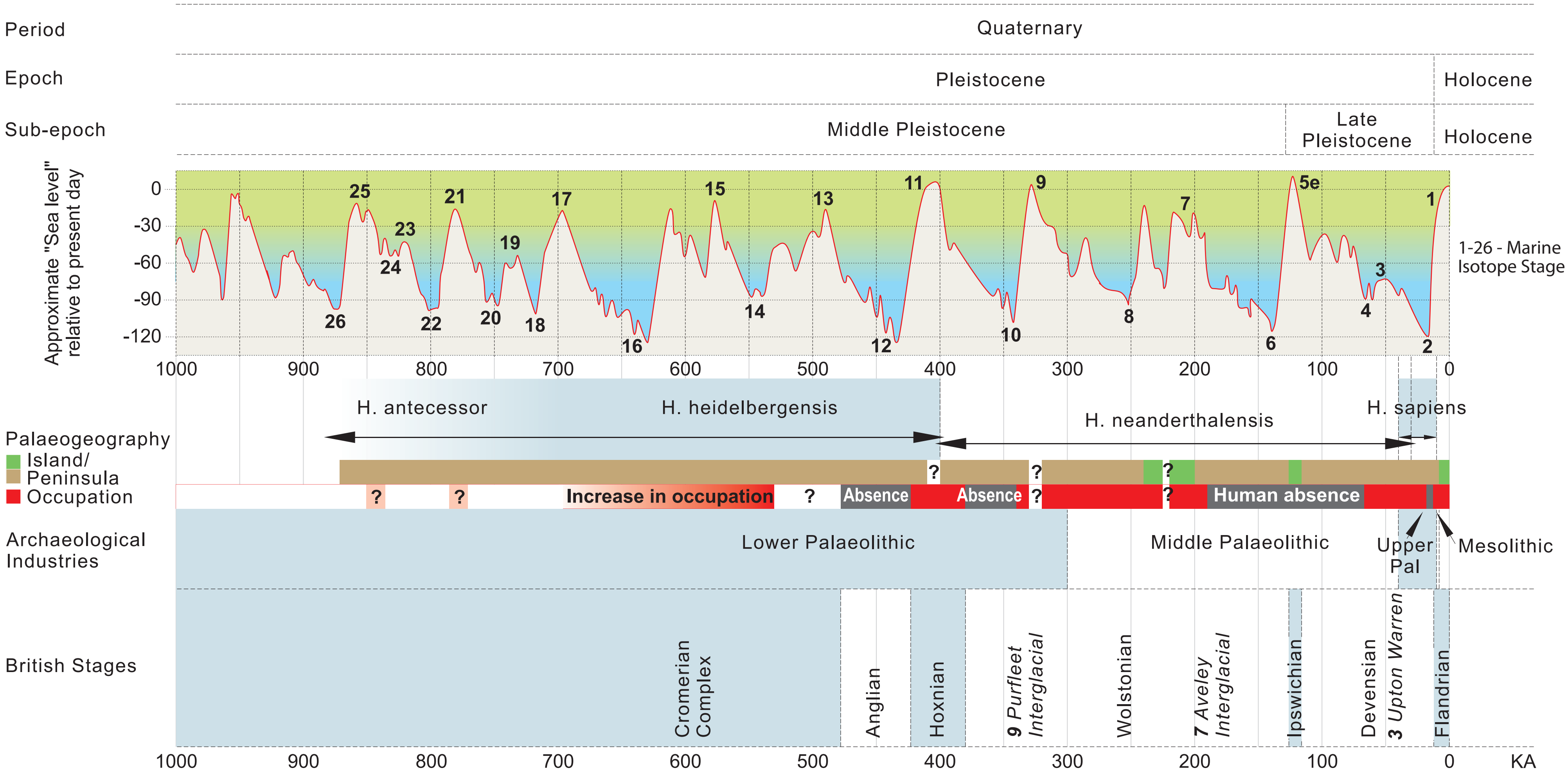


Figure 128 Sea level curve for 100 000 BP to present. Climatic conditions relating to glacials, interglacials, Marine Isotope Stages and geological periods are shown.

axes, known as *tranchet* types, and small multi-purpose tools called microliths (Figure 132).

The sequence of tool types emphasises the fact that prehistory, however remote, was not just one long period in which one species of the class *Hominidae* did a limited number of unchanging tasks interrupted by periods of extreme cold. The further back in time we go the more difficult it is to match archaeological data with specific climatic events but there are key reference points — archaeological sites and assemblages in specific locations on land — that can help us to model the use of what is now the sea bed at different periods.

Analogues

The material that is recovered from under the sea tends to be the equivalent of unstratified material on land: even if *in situ* up to the point of its recovery the circumstances in which it is found, for example dredging, grab sampling and aggregate extraction, means that it is often impossible to know exactly where it came from.

This doesn't mean that the material is useless. As with equivalent material on land, ploughzone assemblages for example, even when there is no direct chronological or stratigraphic context, material from the sea bed can still tell us a lot. Artefacts from the sea bed provide archaeologists with information concerning the large-scale use of landscape, settlement patterns, raw material acquisition and use, and many technical aspects of tool production.

Plants and animals

As the climate got variously better and worse, the types of animals that lived in an area changed. Because we know the sequence of warm and cold stages this gives us another way of working out the ages of particular deposits and assemblages. Faunal assemblages containing woolly mammoth, reindeer, bison and/or cave lion will belong to glacial stages, for instance, while those containing spotted hyaena, straight-tusked elephant, aurochs or wild boar indicate interglacial conditions. Some species, such as horse and red deer, can live in extreme cold tundra and more temperate steppe or woodland conditions and are less useful for dating as a result. Small mammals are particularly useful as they underwent fairly rapid anatomical changes. Analysis of various types of vole has proved particularly useful in distinguishing specific interglacial deposits.

Archaeologists can also work out what environmental conditions were like at particular times and places by studying molluscs and beetles, and micro-organisms known as ostracods, diatoms and foraminifera. These are useful because they have very specific requirements for living conditions: on land; in lakes; in intertidal zones or freshwater; in fast or slow-moving water; in particular temperature ranges. Also, when studied in sequence, they can reveal changes in climate and habitat. Pollen can provide a picture of the wider landscape and indicate larger scale changes, for instance from coniferous to deciduous woodland to open grassland. In combination such organisms, which are widely preserved in a variety of sediments, have the potential to 'flesh out' our understanding of past landscapes. Organic layers, like peat, have the additional potential to provide material for radiocarbon or optically stimulated luminescence dating.

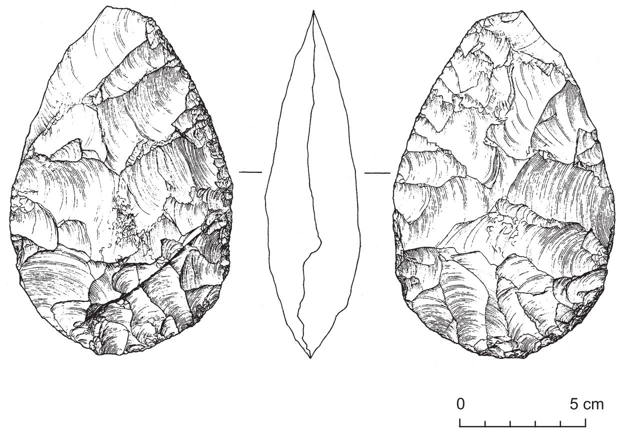


Figure 129 Acheulean biface from the Lower Industry at Hoxne (Wymer, 1999).

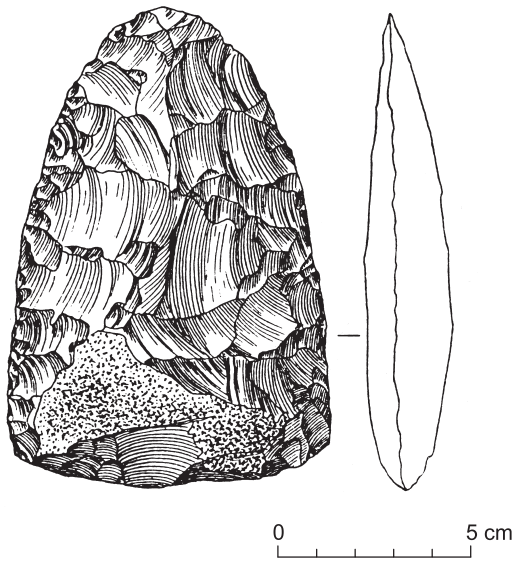


Figure 130 Mousterian handaxe, probably of Devensian age from the Bournemouth gravels (Wymer, 1999).

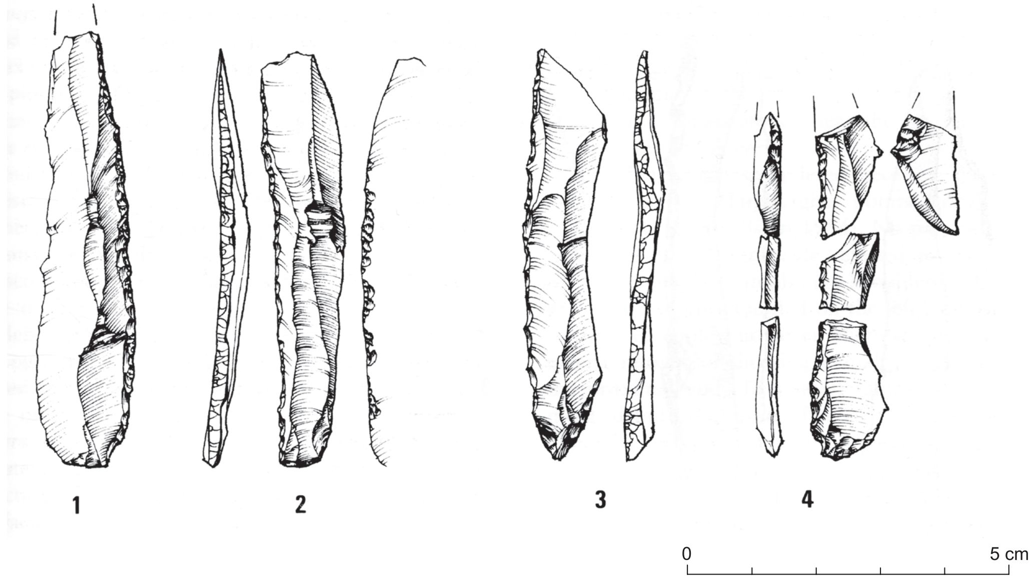


Figure 131 Late Upper Palaeolithic backed blades from Hengistbury Head (Christine Wilson in Barton, 1992).

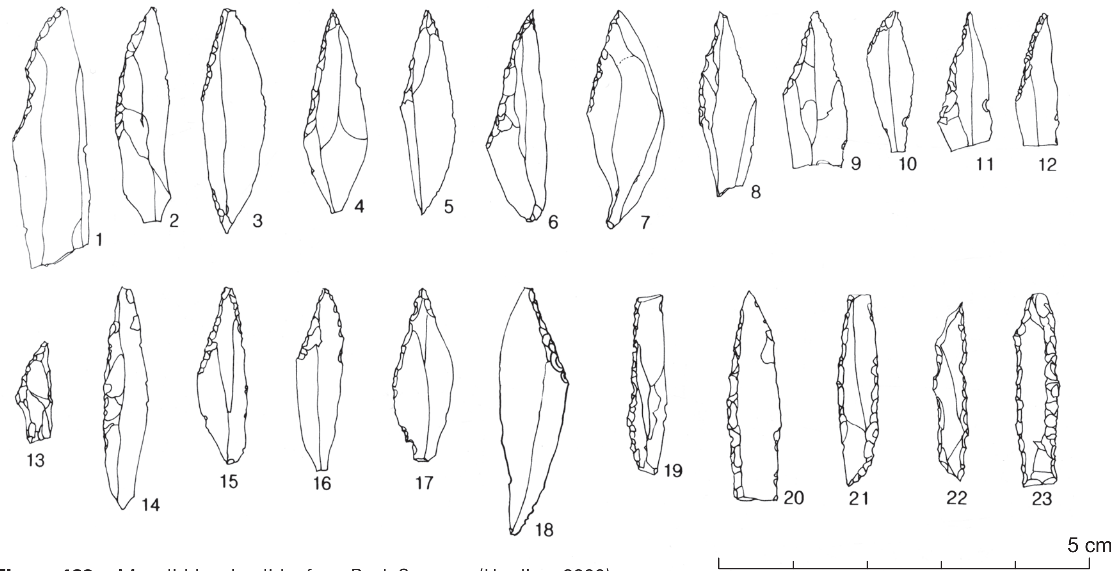


Figure 132 Mesolithic microliths from Rock Common (Harding, 2000).

Ancient landscapes: how were they used?

Archaeological material recovered from the sea bed is not just a collection of objects. Its importance lies in the fact that it indicates the presence of past populations inhabiting a lost landscape. The following sections try to suggest what that landscape might have been like at different points in time.

Living in the landscape

Archaeologists on either side of the English Channel have found plenty of evidence of prehistoric sites along current coastal margins. Archaeologists often talk of a land bridge connecting southern England to the Continental mainland at various stages of the Middle and Late Pleistocene. In the sense that the lands now drowned beneath the English Channel provided routes for the movement of hominins and other fauna this is true, but they would have been more important to the people alive at the time as places to live.

Lower Palaeolithic

12 km inland from the present Sussex coast, a chalk cliff marks the location of a beach half a million years old. At the base of this cliff are a series of Palaeolithic sites, the most famous of them being Boxgrove, where sand and silt deposits preserve *in situ* knapping debris, butchered animals, and hominin remains belonging to *Homo heidelbergensis*.

Sea level changes led to the development of a large salt lagoon which eventually dried out to become open grassland with forest cover on the downland to the north. From the number of flint tools found here, this area seems to have been very attractive to *Homo heidelbergensis*. The tools are mostly ovate handaxes, which were used to butcher giant deer, red deer, bison and rhinoceros. Bones of smaller animals (such as roe deer) do not show evidence of butchery and may not have been exploited. Large beasts seem to have been the target and there is evidence for both scavenging of whole carcasses and hunting.

Similar raised beach deposits with associated handaxes probably of this same date are known elsewhere in the study area, for example, at Bembridge on the Isle of Wight. Elsewhere in Britain at this time other hominin groups were exploiting rhinoceros, bison, deer, horses and straight-tusked elephants in East Anglia and the Midlands.

These finds have important implications for finding material of this date in the English Channel. With a sea level 40 m lower than present, large parts of the current sea bed would have been dry land, and the Boxgrove beach and cliff line, the Slindon Raised Beach, formed part of an embayment that fronted the land connecting southern England and France. Viewed from the northern shoreline the greater part of the contemporary terrestrial landscape seems likely to have been one of a low-lying coastal plain with occasional lakes and pools, framed to the north by the imposing chalk uplands of the South Downs and to the west by the high ridges of the Isle of Wight. The modern-day French coast would have been fronted by a broad low plain, of considerably greater extent than on the northern (English) shore, and drained by the extensions of the Canche, Authie, Somme and Seine which — like the rivers of Hampshire and Sussex — flowed across this plain into Channel rivers.

The Boxgrove material lets us imagine herds of large vertebrates, rabbits, mountain hares, and many other small creatures inhabiting a broad grassy prairie with occasional brackish lagoons and freshwater lakes inhabited by ducks and other waterfowl. This would have been a very attractive landscape for hominins, who appeared to take advantage of locations such as the base of cliffs with grassland backed by wooded upland, saltmarshes and littoral positions. If the presence of animals for hunting was not enough, fish such as conger eel, cod,

Figure 133 Phil Harding with two Lower Palaeolithic handaxes which date from around 400 000 BP. © Wessex Archaeology.

wrasse and blue fin tuna were available. Predators capable of killing hominins were also in evidence, including wolf, bear, spotted hyena and lion. Hominin groups are likely to have sought cover and protection in rock shelters and fissures.

The Boxgrove material belongs to a period known as the Cromerian. This warm phase was followed by a glacial period of very cold temperatures known as the Anglian (MIS 12). The Anglian ice sheet is the most extensive known to have covered Britain, extending as far south as the Thames Valley in the London area and even as far as the north Cornish coast in the west of England (Figure 126). Throughout the coldest parts of this period Britain and much of northern France would have been uninhabited. The Channel would have been dry land.

The Anglian glaciation was followed by the Hoxnian interglacial. At this time, sea level was between 10 m and 15 m lower than today and the coastal plain around the English Channel would have been considerably more extensive, with the Solent estuary and much of the Sussex coast fronted by a wide intertidal zone giving way quite rapidly to comparatively deep water. The Channel seems to have been open for much of this period. The environmental evidence suggests that the chalk hills lying beyond the coastal plain would have been well-wooded supporting a wide range of animals. Elsewhere in southern England there is evidence of a rich faunal and floral record indicating a mixed oak forest with lime, hazel, and alder. Later, hornbeam, spruce and particularly silver fir developed, suggesting acidification of soils. Among the other exploitable animal species recorded are red and roe deer, giant beaver, aurochs (wild cattle), hippopotamus, wild boar and wild ass, as well as fish and birds.

Our understanding of hominin movements and settlement in the Hoxnian interglacial is fragmentary but we might suggest that the coastal plain was used for occasional forays into the intertidal marshes and the lower portions of river valleys for fishing and fowling with some sea fishing.

The best known UK site from this period is at Swanscombe, Kent, where numerous handaxes (Figure 133) have been found along with faunal remains, tusks, teeth, shells and fragments of a human skull. Many handaxes are known from the gravel terraces of the Solent River, including a collection of over a thousand from Priory Bay on the Isle of Wight. On the Sussex coast, handaxes and cores have been retrieved from the Aldingbourne Raised Beach. Equivalent raised beaches are known on Jersey and in northern France.

More handaxes have been found in the gravel terraces of the Somme and its tributaries, from sites at Saint-Acheul and those from the *formation de la Garrenne* at Cagny. These sites tend to be situated on river banks, located to take advantage of flint present in the adjacent chalk cliffs. Consequently, it would seem that the potential for recovery of assemblages of this date in the marine zone is greatest in nearshore areas where remnant river terraces or valleys may be buried.

The following stage is known as the Wolstonian, lasting from 380 000 BP to 130 000 BP. This period was one of alternating periods of warm and cold with fluctuating sea levels and climatic conditions. In warm phases hominins were certainly active in northern France and southern Britain and many Palaeolithic sites and finds occur. Unfortunately, dating evidence is sparse and it is very difficult to identify material belonging to different phases.

Middle Palaeolithic

In northwest Europe the Middle Palaeolithic is synonymous with the appearance of a specific flint technology known as Mousterian which includes distinctive flat-butted handaxes *(bout coupé)* and flakes and cores employing a technique known as Levallois. This technological complex is generally also synonymous with Neanderthals and remained in use until perhaps 40 000 BP. Neanderthal bones from Britain are rare, more common in northern France, but flint implements of Mousterian type are frequent in both areas, suggesting a more widespread human presence than might otherwise be suggested.

A major glacial phase centred on 150 000 BP was followed by very rapid climatic improvement with sea level rising to nearly 10 m above modern levels. Surprisingly, this warm phase (known as the Ipswichian) has not produced any certain evidence of occupation in Britain, although French evidence indicates that this may be a very local phenomenon (if not simply an absence of evidence).

At around 120 000 BP sea level was falling from its highest level over the last 700 000 years. The sea level curve for this period, known as the Devensian, reflects considerable climatic variability with long periods of relative cold and, overall, a general trend towards ever colder conditions, culminating in the last ice age. Comparatively few archaeological sites have been found that can confidently be dated to the earlier part of the Devensian in Britain and it is likely that overall the population was very thin throughout this period.

An open shoreline with grassland was probably fronted by a wide intertidal zone across much of the region. This configuration, coupled with rapidly falling sea level, would be likely to have seen significant erosion of lower river terraces, downcutting of lower river valleys and the loss of archaeological material in high-energy environments. Subsequent fluctuations resulted in a complicated pattern of transgressive and regressive sedimentation and erosion including, on the one hand, the creation of shoreline gravel bars and, on the other, scouring of valleys and surfaces. This would imply that the potential for recovery of Middle Palaeolithic material from the marine zone would be fairly low. However, the climatic history of the period is particularly complex and it is quite possible that remnant terraces, infilled valley profiles, wavecut platforms and beach deposits may survive and preserve archaeological remains.

Upper Palaeolithic

The recolonisation of northwest Europe by anatomically modern humans occurred rapidly after the last glacial maximum at c.18 000 BP. A gradual north and northwestward spread of population brought societies out of the Paris Basin: their material, known as Magdalenian, has been recovered from as far north as Rinxent, Pas de Calais. In the middle reaches of the Somme, sites such as Longpre-les-Corps-Saints and Hangest-sur-Somme attest to a later repeated human presence associated with stone tools of a type known as Federmesser, beginning around 12 000 BP, also present on the Channel coast at Wimereux. Federmesser-type tools are considered to be technological developments associated with reforestation and the replacement of cold fauna with temperate fauna.

Britain had been recolonised by 13 000 BP, by which time cave and rock shelter sites such as Gough's Cave, Badger's Hole and Sun Hole on Mendip, Kent's Cavern, Devon and Robin Hood's cave, Derbyshire were being occupied on at least a seasonal basis. It appears, therefore, that some human groups were arriving even before the onset of warming. This is reflected in the animal bone assemblages from these sites which indicate hunting, mainly of reindeer along with elk, Saiga antelope and giant deer. As the climate warmed, the specifically cold climate mammals retreated north, along with the open steppe country that they habitually grazed, with horse, aurochs, red deer and possibly roe deer becoming more common. Low scrub of juniper and willow began to develop, followed by pine and birch forest.

This palaeo-environmental evidence and faunal remains can sometimes be recovered from the sea floor, with chance finds from marine aggregate dredging, such as an auroch vertebra and a red deer antler (Figures 134 and 135), reported through the BMAPA Reporting Protocol (BMAPA, 2005).

Figure 134 Auroch vertebra found in a dredging area off the southwest of the Isle of Wight (© Tarmac Ltd) and image of an auroch.

Figure 135 Red deer antler found during dredging operations to the east of the Isle of Wight. © Tarmac Ltd.

A number of open air Upper Palaeolithic sites have been recorded which seem to represent hunting camps. These are frequently situated on hilltops and bluffs overlooking open country, as at Hengistbury Head, Dorset. These were visited repeatedly, being ideally suited for exploiting herds of large herbivores. Low bluffs beside rivers, especially at fording points, with easy access to water, flint and a variety of animal and riverine resources, as at La Sagesse, Romsey and Nea Farm, Ringwood, both in Hampshire, were also favoured as locations for short-term camps, probably exploiting seasonally available produce. Flint assemblages of this period consist of large quantities of finely worked and highly portable tools in a much greater variety of forms than in earlier periods. Assemblages show not only regional variation in composition and technology but also local variation and differences between sites, indicating specific activity areas and the performance of a number of different tasks.

All of this material gives the impression of a highly mobile and very adaptable population, skilled in hunting, fishing and gathering, spreading rapidly throughout much of northwest Europe, including England and Wales. Entry points into southern Britain could have been many since, although the climate was changing rapidly and marine influence in the Channel area advanced quickly, at the time of the earliest recolonisation sea level would have been around -80 to -110 m and, for a comparatively brief period, the Channel almost entirely dry land. We might picture the French coastal rivers draining into an undulating plain with trains of gravel deposited by retreating waters, bars and dunes of blown sand, many intermittent cliff lines, relict river channels and the great northern barrier of the high chalklands rising to nearly 600 m above the plain. The chalk itself probably presented a cold and bleak landscape for many generations, dissected by rivers whose courses would have downcut rapidly as meltwaters poured out of the receding ice sheet. The middle parts of these valleys, in turn, became filled with solifluction deposits as large surface areas of the periglacial landscape turned from permafrost essentially to sludge and slumped, creating unstable slope deposits.

The larger and wider valleys, such as the Test, Stour and Hampshire Avon, in contrast, seem to have contained much quieter watercourses in their middle reaches with braided streams flowing between low terraces and gravel spreads with intermittent development of bedded gravels, alluvial and meltwater deposits and stabilisation horizons including peats. Lower valleys were cut into what is now the near-coastal shelf and may have tumbled over the edge of low cliffs into a much-reduced, probably braided, watercourse within the Northern Palaeovalley.

The Channel area is thus likely to have presented a generally very favourable habitat for Upper Palaeolithic herd animals and humans alike, albeit still a cold one prone to dust and sand blows. A combination of open grassland, fresh water, vantage points for hunting and the possibility of rock shelter sites were available. As the climate warmed so vegetation would have changed, producing a mosaic of habitat zones with increasing maritime influence. Almost any location within the marine zone where buried sediments survive has the potential to produce Upper Palaeolithic material, particularly land forms indicative of bluff positions overlooking former river channels, cliff lines and palaeochannels.

Mesolithic

Around 11 000 BP there was a rapid return to cold conditions: parts of northwest Europe were once again deserted by humans and much of southern England was a dry, cold desert. Within a thousand years, however, sharp rises in temperature were accompanied by equally rapid rises in sea level. Sometime during the 9th millennium BC Britain became an island.

Broadly speaking, the shrinking lands around the Channel area will have been occupied by seasonally mobile human groups exploiting a diverse range of resources and leaving behind many thousands of assemblages of artefacts testifying to an organised and diverse lifestyle ranging all across the landscape. River valley sides and lakesides, especially bluff locations overlooking rivers with locally available flint sources, and locations close to spring lines, were particularly favoured.

Current terrestrial areas adjacent to the Solent, Langstone Harbour and Chichester Harbour abound in Mesolithic flintwork ranging in date from the earliest recolonisation period to the 5th millennium BC and these distributions are known to extend into the intertidal zone and beyond.

Langstone Harbour is a shallow basin which developed as part of a low-lying, dry, largely grassy coastal plain supporting some stands of hazel, birch, pine, elm and oak that extended from Southampton Water to Brighton. This was fronted by saltmarshes and gravel bars, and probably contained a few freshwater pools or small lakes formed in former ice-wedge features and by ponding. Areas of marshland akin to the Amberley Wild Brook near Lewes in East Sussex may be envisaged. This picture is likely to have been typical of much of the extended coastal plain.

Mesolithic sites also occur in the valleys of the Yar and Medina on the Isle of Wight as well as offshore. At Bouldnor Cliff a Mesolithic

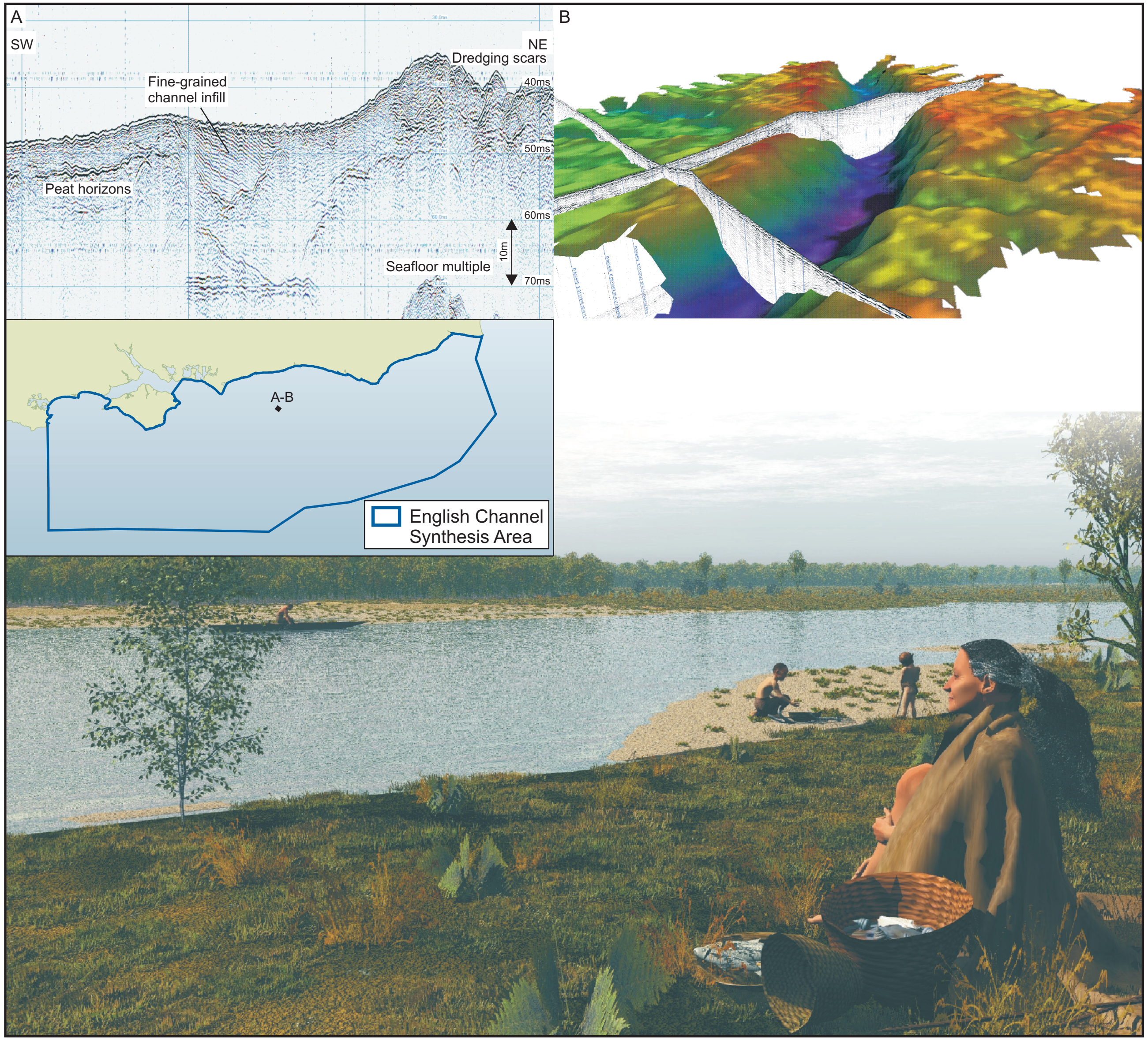


Figure 136 Sub-bottom profile data of the Palaeoarun with a reconstruction of the site from approximately 8 000 BP © Wessex Archaeology.

site lies at the base of the cliff c.12 m below sea level. Flint artefacts are associated with charred hazelnut shells and oak charcoal. Environmental and sediment analyses suggest a camp occupied in the summer, next to a river channel flowing through woodland. In time the vegetation changed, indicating the onset of wetter conditions, with brackish water, saltmarsh or mudflat habitat developing before complete marine inundation. Peat layers further offshore contain the remains of oak and pine forest dated to the 9th millennium BC.

The coastal plain extended across the offshore marine shelf, crossed by the lowest reaches of the various rivers and tributaries that emptied into the Northern Palaeovalley. One of these, the drowned valley of the Arun, contains evidence of an aquatic fen adjacent to slow moving water with local saltmarsh. Preserved pollen indicated an early Mesolithic birch and pine woodland fringing a wetland freshwater and reed swamp. This palaeo-environmental evidence, combined with the results of a geophysical survey, have allowed archaeologists to create a reconstruction of the landscape around the Arun from approximately 9000 BP (Figure 136). Nearly 700 pieces of worked flint were recovered, some of which dated to the early Mesolithic.

This evidence indicates the clear potential for recovery of Mesolithic material and Holocene land surfaces in the old river valleys of the shelf area. A large number of palaeochannels have been recorded off the Sussex coast which have the potential for containing archeaological material. Preserved sediments resting against former terrace edges or river cliffs could also preserve artefacts of this period.

Later prehistory

Sea level continued to rise, though more gently, through the Neolithic and Bronze Age. Today, very low tides occasionally expose fallen trees and tree stumps representing former forests growing on the Mesolithic and Neolithic coastal plain. In Langstone oak and yew trees with an understorey of alder and willow were growing on a peaty land surface beside a palaeochannel at c. 1 m below Ordnance Datum (OD) in the Neolithic. Other examples include fallen trunks in intertidal, former channel edge locations at Littlehampton, apparently associated with red and fallow deer bones and antlers, at depths of up to 3 m below OD. At Wootton-Quarr, on the Isle of Wight, tree stumps have been found *in situ* as well as wooden structures dating to the Neolithic and Bronze Age.

Coastal activity

Throughout the Neolithic and Bronze Age the harbours slowly developed as first brackish and then tidal inlets. Their grass and saltmarsh margins seem to have been largely used on a seasonal basis for grazing livestock and for burial. A later Bronze Age urnfield extends from Portsmouth across Langstone Harbour and the present coastal margin and into Hayling Island. Extensive assemblages of worked and burnt flint also occur and a number of bronze objects have been recovered reflecting the later Bronze Age and Iron Age phenomenon of depositing metal goods in 'wet places'. Neolithic and Bronze Age material is also present in large quantities on the foreshore and coastal margins of the Isle of Wight, especially off Wootton-Quarr. The area around Bournemouth and Christchurch Harbour is particularly abundant in both flint scatters and Bronze Age urnfields, indicating quite intensive settlement. By the Late Iron Age sea level approached its current level and the harbour margins, and possibly other coastal areas such as that around Lymington, seem to have been utilised largely for salt production and fishing with most settlement evidence confined to higher and drier land.

For the Neolithic onwards, therefore, the potential for recovery of archaeological material will be essentially confined to coastal margins.

Maritime archaeology

People have been crossing the Channel or moving around its margins by boat for many thousands of years. These activities have left their traces both as sites on the coasts, from the Bronze Age harbour at Hengistbury Head, Dorset to the modern docks at Southampton, and on the sea bed, where wrecks range from the 3rd century BC log boat in Poole Harbour to post-war losses (Figure 138).

Early shipping

The English Channel contains ports that have been important since at least the medieval period and has one of the densest concentrations of pre-1850 historic shipwrecks anywhere in the UK.

A comprehensive trading network existed between Britain and mainland Europe from at least the Iron Age. Direct evidence for watercraft has been found in Poole Harbour in the form of a 3rd century BC log boat and a Late Iron Age anchor and chain has been found at Bulberry Camp near Wareham, Dorset.

During the Roman period the focus of maritime activity shifted to the Solent and parts of the Sussex coast, where a number of important coastal settlements, villas and military bases developed, including Chichester, Southampton and Portchester.

By the 6th century, Portsmouth Harbour was being used by cross-Channel vessels and a harbour at Hamwic (Saxon Southampton) was also in existence serving both coastal and cross-Channel trade by c. 700 AD. Evidence suggests that goods from as far afield as Scandinavia and the mountains of the Eiffel region of France were being imported at this time.

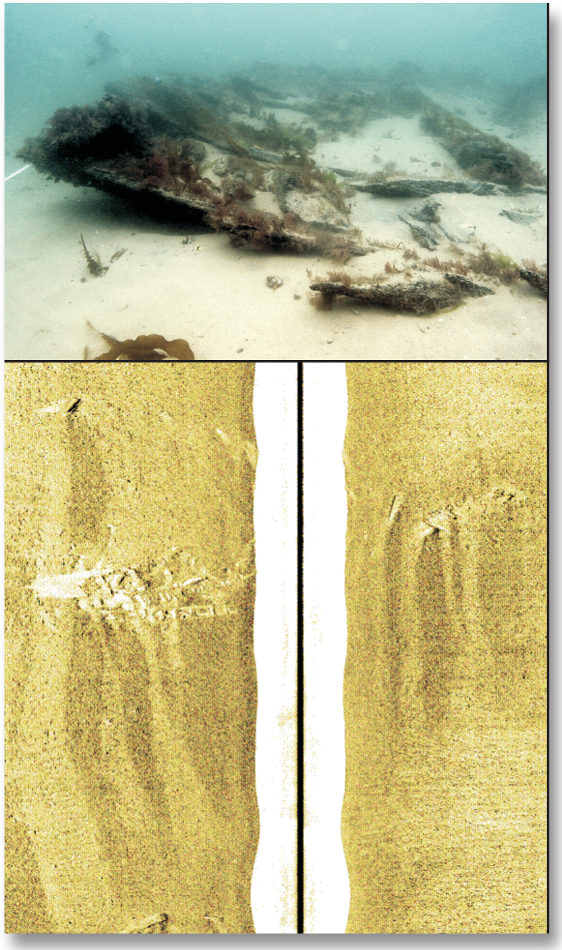


Figure 137 Swash Channel Wreck photo and sidescan image © Wessex Archaeology.

During the medieval period (1066–1540) records of individual shipping losses attest to the international nature of maritime activity, with French, Italian and Spanish vessels recorded as being wrecked. During the later medieval period warships enter the archaeological record, reflecting the growing importance of the Solent and of Portsmouth in particular.

The expansion of overseas trade followed by the stimulus of the industrial revolution resulted in the size of the merchant fleet operating around and from England growing by a factor of five between 1580 and 1680. This growth continued in the 18th century.

In addition to the growth in merchant shipping activity there was also an increase in military traffic, mirroring the rapid growth in the significance of the naval port of Portsmouth and the vulnerability of the south coast to raids and invasion. Nine pre-18th century naval battlegrounds have been mapped within 100 km of the Isle of Wight.

Historic sites

Notable examples of early boats and ships are protected under the Protection of Wrecks Act 1973. These include:

- *Grace Dieu*, a major warship of Henry V's navy, burned to the waterline in 1439 in the River Hamble;
- The remains of a lightly armed merchant vessel, southeast of the entrance to Poole Harbour. Known as the Studland Bay wreck, this vessel was of carvel-style construction thought to date from the 16th century. Carvel is a style of building where the planks of the hull lie edge-to-edge, rather than overlapping as in clinker-

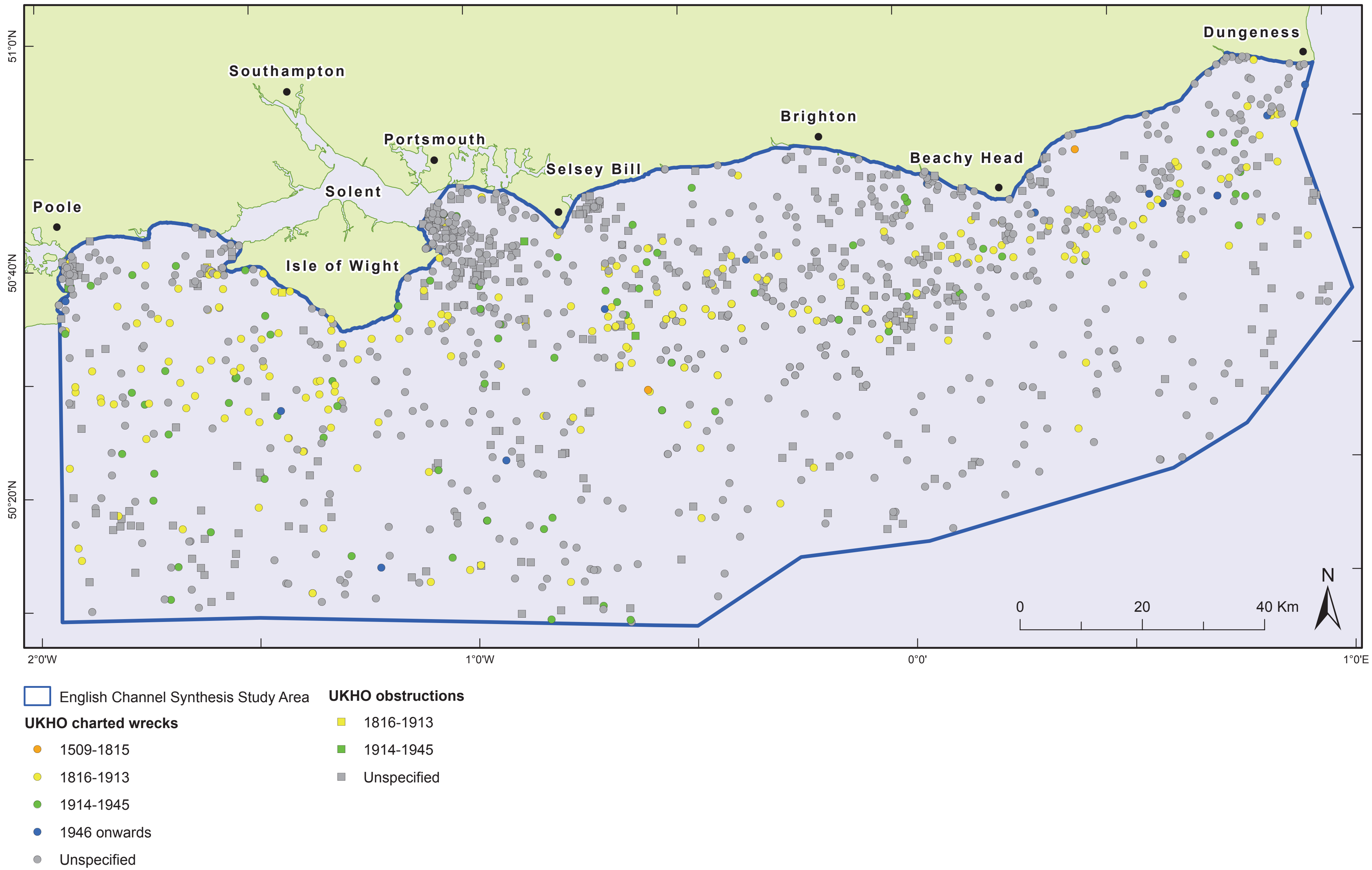


Figure 138 Wrecks and obstructions charted by the UK Hydrographic Office.

built boats. The vessel was carrying a cargo of pottery made in Seville, Spain for export to the West Indies;

- A wreck site just outside the breakwater for Brighton Marina, consisting of a number of bronze cannons, iron guns and other objects belonging to an unidentified armed vessel probably dating to the 16th century;
- A late 16th or early 17th century merchant ship, probably Spanish, lost at Yarmouth;
- A large armed, possibly Dutch merchant ship in the approaches to Poole Harbour. Known as the Swash Channel Wreck, two large sections of the hull survive (Figure 137). Although the identity of the vessel and the circumstances of its loss are unknown, pottery at the site suggests that it is likely to have been wrecked in the mid-17th century,
- *Hazardous* — originally a 3rd rate vessel in the French Navy, the *Hazardous*, built in 1698, was captured by the British in 1703 and refitted and commissioned into the Royal Navy as a 4th rate vessel in 1704. In 1706 the *Hazardous* was one of four vessels escorting a convoy from Virginia into the Thames estuary. Caught in bad weather, the *Hazardous* sought shelter off the south coast of the Isle of Wight but was forced into Bracklesham Bay where the captain ran the ship aground to save the crew;
- Two vessels off The Needles at the western end of the Isle of Wight. One is HMS *Assurance*, a 44-gun, 5th rate warship lost in 1753. The other is HMS *Pomone*, a 38-gun, 5th rate warship lost in 1811. Material from these two wrecks lies scattered over a wide area;
- *Invincible*, built in 1744 as a 3rd rate 74-gun warship in the French Navy before being captured by the British and commissioned into the Royal Navy in 1747. In February 1758 the *Invincible* was anchored in the Solent awaiting orders to sail to Canada when problems with raising her anchor led to the rudder becoming jammed and the vessel running aground on Horse Tail Sands. Despite efforts to lighten her, the *Invincible* rolled over and sank on the 22nd February.

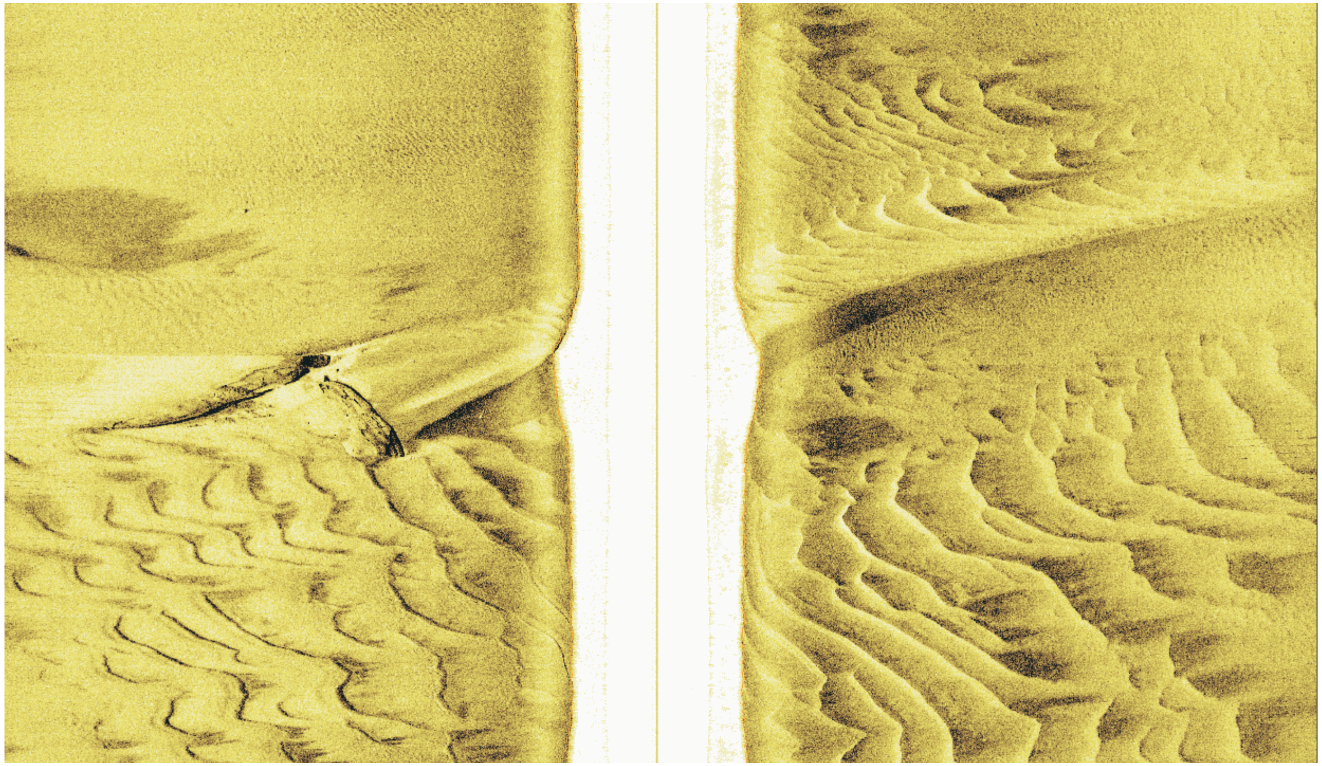


Figure 139 Sidescan sonar image of the *Irisbrook* and *Ville de Bordeaux* © Wessex Archaeology.

Later wrecks and obstructions

Most of the wrecks which can be identified relate to the earliest part of the 20th century, and particularly to the First and Second World Wars.

Dungeness to Beachy Head

The *George Sutton* was a steel brigantine last seen sailing from Newcastle to Cork carrying a cargo of coal on the 27th August 1883.

Although sailing brigantines like the *George Sutton* represent a class of merchant ship that increasingly had to compete against the proliferation of steam-powered coastal and ocean-going tramp ships, these ships still provided a useful and competitive service for home and coastal trades. Wrecks of brigantines in the study area are particularly scarce.

The *Skerryvore* was a 3371 ton British steamer which sank on 15th May 1910 following a collision with a German barque, *J C Vinnen,* whilst on passage from Villaricos to Rotterdam carrying a cargo of iron ore. The vessel sank rapidly killing 22 of the 23 crew onboard.

The *Skerryvore* is representative of a late 19th century ocean-going merchant steamship of a very important class known as the tramp ship. These vessels were the backbone of the world's merchant shipping between the late 19th century and the mid 20th century. They did not operate to a rigid schedule and carried a great array of bulk and general cargoes on an as-available basis.

Several other wrecks of tramp ships have been identified in the study area dating to the period of the Great War (1914–18, the First World War).

The *Branksome Chine* was a 2026 ton steel steam ship constructed by Craig Taylor and Company at Stockton Shipyard in 1899. On the 23rd February 1915 she was torpedoed and sunk approximately 6 miles southeast of Beachy Head by the German U-boat *U-8* while carrying a cargo of coal from Grimsby to Portsmouth.

The *Irisbrook* was a 2759 ton British steel cargo steamer, built in 1902 by John Blumer and Company, Sunderland, and owned at the time of loss by S S Tregannan Company Limited, Glasgow. The *Ville de Bordeaux* was a 1393 ton French cargo steamer, built in 1881 by Napier, Shanks and Bell, Glasgow, and owned at the time of loss by Cie. Des Bateaux À Vapeur Nord, Dunkirk. Both were lost whilst on passage, Swansea to Manaos and Brest to Dunkirk respectively, following a collision on the 23rd March 1911 (Figure 139).

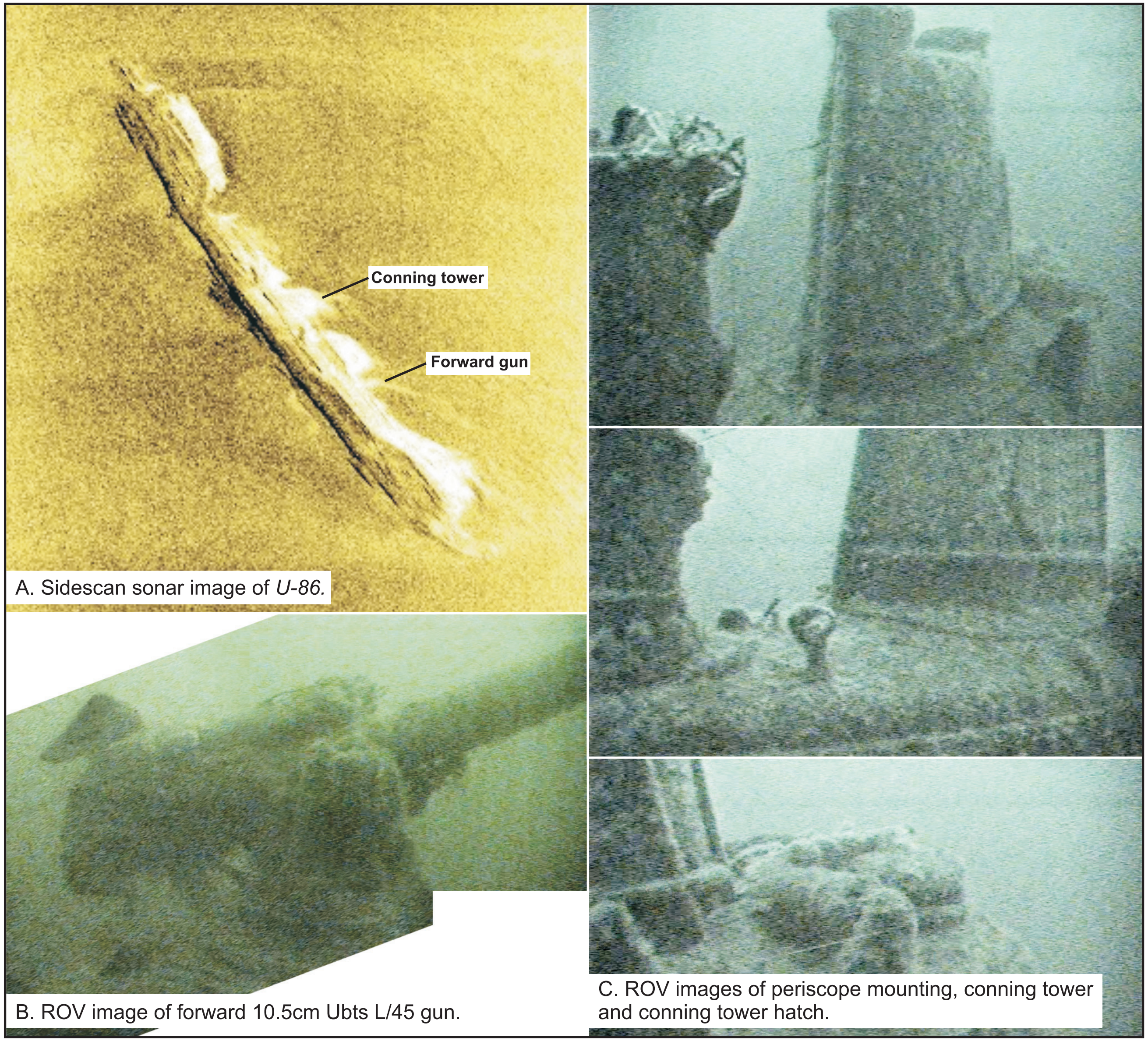


Figure 140 Sidescan sonar image and photographs of the wreck of the U-86 © Wessex Archaeology.

The *Rio Parana* was a large steam collier of 4032 tons constructed in 1902 by Irvine Shipbuilders and Dry Dock Company Limited. The vessel was torpedoed and sunk on the 24th February 1915 by the U-boat *U-8*.

These examples typify the fundamental importance of tramp and other merchant ships during the Great War, during which they transported industrial raw materials, food and munitions and also maintained the delivery of exports. Britain's survival relied on this sea trade of the import and export of goods. The wrecks of these tramp ships represent evidence of German attempts to try and sever Britain's supply links with the rest of the world and starve the nation into defeat.

Other wrecks related to the Great War include German U-boats, the most significant of which is perhaps *U-86* (Figure 140). This boat was commissioned on the 30th November 1916 and was one of the first of the U-81 series of ocean-going U-boats to be built. This boat survived the First World War having sunk 33 ships.

After the war the *U-86* was commissioned into the Royal Navy for a brief period and was towed for scuttling in June 1921.

U-86 is a significant wreck for a number of reasons. As a U-boat, it is representative of a class of warship that played a very significant role in the First World War. U-boats sank a considerable percentage of the Allied shipping lost in that war and are therefore accountable for the existence of a significant proportion of the wrecks in the study area. In terms of design it is significant because it was one of the U-boat designs produced in small numbers, *U-86* being one of only six of the U-81 series.

A similar picture exists of wrecks dating to the Second World War.

The *Caleb Sprague* was a 1813 ton steel steam ship carrying a 2305 ton cargo of steel and timber. On the 31st January 1944 it was struck by a torpedo from German E-boats and sank rapidly.

As an example of a medium-sized tramp ship the *Caleb Sprague* is not unique but instead indicative of the type vessel used to transport vital raw materials around the coasts of Britain and from across the Atlantic to fuel the war effort. These ships were a common target for German U-boats and E-boats and as a result their wrecks are quite common. Four wrecks of steam colliers (the *Broadhurst, Emerald, London Trader* and *Ouse*) sunk in E-boat attacks are also known.

Other wartime losses include barges and landing craft, large numbers of which were involved in Operation Neptune, the seaborne assault of D-Day, and Operation Overlord. Hundreds of vessels including landing craft left harbours and ports all along the south coast to take part in the Normandy Landings. Landing craft played a crucial role in the operations enabling both troops and vehicles to successfully land on the beaches.

U-678 was a VIIC type German submarine. This type was mass produced during the mid-war years between 1941 and 1944 and was known as the work horse of the Kriegsmarine. *U-678* was one of 568 VIIC submarines commissioned during the Second World War. On the 8th June 1944 *U-678* sailed from Marviken, Norway as part of the first wave of U-boats to stop Allied shipping reaching France after D-Day. *U-678* was detected and sunk by depth charge on the 6th July 1944.

U-678 is not particularly unusual but it does represent an important class of warship that performed a significant role during the Second World War. Although *U-678* was not responsible for any recorded losses, U-boats caused the loss of thousands of tons of Allied shipping and were therefore responsible for many of the Second World War wrecks in the study area.

Beachy Head to the Eastern Solent

85 shipwrecks and obstructions have been recorded along this stretch of coastline. Several of these are of identified vessels, including the SS *Lola* and the *Quail* (late 19th century merchant screw steam tramp ships, the former of which foundered in 1929, the latter in 1886); the type VIIC U-boat *U-1195* (lost in a depth charge attack in April 1945); landing craft tank *LCT(A)-2428* (assigned to support amphibious operations on Juno Beach on D-Day but capsizing due to engine trouble on the 5th June 1944); the steam trawler *Inverclyde* which sank under tow during the Second World War while requisitioned as a minesweeper; and the *Girlvine*, a mid-20th century motor fishing trawler.

Also among these wrecks is the SS *Braunton*, torpedoed and sunk by *U-29* on the 7th April 1916 4.5 miles southwest of Beachy Head, while carrying a cargo of 1800 tons of munitions. The ship had been loaded in Halifax, Nova Scotia and was on the last leg of the journey from Boulogne to Newport. Some records suggest the ship was carrying live ammunition and thousands of shell cases have been observed still within the ship's hold and spread out over the surrounding sea bed. Bearing in mind that the ship sank three months before the great Somme offensive it is more likely that she had unloaded her cargo of live ammunition and restocked her holds with spent shell cases to be sent to Newport for recycling back into live ammunition.

Other wrecks are notable for different reasons. One is HMS/m *A1*, the first British designed and built submarine, dating to 1902 (Figure 141).

The HMS/m *A1* sank twice, firstly in 1904 following a collision with another vessel during exercises, and secondly in 1911 while being operated under automatic pilot as a submerged target for anti-submarine warfare training off Selsey Bill. Although the position of the loss was recorded, the wreck could not be found. The wreck was finally discovered some five miles from its last known position, probably due to strong tides and some residual buoyancy.

The Isle of Wight to Poole

Nine shipwrecks and obstructions have been recorded in this area, amongst which are a number of vessels about which information is known. Two are early ships already mentioned above. In addition to these, the SS *Westville* was an armed collier sunk by U-boat *U-35* on 31 December 1917 while *en route* to Blaye carrying 5200 tons of coal.

From Coast to Mid-Channel

59 wrecks and obstructions have been identified in areas off-shore.

The most notable of these is undoubtedly the SS *Mendi* (Figure 142). The *Mendi* was a 4230 ton screw steamer requisitioned as a troopship during the First World War. The wreck is a site of particular archaeological interest. Rammed in fog by the steamer SS *Darro*, she sank in February 1917 with the loss of 646 lives. Among their number were 607 servicemen of the 5th Battalion, South African Native Labour Corps bound for the Western front.

This disaster has largely slipped from public consciousness in the UK and has only recently become a focus of commemorative activity. In South Africa the *Mendi* occupies a more significant place in national remembrance. The regular subject of commemorative events, she was also closely associated with the anti-apartheid liberation struggle. It is largely South African influence that led to renewed interest in the UK and to the acceptance of the site for designation under the Protection of Military Remains Act 1986.

The treatment of relatives of the deceased and the recognition of the sacrifice of those on board are still current issues. The *Mendi* disaster is becoming a regular feature of Black History Month in the UK and the site has an important role to play in developing awareness of the wider historical significance of links between the UK and Africa.

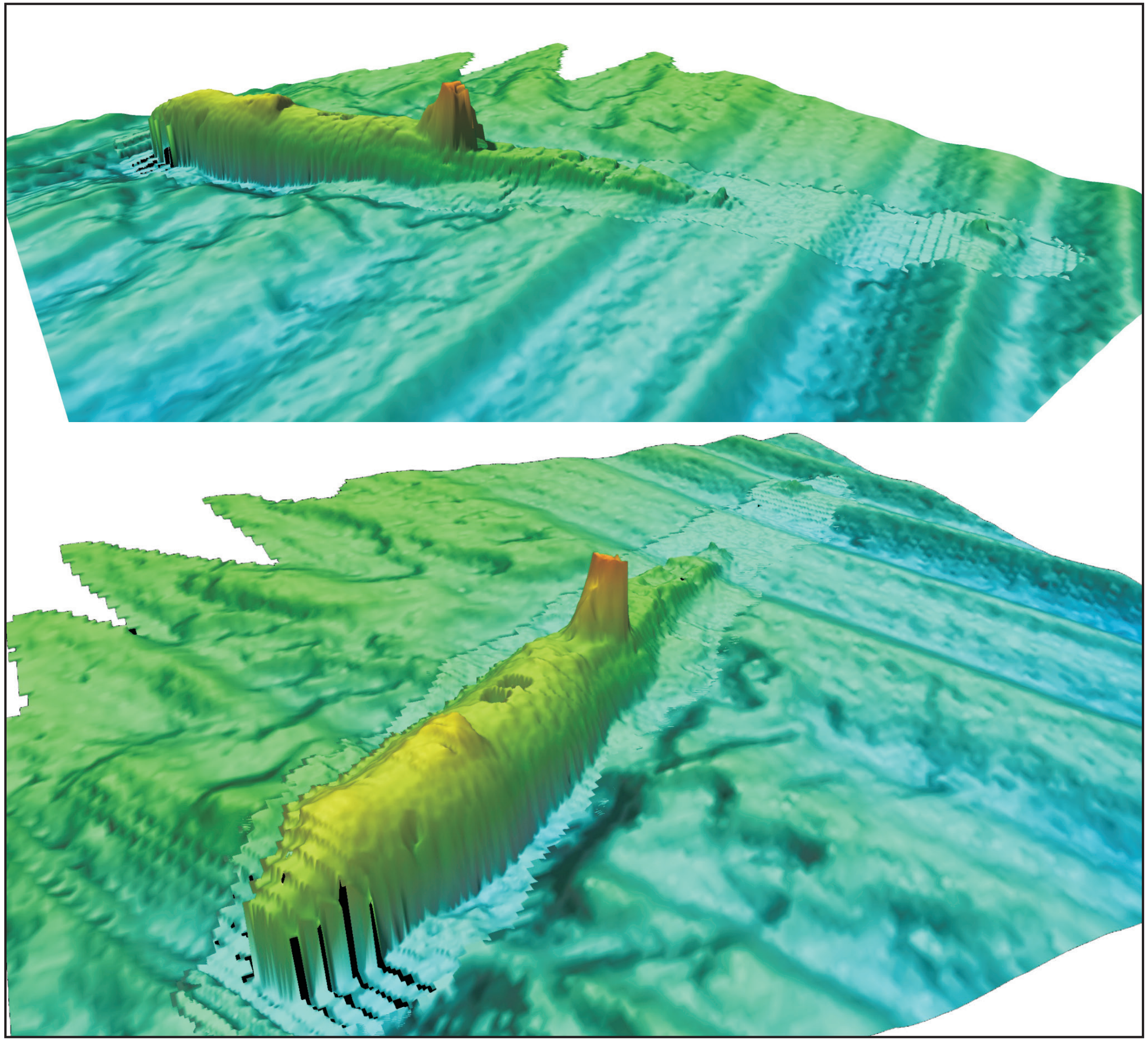


Figure 141 HMS/m *A1* multibeam image (© Wessex Archaeology).

The West Africa-Liverpool trade, of which the *Mendi* was a part, means that the *Mendi* can be understood not only as an event in the Great War but also as an important link between the UK and Africa. The *Mendi* reminds us that the history of the British Isles cannot be separated from the rest of the world.

Other wrecks in this region conform to the pattern of wartime losses elsewhere in the study area. The SS *Pagenturm* was a German merchant steamer seized by the British at the outbreak of the First World War and requisitioned by the Admiralty. It was sunk off Beachy Head by U-boat *U-40* in May 1917.

The *St Rogatien* built in 1901 was 1581 tons, torpedoed and sunk on 17th November 1916 while on passage from Dieppe to Buenos Aires. As a sailing ship of the early 20th century it represents an important class of ship and one that is relatively rare in comparison to its steam contemporaries, the tramp ship.

U-81 was a German U-boat which struck a mine and was then struck by a British patrol boat in December 1917. Only seven of the 34 crewmen survived.

HMS *Acheron* was a 1350 ton destroyer launched in 1930 which served in the North Sea and Northwestern Approaches during the early stages of the Second World War. In July 1940 the *Acheron* was damaged by German dive bombers in the English Channel and repaired in Portsmouth dockyard. During offshore trials in December 1940 she struck a mine and sank with the loss of 196 crewmen.

HMS *Loyalty* was a minesweeper involved in the Normandy landings. She was lost in August 1944 while returning to Portsmouth when she was attacked and sunk by the German U-boat *U-480*.

HMS *Swordfish* was an S class submarine launched in 1931. She departed from Portsmouth on the 7th November 1940 and is thought to have struck a mine off the Isle of Wight soon afterwards with the loss of all 40 crewmen.

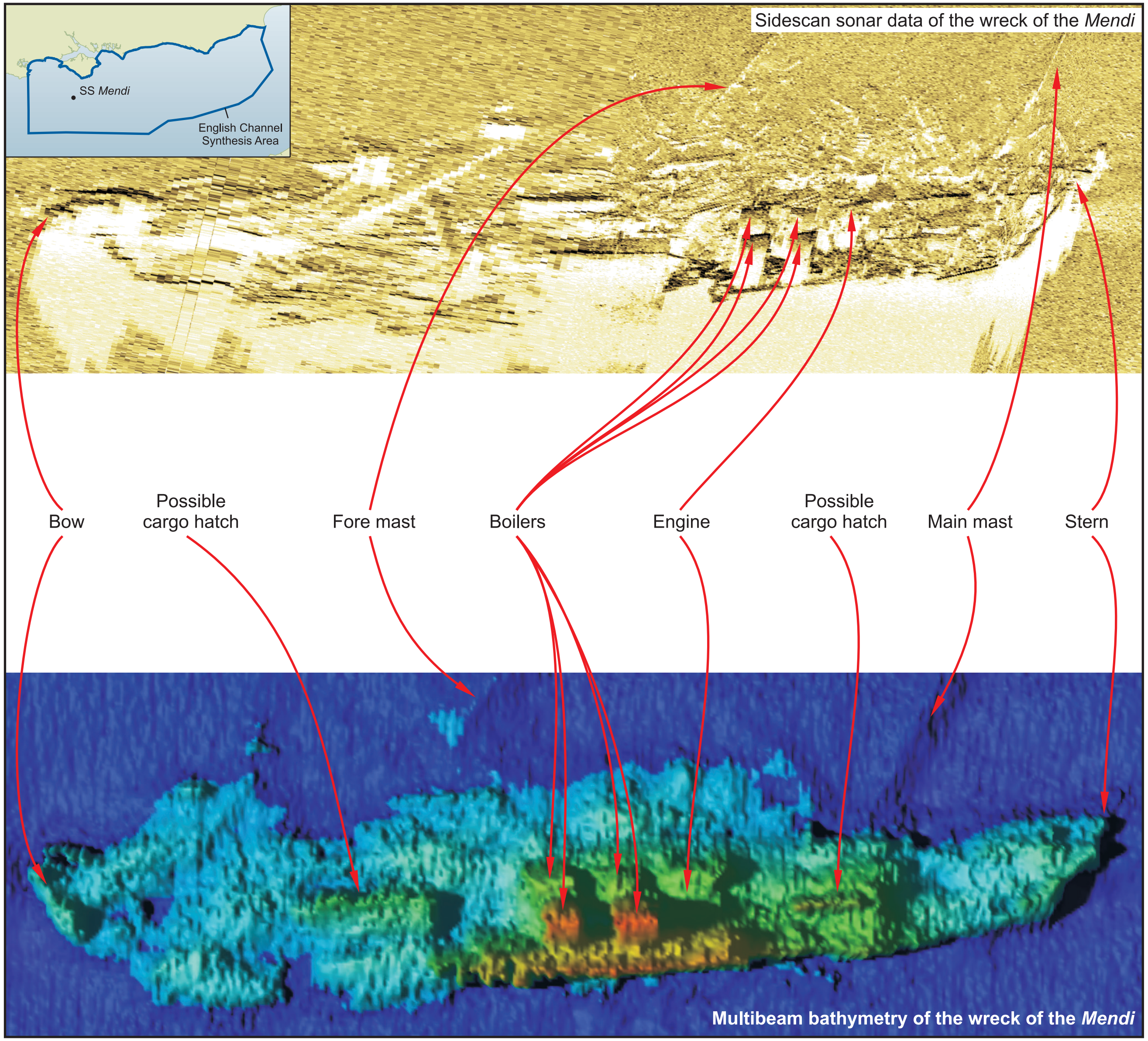


Figure 142 Geophysical data of the SS Mendi and archaeological interpretation © Wessex Archaeology.

Aviation archaeology

The vast majority of aircraft losses in the English Channel have been of military aircraft dating from the Second World War.

Although they received little attention from marine archaeologists until recently, aircraft crash sites, particularly those of historic military aircraft, are increasingly regarded as important archaeological sites.

Physically, aircraft wrecks are relatively fragile compared to shipwrecks. Aircraft frequently break up when they crash or ditch, and their fragility makes them particularly vulnerable to damage and dispersion as a result of natural processes including corrosion and the physical impacts of human activity such as trawling and dredging.

This fragility and the relatively small size of aircraft wrecks makes them very hard to find. Even large aircraft can be hard to recognise unless they are intact and fully exposed. For example, one English Channel anomaly identified as being a probable wooden shipwreck was subsequently identified as a partially intact Consolidated B-24 Liberator four-engined bomber (Wessex Archaeology, 2007). Far more aircraft are known to have crashed than there have been wrecks identified (Figure 144).

Figure 143 Short Stirling Mark III © AnyJazz65 (Flickr).

Aircraft wrecks

The majority of the recorded aircraft losses in the study area date from 1939–1945 and include Allied and German fighters and bombers and Allied air-sea rescue aircraft. While estimates of the numbers of aircraft lost in the region during the Second World War number in the thousands, the locations of very few wreck sites are actually known.

Dungeness to Beachy Head

There are no recorded aircraft wrecks in the eastern part of the study area. A small number of aircraft casualties are recorded but none of these have been identified. In part this will be due to a lack of investigative diving by recreational divers, which tends to take place in shallower inshore waters.

Beachy Head to the Eastern Solent

Several crash sites are known in this region, of Second World War and more recent date. Many cannot be tied to known losses, of which there are approximately 100, but some can be more certainly detailed. One might be part of wreck BF455, a Short Stirling Mark III four-engined heavy bomber (Figure 143) lost whilst returning from a raid on Frankfurt on the night of 10–11 April 1943.

The aircraft, of the 75 (New Zealand) Squadron, based at Newmarket, had been damaged by flak and attacked by night fighters and was forced to ditch, reportedly about 3 miles off Shoreham. All of the crew were subsequently rescued.

A second wreck is recorded approximately 20 km south of Shoreham, West Sussex. Known from dive reports as being the broken up and largely buried remains of an aluminium aircraft with a single V-12 engine and a panel instrument with writing in German, it is likely that it is the wreck of a German Bf 109 fighter (Figure 145).

The Isle of Wight to Poole

Over a 100 losses are recorded within this area, but again very few can be tied to actual known wrecks. One is almost certainly a four engined Handley Page Halifax bomber (Figure 146). That aircraft was introduced in 1940, mainly as a heavy bomber but also in specialised roles such as a glider tug and also with RAF Coastal Command. As a bomber it took part in all of the major Bomber Command raids. In the maritime patrol role it was not retired until 1952. The likelihood is that it was lost during 1940–45.

The partially intact wreck of a C-47, commonly known as a Dakota or Skytrain (Figure 147), is known to lie close to an outfall in Sandown Bay, Isle of Wight. The aircraft has not been identified conclusively but it has been suggested that it is a C-47 of the US 95 Troop Carrier Squadron that ditched after suffering flak damage over France on 7th June 1944.

From coast to mid-Channel

A much smaller number of losses are recorded offshore, for several reasons. One might be that most combat interceptions of German aircraft occurred closer to the coast. Another is that crews of damaged aircraft that had to ditch would have wanted to have done so as close to the coast as possible. In addition, more investigative diving by recreational divers has occurred in shallower inshore waters, resulting in more discoveries there.

A good example of how difficult it can be to identify wreck sites is one located approximately 19 nautical miles southeast of St Catherine's Point. This wreck was first identified in 1983 and described as a small possibly intact wooden shipwreck (Figure 148). Sidescan sonar and magnetometer surveys conducted over this site in 2005 appeared to confirm this interpretation of the site although it was noted that material was spread over a wide area. It was not until investigations using a remotely operated vehicle (ROV) in 2006 that it became clear that the wreck was in fact a partially intact four-engined Consolidated B-24 Liberator heavy bomber (Figure 149), lying upside down.

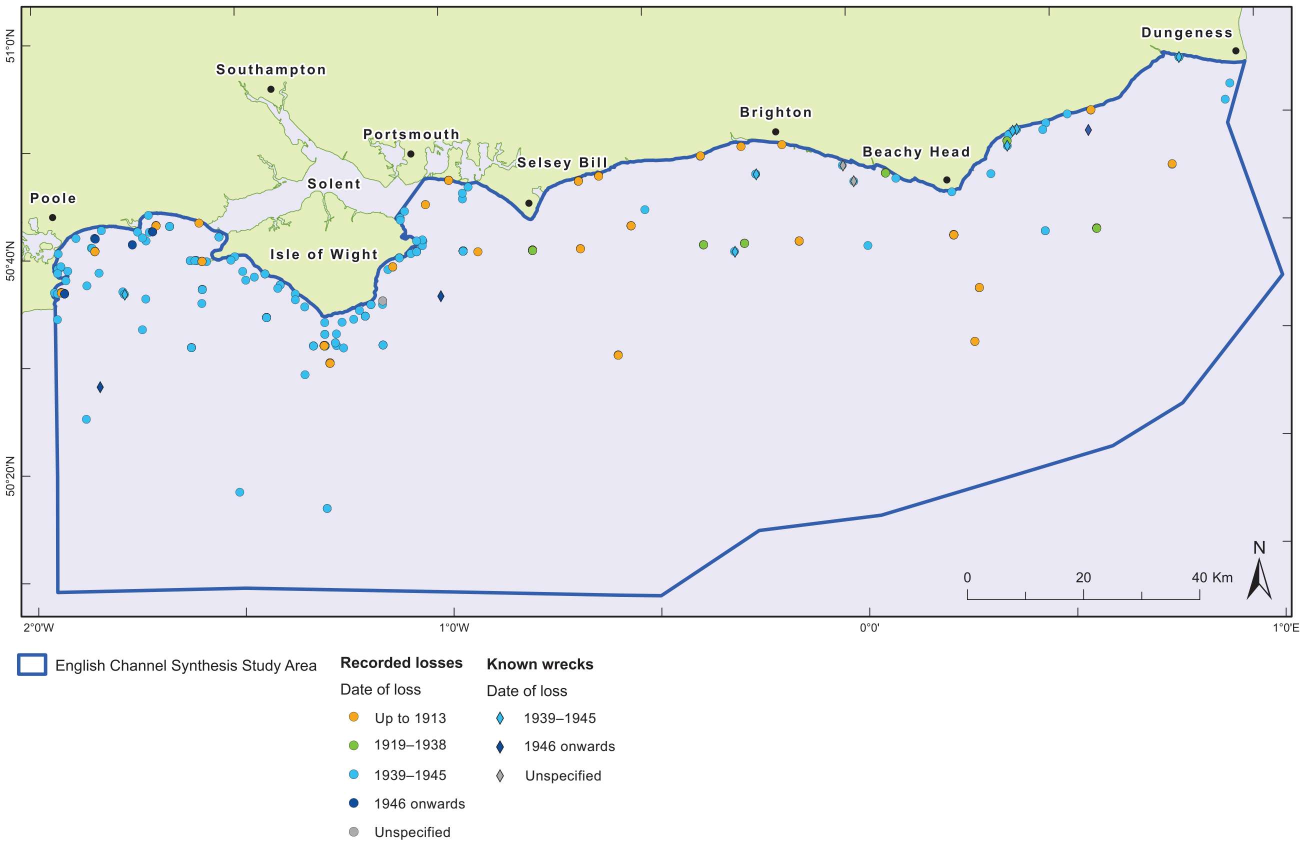


Figure 144 Aviation wrecks and recorded losses.

At least the centre sections of both wings survive, although both are detached from the fuselage which appears to be far less intact. All four engines are present, and three are still attached to the wings (Figure 150). Most of the surviving parts of the aircraft are partially or completely buried, and the condition of the wreck and items, including clothing, found around it suggest that in 2006 it had only been fairly recently uncovered.

The Liberator was produced in greater numbers than any other American combat aircraft and was operated by the RAF and the US 8th Air Force during the Second World War. There are many thousands of recorded losses of Liberators, but not enough information exists to allow the positive identification of this wreck.

Figure 145 Messerschmitt Bf109 © Geoff Collins.

Figure 146 Halifax © Robert Taylor.

Figure 147 C-47 – commonly known as a Dakota or Skytrain © Andrew Dennes.

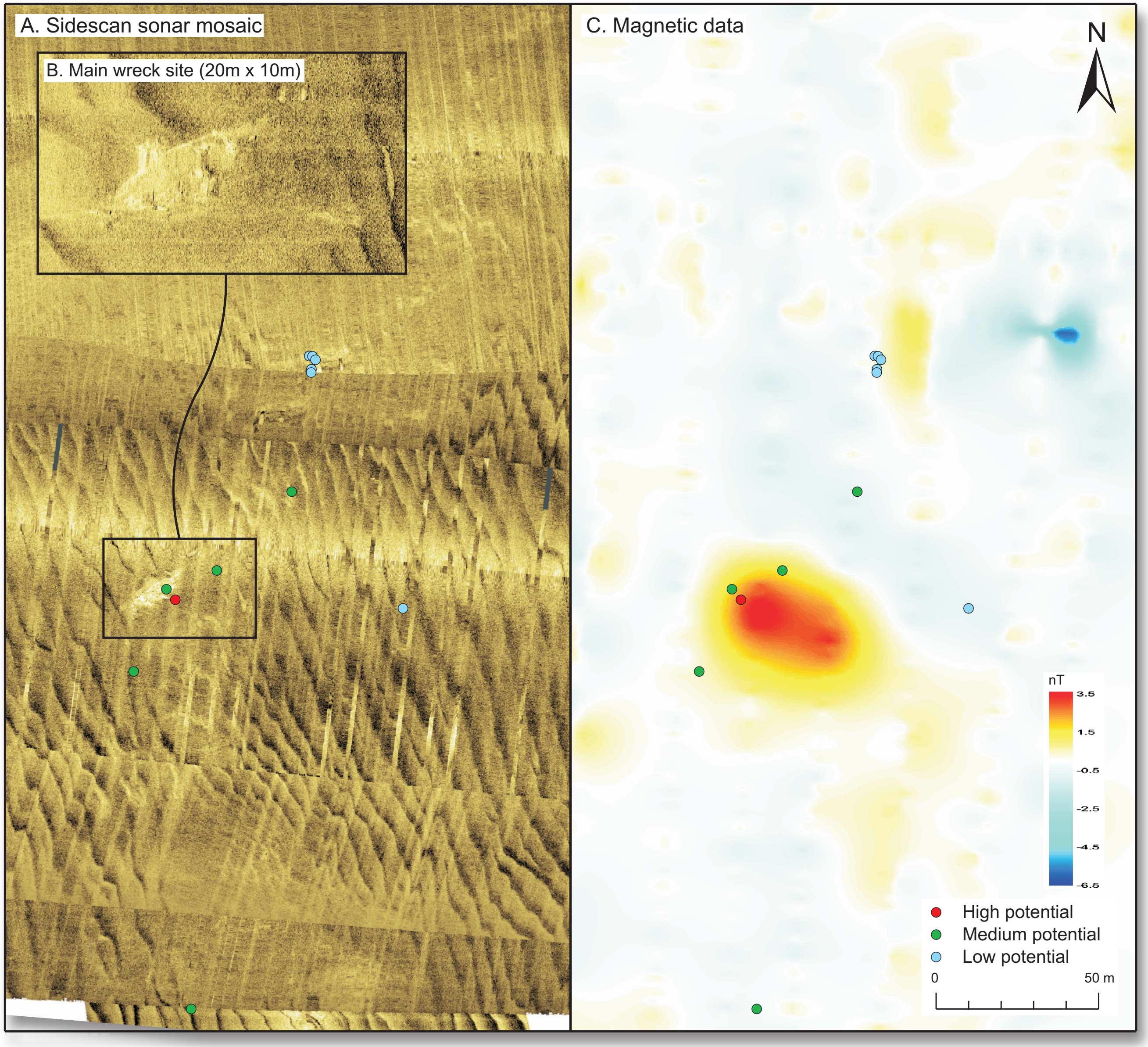
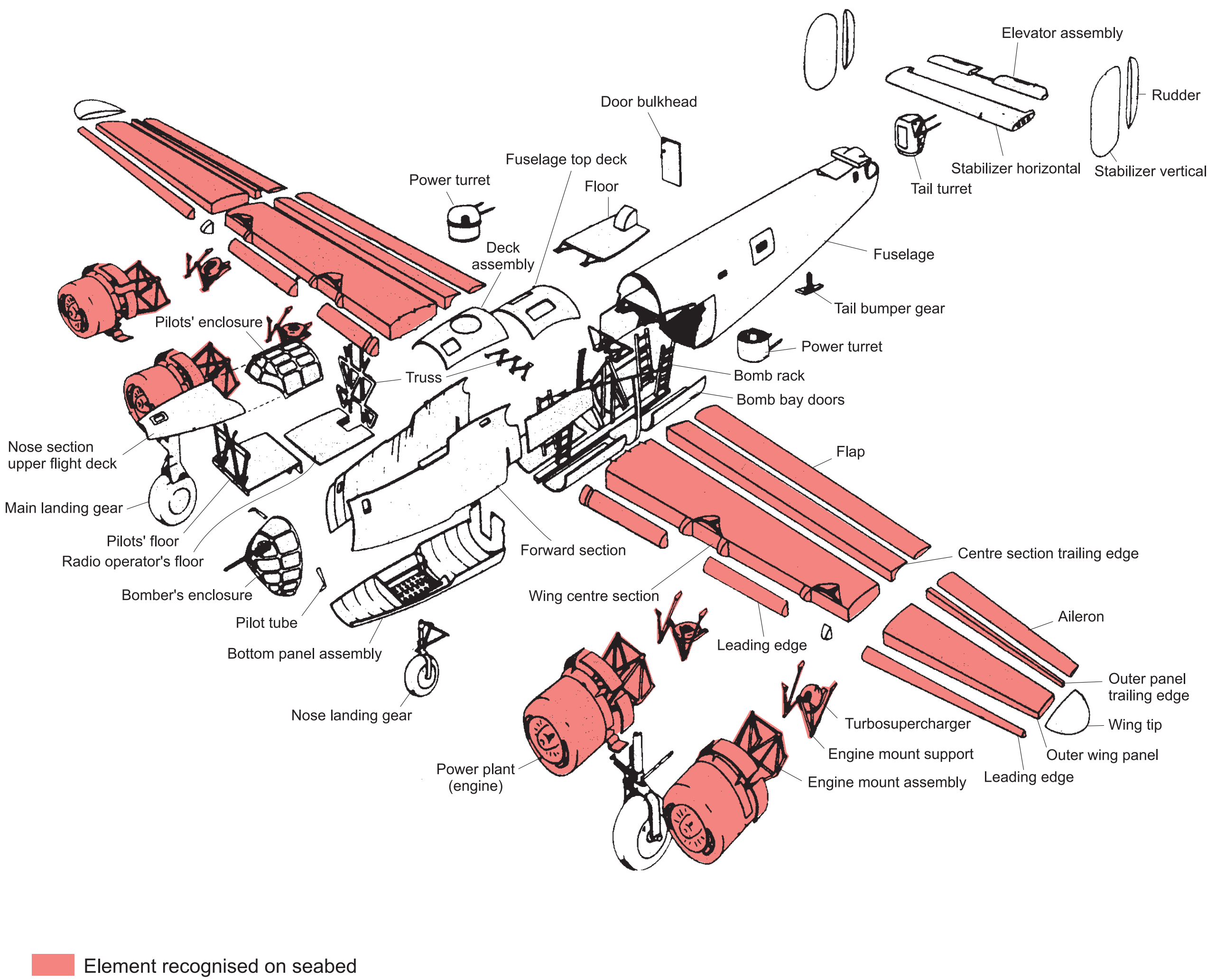


Figure148 Sidescan sonar and magnetic data over the main wreck site of a B-24 bomber. © Wessex Archaeology.

Figure 149 B-24 Liberator © Russa Waldren.



Reproduced from Consolidated B-24 Liberator technical manual.

Figure 150 Sections of B-24 Liberator wreck identified on the sea bed.

Glossary

Accretion	The accumulation of sediment. Indicates deposition of sediment exceeds erosion.
Active dredge zone	Area within an aggregate dredging licence area that is actually dredged.
Aggradation	The accumulation of sediment on a surface.
Amphipod	A group of small, laterally flattened crustaceans that includes the ‘sand hoppers’.
Annelida	Phylum of segmented worms, including earthworms and many freshwater and marine worms. The phylum Anneldia includes the classes Polychaeta (many chaetae on the segments) and Oligochaeta (few chaetae on the segments)
Anticline	Arch-shaped fold in rocks.
Anticlinorium	A regional scale arch shaped structure,may be tens of kilometres across, with smaller anticlines and synclines within the arch form.
Artefacts	Objects of archaeological interest, including stone tools or other man-made objects. Term also used to describe features visible on sidescan sonar records which are caused by the recording process and are not 'real' physical features.
Ascidians	Animals of the subphylum Urochordata. Generally soft-bodied, sometimes colonial, animals attached to stones and rocks. Also known as sea-squirts and tunicates.
Assemblage	An association of interacting populations of organisms in a given area. This term is often used interchangeably with the term community.
Bathymetry	Depth of the sea bed where depth is the distance between the sea bed and the sea surface.
Beam trawl	A net trawl held open at the mouth by a rigid beam and dragged along the sea floor.
Bedding	Layering of sheets of rock.
Bedforms	Sediment structures on the sea bed which have been fashioned by currents and the movement of water, include sand sheets, sand ribbons, megaripples, sand waves and sand banks.
Bedload	The transport of sediment along the sea bed by sliding, rolling and hopping.
Benthic	Associated with the sea bed.
Benthic ecology	The nature and distribution of organisms on the sea bed.
Benthic fauna	Animals living on or in the sea bed.
Biodiversity	The range of species that comprise a particular community or habitat.
Biogenic	Formed by the action of biological organisms.
Biogenic reefs	Topographically distinct structure formed by the action of biological organisms, including coral reef, polychaete reefs and mussel beds.
Biomass	The amount of living material present in a certain moment in a certain area.
Biotope	An area of uniform environmental conditions providing a living place for a specific assemblage of plants and animals e.g. rock pool, mussel bed, cockle bed.
Bivalve	A mollusc with a bilaterally symmetrical two part external shell that completely encloses the body, including clams, oysters, and mussels.
Boomer sub-bottom profiler	Geophysical survey equipment that produces a sound wave that penetrates through the sea bed and is partially reflected or refracted each time a difference in the rock or sediment layering occurs. The recorded data is used to map geological and sediment structures immediately beneath the sea bed and down to a depth normally of 20 to 100 m. See also Hydrophone.
BP	Before present. Relate to dates before the present day which is nominally taken as 1950.

Bryozoa	Mainly colonial animals that can form encrusting growths or leaf-like colonies attached to rocks and stones on the sea bed.
By-catch	Organisms that are caught along with the main target species in fishing nets.
Circalittoral zone	The area of the sea bed where it is too dark for plants to live. Alternative name is the 'aphotic' zone. It is generally from about 25 to 50 metres below the low tide mark.
Community	A collection of species that occur together in space and time often referred to as an assemblage
Crustacea	A subphyllum of the phyllum Arthropoda which includes shellfish such as crabs, lobsters and prawns.
Deeps	Area of sea bed where the depth greatly exceeds that in the surrounding area.
Demersal	An organism which lives at or near the sea floor but has the capacity for active movement.
Dendritic channels	Pattern of channels which resemble branching of trees.
Deep circalittoral	Sub-division of the circalittoral and relates to the area of the sea bed that is so deep it never gets disturbed by waves. It is generally deeper than 50 metres below the low tide mark.
Diversity	In its simplest form the number of species, but more specifically a term used for the degree to which the total number of individual organisms in a given area is divided evenly over different species.
Ebb tide	Period between high tide and the next low tide in which the sea is receding.
Ebb dominance	The ebb tide is stronger than the flood tide.
Echinoderm	An animal belonging to the phylum Echinodermata, a group of radially symmetrical coelomate marine animals including the starfishes, sea urchins, and related forms.
End member	One of two distinct forms of sediment - coarse or fine.
En-echelon	Features which are parallel but slightly offset.
Epibenthic	Living on the surface of the sea bed.
Epifauna	Animals that live on top of the mud, sand, gravel or rock at the surface of the sea bed.
Epilithic	A term for organisms that live attached to rocks.
EUNIS	European Nature Information System
Faulting	The movement and displacement of rock layers relative to each other, which leaves them in a different position to their original location.
Fauna	Collective term applied to animals.
Fines	Sediment particles which are less than 0.063 mm in diameter. Fines can also be called mud, which can be divided further into silt and clay.
Fining	Process of sediment sorting from coarse to fine.
Fissures	Linear splits or cracks.
Flood dominance	The flood tide is stronger than the ebb tide.
Flood tide	The period between low tide and the next high tide in which the sea is rising
Folding	The bending of rock layers.
Foreset laminations	Layering of sediment within a sand wave caused by forward growth of the sand wave as sediment avalanches down its lee slope. See lee slope.
Geogenic reefs	Topographically distinct structure of geological origin, includes rocky reefs and cobble reefs.
Geomorphology	Landforms on the earth's surface.
Geophysical anomaly	Unusual or unnatural feature noted during geophysical surveys, potentially associated with wrecks and archaeological sites.
Habitat	The characteristic space occupied by an individual, population or species.
Hamon grab	A type of grab used for sampling of sea bed deposits and associated fauna.
Handaxe	A stone age tool.
Hydrodynamic processes	Physical processes associated with waves, tides and currents.
Hydrodynamics	See hydrodynamic processes.
Hydroids	Small plant-like colonies of anemone like polyps that live attached to stones and shells on the sea bed.
Hydrophone	Receives boomer produced sound reflected back from depth beneath the sea bed. It is towed just beneath the sea surface behind a survey ship. The acoustic signal received is recorded digitally for further processing and interpretation. See also boomer sub-bottom profiler

Infauna Animals that live within the mud, sand and gravel on the sea bed.

Infralittoral The area of the sea bed below the low tide mark where there is enough light to allow plants to live e.g. seaweed and algae. Alternative name is the 'photic' zone, meaning there is enough light for photosynthesis. It is generally the zone from the low tide mark to about 20 metres water depth, but depends ultimately on the clarity of the sea water.

Interglacial The relatively warm periods between cold glacial periods.

Ka Thousand years.

Lag sediment Sediment on the sea bed from which the finer components of mud and sand have been removed by currents, leaving relatively coarse sediment which cannot be moved on the sea bed. Also known as lag gravel.

Lee slope Short and steep slope of asymmetrical waveforms such as sand waves and ripples. Lee slopes face in direction of dominant currents and sediment moved by these currents avalanches down lee slopes. See also stoss slope.

Lithology The description of the characteristics of rocks which can be identified by the naked eye. Litho is from the Greek lithos which means stone.

Littoral drift The net movement of material along the shore/coastline under the influence of prevailing waves and currents.

Macroalgae Multicellular, large algae, resembling vascular plants but lacking advanced reproductive and water management systems e.g., kelp.

Macrofauna Larger animals generally defined as those retained on a 1mm mesh sieve or large enough to be seen with the naked eye.

Marine aggregates Sand and gravel deposits on the sea bed which can be extracted and used for construction.

Marine transgression Movement of sea across the earth's surface as sea level rises in response to a global event such as the melting of ice caps and continental ice sheets.

Megaripples Asymmetrical sandy waveform which has a height generally <1.5 m. Smaller version of sand waves but bigger than ripples. See also bedforms.

Mollusca One of the largest animal phylum including snails, bivalves and squid.

Monocline The bending of rock into a step like profile with horizontal or gently inclined rock on either side of the steeply inclined rock.

Morphology The shape of the earth and sea bed surface. Similar to topography.

Moraines Deposits of material which have been moved and deposited by ice.

Multibeam echo sounder Measures water depth beneath a survey ship. A multibeam sends a swath of acoustic signals (sound) that fan out across the sea bed which are reflected back to the multibeam. The multibeam calculates the time it takes sound to travel to the sea bed and back and converts the result to water depth soundings in metres. When processed the soundings build up an image of the sea bed, showing its morphology.

Multivariate analysis A form of statistics encompassing the simultaneous observation and analysis of more than one statistical variable.

Mya Million years ago.

Net transport The residual movement of sediment associated with its movement by ebb and flood tidal currents, or under the influence of waves. See flood dominance and ebb dominance.

Orogeny The process of forming mountains by the compression and movement of the earth's crust.

Particle size assessment (PSA) Mechanical separation of sediment sample in a laboratory through a series of sieves with standardised mesh sizes. Sediment retained on each sieve is weighed and recorded. The proportion of mud, sand and gravel in each sample can be compared against a sediment classification system to produce a description of the sample.

Philopatry Individuals returning to the same area to breed.

Photic zone The surface zone of the sea or a lake having sufficient light penetration for photosynthesis.

Photosynthesis The process of energy fixation by plants, in the green pigment chlorophyll, using energy from sunlight and carbon dioxide to produce sugars and oxygen.

Phytoplankton One of two groups into which plankton are divided, the other being zooplankton. Phytoplankton comprise all the freely floating photosynthetic forms in the oceans.

Planation The erosion of the sea bed or earth's surface into a relatively flat or even surface which may be horizontal or at a low angle.

Plankton Animals and plants that drift in the water column.

Polychaetes	A class (Polychaeta) of chiefly marine annelid worms (such as clam worms), usually with paired segmental appendages, separate sexes, and a freeswimming trochophore larva.
Ripples	Asymmetrical sandy waveform which has a height generally <0.1 m. Smaller than megaripples. See also bedforms.
Ross worm	Common name of the polychaete *Sabellaria spinulosa*, a species that forms biogenic reefs by accretion that in turn support a range of dependent species.
Sand bank	Large ridge of sand formed and maintained by the movement of currents. Can be up to tens of kilometres long. Sand bank surface commonly covered by sand waves and megaripples.
Sand waves	Asymmetrical sandy waveform which has a height generally >1.5 m. Larger than megaripples. See also bedforms.
Sand wave field	Area of sea bed covered by sand waves.
Scarp	Cliff-like face or slope, commonly linear, and can be of any height.
Sediment transport	Movement of sediment in the water column or on the sea bed.
Seismic data	Data collected by geophysical methods using sound as a source e.g. boomer sub-bottom profiler, sidescan sonar.
Sessile organism	Literally a 'seated' organism. One whose position is fixed in space except during a dispersal phase, e.g. a rooted plant, barnacles, mussels (*Mytilus*), corals.
Sea bed stress	Force made on the sea bed by a passing current of water. Also called bed shear stress.
Sidescan sonar	Measures the intensity and strength of the acoustic signal that is reflected back from the sea bed. It is cable towed at depth behind the survey ship. The sound received by a sidescan sonar system is a record of sound directly bouncing/reflecting back off features on the sea bed such as rock outcrops, sand waves and wrecks and a diffuse and weaker process called backscatter based on the interaction of sound with the surface texture of the sea bed. The rougher the sea bed, the stronger the backscatter, the darker the record tone. Gravels and rough rock produce good backscatter.
Sorting	Process of naturally selecting and separating sediment particles by agents such as currents in water or wind on land.
Stoss slope	Long and shallow angled slope of asymmetrical waveforms such as sand waves and ripples. Stoss slopes face towards movement of dominant currents and sediment transported by these currents is moved up the stoss slope. See also lee slope.
Stratigraphy	The study and arrangement of rock strata, including their succession and age relationship.
Substrate	The substance or base on which an organism lives and grows. In the marine environment this is the sea bed.
Syncline	Basin-shaped fold in rocks.
Taxon (taxa)	Any organism or group of organisms of the same taxonomic rank; for example, members of an order, family, genus, or species.
Tectonic activity/tectonics	Movement of the earth's crust that causes faulting and folding in rock.
Teleost fish	Bony fish such as herring, sole and cod.
Thermocline	A thin but distinct layer in the sea water column where water temperature changes rapidly, marking the boundary between warmer upper layers and colder lower layers.
Tidal range	The difference in metres between the elevation of high tide and low tide.
Topography	The shape of the earth and sea bed surface. Similar to morphology.
Transgression	Movement of sea across the earth's surface as sea level rises in response to a global event such as the melting of ice caps and continental ice sheets. See marine transgression.
Trawl	A method of fishing using a towed net (trawl).
Turbidity	Reduction in light penetration in the water column due to suspended sediment and particles.
Uplift	Upward movement of rocks and earth's crust. See tectonic activity and orogeny.
Winnowing	Removal of fine sediment from mix of coarse and fine sediment by currents or winds.
Winnowed lag surface	Sea bed from which the finer components of mud and sand have been removed by currents, leaving relatively coarse sediment which cannot be moved on the sea bed. Also known as lag gravel. See lag sediment.

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Appendix 1

Extract of EUNIS classification table covering the biotopes assigned by the synthesis Project. EUNIS levels 1 & 2 are provided for context. Habitats / biotopes were assigned at EUNIS levels 3 & 4 in the modelled map, and at levels 4 and 5 for the point sampling stations. The number of times a class was assigned to a point location is also given. EUNIS codes in brackets have been generated by this project to address the gaps and limitations of the published EUNIS classification (2006 version). MNCR-style codes are provided for those familiar with the system developed during the JNCC's Marine Nature Conservation Review and used in The Marine Habitat Classification for Britain and Ireland (Connor *et al* 2004).

EUNIS Level	EUNIS Code	EUNIS Name	MNCR-style Code	In Model	In Points	Points Assigned
1	A	Marine Habitats				
2	A3	Infralittoral Rock and other hard substrata	IR			
3	A3.1	High energy Infralittoral Rock	IR.HIR	y		
3	A3.2	Moderate energy Infralittoral Rock	IR.MIR	y		
4	A3.21	Kelp and Red seaweeds on moderate energy infralittoral rock	IR.MIR.KR			
5	A3.215	dense miXed Foliose Red seaweeds on silty moderately exposed infralittoral rock	IR.MIR.KR.XFoR		y	2
3	A3.3	Low energy Infralittoral Rock	IR.LIR	y		
3	A3.7	Features of Infralittoral Rock	IR.FIR			
3	(A3.8)	High energy Infralittoral Rock and thin Sediment	IR.HIRthS			
4	(A3.81)	+ thin Coarse sediment	IR.HIRthS.Cs			
4	(A3.82)	+ thin Sandy sediment	IR.HIRthS.Sa			
4	(A3.83)	+ thin Muddy sediment	IR.HIRthS.Mu			
4	(A3.84)	+ thin Mixed sediment	IR.HIRthS.Mx	y		
3	(A3.9)	Moderate energy Infralittoral Rock and thin Sediment	IR.MIRthS			
4	(A3.91)	+ thin Coarse sediment	IR.MIRthS.Cs	y		
5	(A3.912)	Barnacles, Ascidians and Tube worms on moderate energy infralittoral rock and thin coarse sediments	IR.MIRthS.Cs.BAscTbPo		y	3
4	(A3.92)	+ thin Sandy sediment	IR.MIRthS.Sa	y		
5	(A3.921)	interstitial Polychaetes with burrowing Bivalves and Amphipods in moderate energy infralittoral thin sands over rock	IR.MIRthS.Sa.PoBivAm		y	12
6	(A3.9211)	*Echnicocyamus pusillus* and Interstitial Polychaetes in moderate energy infralittoral thin sands over rock	IR.MIRthS.Sa.PoBivAm. EpusInPo		y	

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5	(A3.922)	Barnacles, Ascidians and Tube worms on moderate energy infralittoral rock and thin sands	IR.MIRthS.Sa.BAscTbPo		y	1
5	(A3.923)	*Crepidula* beds on moderate energy infralittoral rock and thin sands	IR.MIRthS.Sa.Cre		y	1
4	(A3.93)	+ thin Muddy sediment	IR.MIRthS.Mu			
4	(A3.94)	+ thin Mixed sediment	IR.MIRthS.Mx	y		
5	(A3.941)	interstitial Polychaetes with burrowing Bivalves and Amphipods in moderate energy infralittoral thin (sandy) mixed sediments over rock	IR.MIRthS.Mx.PoBivAm		y	3
5	(A3.942)	Barnacles, Ascidians and Tube worms on moderate energy infralittoral rock and thin mixed sediments	IR.MIRthS.Mx.BAscTbPo		y	9
5	(A3.943)	*Crepidula* beds on moderate energy infralittoral rock and thin mixed sediments	IR.MIRthS.Mx.Cre		y	2
3	(A3.A)	Low energy Infralittoral Rock and thin Sediment	IR.LIRthS			
4	(A3.A1)	+ thin Coarse sediment	IR.LIRthS.Cs			
4	(A3.A2)	+ thin Sandy sediment	IR.LIRthS.Sa	y		
5	(A3.A21)	interstitial Polychaetes with burrowing Bivalves and Amphipods in low energy infralittoral thin sands over rock	IR.LIRthS.Sa.PoBivAm		y	2
5	(A3.A23)	*Crepidula* beds on low energy infralittoral rock and thin sands	IR.LIRthS.Sa.Cre		y	1
4	(A3.A3)	+ thin Muddy sediment	IR.LIRthS.Mu			
4	(A3.A4)	+ thin Mixed sediment	IR.LIRthS.Mx	y		
5	(A3.A42)	Barnacles, Ascidians and Tube worms on low energy infralittoral rock and thin mixed sediments	IR.LIRthS.BAscTbPo		y	2
5	(A3.A43)	*Crepidula* beds on low energy infralittoral rock and thin mixed sediments	IR.LIRthS.Mx.Cre		y	1
2	A4	Circalittorlal rock and other hard substrata	CR			
3	A4.1	High energy Circalittoral Rock	CR.HCR	y		
4	A4.11	Faunal communities on very Tide-swept circalittoral rock	CR.HCR.FaT		y	2
5	A4.111	*Balanus crenatus* and *Tubularia indivisaon* extremely tide-swept circalittoral rock	CR.HCR.FaT.BalTub		y	1
4	A4.12	Deep Sponge communities on circalittoral rock	CR.HCR.DpSp		y	3
4	A4.13	mixed Faunal turf communities on circalittoral rock	CR.HCR.XFa			
5	A4.131	Bryozoan turf and Erect Sponges on tide-swept circalittoral rock	CR.HCR.XFa.ByErSp		y	3
5	A4.134	*Flustra foliacea* and Colonial Ascidians on tide-swept moderately wave-exposed circalittoral rock	CR.HCR.XFa.FluCoAs		y	16
3	A4.2	Moderate energy Circalittoral Rock	CR.MCR	y		
4	A4.21	Echinoderms and Crustose communities on circalittoral rock	CR.MCR.EcCr			
5	A4.213	*Urticina felina* and sand-tolerant fauna on sand-Scoured or covered circalittoral rock	CR.MCR.EcCr.UrtScr		y	1
5	A4.214	Faunal and Algal Crusts on exposed to moderately wave-exposed circalittoral rock	CR.MCR.EcCr.FaAlCr		y	11
4	A4.22	*Sabellaria* reefs on circalittoral rock	CR.MCR.CSab		y	1
4	A4.24	Mussel beds on Circalittoral rock	CR.MCR.CMus			
5	A4.241	*Mytilus edulis* beds with hydroids and ascidians on tide-swept exposed to moderately wave-exposed Circalittoral rock	CR.MCR.CMus.Cmyt		y	1
3	A4.3	Low energy Circalittoral Rock	CR.LCR	y		

3	A4.7	Features of Circalittoral Rock	CR.FCR			
3	(A4.8)	High energy Circalittoral Rock and thin Sediment	CR.HCRthS	y		
4	(A4.81)	+ thin Coarse sediment	CR.HCRthS.Cs			
5	(A4.811)	interstitial Polychaetes with burrowing Bivalves and Amphipods in high energy circalittoral thin coarse sediments over rock	CR.HCRthS.Cs.PoBivAm		y	1
5	(A4.812)	Barnacles, ascidians and tube worms on high energy circalittoral rock and thin coarse sediments	CR.HCRthS.Cs.BAscTbPo			6
4	(A4.82)	+ thin Sandy sediment	CR.HCRthS.Sa			
5	(A4.821)	interstitial Polychaetes with burrowing Bivalves and Amphipods in high energy circalittoral thin sands over rock	CR.HCRthS.Sa.PoBivAm		y	4
6	(A4.8212)	*Goodalia* community	CR.HCRthS.Sa.PoBivAm.Goo		y	
5	(A4.824)	Crevice dwelling Crustacean community in high energy circalittoral thin sands over rock	CR.HCRthS.Sa.CvCru		y	7
4	(A4.84)	+ thin Mixed sediment	CR.HCRthS.Mx	y		
5	(A4.841)	interstitial Polychaetes with burrowing Bivalves and Amphipods in high energy circalittoral thin mixed sediments over rock	CR.HCRthS.Mx.PoBivAm		y	2
6	(A4.8413)	*Ophiothrix* community	CR.HCRthS.Mx.PoBivAm.Oph		y	
5	(A4.842)	Barnacles, Ascidians and Tube worms on high energy circalittoral rock and thin mixed sediments	CR.HCRthS.Mx.BAscTbPo		y	15
5	(A4.844)	Crevice dwelling Crustacean community in high energy circalittoral thin mixed sediments over rock	CR.HCRthS.Mx.CvCru		y	7
3	(A4.9)	Moderate energy Circalitttoral Rock and thin Sediment	CR.MCRthS			
4	(A4.91)	+ thin Coarse sediment	CR.MCRthS.Cs	y		
5	(A4.912)	Barnacles, Ascidians and Tube worms on moderate energy circalittoral rock and thin coarse sediments	CR.MCRthS.CsBAscTbPo		y	2
4	(A4.92)	+ thin Sandy sediment	CR.MCRthS.Sa	y		
5	(A4.921)	interstitial Polychaetes with burrowing Bivalves and Amphipods in moderate energy circalittoral thin sands over rock	CR.MCRthS.Sa.PoBivAm		y	11
5	(A4.922)	Barnacles, Ascidians and Tube worms on moderate energy circalittoral rock and thin sands	CR.MCRthS.Sa.BAscTbPo		y	1
5	(A4.924)	Crevice dwelling Crustacean community in moderate energy circalittoral thin sands over rock	CR.MCRthS.Sa.CvCru		y	1
4	(A4.93)	+ thin Muddy sediment	CR.MCRthS.Mu			
5	(A4.931)	interstitial Polychaetes with burrowing Bivalves and Amphipods in moderate energy circalittoral thin muds over rock	CR.MCRthS.Mu.PoBivAm		y	1
4	(A4.94)	+ thin Mixed sediment	CR.MCRthS.Mx	y		
5	(A4.941)	Interstitial Polychaetes with burrowing Bivalves and Amphipods in moderate energy circalittoral thin mixed sediments over rock	CR.MCRthS.Mx.PoBivAm		y	12
5	(A4.942)	Barnacles, Ascidians and Tube worms on moderate energy circalittoral rock and thin mixed sediments	CR.MCRthS.Mx.BAscTbPo		y	33
5	(A4.944)	Crevice dwelling Crustacean community in moderate energy circalittoral thin mixed sediments over rock	CR.MCRthS.Mx.CvCru		y	8
3	(A4.A)	Low energy Circalitttoral Rock and thin Sediment	CR.LCRthS			
4	(A4.A1)	+ thin Coarse sediment	CR.LCRthS.Cs			
4	(A4.A2)	+ thin Sandy sediment	CR.LCRthS.Sa	y		
4	(A4.A4)	+ thin Mixed sediment	CR.LCRthS.Mx	y		
2	(A4D)	Deep Circalittorlal Rock and other hard substrata	DCR			

3	(A4D.1)	High energy Deep Circalittoral Rock	DCR.HDCR	y		
4	(A4D.11)	Faunal communities on very Tide-swept deep circalittoral rock	DCR.HDCR.FaT			
5	(A4D.111)	*Balanus crenatus*, *Tubularia indivisa* and Sponge on extremely tide-swept deep circalittoral rock	DCR.HDCR.FaT.BalTub(Sp)		y	1
4	(A4D.12)	Sponge communities on deep circalittoral rock	DCR.HDCR.DpSp		y	4
4	(A4D.13)	mixed Faunal turf communities on deep circalittoral rock	DCR.HDCR.XFa			
5	(A4D.131)	Bryozoan turf and Erect Sponges on tide-swept deep circalittoral rock	DCR.HDCR.XFa.ByErSp		y	1
5	(A4D.134)	*Flustra foliacea*, Colonial Ascidians and Sponge on tide-swept deep ircalittoral rock	DCR.HDCR.XFa.FluCoAs(Sp)		y	3
3	(A4D.2)	Moderate energy Deep Circalittoral Rock	DCR.MDCR	y		
3	(A4D.3)	Low energy Deep Circalittoral Rock	DCR.LDCR	y		
3	(A4D.8)	High energy Deep Circalittoral Rock and thin Sediment	DCR.HDCRthS			
4	(A4D.81)	+ thin Coarse sediment	DCR.HDCRthS.Cs	y		
5	(A4D.811)	interstitial Polychaetes with burrowing Bivalves and Amphipods in high energy deep-circalittoral thin coarse sediments over rock	DCR.HDCRthS.Cs.PoBivAm		y	1
5	(A4D.812)	Barnacles, Ascidians and Tube worms on high energy deep-circalittoral rock and thin coarse sediments	DCR.HDCRthS.Cs.BAscTbPo		y	3
4	(A4D.82)	+ thin Sandy sediment	DCR.HDCRthS.Sa			
5	(A4D.822)	Barnacles, Ascidians and Tube worms on high energy deep-circalittoral rock and thin sands	DCR.HDCRthS.Sa.BAscTbPo		y	2
4	(A4D.84)	+ thin Mixed sediment	DCR.HDCRthS.Mx	y		
5	(A4D.841)	interstitial Polychaetes with burrowing Bivalves and Amphipods in high energy deep-circalittoral thin mixed sediments over rock	DCR.HDCRthS.Mx.PoBivAm		y	2
5	(A4D.842)	Barnacles, Ascidians and Tube worms on high energy deep-circalittoral rock and thin mixed sediments	DCR.HDCRthS.Mx.BAscTbPo		y	6
5	(A4D.844)	Crevice dwelling Crustacean community on high energy deep-circalittoral thin mixed sediments over rock	DCR.HDCRthS.Mx.CvCru		y	2
3	(A4D.9)	Moderate energy Deep Circalittoral Rock and thin Sediment	DCR.MDCRthS			
5	(A4D.911)	interstitial Polychaetes with burrowing Bivalves and Amphipods in moderate energy deep-circalittoral thin coarse sediments over rock	DCR.MDCRthS.Cs.PoBivAm		y	1
4	(A4D.92)	+ thin Sandy sediment	DCR.MDCRthS.Sa	y		
5	(A4D.921)	interstitial Polychaetes with burrowing Bivalves and Amphipods in moderate energy deep-circalittoral thin sands over rock	DCR.MDCRthS.Sa.PoBivAm		y	15
4	(A4D.94)	+ thin Mixed sediment	DCR.MDCRthS.Mx	y		
5	(A4D.941)	interstitial Polychaetes with burrowing Bivalves and Amphipods in moderate energy deep-circalittoral thin mixed sediments over rock	DCR.MDCRthS.Mx.PoBivAm		y	13
5	(A4D.942)	Barnacles, Ascidians and Tube worms on moderate energy deep-circalittoral rock and thin mixed sediments	DCR.MDCRthS.Mx.BAscTbPo		y	13
5	(A4D.944)	Crevice dwelling Crustacean community in moderate energy deep-circalittoral thin mixed sediments over rock	DCR.MDCRthS.Mx.CvCru		y	6
3	(A4D.A)	Low energy Deep Circalittoral Rock and thin Sediment	DCR.MDCRthS			
2	A5	Sublittoral Sediment	SS			
3	A5.1	Sublittoral Coare sediment	SS.SCS			
4	A5.13	Infralittoral Coarse Sediment	SS.SCS.ICS	y		
5	A5.13(B)	interstitial Polychaetes with burrowing Bivalves and Amphipods in infralittoral coarse sediment	SS.SCS.ICS.PoBivAm		y	1

5	A5.13(C)	Barnacles, Ascidians and Tube worms on infralittoral coarse sediment	SS.SCS.ICS.BAscTbPo		y	6
4	A5.14	Circalittoral Coarse Sediment	SS.SCS.CCS	y		
5	A5.14(7)	interstitial Polychaetes with burrowing Bivalves and Amphipods in circalittoral coarse sediment	SS.SCS.CCS.PoBivAm		y	1
5	A5.14(8)	Barnacles, Ascidians and Tube worms on circalittoral coarse sediment	SS.SCS.CCS.BAscTbPo		y	1
3	A5.2	Sublittoral Sand	SS.SSa			
4	A5.23	Infralittoral Fine Sand	SS.SSa.IFiSa	y		
5	A5.23(7)	interstitial Polychaetes with burrowing Bivalves and Amphipods in infralittoral fine sand	SS.SSa.IFiSa.PoBivAm		y	15
5	A5.23(8)	Barnacles, Ascidians and Tube worms on infralittoral fine sand	SS.SSa.IFiSa.BAscTbPo		y	1
4	A5.24	Infralittoral Muddy Sand	SS.SSa.IMuSa	y		
5	A5.24(7)	interstitial Polychaetes with burrowing Bivalves and Amphipods in infralittoral muddy sand	SS.SSa.IMuSa.PoBivAm		y	2
5	A5.24(8)	*Crepidula* beds on infralittoral muddy sand	SS.SSa.IMuSa.Cre		y	1
4	A5.25	Circalittoral Fine Sand	SS.SSa.CFiSa	y	y	1
5	A5.25(4)	interstitial Polychaetes with burrowing Bivalves and Amphipods in circalittoral fine sand	SS.SSa.CFiSa.PoBivAm		y	23
5	A5.25(5)	Barnacles, Ascidians and Tube worms on circalittoral fine sand	SS.SSa.CFiSa.BAscTbPo		y	12
5	A5.25(6)	Crevice dwelling Crustacean community in circalittoral fine sand	SS.SSa.CFiSa.CvCru		y	1
4	A5.26	Circalittoral Muddy Sand	SS.SSa.CMuSa	y		
5	A5.26(3)	interstitial Polychaetes with burrowing Bivalves and Amphipods in circalittoral muddy sand	SS.SSa.CMuSa.PoBivAm		y	1
4	A5.27	Deep Circalittoral Sand	SS.SSa.DCSa	y		
5	A5.27(4)	interstitial Polychaetes with burrowing Bivalves and Amphipods in deep-circalittoral sand	SS.SSa.DCSa.PoBivAm		y	19
5	A5.27(5)	Barnacles, Ascidians and Tube worms on deep-circalittoral sand	SS.SSa.DCSa.BAscTbPo		y	3
3	A5.3	Sublittoral Mud	SS.SMu			
4	A5.33	Infralittoral Sandy Mud	SS.SMu.ISaMu	y		
5	A5.33(7)	interstitial Polychaetes with burrowing Bivalves and Amphipods in infralittoral sandy mud	SS.SMu.ISaMu.PoBivAm		y	2
6	A5.33(71)	*Mysella* and *Lagis* community	SS.SMu.ISaMu.PoBivAm. MysLag		y	
4	A5.35	Circalittoral Sandy Mud	SS.SMu.CSaMu	y		
3	A5.4	Sublittoral Mixed sediment	SS.SMx			
4	A5.43	Infralittoral Mixed sediment	SS.SMx.IMx	y		
5	A5.43(6)	interstitial Polychaetes with burrowing Bivalves and Amphipods in infralittoral mixed sediment	SS.SMx.IMx.PoBivAm		y	6
5	A5.43(7)	Barnacles, Ascidians and Tube worms on infralittoral mixed sediment	SS.SMx.IMx.BAscTbPo		y	3
5	A5.43(8)	*Crepidula* beds on infralittoral mixed sediment	SS.SMx.IMx.Cre		y	2
4	A5.44	Circalittoral Mixed sediment	SS.SMx.CMx	y	y	3

5	A5.44(7)	interstitial Polychaetes with burrowing Bivalves and Amphipods in circalittoral mixed sediment	SS.SMx.CMx.PoBivAm		y	11
5	A5.44(8)	Barnacles, Ascidians and Tube worms on circalittoral mixed sediment	SS.SMx.CMx.BAscTbPo		y	26
5	A5.44(9)	Crepidula beds on circalittoral mixed sediment	SS.SMx.CMx.Cre		y	3
4	A5.45	Deep Circalittoral Mixed sediment	SS.SMx.DCMx	y		
5	A5.45(2)	interstitial Polychaetes with burrowing Bivalves and Amphipods in deep-circalittoral mixed sediment	SS.SMx.DCMx.PoBivAm		y	8
5	A5.45(3)	Barnacles, Ascidians and Tube worms on deep-circalittoral mixed sediment	SS.SMx.DCMx.BAscTbPo		y	12
5	A5.45(4)	Crevice dwelling Crustacean community in deep-circalittoral mixed sediment	SS.SMx.DCMx.CvCru		y	1
3	A5.5	Sublittoral Macrophyte-dominated sediment	SS.SMp			
4	A5.52	Kelp and Seaweed communities on Sublittoral Sediment	SS.SMp.KSwSS		y	
3	A5.6	Sublittoral Biogenic Reefs	SS.SBR			

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