5 PHYSICAL AND CHEMICAL ENVIRONMENT

5.1 Regional overview

The physical and chemical environment of the SEA 6 area is the product of a variety of geological, meteorological and hydrological processes operating over a wide range of both temporal and spatial scales. In recent times, anthropogenic influences have also become important drivers of environmental change. The SEA 6 environment therefore reflects the dynamic balance between these different processes and influences.

On a regional scale, the Irish Sea has been shaped by large scale geology and is underlain by a number of major sedimentary basins, some of which may contain hydrocarbons, although to date, only the East Irish Sea basin has been commercially developed. Topographically, the region consists of a deeper channel in the west, with shallower embayments in the east. The deep channel is open-ended, connected at both ends to the Atlantic Ocean, in the south via St George's Channel and in the north via the North Channel. The extent of Atlantic inflow to the region varies with changes to large scale circulation patterns in the North-east Atlantic and weather, particularly the strength and direction of the prevailing winds.

The present seabed morphology and sediment distribution of the Irish Sea is due mainly to the interaction of historic glacigenic processes and subsequent exposure to tidal currents, waves and storms. Exposed bedrock and diamicton swept clean of sediments (e.g. as found in St George's Channel, north of Anglesey and the Isle of Man, and in the North Channel) characterise the most hydrodynamic seabed environments, with fine muddy sediments restricted to areas with low tidal and wave energy (e.g. the mud belts to the east and west of the Isle of Man). The region contains a range of seabed habitats of conservation interest.

Throughout much of the region tidal mixing is sufficiently intense to ensure that the water column remains well mixed throughout the year. However, there are regions where temperature and/or salinity differences between water masses may result in stratification. These stratified areas are dynamic and defined by frontal areas which often drive significant density flows affecting local circulation patterns and mixing processes. Freshwater run-off is significant in the eastern Irish Sea and can lead to haline stratification throughout the year.

River run-off and inputs from industrialised areas of the coast are responsible for the majority of contaminants in the SEA 6 area with estuarine and coastal sites, such as the Mersey and Ribble estuaries, containing elevated levels of contaminants. In general, the discharges of many contaminants from coastal industries and activities have been declining over the last decade with elevated concentrations often a legacy of former industrial discharges which have become incorporated into seabed sediments. Radionuclide discharges from Sellafield are much reduced with remobilisation of historically contaminated sediments, the main source of radioactive contamination. Monitoring surveys have shown that contamination around Irish Sea offshore oil and gas installations is limited and localised in comparison with some North Sea installations.

5.2 Geology, substrates and shoreline types

5.2.1 Data sources

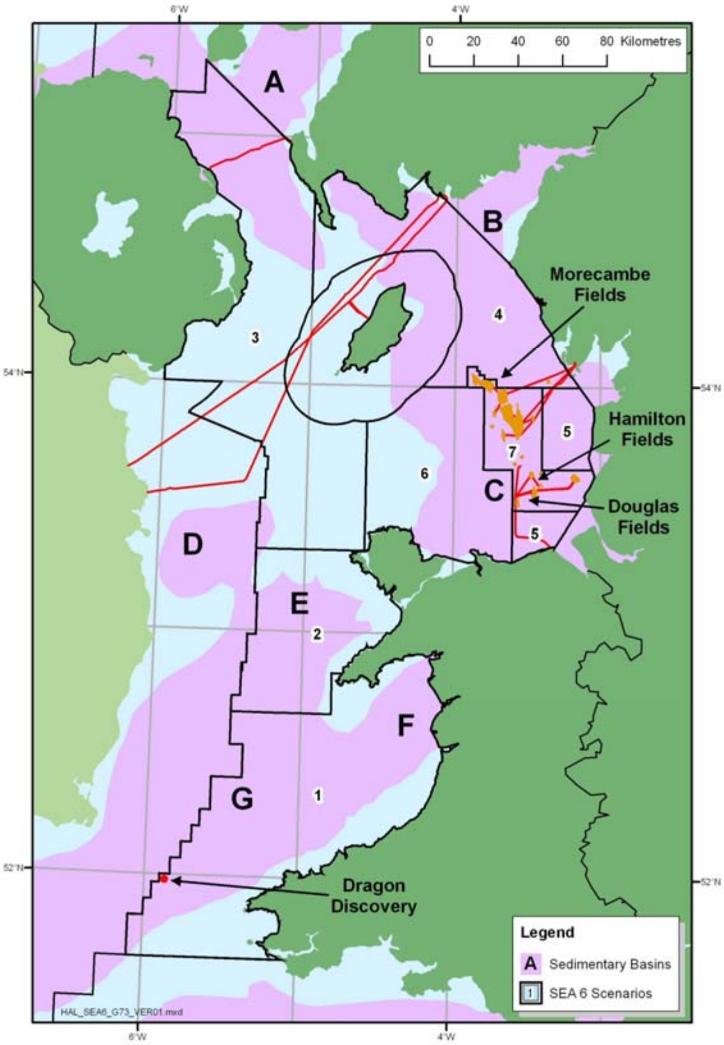
A number of technical reports have been produced for SEA 6 which provide relevant information on the geology and geomorphology of the area. Holmes & Tappin (2005) describe the seabed and surficial geology and processes of the area. Kenyon & Cooper

(2005) consider sand banks and mobile sediment bedforms as well as sediment transport. Of particular relevance is new information on sediment bedforms and dynamics in the eastern Irish Sea strategic area (for windfarm development) collected during the DTI 2004 survey. Judd (2005) provides information on the DTI 2004 survey of habitats of potential conservation importance.

5.2.2 Underlying geology

SEA 6 encompasses the Irish Sea province which can be sub-divided on the basis of regional geological structure into 7 major sedimentary basins (Figure 5.1).

Figure 5.1 – Regional geological setting



*Note: Sedimentary basins - **A** North Channel Basin **B** Solway Basin **C** East Irish Sea Basin **D** Kish Bank Basin **E** Caernarfon Bay Basin **F** Cardigan Bay Basin **G** North Celtic Sea Basin*
Source: Modified from Holmes & Tappin (2005).

Commercial quantities of oil and gas are currently produced only from the East Irish Sea Basin (C), from the Irish sector of the North Celtic Sea basin (not in SEA 6). The petroleum geology of the most prospective sedimentary basins is summarised in Table 5.1.

Table 5.1 – Petroleum geology of prospective basins in the SEA 6 area

Sedimentary basin	Petroleum geology
East Irish Sea Basin	Oil and gas produced from basin since 1985. Production from Lower Triassic, principally aeolian Sherwood Sandstone reservoir, sealed by younger Triassic continental mudstones and evaporites. Potential for hydrocarbons within Carboniferous fluvial sandstone reservoirs.
Caernarfon Bay Basin	Only 2 exploration wells drilled and there remain numerous undrilled targets. Principal target reservoir is the Sherwood Sandstone (as in East Irish Sea Basin).
Cardigan Bay Basin	Forms a continuation of Ireland's North Celtic Sea Basin which has 2 producing gas fields. Potentially producible gas reserves at the Dragon discovery and oil shows in a further 3 wells. Most likely source rocks are early Jurassic marine mudstones.

Source: Holmes & Tappin (2005).

5.2.3 Seabed topography

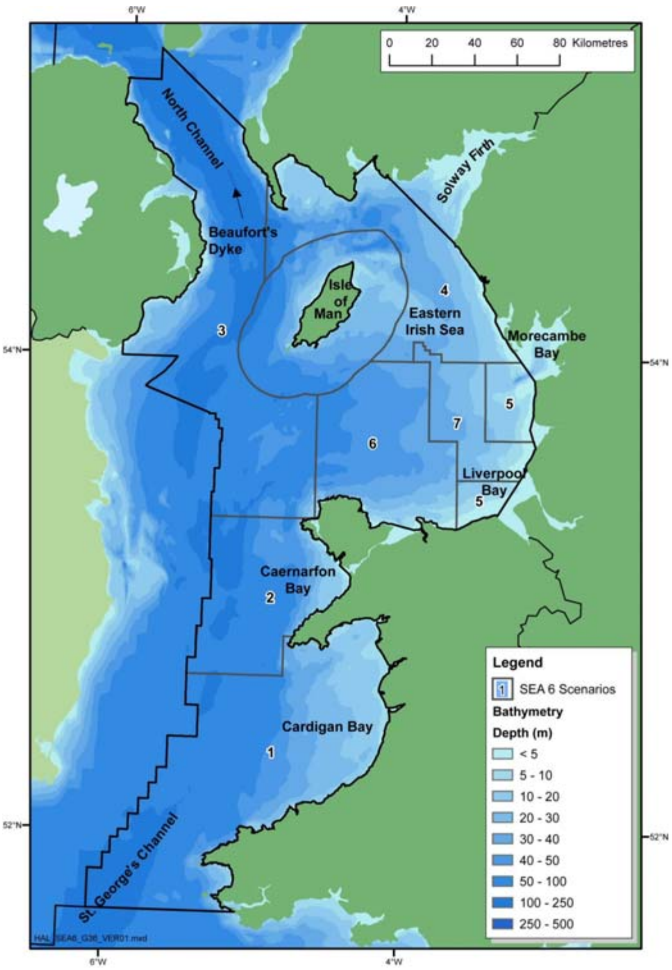


Figure 5.2 – Bathymetry of SEA 6 area

The Irish Sea consists of a deeper channel in the west, with shallower embayments in the east. The channel is open-ended and is connected at both ends to the Atlantic Ocean; in the south via the Celtic Sea and the St George's Channel and in the north via the North Channel (Figure 5.2).

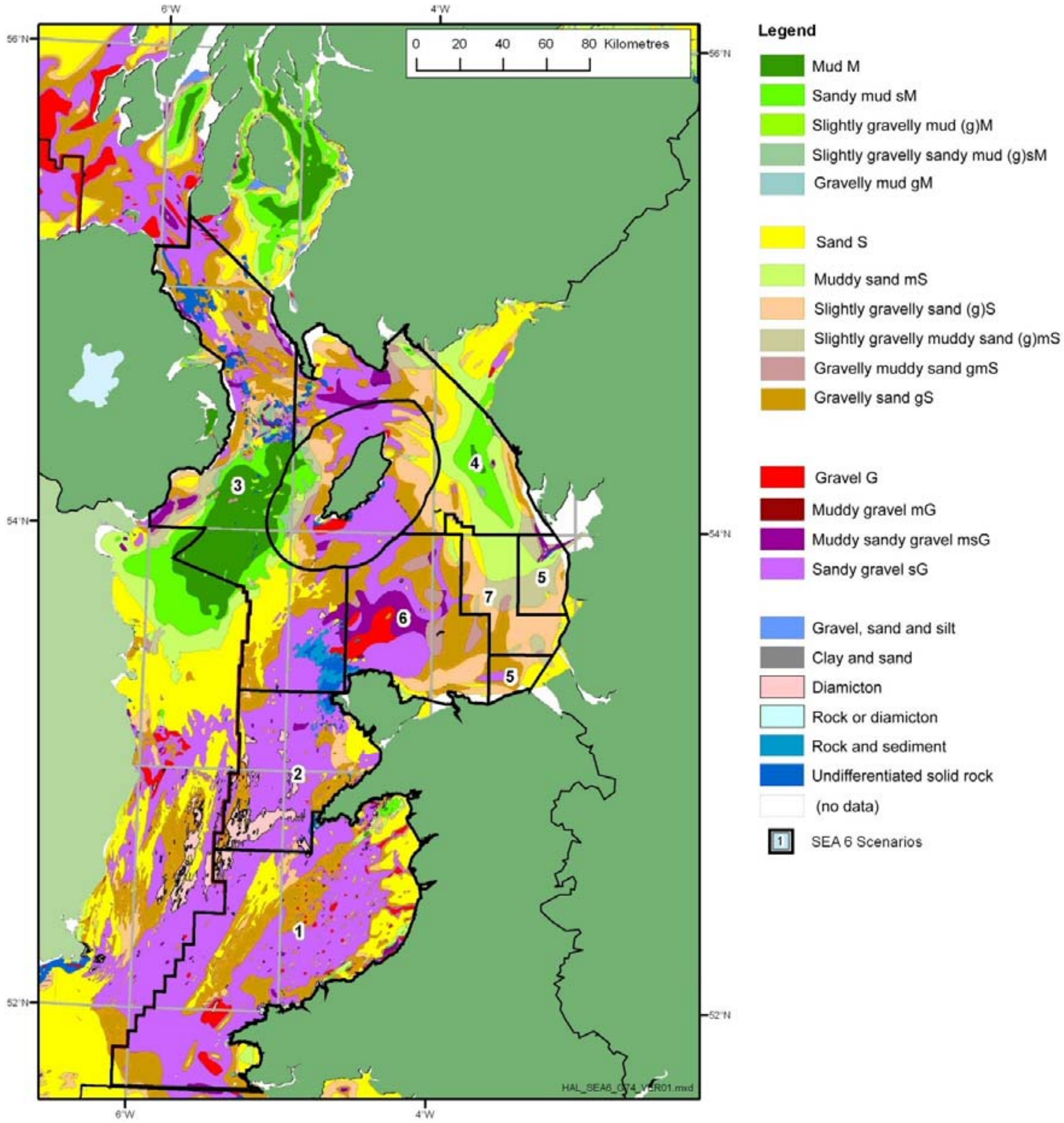
The width of the Irish Sea varies between 75 and 200km but decreases to 30km in the North Channel. Its volume is 2,430km^3, 80% of which lies to the west of the Isle of Man, and its surface area is 47,000km^2. The deep channel is about 300km long and 30–50km wide, with a minimum depth of 80m and a maximum exceeding 275m in the Beaufort's Dyke in the North Channel. The two principal shallow embayments, each with depths less than 50m are Cardigan Bay and the eastern Irish Sea, and there is also the smaller Caernarfon Bay.

5.2.4 Seabed sediments

In the eastern Irish Sea there is a general transition south-east and east of the Isle of Man towards the coast from coarser-grained gravel and sand to mud (the Eastern Irish Sea Mud Belt, Belderson 1964). To the west and south-west of the Isle of Man, the Western Irish Sea

Mud Belt forms an extensive area of muddy sediments (see Figures 5.3 and 5.9). Within sandy and gravelly areas, there are extensive fields of sand ribbons and sand waves as well as barchan dunes. In St George's Channel and Cardigan Bay there is a dominance of coarser sand and gravel (Figure 5.3, Tappin *et al.* 2001).

Figure 5.3 – Distribution of seabed sediments



Source: Holmes & Tappin (2005).

Table 5.2 provides a brief summary of the seabed sediments and bedforms found in each of the SEA 6 scenario areas.

Table 5.2 – Seabed sediments and bedforms in SEA 6 scenario areas

Scenario area	Seabed sediments	Seabed bedforms[1]
1	Predominantly sandy gravel, gravelly sand and gravel. Nearshore areas of sand.	Medium to large sandwaves, sand patches and ribbons over much of the area. Large sand banks and ridges off Lleyn Peninsula.
2	Predominantly sandy gravel with areas of sand and rock to west of Anglesey.	Sandy gravel characterised by sand ribbons with medium to large sandwaves to the west of Anglesey. Extensive offshore areas of diamicton.
3	Localised areas of rock to west of Anglesey and within North Channel. Extensive areas of gravelly sand. Mud and sandy mud to west of Isle of Man.	Sand ribbons associated with sandy gravel in North Channel. Smooth seabed over muddy areas.
4	Sandy gravel and gravelly sand to north of Isle of Man. To east, sand and extensive area of slightly gravelly and sandy mud.	Muddy areas characterised by smooth seabed. Localised areas of sand ribbons and medium to large sandwaves to north of Isle of Man.
5	Muddy sand and slightly gravelly muddy sand in northern part of area. Sand and gravelly sand off the Welsh coast.	Muddy areas characterised by smooth seabed. Large sandbanks and ridges off Mersey and Dee estuaries.
6	Large area of gravel, sandy gravel and muddy sandy gravel to north of Anglesey. Gravelly sand and slightly gravelly muddy sand to the east.	Sand ribbons map extensive area to north and north-east of Anglesey. Rest of area, medium to large sandwaves and undifferentiated bedforms.
7	Slightly gravelly and muddy sand over much of the area.	Smooth seabed over much of the area. Localised large sandbanks and ridges closer to shore.

Notes: See Section 5.2.7 for details of seabed bedforms.

Information on the distribution of sediments and bedforms was used by the recently completed Irish Sea Pilot to generate a map of marine landscapes within the Irish Sea. These may form the basis of conservation efforts in the future (see Section 5.2.8.2).

5.2.5 Seabed processes

The present seabed morphology and sediment distribution is due mainly to the interaction of glacigenic processes operating over the past several 100,000 years and exposure to seabed winnowing processes driven by tidal currents, waves and storms. Modern submarine sediments typically consist of mixtures of reworked former glacigenic and fluvial sediment grains and 5 to 20% or more biogenic carbonate fragments that have mainly originated in post-glacial times. In SEA 6, the proportion of biogenic carbonate is highest in the sand fractions of the coarsest seabed sediments indicating a bias for preservation of fragments of many of the modern shelly biota in areas with the highest near-bed currents (Holmes & Tappin 2005).

Glacial processes

During the last major glacial period (21,000-17,000 years ago), the regional ice sheets had merged across much of the northern British Isles and were flowing south (Lambeck 1995). In areas of SEA 6 where the ice flow was accelerated, it gouged north-south and north-west-south-east elongated basins. During the waning stages, the ice retreated and deposited diamicton over large areas which it had previously eroded. These areas of diamicton were subsequently resistant to marine erosion. Other relevant glacial features are described in Section 5.2.6.

Tidal currents

During fair weather, sediment distribution and the types of sediment bedforms are dominated by stress imposed on the seabed by the strengths and directions of the peak tidal currents. Exposed bedrock and diamicton which are swept completely clean of unconsolidated sediments characterise the most highly stressed seabed environments (Figure 5.4a), with fine muddy sediments restricted to areas of least seabed stress (Figure 5.4b, Holmes & Tappin 2005).

Figure 5.4 – Seabed sediments from high and low seabed stress areas

Notes: a) High seabed stress - embedded cobbles and boulders from very tide swept area to the north-west of Anglesey and b) low seabed stress - muddy sediments with abundant burrows from a pockmark in the western Irish Sea mud belt. Sources: Rees (2005), Judd (2005).

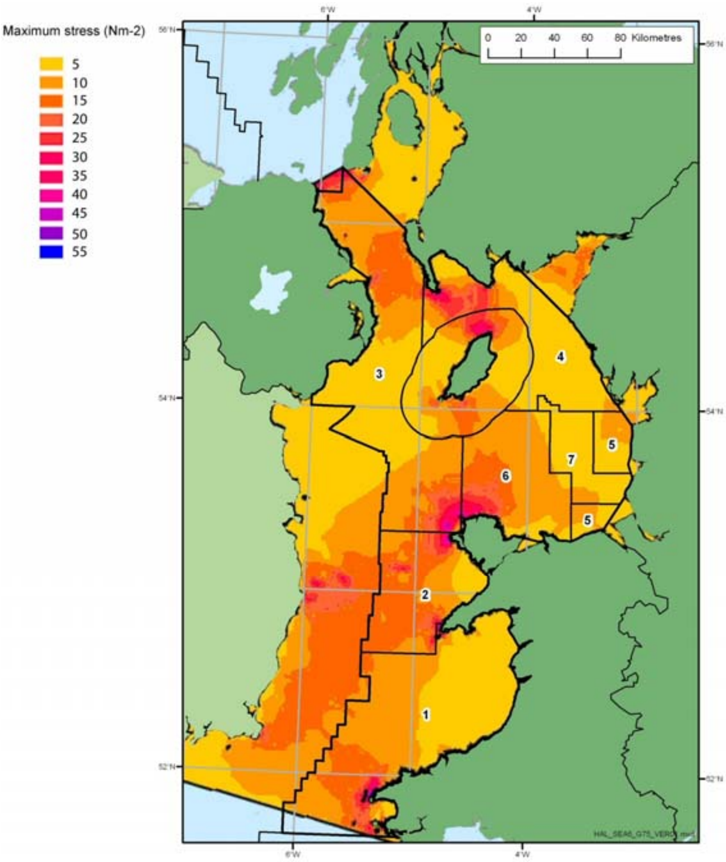


Figure 5.5 – Peak bed stress in the Irish Sea

Note: Maximum bed stress in Newtons/m^2 from a numerical model run for the years 1995 to 1997 forced both by tides and winds, but with no wave contribution.
Source: Modified from Vincent et al. (2004).

Figure 5.5 highlights peak bed stresses experienced in the Irish Sea. Generally, these are less than 2N/m^2 but in a few localised regions (e.g. off Pembrokeshire, north-west of Anglesey, north of the Isle of Man and in the North Channel) they may be greater than 25N/m^2 (Howarth 2005).

Mid-water mean peak spring tidal currents of <0.5m/s encompass the mud belts, >1m/s encompasses most areas of sandy gravel and >1.25m/s encompasses the distribution of gravel and exposed rock and diamicton at seabed.

Waves and storms

Wind drives directional sea-surface wind currents and storm surge currents and also drives non-directional rotational near-bed currents which are generated when wind waves and swell waves interact with the seabed. The effects of erosion and sediment transport by swell and wind waves vary with wave fetch, seabed gradient and tidal range.

Exposure to the largest waves is most pronounced on coasts and submarine shoals facing the longest fetch from the south-west and in environments where the wave energy has been least dissipated by the interaction of the waves with shoaling seabed. Such areas occur off south-west Wales (Scenario area 1), the Lleyn Peninsula (areas 1 & 2), Anglesey (areas 2, 3 & 6) and the Isle of Man (area 4). These areas are also characterised by very strong tidal currents so that the times when the waves have a dominant effect on the seabed will occur only when mean significant wave height is enhanced during severe weather. Observations off the Isle of Man of gravel waves in 50m water depth indicate that gravel may be occasionally mobilised at such depths by long-period storm waves (Jackson *et al.* 1995). However, the effects of storms may be rapidly repaired by tidal currents during the relatively long periods of fair to moderate weather.

5.2.6 Seabed bedforms

Static bedforms

Static bedforms are important in the seabed habitat as they provide stable sites for biota and, where they occur in isolation, contribute to the local diversity and overall patchiness of the seabed.

Evidence of the former peri-glacial terrestrial environment is preserved throughout SEA 6 with areas of the seabed structured by former ice-wedges and pingos (sediment domes formed by expanding ice cores). Drowned former river channels, estuaries, deltas and sandhur plain channels (the latter probably sited on former ice margins (Jackson *et al*. 1995) generate further habitat diversity. In Cardigan Bay there are relict glacial outwash features termed 'sarns', composed of ridges of boulder to pebble-size gravel. These moraines were truncated during the last glaciation when the dominant ice stream was to the south. Similarly, the roche moutonnée (rock outcrops formed sub-glacially) are elongated to the south (Figure 5.6).

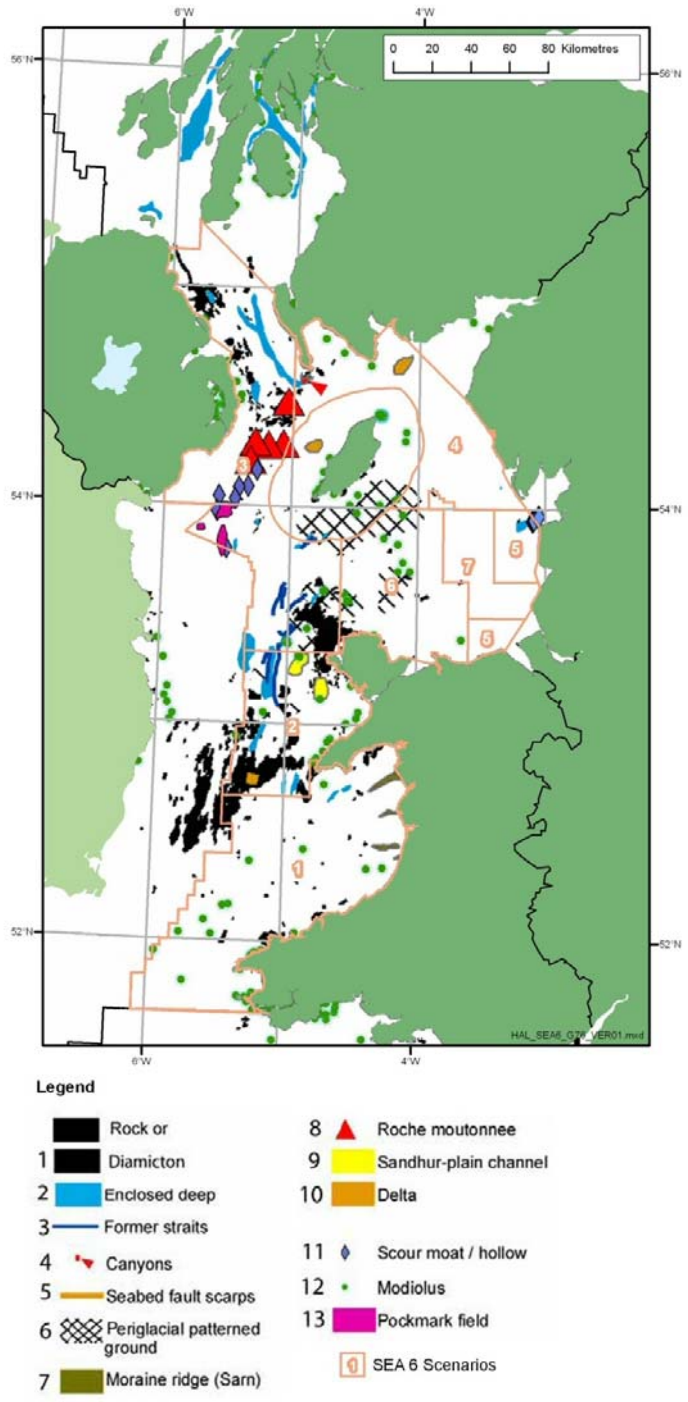
Rock outcrops in Holocene mud-prone sediments form an unusual environment in the region. These are not indicators of a high energy environment but rather a low energy environment where the rocks are in the process of being buried by accumulating muds. Pisces Reef to the west of the Isle of Man provides an example of such an environment and is described with respect to its potential conservation importance in Section 5.2.8.

Other features include prominent opposing scarps composed of glacigenic and rock strata off the coast of Anglesey which are 10–40km in length and with steep slopes of 20-30°. These probably mark the sites of former tidal straits and are characterised by strong peak mean spring tides, the diversion of which is likely to lead to near-bed current acceleration and distinctive seabed habitats.

Although pockmarks are shaped by the dynamic release of methane gas and other fluids from seabed and are commonly elongated in the direction of dominant tidal current flow, they are essentially static bedforms. They typically occur in areas of seabed consisting of Holocene very soft muds or silty very fine sands. A small field of such pockmarks extends for a short distance into the SEA 6 area (Figure 5.6).

As part of SEA 6, Judd (2005) examined the distribution and extent of submarine structures made by leaking gas (which may include pockmarks) as well as other habitats (reefs) relevant to the Habitats Directive. Further details of these seabed features of potential conservation interest are described in Section 5.2.8.

Figure 5.6 – Distribution of static bedforms



Source: Modified from Holmes & Tappin (2005).

Mobile bedforms

Mobile bedforms are generally excluded from the most hydrodynamically stressed environments where bedrock or diamicton are swept clean of sediments, as well as from areas of very low stress where mud deposition dominates. Sand ribbons align parallel to near-bed currents and with bare rock and diamicton, map to the strongest mean peak tidal streams with transverse bedforms peripheral to these areas. Sand patches are restricted to south of approximately 53ºN in areas to the east and west of the strongest mean peak spring tidal streams and with relatively high mean significant wave heights. Sandbanks are also peripheral to the strongest tidal currents and mainly feature in coastal areas and embayments (Figure 5.7, Holmes & Tappin 2005).

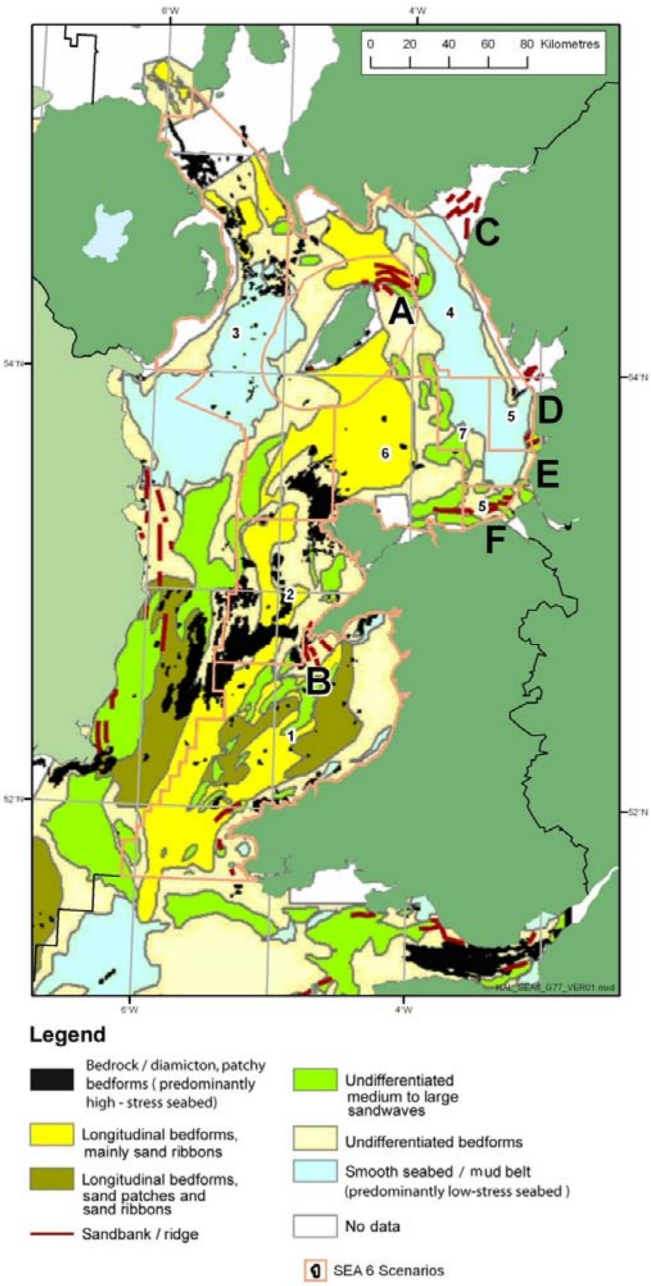


Figure 5.7 – Distribution of mobile bedforms

Note: Numbers relate to sandbank areas including: banner banks off Isle of Man (A), Lleyn Peninsula (B) and wide estuary banks in the Solway Firth (C), Morecambe Bay (D), Ribble (E), Mersey and Dee estuaries (F). Source: Adapted by Holmes & Tappin (2005) after Fyfe et al. (1993), Tappin et al. (1994), Jackson et al. (1995).

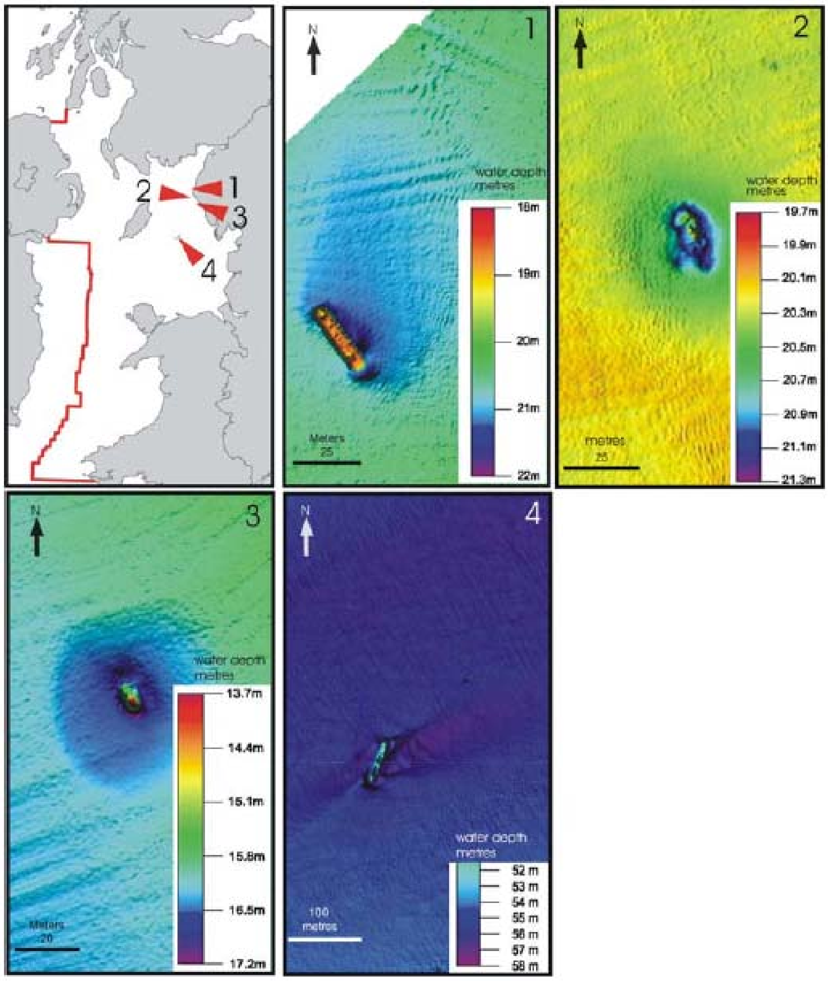
Although sand banks and ridges are traversed by mobile sandwaves, the overall positions of the largest banks and ridges are relatively stable. Figure 5.7 highlights the locations of the largest sand banks within SEA 6. Some areas of offshore sandbank habitat within the region may be protected in the future through designation as Special Areas of Conservation under the EC Habitats Directive. Further details are provided in Sections 5.2.8 and 7.3.

A detailed description of different sand bank types and their classification is presented in Kenyon & Cooper (2005). The report also describes other mobile bedforms and sediment transport in the SEA 6 area.

5.2.7 Sediment transport

The orientation and distribution of mobile bedforms, as well as bedforms generated around static obstacles, provides valuable information on the direction and extent of sediment transport paths. Shipwrecks for example, provide static seabed obstacles around which the near-bed currents are diverted and accelerated. Shipwrecks can thus generate scour and ribbon bedforms that provide information on natural sediment transport in seabed areas that are otherwise featureless (Figure 5.8). Features generated by the shipwrecks can also be used to monitor the possible long-term effects of permanent or semi-permanent seabed installations.

Figure 5.8 - DTI SEA 6 survey – sediment patterns around shipwrecks



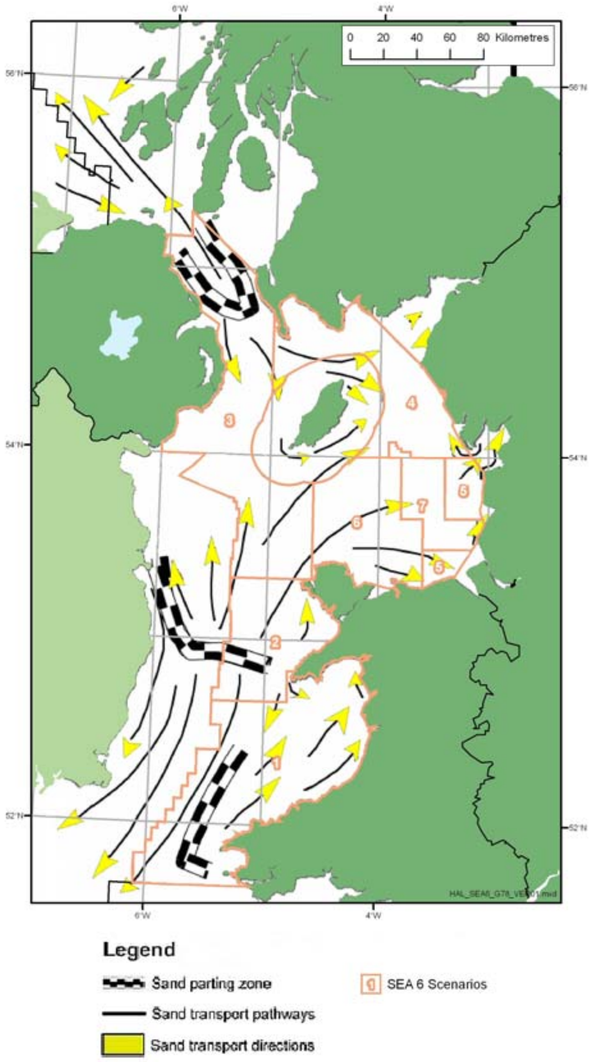
Notes: Shipwreck 1 and 3 set in slightly gravelly mud, 2 in sandy mud and 4 in slightly gravelly sand. Source: DTI 2004 SEA 6 survey dataset, Holmes & Tappin (2005).

Shipwrecks 2 and 3 are exposed to the lowest tidal currents and show little asymmetry in the pattern of seabed scour. Shipwrecks 1 and 4 clearly show stronger scour on the east, the travel direction of the stronger near-bed flood tidal currents. All four examples indicate that seabed scour extends laterally beyond the seabed profiles presented by the wrecks. For example, shipwreck 4 (approximately 50m long and 6m high) has generated scour of approximately 4m depth which tails to shallower scour depths for at least 200m north-east of the wreck.

Analysis of mobile and static bedforms has enabled prediction of the net sand transport pathways present (Figure 5.9, Holmes & Tappin 2005).

The tidal regime with maximum surface velocities of >1.0m/s, results in bed-load parting zones being located off Pembrokeshire, the Lleyn Peninsula and the North Channel. The dominant bed-load transport direction is southward (into the Celtic Sea) and northward (into the Irish Sea) from the Lleyn/Anglesey area. There is a positive correlation between areas of maximum bed-load stress and maximum erosion and in the area of bed-load parting off Anglesey the seabed is swept clean of sediment.

Figure 5.9 – Net sand transport in SEA 6



Source: Adapted by Holmes & Tappin (2005) after Pantin (1991), Jackson et al. (1995), Kenyon & Cooper (2005) and modified by interpretations extracted from the DTI 2004 SEA 6 survey dataset.

5.2.8 Seabed features of potential conservation interest

5.2.8.1 Potential Special Areas of Conservation

Special Areas of Conservation (SACs) are strictly protected sites designated under the EC Habitats Directive. To date, a large number of SACs within nearshore waters have been designated for habitats listed under Annex I of the Directive (see Section 7.2 for details of coastal and nearshore SACs in the SEA 6 area). JNCC are currently identifying areas of Annex I habitat for which SACs may be selected in UK offshore waters (outwith 12 nautical miles) including:

- Sandbanks which are slightly covered by sea water all the time
- Submarine structures made by leaking gases
- Reefs
- Submerged or partially submerged sea caves

Currently, there are no known occurrences of submerged or partially submerged sea caves in UK offshore waters. The following sections detail potential Annex I habitat within the SEA 6 area (see also Section 7.3).

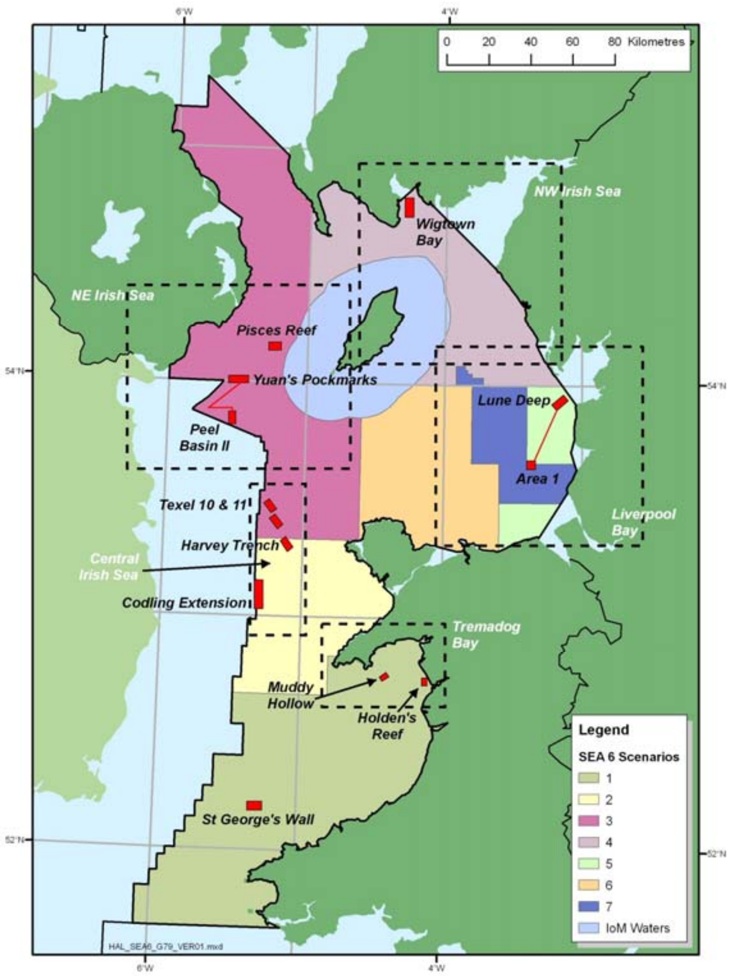
Sandbanks which are slightly covered by seawater all the time

The SEA 6 area contains a number of areas of large sandbanks (see Figure 5.7) which may conform to the Annex I habitat *sandbanks which are slightly covered by seawater all the time*. At present, only King William Bank, a sandbank to the north-east of the Isle of Man has been identified as an area which may be designated in the future, following further survey work (Johnston *et al*. 2004b).

Submarine structures made by leaking gas

Submarine structures made by leaking gas are composed of the normal seabed sediment bound by a carbonate (principally $CaCO_3$) cement; the carbon of this carbonate is derived from methane (CH_4), hence this material is properly called methane-derived authigenic carbonate (MDAC) (Judd 2005).

Figure 5.10 - DTI 2004 survey areas

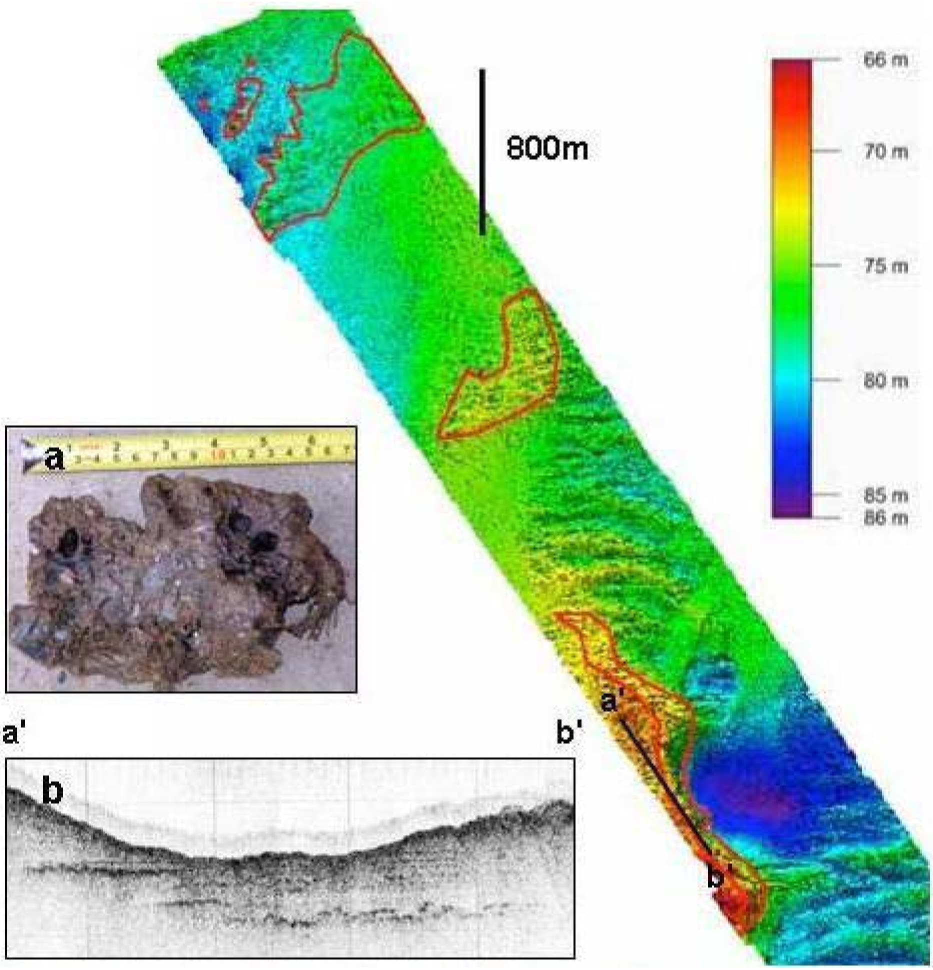


Possible occurrences of MDAC were investigated during the DTI 2004 surveys of the SEA 6 area. Twelve study areas (Figure 5.10) were surveyed and MDAC was confirmed from two sites within the region - Texel 11 and Holden's Reefs.

Texel 11

The seabed of this area is characterised by coarse sediments, scattered boulders and superficial sandwaves and megaripples. Seismic profiles indicate shallow gas approaching the seabed at various locations including the edge of the southern seabed hollow (Figure 5.11b).

Figure 5.11 – DTI survey of Texel 11



Notes: Main picture – anticipated extent of MDAC in Texel 11 (in red), a) one of the MDAC samples collected by grab from the seabed and b) seismic profile showing enhanced reflectors (shallow gas) approaching the seabed at the edge of the southern seabed hollow (see main picture for seismic transect). Source: Judd (2005).

Grab samples contained pieces of a hard material comprised of a sandy sediment bound by a carbonate cement (Figure 5.11a). These cemented hard grounds formed crusts and blocks standing up to about 1m above the seabed. MDAC may be more or less continuously exposed over a distance of at least 500m in cliffs on the western edge of the southern hollow and may be present, but not continuous, over an area of >500,000m^2 (Figure 5.11, main picture). These 'reefs' were colonised by an abundant fauna, including: bryozoans, hydroids, sponges, anemones, starfish, urchins, lobster and squat lobster.

Holden's Reefs

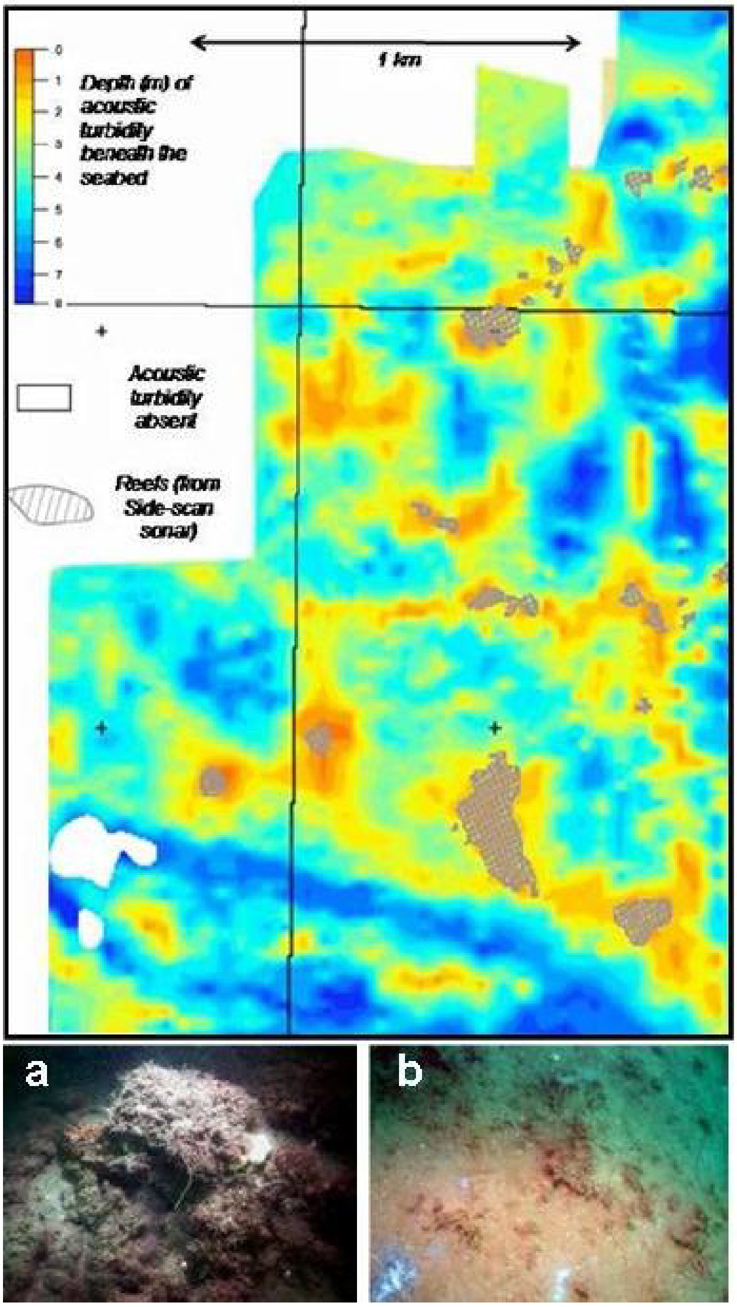


Figure 5.12 – DTI survey of Holden's Reefs

Notes: Main picture – distribution of Holden's Reefs and shallow gas (acoustic turbidity), Source: Judd (2005).

Holden's Reefs is an area of rocky reef off Barmouth. Seismic profiles suggest that shallow gas is present throughout the area, and that it rises towards the seabed in the vicinity of the reefs (Figure 5.12, main picture).

The reefs comprise hard material colonised by a variety of benthic fauna (Figure 5.12a) and contrasts markedly from the normal seabed sediment (fine sands). In some places, the sediment is discoloured by the presence of sulphides (black) and associated bacterial mats (white), assumed to be the sulphide-oxidiser *Beggiatoa* (Figure 5.12b). These are common features of sites of anaerobic oxidation of methane.

Carbon isotope analysis has confirmed that Holden's Reefs are composed of MDAC. The mapping undertaken as part of the DTI survey has shown that Holden's Reefs are far more extensive than previously appreciated. In total, reef structures covered almost 40,000m^2 of the 3.5km^2 survey area (Judd 2005).

Reefs

Pisces Reef

As mentioned in Section 5.2.6, Pisces Reef is a substantial rocky outcrop lying within an area of soft muddy sediments to the west of the Isle of Man. The 'reef' is 600m wide, >1.4km long, and stands about 60m above the normal seabed. It comprises exposed bedrock and rocky boulders, with soft sediments infilling hollows and gullies. These soft sediments are similar in appearance to those of the deeper water surrounding the reef, and are inhabited by *Nephrops* (Figure 5.13, No18).

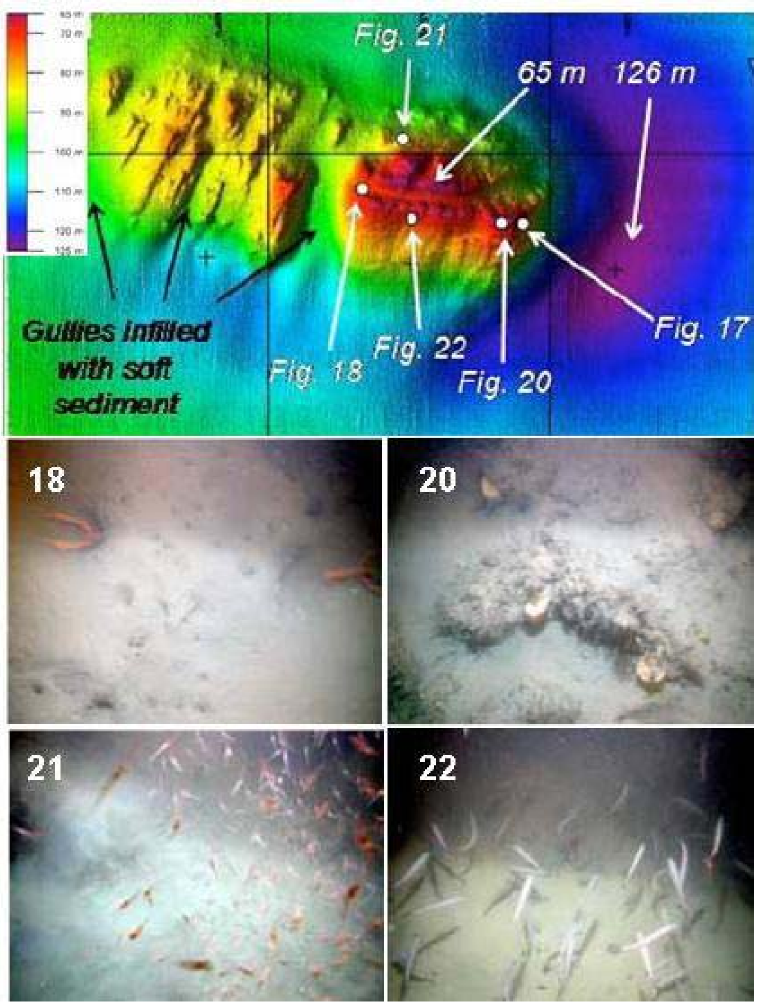


Figure 5.13 – DTI survey of Pisces Reef

Notes: Main picture, multi-beam echo sounder image of Pisces Reef. Nephrops and burrows in soft sediment infilling the central gully on Pisces Reef (18), epifaunal growth on boulders of Pisces Reef (20), shrimp (21) and juvenile fish (22) around Pisces Reef. Source: Judd (2005).

The rocky seabed supports a relatively dense epifauna (Figure 5.13, No. 20) and there were significantly higher densities of shrimp (Figure 5.13, No. 21) and juvenile fish (Figure 5.13, No. 22) around and over the reef than elsewhere in the area.

Judd (2005) indicates that Pisces Reef conforms to the Habitats Directive definition of 'reefs'. The DTI survey found no indications of seabed fluid flow or gas seepage in the immediate area of the reef.

5.2.8.2 Nationally important marine earth heritage areas

As part of the Irish Sea Pilot (Vincent *et al.* 2004), Furze (2003) examined the feasibility of conserving nationally important marine geoscience sites. From this work, the Pilot identified a list of candidate nationally important marine earth heritage areas in the Irish Sea (Table 5.3).

Table 5.3 – Candidate nationally important marine earth heritage areas in SEA 6

Candidate marine areas	Scenario area	Candidate marine areas	Scenario area
The Menai Strait	-	Pingo north-west of Anglesey	3
Sarn Badrig (and/or other sarnau), Cardigan Bay	1	Scour moats main channel west of the Isle of Man	3
Southern Irish Sea linear troughs and incisions	1, 2, 3	Roche moutonnees west of Isle of Man	3
Muddy Hollow Holocene deposits, Tremadoc Bay	1	Tidal scour cauldrons west of Anglesey	2, 3
Morfa Dinlle	2	Periglacial polygonal patterned ground north of Anglesey	6
Submerged drumlins, Morecambe Bay	4, 5	Canyon formations Mull of Galloway	-

Candidate marine areas	**Scenario area**	**Candidate marine areas**	**Scenario area**
Gallows Point Hollow, Menai Strait	-	18 gravel reefs within Cardigan Bay	1
Cold seeps, Muddy Hollow, Tremadoc Bay	1	2 gravel ridge/patches north of Anglesey	6
Isle of Man banner banks	-	Inactive tidal sand ridges west of south Wales Peninsula	1
Lune Deep, Morecambe Bay	5	Linear sand streaks on smooth gravel beds, St George's Channel	1, 2
Large mega-ripples north of Holyhead	3, 6	Giant sand waves within Cardigan Bay	1
Hard rock geology north-west of Holyhead	3	Irish Sea Mounds, north-western Irish Sea near main channel	3
Moribund tidal sand ridges north-east Isle of Man	4	Irish Sea cold seeps	-

Notes: (-) indicates that area is outwith SEA 6. Source: Vincent et al. (2004).

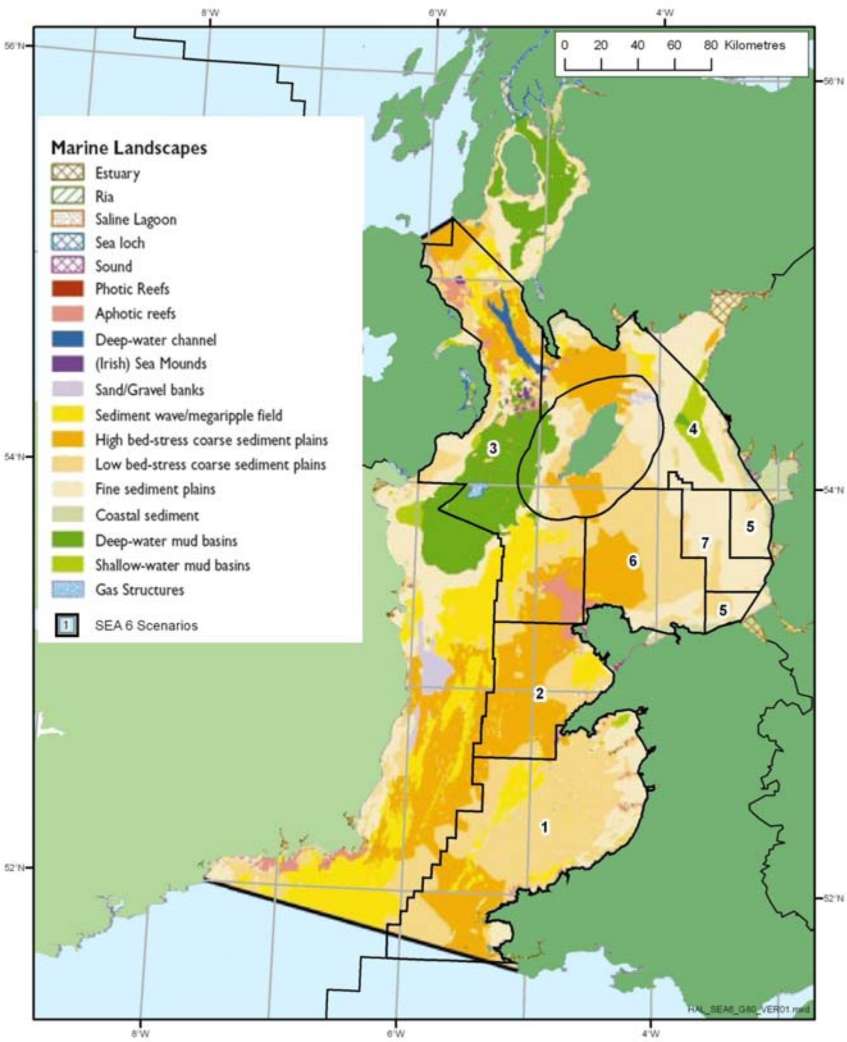


Figure 5.14 – Marine landscapes identified by the Irish Sea Pilot

Source: Vincent et al. (2004).

Vincent *et al*. (2004) concluded that identifying effective and appropriate means of ensuring the practical conservation of these marine areas needed further consideration. They suggested that it could be incorporated within the measures proposed for the conservation of marine landscapes (also identified by the Pilot, see Figure 5.14) and by measures taken to protect the network of nationally important biodiversity areas.

5.2.9 Shoreline types and sensitivity

The coast of south-west Wales is relatively remote and is characterised by a series of cliffs and small sandy bays. North of Aberystwyth, Cardigan Bay supports a sequence of estuaries and sand dunes. Further north the Lleyn Peninsula and Anglesey have a rockier coastline with Anglesey also supporting several sand dune systems (DEFRA 2000).

From Liverpool Bay to the Solway Firth the majority of the land is low-lying and includes a number of important estuaries containing areas of saltmarsh, sand or mud flats and sand dunes. Of the 14 estuaries in this region, all except one are larger than 5,000ha, including Morecambe Bay (which is the second largest area of intertidal mud and sand in the UK after the Wash). Much of the estuarine coast in the south of the region has been highly developed with major industrial and port facilities on the River Mersey and on the Wirral, and to a lesser extent on the River Dee (DEFRA 2000). To the north, rocky shores dominate the coast running from the Solway Firth to the Mull of Galloway. The east and south-west coasts of the Isle of Man also consist of rocky shores with sandy beaches in the exposed north-west (DEFRA 2000).

The coast of Northern Ireland is in general very varied, incorporating high cliffs, extensive sand dunes, mudflats and rocky shores. The principal features are the three sea loughs (Larne, Strangford and Carlingford) which are characterised by fine sand and muddy sediments. Along much of the rest of the coast, sandy beaches and shingle are interspersed along rocky shores with rock outcrops and low cliffs more extensive towards the border with the Irish Republic (DEFRA 2000). The north-east coast of the Irish Republic is characterised by extensive linear sandy and shingle beaches. Rocky shores are confined to small areas to the north of Dublin Bay. Further south, with the exceptions of Dublin Bay and Wexford Harbour, the coast is distinguished by an absence of bays and inlets and a transition from harder intertidal substrates in the north to sandy beaches in the south (DEFRA 2000).

Shoreline sensitivity

The sensitivity of the SEA 6 shoreline to potential activities and accidents resulting from SEA 6 licensing is dependent on a number of factors. The vulnerability of different shore types to oil pollution is largely dependent on substrate type and wave exposure (Table 5.4).

Table 5.4 – Vulnerability of SEA 6 shorelines to oil pollution

Shoreline type	Scenario areas present	Vulnerability to oil
Exposed rocky cliffs and headlands	1, 2, 3	Low vulnerability. Wave reflection keeps most of the oil offshore
Fine and coarse grained beaches	All	Low to moderate vulnerability. Where oil penetrates into the sediment, may persist over several months
Mixed sand and gravel beaches; shingle beaches	All	Moderate to high vulnerability. Oil may penetrate rapidly and be buried resulting in persistence over years. Solid asphalt pavement may form under heavy oiling conditions
Sheltered rocky coasts	1, 2, 3, 4, 6	Moderate to high vulnerability. Oil may persist for years
Sheltered tidal flats	1, 3, 4, 5, 6	High vulnerability. Low wave energy; high productivity and biomass. Oil may persist for years
Salt marshes	1, 2, 3, 4, 5, 6	High vulnerability. Highly productive. Oil may persist for years

Source: Adapted from Gundlach & Hayes (1978), DEFRA (2000).

5.2.10 Relevant data gaps

In comparison to other areas of the UKCS, the geology, seabed substrates and shoreline types of the SEA 6 area are generally well described and although there is considerable local scale variation in the seabed environment, sufficient information is available to enable strategic assessment.

5.3 Climate and meteorology

5.3.1 Data sources

The *West Coasts of England and Wales Pilot* (1999) provides a description of the climate and meteorological conditions in the area. The recently published *Atlas of UK marine renewable energy resources* (DTI 2004) quantifies and spatially maps the potential wave, tidal and offshore wind resources of the UK continental shelf and provides details of wind conditions in the region. The OSPAR Quality Status Report for the Celtic Seas (Region III, OSPAR 2000) describes the physical environmental conditions within the region, including climate and meteorology. The recently published Inter-Agency Committee on Marine Science and Technology (IACMST 2005) contribution to *Charting Progress – an Integrated Assessment of the State of UK Seas* (DEFRA 2005) also provides a relevant assessment of changes to weather and climate.

5.3.2 UK climate trends

An overview of the changes affecting the climate in relation to the marine environment is provided by IACMST (2005). The report also describes the potential drivers of change (e.g. the North Atlantic Oscillation).

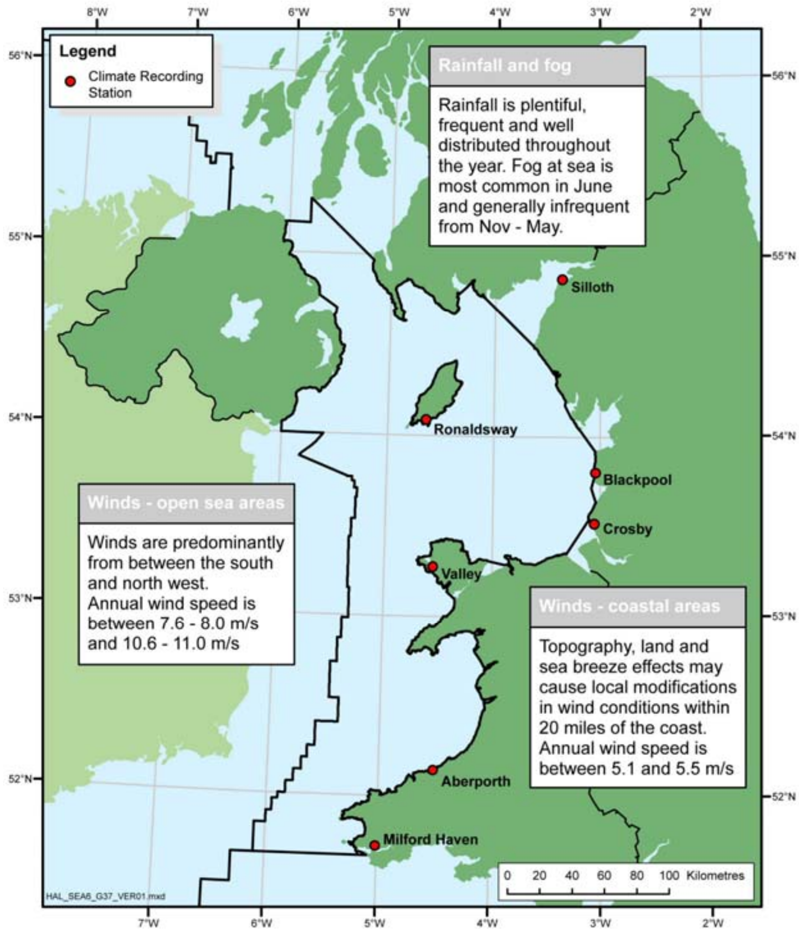
In summary, the IACMST report concludes that:

- The annual mean Central England Temperature has increased by about 0.5°C during the 20th Century. The warmest years since records began in 1659 occurred in 1990 and 1999 and the 1990s was the warmest decade, with five of the six warmest years occurring then.
- The 30-year mean of annual mean temperature in Northern Ireland and Scotland increased by between 0.11-0.39°C from 1873-1902 to 1961-1990.
- The average number of storms in October to March at UK stations has increased significantly over the past 50 years or so, with the largest increases in the south. However, the magnitude of storminess at the end of the 20th century was similar to that at the start.
- The 24-month period ending in March 2001 was the wettest in England and Wales since records of the monthly total precipitation began in 1766. April 2000 to March 2001 was the wettest twelve months on record.
- The most extreme change in the NAO since the 1860s has occurred from about 1960 up to the present, with the Winter Index (December – March average) showing an upward trend. There are indications of several earlier years of comparable values over the past 500 years, but the systematic rise in values from the 1960s to the 1990s is unique.

Mindful of these broadscale changes and trends, the rest of this section will describe the current climate of the SEA 6 area.

Weather conditions are recorded at coastal stations in the SEA 6 area (West Coasts of England and Wales Pilot 1999) and summarised on Figure 5.15.

Figure 5.15 – General weather conditions in the SEA 6 area



5.3.3 Wind

The SEA 6 area enjoys a mild maritime climate, although it can be unsettled with periods of strong winds and rough seas. Although they can occur in any month, gales in the region are more frequent in winter months and can reach storm or hurricane strength on some occasions. In January and July, the percentage frequency of winds with force 7 (mean 15.5m/s; limits 13.9-17.1m/s) or over in the region is 20-25% and 2% respectively. Gale force 8 (mean 18.9m/s; limits 17.2-20.7m/s) or over are reported on about 12% of occasions in December and less than 2% in July, with the most common direction for these gales from between the south-west and north-west. Calm conditions (wind speeds <0.2m/s) are likely to occur less than approximately 2% of the time (OSPAR 2000).

Frequent mobile depressions affect the region and as a result there are often marked variations in both wind speed and direction during any set period of time. However, in late winter and early spring, east to north-east winds may persist for several days when a high cell may become established over central and north-east Europe. The annual mean wind speed in the SEA 6 region is in the range 7.6-8.0m/s to 10.6-11.0m/s in open sea areas, decreasing to 5.1-5.5m/s in coastal areas.

Open sea areas

The predominant winds are from between the south and north-west, with strongest winds generally coming from the west and south. The strongest winds tend to be experienced to the north and west of the region and although there is no evidence of any trend in wind patterns or their strength (based on 30-yr records), there are indications of an increase in the frequency and severity of storms (OSPAR 2000). Depressions passing to the north of the Irish Sea promote northerly and westerly winds over the area and these are likely to increase the incidence of storm surges in the eastern Irish Sea (OSPAR 2000). Within the SEA 6 area there is an increase in the frequency of north to north-east winds in spring and a decrease in east winds in summer.

Generally, the strongest winds are reported during autumn and winter, with winds of force 6 (mean 12.2m/s; limits 10.8-13.8m/s) and over being reported in December on around 40% of occasions in the north of the region and around 35% in the south. This frequency falls to about 6% and 9% respectively by July (West coasts of England & Wales Pilot 1999).

Coastal areas

Within about 20 miles of the coast, local modifications in wind conditions may be caused by the topography and by the land and sea breeze effects. An increase in wind strength due to the funnelling effect is most marked at several places along the coastline including St George's Channel, Milford Haven, Holyhead, River Dee estuary, River Mersey estuary, Morecambe Bay, Isle of Man to North Channel and Solway Firth.

5.3.4 Rain and fog

Throughout the SEA 6 area, coastal rainfall is strongly influenced by the topography of the area. West facing coasts generally experience heavier rainfall, especially where there are mountains close to the coast (OSPAR 2000).

Rainfall at coastal stations in the region varies according to their exposure to the prevailing winds and the proximity of high ground. At those sites which are exposed, the average rainfall is around 1000mm, and 700mm for those in the lee of high ground. In general the driest months are April to July with October to January the wettest, however on the Lancashire and Cumbria coasts February to June are the driest with August to December the wettest (West coasts of England & Wales Pilot 1999).

In winter, rain can be expected at sea on about 18 days per month and in summer on about 10 days (per month) in the south of the region and 15 days (per month) in the north. However, the quantity and duration can vary significantly from one day to another.

Sea fog, with visibility <1km, is most common with south-west winds between April and October and has a maximum frequency percentage of between 2 and 5% in June. This decreases in January when the frequency is generally less than 2%. However this frequency generally increases to between 5 and 10% in areas to the east of 4°W. Land fog is most frequent in the latter part of the year during autumn and winter, particularly around dawn (West coasts of England & Wales Pilot 1999).

5.3.5 Relevant data gaps

Meteorological conditions within the SEA 6 area are well documented, based on an extensive historical dataset, and are not considered to be a significant issue in terms of the

Strategic Environmental Assessment process. Climate issues, in terms of the potential effects of oil and gas combustion, are outside the scope of this assessment.

5.4 Oceanography and hydrography

5.4.1 Data sources

The underpinning SEA 6 technical report (Howarth 2005) covers many aspects of the oceanography and hydrography of the SEA 6 area and provided much of the information for this section. The two sources for many of the figures in this report are a three-dimensional hydrodynamic numerical model of the continental shelf seas around the United Kingdom with a horizontal resolution of 1.8km, and long term measurements from a site less than a mile west of the Mersey Bar Light. The site is part of a project started in August 2002 and expected to last for 5–10 years. Measurements include current profiles, waves and surface and bed salinities and temperatures (for more details see http://cobs.pol.ac.uk). Since there are very few such long term measurements, the measurements are used to test the models and the models then used to estimate spatial (horizontal and vertical) variations.

Other sources of information included the IACMST (2005) contribution to *Charting Progress* (DEFRA 2005), and the DEFRA (2000) *Quality Status Report of the Marine and Coastal Areas of the Irish Sea and Bristol Channel 2000* which formed the basis of the OSPAR Quality Status Report for the Celtic Seas (OSPAR 2000).

5.4.2 Water masses

The Irish Sea is a semi-enclosed body of water which is open to the Atlantic through St George’s Channel in the south and the North Channel to the north. The extent of Atlantic inflow to the region varies with changes to large scale circulation patterns in the north-east Atlantic (e.g. as a result of atmospheric forcing), and weather, particularly the strength and direction of the prevailing winds.

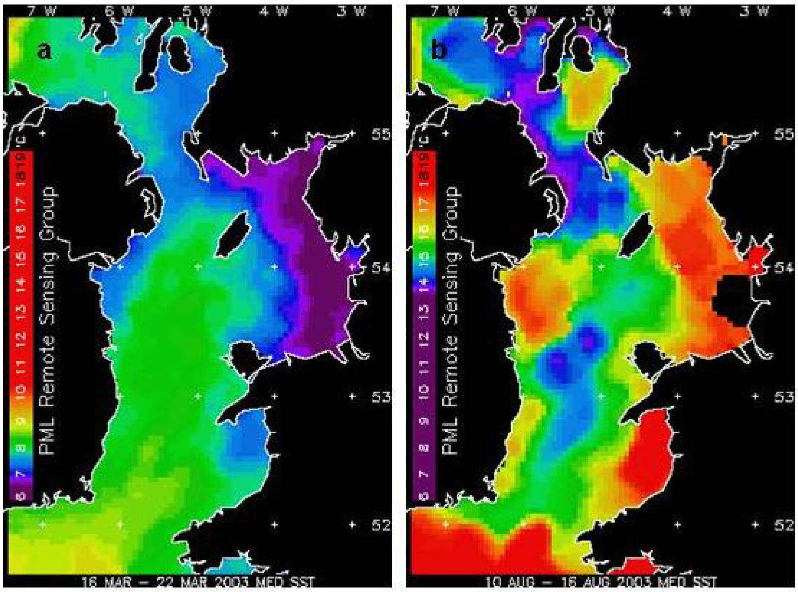
Freshwater run-off is important in determining the character of Irish Sea water masses particularly in coastal and nearshore areas. The Irish Sea receives freshwater run-off from a large area of land, approximately 43,000km^2 compared to a sea area of approximately 47,000km^2 with the majority of the run-off arriving in the eastern Irish Sea, down the Ribble, Mersey and Dee estuaries (adjacent to Scenario areas 5 & 7) and into the Solway Firth (adjacent to area 4) and Morecambe Bay (adjacent to areas 4 & 5). The region is also affected by significant freshwater input from the south via the Bristol Channel. The largest monthly discharge occurs between December and February and the smallest in July (Howarth 2005).

Temperature and salinity

The water is coolest in February or March with temperature decreasing from the deeper channel towards the coasts (Figure 5.1.6a). A warm tongue, with a temperature above 7.5ºC, extends up to the North Channel. The coolest water is towards the coast in the eastern Irish Sea. At this time of year the temperature is uniform with depth.

In contrast, in the warmest month, August, the coolest surface water is in the North Channel (13–14ºC) and the warmest water close to the coasts, exceeding 16-17ºC in Liverpool and Cardigan Bays (Figure 5.16b).

Figure 5.16 – Sea surface temperatures in Irish Sea



Note: Composite satellite images taken between a) 16-22 March 2003 and b) 10-16 August 2003. Note change of scale between images. Source: PML Remote Sensing Group, Proudman Oceanographic Laboratory website - http://cobs.pol.ac.uk/cobs/sat/.

The long term temperature record shows a large degree of variability in the seasonal cycle, although a general increasing trend is apparent, indicating a rise of around 0.6ºC over the last 70–100 years, and particularly an increase in winter temperatures since 1990. The annual mean salinity decreases from south (34.9‰) to north (34‰) and from the centre of the channel (34.3-34.9‰) to the sides (32.0-34.0‰) reflecting the northerly flow of oceanic Atlantic water whose salinity is gradually reduced by coastal freshwater input. Lowest values are found in the north-east, from the Solway Firth to Liverpool Bay, and in the Clyde Sea. Seasonal variations in salinity are small in most areas, although most noticeable near the coasts, being governed by the annual cycle of river flow.

Stratification and frontal systems

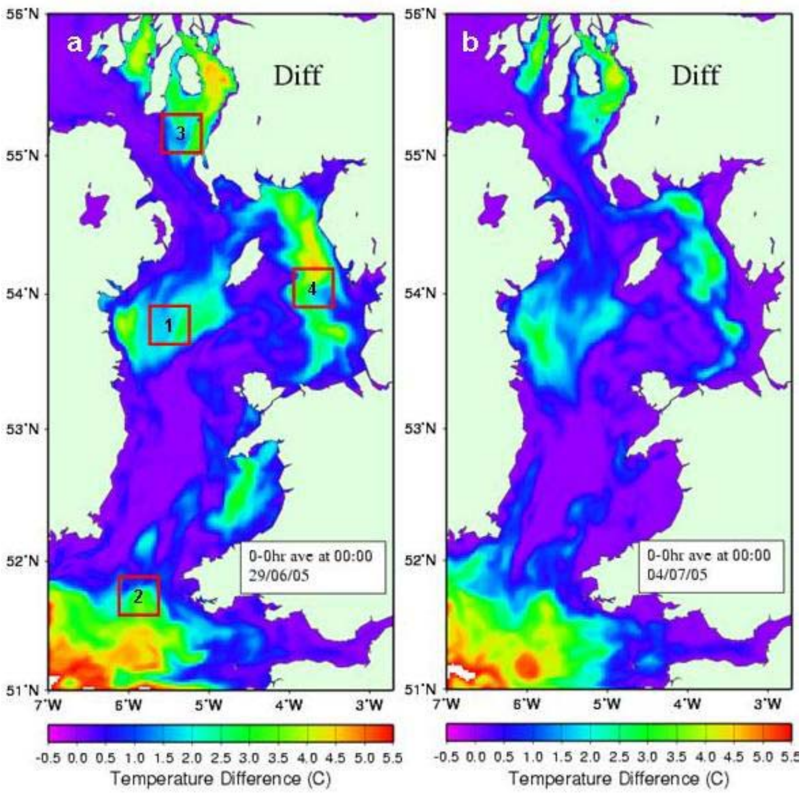


Figure 5.17 – Stratification in the Irish Sea

Notes: POL modeling data of differences between surface and bottom water temperatures for a) 29 June 2005 and b) 4 July 2005. Source: POL website - http://cobs.pol.ac.uk/cobs/sat/.

In much of the region, tidal mixing is such that the water column remains well mixed through the year. However, in some areas temperature and/or salinity differences between water masses may result in seasonal stratification. Figures 5.17a and b highlight potential areas of stratification (i.e. temperature difference of about >3°C).

Stratification is a dynamic process - see Figures 5.17a and b which show the situation at a 5 day interval. In some areas (e.g. Cardigan Bay) stratification is only likely to develop during hot, calm conditions and can easily be mixed away by storms or spring tides. Transitions between mixed and stratified regions are in many cases marked by sharp fronts which may be manifest at the surface and/or near the bed and which have an important influence on water circulation and mixing. Frontal areas are often areas of enhanced biological production and those of particular relevance are highlighted on Figure 5.17a and described in Table 5.5 in association with relevant DTI Scenario areas.

Table 5.5 – Frontal areas and stratification in the SEA 6 area

Frontal area[1]	Scenario area	Period of stratification	Details
1	3	April-October	Maximum surface to bed temperature difference of 5ºC. Bottom fronts drive strong (>0.2m/s) but narrow (10km wide) currents in an anticlockwise direction around the pool of colder water below the thermocline. This gyre tends to retain particulate and biological (e.g. plankton) material in the region.
2	1	April-October	Celtic Sea thermally stratified during summer and surface front stretches across St George's Channel. To the south is a deep pool of cold, saline Atlantic water bounded by strong bottom fronts. These drive strong density flows (of similar magnitude to those described above) which allow restricted circulation between the Irish and Celtic Seas.
3	3	All year	Front separates stratified regime of the Clyde Sea from the well mixed waters of the North Channel. Inputs from the River Clyde and other freshwater sources promote haline stratification throughout the year. During the summer, this is reinforced by strong thermal stratification.
4	4, 5, 6, 7	All year	Differences between saline oceanic inflows and freshwater input cause haline stratification in eastern Irish Sea. The resulting density flows are strongest in winter and spring but can be overwhelmed during periods of strong winds. During the summer, this is reinforced by thermal stratification.

Note: Reference to areas marked on Figure 5.17a. Sources: DEFRA (2000), OSPAR (2000), IACMST (2005), Howarth (2005).

5.4.3 Water circulation and currents

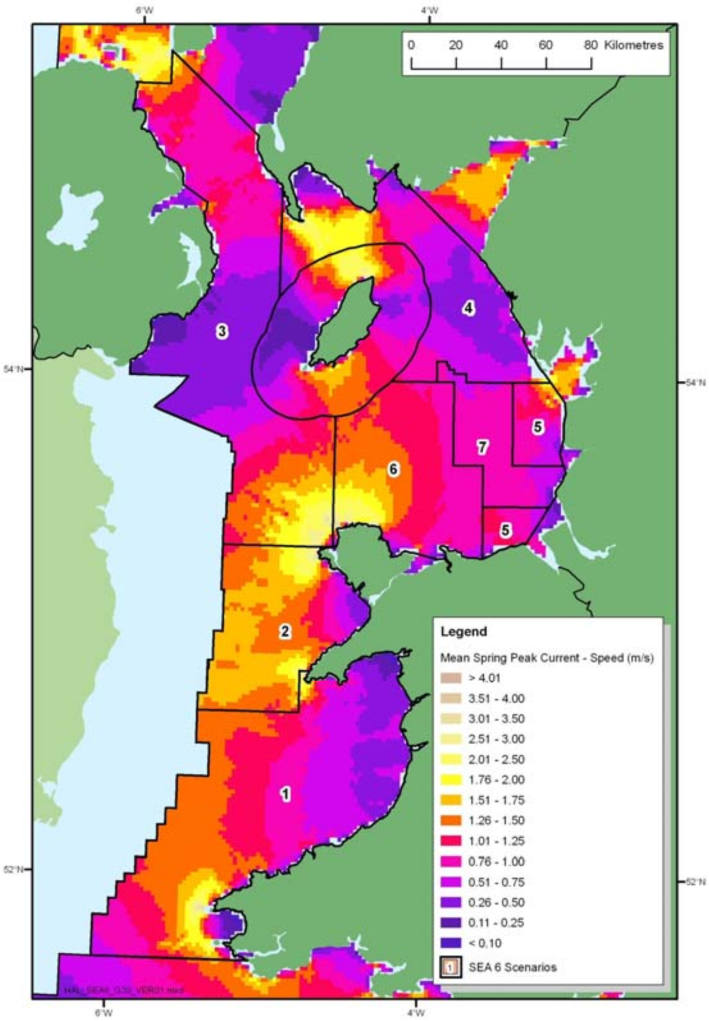
Principally, water is moved by the action of tides, winds and differences in density between adjacent water masses (Bowden 1980). The twice daily flooding and ebbing of the tides provides the most obvious movement of water. However, the strength of the tidal currents varies across the region and this determines many of the physical and biological processes and distributions within the sea. Wind acting on the sea surface generates waves and movement of water with the cumulative effect of individual wind events contributing to the overall long-term (>2 months) mean circulation of the region.

In general, the weakest flows are in response to water density differences between the saline oceanic inflows and freshwater input. However, such currents are persistent and produce a major contribution to the residual flow, especially in the eastern Irish Sea. More notable are the strong, persistent, circulations associated with summer heating and stratification of the water column, particularly in the deep basin of the western Irish Sea, (DEFRA 2000).

Tides and tidal flows

There is considerable variation in the tidal range experienced around the Irish Sea. Liverpool Bay, for example, experiences a very large tidal range (>10m on the largest spring tides, the second largest in the British Isles) whilst areas of very small tidal range are found in the vicinity of Arklow in St George's Channel and between Islay and the Mull of Kintyre in the North Channel (adjacent to Scenario area 3, Howarth 2005).

Figure 5.18 – Mean peak spring tidal currents



Note: Unit of measurement (metres/sec). Source: DTI Atlas of Renewable Energy (2004).

The tide propagates into the Irish Sea from the Atlantic Ocean through the St George's Channel and the North Channel (Robinson 1979). The tidal waves from both directions meet to the south-west of the Isle of Man causing this to be an area of very weak tidal currents (<0.35m/s) - see Figure 5.18. Areas of strong tidal currents (depth-averaged values up to 2m/s at spring tides) and hence of vigorous tidal mixing and peak bed stresses are generally throughout St George's Channel, north-west of Anglesey, north of the Isle of Man and in the North Channel (Howarth 2005). In shallow water, sudden changes in bathymetry and/or topography may generate locally high velocities near headlands, islands and estuaries (DEFRA 2000).

Residual flows

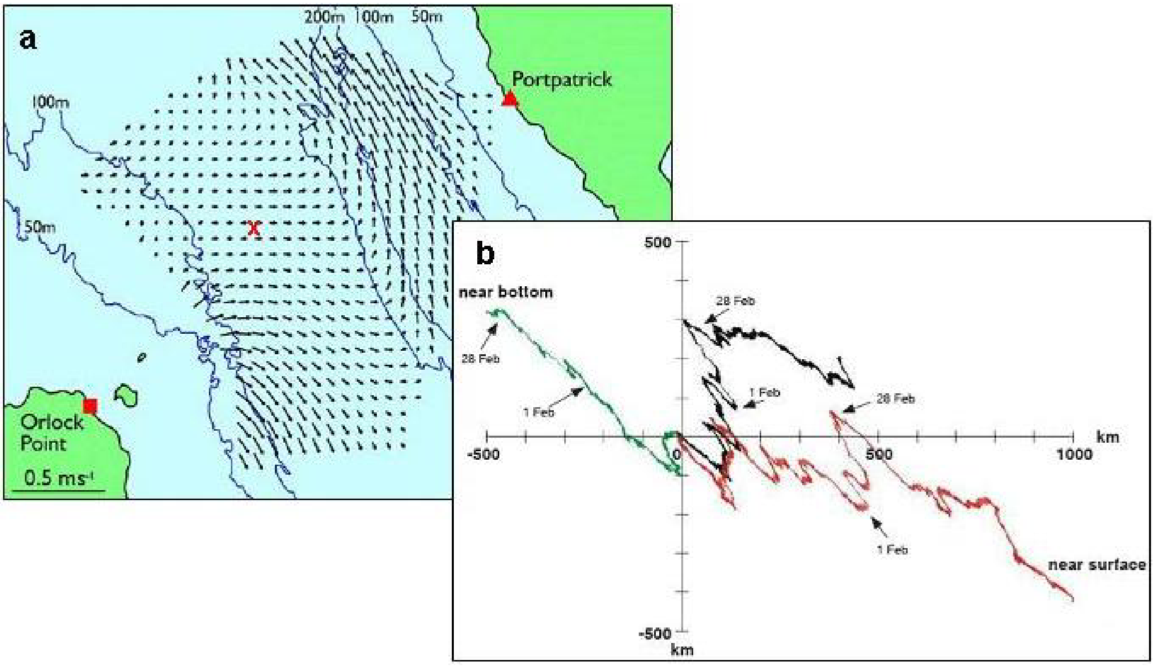
The mean or residual flow is weak, generally less than 0.1m/s and about 0.01m/s in most places. The main inflow of water is from the Atlantic, flowing south to north through St George's Channel. The main flow may veer towards the Welsh coast as it moves north, with a weaker flow, generally northward, to the west of the Isle of Man. A minor component of the flow enters the eastern Irish Sea to the north of Anglesey and moves anti-clockwise round the Isle of Man before rejoining the main flow to exit through the North Channel (DEFRA 2000). Transit times from Sellafield to the North Channel have been estimated in the range 6 to 12 months with a mean residence time for the Irish Sea of 1–2 years (Howarth 2005).

Although on average the flow is northward, water movement is strongly influenced by the wind, so that this flow can be reversed for months at a time. There are also horizontal and vertical differences in flow direction and magnitude within the water column.

For example, Knight and Howarth (1999) measured flow through the North Channel over a 15 month period (July 1993 to October 1994), recording a residual northward outflow of 0.02-0.03m/s. However, the current was not distributed uniformly across the channel with the overall outward flow strongest (up to 0.15m/s) on the eastern (Scottish) side of the channel, with a weaker surface return flow along the Irish coast (Figure 5.19a). This northerly flow through the North Channel forms the basis for the Scottish Coastal Current which flows northward past the west coast of Scotland (Howarth 2005).

Knight & Howarth (1999) also found considerable variability in the vertical structure of the flows through the North Channel (as measured at a site marked on Figure 5.19a). Figure 5.19b indicates that the near-surface mean flow (red) was directed towards the Irish Sea, depth-averaged mean flow (black) was directed across the channel towards the Scottish coast and near-bottom flow (green) was directed towards the Malin Shelf. There were large temporal variations in flow at the near-surface, while at the near-bottom the flow was more stable. Strong winds from the south-east (up to 25m/s) between 1 February and 28 February 1994 caused the largest reversals of near-surface flow from the direction of near-surface mean flow (Knight & Howarth 1999).

Figure 5.19 – Water flows in the North Channel



Notes: a) Mean surface flows in the North Channel b) progressive vector diagram of currents measured at the site marked on Figure 5.4.4a, 13 July 1993 to 28 October 1994. Sources: a) Knight and Howarth (1999) b) IACMST (2005, courtesy of John Howarth, POL).

Similar long-term current measurements have been recorded from the Liverpool Bay Coastal Observatory mooring. In this area density gradients drive a circulation offshore at the surface and onshore near the seabed. Overall the density gradients drive a clockwise circulation around the coasts of the bay, in opposition to the winds. However at wind speeds >5-10m/s from between south-west and north-west, this pattern is reversed (Howarth 2005).

Waves and surges

The magnitude of surface waves depends on the duration and fetch of the wind. Since the Irish Sea is sheltered with only two relatively narrow 'windows', along the axes of the St George's and North Channels, the majority of waves are locally generated and of fairly short period and are therefore steep. Swell waves are only present near the entrances of the St George's and North Channels. Hence, the wind direction leading to the largest waves will depend very much on the locality, for instance in Liverpool Bay winds from the north-west cause the largest waves (Howarth 2005).

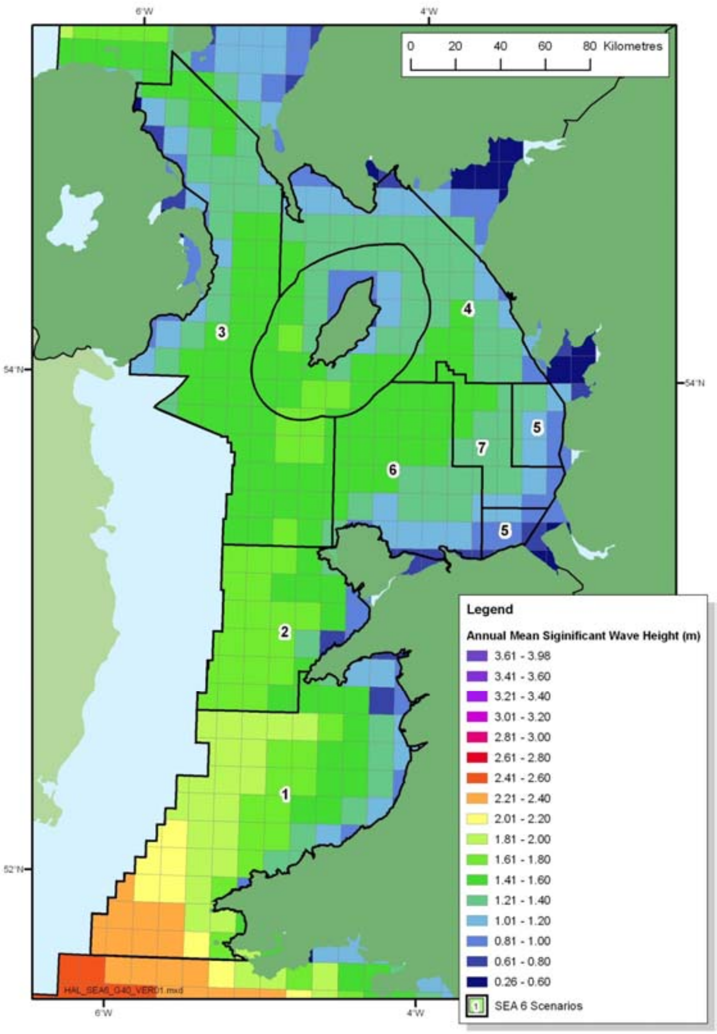


Figure 5.20 – Annual mean significant wave height

Source: DTI Atlas of Renewable Energy (2004).

The annual mean significant wave height (Figure 5.20) is greatest at the entrance to St George's Channel (about 2.3m) with values decreasing northwards. Lowest mean significant wave heights are experienced in sheltered coastal regions particularly Morecambe Bay and the Solway Firth (<0.6m). The 50-year return value of significant wave height varies between 8m within the Irish Sea to about 12m at its outer entrances. The effect of waves on processes such as sediment transport will be significant during storms especially in shallow areas of the eastern Irish Sea (Howarth 2005).

As mentioned above, local wind forcing rather than tidal or density driven flow is the principal driving mechanism for flow through the North Channel (Knight & Howarth 1999) with the largest transports generated by along-channel winds.

The largest storm surges are generally associated with storms tracking eastward between Inverness and Shetland and occur in the eastern Irish Sea, with maximum surge levels of about 2m predicted for the Lancashire and Cumbria coasts associated with westerly winds, whilst the maximum surge levels are between 1.25m and 0.75m on the Irish coast and across the St George's Channel (Flather 1987). The impact of surges also depends critically on the state of the tide with the biggest risk of flooding occurring if the surge peak coincides with high tide on a spring tide (Howarth 2005).

5.4.4 Potential impacts of climate change

Broadly, the atmospheric pressure distribution over the north Atlantic in winter can be characterised as two alternate states: (1) an intense Icelandic low and a strong Azores ridge to the south; (2) a weak Atlantic low and Azores high. The oscillation between these characteristic patterns is the dominant mode of atmospheric behaviour over the north Atlantic, and is termed the North Atlantic Oscillation (NAO) (e.g. Rogers 1984). State (1), termed a positive index, is associated with strong mid-latitude westerlies, higher frequency of

Atlantic storms and increased wave height in the north-east Atlantic when compared to state (2), a negative index (e.g. Dickson 1997, cited by DEFRA 2000). The most extreme change in the NAO since the 1860s has occurred from about 1960 up to the present, with the Winter Index showing an upward trend (IACMST 2005).

A direct link with the hydrography of the Irish Sea and the NAO has not been established, however, it is reasonable to expect a degree of correlation. For example, a positive index results in a higher frequency of Atlantic storms, the centres of which track to the north of Britain favouring more frequent resuspension of sediment in shallow coastal environments through increased wave activity. Additionally, depressions passing to the north of the Irish Sea promote northerly and westerly winds over the region which are likely to increase the incidence of storm surges in the eastern Irish Sea and Liverpool Bay (Flather 1987).

5.4.5 Relevant data gaps

In general, the hydrography of the Irish Sea has been relatively well described and modelled. Direct measurements of hydrographic parameters are limited particularly in terms of long term monitoring. However, for the purposes of dispersion and trajectory modelling, large-scale (i.e. hydrographic) physical forcing processes are well parameterised, although there remain some difficulties in modelling small-scale dispersion processes.

5.5 Contamination of water and sediments

5.5.1 Data sources

The CEFAS technical report produced for SEA 6 (Kenny *et al*. 2005) describing the contaminant status of the Irish Sea was a prime information source. Data from the United Kingdom National Marine Monitoring Programme (NMMP) is given in a number of publications including the CEFAS Aquatic Environment Monitoring Reports (CEFAS 2001, 2003), OSPAR Quality Status report - Region III Celtic Seas (OSPAR 2000), UK NMMP second report, 1999-2001 (Marine Environment Monitoring Group 2004) and *Charting progress: An Integrated Assessment of the State of the UK Seas report* (DEFRA 2005).

5.5.2 Contamination

A comprehensive study was carried out between 2000 and 2002 to determine the inputs of a number of organic and metal contaminants to the waters of northern Europe, including the Irish Sea (OSPAR 2004).

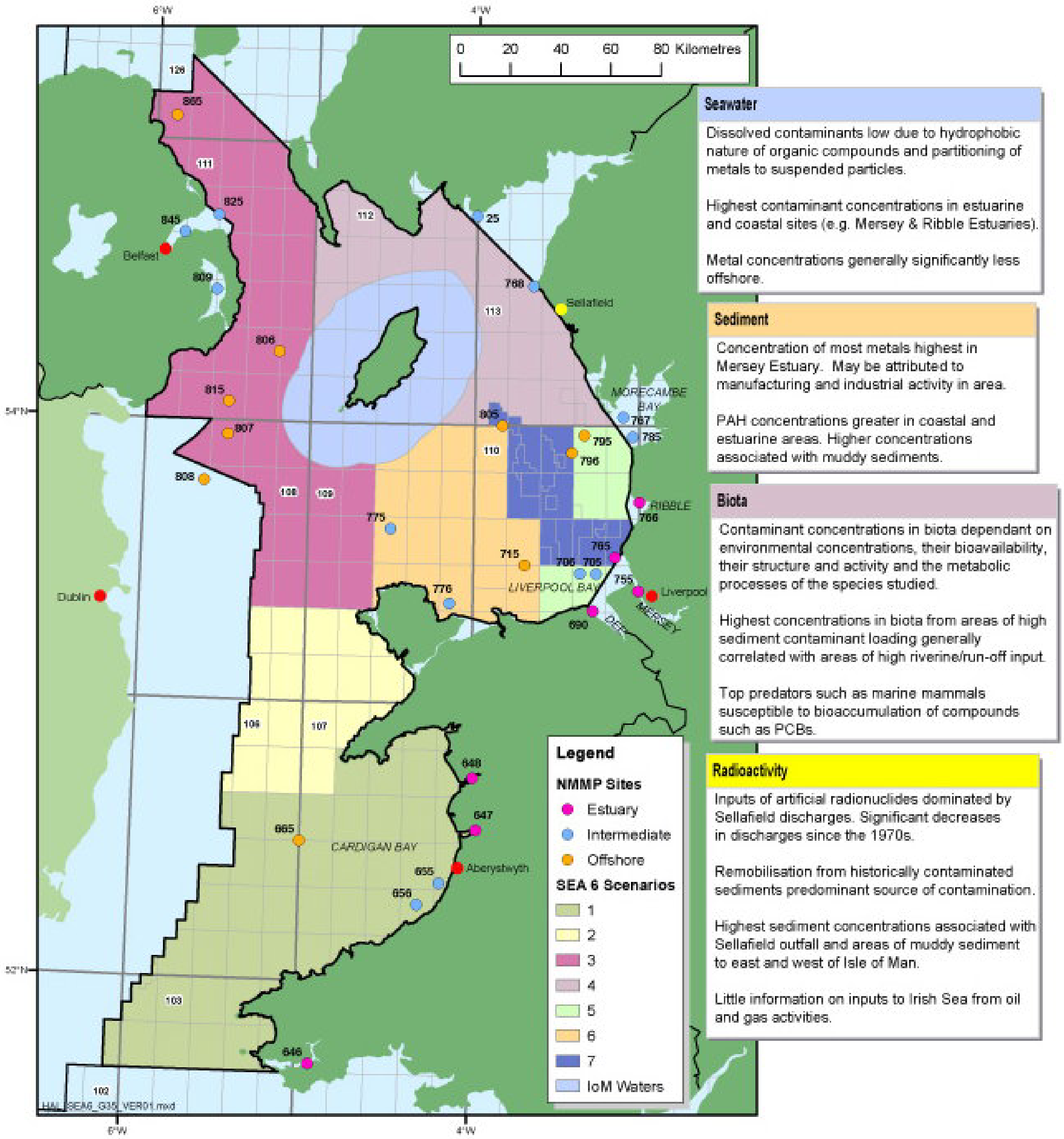
Studies that have measured the contribution of riverine inputs of metals to the Irish Sea compared to direct discharges show that riverine inputs contribute >80% of most metal concentrations measured. An exception to this is mercury, where direct discharge and river inputs were approximately equal (OSPAR 2004). Time series of average concentrations of mercury in fish flesh from Liverpool and Morecambe Bays between 1983 and 1996 indicate a sustained decline in contaminant burdens over time following reductions from chlor-alkali plants in north-west England (Matthiessen and Law 2002).

The major industrial locations within the region are found in Merseyside and Lancashire. Small areas of industrial development are also found in Cumbria and on Deeside in Clwyd. On the western side of the Irish Sea the main industrial areas include Belfast and Dublin. All of these areas are likely to contribute to the contaminant input to the Irish Sea.

The NMMP provides an important source of data for the Irish Sea for the last five years. As part of the NMMP, physical, biological and chemical data have been collected from a series of estuarine, intermediate and offshore sites in the Irish Sea (Figure 5.23).

A summary of NMMP data for the Irish Sea is presented in Kenny *et al.* (2005), an overview of which is given in Figure 5.23.

Figure 5.23 – Summary of contamination in the SEA 6 area



Source: *Kenny et al. (2005).*

Inputs of artificial radionuclides around the UK are dominated by discharges from Sellafield, on the Cumbria coast. In most cases current discharges are at least 100 times lower than historic peak discharges. The last survey to assess the inventory of artificial radionuclides in the Irish Sea sediments was carried out more than a decade ago (Poole *et al.*, 1995;

Kershaw *et al*., 1999). These studies showed that the sub-tidal sediments of the Irish Sea contain a very substantial repository of Cs, Pu and Am radionuclides. The highest concentrations in surface sediments are associated with the outfall and a zone of muddy sediments running parallel to the English coast. A second area of fine-grained sediments between the Irish coast and the Isle of Man also has elevated concentrations. Although anticipated to be localised, the influence of oil and gas activities upon sediment remobilisation and hence to associated radionuclide availability in the water column should be considered during project specific assessments.

Remobilisation from sediments contaminated by historical discharges is now the predominant source of ^{137}Cs, $^{239+240}$ Pu and ^{241}Am to the water column and appears to be largely governed by natural sediment mixing and re-suspension processes. The highest concentrations of these radionuclides in surface sediments are associated with the Sellafield outfall and a zone of muddy sediments running parallel to the English coast. A second area of fine-grained sediments between the Irish coast and the Isle of Man also has elevated concentrations.

The oil and gas industry in the Irish Sea is small by comparison to that of the North Sea (see Section 8.4). The two main sources of potential contamination from oil and gas exploration and production are from drilling activities and production discharges, mainly produced water. The Water Framework Directive aims to protect the physical and biological integrity of aquatic systems. The overall objective is good status to be achieved by December 2015. The main focus of the directive is groundwater and surface water quality out to 1 nm from the coast. However the UK government's vision for management of our marine resources supports an integrated approach to the management of estuaries, the coastal zone and associated coastal waters. In this context the quality and status of the marine environment associated with offshore oil and gas installations is important.

The majority of drilling fluids currently used in Liverpool and Morecambe Bays are water-based, though organic phase fluids (either mineral oil or synthetic-based) may be used for some well sections, with these cuttings taken to shore for cleaning and disposal. The majority of compounds making up the drilling mud system are inorganic salts and clays, which disperse relatively rapidly and are of low toxicity. Modelling of drill cuttings deposition around a number of wells in Morecambe Bay indicates cuttings distributed ~400m in each direction along an east-west axis from well sites with the bulk of cuttings within 50m of the well location and cuttings depths of less than 15mm over approximately 93 percent of the deposition area (Burlington Resources Environment Statement - Rivers Fields Development 2002, Crosby exploration well 110/14-F and Greeba exploration well 110/12-5, cited by Kenny *et al.* 2005). Remote vehicle surveys of the seabed in the vicinity of the Lennox platform immediately after completion of drilling operations did not indicate cuttings accumulation. A similar situation is likely for drilling operations in Morecambe Bay.

Selected metals in sediments were measured and compared from locations within 5km of the Liverpool Bay production installations between 1994 and 2001 (Holt & Shalla 2001). Mean sediment metal concentrations were generally lower in 2001 compared to those in 1994, although barium concentrations (often used as a marker of drilling activities) increased but still remained at generally low levels. For all metals, there was no clear concentration trend with distance from each of the installations although the co-occurrence of barium suggested contamination may be related to drilling activity. The sediment metal concentrations for copper, lead and zinc, all overlapped their respective ecotoxicological assessment criteria (EAC, OSPAR 1997) ranges suggesting potential for biological effects as a result of sediment metal exposure to benthic organisms.

Oil and gas removed from subsea strata may be associated with formation water and sometimes with water injected to maintain reservoir pressure. Following physical and chemical treatment to separate the majority of oil, the remaining water is usually discharged to sea. This produced water contains residual oil and a range of production chemicals. Much more water is co-produced with oil than with gas. Thus, the produced water volume from the Douglas platform discharged in Liverpool Bay ranges between 5,000-10,000m^3/day, whereas the same volume of water would be discharged from the Morecambe South platform over one year. Gas production also generally uses fewer production chemicals than oil production. Residual oil is thought to contribute most to the toxicity of produced water (Slager *et al.* 1992). However low molecular weight dissolved hydrocarbons may also make a relatively high contribution to the toxicity of produced water from gas platforms.

Five metals (zinc, nickel, chromium, cadmium and lead) were measured in the water column immediately downstream of the main installations (Hamilton, Hamilton North, Lennox and the Douglas OSI) in Liverpool Bay in 1993, 1994 and 2001. The mean concentrations were below the UK environmental quality standard value for seawater for each of the metals measured over all three years (Holt & Shalla 2001). Seabed surveys have been carried out around the Morecambe Bay installations since 1985 (UKBenthos 2000). No particularly elevated concentrations of hydrocarbons or metals were recorded and no significant biological effects detected (Rees 1994).

Produced waters may contain in vitro estrogen receptor (ER) agonists in the form of short-chain (C1 to C5) and long chain (C9) alkylphenols which are natural components of crude oil but partition to the aqueous phase during oil–water separation (Thomas *et al.* 2004, Dale *et al.* 1995, Taylor *et al.* 1997). Produced water from Douglas had a very low ER agonist activity of <0.1ng E2 equivalents l^{-1} (Thomas *et al.* 2004).

In general, dilution of produced water to below the level at which acute toxic effects are observed usually occurs within 50-1,000m of the discharge point.

Produced waters and solid sludge contain natural radioactivity (NORM), mainly ^{226}Ra, ^{228}Ra and their daughter products although the activity of wastes from oil and gas production wells varies widely.

5.5.3 Biological evidence of contamination

The fate and effects of contaminants within the marine environment have been described by previous SEAs. Contaminant exposure may occur via passive diffusion or active uptake processes. Biological effects of petroleum hydrocarbons on marine organisms are dependent on their bioavailability and persistence, the ability of an organism to accumulate and metabolise compounds and the ability of hydrocarbons to interfere with normal metabolic pathways that may alter an organism's chances of survival to reproduction (Capuzzo 1987).

Scope for Growth (SFG) measurements provide a measure of physiological stress response in marine mussels. Between 1996 and 1997, Widdows *et al.* (2002) measured SFG and chemical contaminant loads in mussels from 38 coastal locations around the Irish Sea. Declines in the SFG of mussels were associated with a general increase in contaminant levels particularly in coastal areas of Liverpool and Morecambe Bays (Scenario areas 5 & 7). At a majority of sites c. 50 to >80% of the observed decline in SFG was due to PAH as a result of fossil fuel combustion and oil spills (Widdows *et al*. 2002). Concentrations of 2- and 3-ring PAH were highest in mussels from Milford Haven (22.5μg/g dw), 6 months after the

Sea Empress oil spill (Widdows *et al*. 2003). Repeated sampling the following year (1997) found a reduction in the PAH concentration to 7.87μg/g dw.

Metal concentrations in mussels from inshore areas of the Irish Sea have been recorded as part of the NMP. Elevated concentrations of the majority of metals (e.g. cadmium, copper lead and mercury) were found in mussels from the Mersey estuary and Morecambe Bay.

Fish sampled in Morecambe and Liverpool Bay, Burbo Bight and off the Cumbria coast had elevated levels of the enzymes responsible for detoxification of compounds found in oil relative to fish sampled from other sites. Significantly, metabolism of PAH may result in the production of genotoxic metabolites with potentially mutagenic and carcinogenic properties. Measurement of these, by way of DNA adducts analysis, showed highest values in samples from Burbo Bight (inner Liverpool Bay). Fish diseases and pathological changes in the liver have long been used as indicators of environmental stress on fish populations. Within the Irish Sea, liver nodules in dab are most common at sites in Liverpool Bay and Cardigan Bay. They are also present in most other regions at lower levels.

Marine mammals are susceptible to bioaccumulation of oleophilic compounds, such as PCBs, due to their high trophic level and long life span. The relationship between the levels of PCB and infectious disease prevalence in harbour porpoises has been studied by Jepson *et al.* (1999). They found that animals that died of infectious disease had significantly greater levels of chlorobiphenyl congeners in their blubber than healthy animals that had died as a result of physical trauma (mainly by-catch).

Few studies to date consider chronic toxicity of compounds discharged in produced water but potential effects may be more widely spread as they commonly occur at lower exposure concentrations. The ICES BECPELAG (Biological Effects of Contaminants in Pelagic Ecosystems) study utilised a variety of techniques to monitor the medium to longer term effects of contaminants on different components of the pelagic ecosystem (e.g. bacteria, zooplankton and fish). A variety of detectable responses (in caged organisms) to proximity to an oil platform were observed and attributed to produced water effects including:

- PAH concentrations in fish and zooplankton increased.
- CYP1A (detoxification enzyme) levels in herring showed a possible rise as the hydrocarbon content of the water increased.
- PAH derived bile metabolites increased in fish.
- DNA adduct levels rose in fish.
- Histological changes to both cod and mussels were detected.
- Increased levels of glutathione-s-transferase activity in cod.
- Some estrogenic activity found in all extracts.

However, the ecological significance of these responses is unclear. References for the various BECPELAG findings are given in Kenny *et al.* (2005).

Analysis of the biota in the vicinity of each of the installations in Liverpool Bay in 2001 showed no major detrimental changes within sites as a result of developments since 1994 (Holt & Shalla 2001). Similar data collected for the Morecambe Field did not indicate an impact of the development upon the diversity of benthic organisms (Rees 1994).

On 15 February 1996 the *Sea Empress*, bringing crude oil to Milford Haven in southwest Wales, ran aground and over the following week released 72,000 tonnes of crude oil and 480 tonnes of fuel oil into the sea. Despite a rapid and effective clean-up response at sea, oil came ashore along 200km of coastline within and adjacent to SEA 6 (SEEC 1998).

The main environmental impacts of the spill included:

- Large numbers of marine organisms killed either as oil came ashore (e.g. limpets and barnacles) or when raised levels of hydrocarbons in the water column affected bivalve molluscs and other sediment-dwelling species.
- Populations of amphipods disappeared from some areas and were severely depleted in others.
- Several thousand oiled birds washed ashore, with the total number of birds killed likely to be far greater than this. Greatest impact was observed in bird species which spend much of their time on the sea surface - common scoter, diver species, guillemots and razorbills.
- A significant decrease in the population of the rare cushion starfish *Asterina phylactica* in West Angle Bay (SEEC 1998).

In addition, high levels of mortality in certain shoreline species resulted in disturbance of community structure; with temporary increases in other species, such as green algae where limpets had been killed and some species of polychaete worms in sediment shores. Concentrations of oil in bivalve molluscs, such as mussels, remained high for many months.

Subsequent studies looking for further impacts both immediate and longer term concluded that:

- There appeared to have been no impacts on mammals.
- Although tissue concentrations of oil components increased temporarily in some fish species, most fish were only affected to a small degree and very few died.
- Several important populations of seabirds were not significantly affected, and there was no evidence of any effects on seabird breeding success (SEEC 1998).

The main impacts all occurred at the time of the spill or shortly afterwards, and there appear to have been few major longer term effects.

It appears that although a very large amount of oil was spilled in a particularly sensitive area, the impact was far less severe than many expected. This was due to a combination of factors, in particular, the time of the year, the type of oil, weather conditions at the time of the spill, the clean-up response and the natural resilience of many marine species (SEEC 1998).

5.5.4 Relevant data gaps

A number of data gaps were identified by the CEFAS SEA 6 technical report. Several are in fact already addressed by existing data or work in progress. In particular, the near and further field effects of fields in the Liverpool Bay area have been reported by a series of studies by the University of Wales, Bangor (e.g. Rees 1994) and Port Erin Marine Laboratory (e.g. Shalla *et al*. 1997, Holt & Shalla 2002). The potential effects of water-based muds and cuttings on intertidal and shallow water bivalves is the subject of a UKOOA funded PhD studentship.

The last survey to assess the inventory of artificial radionuclides in the Irish Sea was carried out more than a decade ago. The lack of recent data whilst not significant for SEA should be borne in mind by operators in the area.