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Synthesis of Information on the Benthos of Area SEA 6

Final Report
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Contents

1. INTRODUCTION AND SCOPE

In 1999, the Department of Trade and Industry (DTI) initiated the process of Strategic Environmental Assessments (SEA) for the UK prior to the issue of licences allowing oil and gas exploration and exploitation.

The Strategic Environmental Assessment process involves extensive consultation with the public and stakeholders. This document forms part of the consultative process covering SEA area 6 (SEA6). SEA6 includes the UK's territorial waters in the Irish Sea extending from a line drawn between the entrance of Loch Ryan (Stranraer), the Mull of Kintyre and the Northern Irish coast in the north to Milford Haven, Pembrokeshire in the south (Figure 1). England, Scotland, Wales, Northern Ireland and the Isle of Man all border SEA6. This area includes the important industrial estuaries of Morecambe, Liverpool and Mersey, together with a number of minor estuaries, and the major islands of Anglesey and the Isle of Man.

This review aims to provide a synthesis of current information pertaining to benthic communities and seabed habitats in SEA6. This will be done in the context of the hydrography, hydrology and sedimentology of the area. The focus will be on dominant species and broad descriptions of community types (biotopes). However, where appropriate, details of rare or unusual species will be included together with the threat offered by oil and gas related activities. It also reviews existing major human activities in the SEA6 area that are currently affecting the benthos. Finally, it aims to identify knowledge gaps and areas that may deserve special protection with respect to anthropogenic activities specifically related to oil and gas exploitation.

2. OVERVIEW

2.1 Historical Overview and Information Sources

The Irish Sea is one of the best and longest studied marine environments in the UK. Research started in the early nineteenth century and was mainly conducted by dredging, a relatively recent and then fashionable method of sampling the benthos. Also initiated were time-series of simple oceanographic measurements such as temperature and salinity. Scientists were based at institutes such as University of Liverpool's Port Erin Marine Laboratory (established 1892) and the Aberystwyth (established 1872) and Bangor (established 1884) colleges which became the University of Wales in 1893. Other institutions also contributed greatly to research, such as the Belfast Natural History Society established in the mid nineteenth century (Roberts *et al.*, 2004b) and the Liverpool Marine Biological Committee that created a marine station on Puffin Island, off Anglesey, in 1887 (Mills, 1998b). A wealth of postgraduate research has been carried out by these, and other organisations, and over 600 MSc and PhD theses, relevant to the SEA6 area, are known to exist.

Early work, such as Forbes' (1838) catalogue of molluscs, was often descriptive and resulted in species lists and oceanographic data for numerous locations within SEA6. During the early to middle twentieth century further benthic survey work was conducted in the Irish Sea to examine community relationships. The work remained descriptive but attempted to classify the benthos into broad categories (*sensu* Petersen, 1913). During the 1950s, a majority of the research relevant to the SEA6 area concerned specific benthic taxa to the exclusion of more holistic surveys, but with some notable exceptions (e.g.Jones, 1951; Stopford, 1951; Lewis, 1953; Southward, 1953; Connell, 1956). These researchers, and others, became some of the principal ecologists of the time, formulating ecological theory which persists today.

Establishment of the nuclear industry in the region during the 1960s resulted in the commissioning of several baseline surveys of the benthos. This work continued and was complemented by additional work, initiated in the 1980s, by various government agencies including the Nature Conservancy Council (NCC), the Joint Nature Conservation Committee (JNCC), the Countryside Council for Wales (CCW), the Centre for Environment, Fisheries and Aquaculture Science (CEFAS), the Irish Sea Forum and the Review of Marine Nature Conservation. In addition, the work of the Proudman Oceanographic Laboratory has done much to advance hydrographic knowledge of the area. Of particular relevance to this report are the findings of the Irish Sea Forum, the NCC/JNCC commissioned Marine Nature Conservation Review and Review of Marine Nature Conservation and the findings of the Strangford Lough Ecological Change Investigation (SLECI).

The Irish Sea Forum was established in 1992 and had the remit of reporting on the environmental health and sustainable management of the Irish Sea. The Irish Sea Forum publications are an invaluable source of material concerning various human and environmental issues pertaining to the SEA6 area. Funding for the Irish Sea Forum will cease in 2005 and the organisation will be wound up.

The Marine Nature Conservation Review (MNCR) ran between 1987 and 1998 and was commissioned to provide a comprehensive baseline of information on marine habitats and species, to aid coastal zone and sea use management and to contribute to the identification of areas of marine natural heritage importance throughout Great Britain and including the SEA6 area. The focus of MNCR work was on benthic habitats and their associated communities with the main objectives of identifying sites and species of nature conservation importance, extending knowledge of benthic marine habitats and informing policy makers.

The Review of Marine Nature Conservation was established in 1999 and aimed to assess how effectively the UK system of marine nature conservation was working and make proposals for improvements. In 2002, the Irish Sea Pilot project was commissioned to test the potential for an ecosystem approach to managing the marine environment at a regional sea scale. The final report (JNCC, 2004) detailed 64 recommendations, taking advice from 23 separately commissioned studies. Amongst its principal conclusions, it stated that there should be greater co-operation between organisations, publicly and privately funded, engaged in environmental data collection and research to facilitate a national marine information network. Other initiatives have focussed on a more local scale. The Strangford Lough Ecological Change Investigation (Environmental and Heritage Service, Department of Agriculture and Rural Development, Northern Ireland) co-ordinated an investigation of the environmental and ecological status and population trends shown in Strangford Lough with the purpose of identifying drivers of change and appropriate management strategies (Roberts *et al.*, 2004d).

A significant proportion of this report has been derived from the sources referred to above, many of which were included in an externally commissioned literature search, provided to the authors, which identified over 5000 potential data sources published over the period 1814 – 2004 (National Museum of Wales, 2004). This document attempts to provide a synopsis of the historical and current status of the benthos in SEA6, as inferred from the references supplied, in a limited time frame. It cannot, therefore, claim to be a completely comprehensive review of all the existing data, much of which is, in any case, obscure, unpublished and difficult to access within the timescale of this review.

2.2 An Overview of the Physical Environment

The Irish Sea is mostly between 75 and 200 km wide but decreases to 30km in the North Channel (Figure 2). It encompasses a broad range of physical environments including exposed rocky coastlines, marshes, extensive intertidal sandbanks and deep water muds. Within the SEA6 area there are numerous internationally important and recognised marine nature reserves, special areas of conservation (SACs), Ramsar sites (designated under the Convention of Wetlands) and sites of special scientific interest (SSSIs). A brief overview of the physical environment is given below and additional detail is given under each regional subdivision where relevant.

3. HYDROGRAPHY

Hydrography is a major factor in determining, both directly and indirectly, the nature of the biological assemblage and the transport of oil and gas related pollutants. The hydrography of the Irish Sea is well researched (see recent review by Howarth (2005)) and, with documented hydrographic surveys dating back to 1906, the Mersey Estuary is perhaps one of the most intensively studied worldwide (Lane, 2004).

The Irish Sea is subject to prevailing south-westerly winds. In the most simplistic form this prevailing wind drives the water movements in the Irish Sea with a net flow from the south towards the north (Davies and Gerritsen, 1994) and is responsible for spatially and temporally variable tides in the

North channel (Davies and Xing, 2003). The constricted nature of the Irish Sea basin makes it liable to storm surges (Jones and Davies, 2001) resulting in unpredictable currents of high speed. However, this simplistic wind-driven model is complicated by seasonal thermal stratification which occurs during summer.

During the summer, the deep water to the south of the Irish Sea becomes stratified as a consequence of localised heating whereas tides in the shallower Irish Sea maintain a mixed water column preventing stratification. The boundary between these two bodies of water is termed the Irish Sea Front. During the summer water moving northwards under the influence of the prevailing wind is deflected to the south of Ireland by the Coriolis force along the Irish Sea Front. The front is normally formed by April and is dispersed by autumnal storms during October. A similar, smaller, frontal system forms around the deep water to the west of the Isle of Man where summer stratification results in the formation of a small gyre (Horsburgh and Hill, 2003) preventing the mixing of gyre-trapped water with the rest of the well mixed Irish Sea water. This has implications for the transport and genetic isolation of summer reproducing benthic species in this area.

During the winter months, following the break down of summer stratification, the residual current in the Irish Sea is from the south to the north (Irish Sea Study Group, 1990). Superimposed on this tidal system are other influences. For example, the Irish Sea receives Atlantic water influences and inputs through both the North and St. George’s Channel. These inputs form a standing wave to the south-west of the Isle of Man. The hydrography of the Irish Sea, including various regions within it, has been described in detail (Table 1).

Table 1 Summary of source material relating to the hydrography of the Irish Sea

Area	*Reference*
Irish sea summary	(Irish Sea Study Group, 1990); Howarth (2005)
East Irish Sea	Aldridge and Davis (1993)
Morecambe Bay	Aldridge (1997)
Upper Ribble Estuary	Conlan (1987)
Liverpool Bay	Foster (1977) Foster and Hunt (1977)
Mersey Estuary	Lane (2004)
Menai Strait	Ewins (1964)
Cardigan Bay	Lee and Bamster (1981)
Milford Haven	Bagherpour (1978)

3.1 Bathymetry

The Irish Sea consists of two shelves, the east (SEA6; English, Welsh and Scottish) shelf and the Irish Shelf to the west. The two shelves are separated by the Celtic Trough which is up to 70 km wide and is greater than 60 m deep (Figure 1). The trough runs northwards from the Celtic Sea to the Malin Sea through St. George's Channel, the western Irish Sea and the North Channel. The eastern shelf is predominantly flat and featureless (Holt *et al.*, 1990a). The SEA6 area includes the whole of the Irish Sea except an approximate area south of 54°N and west of 5°25'W and the territorial waters around the Isle of Man. A majority of the SEA6 area is <50 m deep (Table 2).

Table 2 Bathymetry in the SEA6 area showing area and proportion of the total area for various depth bands.

Range	Km^2	%	Cumulative %
0 –10 m	2881	7.7	7.7
10 –20 m	4643	12.4	20.0
20 –50 m	15284	40.7	60.8
50 –100 m	11069	29.5	90.2
100 –150 m	3244	8.6	98.9
150 –200 m	338	0.9	99.8
Over 200 m	85	0.2	100.0
Total	37544	100.0	

The southern part of St. George's Channel is generally about 100 m deep with a predominantly smooth seabed exhibiting occasional sand wave fields and local enclosed deeps of >125 m (Holt *et al.*, 1990a). Further north, in St. George's Channel, the water depths decrease and the topography is made more complex by frequent sand wave fields, some of up to 40 m in height, together with more frequent enclosed deeps of between 130 – 180 m depth (Holt *et al.*, 1990a). These localised depressions include the Lune Deep, off Morecambe, Muddy Hollow to the south of the Lleyn Peninsula, and the Manx Basin to the west of the Isle of Man (Holt *et al.*, 1990a).

The North Channel is deeper and the seabed predominantly hard with rocky outcrops and localised enclosed deeps, notably Beaufort's Dyke. This dyke, which lies to the east of the Channel, reaches a maximum depth of 315 m and is the deepest point in the SEA6 area (Figure 1).

The volume of the Irish Sea is approximately 2,430 km^3 (ca. 6% of the North Sea). Eighty percent of this volume lies to the west of the Isle of Man (Dickson, 1987).

3.2 Geology

The SEA6 coastline exposes a great variety of rock types ranging in age from the pre-Cambrian of Anglesey to more recent formations. Volcanic activity has resulted in the formation of ore rich veins which have been historically mined for valuable metals (for example see 4.4.3.3). There are rich fossil deposits around St. David's Head, hence its SSSI status. The range of rock types exposed at the coastline add to the spatial heterogeneity offered by the region and hence epibenthic biodiversity. The carboniferous limestone making up much of the Pembrokeshire coastline promotes the formation of caves which support several rare species. The Irish Sea basins are upper Palaeozoic to Tertiary sedimentary basins with Precambrian to Palaeozoic basement blocks and ridges. During the middle to late Pleistocene, the area was subject to periods of intense glaciation and consequent erosion. Much of the sediment in the Irish Sea is glacial relict and therefore may have a distant origin and not be related to the underlying rock type.

For an overview of the geology of the SEA6 area see Holt *et al.* (1990b) and Holmes and Tappin (2005).

3.3 Sedimentology

There are a variety of sedimentary environments in the SEA6 (Figure 2). These include coarse lag gravels, sand wave fields, sand banks and mud filled depressions. Their distribution is a function of a number of factors including glacial and post-glacial processes, sea level rise and oceanic processes, primarily currents and waves (James and Philpot, 2004; Rees, 2004a).

Gravelly sediments, with glacial or local origins, are common in the Irish Sea and occupy a broad central belt extending southwards from Scotland, past the Isle of Man, to Anglesey. Gravelly sediments also dominate the North Channel, Cardigan Bay and St. George's Channel and in other areas exposed to strong currents (Holt *et al.*, 1990a) which presumably prevent deposition of finer material. Sandy sediments are also common and found in relatively narrow zones both nearshore and offshore. The sand is formed into sandwaves and ripples, including the megaripples which occur to the north of the Isle of Man, Liverpool and Cardigan Bay and St. Georges Channel. Tidal sand banks are also found in the SEA6 region, particularly around the Solway Firth, north of the Isle of Man, Liverpool Bay and south of the Lleyn Peninsula (Holt *et al.*, 1990a). Muddy sediments, of mostly relict origin, mainly occur in the north in two large areas separated by the central belt of gravels. The main muddy area lies to the west of the Isle of Man and is a deep area of relatively low current speed. This is also an area associated with higher sedimentary pigment concentrations and respiration than coarser sediments to the east, indicative either of higher primary productivity in overlying waters or that the western Irish Sea acts as a sink for productivity transported from other surface water sources (Trimmer *et al.*, 2003).

Within the SEA6 area there are several zones where the sediment carried in the current separates into two directions. These are known as areas of bedload parting. These include a zone extending westwards from the Lleyn Peninsula with sand being transported northwards or south-eastwards into Liverpool Bay from this zone. Less significant is the bedload parting zone that extends approximately south-west from the tip of the Lleyn Peninsula, to St. David's Head, and which demarks the transport of sand southward from that heading north-east into Cardigan Bay.

A useful concept for division of the seabed is that of 'marine landscapes', defined during the Irish Sea Pilot project (Golding *et al.*, 2004). Seabed areas are classified using geophysical, hydrographical and ecological data and thus have greater meaning in terms of policy definition, conservation and management of human resource exploitation. The areas and relative area of the various marine landscapes found in the SEA6 area are shown in Table 3.

Table 3 Summary of marine landscapes of the Irish Sea sorted in descending order (modified from Table 3.5, Golding (2004)).

Marine Landscape	Area (hectares)	Area (percentage)
Low bed stress coarse sediment plain	15,186	25.1
Fine sediment plain	13,218	21.9
High bed stress coarse sediment plain	11,760	19.4
Sediment wave/megaripple field	6,630	11.0
Deep water mud basin	5,024	8.3
Coastal sediment	3,606	6.0
Aphotic reef	1,237	2.0
Estuary	939	1.6
Shallow water mud basin	980	1.6
Sea loch	600	1.0
Sand/ gravel banks	540	0.9
Photic reef	278	0.5
Deep water channel	234	0.4
Ria	49	0.1
Sound	69	0.1
Gas structures	58	0.1
(Irish) Sea Mounds	74	0.1
Saline lagoon	8	<0.1

3.4 Biogeographical Divisions

In broad terms the Irish Sea can be considered a single body of water therefore splitting the area into biogeographical regions is a relatively arbitrary process.

Surveys of the Irish Sea benthos are numerous, with agencies such as Nature Conservancy Council, Joint Nature Conservation Committee (JNCC) and regional (Irish and Welsh) agencies all having commissioning quite detailed reports and assessments of the benthos. This review will, broadly speaking, replicate the MNCR biogeographical divisions. The order of those regions reported here is from Mull of Galloway to the Solway Firth, southwards down the east coast of the Irish Sea, followed by a description of the Isle of Man and the Northern Irish coast.

3.5 Sampling and Describing the Benthos

There are numerous methods by which the benthos can be sampled. Each method has advantages and disadvantages and is selected after consideration of the objectives of the sampling programme. Most surveys are a compromise between scope, scale, resolution, accuracy, cost and objective. In this overview it is worth mentioning the alternative scales at which the surveys reviewed have been conducted.

The approaches used in the surveys reviewed here range from broad scale surveys, covering complete bays or loughs to very detailed surveys of single features such as a beach or marine cave.

Traditionally, benthic communities have been sampled remotely with the use of trawls, grabs and cores. More recently, broad scale surveys are frequently conducted using acoustic techniques. These can be used to generate acoustic maps of the seabed. However, in order to relate the acoustic signal of the seabed to the benthos, ground truthing needs to be conducted. This often takes the form of either video and/or photographic work or sample collection. Video and still photography allow a holistic and intuitive view of the benthos but are limited by resolution, whereas seabed sampling has the advantage that individuals are collected in a quantifiable manner and can be identified and enumerated at leisure in the laboratory.

Some of the information reviewed here has been gathered by professional diving ecologists. Diving surveys have the advantages that they are not limited by substratum hardness (compared with remotely operated grabs) and that a holistic feel for the environment can be achieved. Still and video photographs taken by divers are an excellent method of surveying in some situations. However, diver surveys are inherently subjective and suffer from the vagaries of weather, water turbidity, diver ability and condition. Divers cannot survey very small organisms and exhibit a bias towards large, striking epifauna. In addition, divers cannot stay underwater for long periods and are depth limited reducing the scope of some surveys.

The results from benthic surveys can be expressed in a number of ways depending on the survey method. Where broad scale acoustic methods are used, with ground truthing, the benthos is generally split into broad categories where each category indicates the likely presence of one or more species. This system of classification works well as a consequence of the often close correlation between biological community and the physical variables sediment type and current exposure. This type of categorisation closely resembles the classification of the benthos by Peterson (1913). The results from intensive, single feature, surveys are usually expressed as a simple species list. The inter-relationships between species lists from different sites can then be investigated using complex multivariate statistical techniques.

4. INSHORE AREAS – LITTORAL AND SHALLOW SUBLITTORAL

The inshore areas of the Irish Sea, including littoral areas, form the largest area within SEA6 (60% is less than 50 m deep; Table 2) and represent the greatest environmental gradients and associated high biodiversity and sensitivity.

For the purposes of this report each geographical division will be discussed in terms of the benthos associated with the littoral (intertidal) and sublittoral zones. Aspects or conservation importance are mentioned but the current report is not intented to be comprehensive and for a full review see Moore (2005).

4.1 Solway Firth to Liverpool Bay

This region, which equates to Marine Nature Conservation Review Sector 11, extends from the Mull of Galloway in the north, through Luce Bay, Wigtown Bay, the Solway Firth, Morecambe Bay and the industrialised Mersey estuary, to Colwyn Bay in the south. The region encompasses a range of habitats but is predominantly sedimentary in nature and includes some of the UK's most extensive sand/mud flats. For the purposes of this report the area will be split into the major geographical features of the Solway Firth, Morecambe Bay and Liverpool Bay. Notes on areas of particular interest that lie between these sub-regions will be made where appropriate. Survey work relevant to the Sellafield nuclear reprocessing facility is also included.

4.1.1 Solway Firth

The Solway Firth is a triangular-shaped firth facing south-west into the Irish Sea. The inner part of the Firth is predominantly sedimentary in nature, with large expanses of mobile sediments (Figure 3) and constantly migrating river channels originating from two rivers (Esk and Eden) that enter at the head, via a series of internationally recognised (Ramsar designated) salt marshes. Within the inner Firth hard substratum is limited to a few areas of glacially derived boulders in the south and rocky shores fringing the sediment flats to the west of Southerness Point (Covey and Emblow, 1992). The tidal range for the area is 6 – 7 m and there are extensive intertidal regions that are commonly greater than 500 m in width.

The coastline of the middle and upper Firth is largely linear with few interruptions from rivers. Towards the outer Firth the north shore becomes increasingly rocky, the boundary between predominantly rocky and sedimentary shores being Auchencairn Bay (Covey and Emblow, 1992).

4.1.1.1 Solway Firth: Littoral Zone

The inner Solway Firth is an area of predominantly sedimentary substrata typified by large expanses of mobile sediments and migrating river channels, particularly in the inner estuary. Further from riverine influence the shoreline becomes increasingly rocky.

Within the Solway Firth area seven soft substrata and their associated biological communities have been described (see table 5, Covey and Emblow, 1992), the nature of which is primarily determined by exposure, riverine sediment supply and salinity. At the head of the firth the sediment is primarily fine and consists of muds and silts with varying degrees of fine sand. The major communities found in these areas are typified by the shrimp *Corophium* sp.*,* the gastropod *Hydrobia* sp. and bivalve *Macoma* sp. Where exposure to reduced salinity occurs, for example bordering salt marshes, the community is dominated by the polychaetes *Pygospio elegans, Hediste diversicolor* and unspecified nematodes. The bivalve *Scrobicularia plana* is associated with an increase in the proportion of fine sand in the sediment (Covey and Emblow, 1992). The transition zone between the muds of sheltered bays and the open coast fine sands supports the polychaetes *Nephtys* spp., *Scoloplos armiger* and *Arenicola marina* in addition to the amphipod *Bathyporiea pelagica* (Covey and Emblow, 1992). On the open coasts, fine sands dominate the substratum and support a diverse range of species with polychaetes, amphipods, echinoderms and mollusc all well represented. The lower shore of Luce Bay was particularly diverse and contained the echinoderm *Echinocardium cordatum*, and the molluscs *Donax vittatus*, *Fabulina fabula* and *Chamelea gallina*. Polychaetes found here included *Nephtys cirrosa, Arenicola marina,* and *Lanice conchilega* together with the amphipod *Bathyporeia pelagica* (Covey and Emblow, 1992). In contrast, the sedimentary upper littoral zone, which dries between tides, was virtually barren with only three unspecified species recorded (Covey and Emblow, 1992).

Sedimentary shores containing cobbles and boulders intermixed with finer material hosted the edible mussel *Mytilus edulis* and associated polychaetes such as *Arenicola marina* and *Lanice conchilega*. Where an increase in fine material occurred, mixed sediment shores hosted species that are typical of both sedimentary and hard substratum shores (Covey and Emblow, 1992).

Hard substrata within the Solway Firth hosted a range of species that were primarily dependent on exposure and height on the shore. The supralittoral fringe hosted lichens such as *Xanthoria parietina* (Covey and Emblow, 1992) whilst the upper littoral zone supported the algae *Pelvetia canaliculata* and *Fucus spiralis* and the gastropods *Littorina saxatilis* and *L. littorea* (Covey and Emblow, 1992).

Lower eulittoral bedrock was characterised by typical *Fucus*-barnacle and dogwhelk (*Nucella lapillus*) communities. Also present were the barnacles *Balanus balanoides* and limpets typical of the North East Atlantic. Numerous epifaunal plant and animal species typical of rocky shores were found along the Solway firth including species such as the algae *Corallina officinalis, Chondrus crispus, Ceramium rubrum, Ascophyllum nodosum* and *Fucus serratus* and the barnacles *Balanus balanoides* and *B. crenatus* (see page 28 of Covey and Emblow, 1992). Further details of epifaunal algal communities found in the Solway Firth can be found in Burrows (1960).

4.1.1.2 Solway Firth: Sublittoral Zone

According to Mackie (1990) the sublittoral zone of the Solway Firth is dominated by the shallow *Venus* community. In this community the bivalve *Fabulina* (syn *Tellina*) *fabula*, the polychaete *Magelona mirabilis* are typically found in the less disturbed areas whilst in those areas subject to higher levels of disturbance, and where coarser material is present, the *Spisula* sub-community dominates. This community consists of the bivalve *Spisula elliptica* and the polychaete *Nephtys cirrosa*. Sediment off Kirkudbright Bay, at the mouth of the Solway Firth, consists of a muddy gravel and typically supports a rich epi- and infaunal community, members of which include the bivalve *Abra alba*, the tubeworm *Lagis koreni* and the echinoderms *Ophiura albida* and *Echinocardium cordatum* (Covey, 1998).

During benthic surveys , Ellis and Rogers (2000) identified *Astropecten irregularis, Asteris rubens, Ophiura ophiura, O. albida, Psammechinus miliaris, Echinocardium cordatum* and *Spatangus purpureus* from the outer Solway Firth.

4.1.1.3 Solway Firth: General Comments

The Solway Firth supports a commercial fishery for the brown shrimp *Crangon crangon* (Lancaster and Frid, 2002) and thornback ray *Raja batis* and an extensive fishery for cockles (Hall and Harding, 1998). On the north shore (Scottish coast) stake nets have been used to catch salmon (Covey and Emblow, 1992). In addition there is a limited, opportunistic shellfish fishery, occurring at low tide where crabs and lobsters are taken. The north coast of the Solway Firth is also a popular holiday destination (Covey and Emblow, 1992).

The water quality in the Solway Firth is generally considered to be good, the Esk and Eden’s catchment areas being predominantly rural. Of geomorphological interest are the stepped saltmarshes found at the head of the Solway Firth. These are formed through the combined influence of creek migration and uplift and are unique within the UK (Holt *et al.*, 1990b).

4.1.2 Sellafield

The Sellafield nuclear reprocessing facility lies 15 km to the south-west of St. Bee’s Head on the relatively unpopulated Cumbrian coast. The contentious nature of the facility and its potential impacts means that additional benthic survey work has been conducted in this area.

4.1.2.1 Sellafield: Littoral and Sublittoral Zone

Whilst there are radiation monitoring studies from the littoral zone, including from various biota (Kershaw *et al.*, 1992), there are a paucity of data relating to species occurrences and distributions along this coast.

The sediments off Sellafield are predominantly mud mixed with various proportions of sand and gravel (Swift, 1993; Hughes and Atkinson, 1997). The fate and behaviour of the radionuclides released by the nuclear reprocessing facility into this environment muddy area there has been the subject of much research (see 5.2.2).

From an extensive survey of sublittoral benthic fauna around Sellafield (Swift, 1993) identified 40 taxa and several distinct assemblages associated with differences in substratum type. For each species a bioturbatory activity index was assigned in order to evaluate the potential for the redistribution of surface radiological contamination. This research was taken forward during a survey targeting bioturbating megabenthic species. The following species were identified: the burrowing shrimp *Callianassa subterranea*, the echinuran worm *Maxmuelleria lankesteri,* the crab *Goneplax rhomboides*, the Norway lobster *Nephrops norvegicus* and several other burrowing shrimp species (Hughes and Atkinson, 1997). These species, capable of significant bioturbation, are likely to be found in other areas within SEA6 where similar sediments occur.

Ellis and Rogers (2000) identified *Astropecten irregularis, Asteris rubens, Ophiura ophiura, O. albida, Psammechinus miliaris* and *Echinocardium cordatum* from the Cumbrian coast south of St Bees Head.

4.1.3 Morecambe Bay

Morecambe Bay is a broad irregularly-shaped bay that faces south-west into the Irish Sea. It has an overall area of 45,462 hectares. Morecambe Bay is the outlet for the Wyre, Lune, Keer, Kent and Leven rivers whose estuaries combine to form an extensive bay of shallow coastal sediments (Sotheran and Walton, 1997). The Bay consists of a flat system of interlocking tidal pools and channels, the substratum is predominantly sands and muds

4.1.3.1 Morecambe Bay: Littoral Zone

The predominantly sedimentary littoral zone surrounding Morecambe Bay is the largest in the UK extending to approximately 34,000 hectares (Figure 4). This occurs as a consequence of the large tidal range (>10 m) (Rostron, 1992) in the area and the gently sloping local topography. Sand dunes are common at the tops of many beaches in the area. In the upper reaches of Morecambe Bay itself there are extensive salt marshes (Adam, 2000) and this, together with the abundant benthic infauna found in the intertidal zone, provide an important haven for wading birds.

The coarse, well drained sands at the top of the shores support only an impoverished fauna. This includes amphipods and the isopod *Eurydoce pulchra*. Further down the shore where the sediments tend to be finer, benthic communities are characterised by *Arenicola marina* in addition to burrowing amphipods and other polychaetes (Covey, 1998). As sediment conditions become increasingly stable they were successively colonised by the bivalve molluscs *Donax vittatus*, *Angulus tenuis* and *Mactra stultorum*. Polychaete and cockle (*Cerastoderma edule*) communities dominate much of the central intertidal area of Morecambe Bay and form the basis of an extensive fishery (Covey, 1998).

Areas subjected to reduced salinity are characterised by the polychaete *Hediste diversicolor* and the bivalve *Macoma balthica* (or *Scrobicularia plana* in areas of finer sediment). In low salinity areas where mud accumulates, the shrimp *Corophium voluator* dominates (Covey, 1998).

Areas of intertidal hard substratum are very limited in the Morecambe Bay area. Where found, for example around Chapel Island, Humphrey Head and Heysham, they are characterised by a typical zonation with yellow and grey lichens at the top of the shore, progressing through the upper shore algae such as *Pelvetia canaliculata* through *Fucus spiralis*. The community below this zone is controlled by exposure with exposed locations being characterised by barnacles and limpets whilst more sheltered areas support *Fucus vesiculosus* and *Ascophyllum nodosum* (Covey, 1998).

Mixed substrata are more common than solid bedrock and support a diverse range of benthic organisms. Among these are the commercially harvested mussel *Mytilus edulis* and locally rare (though unspecified) communities of sponges and ascidians (Covey, 1998).

4.1.3.2 Morecambe Bay: Sublittoral Zone

The Morecambe Bay area is predominantly shallow and dominated by areas of uniformly sparse faunal turf, particularly towards the western side of the Bay. Scoured sands prevent the formation of stable communities but support epifaunal organisms such as crabs *Liocarcinus depurator*, *Carcinus maenas* and *Pagurus bernhardus* and the common starfish *Asteris rubens*. Typical zonation occurs, where the amphipod *Bathyporeia pelagica* and polychaetes *Magelona mirabilis* and *Nephtys* spp. become increasingly common towards deeper water (Covey, 1998). Deeper sediments host a rich community dominated by the brittlestar *Amphiura filiformis* and bivalves *Abra alba, Nucula nitida* and *Corbula gibba* (Covey, 1998).

Deeper water (up to 40 m) is found in the area in the form of a glacial ‘kettle-hole’, called the Lune Deep, off Morecambe (Emblow, 1992). The Lune Deep is currently used as a spoil dumping ground, the bottom of which is muddy and supports the bristle worm *Lagis koreni* and bivalve *Mysella bidentata* indicating a relatively unstable community (Boyd, 1999). The sides of this kettlehole are steep with a substratum consisting of boulders and cobbles supporting dense hydroid and bryozoan turf communities (Emblow, 1992). Encrusting growth occurring on the coarse substratum of Lune Deep include the hydroid *Nemertesia antennina*, the bryozoan *Flustra foliacea* and the erect sponge *Haliclona oculata*.

The echinoderms *Astropecten irregularis, Asteris rubens, Ophiura ophiura* and *Ophiothrix fragilis* have been recorded in the Morecambe Bay area (Ellis and Rogers, 2000).

4.1.3.3 Morecambe Bay: General Comments

The Morecambe Bay catchment area predominantly agricultural although there are population centres around Barrow, Morecambe and Fleetwood. Several rivers run into Morecambe Bay including the Leven, Kent, Lune and Wyre. Water quality in the bay is generally good (Covey, 1998) although several (possibly ubiquitous) contaminants including polychlorinated dibenzo-para-dioxins, polychlorinated dibenzofurans, polyaromatic hydrocarbons (PAH), tributyl tin (TBT), dieldrin, gamma-hexachlorocyclohexane (gamma-HCH), and polychlorinated biphenyls (PCB) have been found in Morecambe Bay sediments (Tyler *et al.*, 1994; Widdows *et al.*, 2002).

The Morecambe Bay area hosts several important fisheries, most notably for cockles and mussels, and some bioaccumulation of pollutants by these filter feeders is possible. Also fished are the brown shrimp *Crangon crangon*, trout, salmon and flatfish (Covey, 1998). Species of particular note found in the area include the rare worm *Ophelia bicornis* that has been reported from the Ribble estuary, south of Morecambe Bay (Barne *et al.*, 1996).

4.1.4 Liverpool Bay

Liverpool Bay is a broad, approximately triangular bay that faces west into the Irish Sea (Figure 5) with the Mersey and Dee Estuaries at the south-eastern point. The river catchment area is highly industrialised and urbanised and much of the foreshore has been modified.

4.1.4.1 Liverpool Bay: Littoral Zone

Much of the Mersey estuary and foreshore is restrained by concrete banks and surrounding by industrial and urban developments. As a consequence there is a paucity of natural coastal/shore habitat and little literature concerning the benthos in this region. Sand dunes are present to the north of the estuary mouth. Upstream of Liverpool there are extensive mud shores supporting ragworm *Hediste diversicolor* and oligochaete communities (Covey, 1998) typical of low salinity muds.

The shoreline of the Dee estuary on the English, northern side is predominantly residential, in contrast to the highly industrialized nature of the southern, Welsh shore line. The estuary contains extensive sand and mudflats and salt marshes and provides feeding and roosting ground for several species of wader and duck (JNCC, 2005a).

4.1.4.2 Liverpool Bay: Sublittoral Zone

The seabed around Liverpool Bay consists of a range of sediment types. In the outer part of Liverpool Bay there are extensive areas of mixed gravely sand containing some fine material (Rees, 2004a).

During the 1970s a complex mosaic of community types, related to sediment type, were found in Liverpool Bay. Towards the north and west a relatively rich fauna was described whereas in the south the substratum was dominated by relatively sparsely faunated, current swept sand. Eagle (1973, 1975), working in the southeast of Liverpool Bay, identified two primary habitat types, one of muddy sand and the other of clean sand. *Pectinaria koreni*, *Lanice conchilega* and *Abra alba* were numerically dominant across the area but differed between habitats in terms of their ratios. In muddier areas, differences in species richness and diversity were attributed to destabilisation of sediments, through bioturbatory activity, which were then subject to erosion by currents. More recently, benthic infauna has been described as highly variable exhibiting long term shifts in abundance (Rees and Walker, 1984; Rees *et al.*, 1994). Mackie (1990) reported the community to be a shallow *Venus* community. In this community the bivalve *Fabulina* (syn. *Tellina*) *fabula*, the polychaete *Magelona mirabilis* are typically found in the less disturbed areas. In those areas subject to higher levels of disturbance, and where coarser material is present, the bivalve *Spisula elliptica* and the polychaete *Nephtys cirrosa* tend to dominate.

Epibenthic megafaunal surveys are scarce although Ellis and Rogers (2000) identified *Astropecten irregularis* and large populations of *Asteris rubens* and *Ophiura ophiura* from the Liverpool Bay area. *Crangon* sp., *Liocarcinus depurator* and *L. holsatus* have also been recorded in the area, together with the Thumbnail crab *Thia scutellata* (Wilson 2005).

4.1.4.3 Liverpool Bay: General Comments

The urbanisation and industrialisation of much of the catchment area of the Mersey and the presence of a large container port in the area has resulted in Liverpool Bay becoming moderately contaminated with substances such as mercury (Langston, 1986), polyaromatic hydrocarbons, tributyl tin, dieldrin, gamma-HCH, and polychlorinated biphenyls (Widdows *et al.*, 2002). Many of the pollutants transported by the Mersey settle in the immediate vicinity of the estuary but are transported to deeper water off Liverpool during dredging operations (see 5.2.3). The benthic impacts of such dumping were monitored over the period 1970 – 1984 and may provide valuable time-series data for the region (Rees and Walker, 1984).

Boyd *et al* (2000) monitored the dump site in Liverpool Bay using the nematodes from the *Sabatieria pulchra* group and *Daptonema tenuispiculum*. They concluded that nematodes were a useful method for the monitoring of spoil dumping in Liverpool Bay. This followed work in Liverpool Bay demonstrating that sediment collection technique influences the apparent nematode community (Somerfield and Clarke, 1995) and that meiofaunal community structure was influenced by dredging activity and sediment metal concentrations (Somerfield *et al.*, 1995). For a review of the biological communties and status specifically of the Dee Estuary see Buxton(1977) and the PhD thesis of Al-Masnad (1991).

4.1.5 Colwyn Bay

Colwyn Bay is a shallow bay on the north coast of Wales that faces north into the Irish Sea (Figure 6). The North Welsh coast is a popular tourist destination and much of the coastal hinterland is developed. Consequently, much of the upper shore is modified in order to protect settlements from the sea including the use of groynes.

4.1.5.1 Colwyn Bay: Littoral Zone

The littoral environment of Colwyn Bay is characterised by mobile, well drained, fine sands that support sparse amphipod and isopod communities. Hard substrata are rare in this region but, where present, consist of sand scoured boulders supporting a few barnacles, mussels and the algae *Enteromorpha* sp. (Covey, 1998). Sediment adjacent to hard areas supports large population of the sand mason *Lanice conchilega*. In muddier areas the ragworm *Hediste diversicolor* has been recorded.

4.1.5.2 Colwyn Bay: Sublittoral Zone

The predominantly sandy littoral zone continues into the sublittoral with small patches of muddy sand towards the west side of the bay (Covey, 1998). Shallow sublittoral sediments are likely to be highly mobile and support sparse populations of amphipods and isopods. Richer communities are found further offshore with characteristic communities consisting of polychaetes, amphipods, isopods and bivalves (Covey, 1998).

Notable species present in this region include the opportunistic polychaete *Lagis koreni*, the large bivalve *Mya truncata* and the starfish *Asteris rubens* predating the bivalves *Spisula subtruncata*, *Abra alba* and *Nucula* sp. Also present are the echinoderms *Astropecten irregularis* and ‘sea potato’ *Echinocardium cordatum* (Rees, 2004b). This area also forms an important spawning ground for the commercial fish species sole (*Solea solea*) and plaice (*Pleuronectes platessa*) (Rostron, 1992a).

During benthic surveys, Ellis and Rogers (2000) identified *Astropecten irregularis, Asteris rubens* and *Ophiura ophiura* off Colwyn Bay, in addition to the largest population density (ca 9 kg/hr of trawling) of the burrowing purple heart urchin *Spatangus purpureus* found in the Irish Sea. Large burrowing urchins have a significant role in sediment bioturbation and may play a significant role in both structuring benthic communities and maintaining biodiversity (Widdicombe and Austen, 1998).

4.2 North Wales to Cardigan Bay

This region, which equates to Marine Nature Conservation Review Sector 10, extends from Rhos-on-Sea, Conwy, in the north to Newport, Pembrokeshire in the south (Figure 6). It includes the major topographical features of Anglesey, Caernarfon Bay, the Lleyn Peninsula and Tremadog and Cardigan Bays. The prevailing northerly residual current of the Irish Sea is diverted by the Lleyn Peninsula and forms a back-eddy in Cardigan Bay (Lee and Ramster, 1981).

This region includes a wide range of benthic biotypes ranging between the extensive littoral and sublittoral coarse glacial deposits in Cardigan Bay, the rocky promontories on the Lleyn Peninsula, the coarse substrata and tidal races of the Menai Strait and the finer sediments to the east of Anglesey. The region hosts several candidate Special Areas of Conservation (cSAC), proposed under the 1992 Habitats and Species Directive. In addition, Moore (2002) prepared a comprehensive list of species, potentially under threat, for the Welsh coast and off shore areas and identified 76 species, species groups and habitats.

4.2.1 Anglesey and the Menai Strait

The south-west coast of Anglesey contains sandy estuaries, salt marshes and sand dune systems. The north and west coasts of Anglesey are rocky, particularly around Holyhead where the shore is backed by high cliffs. On the north coast, Cemlyn lagoon, a saline coastal lagoon with a relatively diverse fauna and flora, some of which are specific to this habitat, is considered to be one of the finest examples in Wales (Bamber, 2004). Further east, along the north coast of Wales, the littoral zone is mostly sandy. Anglesey is separated from the Welsh mainland by the Menai Strait which are narrow and exposed to very strong tidal currents and which support 23 different biotopes (Moore, 2004). The Menai Strait was a candidate Marine Nature Reserve on the basis of basis of its high biodiversity, particularly around the Black Rocks and Church Island locations (Olive, 1987).

There is a large industry cultivating (on growing) mussels, which have been collected from Morecambe Bay, on the intertidal sand flats of Traeth Lafan in the Menai Strait. This activity is considered beneficial to the dense populations of wading birds that use the area possibly owing to increased abundances of certain polychaetes or changes in activity patterns making prey species more available. However, some polychaete species (cirrarulids, *Polydora* sp., *Nephtys* sp., *Notomastus* sp.) and *Corophium* spp. declined or disappeared (Caldow *et al.*, 2003).

4.2.1.1 Anglesey and the Menai Strait: Littoral Zone

The rocky shores of the Menai Strait are characterised by dense beds of the brown seaweed *Fucus serratus* with a rich and diverse sub-boulder community (Moore, 2004). In the Menai Straight, King ragworms *Nereis* *virens* are collected extensively for use as fishing baits. Mud flats in the area are populated by the King ragworm, *Nereis virens,* and these are extensively collected for use as fishing bait. They have been highlighted as unusual amongst British populations because of the particularly large size of individuals, a fact making them perhaps more susceptible to over exploitation (Olive, 1987).

To the south of the Menai Strait beaches such as those around Traeth Melynog are relatively sheltered and sandy. They contain a typical fauna including cockles *Cerastoderma edule*, amphipods *Bathyporeia pilosa* and *Corophium arenarium* and the polychaete *Scoloplos armiger* (Rees and Walker, 1976). Also of note are beds of dwarf eelgrass, *Zostera noltei* (JNCC, 2005b). *Oliver et al.* (1986) also produced detailed mollusc and polychaete species lists for several intertidal sites in the Straits.

4.2.1.2 Anglesey and the Menai Strait: Sublittoral Zone

Anglesey is a relatively current swept island and, consequently, the nearshore environment is coarse sedimentary or bedrock. This makes grab sampling difficult and may explain the paucity of infaunal studies in this region. Conversely, epifaunal studies are relatively comprehensive as considerable survey work has been conducted.

Hiscock (1976) split the characteristic epibiota into four groups corresponding to north, south, east and west of the Island and assigned these differences to differences in water quality (suspended material) and exposure. West coast epibiota was characterised by dense coverings of bryozoans, polyclinid tunicates, the hydroid *Nemertesia antennina*, the crinoid *Antedon bifida*, dead man's fingers *Alcyonium digitatum* and the sponge *Cliona celata*. On the north coast of Anglesey, *Antedon bifida* and the brittlestar *Ophiothrix fragilis* have been observed in dense beds associated with the sponges *Polymastia* spp. and *Suberites carnosus* whilst the east side supports high densities of the soft coral *Alcyonium digitatum* and anemone *Metridium senile*. In addition, *Modiolus* beds have been reported off the north west coast of Anglesey, with small clumps occurring on the sea bed between here and the Isle of Man (Holt *et al.*, 1998). *Thia scutellata*, the thumbnail crab is also know from this area (Wilson, 2005).

In 2004 fifteen sites off the north-west coast of Anglesey were surveyed as part of the Biodiversity Action Plan on the basis of the presence of 'Tidal Rapids'. A total of 12 biotopes were identified during this survey (Moore, 2004). The environment supports dense foliose algal carpets of *Phycodrys rubens, Cryptopleura ramose, Membranoptera alata* and *Plocamium cartilagineum*, the barnacle *Balanus crenatus*, the bryozoan *Flustra foliacea* and the hydroid *Serularia argentea*. Other communities were found on circalittoral rock consisting of low encrusting sponges, hydroids, anemones, bryozoans and ascidians. For a species list see Moore (2004).

Anglesey is separated from mainland Wales by the Menai Strait, a proposed Marine Nature Reserve (1998), which is a narrow channel that experiences rapid tidal flows. The Menai Strait has been surveyed as part of the Biodiversity Action Plan when 31 sites were examined. The central part of the channel, locally known as the 'Swellies', experiences the highest current flows and is characterised by the sponges *Halichondria panicea* and *Esperiospsis fucorum* with the anemone *Sagartia elegans* and hydroid *Tubularia indivisa*. Dense coverings of the brown seaweed *Laminaria digitata* covered the infralittoral fringe (Moore, 2004). Of conservation importance within the Anglesey and Menai region is the burrowing anemone *Edwardsia timida* which was found off Plas Newydd on a tide swept mixed substratum (Moore, 2004).

During surveys around the narrow stretch of water separating Holy Island from Anglesey (Four Mile Bridge) a variety of infra- and sublittoral habitats were found supporting a particularly diverse range of algal species including *Laminaria hyperborea*, *Griffithsia corallinoides* and filamentous brown algae. In addition, dense beds of the green crenella mollusc *Musculus discors* have been recorded around Holy Island and also north of the Lleyn Pennisula (Brazier *et al.*, 1999). Rare species found at this site include the ascidian *Pycnoclavella aurilucens* and red alga *Gracilaria bursa-pastoris* (Moore, 2004).

The seabed in the north-east section of the Menai Strait is subject to weaker currents and is predominantly muddy shingle and gravel. Characteristic fauna at this site were the anemones *Sagartia troglodytes* and *Cerianthus lloydii*, the hydroids *Nemertesia* spp. and *Hydrallmania falcata* with encrusting sponges. To the west of the Straight the substratum is predominantly sandy with correspondingly less conspicuous fauna. Detailed epifauna species lists for the Menai Strait are available (see references in Hiscock, 1998; Moore, 2004).

Analysis of video footage along a transect running approximately 100 km NW from the north coast of Anglesey has indicated that the sediment consists predominantly current swept sand and gravel with shell fragments with some scoured rock outcrops with depths ranging between 35 and 70 m. Epifauna in this rather harsh, scoured environment is scarce and consists of the urchins *Echinus esculentus, E. elegans* and the scallop *Aequipecten* sp. On exposed rock, particularly closer to Anglesey, the anemone *Urticina* sp. was observed together with the hydroid *Nemertesia antennina* but was otherwise barren of visible fauna. During the same survey a site approximately 20 km west of the Menai Strait, in Caernarfon Bay, was also surveyed. This location was characterised by a finer sediment (muddy sand) and the bivalves *Abra alba, Fabulina fibula* and *Arctica islandica*. Other epifaunal species included the brittlestar *Ophiura ophiura* and hermit crabs. Whilst video footage of the site indicated that burrowing megafauna were common identification was largely impossible (Golding *et al.*, 2004). During benthic surveys targeting echinoderms Ellis and Rogers (2000) identified *Astropecten irregularis, Asteris rubens, Ophiura ophiura, Psammechinus miliaris* from around Anglesey. The south-west entrance to the Menai Strait was also reported to contain the highest number of sea cucumbers (Holothuroidea) in the Irish Sea (Ellis and Rogers, 2000) while to the east of Anglesey, during the BIOMÔR 1 survey, three solenogastres species (simple molluscs) have recently been observed for the first time in UK waters (Caudwell *et al.*, 1995).

Red Wharf Bay lies on the east side of Anglesey and forms part of a Special Area of Conservation on the basis of its shallow coarse sediments that are covered by water at all states of the tide. However, ecologically the most interesting and sensitive sediments are areas of partly sheltered muddy sand, which form part of the large shallow bay. Depositional gradients between tide swept areas and less exposed parts of the bays cause the advection and selective settlement of organic matter in the muddy sand patches. This causes localised enrichment of the benthos that can cause near-bed hypoxia and mass mortality of the benthos following intense phytoplankton blooms. Compared to other bays in the region Red Wharf is bivalve rich, of particular note in recent years being large populations of razor shells *Pharus legumen*. There is also an area with a substantial population of bivalves *Mya truncata*. Rare species present include the thumbnail crab *Thia scutellata* which is frequently recorded. A full description of Red Wharf bay and its associated biota is provided by Moore (1983) and Rees (2004b).

4.2.2 Lleyn Peninsula and Cardigan Bay

The Lleyn Peninsula is a relatively remote region of Wales with much of the coastline being sparsely inhabited. Approximately 4 km from the western tip of the Lleyn Peninsula is the island of Bardsey. The region is relatively exposed and much of the coastline, particularly on the north side of the Lleyn Peninsula, consists of rocky headlands separated by sandy bays. The south coast of the Lleyn Peninsula, which forms the northern boundary of Tremadog Bay (Figure 6), is rocky from the peninsula's tip to Hell's Mouth and is then predominantly of sand and shingle. Tremadog Bay forms the northern part of Cardigan Bay (and is subsumed under the name) and faces south-west into the Irish Sea. Tremadog Bay is bordered to the east by the sparsely populated coast of Gwyned. At its head is an estuary on which the small town of Porthmadog lies.

Cardigan Bay is a broad curved bay that extends from Cardigan in the south to the tip of the Lleyn Peninsula in the north. The bay faces predominantly west into the Irish Sea. Within Cardigan Bay there are three principle estuaries. These are the Dyfi, Barmouth and the Glaslyn/Dwyryd systems. The shores of Cardigan Bay, north of the Dyfi Estuary, are predominantly sandy, many of which are backed by sand dunes. South of the Dyfi the coastline is predominantly boulder strewn and backs onto cliffs. Whilst exposed to westerly winds offshore reefs, termed 'sarns' (described below), reduce the wave energy reaching the shore.

Cardigan Bay is largely unpopulated and most of it backs onto countryside. The largest population centre in the region is Aberystwyth which lies approximately in the centre of the bay.

4.2.2.1 Lleyn Peninsula and Cardigan Bay: Littoral Zone

Whilst the intertidal ecology of the Lleyn Peninsula has been extensively studied much of the information remains unpublished (Hiscock, 1998). The Lleyn Peninsula has been considered a boundary for many species at the limits of their northern distribution (Crisp and Knight-Jones, 1955), this may be as a consequence of the back-eddy formed by the intersection of the Peninsula and the prevailing northward flowing current. The island of Bardsey, a Marine Nature Reserve and SSSI, is an important breeding area for many seabirds, notably the Manx Shearwater.

The Bardsey Island Charitable Trust oversees the island. The littoral environment is predominantly exposed and with typical wave/tide exposed biological communities (Rostron, 1984). A large cave on near by St Tudwal's Island is also quoted as having a high conservation interest with a diverse range of sponges, hydroids and bryozoans competing for space with barnacles (Rostron, 1984).

Hiscock (1998) describes four beach assemblages, on the Lleyn Peninsula, largely determined by the degree of exposure. These four groups include very unstable beaches supporting sparse isopod *Eurydice pulchra* and amphipod *Bathyporeia pelagica*/ *Haustorius arenarius* communities grading to unstable beaches that additionally host the polychaetes *Paraonis fulgrens, Phelia rathkei* and *Scolelepis squamata* to stable or very stable beaches that contain a more diverse community consisting of polychaetes such as *Lanice conchilega, Scoloplos armiger, Arenicola marina Clymene oerstedii* and *Pygospio elegans* and molluscs including *Cerastoderma edule* and *Angulus tenuis*.

The Dyfi estuary contains a low diversity of fauna including *Corophium* and *Macoma* (Mills, 1998a) whilst the Glaslyn/Dwyryd system supports characteristic sand beach species such as the amphipods *Bathyporeia* spp. and *Haustorius arenarius* and the bivalve *Angulus tenuis*. Transitional zones, which are exposed to reduced salinity, typically host large communities of the shrimp *Corophium volutator* and the bivalves *Mya arenaria* and *Scrobicularia plana*. The beaches around Aberystwyth are predominantly coarse consisting of 'clean', unstable gravel sustaining low species diversity and abundance. However, one species that has been recorded in this unstable intertidal zone is the amphipod *Pectenogammarus planicrurus* (Bell, 1995).

Some of the early intertidal survey work conducted in Cardigan Bay was done by Evans (1947) who concentrated on the shores approximately 5 miles either side of Aberystwyth. In this zone the shore is described as predominantly rocky (cliffs up to 300 ft high) interspersed with boulder, shingle and some sandy beaches. Evans (1947) gives a detailed description of faunal and floral zonation patterns in addition to temperature, wind and wave exposure information. No particularly unusual species were recorded and a typical zonation pattern, consisting of *Pevetica* sp., fucoids, *Ascophyllum nodosum* and *Laminaria* sp. and associated fauna such as winkles *Littorina* spp., dogwhelks *Nucella* sp. and limpets *Patella* sp. was observed. More recently the MNCR have reviewed this area (Brazier *et al.*, 1999) and the rare amphipod *Pectenogammarus planicrurus* has been recorded on the gravel shores at Traeth Crugan (JNCC, 2005b).

The Cardigan Bay area hosts saline lagoons near Tywyn, , within the Lleyn Peninsula and the Sarnau candidate Special Area of Conservation identified under the EU Habitats Directive). Twelve invertebrate and plant species found within these and other lagoons along the north coast of Wales, Angelsey and in the Milford Haven area, have protected status under the Wildlife and Countryside Act 1981 (Moore, 2002). In addition, nine species, specific to coastal saline lagoons, were identified: the polychaete *Alkmaria glaucum*, molluscs *Cerastroderma glaucum* and *Ventrosia ventrosa*, crustaceans *Gammarus chevreuxi*, *Idotea chelipes* and *Lekanesphaera hookeri*, the bryozoan *Conopeum seuratii* and plants *Chaetomorpha linum* and *Ruppia maritime* (Bamber, 2004). The lack of natural history information pertaining to these species was highlighted, hindering conservation efforts in these fragile habitats. In addition, these areas are inherently unstable and variable, confounding efforts to identify trends and status of the lagoons.

The southern part of Cardigan Bay, from Cemaes Head to St. David's Head, faces north or northwest and is predominantly exposed or very exposed (Powell *et al.*, 1979). Powell *et al.* (1979) describes the intertidal zone in the St. David's Head region as being mostly rocky and exposed to intense wave and tidal currents. The littoral zone is typically zonated with barnacles *Balanus balanoides,* limpets *Patella vulgata* and dogwhelks *Nucella* sp. all being present. Locally the flora is notably diverse. Rock pools are common in the intertidal zone and much influenced by sand. Typical algal communities are present within these rock pools and include *Ahnfeltia* sp., *Polyides* sp., *Audouinella* sp. and *Corrallina* species. Further down shore *Fucus* and *Laminaria* communities are found together with *Himanthalia* sp. Additional species detail in this area is provided by Powell *et al.* (1979).

4.2.2.2 Lleyn Peninsula and Cardigan Bay: Sublittoral Zone

The sublittoral environment of Cardigan Bay is primarily sedimentary consisting of sands in the south to impressive glacial features known as sarns towards the north. Clumps of Modiolus are known from the north side of the Lleyn Penninsula where acoustic surveys have show that they form distinct reefs, some of which are over 1 m off the sea bed (Holt et al., 1998). On the south side in Tremadog Bay, Zostera marina beds have been recorded at Criccieth. The distribution of beds in the Welsh region is being addressed by the CCW Phase 1 intertidal biotope mapping surveys (Moore, 2002). The Countryside Council for Wales hope to conclude surveys by 2005 providing comprehensive data on biotopes and species for the entire Welsh coast. Diversity of the associated communities in this and other known areas of Zostera spp. in Cardigan Bay and along the Welsh coast have been surveyed by The Countryside Council for Wales (2002).

Tremadog Bay has a richly abundant and diverse fauna associated with a mosaic of seabed habitats including cobble, reef, seagrass (*Zostera angustiflora*), sand gravel and muddy sediments (CCW, 2005; JNCC, 2005b). Interestingly, the bay also hosts one of the largest known beds of the mantis shrimp *Rissoides desmaresti* which is known from only a few southern and western British locations (Ramsay and Holt, 2001). This is predominantly a southern, Mediterranean species, as is the red seaweed *Anotrichium barbatum* which is also found in the bay (JNCC, 2005b). Muddier sediments support megafaunal burrowing communities and include seapens, *Nephrops norvegicus* and *Callianassa sunterranea* (JNCC, 2005b).

The sarns are an interest feature of Cardigan Bay and consist of long (>10 km), narrow ridges of poorly sorted glacial outwash and moraine. They are frequently 6 - 8 m in height and up to 500 m across and occasionally exposed during low spring tides. Sarns are exposed to storms, as a consequence of being shallow, in addition to erosion as tidal streams are accelerated over their tops during certain periods of the tide. As a consequence the sarn environment is unstable and the associated biota somewhat ephemeral in nature (Hiscock, 1986), dominated by epibenthic algae, particularly Phaeophytes, with fauna being both less abundant and diverse. On the sarn crests the alga *Chorda filum* is common whilst in slightly deeper water the algae *Laminaria digitata*, *L. saccharina* and *Halidrys siliquosa* and their epiphytes dominate. In this harsh, mobile environment the most notable fauna are mussels *Mytilus edulis*, starfish *Asterias rubens*, corkwing wrasse (fish) *Crenilabrus melops* and dogfish *Scyliorhinus canicula*. The sarns also support numerous other epibenthic species, notably sponges, barnacles, and byrozoans (for a species list see Hiscock, 1986).

Between the sarns, expanses of shallow, diatom covered, sands host numerous echinoderms such as *Astropecten irregularis*, *Ophiura ophiura*, *Echinocardium cordatum* and *Labidoplax digitata* (Hiscock, 1986). Ellis and Rogers (2000) also recorded *Astropecten irregularis, Asteris rubens and Ophiura ophiura* from the bay.

Away from the sarns, towards the south and further offshore, finer sediments dominate the substratum. The sedimentary environment off Aberystwyth, where some of the earliest grab sampling work in the UK was done (Laurie and Watkin, 1922), consists of muddy sand and is locally referred to as the ‘Gutter’. The ground here supports an *Amphiura* type community (Rees, 1993). The benthic biotopes of Cardigan Bay consist of fine sediments hosting *Amphiura* and shallow *Venus* communities while muddier areas contain spionid polychaetes, the tubicolous ampharetid *Mellina palmata*, the brittlestar *Amphiura filiformis* and the bivalve *Abra alba* (Mackie, 1990). In addition, the large burrowing crustacea *Upogebia deltaura* and *Callianassa* sp. have been recorded. Further offshore the community resembles the deep *Venus* communities typical of a hard, stony substratum exemplified by the presence of tubeworms such as *Hydroides norvegica, Pomatoceros lamarkii* and *Sabellaria spinulosa* and the ascidian *Dendrodoa grossularia.*

4.2.2.3 Lleyn Peninsula and Cardigan Bay: General Comments

Cardigan Bay hosts one of the UK's populations of bottlenose dolphins. This is an important tourist attraction and an emotive conservation issue. Another rarity found in Cardigan Bay is *Anotrichium barbatum*, the only marine red alga that was identified under the UK Biodiversity Action plan as a priority species. However, the single reproductive colony, found on an old oyster bed off Pwllheli, has subsequently died out (by 2001) for unknown reasons (Maggs, 2003).In addition to the high conservation value of much of MNRC Sector 10 this region supports important fisheries, notably for the lobster (*Homarus gammarus*) and a high amenity value through tourism.

4.3 Pembrokeshire, from Newport to Milford Haven

The Pembrokeshire Peninsula forms the south-west part of Wales and includes Milford Haven, one of the UK's best examples of a ria and the southern boundary of SEA6. This region includes the Marine Nature Reserve of Skomer and much of the Pembrokeshire Coast National Park. In addition, coastal saline lagoons, listed as a priority habitat under the Habitats Directive, are present in the Pemrokshire Marine candidate SAC (Bamber, 2004).

Much of the region is exposed to the prevailing south-westerly winds and consequently most of the coastline is exposed or very exposed, the one exception being Milford Haven which is deemed to be very sheltered (Powell *et al.*, 1979). Important geographical features in this region include Milford Haven, St. Brides Bay, St. David's Head and Strumble Head. In geological terms the area is also very varied consisting of extremely ancient (Ordovician to pre-Cambrian) volcanic ashes and sandstones variously metamorphosed over time. Outcrops of limestone along some of the coastline has facilitated the formation of sea caves (Bunker and Holt, 2003).

Most of the coastline is unpopulated and, with the exception of Milford Haven, is not industrialised. Milford Haven hosts an important dock, oil terminal and oil refinery. Unsurprisingly, there have been a number of pollution incidents associated with the docks and oil refinery operations at Milford Haven. These accidents, most notably the Sea Empress oil spill, have formed the basis for numerous studies examining the impacts of oil on the benthos with obvious relevance to this DTI review. Some of these studies have indicated oil spill impacts lasting several years on certain parts of the benthic fauna (Nikitik and Robinson, 2003) while other indicate only short term impacts (<9 months) (Moore *et al.*, 1997). The impacts of the oil refining industry based at Milford Haven have been monitored by the Countryside Council for Wales (CCW) as part of an ongoing programme (MHWESG, 2001) and are an excellent source of data on the response of benthic communities in the region, particularly in sheltered locations, to some oil and gas operations.

4.3.1 Milford Haven

Milford Haven is one of the few good examples of a ria system in the UK, the upper reaches of which exhibit sufficiently low salinity to support an estuarine flora and fauna. Milford Haven is also unusual in as it host's the UK second largest oil terminal. Oil arrives at the terminal by tanker and one of these, the Sea Empress, grounded off the Dale Peninsula, which lies at the entrance of Milford Haven, and resulted in the release of approximately 72,000 tonnes of crude oil. This disaster, which occurred in February 1996, together with several other oil and product releases in an area of outstanding natural beauty, has initiated a considerable amount of research into the effects of the oil on the benthos, both in the short- and long-term. This post-impact assessment was greatly assisted by the pre-disaster assessments of the benthos that had been routinely undertaken over previous decades. A detailed assessment of the results of this survey work is beyond the scope of this review and there are, to the author's knowledge, no peer assessed reviews of the results from the numerous studies undertaken thus far. The results, albeit in a somewhat dispersed form, from this disaster are invaluable in assessing the likely sensitivity of much of the SEA6 area to oil spills partly because the acutely affected area included both sheltered and exposed shores. Much of the research conducted following the Sea Empress oil spill is not published in peer reviewed journals. Further to the synopsis provided below, interested readers should consult Moore (1997), Rostron (1998b), Moore (1998), MHWESG (2001), Rostron (1998a) and contact the Countryside Council for Wales.

4.3.1.1 Milford Haven: Littoral and Sublittoral Zone

The beaches in Milford Haven are generally coarse sedimentary, consisting of gravels to sands with an occasional covering of a thin veneer of silty sand. This unstable environment had a low associated biodiversity and biomass according to Withers (1977). However, following an extensive survey of 30 sites along the length of Milford Haven Moore (2004) concluded that the biodiversity is dominated by the gradient in salinity extending from estuarine conditions north of Llangwm to full salinity at the mouth. Other physical factors influencing the community include wave/tide exposure and siltation (Moore, 2004).

The upper estuarine-like part of Milford Haven (Daugleddau) supports marshes consisting of *Spartina* and *Zostera* spp. (Powell *et al.*, 1979) and the diverse range of epiphytes associated with seagrass (Countryside Council for Wales, 2002). Hard substrata in the upper reaches is limited, consisting of cobbles and empty shells, colonised by a low diversity of sponges, hydroid, anemones and mussels. Algae are sparse subtidally, presumably as a consequence of the high turbidity of the water. Further down the estuary, towards the sea, bedrock and boulders are more common (around Beggars Reach and Castle Reach) and are swept by stronger currents. This region supports a variety of sponges, notably *Halichondria panicea*, *H. bowerbanki, Haliclona oculata* and *Raspailia ramose*, anemones including *Diadumene cincta* and *Actinothoe sphyrodeta* and the bryozoans *Alcyonidium diaphanum* and *Anguinella palmata* (Moore, 2004). In the mid channel *Ostrea edulis* (The UK Biodiversity Group and English Nature, 1998-9a), the slipper limpet *Crepidula fornicata* (Moore, 2004) have been observed together with an empty shell of the rare bivalve *Atrina fragilis* (The UK Biodiversity Group and English Nature, 1998-9b). The intertidal zone in this region is dominated by typical wave sheltered flora consisting of various fucoid species and the barnacle *Elminius modestus* (Moore, 2004). Two nationally rare species of filamentous algae *Aglaothamnion feldmaniae* and *A. trispinnatum* are also found in the mid reaches of Milford Haven (Rostron, 1997). Further toward the mouth of Milford Haven, around the Stack Rock, scattered maerl beds, and associated diverse algal communities, have been recorded (Davies, 1991).

At the entrance to Milford Haven the salinity is normal and the substratum characterised by low bedrock reefs and boulder-cobble habitats. Subtidally, encrusting species such as the sponge *Halichondria panicea* and *Dysidea fragilis* and the anemone *Urticina* sp., together with the bryozoan *Alcyonidium diaphanum* are common. The red algae *Rhodymenia holmesii* is also present and small areas of maerl have been found in the Milford Haven area (Birkett *et al,.* 1998).. The intertidal zone is highly encrusted with a diverse range of species typical of such environments (Moore, 2004).

Following the Sea Empress disaster numerous surveys were initiated in Milford Haven and surrounding areas. Individual studies tend to concentrate on particular parts of the benthos. For example, Nikitik and Robinson (2003) showed that the oil pollution caused a decline in the benthic amphipods of the genera *Ampelisca* and *Harpinia* and the family Isaeidae and that this was accompanied by increases in both the diversity and abundance of polychaete populations as opportunist species took advantage. In one of the few pieces of research looking at meiofauna in the SEA6 area (see section 6). Moore and Harries (1997) found no substantive impacts, on the Angle Bay meiofaunal population, nine months following the oil spill. Meiofaunal species lists are available from Angle Bay, Milford Haven, from both before and after the Sea Empress oil spill (Moore *et al.*, 1997).

4.3.2 Skomer to Strumble Head

Outside Milford Haven, the Pembrokeshire coast is predominantly exposed and consists of sandy bays separated by rocky headlands (Figure 7). Much of the coastline, for example around the islands of Skomer,Gateholme and Ramsey, consists of spectacular, windswept, high cliffs that are important areas for seabirds and specialised higher plants. Extensive limestone outcrops in the area have allowed the development of marine caves. The epifaunal colonisation of these caves has been extensively reviewed as they can be associated with rare and specialised biological communities (Bunker and Holt, 2003). The region is popular with tourists and students of coastal morphology and ecology (Powell *et al.*, 1979). Artisanal fishermen, using creels and pots, target brown and spider crabs and lobsters along the rocky coast (Skomer Marine Nature Reserve, 2002). The area also supports commercial quantities of scallops *Pecten maximus*.

Skomer Island was made a Nature Reserve in 1982 (Rostron, 1997) and this and the historical use of the area as a site for students of marine ecology has meant that there is a wealth of material available concerning the biodiversity and ecology of the region. Importantly, this includes time series data for communities occupying rocky reefs and sediments and detailed surveys quantifying rare, commercially important or ecologically interesting species that are found in the area. These species include the sea fan *Eunicella verrucosa*, the red sea finger *Alcyonium glomeratum*, scallop *Pecten maximus*, nudibranchs and territorial fish (Burton *et al.*, 2003a). The islands of Ramsey and Grassholm are owned by the Royal Society for the Protection of Birds (Davies, 1991).

4.3.2.1 Skomer to Strumble Head: Littoral Zone

The littoral zone in this region consists of a series of bays separated by headlands. Even within the bays the majority of the substratum is rock; sedimentary shores are limited to bays at Marloes, St. Brides, Whitesands and Fishguard harbour. This region contains numerous sites of special scientific interest (SSSIs) that include the sedimentary beaches (Powell *et al.*, 1979).

The intertidal zone is characterised by a relatively impoverished fauna, one that is battered by storms and scoured by water and aerially borne sand. In areas of relative shelter, for example, between boulders a typical flora and fauna have been recorded and are largely determined by the degree of exposure. Detailed species lists have been complied for this region and can be found in Powell et al (1979) but it is worth noting that the intertidal zone supports severally locally unusual species that are present at the limits of their distribution. These include the brown algae *Bifurcaria bifurcata*, the molluscs *Monodonta lineata* and *Patella depressa*, the barnacle *Balanus perforatus* and the cup coral *Balanophyllia regia* (Powell *et al.*, 1979).

Skomer supports a small patch of seagrass (Zostera marina) that provides habitat for a diverse range of epiphytic species (Countryside Council for Wales, 2002).

Meiofaunal species lists are available from Whitesands Bay, Newgale Sands, Broad Haven, Marloes and Westdale Bay, from both before and after the Sea Empress oil spill. It may be worth noting that, nine months after the oil spill, no convincing evidence for any impact on the meiofaunal population could be found in these localities (Moore *et al.*, 1997).

4.3.2.2 Skomer to Strumble Head: Sublittoral Zone

There are numerous records of epifaunal colonisation at various localities within this region. These, relevant to Skomer, include generic time-series studies of rocky reef, algal, and sponge communities as well as sedimentary epi- and infaunal studies. In addition, fine scale time-series research is also being conducted focusing on rare species such as the sea fan *Eunicella verrucosa,* the anemone *Parazoanthus axinellae* and the hydroid *Alcyonium glomeratum* (Burton *et al.*, 2003a).

Hiscock (1983) observed a rich flora and fauna in the region, but no specifically unusual communities, during early survey work. However, in a later survey of tide swept regions of North Wales and Pembroke, Moore (2004) noted the presence of five species that are considered scarce or rare. These species were the sponges *Axinella damicornis* and *Tethyspira spinosa*, the sea squirts *Pycnoclavella aurilucens* and *Polysyncraton lacazei* and the brown seaweed *Carpomitra costata*. Other rarities found in this region include the Pink Sea Fan *Eunicella verrucosa* (The UK Biodiversity Group and English Nature, 1998-9c) and the Yellow trumpet anemone (*Parazoanthus axinellae*) (Burton *et al.*, 2003b) and a diverse range of nudibranchs (Luddington, 2002)

In a study of ghost fishing Bullimore (2001) used pots to sample the megabenthos around Skomer Island. The pots captured crabs *Cancer pagurus*, *Liocarcinus puber*, lobsters *Homarus gammarus* and fish such as Ballan wrasse *Labrus bergylta* and dogfish *Scyliorhinus* spp*.*

North–east of Skomer Island lies St. Brides Bay supporting both sedimentary and hard-substratum communities, the latter being similar to Skomer Island with the exceptions of large clumps of the colonial ascidian *Stolonica socialis*, a greater abundance of spider crabs *Maja squinado* and prawns *Palaemon serratus*. However, within the St. Brides area 'urchin barrens', created by the urchin *Echinus esculentus,* are more common. Nearby Stack Rocks are covered with beds of the featherstar *Antedon bifida*, anemone *Anemonia viridis* and numerous fish and starfish. The rocky reefs in the north of Pembrokeshire, such as Bola Bleiddyn and Llechganol are rich in sponges and southern species such as the colonial hydroid *Gymnangium montagui* and the anemome *Parazoanthus axinellae* (Rostron, 1997).

Ramsey Island lies a few hundred meters from St David's Head. The seaward facing part of the island is very exposed and tidal races occur in Ramsey sound which separates the island from St. David's Head. The sublittoral environment around Ramsey has been extensively surveyed (Hiscock, 1978) and includes several caves of note, four of which are described in (Bunker, 2003). In one of these, Seal Run cave, the cup coral *Balanophyllia regia* was found on the bedrock floor at the cave entrance. Also of note in this cave were the large growths of the sponges *Pachymatisma johnstonia* and *Dercitus bucklandi* and rich faunal turf on un-scoured areas of wall and under overhangs. The presence of the un-described 'pin head' ascidian (Clavelinidae indet.) was also recorded [(Bunker, 2003).

4.3.2.3 Skomer to Strumble Head: General Comments

In 1998, the rarely recorded red alga *Polysiphonium foetidissima* was found in South Pembrokeshire. This species, which had not been recorded since

1855, may have become noticeable as a consequence of the series of warm winters, over the period 1997 – 1998, as this species is present here at its northern limit.

The limited size of the Skomer reserve makes it susceptible to anthropogenic activities occurring outside the area. This includes siltation that may be occurring as a consequence of nearby dredging (fishing), spoil dumping or civil engineering projects (Rostron, 1997).

Whilst the majority of this area is largely unpolluted the sediments of Milford Haven are highly enriched with combustion derived polyaromatic hydrocarbons that are considered acutely toxic to some members of the benthos (Woodhead *et al.*, 1999). As a consequence the Milford Haven benthos was considered under threat by from oil refining and power generation industries based in Milford Haven (Rostron, 1997).

Some of the SACs include areas chosen on the basis of ‘submerged or partially submerged sea caves’ and their associated fauna. Rare species found in such environments include the red alga, *Schmitzia hiscockiana*, the scarlet and gold star cup coral *Balanophyllia regia* and the sea anemone *Anthopleura balli* as well as three undescribed sea squirts (ascidians) (Bunker and Holt, 2003).

4.4 Northern Ireland and the Isle of Man

The SEA6 area includes a proportion of the relatively sheltered east coast of Northern Ireland and the exposed Isle of Man. The Northern Irish coastline included in the SEA6 area extends northwards from (but not including) Carlingford Lough to Red Bay near Cushendall on the eastern coast. It includes Strangford and Belfast Loughs.

4.4.1 Strangford Lough

Strangford Lough is situated in County Down and is a shallow, glacially formed sea lough that is 24 km long, 4 – 8 km wide and linked to the Irish Sea via the ‘narrows’. The lough is a complex tidal estuary and tidal flows through the narrows can reach eight knots (Nunn, 1994). Mean currents speeds decrease towards the head of the lough. The lough is fully saline throughout its length and mostly sheltered with only the east-coast experiencing any significant wave action (Nunn, 1994). There is a close correlation between exposure to currents and sediment type. On the east (exposed) side of the lough, at depths of less than 10 meters, the substratum is coarse. This is not reflected on the west coast where the substratum is much softer and includes muds. The entrance to the lough consists of bedrock and boulders grading to coarse gravels and sands towards the main lough basin (Figure 8).

The wide variety of habitats in the lough makes it an area of high biological diversity. Strangford Lough is a Statutory Nature Reserve, with 10 reserve-type designations (Nunn, 1994), and this, together with the relative logistical

simplicity of sampling in the lough, has resulted in a considerable amount of ecological research and monitoring having been conducted in the area. This research includes the extensive survey conducted by Wilkinson *et al.* (1988) and more recently research conducted under the auspices of the Strangford Lough Ecological Change Investigation (SLECI) funded by the Department of the Environment, Northern Ireland, (Roberts *et al.*, 2004d) whose reports are on the SLECI web site.
(www.ehsni.gov.uk/natural/conservation/SLECI/sleci.shtml)

4.4.1.1 Stangford Lough: Littoral Zone

The littoral zone in Strangford Lough extends to 77 km^2 and consists of a broad range of rocky and sedimentary habitats.

Towards the north and west there are wide intertidal zones consisting of mud and sandy mud. At the top of this zone the seagrass *Spartina angelica* is found (Hammond *et al.*, 2002). Further down shore these flats support cockles *Cerastoderma edule* and mussels *Mytilus edulis,* with the bivalve *Macoma balthica*, the polychaete *Hediste diversicolor* and the amphipod *Corophium* sp. also being common. The intertidal molluscan fauna has been extensively studied and reviewed by Nunn (1994) who surveyed 117 representative littoral sites around the lough. A full species list is available (Nunn, 1994). The diverse and productive sand/mud flats and seagrass beds provide an internationally important habitat that supports 25,000 wildfowl and 50,000 wading birds (Navas *et al.*, 2002)

Towards the lough entrance rocky shores are more common. They exhibit a typical zonation pattern consisting of a splash zone at the top of the shore, followed by zones of the algae *Pelvetia canaliculata*, Fucus *spiralis*, *Ascophyllum nodosum, Fucus serratus* with *Laminaria* sp. at the bottom of the shore (Wilkinson *et al.*, 1988). Comparisons between the surveys conducted in 1988 (Wilkinson *et al.*, 1988) and those conducted more recently under the aegis of SLECI, indicate that *A. nodosum* is decreasing in abundance while the exotic species *Sargassum muticum* is becoming increasingly common (Roberts *et al.*, 2004c). Roberts (2004c) also comments that the limpet *Patella* sp. is becoming increasing common but raises concerns about the unregulated hand collection of littorinids. However, as pointed out by Roberts (2004c), from the comparison of only two sampling periods it is impossible to comment whether any observed changes are significant or simply reflect natural fluctuations in community composition.

Trends in meiofaunal abundance as a function of beach height and location, have also been assessed for beaches in Stranford Lough (Maguire, 1977). A comparison on nine locations revealed dominant four community associations. The composition and distributions of these were explained by exposure and sediment redox conditions, with highest diversity found in the surface sediments of moderately exposed beaches at Ballymaconnel and Benderg. *Protodriloides symbioticus* was particulary abundant whilst finer sediments contained a greater proportion of nematodes.

4.4.1.2 Strangford Lough: Sublittoral Zone

Subtidal areas of Strangford Lough have been extensively surveyed using a variety of methods, including ground truthed acoustic techniques, and have resulted in the generation of biotope maps (Magorrian *et al.*, 1995; Magorrian, 1996; Magorrian and Service, 1998). These maps give a very useful overview of the lough. The sublittoral zone is biologically diverse and hosts 72% of the sublittoral species recorded around Northern Ireland (Erwin *et al.*, 1986). More specifically, Nunn (1994) comments that the total number of molluscan species recorded in Strangford Lough was 281 making Strangford Lough one of the most diverse habitats for molluscs in the UK.

Strangford Lough consists of a range of sediment types including extensive *Modiolus* (horse mussel), maerl, brittlestars *Ophiothrix* sp. *and Ophicomina* sp*.,* the seapen *Virgularia mirabilis* and burrowing crustacean *Nephrops* (Vize *et al.*, 2003; Roberts *et al.*, 2004a).

Modiolus beds host an unusually high biological diversity, with over 300 infaunal and epifaunal species being associated with them (Roberts *et al.*, 2004c). In Strangford Lough two separate *Modiolus* communities have been found, one with and one without the bivalves *Chlamys* sp. or *Aequipecten* sp*.* During the late 1980s there was a rapid increase in the dredging for scallop in Strangford Lough. This was suggested as the most likely cause of the severe decline in populations of *Modiolus modiolus* since the 1970s. This mussel forms biogenic reefs, for which the loch received candidacy for Special Area for Conservation (SAC) status under the UK Habitats Directive. Other changes noted included increased populations of native oysters *Ostrea* and seagrass *Zostera* and distributional changes in the gastropod molluscs *Gibbula umbilicalis* and *Osilinus lineatus* (Roberts *et al.*, 2004d).

The *Ophiothrix/Ophicomina* brittlestar beds are characterised by dense aggregations of the brittlestar *Ophiothrix fragilis* and *Ophicomina nigra*. These beds are found mainly in the lower lough on areas of coarse substratum. In areas of sandy mud the seapen *Virgularia mirabilis* is common and is associated with high densities of the burrowing brittlestar *Amphiura chaijei,* the gastropod *Turritella communis* and the sea anemone *Cerianthus llyodii.* In areas of muddy sand *Amphiura filiformis* is common together with the bivalve *Arctica islandica* and the burrowing urchins *Echinocardium cordatum* and *Echinocardium flavescens.* As the sediment becomes increasingly muddy the crustacean *Nephrops* becomes increasingly common together with the burrowing crab *Gonoplax rhomboides* and the prawn *Calocaris macandreae.* This habitat is typically found in deeper areas where there very little water movement.

Within all the biodiversity present in the diverse environment of Strangford Lough is the rare burrowing anemone *Edwardsia timida* (Moore, 2004).

4.4.1.3 Strangford Lough: General Comments

A variey of anthropogenic impact studies have been conducted on samples from Strangford Lough. These impacts stem mainly from physical disturbance occurring as consequence of trawling (Magorrian, 1996) and pollution. A number of chemical contaminants have been isolated from Strangford Lough. These include pesticides and their degradation products, linear alkylbenzene surfactants (LABS), the latter indicating domestic sewage input (Widdows *et al.*, 2002) together with tri butyl tin, an antifouling chemical used on boat hulls (Roberts *et al.*, 2004c). In addition, aerially derived polyaromatic hydrocarbons (Guinan *et al.*, 2001) and radionuclides have also been isolated (Ledgerwood *et al.*, 1999).

There is currently no finfish fishery within the lough, however, it does support commercial quantities of scallops, *Nephrops,* lobsters, brown crabs, velvet swimming crabs and, until 1996, whelks. The sustainability of these fisheries and their environmental impacts were assessed by Edwards *et al*. (2002) who concluded that conservation measures were required for whelks and velvet swimming crabs and that such conservations measures would have more generic benefits to the lough, such as maintaining ecological diversity. Current legislation prohibits the use of benthic fishing gear in the loch (Roberts *et al.*, 2004d).

4.4.2 Belfast Lough

Belfast Lough faces north-east into the Northern Channel of the Irish Sea. At the head of the lough is the large city of Belfast. The lough is shallow, reaching a maximum depth of 23 m, with a complex current system influenced by tidal dynamics in the inner lough and the Northern Channel current in the outer lough (Breen and Service, 2002). Belfast is an important dock and hosts heavy industries such as ship building.

Detailed benthic survey work was conducted in Belfast Lough during the mid nineteenth century when it was highly regarded for the variety of specimens present (Kinahan, 1859). However, Belfast Lough is now viewed by some as being synonymous with pollution and a severely impacted fauna (Parker, 1980a, b). Despite its reputation over 580 taxa, including polychaetes, oligochaetes, isopods and amphipods are all recorded in the benthos making it relatively diverse (Breen and Service, 2002). In addition, Belfast Lough also hosts wading birds exploiting large expanses of intertidal mudflat (Breen and Service, 2002).

Whether the benthic status of Belfast Lough is improving requires further research. Pollution from sources such as sewage sludge and untreated sewage should have been phased out but the lough is subject to 5-yearly dredging disturbance which may redistribute pollutants, potentially increasing their bioavailability, for decades to come.

4.4.3 Isle of Man

The Isle of Man lies midway between the Cumbrian coast and Northern Ireland in the north of the Irish Sea (Figure 9). The island is approximately 60 miles long and up to 10 miles wide with an area of 221 square miles. The Isle of Man is a British Crown Dependency and is not part of the United Kingdom.

The Isle of Man is relatively exposed and the water around the island is predominantly shallow consisting mainly of coarse, current swept sands and gravels with gravelly mud grading to mud further offshore (MarLin, 2003).

4.4.3.1 Isle of Man: Littoral Zone

The coastline of the Isle of Man can be divided into two broad categories: sandy and rocky. Sandy shores dominate the coastline moving north from Kirk Michael on the west coast, around the northern end of the island and south to Ramsey. Rocky shores dominate the rest of the island with the exceptions of a few sandy bays.

The rocky beaches support the algal turf *Osmundea pinnatifida* and numerous associated species (Prathep *et al.*, 2003) while the harsh environment of the sandy beaches, which supports few species, have been recorded as hosting the amphipod *Pectenogammarus planicrurus* (Bell, 1995). Studying benthic patchiness (Cushnie, 1998) describes typical exposed midshore *Laurencia* turf communities from Perwick and Castletown Bays alongside green and brown algae *Cladophora rupestris* and *Fucus* spp. respectively together with limpets.

A detailed study of Manx meiofauna was conducted by Moore (1975). This PhD thesis may provide essential data for any assessment of changing community structure.

4.4.3.2 Isle of Man: Sublittoral Zone

Near shore, the sediment around the Isle of Man is predominantly sand and gravel mixed with various quantities of shell fragments (Bradshaw *et al.*, 2003) or exposed bedrock. Subtidal bedrock is rare in the north-east Irish Sea except around the Isle of Man where is supports, with other coarse substrata, large numbers of encrusting biota, 16 of which are recorded as being nationally rare or scarce Sanderson (1996). The rare species recorded are the sponge *Stryphnus ponderosus*, the sea snail *Jordaniella truncatula*, the sea slug *Aeolidiella sanguinea* and the bryozoan *Hinksina flustroides*. The remaining scarce species are also listed in Sanderson (1996) with details of habitat, species associations and further reading. The habitat complexity offered the diverse epifauna found in this region has been identified as providing a suitable habitat for other species including *Cellaria* spp., *Crisia* spp., *Ascidia* spp., *Ascidiella* spp., *Ciona intestinalis* and *Alcyonium digitatum* (Bradshaw *et al.*, 2003) and *Thia scutellata* (Wilson, 2005). In addition, *Modiolus* beds are known to occur at both ends of the Isle of Man. In the south these areas are believed to have been greatly reduced in recent years, possibly as a result of scallop dredging. At the northern site, an area of 6 km^2

was discovered recently where tidally swept gravel and shell banks, approximately 1 m high, support a rich faunal growth including *Modiolus* (Holt *et al.*, 1998).

The benthos associated with sedimentary habitats was extensively researched by N. S. Jones during the period 1939 – 1956. Jones (1951) reports four sedimentary types off the south coast of the Isle of Man. These consist of gravel and shell, fine sand, muddy sand and mud. Jones (1951) lists, in considerable detail, fauna and flora associated with each sediment type together with details of the sediment such as organic carbon content. This research has been subject to re-analysis, using modern statistical techniques, by Pennington *et al.* (1998) and has been used as pre-impact baseline data in an examination of the impacts of scallop dredging by Bradshaw *et al* (2002). This research identifies species that have changed since the work by Jones, as identified using multivariate techniques. Although species lists are not presented in Bradshaw *et al.* (2002) they may, if made available by the authors, provide a current status of the benthos essential in determining further anthropogenic impacts. Early work by Jones (1956) also includes a detailed analysis of a patch of muddy sand approximately 7 miles north-west of Port Erin. This research included an examination of small scale spatial and temporal variation in the abundances of macrofauna making this an essential data set for further research in to the benthos in this and similar regions. Also recorded were the abundances of 20 fish species.

The impact of scallop dredging on the benthos has been a cause of some concern. The result of scallop dredging, around the southern tip of the Isle of Man, is an increase in the abundance of mobile, robust, scavenging taxa to the detriment to slow moving or sessile fragile species. This effect increases with the time an area is subject to fishing activity rather than the intensity of this activity (Bradshaw *et al.*, 2002). In addition, Hill (1999) identified changes in benthic communities around the Isle of Man, including an increase in the ratio of polychaetes to molluscs and loss of many sensitive species, consistent with the disturbance caused by heavy scallop dredging activities. However, community changes were also recorded in lightly dredged areas and reasons for the observed differences could not be attributed.

4.4.3.3 Isle of Man: General Comments

The coastline around the Isle of Man has a high amenity value and attracts tourists which form an important part of the islands economy. In order to protect this amenity value 14 Manx National Heritage sites around the coast and four Wildlife Trust Reserves have been designated (Keddie, 1996). However, the Isle of Man also hosts numerous coastal quarries and four coastal landfill sites (Crumpton and Goodwin, 1996).

Scallops currently form the largest fishery around the Isle of Man. Most scallops are fished using dredges, an activity linked with the destruction of the diverse benthic community found in the region (Bradshaw *et al.*, 2002).

The water quality around the Isle of Man is varied. In 1993 only one of the thirteen EC designated bathing beaches passed (Crumpton and Goodwin, 1995). The Isle of Man has a long history of mining for metals such as zinc, copper, lead and iron. Although mining ceased in 1919, this activity has lead to the contamination of certain estuarine systems with accumulation of metals in sediments and fauna, particularly bivalves (Southgate *et al.*, 1983), although there does appear to have been improvement in contamination levels measured in recent years (Daka *et al.*, 2003).

4.5 Deep Water and Offshore Areas

Sea Area 6 comprises mainly the eastern half of the Irish Sea. This area is predominantly <50 m (see Figure 1 and Table 2). For the purposes of this report deep water is considered to be that >50 m and represents approximately 40% of the total SEA6 area. Considering the significant deep water area that exists, biological information is proportionally more sparse than for coastal regions.

Available information on offshore benthic communities of the Irish Sea are excellently summarised in Mackie (1990) where source references are also provided. In addition, benthic biodiversity of the southern Irish Sea from Anglesey to the Celtic Deep was surveyed in 1989 and 1991 by Mackie et al. (1995) during the BIOMÔR 1 project. A richly abundant and diverse polychaete dominated fauna was found, comparable to other deep water communities. and included and number of new species and species previously unrecorded in UK waters. The BIOMÔR 2 project (Wilson *et al.,* 2001) survey the south-west Irish Sea but also included areas to the north of Anglesey, part of Cardigan Bay, St. Bride's Bay and the Celtic Deep

Offshore sediments in the Irish Sea are predominantly sedimentary many of glacial origin consisting mostly of sands and muddy sands. Most of the benthos of the Celtic Trough is described as either 'deep *Venus*/hard' or 'deep *Venus*' by Mackie (1990). The deep Venus community is characterised by the urchin *Spatangus purpureus* and the bivalves *Glycimeris* sp.*, Astarte sulcata* and *Venus*. In sand wave areas the communities also often contain elements of both shallow (*Spisula* sub-communities) and deep *Venus* communities. These two communities are the most dominant in the offshore benthic environment. Other reports confirm the generalisations made by Mackie (1990). For example, to the east of Tremadog Bay a 2 x 2 mile box to the north-north-west of the Lleyn Peninsula was surveyed using ground truthed acoustic methods. The survey indicated that the seabed was varied but dominated by current swept coarse cobbles sustaining, in places, minimal epifauna. However, in areas with micro-relief (formed by the presence of cobbles protruding into the current) the bivalve *Glycimeris glycimeris* was common (Rees, 1993) accumulations of which have also been recorded from the St. Georges Channel in the south of the SEA6 area (Rees, 2004a).

The southern Irish Sea, considered to represent a boundary between different biogeographcial regions with several species reaching their distribution limits, is regarded as a significant source of benthic biodiveristy (Mackie *et al.*, 1995). During the BIOMÔR 1 project, Mackie *et al.* (1995) recorded 4 dominant assemblages, arranged in a continuum of overlapping mosaics. The deep soft muds of the Cetlic Trough were characterized by small polychaete species, 12 of which were exclusive to this assemblage, including *Glycera rouxii*, *Prionospio dubia* and *Ampharete falcata*. A second assesmblage was primarily associated with inshore sands qand muddy sands and showed similarity to the '*Amphiura*' and 'shallow *Venus'* communities.. The richest assemblage, and that with the most extensive geographical coverage, was that associated with gravelly sediments and included conspicuous serpulids, other large polychaetes (*Polydora* spp.), an exclusive tubiculous ampharetid species and the amphipod *Guernea coalita*. A fourth less strongly defined assemblage appeared to be associated with shallow stony ground in Cardigan Bay and included polychaetes, gastropods, bivalves and crustaceans, none of which were exclusive to the assemblage.

The JNCC (2005) note that megafaunal burrowing communities are present in the deep muds of the northern Irish Sea and the Celtic Deep, producing considerable biogenic topography on the seabed, and include seapens, *Virgularia mirabilis* and *Pennatula phosphorea,* together with several burrowing crustaceans, namely *Calocoaris macandreae*, *Callianassa subterranea* and *Goneplax rhomboides.* Several epibenthic species are also common and include *Amphiura* spp., *Asteria rubens*, *Pagurus bernhardus* and *Liocarcinus depurator.*

Meiofaunal information for offshore areas is sparse. However, Schratzberger (2000), examined stations around the UK, including three at Burbo Bight (Liverpool Bay), Cardigan Bay and the Celtic Deep and found generally more abundant and diverse communities at deep sites. This appeared to be linked to differences in particle size distribution and sediment trace metal concentrations which were typically higher at inshore locations.

The largest area of muddy ground in the SEA6 area occurs to the west of the Isle of Man and supports a substantial *Nephrops* fishery. Smaller pockets occur locally, for example to the south-west of the Lleyn Peninsula. Deep water offshore bedrock outcrops are also rare, examples can be found west and north-west of Anglesey and off Strangford Lough (Barne *et al.*, 1996).

Deep water can act as a depository for anthropogenic pollutants particularly those associated with fine sedimentary particles. This makes them a potential sink for anthropogenic pollutants, including those derived from oil and gas operations. Deep water has also been used as a dump site. For example, Beaufort's Dyke, which reaches a maximum depth of 315 m, was used as a munitions dump following both world wars. This dump site gained a certain notoriety following the relocations of some of the munitions dumped there onto local beaches and their subsequent ignition. Whilst the Fisheries Research Services (FRS) has demonstrated negligible leaching of toxic components from these munitions very little benthic survey work seems to have been recorded (Scottish Office Agriculture and Environment and Fisheries Department (SOAEFD), 1996; Shaw, 1999; Saward, 2000).

5. ANTHROPOGENIC ACTIVITIES AND IMPACTS

The Irish Sea is subject to numerous anthropogenic input and impacts and a detailed analysis is beyond the scope of this review. However, human activities have the potential to significantly alter the benthos and, in many areas, this is already occurring. Fortunately, the status (at 1990) of the anthropogenic activities and their influence on the receiving environment, including the benthos, has been extensively reviewed by the Irish Sea Study Group and summarised diagrammatically (Irish Sea Study Group, 1990).

The most influential activities affecting or likely to affect the benthos of the SEA6 area can be split into several areas: oil and gas developments, waste disposal, fishing and eutrophication (Irish Sea Forum, 2000a).

5.1 Oil and Gas Developments

There are a number of areas (blocks), within SEA6, that are proposed for oil and gas exploration. These blocks are located throughout the region including south-west and west Wales, Colwyn Bay, Liverpool Bay, outer Solway Firth and through the Northern Channel (Thorpe, 1994). The Colwyn Bay blocks are the closest to land.

The offshore exploration and production of oil and gas offers a number of threats to the marine environment. These include the routine disposal of production by-products (cuttings, production water, deck drainage, domestic waste and water treatment chemicals), the accidental spillage of oil and the physical presence of related infrastructure (platforms, pipelines and near shore handling and/or processing facilities) (Dicks (1982) cited and described in Mackie (1990)).

Oil platform operators routinely (where licensed) dispose of rock fragments, called cuttings, that are generating from drilling operations. These cuttings are, to some extent, contaminated with cutting fluids. Cutting fluids (muds) are injected into the borehole and serve to lubricate and cool the cutting head, to carry away cuttings and to maintain hydrostatic pressure in the borehole. Whilst cutting muds are ubiquitous in any drilling operation their nature varies depending on the cutting task, licensing conditions and any technological developments. Whilst a majority of the cutting muds are recycled some is left coating the cuttings and is subsequently dumped onto the seabed. The impact of cuttings and associated muds in the North Sea is relatively well documented (Davies, 1984) but less work has been conducted in the Irish Sea where, in any case, the receiving environment is likely to be different. In a review of the environmental impact of ongoing oil and gas exploitation operations within SEA6 Rees (1994) found no evidence of extensive ecological damage occurring as a consequence of production activity which was attributed to careful licensing of discharge consents. However, changes could be detected at a distance of more than 500 m around platforms (Rees, 1994).

Oil platforms, and their associated sea bed fixed and suspended structures, are massive. These structures offer attachment points to epifaunal communities and act as artificial reefs and, within the Irish Sea, the major epifaunal organisms colonising such structure are mussels (*Mytilus edulis*) which can accumulate at up to 30 $kg/m^2/yr$ (Southgate and Myers, 1985). Such 'natural' changes can have knock-on consequences to the receiving environment, for example mussels produce organically enriched pseudofaeces, and shells, which sink to the bottom and cause localised changes to sediments. The exclusion of fishing activity around production platforms protects areas of seabed from fishing activity resulting in further differences between platform sites and 'control' (i.e. fished) sites. Fish are also attracted to such structures. Whether these differences are considered detrimental is open to debate (Rees, 1994).

Most oil production operations in SEA6 will be occurring several kilometres offshore. The inshore areas will, therefore, be buffered by distance from the routine emissions of offshore oil rigs and platforms. However, the accidental spillage of oil appears to be an inevitable consequence of oil and gas exploitation, despite assurances to the contrary. Around the UK there have been several very well publicised oil spills occurring as a consequence of the foundering of oil tankers plus numerous smaller spillages occurring from associated shipping activities and operations such as the flushing of tanks and leaks in pipelines. Oil floats on water and, in high energy environments, can be converted to an emulsion. Floating oil or oil/water emulsions move in concordance with the prevailing wind or current direction. Given the prevailing wind and current direction and enclosed nature of the SEA6 area any oil spill is likely to result in the deposition of oil on shorelines. It is therefore essential to examine the susceptibility of the SEA6 coastline to such an eventuality. However, it should also be acknowledged that much of the production in the Irish Sea is gas and, as such, oil production related incidents are less likely.

Intertidal areas in the Irish Sea support both fisheries, upon which numerous livelihoods are dependent, and have a high conservation value. There are a number of factors which influence the ecological susceptibility of shorelines to oil. These include the nature of the oil, where volatile oils (lighter fractions) are more acutely toxic (but shorter lived) and the shoreline exposure. Perhaps the most susceptible areas are those of low exposure such as estuaries. However, the longevity of ecologically damaging quantities of oil, even in low energy environments can be relatively low, for example Moore and Harries (1997) found no evidence of meiofaunal change nine months following the Sea Empress oil spill (SW Wales) even in low energy environments.

5.2 Waste Disposal

The Irish Sea has historically been used as the final depository for a number of waste products. Waste disposal at sea is continuously under statutory (UK and EU) review predominantly to the effect of reducing marine disposal. However, the Irish Sea has a long history of receiving waste products, both dumped directly and river borne. There are a number of categories worth considering separately such as heavy metal contamination (excluding radionuclides), nuclear industry related inputs, dredge spoil dumping and the consequences of historic sewage sludge dumping.

5.2.1 Heavy Metals

Within the SEA6 area there are localised high concentrations of heavy metals that are derived from either natural or anthropogenic processes. Natural sources of heavy metal enrichment include rocks that are enriched with metal bearing mineral deposits. These rocks have been eroded and deposited in the sea by both natural and anthropogenic (mining) erosion over thousands of years. More recently, significant inputs have resulted from metal working operations such as smelting and some light industries such as electronics, which have made a significant contribution of mercury, arsenic, lead and cadmium in coastal sediments (Wither, 2000).

A majority of heavy metals are attracted to particulates in the water column. Subsequent sedimentation of the particulate effectively removes the metal from the water column and adds it to the benthos. A majority of the SEA6 water column therefore exhibits normal heavy metal concentrations. However, localised heavy metal enrichment of sediments is apparent particularly in and around estuaries such as Liverpool, Morecambe, and Solway. In addition, the Mersey Estuary is a major contributor of trace metals (Achterberg and van den Berg, 1996), specifically nickel, copper and zinc which are redistrubted through the eastern Irish Sea by counter-clockwise currents, and and PCB's (Camacho-Ibar and McEvoy, 1996).

The relationship between heavy metals and the benthos is one of interest and consequently much of the sedimentary benthic research has concentrated in regions, such as Liverpool Bay, where there are elevated metal concentrations (Mackie, 1990). Whilst the trend, at least in Mersey Estuary sediments, is improving with a majority of sedimentary trace metals decreasing in concentration concerns are being raised that increased storm activity, occurring as a consequence of climate change, may stir up the seabed releasing previously stored heavy metals back into the water column (Irish Sea Forum, 2000a). Work in the Mersey and other estuaries (Bryan and Langston, 1992) demonstrated bioaccumulation of metals by bivalves, and highlighted the possible biomagnification of methylmercury, although the research was unable to provide specific evidence of any adverse effect on benthic populations. For further information on heavy metal pollution related issues, in the Irish Sea, see Wither (2000).

5.2.2 Nuclear Industry Related Disposal

In 1990 there were nine nuclear facilities bordering the SEA6 area. These are at Chapelcross (Solway Firth), Sellafield and Calderhall (Cumbria), Glasson, Heysham and Springfields (Lancashire), Capenhurst (Cheshire), Wylfa (Anglesey) and Trawsfynydd (Gwynedd) and are either active or in some stage of decommissioning. Some of these facilities have or had role in electricity generation, the manufacture weapons grade plutonium, the reprocessing of nuclear waste or the production of enriched uranium fuel (Irish Sea Study Group, 1990). Sellafield is, perhaps, the most notorious of these installations and is associated with both routine and accidental releases of a variety of radionuclides. These releases have been tracked throughout the Irish Sea and beyond (Lindahl *et al.*, 2003 and references therein).

Nuclear facilities are an emotive and contentious subject and subsequently there is a considerable monitoring of radioactivity in the Irish Sea. In 1990, the Irish Sea contained 2 Bq of man made radionuclides which equates to approximately one sixth of the normal background level. However, around the Sellafield discharge site this rose to 20 Bq although was largely due to tritium, a radionuclide that is considered of low radiotoxicity (Irish Sea Study Group, 1990). In a survey of technetium-99, highest levels were most apparent in surficial sediments closest to the Cumbrian coast (Leonard *et al.*, 2004). Betti (2004) examined the impact on biota and concluded that in recent years doses of radionuclides from Sellafield are comparable to those introduced by background radiation. In the past, radionuclides have come from the use of phosphogypsum in the fertilizer industry, although discharges from this source have now virtually ceased, and from the oil and gas industry which is now the primary source of alpha radionuclides discharges to the eastern Irish Sea (Betti *et al.*, 2004).

The fate and behaviour of radionuclides released into the Irish Sea depends on several factors but particularly the type (element) concerned. For example, caesium-137 is highly water-soluble and is dispersed rapidly by currents once in the environment. Others, such as plutonium and americium, are readily absorbed by particulates and are consequently concentrated in the benthic phase around the release site. Surficial sediments, contaminated or otherwise, are subject to bioturbation in the presence of benthic organisms. Two of these bioturbating organisms, the echiuran worm *Maxmuellaria lankesteri* and the shrimp *Callianassa subterranea*, have been implicated in the (possibly permanent) transfer of surface sediments, and contaminants, to deeper within the sediment column (Swift and Kershaw, 1986; Hughes *et al.*, 1996a; Hughes *et al.*, 1996b).

Extensive studies have been conducted to detect any deleterious effects occurring as a consequence of the introduction of additional radionuclides into the Irish Sea, but there is little convincing evidence of an adverse effect on fish, benthic infauna or humans (Irish Sea Study Group, 1990).

5.2.3 Dredge Spoil and Sewage-Sludge Dumping

Harbours and shipping channels require a minimum water depth in order maintain access to shipping. This is achieved in some cases by dredging. The dredged material is usually dumped further out to sea at licenced dump sites. In the SEA6 area the most dredging occurs in the Mersey estuary and at Morecambe Bay. Current dump sites and the amount of dredged material dumped (in tonnes during 2001) include Liverpool Bay (2,600,000), Belfast Lough (2,400,000), Morecambe Bay (1,600,000), Solway Firth (140,000), Anglesey (11,000), Carlingford Lough (8,000) and Milford Haven (939) (Law *et al.*, 2003).

Dumped material, which is sometimes contaminated by heavy metals, causes an impact by smothering the benthos and by causing localised increases in suspended material and turbidity. Research into the effects of spoil dumping, in Liverpool Bay, a major dump site, has been conducted. Results indicate that the major impact from the dumping of inert solid waste occurs through smothering. Other effects, such as increasing water turbidity are very localised (spatially and temporally) and, whilst dumping might change the particle size distribution at the dump site, this is not necessarily damaging. Of greater concern are the associated increases in heavy metal and other contaminants at the receiving environment that originate as contaminates of the dredge material (Rowlatt *et al.*, 1984; Rowlatt *et al.*, 1986). Somerfield *et al*. (Somerfield *et al.*, 1995) attributed changes in meiofaunal community structure to dredging dosposal and also to the concentrations of metals in sediments.

Sewage sludge is enriched in a variety of toxic materials that are derived from industrial waste and, up until 1998, large quantities were dumped off the UK coastline, including Liverpool Bay. Sewage dump sites are associated with severe changes in the benthos as a consequence of the accumulation of organic material. However, following cessation of dumping the macrobenthos shows quite remarkable rates of recovery (for the Clyde Sea see Moore and Rodger, 1991a, b).

5.3 Fishing

While aspects of fisheries ecology do not form part of this report fish and shellfish, whether commercially important or not, form a critical component of the benthos. The Irish Sea is an important nursery area for numerous commercially important species, including flatfish such as plaice *Pleuronectes platessa* (Watts *et al.*, 2004) and supports a large scale scallop fishery, particularly in the vicinity of the Isle of Man (Beukers-Stewart *et al.*, 2003; Brand *et al.*, in press). Commerical fishing has been identified as a pervasive mechanism of ecosystem modification within many of the worlds seas including the Irish Sea (Roberts *et al.*, 2003).

The Irish Sea fishery is exploited both internationally and nationally. The sublittoral fishery is regulated, quota-fashion, through the Common Fisheries

Policy (CFP) whilst the management of inter tidal shellfish, and some near shore crustacean fisheries, is carried out under the auspices of Sea Fisheries Committees (Irish Sea Forum, 1997). Inshore shellfisheries include those around Morecambe, where the main target species are mussels, cockles and shrimps. The Irish Sea also supports considerable numbers of fishing boats targeting the offshore demersal species cod, haddock, whiting, saithe, plaice, sole, scallops, prawns, shrimps and scampi (*Nephrops norvegicus*) (Irish Sea Study Group, 1990). Many of these stocks are overexploited, particularly the whitefish (cod, haddock and whiting) (Irish Sea Forum, 2000b).

Much of the fishing in the Irish Sea is done using trawled gear. This activity damages the seabed, the extent of which depends on the nature of the substratum. Stable seabeds, such as maerl or *Modiolus* beds or deep water muddy habitats, are highly vulnerable (Kaiser and Spencer, 1996; Kaiser, 1996; Service and Magorrian, 1997; Hall-Spencer and Moore, 2000) whilst the benthos associated with sandy, motile sediments, is less liable to damage, adapted as it is to constant change. Intertidal shellfish beds are also liable to the physical damage caused by both mechanical and hand dredging operations. Research has demonstrated that mechanical harvesting methods impose high levels of mortality on non-target benthic fauna but that recovery of disturbed sites is rapid with minimal long term effects on populations (Hall and Harding, 1997). In further work, the impact of the hand collection of cockles has also been stated to be relatively short term (ca. one year) (Kaiser *et al.*, 2001).

Concerns regarding fishing sustainability have led to a number of measures to limit stock declines and address issues relating to the survival non-target organisms returned to the sea (discards). Many discards are juveniles of commercial species or species that cannot be landed as a consequence of quota restrictions (Briggs, 1983; Bergmann and Moore, 2000; Stratoudakis *et al.*, 2001; Bergmann *et al.*, 2002). More specific measures have been introduced to protect the cod and lobster fisheries (Irish Sea Forum, 2000b). Cod fishing is limited by gear and effort limitation measures while lobster stocks are protected by the banning of the landing of female lobsters carrying eggs (Irish Sea Forum, 2000b). Further fisheries protection measures are offered by effort exclusion orders. One of these, off the Isle of Man, bans all fishing activity and allows the study of the recovery of scallops. In other areas, where the substratum has a particularly high value in terms of biodiversity, fishing using trawled gear is banned in order to protect the whole environment rather than just the fishery. Such areas include Strangford Lough and the Skomer Marine Reserve.

Fishing, particularly trawling, remains a source of habitat modification in much of the Irish Sea and it has been concluded that it is the most important ecological issue by the Irish Sea Forum (Hillary Davies, personal communication, 2005). How society deals with this threat, whilst retaining a viable fishing fleet and feeding a growing population, is an ongoing issue.

5.4 Eutrophication

Marine algae show natural seasonal cycles in abundance and classically exhibit two seasonal blooms around UK waters. These blooms, which occur in spring and, to a lesser extent, in the autumn, are controlled by light, temperature and the concentration of nutrients (nitrates, phosphates, silicates). In oligotrophic waters, such as the Irish Sea, low nutrient levels limit algal growth and the extent and size of natural algal blooms.

Many of man's activities increase the concentration of nutrients in coastal waters thereby increasing the potential growth of algae. This phenomenon is known as eutrophication and the resultant algal blooms are associated with deleterious reductions in oxygen concentration and their direct toxicity.

There is no doubt that the mean concentration of nutrients is increasing in the Irish Sea (Hartnoll *et al.*, 2002) although the pattern is not homogenous over the entire region. Hyde and Gowen (2000) reported region wide increases in phosphorous and silicate concentrations but only localised, near shore elevations in nitrate levels, particularly around the urbanised Liverpool Bay area. Whist there is an irrefutable increase in nutrient levels there have not been such clear cut associated problems. This may be as a consequence of the tidal mixing that prevents extensive stratification of much of the Irish Sea and promotes that mixing of surface waters. This mixing effectively dilutes nutrients throughout the entire water column and removes algae from optimal surface conditions thus reducing the scope for growth.

The discharge of nutrients into coastal waters is under national and EU regulation from the EU and is under continuous review. It seems likely that the trend of nutrient discharge reductions will continue and that the nutrient enhancement in the Irish Sea will decline.

6. INFORMATION GAPS

The Irish Sea is an extensively studied body of water, with research covering aspects of geology, sedimentology, hydrography, biology and ecology. This research has been carried out over many decades and useful records extend back to the early to mid nineteenth century. Earlier work has provided a wealth of taxonomic data and, more recently, work by organisations such as the JNCC has been invaluable in defining and cataloguing the presence of individual species and communities, and in their attempts to categorise habitats and ecological associations.

Generic survey work or work that concentrates on specific aspects of a biological community serves to improve our knowledge of the SEA6 area. However, there are two significant (and related) areas of information deficiency pertinent to this review. One relates to deficiencies in marine survey work that are not specific, but do apply to, the SEA6 area and the other to specific geographical areas that have not been adequately or recently surveyed within the SEA6 area. The latter is relatively easily rectified by initiating additional survey work. The former is more complicated.

Species lists and descriptions of the benthic environment are an essential prerequisite to understanding the benthic ecosystem. However, in addressing conservation issues it is important to clearly state the conservation objectives and understand the benthic ecosystem function that is being provided by any given environment/habitat. Often these objectives include the conservation of *known* biodiversity or fisheries but are sometimes not stated. In the SEA6 area, future survey and experimental research should focus more attention on integrated approaches where the community is viewed as a linked network of biological, chemical and physical parameters and where the functionality, sensitivity, resilience and natural variability of communities is addressed.

There are many gaps in our understanding of the benthic environment that are not particular, but are relevant, to the SEA6 area. All benthic surveys represent compromises between spatial coverage, the assessment of temporal and spatial patchiness and cost. To date there has been an emphasis on the assessment of large scale patchiness where dispersed samples are taken throughout a study area. This sort of experimental design does not allow the assessment of small scale patch variability, within the scale of the study, or temporal changes. Some benthic communities, particularly short-lived groups such as meiofauna, could be expected to show large seasonal and possibly interannual variability. The lack of adequately randomised and spatio-temporally replicated time-series data reduces our scope for determining where significant anthropogenically induced changes are occurring (Azovsky *et al.*, 2004). Rectifying this deficiency will take considerable funding and patience from funding bodies as long term population cycles can take decades to detect.

Much of the survey work reported here comes from either visual surveys of epifauna, for example many of the MNCR surveys, or from grab samples of soft sediment. Grab sampling and diver surveys tend to under sample two components of the biological community or cannot be used in certain areas. Grab sampling is limited by substratum type and effectively cannot sample hard or stony ground or soft ground that contains stones. Where suitably shallow such environments can be surveyed by diver but such surveys cannot adequately quantify most benthic infauna. In addition, neither diver surveys nor grab sampling can adequately sample the motile megabenthos making this component of the benthos difficult to quantify and subsequently bias the survey database and there is a lack of information pertaining to stony, cobbly ground including the relatively deep, hard glacial lags that are common in the SEA6 area. Increased use of remote survey methods, such as ROV, may go some way to addressing this deficiency. However, standard methods and protocols are required to ensure quantitative data result.

Despite the limitations to benthic sampling using grabs, numerous macrofaunal surveys have been successfully conducted in the SEA6 area. However, the class of organisms smaller than this (below 300 μm), the meiofauna, are potentially sensitive indicators of community change associated with anthropogenic influence (Schratzberger *et al.*, 2000). Quantification of this important group is lacking for much of the SEA6 area with some exceptions such as around the Isle of Man (Moore, 1975), parts of Pembrokeshire (Moore *et al.*, 1997) and Liverpool Bay (Somerfield *et al.*, 1995; Somerfield and Clarke, 1997; Schratzberger *et al.*, 2000). Prior to rectification of this knowledge gap method standardisation is required (Somerfield and Clarke, 1997).

There are many areas within the SEA6 area that are either proposed for, or have, some type of protective status on the grounds of their flora or fauna. These range from Sites of Special Scientific Interest (SSSIs) to Special Areas of Conservation and Marine Nature Reserves. From the perspective of this review a collation of these designations, and basis for their candidacy, would have been useful and would serve to highlight, in a more co-ordinated fashion, areas of high conservation value. The same applies to the Sea Empress oil spill where a peer reviewed collation of data would be a useful tool in determining the likely impact of future oil spills in the SEA6 environment.

Whilst coastal areas of this region have received considerable attention in terms of survey and research, off shore areas of the Irish Sea have been less well studied and there is consequently a paucity of high quality data which might be used in planning and policy initiatives (JNCC, 2004). Of particular note is the omission of basic information on the community structure of deep water areas, which comprise approximately 40 % of the SEA6 area.

A number of potentially useful publications are in press which may address some of the current information gaps. Most notable are a biotope classification of the eastern Irish Sea (Covey, in prep), a report on inlets of south-west Britain (Moore, in prep), benthic surveys of the bays of south west Wales (Mackie *et al.*, in prep.-a) and specifically, a survey of ‘The Gutter’ (Mackie *et al.*, in prep.-b).

Recognition of the need for greater cohesion in conservation and management of marine resources has led to initiatives such as Irish Sea Pilot project (Joint Nature Conservation Committee, 2004) which recommends collaboration in marine data collection, storage and access and a more nationally driven approach to conservation. A number of areas of high biodiversity were recommended as ‘nationally important’. Of 26 Irish Sea estuaries tested, 22 contained more than one species or habitat considered important in the Irish Sea, and the Solway Firth alone contained ten. Similar analysis for coarse sediment plains produced no meaningful data, highlighting the paucity of information for off shore sediment dominated areas in the SEA6 region. Although the criteria for defining ‘national importance’ are currently not set, the usefulness of GIS based techniques in defining areas valuable in terms of conservation and potentially susceptible to anthropogenic influence is apparent.

Implementation of the recommendations of the Irish Sea Pilot will undoubtedly go some way to addressing some the gaps in knowledge of the benthos in the Irish Sea.

7. CONCLUSIONS

The SEA6 area is a predominantly shallow, well flushed, fully saline partially enclosed temperate water sea. The seabed is mainly sedimentary ranging between mud and cobbles but consisting mainly of sand. The coastal fringe hosts excellent examples of a broad range of habitat types including exposed rocky shores, sheltered rias, highly productive sand flats, estuaries and areas exposed to rapid tidal currents. This diverse range of habitats supports a broad range of animals and plants with numerous species being protected under national and international legislation.

Anthropogenic activity within and bordering the SEA6 area has a long history but is variable in extent. Some areas, for example around Liverpool, are highly modified by man's activity while other areas, for example along the Cumbrian and Welsh margins, suffer much less from man's influence. Human alteration of the benthic environment includes both direct and indirect (via rivers) dumping, fishing and oil and gas exploitation.

The expansion of oil and gas exploitation operations within the SEA6 area has a range of potential implications for the benthic environment. These can be split into two groups, firstly those associated with the routine operations associated with production and secondly those occurring as a consequence of accidents, most notably the spillage of oil.

The long term consequences of oil production are well documented in many marine environments, particularly the North Sea (Davies, 1984; Rees, 1994), and are useful in predicting the likely consequences in the Irish Sea. However, changes in the nature of drilling muds that accumulate at the base of oil platforms limit the relevance of some published research, particularly as the SEA6 receiving environment is of predominantly higher energy compared with the North Sea. This has implications for the dilution and dispersal of damaging contaminants.

Perhaps of more concern, and potentially greater media interest, are accidental releases of oil. The enclosed nature of the Irish Sea and the prevailing wind direction mean that any spilled oil is likely to impact the coastal fringe. Intertidal and shallow subtidal communities will be at most risk from oil slicks as they may come into close contact with the material. Despite graphic and occasionally disturbing media output following oil spills the benthic environment has shown itself to be fairly resilient to the effects of oil. However, oil slicks would have considerable economic consequences on coastal communities that rely on tourism and/or shellfish collection. Tourism will be adversely affected, particularly where oil remains on popular beaches while shellfish collection is likely to be prohibited for a time following exposure to oil and be associated with a pollution incident resulting in a decline in reputation. From an ecological perspective the most susceptible coastlines include sheltered estuaries and rias that are not subject to intense weathering. These environments are relatively scarce within the SEA6 area, as a majority of the coastline is relatively exposed. However, such environments have a very high ecological value, particularly for birds which are dependent on the benthos for food. Unique habitats such as coastal saline lagoons and marine limestone caves sould also be considered at risk from local oil pollution events.

Expansion of oil and gas operations in the SEA6 area should not, with careful management, result in a substantial decline in the seabed environment and its associated animals and plants.

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9. FIGURES

Figure 1 SEA6 area showing bathymetry (Derived from 1:250000 scale BGS Digital Data under licence 2005/015. British Geological Survey © NERC)

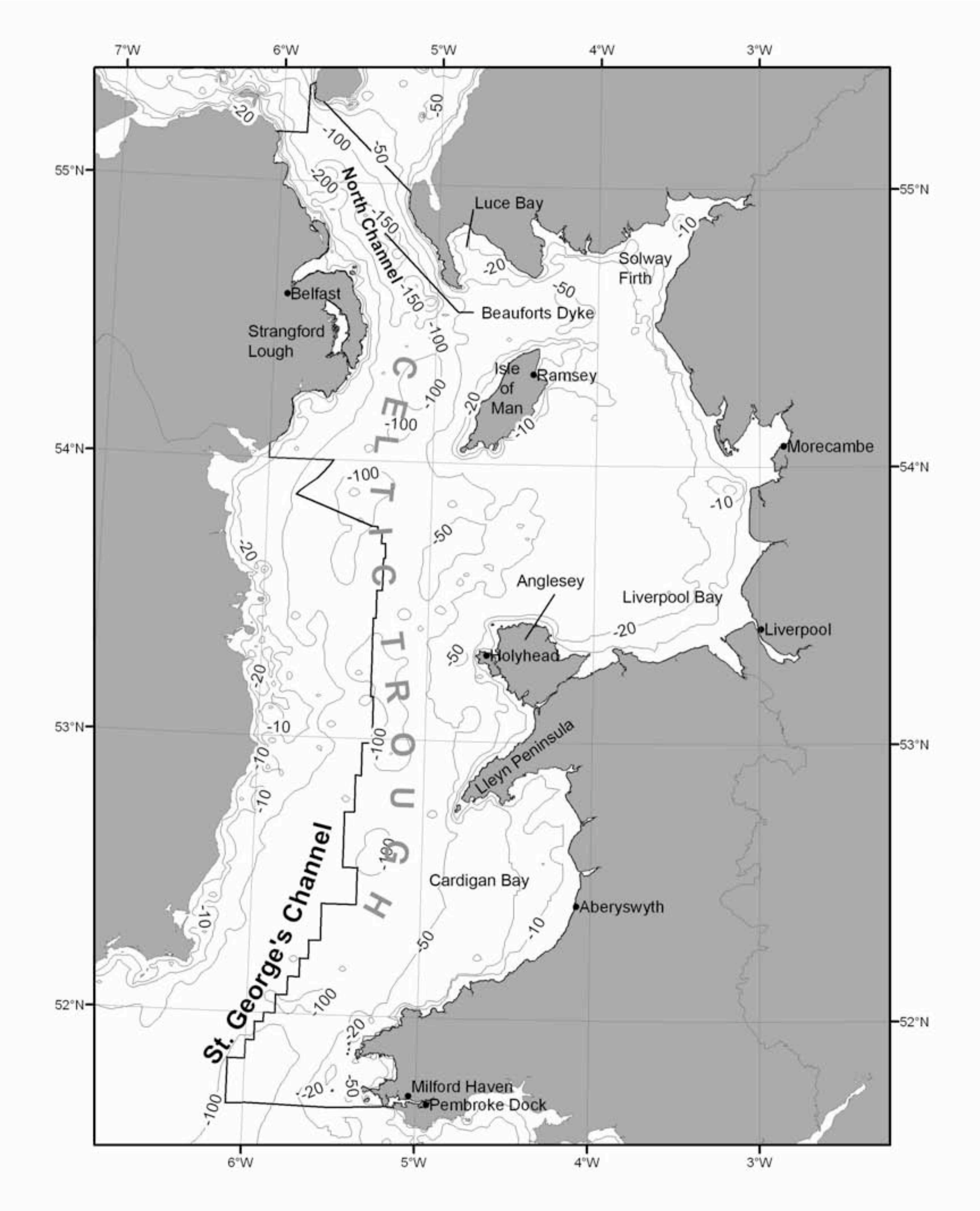

Figure 2 SEA6 area showing seabed type (Derived from 1:250000 scale BGS Digital Data under licence 2005/015. British Geological Survey © NERC)

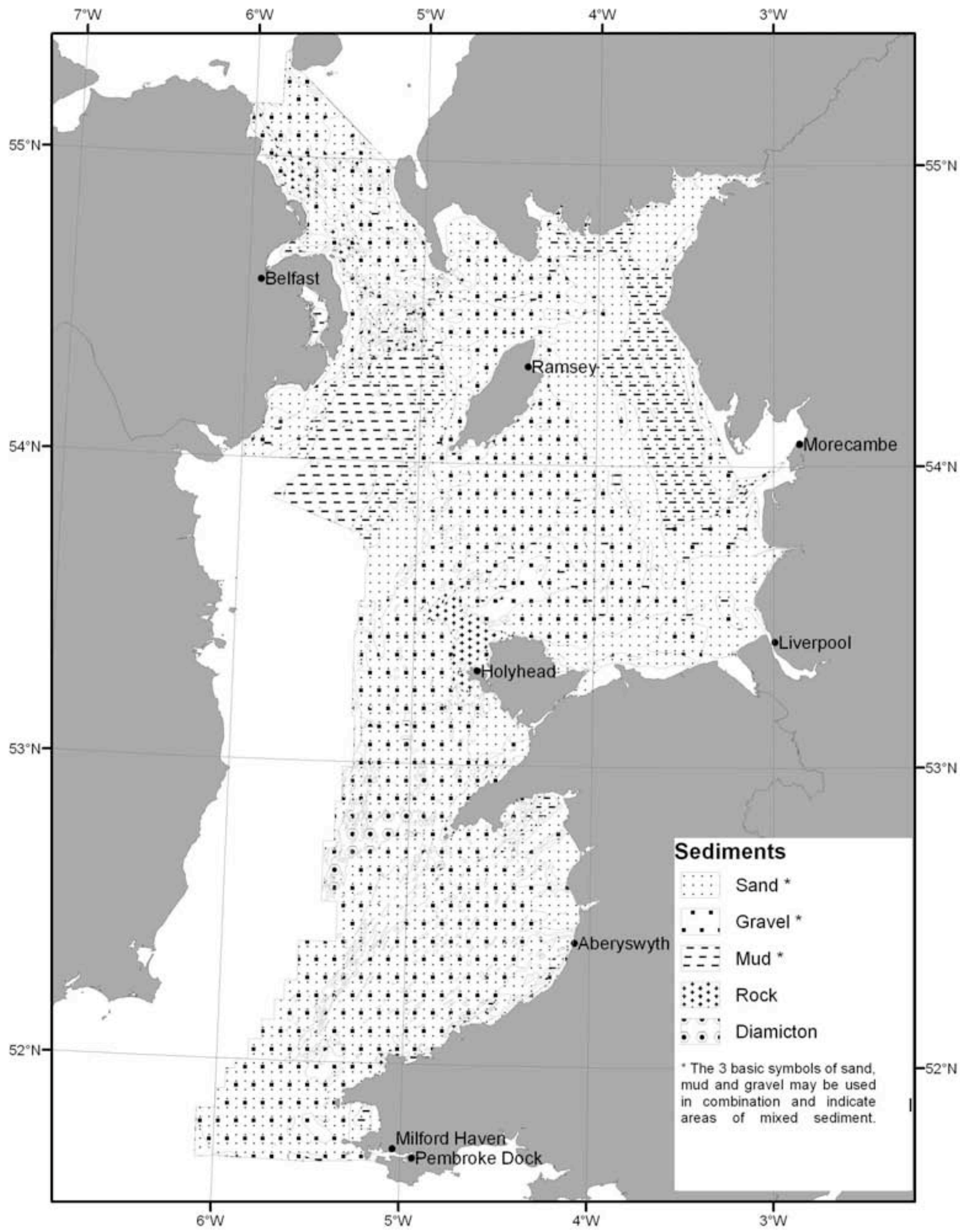

Figure 3 The Solway Firth showing sediment type (Derived from 1:250000 scale BGS Digital Data under licence 2005/015. British Geological Survey © NERC)

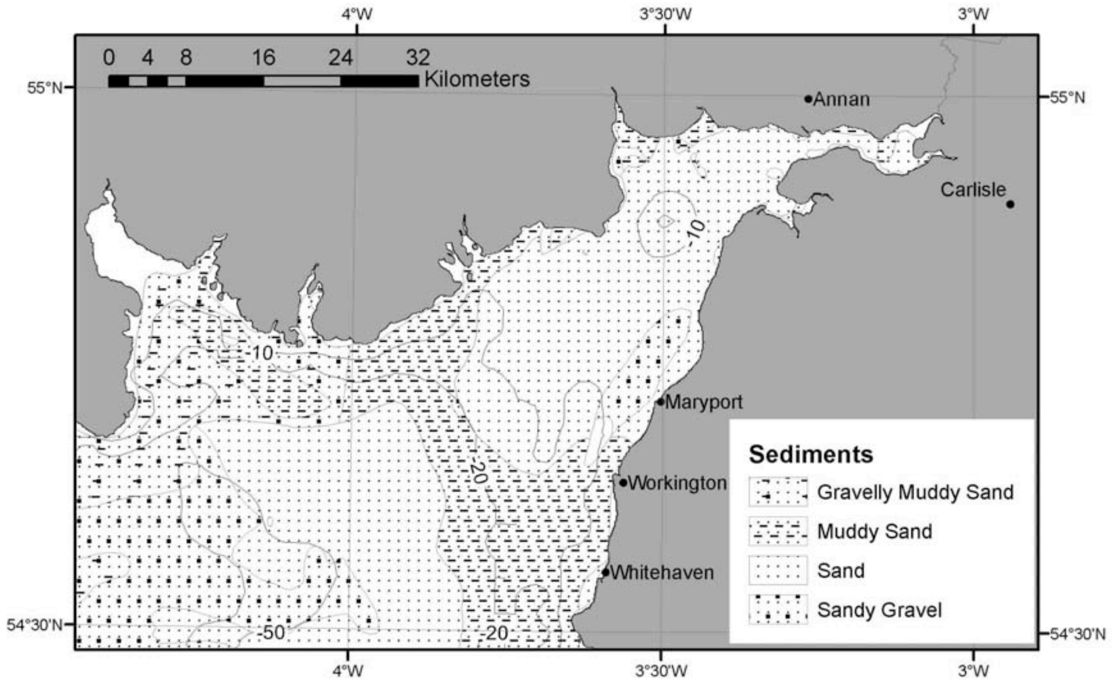

Figure 4 Morecambe Bay showing sediment type (Derived from 1:250000 scale BGS Digital Data under licence 2005/015. British Geological Survey © NERC)

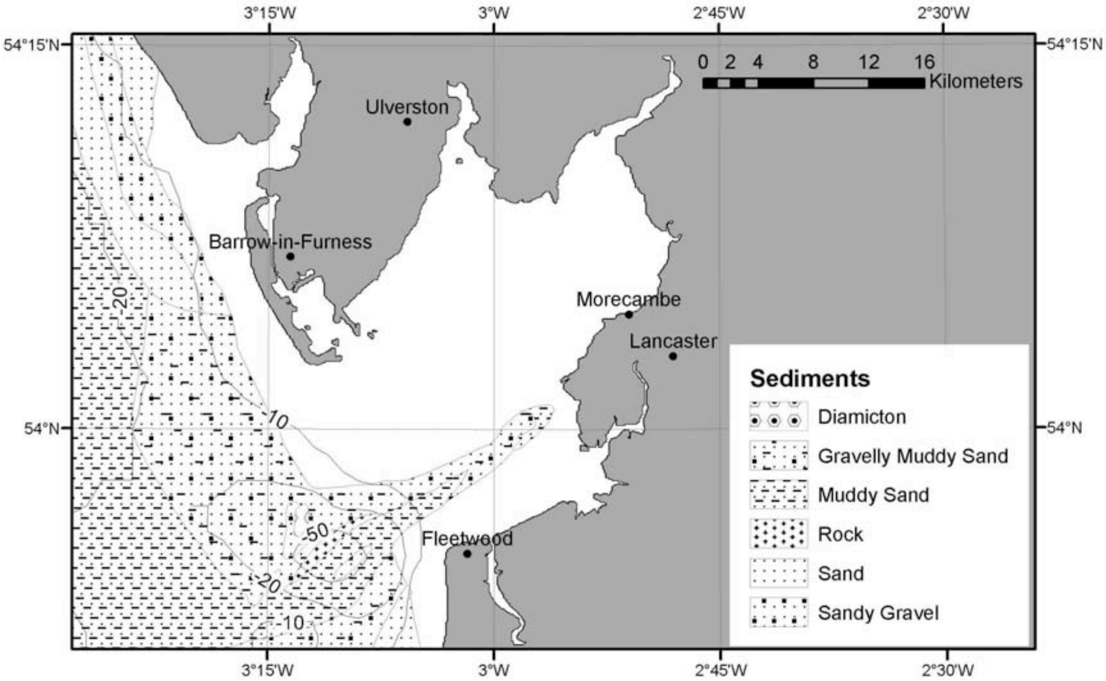

Figure 5 Liverpool Bay showing sediment type (Derived from 1:250000 scale BGS Digital Data under licence 2005/015. British Geological Survey © NERC)

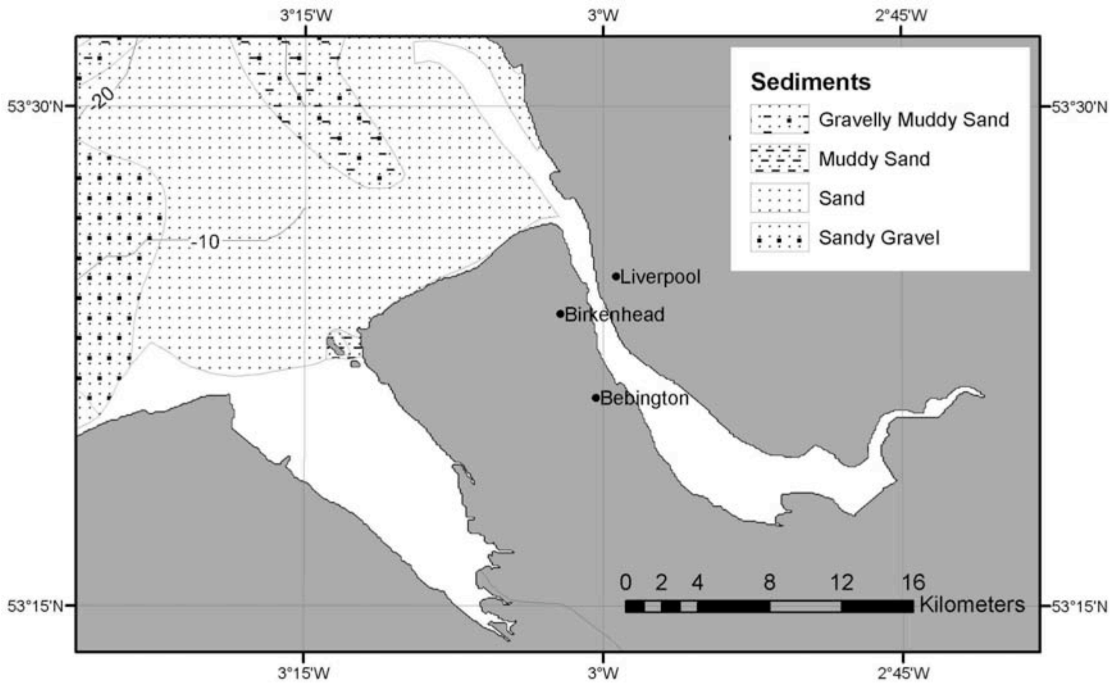

Figure 6 Anglesey and North Wales showing sediment type (Derived from 1:250000 scale BGS Digital Data under licence 2005/015. British Geological Survey © NERC)

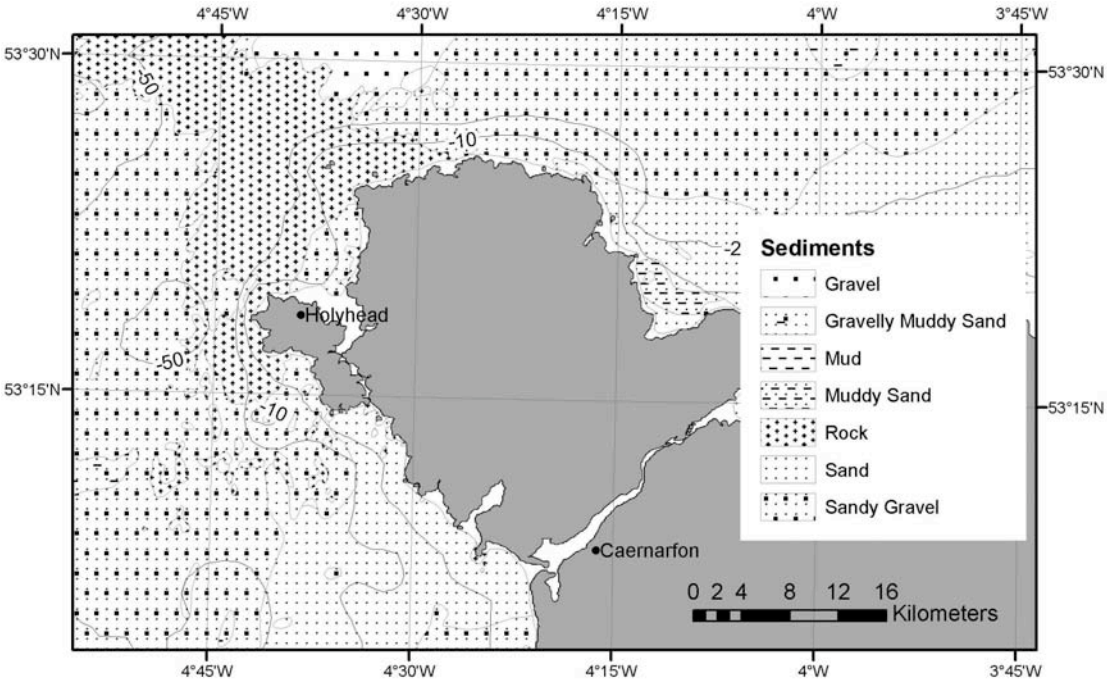

Figure 7 Pembrokeshire showing sediment type (Derived from 1:250000 scale BGS Digital Data under licence 2005/015. British Geological Survey © NERC)

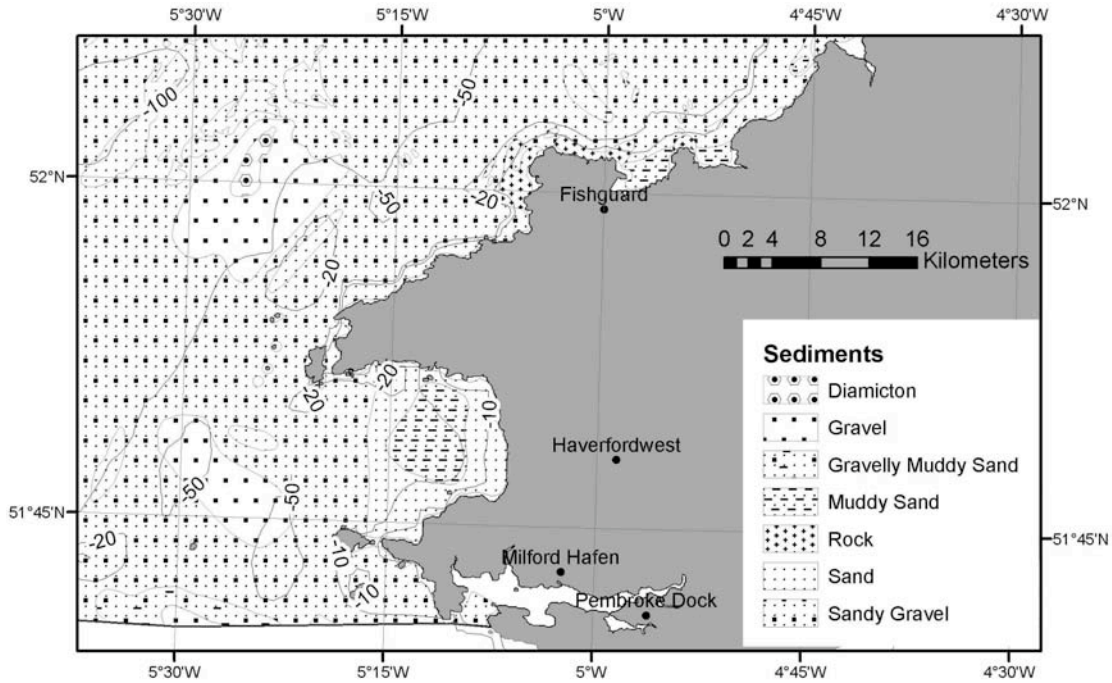

Figure 8 Strangford Lough showing sediment type (Derived from 1:250000 scale BGS Digital Data under licence 2005/015. British Geological Survey © NERC)

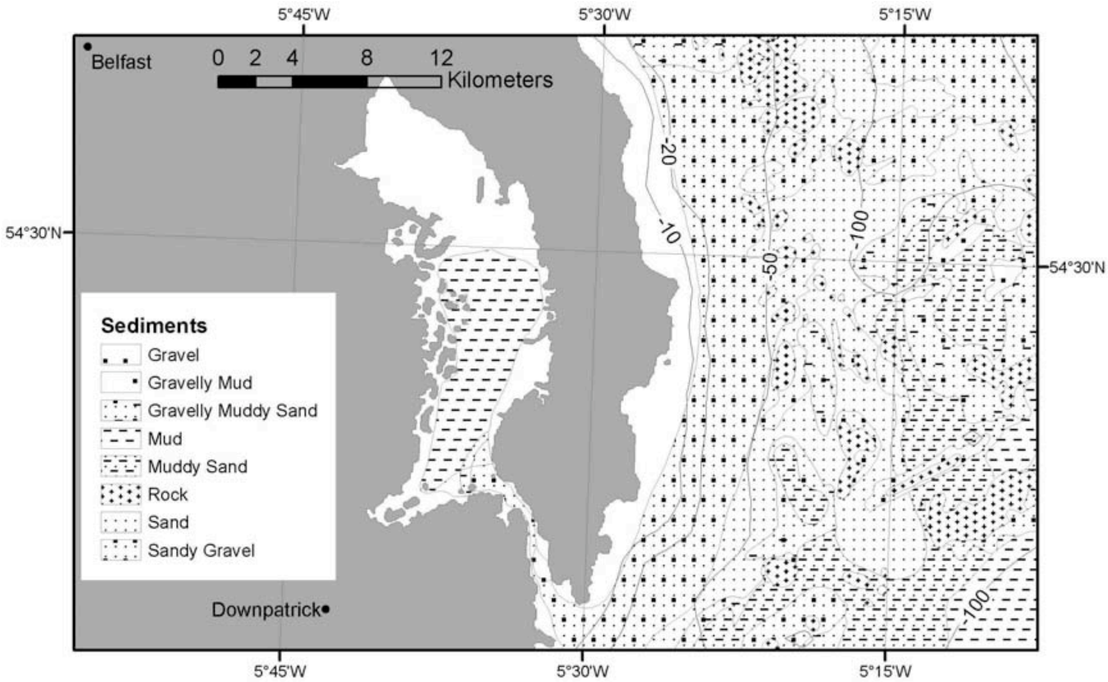

Figure 9 Isle of Man showing sediment type (Derived from 1:250000 scale BGS Digital Data under licence 2005/015. British Geological Survey © NERC)