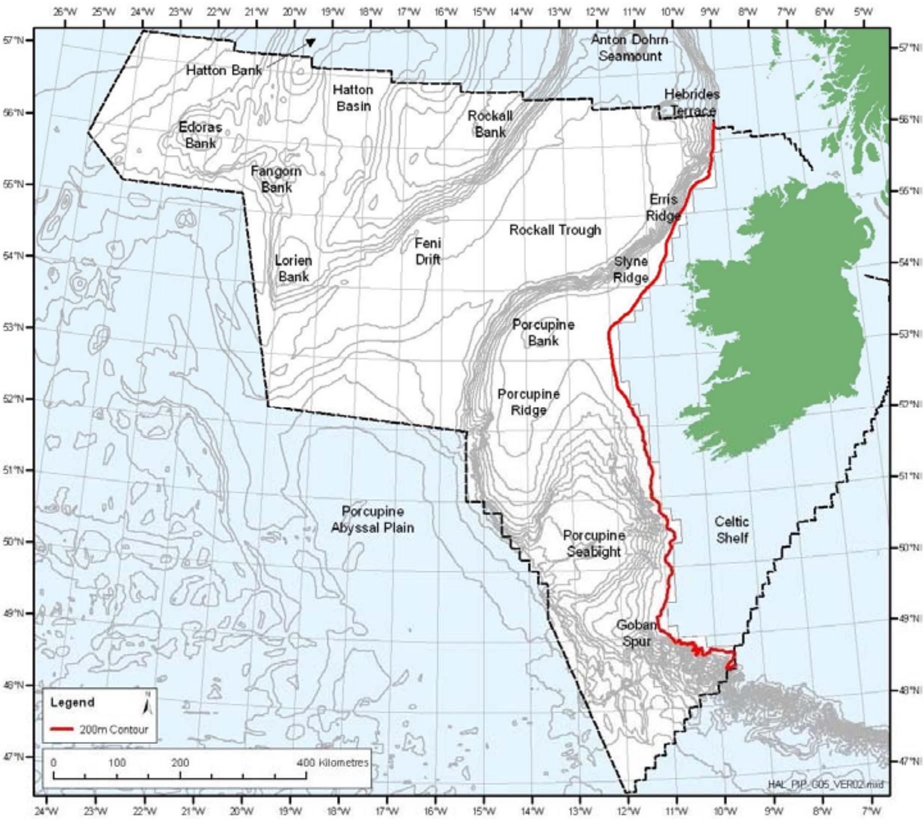
PIP

Petroleum Infrastructure Programme

Report to the Irish Shelf Petroleum Studies Group Project IS03/21

Deep water environment to the west of Ireland



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1 INTRODUCTION

1.1 Background

The deep water environment to the west of Ireland has been the subject of scientific survey and research since the exploration of the area by Wyville Thomson and colleagues onboard *HMS Porcupine* during 1869. However, the scale of the region and the technical challenges involved in surveying and sampling it has meant that our understanding of the deep water environment has lagged behind that of shelf regions. The expansion of fisheries and oil and gas exploration into the area over the last 30 years has increased greatly the need for baseline environmental information to allow assessment of potential impacts from human activities.

In response to this challenge, a joint oil and gas industry-government partnership, the Petroleum Infrastructure Programme (PIP) was established in 1997 by the Petroleum Affairs Division of the Department of Communications, Marine and Natural Resources. As part of the PIP Sub-programme (1997-2002), the Rockall Studies Group (RSG) (1997-2001) and Porcupine Studies Group (PSG) (1999-2002) have actively promoted and commissioned significant research and data gathering projects to improve environmental understanding of the Rockall Trough and Porcupine areas. These were succeeded by the Irish Shelf Petroleum Studies Group (ISPSG), which continues the work of PIP throughout the Irish offshore area.

1.2 Purpose of report

This synthesis was commissioned by ISPSG to describe the current understanding of the deep water environment to the west of Ireland. In particular, it distils the considerable environmental information and data generated by the Rockall and Porcupine Studies Groups and places it within a regional context. The aim of the work was to provide an accessible information resource for use in site specific, regional and strategic assessments.

RSG and PSG commissioned research has tended to focus on aspects of the environment of particular relevance to the oil and gas industry (e.g. geology and sediments, meteorological conditions, benthos, seabirds and marine mammals). Within this report, other key features of the environment including plankton, cephalopods, fish, and other human users (e.g. fisheries and shipping) are described to provide a fuller understanding of the deep water environment. Significant data gaps have also been identified and these may focus future research effort.

The deep water area to the west of Ireland cannot be described in isolation. There is considerable movement and interchange of physical and biological factors between it and the shallow shelf area. For example, many animals migrate between the shelf and continental slope to feed or spawn; oceanic and shelf currents may transport plankton and other organisms between both environments and deep water sediments are often the sink for contamination from sources on the shelf or coast. Relevant shelf and coastal features are therefore also described in this report.

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2 PHYSICAL AND CHEMICAL ENVIRONMENT

2.1 Regional overview

The deep water area to the west of Ireland which extends from the 200m depth contour out to the limits of Irish waters (see Figure 2.1) is topographically dominated by the Rockall Trough and Porcupine Seabight. These deep water embayments are surrounded by a number of higher plateau areas including the Rockall Plateau, Porcupine Bank and Slyne and Erris Ridges. The smaller-scale seabed landscape is a relict of several glacial periods when large volumes of material were eroded from the land and shelf and deposited at the shelf edge and over the continental slope. Sediment reworking and redistribution by often strong near bottom currents and gravity-driven processes characterise the modern sedimentary regime. Locally, the degree to which these processes impinge upon the seabed is reflected in the seabed substrates and bedforms present. A number of seabed features within the region, including pockmarks and mounds, are of considerable research interest.

The region's oceanography is complex and water masses with distinct temperature and salinity characteristics enter from the north, south and west. These interact and mix at different depths and on varying timescales to influence water currents and flow. An important feature of the upper layer circulation is the poleward flowing slope current which runs along the northeast Atlantic margin. The pathways by which deeper water masses enter and circulate around the area are not as well understood or described as those of the upper layer circulation. Tidal currents, internal waves, large scale eddy features and cascading events characterise deep water areas particularly over the continental slope, with seabed topography influencing water flows at all depths.

The region has a variable climate and experiences some of the harshest metocean conditions in the world. It is exposed to the full force of Atlantic storms with predominant winds from the west and southwest. The North Atlantic Oscillation (NAO), a large scale fluctuation in atmospheric mass between the subtropical high and the polar low, is a dominant factor in winter climate variability in the area. A positive NAO index phase shows a strong subtropical high and a deep Icelandic low. The high differential pressures result in more and stronger winter storms crossing the Atlantic. A negative NAO index phase shows a weak subtropical high and a weak Icelandic low, resulting in fewer and weaker winter storms. Though the NAO index varies from year to year, it also tends to remain in one phase for several years at a time.

In general, deep water marine environments have relatively low contaminant burdens in comparison to coastal waters. Given the region's distance from major areas of industrial activity, the relatively low amount of exploration and appraisal drilling that has taken place and the dispersive nature of the environment, sediment and water contamination levels are expected to be within background ranges.

2.2 Geology, seabed substrates and features

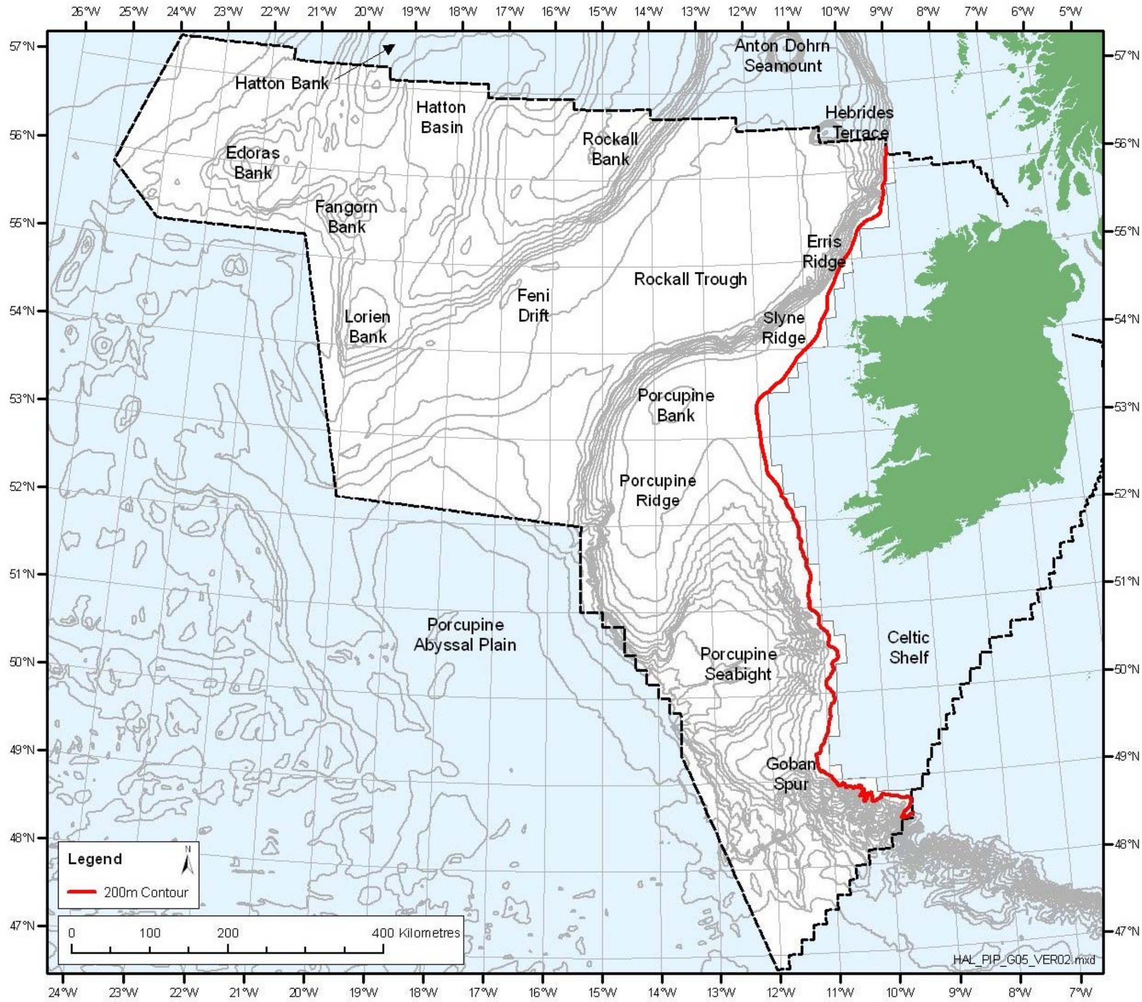
2.2.1 Overview

The overall modern topography of the deep water area to the west of Ireland originates from the influences of deep geological structure on the patterns of basin subsidence, uplift and climate on sediment input. The smaller-scale seabed landscape is a relict of several glacial periods when large volumes of material were eroded from the shelf and land masses and deposited at the shelf edge and over the continental slope. The modern sedimentary regime is dominated by sediment reworking and redistribution by often strong near bottom currents and gravity-driven processes. Locally, the degree to which these processes impinge upon the seabed is reflected in the seabed substrates and bedforms present.

2.2.2 Topography

Details of the structural morphology of the region come largely from initiatives lead by RSG and PSG to establish a structural nomenclature system for the Rockall-Porcupine area (Naylor *et al*. 1999, 2002). The topographic features described in the text are highlighted on Figure 2.1.

Figure 2.1 – Regional topography



Note: Bathymetry described by 200m contour lines.
Source: PIP GIS data, Naylor et al. (1999, 2002).

The continental shelf west of Ireland extends out more than 300km in many places, particularly in the region of the Rockall Plateau. This extensive shallow water area (220,000km^2 shallower than 1,000m water depth) around the Hatton Basin includes the Rockall, Hatton and George Bligh Banks (Naylor *et al.* 1999). The Rockall Trough and Porcupine Seabight are deep water embayments within the shelf which separate a number of higher plateau areas.

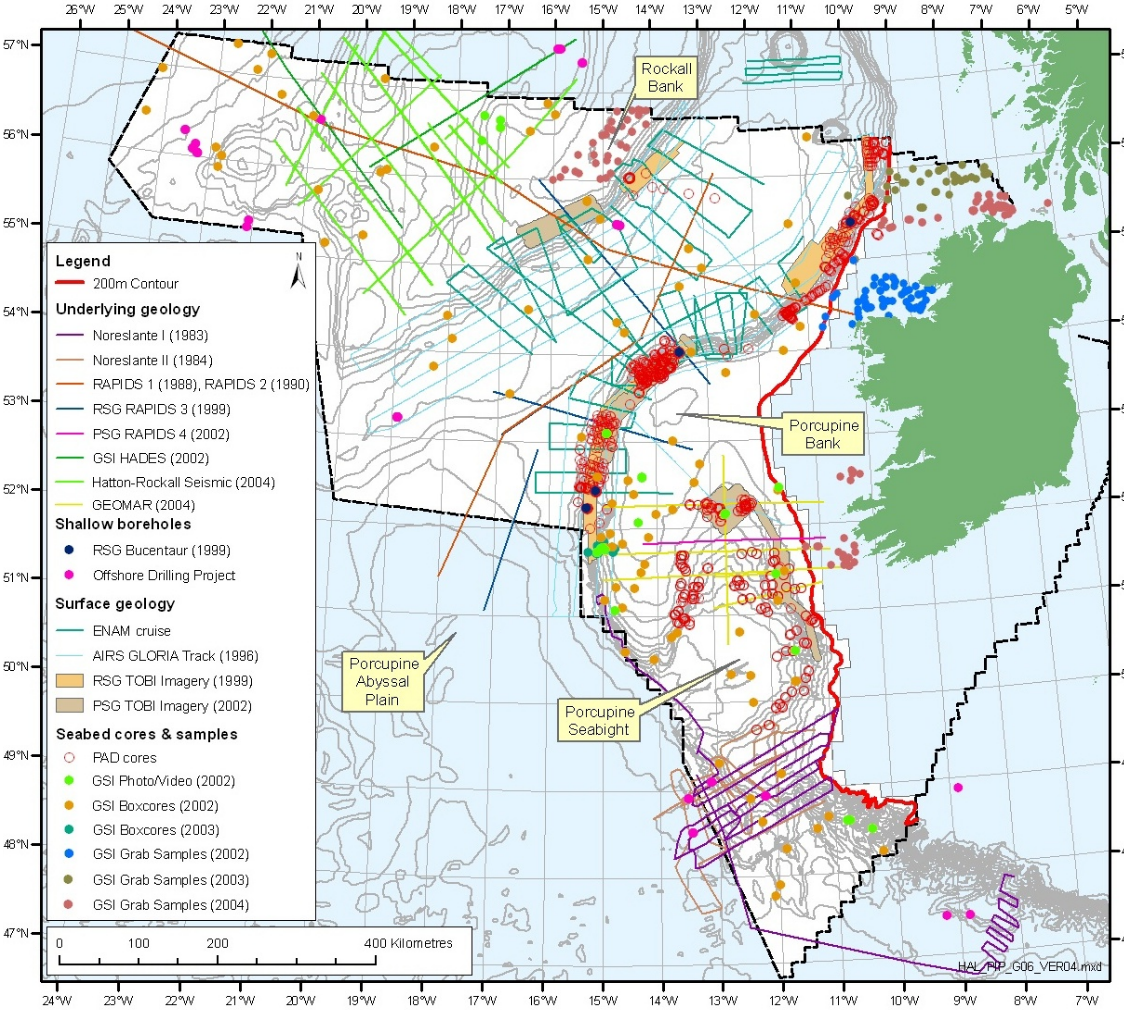
The Rockall Trough is an elongate depression 1,000km long and 250km wide trending approximately NNE-SSW (Naylor *et al*. 2002). In Irish waters it is bounded to the west by the Rockall Bank and to the east by the Erris and Slyne Ridges, northern slopes of the Porcupine Bank and the Porcupine Ridge. Slope gradients along the Trough's margin range from 2 to >20º, and water depths from 300 to >3,000m (Øvrebø 2002).

To the south, the Porcupine Seabight is a large (320 x 240km) north-south trending deep water area which opens southwestwards onto the Porcupine Abyssal Plain. Water depths increase from about 350m in the north of the Seabight to more than 3,000m in the south. The Seabight is bounded by the Irish Mainland Shelf and Celtic Shelf to the east; the Slyne and Erris Ridges to the north, whilst the western boundary is formed by the Porcupine Ridge which extends southwards from the Porcupine Bank. The Goban Spur which slopes to depths of 2,000m forms the Seabight's southern boundary. South of the Goban Spur, the continental slope is cut by deep canyons (Naylor *et al*. 2002).

2.2.3 Geological survey and research

A summary of the range and coverage of geological surveys is presented in Figures 2.2 and 2.3.

Figure 2.2 – Geological surveys in the region



Source: PIP GIS data.

Given the physical scale of the region and the technical difficulties in surveying and sampling it, international collaboration has been central to many of the region's geological research programmes. For example, much of the research into the geological and ecological significance of seabed mounds has progressed through EU funded projects (GEOMOUND, ECOMOUND and ACES). Other survey programmes include the Atlantic Irish Rockall Survey (AIRS96), CORSAIRES, Training Through Research (TTR), Noreslante I and II, ENAM and GEOMAR. The discovery of hydrocarbons in the region has generated significant research interest. The Irish government has commissioned deep seismic (e.g. HADES) and coring projects (e.g. PAD cores) whilst the Rockall and Porcupine Studies

Groups (RSG and PSG respectively) of the Irish Petroleum Infrastructure Programme (PIP) has sponsored significant research in the region into both the underlying geology (e.g. RAPIDS 3 (RSG project 97/11) & 4 (PSG project 00/3b), Hatton-Rockall seismic (in association with GSI), deep coring project (RSG Bucentaur 1999)) and the surface sediments and features (e.g. TOBI sidescan - RSG TRIM project 97/14 and PSG project 00/19) of the region. The ongoing Irish National Seabed Survey has also provided good quality data on many aspects of the region's surficial geology.

Irish National Seabed Survey

Initiated in 2000, the Irish National Seabed Survey is a seven-year, €32m survey of Ireland's seabed. The survey is being managed by Geological Survey of Ireland (GSI), in co-operation with the Marine Institute and other strategic partners. The INSS is primarily a multibeam sonar survey of an area of 525,000km^2 in size and represents one of the largest seabed mapping projects undertaken anywhere in the world.

The multi-beam survey is providing detailed bathymetry data and information on the nature of the seabed and its overlying sediments. Magnetic and gravity data area also collected and are helping to evaluate the nature and structure of the deeper geology. Other survey techniques which are being used include:

- Single beam echo sounder
- Sub-bottom profiler (shallow seismic)
- water column measures of salinity, conductivity, temperature and speed of sound profiles
- Seabed ground-truthing (including grab samples, seabed cores, and video/still photography)
- Sidescan sonar

In addition, the INSS has supported a variety of ancillary projects throughout the survey programme, ranging from physical oceanography to cetacean and seabird recording.

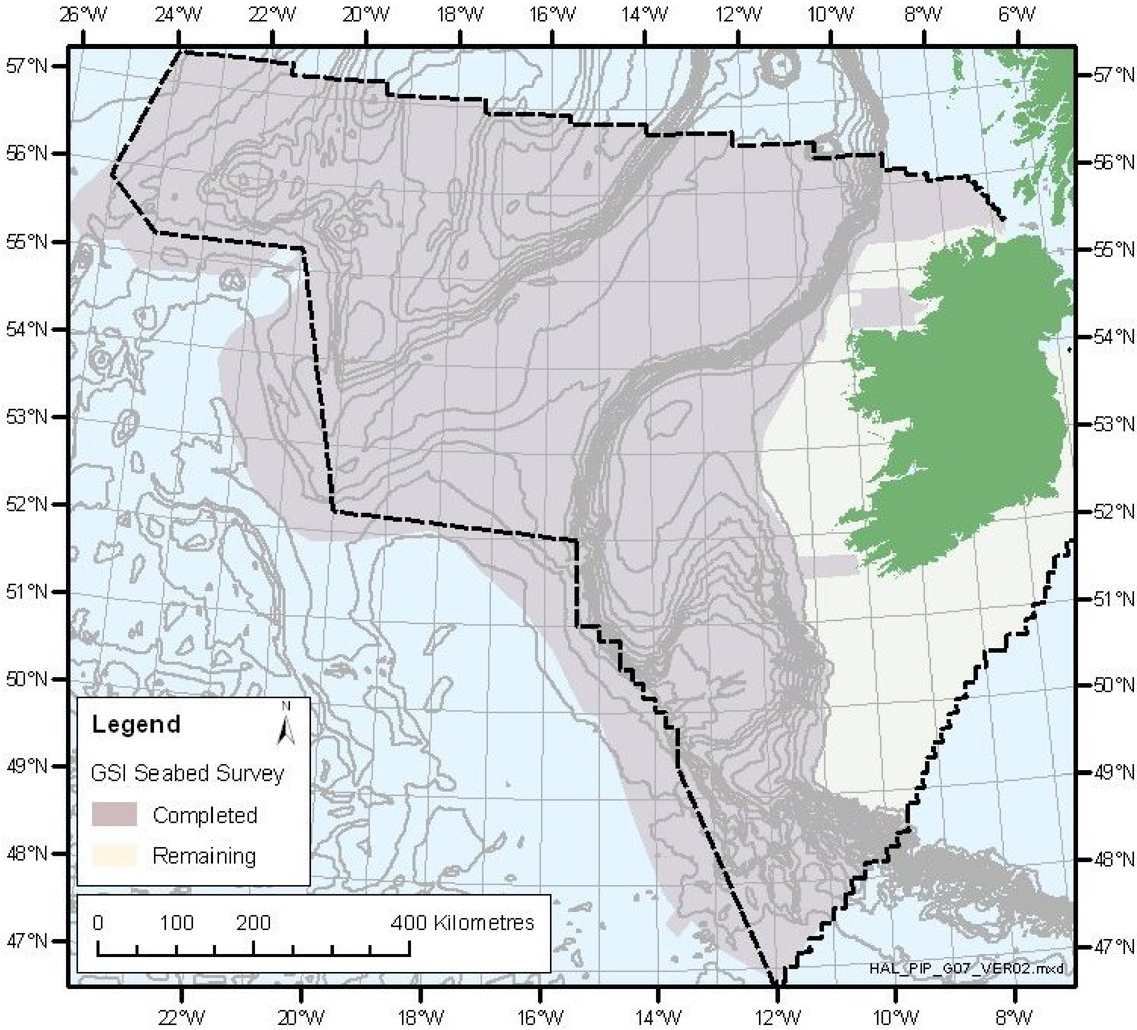
Recent INSS survey work (July 2004) included a high-resolution seismic survey to investigate possible hydrate deposits west of Rockall and the extent of sedimentary rock in the Hatton area. The survey was done in conjunction with PAD and the Irish Shelf Petroleum Studies Group.

The deep water area to the west of Ireland (INSS Zone 3, 200-4,500m water depth) has now been completely surveyed and detailed studies of almost 450,000km^2 of the Irish seabed have now been completed. Figure 2.3 highlights survey coverage to date and includes both INSS and Petroleum Affairs Division data coverage (pers. comm., E Doyle GSI, M Davies PIP, INSS website – http://www.gsiseabed.ie).

Details of survey progress and associated projects are presented at annual INSS seminars, the most recent at Cork in November 2005. Presentations from this and previous seminars contain a wealth of data and are available on CD through the INSS website (http://www.gsiseabed.ie).

The comprehensive bathymetric and geological maps that are being produced by the INSS are regarded as a pre-requisite for the policy evolution, management and sustainable development of Ireland's marine resources (INSS website).

Figure 2.3 – INSS seabed coverage



Source: pers. comm., E Doyle, GSI

The maps will be useful in indicating the likely distribution, extent and location of potential mineral deposits (e.g. sands, gravels, gas hydrates) or potential hydrocarbon indicators. Fish habitats are often controlled by the nature of the seabed, and fishery interests seek information which makes fishing more economical while minimising the environmental impacts of trawling. Baseline maps will also assist in studying natural hazards as well as global environmental changes. Ocean engineering including cable and pipeline laying, and the siting of rigs and offshore installations also will benefit greatly from the results of the survey. Survey results will also be useful to those with interests in offshore aquaculture, navigation, deep sea cold water corals, heritage (including shipwreck identification), renewable energy developments and waste management (INSS website)

2.2.4 Underlying geology

The present day morphology of the eastern Atlantic margin largely results from rifting activities during the Mesozoic which resulted in the formation of the North Atlantic Ocean (De Haas *et al*. 2000). The major rifting episodes were of Permo-Triassic, Middle and Late Jurassic, and Early to Late Cretaceous age. Rifting between Rockall and Norwegian basins during the Cretaceous first created the unity of the region which following Atlantic opening, finally became the Atlantic Margin (Naylor *et al*. 2002).

Within the Irish sector a band of narrow (inboard) basins, including the Slyne and Erris basins, lie landward of a set of larger (outboard) basins that include the Rockall, Hatton and Porcupine basins. A number of small, elongate, probably early Mesozoic basins are located in the footwalls of the Rockall Basin (Naylor *et al.* 1999). The topographic highs and lows west of Ireland are the product of several successively failed attempts to extend the axis of mid-Atlantic sea-floor spreading to the northeast. The Porcupine Seabight, Rockall Trough and Hatton Basin are the remainders of abandoned (initial) spreading centres, leaving the Porcupine, Rockall and Hatton Bank as topographic highs (De Haas *et al*. 2000). The crust beneath the basins is continental in nature and is typically 15-25km thick beneath the inboard basins but thins to as little as 7km beneath the outboard basins (e.g. Makris *et al.* 1991, Shannon *et al*. 1994).

Post-rifting Mesozoic to Quaternary sedimentary covering finally resulted in the present day morphology of the area. Basins in the region contain a variable thickness of Upper Palaeozoic to Recent strata with the thickest succession in the Porcupine Basin where in excess of 10km are preserved. The basins in the Rockall region contain up to 6km of strata (Shannon *et al.* 1995, 1999) while the thickness of strata in the Slyne and Erris basins is typically of the order of 3-4km (e.g. Chapman *et al.* 1999, Dancer *et al.* 1999).

The bathymetric configuration of the Rockall Trough has changed little since the mid-Cenozoic when Late Eocene-Oligocene differential subsidence deepened the trough. This deepening was associated with the onset of bottom-current circulation in the region (Stoker *et al.* 2001). By the Early Miocene, the Greenland-Scotland Ridge (including the Wyville-Thompson Ridge) was submerged and deep-water exchange between the Arctic and North Atlantic oceans was established (Boldreel & Andersen 1995). The Early Miocene to Early Pliocene was thus characterised by strong deep-water bottom current circulation resulting in the accumulation and development of contourite sediment drifts and waves in the region (Stoker *et al*. 2001). The Plio-Pleistocene transition marked a period of major cooling in the North Atlantic and the initiation of northern hemisphere glaciation (Øvrebø *et al.* 2006).

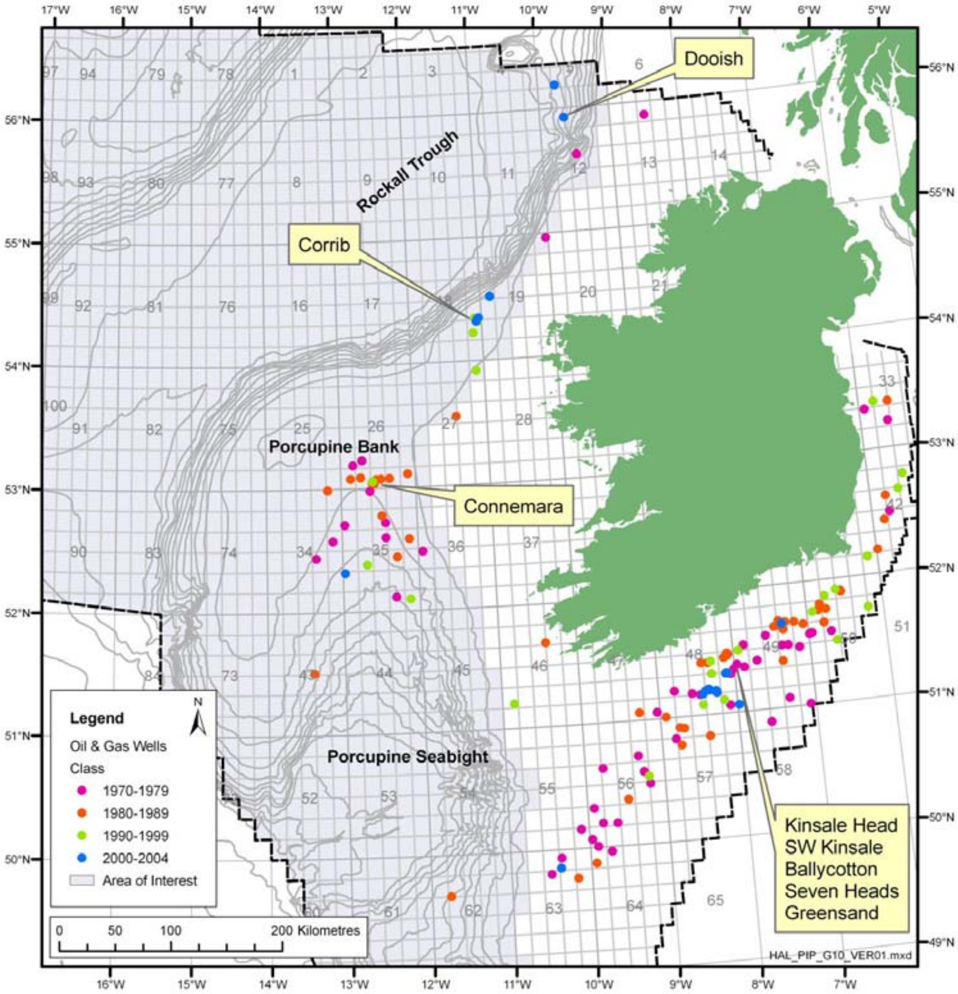
Petroleum geology

Since the early 1970s, over 160 offshore exploration and appraisal wells have been drilled in Irish waters, predominantly in the Celtic Sea basins (Fastnet, North Celtic Sea, South Celtic Sea basins) (see Figure 2.4). To date, gas is produced commercially from a number of fields in the Celtic Sea basin including Kinsale Head, Ballycotton, SW Kinsale, Seven Heads and Greensand.

To date, the only commercially viable hydrocarbon discovery to the west of Ireland is the Corrib gas field currently under development. Discovered in 1996, the field lies in the Slyne Basin approximately 65km off the northwest coast of Co. Mayo in frontier acreage blocks 18/20 and 18/25 (Figure 2.4).

The field extends over an area of 15km^2 over which water depths vary between 330-370m. The reservoir is formed from Triassic (245-208Ma) sandstones with overlying Triassic mudstone and halite (salt) providing an effective topseal (Enterprise Energy Ireland 2001a).

Figure 2.4 – Exploration and appraisal drilling in the region.



Note: Includes 24 appraisal wells, 9 appraisal/development wells, 137 exploration wells and 3 pre-development appraisal wells.
Source: PAD website – www.pad.ie

The region's deep water basins have seen little exploratory drilling (37 exploration wells west of Ireland of which only 9 were drilled in last 10 years), so that only the subsurface geology of the northern part of the Porcupine Basin, with some 26 exploration wells (Figure 2.4) and greater seismic coverage is understood to any significant extent (Naylor *et al.* 2002). A number of wells in the Porcupine Basin have shown the presence of good quality oil or gas (Croker & Shannon 1995) although none have yet yielded commercially extractable quantities. These include Connemara, a currently sub-commercial oilfield first drilled by BP in 1979 and subsequently reappraised by Statoil in the mid 90s. The Dooish prospect, a gas condensate discovery in the Rockall Trough was first drilled in 2002 (see Figure 2.4 for field locations).

2.2.5 Seabed substrates and features

Seabed processes

The morphology and distribution of surficial sediments in the region has resulted largely from the interplay of glacial processes (e.g. iceberg rafting, debris flows), and palaeo- and modern-day physical processes including bottom currents and gravity-driven slope processes. The relative importance of these processes has varied both temporally and spatially. Through PIP-funded projects, extensive areas of seabed along the Rockall and Porcupine margins have been mapped (e.g. O'Reilly *et al.*

2001, Wheeler *et al*. 2003) providing a wealth of data on seabed sediments, features and processes. Further information as to the nature of the region's seabed sediments is becoming available through the ongoing Irish National Seabed Survey (http://www.gsiseabed.ie). For the present report, seabed sediments are described in relation to important seabed processes and features.

Huvenne *et al.* (2003) identified a range of processes (and associated features) which have affected the continental slope in the Porcupine Seabight including those associated with channel and canyon systems linking the shelf edge with the abyssal plain (e.g. the Gollum Channel system, Kenyon *et al.* 1978); mass flows and submarine slope failures resulting in downslope sediment transport (Moore & Shannon 1991); alongslope sediment transport and associated contourite and drift deposits (Van Rooij *et al.* 2003), and superimposed local current effects. Iceberg ploughmarks and seabed scouring have also been observed on the shelf and slope (Games 2001).

A wide range of processes have operated in the Porcupine Bank area: pelagic and hemipelagic settling, ice-rafting, bottom current reworking and deposition and gravity flows (Øvrebø 2001). Whilst there is evidence of mass flow deposits (particularly associated with canyon systems), sediment analysis suggests that active bottom currents were the main process on the Porcupine Bank slope depositing and reworking sediments (Øvrebø 2001, 2002). However, late glacial climate changes determined whether the depositional processes were pelagic, hemipelagic, ice-rafting or current reworking (Øvrebø 2001). There is also evidence that weaker bottom currents were active during periods of glaciation than during deglaciation (Øvrebø 2001, 2002). Bedform geometry (Kenyon *et al.* 2003), current meter data (Howe 1995); oceanographic modelling (New & Smythe-Wright 2001), and contourites on the Porcupine Bank suggest that the enhanced interglacial flows may have flowed from south to north (Øvrebø *et al.* 2006.).

The record of ice rafting indicates a glacial influence across the Atlantic margin since the late Pliocene (ca. 2.54Ma) (Shackleton *et al.* 1984). Widespread expansion of ice sheets across the Irish shelf in the mid- to late Pleistocene interval resulted in widespread erosion of the shelves as the ice sheets extended to the shelf edge. At their maximum extent, the ice sheets delivered sediment directly to the continental slopes resulting in considerable shelf margin progradation (Stoker 1995).

Evidence of extensive ice-rafting (e.g. significant coarse granule and pebble debris) and ploughmarks have been recorded on the Porcupine Bank (Figure 2.5) but are less evident elsewhere indicating that ice rafting was either more subdued or deposits have been reworked by other processes (e.g. gravity currents) (Øvrebø 2001). Potential iceberg ploughmarks up to 7km long and 150m wide have been noted on the Rockall Bank (Kenyon *et al.* 2003). Extensive iceberg scouring has also been described at the Corrib field in the Slyne Basin (Figure 2.6). In this area, iceberg ploughmarks were characterised by coarse gravel and cobbles on ploughmark shoulders and very soft clay infill (Enterprise Energy Ireland 2001a).

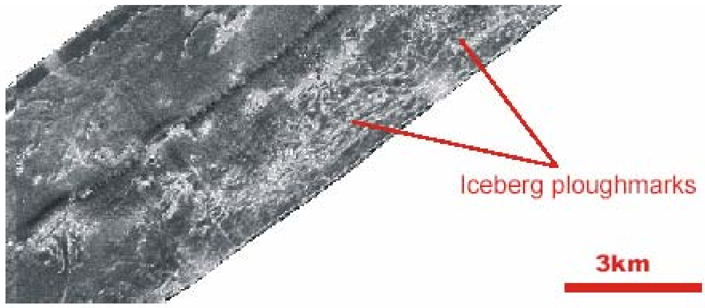
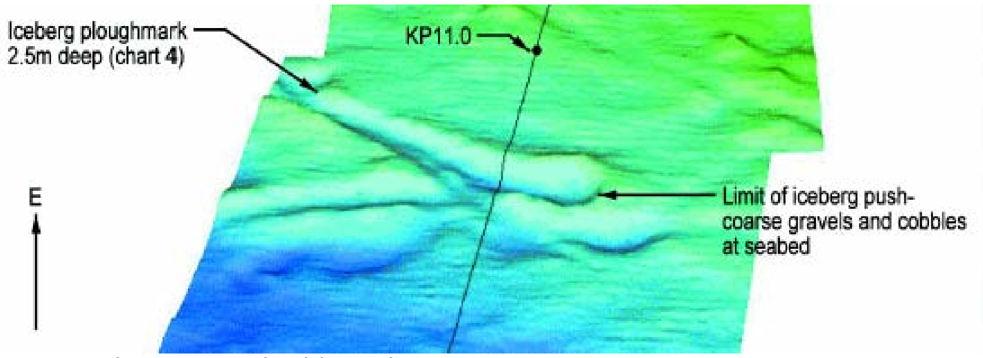


Figure 2.5 - Iceberg ploughmarks on Porcupine Bank.

Source: Wheeler et al. 2003

Figure 2.6 – Iceberg ploughmark in the vicinity of the Corrib field



Source: Enterprise Energy Ireland (2001a).

The flux of glaciogenic sediments was highest along the Rockall margin close to the Hebrides Terrace Seamount. Slope processes in this region were dominated by glaciomarine sedimentation with the deposition of debris flows and megaturbidite sequences along the Donegal Fan (O'Reilly *et al.* 2001). The modern-day creased and folded seabed topography generated by these mass down slope movements determines the distribution of sandier sediments, with sand present in depressions and absent from highs. These slope failures may have been important conduits whereby sand was delivered to deeper water (Øvrebø 2001).

Slope failure processes were also important on the east flank of the Rockall Bank, against a background of hemipelagic and pelagic settling and current reworking and deposition (Øvrebø 2001). Contourites, winnowed lags and active seabed erosion on the northeast flank of the Rockall Bank indicate the increased importance of current reworking and deposition further north (Howe *et al.* 2001).

In general, glacial processes had a very strong influence on the development of the slope along the eastern margin west and northwest of Donegal. These become progressively less significant in shaping the geomorphology of the margin towards the southern Porcupine Bank where fluvial and shelf transport processes were more important in supplying sediments to the margin slope. The present day slope processes are dominated by contour parallel currents on both the eastern and western margins of the Rockall Trough and these form a large cyclonic circulation system within the Rockall Trough (O'Reilly *et al*. 2001).

Seabed features

A lot of information on seabed processes and substrates has come from the study of particular seabed features. A description of some of the most notable features provides additional information on the seabed morphology of the region.

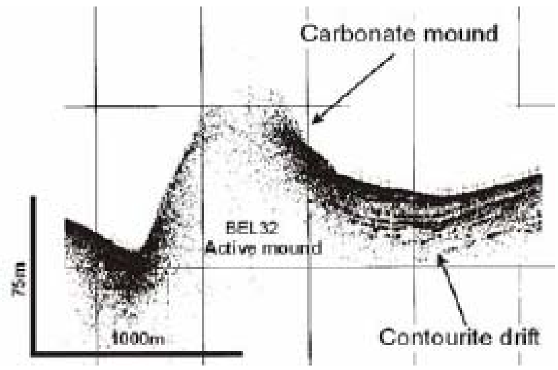
Contourites & drifts

Contourites are deposits from bottom currents which flow in deep waters approximately parallel to bathymetric contours (i.e. along slope). They occur widely over the region, particularly along the eastern margin of the Rockall-Porcupine region and can be areas of rapid sedimentation, bottom scour or unstable foundation (Austin 2000). Howe (1995) described both sandy and muddy contourites on the Hebrides Slope in the northern Rockall Trough. Sediments for these contourites were supplied by hemipelagic and glaciomarine processes, being redistributed under the influence of alongslope-current activity.

A number of large-scale sediment bedforms have been described from the northeast Rockall Trough including broad sheeted drifts, elongate drifts, sediment waves and thin contourite sheets (Masson *et* *al.* 2002). These bedforms have evolved through a complex interaction between bottom currents of variable intensity, sea level change and sediment input. The present sea level highstand is characterised by minimal sediment input and redistribution of sediments by strong bottom currents, giving active bedform growth and contourite development (Masson *et al*. 2002).

In the Rockall Trough and Hatton Basin extensive sediment drifts are present which were formed under the influence of bottom currents (De Haas *et al.* 2000). For example, the Feni Drift in the western and central Rockall Trough is the oldest and one of the largest sediment drifts in the NE Atlantic, consisting of a main ridge some 600km long and a subsidiary ridge to the southeast of the main one (Vermeulen 1997). The 500m or so thick sediments of the drift consist largely of fine-grained material eroded from sources to the north and deposited by the southwestward- flowing currents since the Oligocene-Miocene. The surficial sediments of the drift are characterised by sediment waves parallel to the depth contours, particularly on the eastern flanks of the ridge. These waves have amplitudes up to 50m and wavelengths up to about 4km.

Figure 2.7 – Contourite drift associated with a Belgica mound



Note: Image from 3.5kHz sub-bottom profiler.
Source: Wheeler et al. (2003).

Locally, smaller scale contourite drifts may be associated with seabed features such as carbonate mounds. For example, the Belgica mound province in the eastern Porcupine Seabight is characterised by relatively strong bottom currents and contourite drifts consisting of well-sorted sands may bury some of the upslope flanks of the mounds (Figure 2.7, Wheeler *et al.* 2003).

Slides & slumps

The gradients of marine slopes within the region regularly exceeds 5° and are occasionally greater than 15° (Austin 2000). Relatively abrupt increases of slope angle and slope angles in the order of 2º or more are associated with sediment-drift (contouritic) bedforms, rock crop at or near seabed in areas with very strong currents and features formed by canyon and submarine landslide processes (Holmes *et al.* 2002).

In the NE Rockall Trough, modern submarine landslides occur south of approximately 56.5ºN on the Barra and Donegal Fans. These features map to relatively steep slope angles, prograding deposits associated with fan build-out towards deep-water and to proximity to the epicentres of modern seismicity (Holmes 2002).

The buried Gullwing/Erris base-of-slope wedge is a massive example of a gravity-driven submarine slide or more likely a rapid series of slides and associated debris flows on the Erris slope in the eastern Rockall Basin (Austin 2000). This mass wasting feature is some 256km in length and whilst narrow in the south has a classic gullwing shaped geometry further north where it extends out into the basinal environment for 100km. The wedge was formed by the large scale collapse of the upper slope probably due to late Miocene-early Pliocene faulting (Austin 2000).

The deep-water areas of the western Rockall Trough and further west have been relatively sediment starved compared to those of the eastern Rockall Trough and there are relatively few submarine landslides (Holmes *et al*. 2002).

Canyons & channels

The continental slope from Iberia to the southern Rockall Trough is dominated by deeply incised canyons (Weaver *et al.* 2000). These canyons are near the southern limits of the Quaternary ice cover, and may have been fed by coarse sediments contained in meltwater. Canyons were most active during low sea level stands as more material was transported to the canyon head at these times. Many canyons are largely inactive during interglacials, and can become partly infilled with pelagic and hemipelagic sediments (Weaver *et al.* 2000).

The Celtic Sea slope is cut by a network of large channels and canyons which feed sediments to deeper areas. In contrast, there is only one major sediment-supplying channel system, the Gollum Channel present on the southern margin of the Porcupine Seabight (Kenyon *et al*. 1978, Van Rooij *et al*. 2003). This consists of a number of east-west trending channels which converge into one deeply incised canyon on at water depths of 3,000m which flows into the Porcupine Abyssal Plain (Van Rooij *et al.* 2003). The northernmost of these channels is the widest and deepest, reaching a depth of about 400m and a width of 1.5km. Channel slopes are up to 25° steep (Beyer *et al*. 2003).

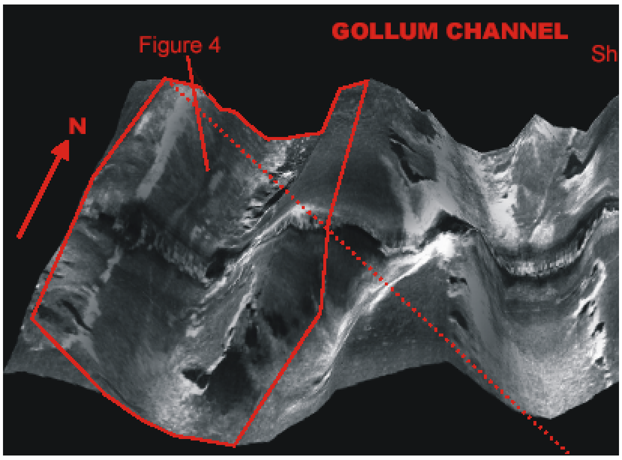


Figure 2.8 – Gollum Channel system

Note: TOBI side scan image
Source: Wheeler et al. (2003).

The steep-sided channels of the Gollum Channel system are highlighted in Figure 2.8. Canyon flanks are characterised by high backscatter implying coarse-grained and/or consolidated material with slide scarps and gullying implying slope failure and erosion of the canyon sides. Debris lobes in some canyons suggested reduced down-canyon activity at present. The canyon floors consist of coarser-grained material with meandering channels. Between canyon areas are typified by homogenous muddy substrates (Wheeler *et al*. 2003).

Seabed mounds

Recent discoveries of extensive clusters of reefs and mound structures in the North Atlantic have generated significant scientific interest. The mound structures have been identified at the seabed or in the shallow subsurface and their formation is generally linked to the development and growth of deep, cold-water coral species such as *Lophelia pertusa* and *Madrepora oculata* (Unnithan & Shannon 2003).

To the west of Ireland, carbonate mounds are very numerous (>1,000), of various sizes and occur as both seabed features and buried mounds. The mounds lie in water depths ranging from 500 to 1500m and are generally located towards the upper parts of the shelf-slope break along the basin margins, and also on the main basin-bounding banks. Their morphology and shape range from simple cones to complex amalgamated ridge features covering up to 5km^2 and standing up to 300m in height. The matrix of the mounds consists of interbedded layers of foraminiferal ooze and coral debris (both *Lophelia pertusa* and *Madrepora oculata)* while thickets of living coral and associated benthic community cover the upper parts of the mounds (Kenyon *et al.* 2003). The cold water coral communities found on carbonate mounds are described further in Section 3.3. Various models for the origin and growth of carbonate mounds have been proposed ranging from hydrocarbon seepage and nutrient models to oceanographic and current influences. However, as yet conclusive evidence as to their origin and growth is lacking (Unnithan & Shannon 2003). In addition to carbonate mounds, volcanic cones and possible mud volcanoes (mud mounds) have also been identified.

In the past decade, a significant amount of new data has been gathered on the geological, ecological and biological aspects of the seabed mound structures found to the west of Ireland and the UK. Large scale European studies (e.g. GEOMOUND, ECOMOUND and ACES) continue to provide insight into important geological and biological aspects of the mounds. Seismic data has provided an overview of their geological context (e.g. De Mol *et al.* 2002, Huvenne *et al*. 2003) with cores and ROV video observations providing local information of the seabed and shallow subsurface on and around mounds (e.g. Kenyon *et al.* 1998, Olu-Le Roy *et al.* 2002). Seabed mapping projects (e.g. O'Reilly *et al.* 2001, 2003, Wheeler *et al.* 2003, Huvenne *et al.* 2005) have also provided details of seabed geomorphology, geology and processes in a number of mound areas in the Porcupine-Rockall region.

On the basis of ROV, multibeam, sidescan sonar, echosounder and seismic records, a number of mound provinces have been identified in the northern and eastern Porcupine Seabight, Porcupine, Rockall, Hatton and Fangorn banks, to the west of Ireland (Figure 2.9, Unnithan & Shannon 2003).

Within the Porcupine Seabight, the Belgica mound province on the eastern flank comprises a set of mostly conical mounds, the majority of which are still visible at the present-day seafloor, reaching a height of up to 100m above the seabed (Huvenne *et al*. 2005). The Hovland province is located to the north and the mounds are conical to elongated, ridge-like structures, reaching up to 150m above the seabed. Just to the north and west, the Magellan mound province consists of a large number of mounds which are mostly buried under sediments (Huvenne *et al.* 2003).

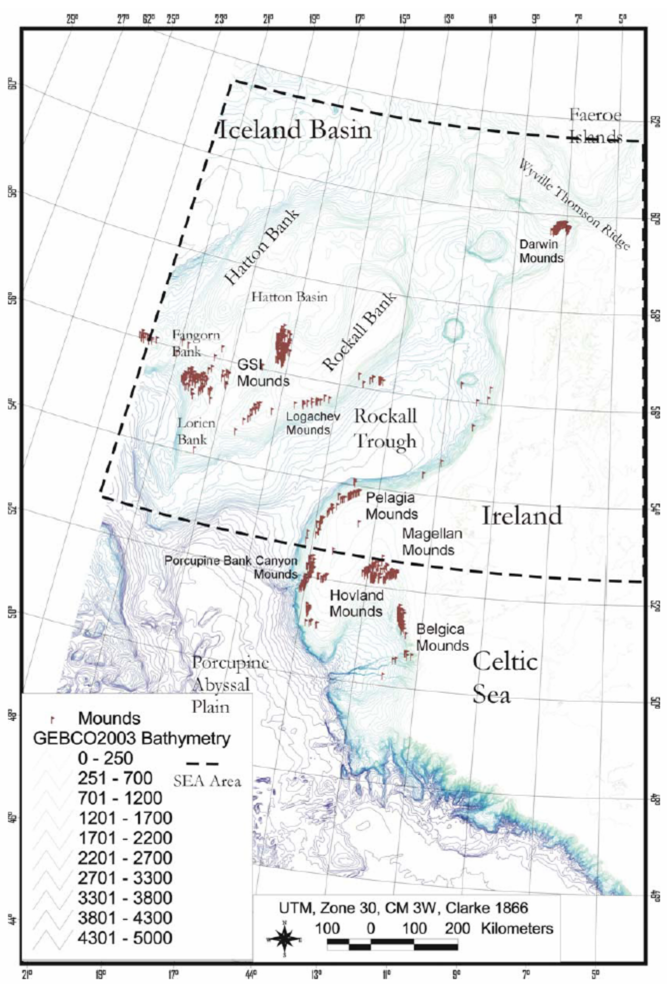


Figure 2.9 – Location of mound provinces in the region.

Source: Unnithan & Shannon (2003)

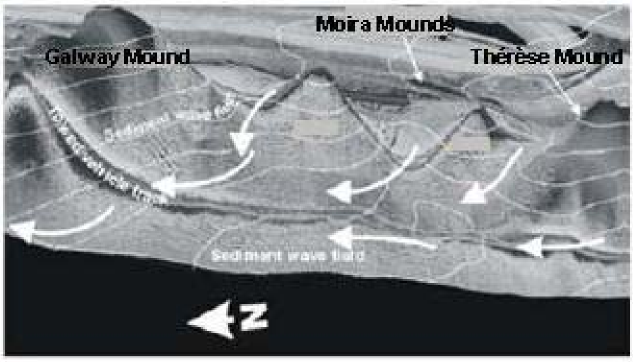
Side-scan sonar and ROV video observations indicate marked differences between the Seabight mound provinces.

The Belgica mound province appears to be a much more dynamic environment than the Magellan and Hovland provinces.

Sediments indicative of strong bottom currents such as gravel lags and coarse sediments are found in the Belgica province, together with patches of sorted sands, striations, barchan dunes, and sediment waves.

The richest coral communities with the most abundant live coral occurrences are also found in this area (Huvenne *et al.* 2005).

Figure 2.10 – Bottom currents through the Belgica province



Note: 3-D prospective of 100kHz side scan sonar mosaic draped over multibeam bathymetry. White arrows indicate benthic current directions. Thin white curves show bathymetrical contours. Source: Wheeler et al. (2003).

Figure 2.10 highlights the bottom current direction through part of the Belgica province as interpreted from sediment bedforms. The sedimentary pattern and bedform occurrence fits well with observations of a northward directed slope- or bottom current. For example, the highest residual bottom currents have been measured along the eastern slope of the Seabight (11cm/s, in a NNW direction, Pingree & Le Cann 1989), while mean values for the northern Seabight do not exceed 5cm/s (White 2001). However, episodic increases in bottom current associated perhaps with strong internal tides may be responsible for creating bedforms such as barchan dunes which require stronger currents (Huvenne *et al*. 2005).

Compared to this current-influenced area, the Magellan and Hovland provinces are much quieter. No bedforms are found, the sediment is finer, bioturbated and watery. However, higher current speeds may have affected the area in the past, as evidenced by moat formation around both Magellan and Hovland mounds and from the scouring of channels in the Hovland province (Huvenne *et al*. 2005). The Hovland mounds are specifically located along these channels and may benefit from the enhanced currents that these provide. Scouring in the Magellan province only happened as a result of the presence of the mounds, and it appears that current enhancement in this area never reached the same levels as in the Hovland province. This may explain why the Hovland mounds could develop to much larger structures and escape early burial as happened with the Magellan mounds (Huvenne *et al*. 2005).

Carbonate mounds are also found associated with the Porcupine Bank Canyon on the southern margin of the Porcupine Bank, as well as the Pelagia Mound province on the northwest Porcupine Bank. The Pelagia Mounds are larger (average 300m in height, covering a few square km) than the Hovland and Belgica mounds and are also found in slightly deeper waters (750 to 1,200m) (Unnithan & Shannon 2003). Numerous erosional features (e.g. iceberg ploughmarks, scarps and scours) are present within the province (Wheeler *et al.* 2003).

The Logachev Mound province on the eastern margin of the Rockall Bank consists of highly complex field of closely spaced, contiguous mounds (Kenyon *et al*. 2003). The mounds have a variety of shapes and the larger ones are very steepsided, up to 350m high and 2km wide at the base. Sediment bedforms on the SE Rockall Bank show evidence for strong alongslope currents with significant accumulation of coarse sandy material between the mounds being transported and deposited by strong currents. Carbonate mud waves on the mound flanks appear to be moulded by across-slope directed internal tidal currents and/or cascading currents (Kenyon *et al.* 2003). The Rockall Bank mounds are covered by a carpet of coral debris which supports a living coral fauna consisting mainly of *L. pertusa* and *M. oculata* (Unnithan & Shannon 2003). Abundant boulders, stone and gravel fragments provide the hard substrate required for coral settlement (Wilson 1979).

The discovery of new mounds on the Rockall, Hatton and Fangorn banks has been reported by the Geological Survey of Ireland and detailed analysis of the extent, size and morphology of these mound structures is ongoing (Geoghegan & Monteys 2003). Preliminary examination of the Fangorn Bank mounds suggests that they are morphologically similar to the Hovland mounds. They have distinct moat structures, are generally conical in shape, and are about 350m in height. However, the mounds are found in slightly deeper water (around 1,250m) than the Hovland mounds (Unnithan & Shannon 2003).

To the north, the Darwin Mounds were discovered on the Wyville Thomson Ridge in 1998 during the AFEN and later 1999 DTI surveys north and west of Scotland. There are in excess of 225 mounds and each mound is approximately 50-100m in diameter and up to 5m high. The mounds are found in water depths of 900 to 1,060m, north of a large area of pockmarks and appear to be closely related to these fluid escape features (Masson *et al.* 2003). The tops of the mounds are covered by *Lophelia pertusa* and less abundant *Madrepora oculata* and associated fauna. The mound tails are characterised by high-density populations of xenophyophores, which are giant protozoans unique to the deep-sea (Unnithan & Shannon 2003). The Darwin Mounds have recently been put forward as the UK's first offshore candidate Special Area of Conservation under the EC Habitats Directive.

Whilst the last decade has seen considerable progress in defining the nature, composition, structure and distribution of seabed mounds within the region, information on their origin remains elusive. Various oceanographic, biological and palaeoclimatic variables and their influence on cold water bioherms and mounds are likely to play a role in the initiation and growth of the carbonate mounds (Unnithan & Shannon 2003).

Geophysical evidence has been obtained to suggest the presence of some active mud volcanoes or mud mounds in the Porcupine Seabight (Jean-Pierre Henriet, pers. comm., cited by Unnithan & Shannon 2003).

Seamounts

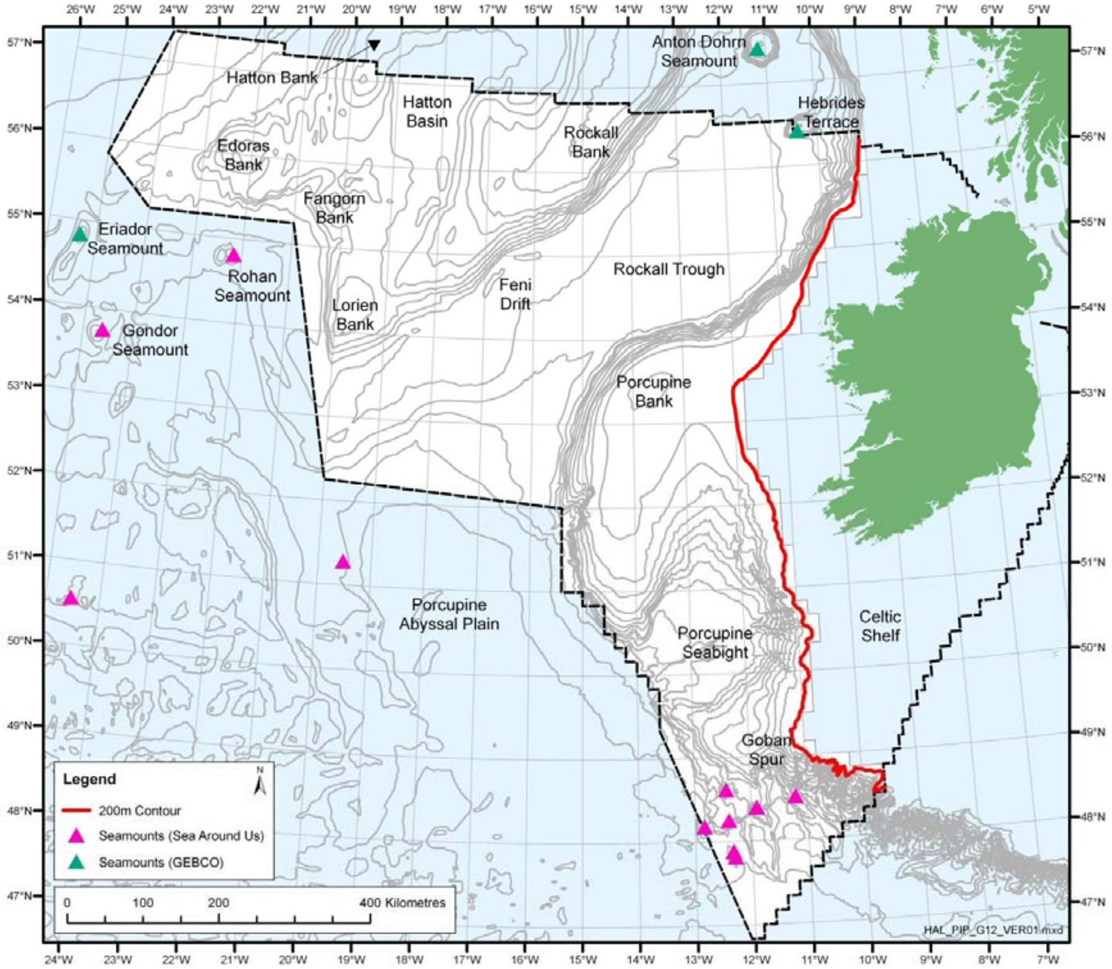
Seamounts are undersea mountains (usually of volcanic origin) rising from the seafloor and peaking below sea level (Duxbury & Duxbury 1989, Kennish, 2000). There are many opinions on what defines a seamount, but one widespread definition states that a seamount should be steep-sided and rise 1,000m or more from the sea floor (Duxbury & Duxbury 1989, Epp & Smoot, 1989). The ICES Working Group on Deep Water Ecology defined seamounts as bathymetric features rising at least 1,000m above the surrounding seafloor (ICES 2005). Most seamounts are circular or elliptical (Epp & Smoot 1989), although very elongated seamounts do occur (Wessel & Lyons 1997). Seamounts may have associated moats which can of significant size for example, the continuous moat around Rosemary Bank reaches over 200m deep (K Hitchen, pers. comm.).

Their relief above the seabed has profound effects on the surrounding oceanic circulation, with the formation of trapped waves, jets, eddies and closed circulations known as Taylor columns (Taylor 1917 in Rogers 1994, cited by OSPAR 2004c). The enhanced currents around seamounts provide ideal conditions for a range of benthic suspension feeders such as corals, sponges and hydroids, as well as concentrations of commercially important fish species, such as orange roughy (Gubbay 2002). Seamount biological communities may also have high levels of species endemism with Wilson & Kaufmann (1997) estimating that 12-15% of all seamount species were endemic, while other sampling programmes have found levels of more than 30% for benthic invertebrates (e.g. Koslow *et al.* 2001). However, more comprehensive survey is required to support this data.

Information on the biological importance and vulnerability of seamount habitats and species to activities such as demersal fishing is limited. However, seamounts have been included on the initial list of OSPAR threatened and/or declining habitats and species and information on their distribution and ecological status is being collated (ICES 2005).

Seamounts are widespread within the OSPAR area particularly along the Mid-Atlantic Ridge. To the east of the Ridge, a number of seamounts (or potential seamounts) have also been identified with those of relevance to the current project highlighted on Figure 2.11.

Figure 2.11 – Potential seamounts in the region



The exact number of seamounts present within the region varies depending on the seamount definition and bathymetric map used. Seamounts identified by OSPAR (2005) were based on records in the Seamounts Online database (http://www.seamounts.sdsc.edu) which were overlain on a GEBCO (General Bathymetric Chart of the Oceans) map to distinguish those seamounts rising over 1,000m from the seafloor (Figure 2.11). However, as no set distance was recommended in the OSPAR definition over which to measure the height of a seamount (i.e. the steepness of slope) a degree of interpretation was required to validate each seamount record. Additionally positional differences between GEBCO (a low resolution map) and the Seamounts Online dataset meant that some seamount features did not coincide with GEBCO bathymetric features (ICES 2005).

Kitchingham & Lai (2004) utilised a more up-to-date US National Oceanographic and Atmospheric Agency (NOAA) digital global elevation map to identify potential seamounts as part of the *Sea Around Us Project* (http://www.seaaroundus.org) (see Figure 2.11).

A range of geophysical (e.g. seismic, gravity, magnetics, bathymetry) and coring/drilling projects have been undertaken by BGS and others on seamounts in UK waters of the Rockall Trough including Rosemary Bank (a seamount in the northern Rockall Trough), the Anton Dohrn seamount and the Hebrides Terrace seamount (Figure 2.11, e.g. Morton *et al.* 1995, Hitchen *et al.* 1997, O'Connor *et al.* 2000, K Hitchen, pers. comm.). Hitchen (2004) has also described a series of former volcanoes including Sandastre and Mammal which form large volcanic domes at the seabed in the Hatton Basin.

In Irish waters, recent surveys suggest the presence of numerous volcanic seamounts in the vicinity of Lorien Bank (Peter Croker, pers. comm., cited by Unnithan & Shannon 2003). The Irish National Seabed Survey has also highlighted new mound structures of presumed volcanic origin in the southern Rockall Trough, Fangorn Bank and Eriador Seamount (Unnithan & Shannon 2003). Further analysis of INSS data will undoubtedly lead to a better definition of seamounts within Irish waters.

Pockmarks

Pockmarks have been described from a number of locations in the deep water area to the west of Ireland although detailed information as to their morphology and distribution is presently unavailable. The ongoing Irish National Seabed Survey may provide valuable information as to their extent and location although at present data is restricted largely to water depths of less than 200m as image resolution in deeper waters is generally too low to definitively identify and map pockmark features.

Pockmarks are thought to form at times of fluid/gas escape at the seabed and often appear as small depressions or 'pockmarks' associated with areas of soft mud (Figure 2.12). Where pockmarks are associated with modern fluid/gas escape, they may contain carbonate material formed from the biogenic oxidation of methane. Such pockmarks may be of considerable ecological importance as they may conform to the EC Habitats Directive Annex I habitat, *Submarine structures made by leaking gases* (Judd 2001, DTI 2001, 2004a).

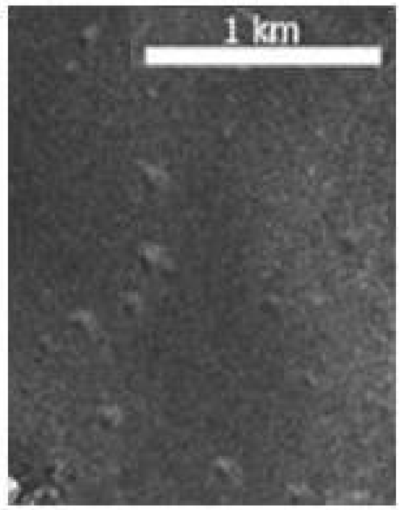


Figure 2.12 – Small pockmarks in the Belgica mound province

Source: Wheeler et al. (2003).

Potential areas of pockmarks have been observed in the northern and eastern Porcupine Seabight. Recent survey work suggests that pockmarks surveyed between the Gollum Channel and Belgica mound province were located partly over buried carbonate mounds (J-P Henriet, pers. comm., cited by Wheeler *et al.* 2003). The pockmarks had an average diameter of 140m (Figure 2.12). A few pockmarks have also been observed within the Magellan and Hovland mounds (Huvenne *et al*. 2005). Pockmarks observed in the mound provinces are not thought to be active structures but may have been active in the recent past (Unnithan & Shannon 2003). Potential small pockmark features were observed on sonar records of the Corrib field (Enterprise Energy Ireland 2001a), and both hydrocarbon seepage at the seafloor (Games 2001) and pockmarks (Huvenne *et al.* 2003) have been recorded from the area of the Connemara oil discovery in the northern Porcupine Basin, although whether they are directly related is currently unknown. No evidence of pockmarks was found in surveys of mound provinces on the northern Porcupine Bank or the Logachev mounds (van Weering *et al*. 2003).

Hydrates

The Irish designated area contains two large deep water basins, Rockall and Porcupine, which have suitable conditions for the formation of methane hydrate. The NUI Galway study assessed the potential for the formation of commercially extractable deposits of methane hydrate in these basins. The hydrate stability zone (HSZ) is that portion of the sedimentary accumulation in the basins, in which the temperature and pressure conditions are suitable for hydrate formation. The two main factors governing thickness of the HSZ are the seabed temperature and the geothermal gradient. Using the data available for these factors, the variation of the HSZ with depth was calculated for the Porcupine and Rockall Basins. The calculated HSZ increases in thickness from 0 m at about 700 m water depth, to 650 m in the Rockall Basin and to 720 m in the Porcupine Basin. These figures are based on poorly constrained hydrothermal and geothermal data and local variations can be expected. A geological model for the formation of commercial deposits of hydrate was created. This model necessitates the presence of a thermogenic source of methane, a migration pathway to the HSZ and reservoir quality sands and gravels in the HSZ, with sufficient pore space to allow high concentrations of hydrate to form. Both basins have evidence of active hydrocarbon systems capable of providing a thermogenic source of methane so this study focused on assessing the presence and quality of migration pathways and reservoirs. The NE Rockall Basin was identified as the most promising area for further research into hydrates.

2.2.6 Data gaps

Whilst knowledge of the subsurface and surface geology of the deep water region has improved considerably, particularly over the last decade, there are still large gaps in our understanding. Large scale seabed mapping projects have highlighted particular features (e.g. seabed mounds, pockmark fields) which require further local scale survey and sampling in order to better understand their formation, geological and ecological importance.

Many of the seabed features described above are regarded as potential geohazards to hydrocarbon exploration and development. Following an assessment of geohazards within the Rockall Basin, Austin (2000) identified a range of features that required further investigation. These included issues relating to: slope canyon and valley systems; slumps and debris flows; contourite deposits; areas of active fluid or gas escape; possible occurrences of gas hydrate accumulations, carbonate build-ups and reef development.

2.3 Oceanography and hydrography

2.3.1 Overview

The deep water region to the west of Ireland displays a complex oceanography. Water masses of distinct temperature and salinity characteristics enter the region from the north, south and west. These interact and mix at different depths and on varying timescales to influence water currents and flow dynamics in the region.

The scale of the region and the inherent difficulties in surveying it has meant that detailed oceanographic information is limited both spatially and temporally. Whilst there are examples of long-term survey and monitoring (e.g. Ellett *et al*. 1986), much of our current understanding has derived from modelling work. Therefore, whilst there is good agreement on many aspects of the region's oceanography, there are still areas which are as yet poorly understood.

2.3.2 Water masses and circulation

Water masses

The waters of the region are composed of a number of water masses with different origins and distinguishable temperature and salinity characteristics. Water mixing processes over varying temporal and spatial scales result in the gradual modification of the original characteristics of these water masses. Thus, at a given point the characteristics of a water mass carry imprints of its formation and subsequent mixing history, and provide insights into the underlying processes of circulation and mixing (Curry *et al*., 1998).

The water masses within the region fall into several categories - upper water to a depth of about 700m, intermediate waters down to 1600-1900m and deeper waters below this depth. Within these categories a number of different water masses are present.

Upper water

Wintertime mixing of the near-surface layers in the region usually occurs to depths of 500–700m (Ellett & Martin 1973, Meincke 1986; Holliday *et al*. 2000), but there is evidence of deeper mixing, possibly to 1,000m (Ellett *et al*. 1986). This mixing forms relatively homogeneous upper layer waters, identified primarily as a saline Eastern North Atlantic Water (ENAW) entering the region from the south, and occasionally a fresher Western North Atlantic Central Water (WNAW) from the northwest. ENAW forms in the Bay of Biscay (Pollard *et al.* 1996) and is transported northwards by the Shelf Edge Current through the region and beyond (Ellett & Martin 1973, New *et al.* 2001). The less saline WNAW is carried into the area by the main branch of the North Atlantic Current (NAC) but generally turns northwards to the west of Hatton Bank and does not usually enter the Rockall Trough (Schmitz & McCartney 1993, Pollard *et al.* 1996, Holliday *et al*. 2000).

However, fresher Sub-Arctic Intermediate Water (SAIW, Ellett *et al*. 1986) may often be carried by a branch of the North Atlantic Current which sweeps eastwards from the western North Atlantic before turning northwards and branching into the Rockall Trough (Pingree 1993, McCartney & Mauritzen 2001), mixing with the more saline ENAW as it does so (Ellett *et al*. 1986, New & Smythe-Wright 2001). New & Smythe-Wright (2001) found upper layer (400-500m deep) salinities within the Rockall Trough were markedly fresher (35.44-35.50‰) at and above 54°N than those observed at 52°N (35.50-35.58‰) implying a possible inflow of fresher waters between 52 and 53°N either from the west or north. Holliday *et al*. (2000) suggested that periods of low salinity in the Rockall Trough may be a reflection of greater influence of WNAW and SAIW.

Intermediate water

The presence and extent of Mediterranean Outflow Water (MOW) in the region is as yet unclear. Reid (1979) conjectured that Mediterranean Outflow Water (MOW) flowed northwards through the area as a high-salinity core typically at depths 1000–1200m. However, McCartney & Mauritzen (2001) questioned the presence of MOW in the Rockall Trough indicating that MOW did not penetrate further northwards than about the Porcupine Bank.

Deeper in the water column, the presence of Labrador Sea Water (LSW) in the Rockall Trough is unambiguous. This water mass typically occurs in the depth range 1,600–1,900m, and is denoted by a marked salinity minimum (34.92‰), and associated temperature and density of approximately 3.4°C and 1027.7kg m^{-3} respectively (New & Smythe-Wright 2001). LSW has been clearly noted in the Trough by Ellett & Martin (1973) and Ellett *et al.* (1986) as far north as 57.5°N, who indicated that, since there are no exit channels in the north of the Trough deeper than 1,200m, the LSW must both inflow and outflow through the southern entrance. Furthermore, Holliday *et al.* (2000), analysing the LSW variability at 57.5°N and finding that this was larger than the magnitude expected from changes in the source characteristics, raised the speculation that the LSW could flow into the Trough in a series of periodic pulses. However, circulation pathways by which the LSW might enter and circulate around the Trough are as yet unconfirmed.

Deep and bottom water

In the north, Norwegian Sea Deep Water (NSDW) is known to flow episodically southwards over the Wyville–Thomson Ridge and into the Rockall Trough. Although reliable estimates of the amounts which do so are not yet known, fluxes at the ridge crest may be typically 0.3–0.4Sv (Ellett *et al*. 1986, van Aken & Becker 1996), though there may be a large seasonal variability, being greatest in the summer (Dickson *et al*. 1986). At the general level of the ridge crest (500–600m), the NSDW has a salinity near 34.94‰, temperatures close to 1°C, and a density near 1028.0kgm^{-3} (Ellett *et al*. 1986). As the NSDW moves southwards into the Trough it sinks and mixes with surrounding waters forming a deep salinity maximum at between 2,300 and 2,500m depth (Ellett & Martin 1973, van Aken &

Becker 1996). Near the southern entrance to the Trough, this salinity maximum may also derive from products of NSDW which have overflowed the Iceland–Faeroe Ridge or the Faeroe Bank Channel and circulated southwards around the western flanks of the Hatton and Rockall Banks (Ellett & Martin 1973). This salinity maximum was called North East Atlantic Deep Water (NEADW) by Ellett and Martin (1973), who showed it was associated with an oxygen maximum (New & Smythe-Wright 2001).

NEADW in the Trough is associated with high levels of silicate, indicating a southern influence (Ellett & Martin 1973). Van Bennekom (1985) has shown that the deepest waters (below 3,000m) in the northeast Atlantic are rich in silicate derived from the Antarctic Bottom Water (AABW). The AABW is likely to flow northwards along the eastern side of the northeast Atlantic (Lonsdale & Hollister 1979, Van Aken & Becker 1996).

Water circulation

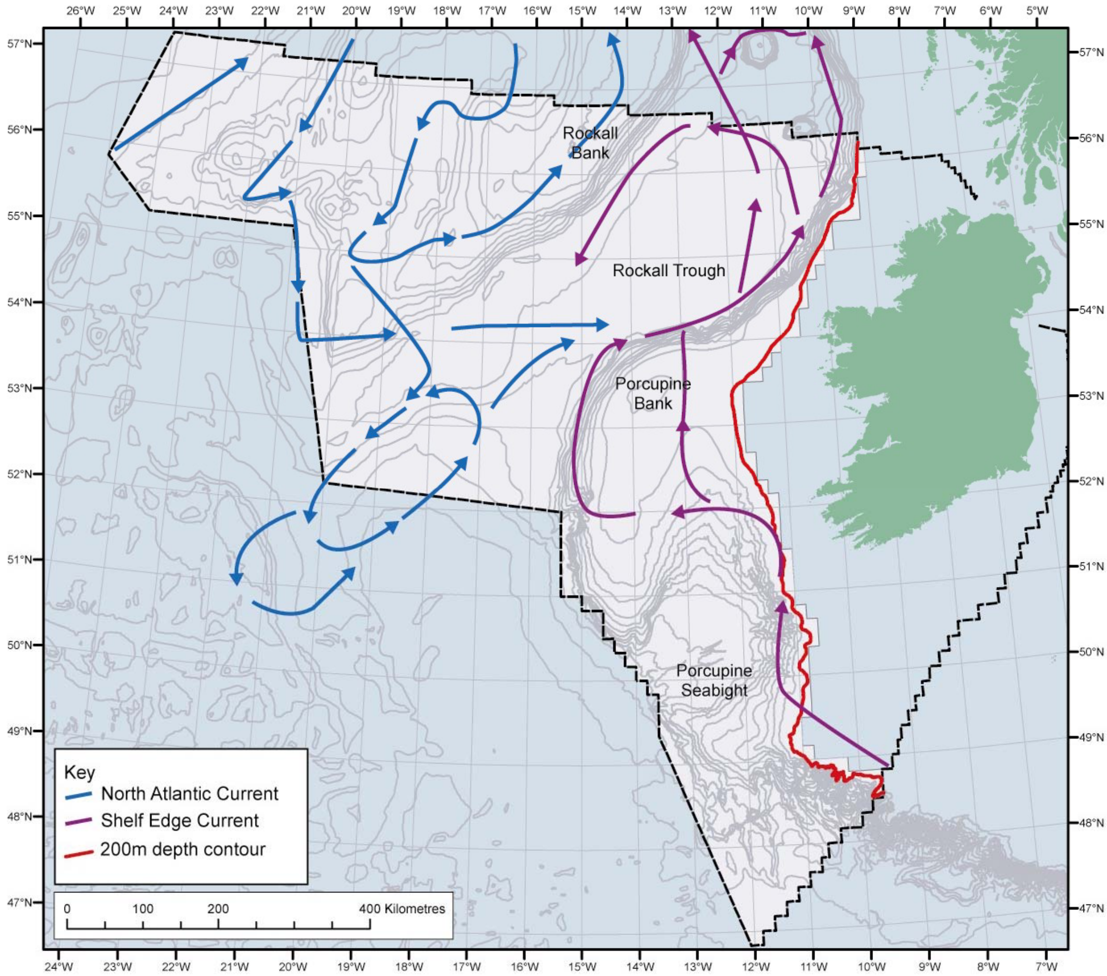
General patterns of circulation for the region have been established through research over the last few decades and there are now several reviews of the large scale circulation in the region (Ellett *et al.* 1986, Ellett 1995, Pingree & LeCann 1989, 1990, Huthnance 1986). The region falls in between the two main gyre circulation systems of the North Atlantic - the sub polar and sub tropical gyres. The main branch of the North Atlantic Current (NAC) sweeps eastwards from the western North Atlantic before turning in a more northerly direction close to the northwestern extent of Irish waters. Southerly branches from the NAC enter the Hatton-Rockall area from the north and circulate over the Rockall Bank and further to the south. A poleward flowing slope current is present along the continental margin comprising at the upper levels, a relatively warm and saline Shelf Edge Current (SEC) and below this, deep water recirculation. Large scale banks and seamounts add complexity to both upper and deep water circulation patterns.

Upper layer flows

Upper layer flows in the region are summarised in Figure 2.13. An important feature of the upper layer circulation is the poleward flowing slope current which runs along the northeast Atlantic margin (Huthnance 1986, Pingree & LeCann 1990). The current is primarily density driven with sea surface height differences between shelf and deep water areas driving a northward current. The resultant slope current has a warm, saline signature (Hill & Mitchelson-Jacob 1993, White & Bowyer 1997) derived from ENAW formed in winter to the northwest of the Iberian margin (Pollard *et al* 1996) and advected north in the slope current. The current occupies depths of 150-400m (Hill & Mitchelson-Jacob 1993) with a relatively narrow core (up to 50km wide). Poleward transport has been estimated between 1.2-3Sv (Huthnance 1986, Holliday *et al.* 2000).

To the north of the Porcupine Bank, mean poleward slope current flows of 10-20cm/s have been recorded (White & Bowyer 1997), with equivalent or higher flows found further north along the Hebrides slope (Booth & Ellett 1983). Mean flows are highest close to the seabed where the topographic steering effect is most apparent. Seasonality in the slope current has been recognised by Pingree & LeCann (1989) in measurements made in the Bay of Biscay, Celtic and Porcupine slopes. There is a weakening of slope flow, or even a reverse in direction often measured in March and April with a further change in the flow patterns in Sept-Oct. Termed the SOMA (Sept-Oct-Mar-Apr) response, this may be partly attributed to changes in large scale density/pressure forcing or a change in the wind stress at these times. The cause and timing of the response varies regionally though a similar response does not appear to happen on the Malin slope probably due to the increased topographic currents close to seabed (Cahill *et al*. 1998).

Figure 2.13 – Upper layer flows in the region



Source: Modified from Øvrebø (2002), New et al. (2001).

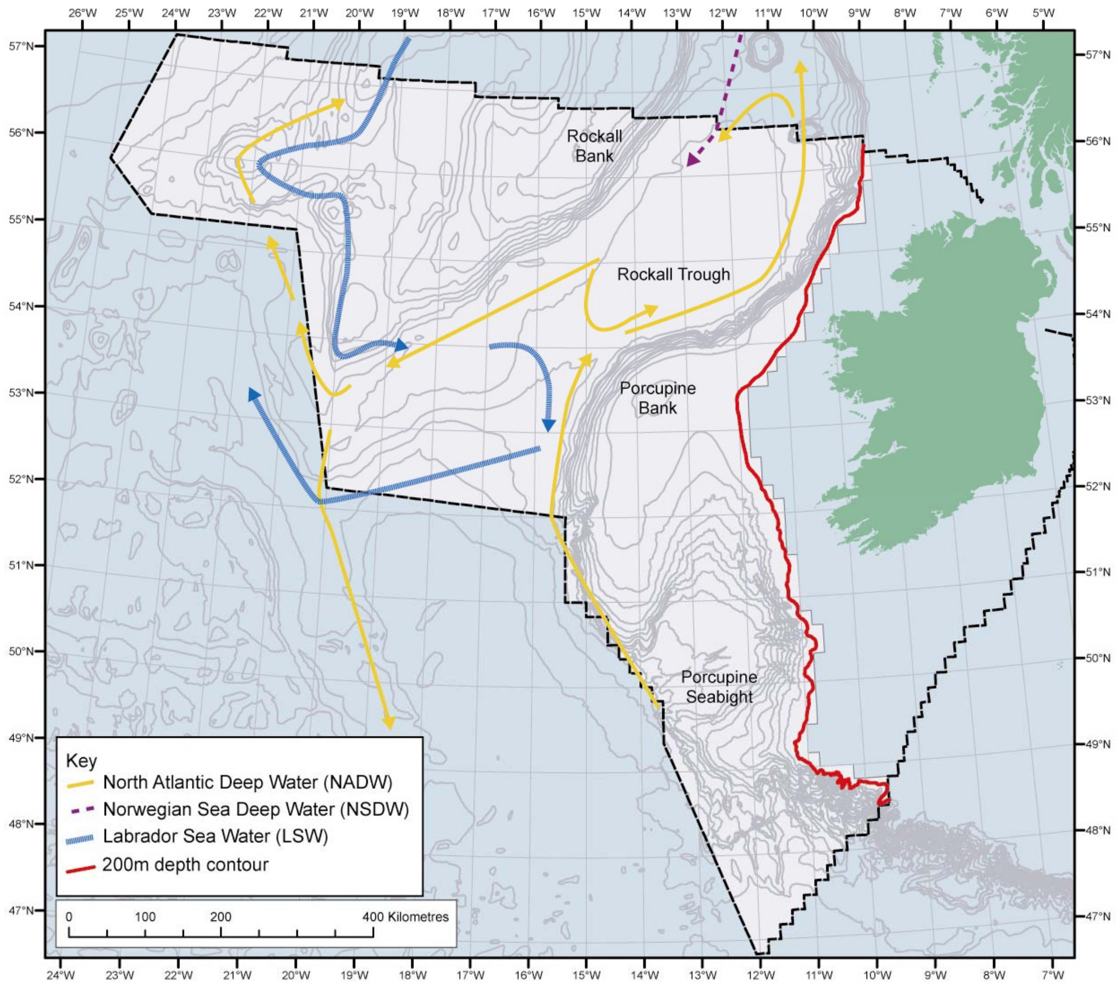
Modelling of the upper layer circulation through the Porcupine-Rockall region (New & Smythe-Wright 2001) indicates that the slope current may split, partly flowing northwards around the western slopes of the Porcupine Bank, and partly crossing the saddle point between the Porcupine Bank and the Irish Shelf at 12°W. These flows meet and partially mix with the fresher water flowing in from the west (on a branch of the North Atlantic Current) on the northern Porcupine Bank, to form a broad northward flow of intermediate salinity through the Rockall Trough which typically extends between the central Trough and the shelf. To the north, this flow splits with the slope edge current running north and the Rockall Trough Current flowing to the west of the Anton Dohrn Seamount before the currents re-merge and flow northwards over the Wyville–Thomson Ridge into the Nordic Seas (New & Smythe-Wright 2001). Ellett & Martin (1973) estimated a net northeastward transport in the Rockall Trough of 3.7Sv in the upper 1200m of the water column (2.75Sv in the upper 500 m and 1Sv between 500-1200m depth) with considerable variability due to large eddy motions in the deeper layers.

Bottom layer flows

The pathways by which intermediate and deeper water masses enter and circulate around the area are not well understood or described. Circulation models (New & Smythe-Wright 2001) and evidence from sediment bedforms within the Rockall Trough (Lonsdale & Hollister 1979) suggest an overall cyclonic flow of deeper water (>1,200 m depth), with LSW and NADW entering the Rockall Trough from the south adjacent to the Porcupine Bank. The deep flows then diverge from the slope current and are topographically steered anticlockwise around the Trough, leaving the region immediately to the south of Rockall Bank. These southwestward bottom flows are thought to occur primarily on the southeastern side of the South Feni Ridge and on the lower slopes of the Rockall Bank (both near 2,400m depths at 55°N), which are areas being built up by the deposition of bottom sediments suspended from the Irish slopes (New & Smythe-Wright 2001). New & Smythe-Wright (2001) indicate that LSW may penetrate the Trough to about 56.5°N. Typical current speeds were estimated to be between 3-4cm/s with a maximum speed of 13.5cm/s. High silicate values indicative of AABW permeating into the deepest levels of the Trough from the south were traced to at least 56°N. The flow patterns of NADW and AABW were found to closely follow those of the overlying LSW layer (New & Smythe-Wright 2001). Estimates of deep water transport suggest that 3.8Sv of waters of NADW origin and deeper, flow northwards along the western slopes of the Porcupine Bank. Of this flow, 0.9Sv circulates cyclonically into the southern Rockall Trough, while the remainder passes the southern entrance to the Trough in a northwesterly direction (Van Aken & Becker 1996).

The overflow of Norwegian Sea Deep Water (NSDW) into the Rockall Trough provides a small but steady input of deep water in the region (Ellett 1995). Estimates of the southerly flow at the ridge crest are typically 0.3–0.4Sv (Ellett *et al*. 1986, van Aken & Becker 1996), though there may be large seasonal variability, being greatest in the summer (Dickson *et al.* 1986). The dense NSDW flows down along the eastern slope of the Rockall Bank into the Trough enhancing the cyclonic circulation in the Trough (Fugro GEOS 2001). Aspects of the intermediate and deep water circulation are summarised in Figure 2.14.

Figure 2.14 – Bottom layer flows in the region



Source: Modified from Øvrebø et al. (2006) New et al. (2001).

Flow processes and features

Tidal currents and flows

Highest tidal energy is found on the shelf, with typically 2/3 of the total energy in the currents associated with the tidal currents. This may be reduced to 1/2 over the continental slope and is typically about 1/4-1/3 of the total energy in deep water. Current magnitudes can vary from 50cm/s on the continental shelf, down to 5cm/s in the deep ocean. Daily or diurnal tides are generally very small except in some locations in the region (Fugro GEOS 2001). Along the Porcupine Sea Bight boundary and Porcupine Bank diurnal components are relatively large compared to the semidiurnal tide and may exceed it close to the seabed.

Tidal models have demonstrated the trapping of diurnal period waves on the Porcupine Bank (Pingree & Griffiths 1984), and analysis indicates that currents on the Rockall Bank are partly due to a resonance condition for the diurnal tides, which results in trapped waves of diurnal period propagating around the bank (Huthnance 1974). Lonsdale & Hollister (1979) have attributed strong oscillatory currents for the formation of bedform features on the northern slope of the Porcupine Bank indicating the possibility of locally enhanced tidal currents around the continental margin.

Internal waves are periodic oscillations of the water column through disturbances in the vertical density stratification. Essentially, tidal flow across the shelf edge causes the thermocline to depress and this depression propagates away from the shelf edge region as a wave. The NE Atlantic is a prolific area of internal wave generation (Baines 1986) and internal waves have been observed in SAR (Synthetic Aperture Radar) images through the changes in surface roughness associated with the sub-surface motions (New 1988). SAR images show the generation points at the shelf edge and packets of internal waves propagating away from the source region periodically on every tide. Numerous observations of internal waves have been made on the Celtic and Biscay margins (New & Pingree 1990, Pingree *et al.* 1983) and the Malin Shelf slope (Sherwin 1988). Booth (1981) suggested that strong oscillatory currents found in the deep northern sector of the Rockall Trough were a result of internal tidal motions. Non linear internal waves (solitons) measured during the LOIS Shelf Edge Study (SES) between 56°N-58°N were associated with oscillations in the thermocline of up to 50m and occasional strong currents (up to 50cm/s). Solitons favour turbulence, internal mixing, and enhanced chlorophyll near the shelf break (e.g. New 1988, New & Pingree 1990). Such mixing in association with internal tides can thicken the summer thermocline internally and cool the sea surface by 1–2°C in an irregular band 50–100km wide over the Celtic Sea shelf break. The phenomenon is most intense where cross-slope tidal currents are strongest, as in the southern Celtic Sea (Huthnance *et al*. 2001).

Amplified bottom currents may be expected where the slope of the seabed matches the angle at which the internal wave energy propagates (Thorpe 1987, Garrett & Gilbert 1988). In regions where internal waves reflect from the continental slope, periodic mixing of water adjacent to the seabed is often observed (White 1994). On the slope west of the Porcupine Bank, such conditions have been postulated as the cause for the generation of nepheloid layers observed in the water adjacent to the slope (Thorpe & White 1988). Nepheloid layers are regions of suspended sediment, where the sediment has been lifted into suspension by the mixing processes at the seabed (forming bottom or benthic nepheloid layers - BNL). These BNLs may be subsequently transported into the ocean interior as the mixed water containing the sediment spreads away from the slope, forming discrete layers within the ocean, or Intermediate Nepheloid Layers (INLs) (Fugro GEOS 2001).

Eddies and trapped waves

Variability in both upper and deep circulation due to eddies has been measured in the Rockall Trough (Dickson *et al.* 1986, Booth 1988) and the Porcupine Sea Bight (Pingree 1993, Pingree *et. al.* 1999).

The scale of such features is 10-100 km, with mesoscale variability greatly reduced on the continental shelf. Dickson *et al.* (1986) found the largest eddies in terms of kinetic energy were found in deep abyssal depths which lagged the peak in winter wind stress by 1-3 months.

Eddy activity is greatest just north of the Porcupine Bank, in the Porcupine Sea Bight and around the seamounts of the northern Rockall Trough. Drogued buoys[1] and satellite imagery have shown the presence of an eddy northwest of the Porcupine Bank (Booth 1988) with baroclinic instability of the slope current suggested as a possible generation mechanism. Pingree (1993) showed an anticyclonic eddy in the Porcupine Seabight persisting for about 6 months. In the region of the seamounts, cyclonic eddies have been revealed by drifting buoys and Booth (1988) has suggested that these are a result of Taylor Column circulation around Anton Dohrn Seamount. A Taylor Column is an enclosed circulation pattern over a topographical feature which forms if conditions based on topography, flow speeds and stratification are met. Evidence of Taylor Column circulations above the Porcupine Bank (White *et al.* 1998), and the Rockall Bank (Dickson *et al.* 1986) have been noted.

When water is moved across a region of rapidly changing depth, such as the continental slope, it undergoes changes in its angular momentum balance or vorticity. These changes are propagated along the slope as waves of period longer than those of the tide, generally between 2-10 days. Such waves have been measured west of Porcupine Bank and also at the Malin Shelf edge (Thorpe *et al.* 1990, White & Bowyer 1997). The waves are trapped to within about 10-20km from the slope and may periodically reverse the mean poleward slope current flow. Long term measurements west of Porcupine Bank (Thorpe *et al.* 1990) indicate that the timescales of subtidal variability become shorter closer to the slope.

Cascading

Winter cooling of oceanic water occurs at different rates over the shelf and deep ocean, such that the reduction in temperature is greater on the shelf than the deep ocean. Water on the shelf may become colder and denser than the water off shelf, such that it sinks over the shelf edge in the form of a density driven gravity current, a process known as cascading. Cooper (1952) makes reference to cascaded waters from the Celtic Shelf and also the Rockall and Porcupine Banks. Spring transects across the Irish and Malin Shelf also show leakage of relatively cold, dense water off-shelf (White et al., 1998). Hill *et al.* (1998) and Shapiro & Hill (1997) have reported a dense cascade of saline water off the Malin Shelf near 56°N.

Stratification and fronts

Sea surface temperatures (SST) over the Porcupine-Rockall region show the expected seasonal patterns with a typical maximum in August/September (mean SST ranging from 13.7°C in the north to 17.2°C in the south) and a minimum in February/March (mean SST 9.2°C in the north and 11.0°C in the south (Fugro GEOS 2001).

Figure 2.15 represents mean vertical temperature profiles for the Rockall Bank and Porcupine Seabight areas in August (Fugro GEOS 2001).

During spring and summer months the water column undergoes thermal stratification with an upper mixed layer down to approximately 75-100m. A similar stratification pattern is present throughout much of the deep water area although the nature and extent of stratification varies both spatially and temporally. Note, the water temperature continues to decline with increasing depth.

[1] Drogues are devices which may be attached buoys; vessels etc. to provide drag and slow them down.

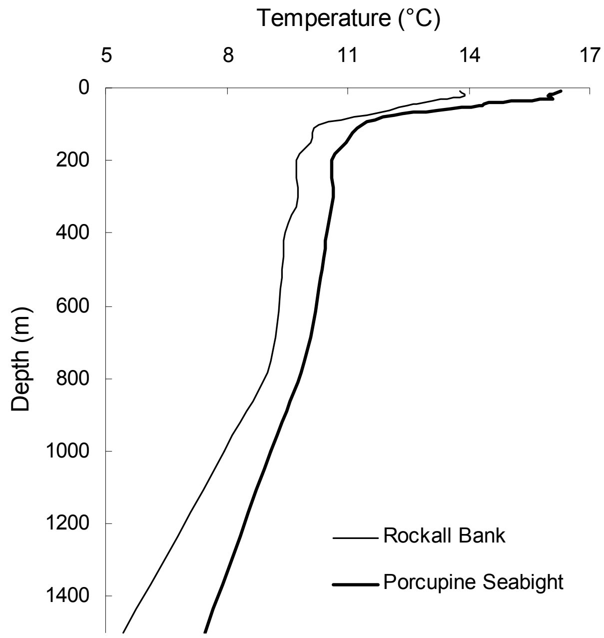


Figure 2.15 – Vertical temperature profiles of the water column

Source: Fugro GEOS (2001)

The Ocean Margin EXchange (OMEX) I project (1993-1996) studied physical and biological processes at the Celtic Sea shelf edge in the region of the Goban Spur. The onset of spring stratification in this region occurred at different times and tended to be earliest on the shelf in April and latest in deepest water (water depths >3,000m) (Joint *et al.* 2001). However, there was great variability due to internal tides and there was often no unique mixed layer but a sequence of layers with several thermoclines. There was also variability in the depth of the mixed layer in summer with the most variability occurring over the upper slope (water depths 500-1,000m), where satellite thermal images suggest that upwelling takes place (Joint *et al.* 2001).

Generally, stratification breaks down with the onset of autumn cooling and associated more energetic conditions. Heat loss (often aided by strong winds) and hence convection lead to winter mixing to depths of 500m (in the region of Goban Spur) increasing northwards, with mixing as deep as 1,000m in the Rockall Trough (Huthnance *et al.* 2001). This mixing process is reflected in winter (January-March) temperatures which are fairly constant (9-10°C) through the water column down to about 500-750m, and reach 5-6°C by 1,500m (Fugro GEOS 2001).

Sea surface salinity values (extracted by Fugro GEOS (2001) from the National Oceanographic Data Centre database) are generally lower on the continental shelf (<35.00) and increase to the south and west. The maximum recorded salinity was 35.84 in the southern half of the Porcupine-Rockall area.

Salinity plays a predominant role in defining the position of the Irish Shelf Front which separates coastal waters to the west of Ireland from oceanic waters further offshore. The frontal boundary (at approximately 11°W) extends along the whole western Irish coast with both temperature and salinity increasing seawards (McMahon *et al.* 1995). Defined largely by the 35.3 isohaline, the front is present throughout the year although its exact position varies on a seasonal basis with thermal stratification of oceanic waters in summer months augmenting the front. The extent and persistence of the front suggests that it may play a significant role in determining the genera1 circulation of western Irish coastal waters and also in the lateral exchange of parameters such as heat, salt, organic and inorganic materials between the coastal and oceanic waters (McMahon et al. 1995). Furthermore, mesoscale frontal waves and eddies are important mechanisms for lateral exchange processes and such features have been noted along the Irish Shelf Front by Huang *et al.* (1991).

Waves and storms

The deep water area to the west of Ireland experiences some of the harshest metocean conditions in the world. The long Atlantic fetch allows waves of considerable size to develop and these cross the area, particularly during winter months and the region is exposed to the full force of storms generated in the Atlantic Ocean.

Fugro GEOS (2001) utilised modelled (UK Meteorological Office Global Wave Model) and measured wave data from a number of relevant buoys to describe the region's wave climate (see Figure 2.16 for buoy locations).

Across the region the dominant wave directions for the majority of the year are from the southwest and west with maximum observed significant wave heights varying from 12m in the north to in excess of 14.5m in the south. The highest maximum significant wave heights were observed in February (predominantly southwesterly and westerly) and the lowest in July. In April and May, whilst waves from the southwest and west still predominate, there are more waves from northerly and northeasterly directions (Fugro GEOS 2001).

Analysis of the numbers of days each month that, on average, exceed the significant wave height thresholds of 2, 4 and 6m indicates that December and January showed the greatest occurrence of daily maxima greater than 6m (up to 10 and 12 days respectively) with wave height rarely exceeding 6m between May to September. Significant wave heights greater than 2m were observed for the majority of the time during the 'winter' months and for approximately half to two thirds of the time during the 'summer' (see Table 2.1).

Table 2.1 – Significant wave heights exceeded during winter and summer

Significant wave height threshold	December-February Mean days exceeded	Mean % of month	July-August Mean days exceeded	Mean % of month
>2m	28	93%	17	55%
>4m	19	63%	2	6%
>6m	10	33%	<1	<3%

Source: Fugro GEOS (2001).

Data on the occurrence of storms in the region is limited. However, analysis of wind data provided by Fugro GEOS (2001) indicates that wind speeds of over 20.8m/s (approximating to Beaufort Force >9 and described as strong gale through to violent storm) occur approximately 0.6-1.2% of the year. These storm conditions are primarily associated with the winter months (January, February and December).

2.3.3 Data gaps

Whilst there is considerable information available relating to the oceanography and hydrography of the region, there is still much discussion as to the exact nature and dynamics of the different water masses present. Much of the current understanding results from large-scale modelling work and there is a need for significant survey work to verify and strengthen these models further. Details of local currents and water conditions are extremely limited.

Oceanographic conditions in the region are extreme and represent a real challenge to hydrocarbon exploration and production activities. However, the ongoing development of the Corrib field and of fields to the north and west of Scotland indicate that the industry can operate under such conditions.

2.4 Climate and meteorology

2.4.1 Overview

The deep water region to the west of Ireland has a highly variable climate and the area experiences some of the harshest metocean conditions in the world, with respect to wind and waves (Cahill *et al.* 1998). The region is exposed to the full force of the storms generated in the Atlantic Ocean and the frequent occurrence of severe winds is widely known.

A major controlling factor of the North Atlantic weather is the North Atlantic Oscillation (NAO). The NAO is linked to a waxing and waning of the dominant middle-latitude westerly wind flow during winter. It is generally expressed as an index based on the pressure difference between the Azores high and the Icelandic low pressure areas (Jennings *et al.* 2000). When the pressure difference is large, with a deep Icelandic low and a strong Azores high, the NAO is said to be in a positive phase, and is negative when the opposite occurs. When in a positive phase, the storm tracks moving across the North Atlantic Ocean are stronger, bringing depressions northeastward into Europe. A positive NAO index is, therefore, associated with an increase in wind speeds from the west, together with an increase in temperature and rainfall in Northern Europe in winter (Jennings *et al*. 2001). The index is most relevant in winter when the pressure gradients are at their strongest.

The NAO is an intermittent climate oscillation with active and passive phases and approximate decadal oscillations with a peak every 6 to 10 years have been described (Hurrel & van Loon 1997, as cited in Jennings *et al.* 2000). In recent decades the NAO has been found to explain over 30% of variation in monthly sea surface temperature and has also been linked with variations in wind strength and direction and rainfall. Winter precipitation in Ireland has been shown to be above average when the NAO index value is highly positive (Daultry 1996, Butler *et al.* 1999, as cited in Jennings *et al* 2000).

Another influencing factor is the North Atlantic Drift, which is a slow-moving body of water considered to be an extension of the North Atlantic Current. It is a shallow, widespread and variable wind-driven surface movement of warm water that covers a large part of the eastern North Atlantic and spills into the Nordic seas. The influence of the warm waters of the North Atlantic Drift can result in milder winters and higher temperatures during summer.

2.4.2 Data sources

The Fugro GEOS report (2001) provides a detailed description of the regional climatology of the Rockall-Porcupine region. The report utilises data from the United Kingdom Meteorological Office (UKMO) European/Global Wave Model, UKMO Measured buoy data, National Data Buoy DB-1, the Proudman Oceanographic laboratory's North East Atlantic and Fine Resolution Continental Shelf Tidal Models and the National Oceanographic Data Centre (NODC) CDROM. It is also an extension and makes use of the Petroleum Infrastructure Programme summary report *Metocean Strategy for the Rockall Area* (Cahill *et al.* 1998). Information on wind speed and direction for the offshore area has been generated from analyses of modelled (UKMO European/Global Wave Model) and measured data (UKMO buoys, K2 and K4) (see Figure 2.16 for buoy locations) (Fugro GEOS 2001).

A concise summary of the climate and the weather conditions for open ocean and inshore waters around the southwest and west coast of Ireland can be found in *The Irish Coast Pilot* (1997). The Met Éireann (Irish Meteorological Services) website (http://www.met.ie) provides climatic information for both the west and east coast of Ireland, while additional brief overviews can also be found in *Ireland's Marine and Coastal Areas and Adjacent Seas; an environmental assessment* (Marine Institute 1999) and the OSPAR Commission Quality Status Reports for Region V (Wider Atlantic) (OSPAR 2000a) and Region III (Celtic Seas) (OSPAR 2000b).

2.4.3 Wind

Offshore areas

The Atlantic Ocean is the second largest ocean in the world and experiences some of the harshest metocean conditions. The deep waters off the west coast of Ireland are no exception. The predominant winds are from the west and the southwest (Irish Coast Pilot 1997). Winds of force 5 and over (i.e. >8m/s) are reported on approximately 70-75% of occasions in winter and 30-35% of occasions in summer (Irish Coast Pilot 1997).

Generally, the dominant wind direction in the region is from the southwest and west, with the exception of May, when the wind direction throughout much of the region is from the north or northeast (Fugro GEOS 2001 - data set 1994 to 1999).

Maximum observed wind speeds occur during the winter months and reach up to 32.9m/s in the north (57ºN) and 27.2m/s in the south (51ºN) (Fugro GEOS 2001). There is more variation in the direction of the maximum observed wind speed compared to the dominant wind direction (Table 2.2).

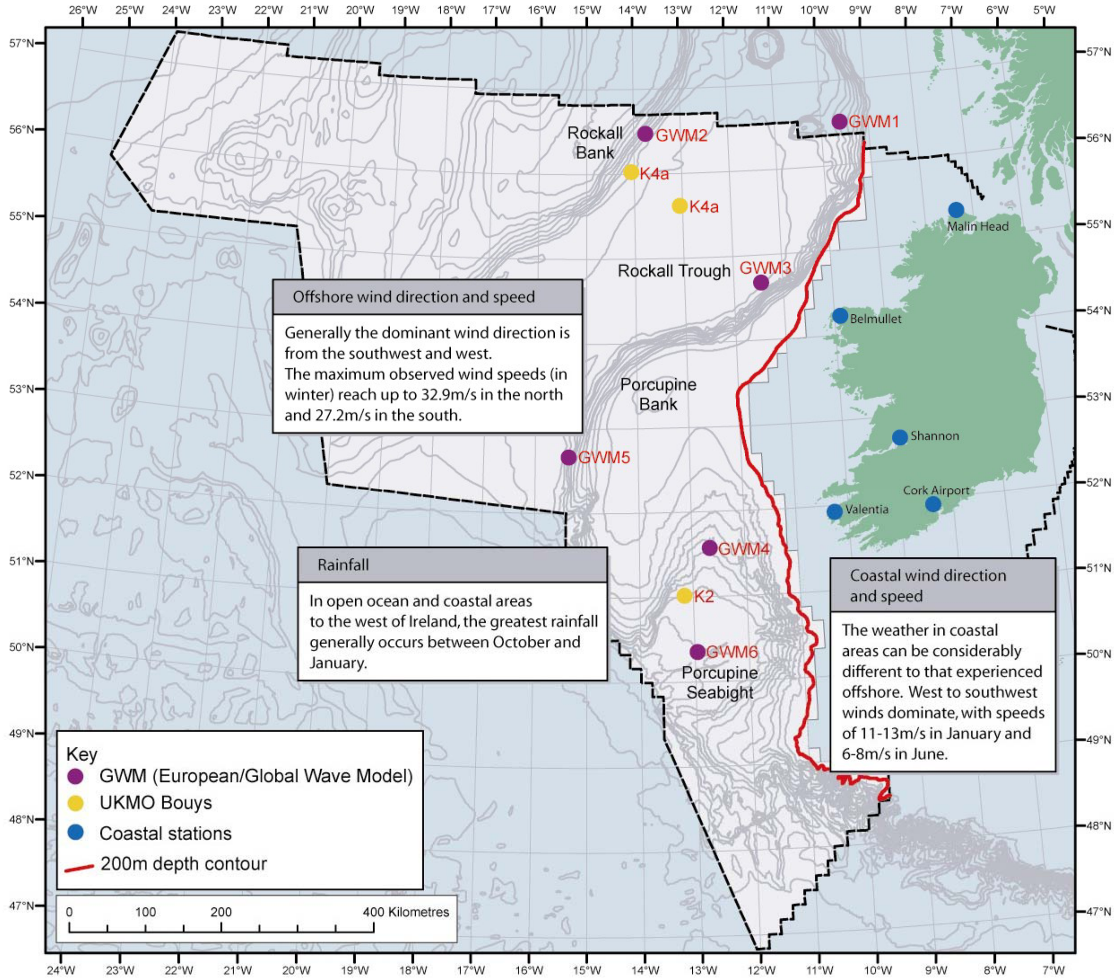
Table 2.2 - Max observed hourly mean wind speed (m/s) & direction (1994-1999).

Site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	All year
Maximum observed hourly mean wind speed (m/s)													
GWM-1	25.7	24.2	23.6	21.6	22.1	16.9	18.5	18.5	21.6	23.1	29.8	29.8	29.8
GWM-2	32.9	27.2	24.7	23.1	22.1	18.0	20.6	18.0	22.1	23.6	27.8	32.9	32.9
GWM-3	28.3	25.2	26.2	20.0	21.6	17.0	18.0	17.5	22.1	24.2	30.3	30.3	30.3
GWM-4	25.7	28.8	22.6	20.6	22.1	19.5	16.7	23.6	19.0	26.7	25.7	28.3	28.8
GWM-5	27.2	26.2	25.2	20.6	20.6	15.9	19.5	22.1	18.5	24.2	27.2	27.2	27.2
GWM-6	27.8	26.7	22.6	28.3	22.1	19.5	17.0	20.6	24.7	27.8	25.2	28.3	28.3
K-2	27.5	26.8	23.8	22.5	22.5	20.1	15.9	23.8	20.7	21.9	26.8	28.7	28.7
K-4	29.3	23.2	28.1	22.5	29.3	15.9	19.5	18.9	25.0	25.0	26.9	29.3	29.3
Direction associated with maximum observed hourly mean wind speed (from)													
GWM-1	W	W	W	N	SW	S	W	SE	SW	N	W	W	W
GWM-2	NW	NW	A	N	NE	SW	W	S	S	S	W	W	NW
GWM-3	W	SW	SW	NW	N	SW	S	SE	SW	N	W	W	W
GWM-4	SW	W	W	N	N	W	S	NW	NE	W	SW	W	W
GWM-5	NW	W	SW	N	N	N	S	NW	SW	S	W	W	NW
GWM-6	W	SW	SW	SW	N	W	SW	NW	NE	W	NW	W	W
K-2	W	W	W	N[1]	S	W	SW	W	SE	SW	SW	W	W
K-4	S	W	S	N	NE	W	W	S	S	SW	W	SW	SW

Note: [1]No direction associated with max. wind speed, direction associated with 2nd greatest wind speed used. Data from period 1994-1999.
Source: Fugro GEOS (2001)

Figure 2.16 provides an overview of the region's weather including wind speed and direction for offshore and coastal areas.

Figure 2.16 – Climate and meteorology of the region



Source: Fugro GEOS (2001), Irish Coast Pilot (1997)

Coastal areas

The west coast of Ireland is exposed to gales and the full force of the Atlantic swell (Irish Coast Pilot 1997). The weather and the wind close to shore can be considerably different to that experienced farther seaward. Gales occur in any month, but are more frequent in winter months, with winds reaching storm to hurricane strength on some occasions.

Along the southwest coast of Ireland, west to southwest winds dominate with the highest average wind speeds (11-13m/s) occurring in January and the lowest (6-8m/s) in June (Boelens *et al.* 1999). The predominant wind direction for the west coast is also from the south/southwest. Table 2.3 below describes the weather conditions recorded at several stations along the southwest, west and northwest coast of Ireland (see Figure 2.16 above for station locations).

Table 2.3 – Weather conditions recorded at coastal stations

	Mean daily temp (°C)		Mean rainfall	Predominant wind direction		Mean wind speed (m/s)		Gales	Fog
Month	**Max**	**Min**	**(mm)**	**(0900hrs)**	**(1500hrs)**	**(0900hrs)**	**(1500hrs)**	**(days)**	**(days)**
Malin Head (1931 to 1992)									
Jan	7	3	103	S	SW	10.3	10.3	7	*
Apr	11	5	59	SW	W	7.7	7.7	2	1
July	16	12	85	W	W	6.7	7.2	*	1
Oct	13	8	110	S	W	9.3	9.3	3	*
Belmullet (1956 to 1992)									
Jan	8	3	112	SW/W	SW/W	8.2	8.2	4	1
Apr	12	5	64	SW	NE	6.7	7.7	1	1
July	17	12	78	SW	SW	6.2	6.7	*	2
Oct	13	8	113	SW	SW	7.2	7.7	2	1
Shannon (1941)									
Jan	8	3	94	SE	W	5.7	6.2	2	2
Apr	13	5	57	N/SE	W	4.6	6.2	1	1
July	19	12	70	W	W	4.6	5.7	*	1
Oct	14	8	86	SE	W	0.5	5.1	1	2
Valentia (1931 to 1992)									
Jan	9	5	161	S	SW	6.7	7.2	1	*
Apr	13	6	85	N	W	5.1	6.2	*	1
July	18	12	94	W	W	4.6	5.7	0	1
Oct	14	9	142	S	S	5.7	6.7	*	*
Cork Airport (1941-1992)									
Jan	8	3	156	SW	SW	6.2	7.2	2	4
Apr	11	4	75	N	NW	5.7	6.7	*	3
July	19	11	76	SW	SW	5.1	5.7	0	3
Oct	13	8	113	SW	SW	5.7	6.7	1	5

*Notes: *Rare*
Source: Irish Coast Pilot 1997.

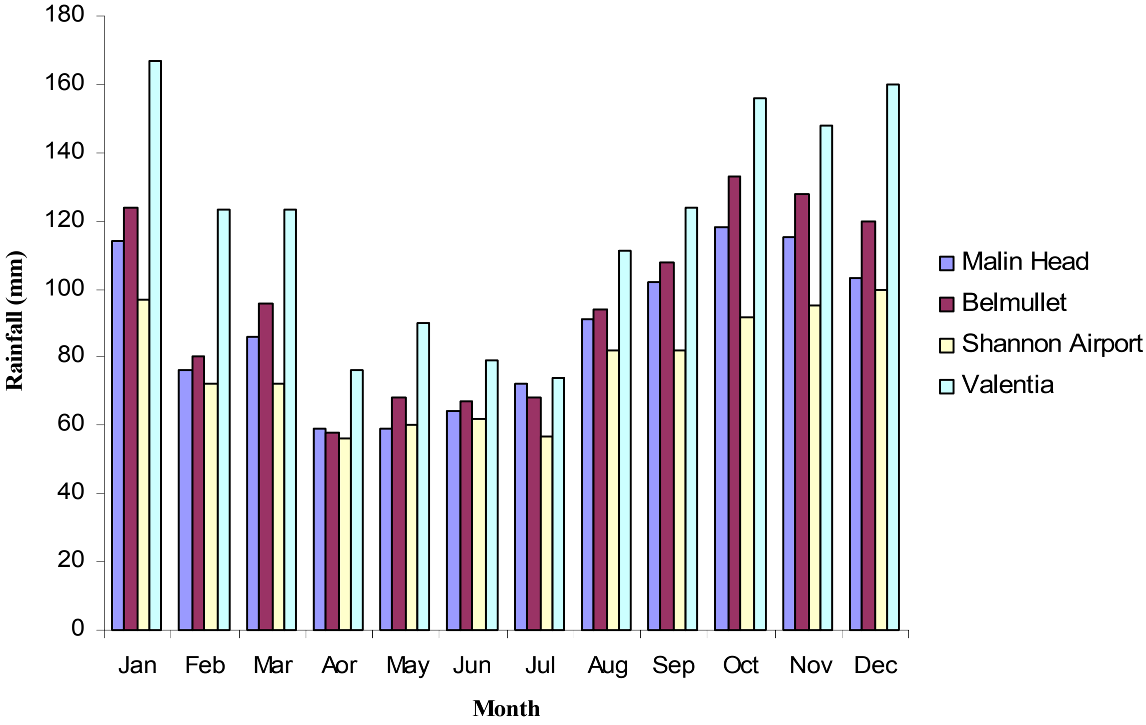
2.4.4 Rainfall

There is a significant seasonal variation in rainfall, with March to June being the driest months in most years. The wettest months are usually from October to January, with around 20 days of rain in each month (Irish Coast Pilot 1997). Rainfall in the west of Ireland averages between 1,000–1,250mm a year and in many mountainous districts rainfall exceeds 2,000mm per year (Met Éireann website - http://www.met.ie/climate/rainfall.asp). The 30 year (1961-1990) average mean rainfall recorded from four west coast stations is summarised in Figure 2.17.

In winter, over the open ocean, the percentage frequency of occurrence of all types of precipitation increases from approximately 15% in the south east to 25% in the northwest. By July it falls to 10 and 20% respectively. The amount and duration of precipitation can vary significantly from one period to the next (Irish Coast Pilot 1997).

Over open sea areas sea fog may be encountered mainly between April and October, with the percentage frequency of fog in June about 5-8%. Sea fog can occasionally affect coastal areas in summer, however poor visibility (less than 2 miles) is infrequent, where the frequency of occurrence is <10% (Irish Coast Pilot 1997).

Figure 2.17 - Mean recorded rainfall from coastal stations on the west coast of Ireland



Note: Mean rainfall (30 year average 1961-1990)
Source: Modified from Met Éireann website - http://www.met.ie/climate/rainfall.asp

2.4.5 Data gaps

North Atlantic Oscillation

The NAO is known to be a major determinant of the atmospheric circulation and climate of the North Atlantic region exerting a strong influence on year to year climate variability. However, the mechanisms which drive the NAO oscillation between positive and negative states are not yet fully defined. Research is ongoing in an attempt to fully understand the NAO which will in turn facilitate more accurate long range winter forecasting.

Climate change

Warming of the atmosphere will inevitably cause changes in precipitation due to an intensified hydrological cycle and it is likely that this will have more important impacts on human and environmental systems than any change in temperature. Significant indications of changes in climate have been detected in data from the west coast of Ireland, some of which could be regarded as positive, e.g. higher minimum temperatures, decrease in occurrence of frost days and longer growing seasons (Sweeney *et al.* 2002). However, other changes including increased winter-time precipitation levels and decreased sunshine levels may not be regarded as beneficial. It is projected that the build-up of greenhouse gases in the atmosphere will lead to climate changes in the future, however a great deal of uncertainty remains as to what exactly these changes will be and there is a possibility that long-term climate changes for Ireland may be extreme (Sweeney *et al*. 2002).

The oil and gas industry have been operating within the deep water region to the west of Ireland for the past 30 years and are familiar with the challenges presented by the region's climate. Progressive technological advances have facilitated the capacity of the industry to remain operational within the region in all but the most extreme conditions. Whilst significant gaps exist in data coverage, particularly at a local level, these are unlikely to significantly jeopardise operational capacity.

2.5 Contamination

2.5.1 Overview

Anthropogenic contamination of the environment can be defined as the introduction by humans of materials in locations or concentrations in which they do not occur naturally. If present in sufficient concentrations, contaminants have the potential to disturb biological processes through a variety of mechanisms, including increased availability of food and nutrients, toxicity, mutagenicity and interference with reproductive physiology (DTI 2003a).

Large-scale contamination of the marine environment is principally associated with industrial development, with major sources comprising terrestrial emissions and discharges (transported to the marine environment via rivers and atmospheric transport); shipping; military activities, and offshore industries including oil and gas production. The relative importance of input sources for individual contaminants varies between regions. For offshore areas remote from riverine and direct discharges, atmospheric inputs are likely to dominate (OSPAR 2000a).

Table 2.4 provides information on atmospheric metal concentrations and deposition measured in 2000 on the southwest coast of Ireland (Valentia Island, Co. Kerry) as part of the OSPAR Comprehensive Atmospheric Monitoring Programme (CAMP) (OSPAR 2002).

Table 2.4 – Metal concentrations in air measured at Valentia Island, 2000

	Mean concentration in precipitation (µg/l)	**Estimated annual wet deposition (µg/m^2)**	**Mean annual air concentrations (ng/m^3)**
Arsenic	0.41	722	0.35
Cadmium	0.04	74	0.08
Chromium	0.41	722	0.37
Copper	2.32	4,109	1.18
Lead	0.5	889	4.94
Mercury	50ng/l	88,445ng/m^2	-
Nickel	0.41	722	1.44
Zinc	32.59	57,649	10.3

Source: OSPAR (2002).

The CAMP report (OSPAR 2002) noted that monitoring coverage for the wider Atlantic was very limited. The relative paucity of survey and monitoring data for oceanic Atlantic waters was also noted in the OSPAR Quality Status Report (OSPAR 2000a). Surveys from the Atlantic Frontier to the north and west of Scotland by the Atlantic Frontier Environment Network (AFEN) and the DTI provide information on sediment contaminant concentrations and are very relevant to the present study. In general, deep water marine environments have relatively low contaminant burdens in comparison to coastal waters (DTI 2003a). The deep water area to the west of Ireland is remote from areas of major industrial activity suggesting low levels of direct contamination.

2.5.2 Effects and fates of contaminants

Many of the contaminants of concern in the marine environment have low water solubility and a high affinity for particles. In deep water areas, contaminants reach the seafloor via a number of processes including gravitational sedimentation, vertical migration associated with zooplankton and other organisms, and down slope transport. Once on the seafloor, contaminants may become incorporated in seabed sediments where they may be subjected to resuspension and bioturbation, leading to the potential re-mobilisation of contaminants or their burial in deeper layers (OSPAR 2000a). Contaminants can be taken up by organisms either directly, by absorption from sea water or by ingestion of particles and can be relayed to successively higher levels in the food chain via grazing and predation (OSPAR 2000b).

Metals

Metals, including barium, cadmium, copper, iron, lead, mercury, nickel and zinc, are naturally present in seawater and marine sediments, in a range of forms and concentrations. In excessive concentrations, metals can cause toxicity and result in significant environmental effects; with cadmium, lead and mercury generally regarded as the elements of greatest concern (OSPAR 2000a, b). Concentrations of metals in seawater and sediments are greatly influenced by adsorption on to clay particulates, and suspended solids loading and sediment particle size distribution therefore have a significant effect on measured concentrations (DTI 2003a). Anthropogenic inputs from domestic, industrial and shipping activities are ultimately accumulated on the seabed and incorporated into sediments, which are considered to be the ultimate sink for heavy metals released into the environment (Tyrrell 2001). It is well established that trace metal contaminants are preferentially associated with the fine fractions of sediments (DTI 2004b).

Sediment samples collected during a British Geological Survey gravity core survey of the Rockall Trough in 1998 for the Rockall Studies Group (Petroleum Infrastructure Programme) were analysed for trace metals by the Marine Institute (Tyrrell 2001). Methods were developed and validated for lead, cadmium, chromium, copper, nickel, zinc, vanadium, strontium, barium, lithium and aluminium using atomic absorption spectroscopy following total digestion, and for mercury, using cold vapour atomic fluorescence spectroscopy following partial digestion. The measured metal concentrations were also normalised to lithium to compensate for the influence of natural variability in the concentrations of metals in sediments (Tyrrell 2001). Sediment metal concentrations are described in Table 2.5 and compared to those of sediments sampled at the Corrib Field (Enterprise Energy Ireland 2001b), at sites to the north and west of Scotland (DTI 2003a), as well as provisional OSPAR Background Concentrations (ACME 2004). To facilitate comparison, all values with the exception of the OSPAR concentrations represent measured rather than normalised values.

Mercury levels in Rockall Trough sediments ranged from 0.025 to 0.353µg/g with a median concentration of 0.045µg/g which is below the provisional OSPAR background value (0.05µg/g).

Whilst the median cadmium concentration (0.144µg/g) was within the provisional background value of 0.2µg/g, the maximum cadmium concentration (2.57µg/g) was found in a sample taken from the flank of the Porcupine Bank consisting mainly of coral fragments, which may account for the high concentration of cadmium as compared to the lower concentrations present in sand and clay samples (maximum measured value of 0.521µg/g). These values were close to those measured in the ICES baseline study of sediments in the North Sea where a range of 0.010 to 0.38µg/g was detected (Tyrrell 2001).

The Porcupine Bank coral sample also contained higher concentration of chromium, zinc and strontium (both before and after lithium normalisation) as compared to sand and clay samples. Metals may bioaccumulate in coral tissue and skeleton (Esslemont 2000) and therefore these materials may contain higher levels compared with surrounding sediments (Tyrrell 2001). At present there is limited information on the uptake or bioaccumulation of metals by deep water corals.

Table 2.5 – Metal concentrations (μg/g dry weight) from the area and from surveys to the north and west of Scotland

Metal	Rockall Trough[1] Measured values	Rockall Trough[1] Median values	Corrib[2] Field	North and west of Scotland[3] AFEN 1996	North and west of Scotland[3] AFEN 1998	North and west of Scotland[3] DTI 2002	Provisional OSPAR BC's[4]
No. of samples	**32**	**32**	**27**	**206**	**83**	**61**	
Mercury	0.025–0.353	0.045	-	-	-	-	0.05
Lead	3.43–16.2	8.45	3.3-23	2-39.3	3-14	3-20	25
Cadmium	0.027–2.57	0.144	<0.01-0.06	-	-	-	0.2
Chromium	15.1–54.2	27.4	7.7-12	11-71	21-86	10-35	60
Copper	5.89–42.7	14.6	2.7-12	4-35.5	5-37	2-39	20
Nickel	8.83–38.9	15.5	6.6-16	9-45	11-41	5-34	45
Zinc	18.0–149	32.9	12-78	11-88	22-68	15-76	90
Vanadium	16.4–139	40.3	6.1-19	-	-	-	-
Strontium	214–2089	939	169-326	-	-	-	-
Barium	115–543	316	25-4550[5]	84-546	188-824	208-349	
Lithium	4.51–55.7	17.4	-	-	-	-	-
Aluminium (%)	0.860–6.23	2.6	-	-	-	-	-

Notes:

1. *Surface sediment samples collected at water depth ranges from 700-2,774m from 32 sites within the Rockall Trough. Metal concentrations measured following complete digestion of 0.2g of sediment.*
2. *Appendix 8.1: Corrib Field and pipeline route sediment physio-chemical data (Enterprise Energy Ireland 2001b).*
3. *AFEN 1996 & 1998 surveys covered the Atlantic Frontier region. DTI 2002 survey covered the DTI SEA 4 area to the north and west of Shetland and Orkney.*
4. *Provisional Background Concentrations developed through the OSPAR/ICES Workshop on the Evaluation and Update of Background Reference Concentrations (B/RCs) and Ecotoxicological Assessment Criteria (EACs) and How These Assessment Tools should be Used in Assessing Contaminants in Water, Sediment and Biota (Moffat et al. 2004). Metal concentrations normalised to 5% aluminium.*
5. *The high values probably represent evidence of past drilling with barite*

Sources: Tyrrell 2001, DTI 2003a, ACME 2004.

Rockall Trough sediment concentrations of lead, chromium, copper, nickel and zinc were of a similar range as those of AFEN and DTI sediments and median values were below OSPAR background concentrations.

Barium concentrations from the Rockall Trough (range 115-543μg/g) were equivalent to background concentrations recorded by the AFEN 1996 survey. In contrast, barium concentrations measured within 500m of the Foinaven drill centres to the north and west of Shetland were between 1,560-6,560μg/g indicating a moderate accumulation of drilling wastes. However, concentrations were lower than levels typically recorded around well centres in the North Sea (DTI 2003a). The relatively high barium concentrations recorded at the Corrib field were associated with a number of exploration wells (Enterprise Energy Ireland 2001b).

Median metal concentrations detected in the Rockall Trough sediment samples were all below background concentrations. In general, metal concentrations recorded within the Rockall Trough accord with concentrations recorded at the Corrib Field and during the AFEN and DTI surveys to the north and west of Scotland. Deeper water regions are rarely exposed to the same levels of anthropogenic inputs as coastal regions and as a result lower concentrations are to be expected (Tyrrell 2001).

Similarly, sea water metal concentrations for oceanic and offshore areas are likely to be comparable to background reference concentrations, indicating that widespread contamination is not a general problem (OSPAR 2000c). In oceanic areas, cadmium, and to a lesser extent copper, become incorporated onto particulate material, depleting concentrations in the dissolved phase. The decomposition of the particulate material as it sinks leads to a regeneration of the incorporated elements, and a consequent increase in dissolved phase concentrations with depth. By contrast, the depth profile for lead (with a dominant atmospheric source) exhibits a surface maximum in concentration, followed by a decrease with depth associated with dilution and scavenging by particles (OSPAR 2000c). In coastal and estuarine waters the observed pattern of dissolved trace metal distributions reflects the increased importance of riverine inputs, and also the extent to which the elements interact with suspended particulate material.

Elevated levels (in comparison to uncontaminated shelf areas) of trace metals have been found in some deep water biota. Mormede & Davies (2001a) examined concentrations of arsenic, cadmium, lead, copper and zinc in five commercial species of deep water fish (monkfish, black scabbard, blue ling, blue whiting and hake) from the Rockall Trough (400-1,150m water depth). Metal concentrations in muscle tissue were all well within EU limits for human consumption. However, in some cases, particularly for cadmium and zinc in black scabbard livers, concentrations exceeded EU limits (Mormede & Davies 2001a). Median metal concentrations found in a number of deep water fish species are presented in Table 2.6.

Table 2.6 – Metal concentrations (mg/kg) in muscle tissue of Rockall Trough fishes

Species		Arsenic	Cadmium	Copper	Lead	Mercury	Zinc
Roundnose grenadier[1]	Range	-	ND-0.01	0.03-0.54	ND-0.06	0.02-0.28	1.7-2.9
	Median	-	0.02	0.08	0.004	0.07	2.2
Roughhead grenadier[1]	Range	-	ND-0.21	ND-0.24	0.003-0.04	0.15-0.88	2.8-3.9
	Median	-	0.01	0.01	0.01	0.34	3.2
Orange roughy[1]	Range	-	ND-0.01	0.04-0.19	ND-0.66	0.11-0.86	2.0-3.4
	Median	-	0.01	0.09	0.01	0.42	2.7
Mediterranean grenadier[1]	Range	-	ND-0.07	ND-0.89	0.07-2.4	0.02-0.34	2.6-8.5
	Median	-	0.02	0.48	0.72	0.07	5
North Atlantic codling[2]	Range	-	0.003-0.013	0.13-0.24	ND-0.011	0.038-0.398	2.16-3.56
	Median	-	0.005	0.17	0.002	0.077	2.62
Monkfish[3]	Range	2.7-21.47	<0.002-0.041	0.06-0.22	<0.002-0.041	-	-
	Median	8.63	<0.002	0.15	<0.002	-	-
Black scabbardfish[3]	Range	<0.002-26.49	<0.002-0.017	0.07-0.27	<0.002-0.052		2.12-3.9
	Median	1.25	0.004	0.12	0.009	-	2.85
Blue ling[3]	Range	1.84-13.09	<0.002-0.004	0.10-0.41	<0.002-0.008	-	-
	Median	8.03	<0.002	0.15	0.003	-	-
Blue whiting[3]	Range	0.37-6.10	<0.002-1.178	0.19-0.45	0.005-0.03	-	-
	Median	2.24	0.022	0.29	0.008	-	-
Hake[3]	Range	0.08-3.3	<0.002-0.062	0.16-0.54	<0.002-0.047	-	-
	Median	1.37	0.034	0.27	0.008	-	-

Note: Metal concentrations in mg/kg wet weight
Sources:
1. *Cronin et al. (1998).*
2. *Mormede & Davies (in press, cited by Mormede & Davies (2001a)).*
3. *Mormede & Davies (2001a).*

Fish and shellfish tend to contain high concentrations of mercury in relation to other animals principally because fish feed on aquatic organisms that contain methyl mercury (WHO 2003, Seixas *et al.* 2005). The amount of mercury in fish is normally correlated with a number of factors including the size and age of the fish, its trophic position, as well as the mercury content in water and sediment and the pH of the water (WHO 2003). Gordon *et al.* (1995) suggested that as continental slope fish tend to live longer and to feed at higher trophic levels than their shelf counterparts, the potential for the accumulation of trace metals may be greater. However, the exact nature of the uptake, bioaccumulation and metabolism of metals between different fish species with depth has not been fully described.

Cephalopods are known to accumulate high levels of certain contaminants, notably cadmium and mercury (Craig 1996, Monteiro *et al.* 1992; Bustamante *et al.* 1998a; Frodello *et al.* 2000). Cadmium is mainly accumulated in the digestive gland of cephalopods (Finger & Smith 1987, Miramand & Bentley 1992, Bustamante *et al.,* 1998b) representing up to 98% of the total body cadmium in some species. Squid taken from the Atlantic Irish shelf had mean whole body cadmium concentrations ranging from 0.11mg/kg (*Loligo forbesi*, 18 indivduals) to 8.41mg/kg (*Todarodes sagittatus,* 5 individuals) (Bustamante *et al.* 1998a). Cephalopods from sub-polar areas showed higher levels of cadmium than those living in temperate areas (Bustamante *et al.* 1998a, b), despite exposure to soluble metals in natural seawater being extremely low in polar regions (Mart *et al.* 1982; Donat & Bruland 1995). Analysis of mercury concentrations from a range of tissues from octopus taken from off the Portuguese coast found the highest mercury concentrations (0.58-3.43mg/kg) in the digestive glands suggesting that food is a major pathway for mercury accumulation in octopus (Seixas *et al.* 2005).

Cephalopods are regarded as key species in many marine ecosystems (Amaratunga 1983, Rodhouse 1989), and are eaten by many marine top predators such as fish, birds and mammals (e.g. Clarke 1996, Croxall & Prince 1996). Cephalopods are considered to be a vector for the transfer of cadmium to top marine predators (Honda & Tatsukawa 1983, Muirhead & Furness 1988, Bustamante *et al.* 1998b). The high bioavailability of cadmium in the digestive gland cells indicates a high potential for the trophic transfer of the metal to predators such as marine mammals and seabirds (Bustamante *et al.* 2002). High cadmium levels in cephalopods from the sub-Arctic zone were found to correspond closely to reported high cadmium concentrations in the tissues of top vertebrate predators (marine mammals and seabirds) from the same area. Species that feed on euphausiids and cephalopods tend to have higher cadmium contents than those that feed on fish with coastal-dwelling species generally having higher loads than oceanic species (OSPAR 2000b).

Hydrocarbons

Hydrocarbons occur naturally in seawater and marine sediments from biogenic (e.g. phytoplankton and other marine biota) and petrogenic (hydrocarbon seeps) origins. However, hydrocarbon contamination from anthropogenic inputs is widespread in the marine environment, with inputs from the offshore E&P industry, shipping, atmospheric transport and coastal sources. Riverine inputs constitute a significant part of the overall load of oil entering the maritime area (OSPAR 2000c). On a global scale the inputs of oil-based hydrocarbons from human activities on land and at sea are small compared with those from natural sources however they can cause significant local damage to marine life and amenities (OSPAR 2000b). Hydrocarbons discharged to the water column are subject to a range of physical processes and biodegradation, and elevated concentrations of most petrogenic hydrocarbons are limited to the vicinity of point source discharges, in areas of intense shipping and in major estuary systems (OSPAR 2000b).

Offshore discharges of oil and organic phase fluids into the OSPAR maritime area are monitored and reported by OSPAR. The total discharge and spillage of dispersed oil (mainly from produced water) was 9,209 tonnes in 2002 (mainly to the North Sea). Ireland recorded zero discharges or spillages of oil from offshore oil and gas activities in 2002 (OSPAR 2004a).

Analyses of seabed samples from the vicinity of producing fields to the north and west of Scotland (Foinaven, Vrackie, Schiehallion and Clair), together with samples taken by the AFEN 1996, AFEN 1998, DTI 2000 and DTI 2002 surveys, indicate that hydrocarbon contamination is localised and associated primarily with discharges of oil-based cuttings from exploration, appraisal and development drilling (DTI 2003a). Seabed surveys of the Corrib Field indicated that base oil concentrations associated with the drilling of a number of wells were generally very low or not detectable. Well 18/20-3 drilled in 2000 with a synthetic mud system showed localised (within 100m of drill centre) base oil contamination (maximum conc. 3,800µg/g) in a post-drilling survey in the same year. However, base oil concentrations are now expected to be virtually undetectable (Enterprise Energy Ireland 2001b).

With the exception of two samples clearly associated with drilling discharges and one sample which contained a large quantity of phytodetritus, total hydrocarbon concentrations in the AFEN 1996 and 1998 baseline samples from west of Shetland were between 0.5 and 11.5µg/g (dry weight sediment). Total hydrocarbon concentrations in samples taken in the SEA 4 area in 2002 had a very similar range (0.8 to 11.0µg/g), which is comparable with typical background values for North Sea areas remote from offshore oil activities (0.2-5µg/g; DTI 2003a).

Further analysis of the AFEN and DTI samples indicated a biogenic rather than petrogenic origin for the majority of aliphatic hydrocarbons. Gas chromatographic profiles suggested low level contamination of sediments with heavily weathered oil or its degradation products, most probably from historic and dispersed shipping sources (DTI 2003a).

Given the dispersive environment and the relatively low amount of exploration and appraisal drilling that has taken place in the deep water area to the west of Ireland, sediment hydrocarbon concentrations are expected to be low and within background ranges. Whilst the area is not exposed to particularly heavy shipping pressures, sediments may contain traces of contamination from shipping sources similar to that described for the AFEN and SEA 4 areas.

Polycyclic Aromatic Hydrocarbons (PAHs) are a group of organic chemicals which are toxic and bioaccumulate particularly in invertebrates. In general the two main contributors of PAHs to the environment are fossil fuels, mainly crude oil, and the incomplete combustion of organic materials such as wood, coal and oil. Offshore activities, oil spills, offshore installations and shipping exhausts are also important sources with both the atmospheric and aquatic pathways to the maritime area important (OSPAR 2004b). Background PAH levels are also present as a result of biosynthesis and natural oil seeps (OSPAR 2000b).

As a consequence of their hydrophobic nature, PAHs in aquatic environments associate rapidly with particulates and sediments therefore represent the most important reservoir of PAHs in the marine environment. PAH concentrations in Atlantic sea water range from 0.3ng/l for individual, more water-soluble, lower molecular weight PAHs (two and three ring compounds) to less than 0.001ng/l for the high molecular weight PAHs (five or more ring compounds). Higher concentrations are generally found in coastal and estuarine samples with total PAH concentrations ranging from not detectable to 8,500ng/l (OSPAR 2000b, 2004b).

Total 2-6 ring PAHs recorded in sediments in the AFEN 1996 and 1998 surveys were in the range 15-238ng/g (dry weight sediment), which are broadly typical of uncontaminated sediments. Concentrations from the DTI 2002 survey were comparable, in the range 5-519ng/g (DTI 2003a). Provisional OSPAR Background Concentrations for a number of PAHs in sediments range from 3-50ng/g (ACME 2004). Sediment PAH concentrations from the deep water region to the west of Ireland are expected to be low and close to background levels.

Persistent organic contaminants

A range of organic contaminants are characterised as persistent, i.e. are biodegraded or degraded by physical processes (e.g. photo-oxidation) very slowly. Such contaminants may be transported over global scales, and in some cases are highly toxic or contribute to adverse global environmental effects. Persistent organic contaminants include chlorinated hydrocarbons such as polychlorinated biphenyls (PCBs), chloro-fluorocarbons (CFCs), polychlorinated dioxins and dibenzofurans (PCDD/Fs) and organochlorine pesticides; brominated flame retardants; perfluorooctane sulphate (PFOS);

octylphenol and nonylphenol ethoxylates (OPE and NPE) and organo-metallic compounds such as tributyl tin (TBT) (DTI 2004b).

Polychlorinated biphenyls (PCBs) were first introduced in the 1920s and have been used for a variety of industrial purposes (OSPAR 2000a). Although the deep sea is distant from the primary sources of these compounds, most organochlorine compounds are transported through the atmosphere to the poles where they condense into the cold waters that subsequently provide the bulk of deep oceanic waters (Ballschmiter 1992). Atmospheric inputs of PCBs to the OSPAR area are estimated to be about 20 tonnes/year. These compounds are often resistant to biochemical degradation, have a tendency to accumulate in lipids in the marine biota (Mormede & Davies 2001b) and are regarded as widespread and threatening contaminants in the marine environment for top predators such as fish-eating seabirds and marine mammals (OSPAR 1994).

Mormede & Davies (2001b) found higher levels of chlorobiphenyl congeners and organochlorine pesticides in deep water monkfish than those caught over shelf areas around Scotland, although they were lower than those from industrialised areas such as the Firth of Clyde. Levels however were at least five times lower than the UK and strictest European dietary guidelines. Concentrations of some of these compounds were positively correlated with fish length implying a gradual accumulation of these compounds over time with evidence suggesting that there was little metabolic breakdown of these contaminants in deep sea fish (Mormede & Davies 2001b).

Marine mammals have a low ability to metabolise PCBs and some species carry very high loads which can depress their reproductive potential and immune system. Species that stay in waters where contamination is low carry smaller burdens than those, like pilot whales, that migrate regularly into more polluted areas (OSPAR 2000a). Seventeen Atlantic white-sided dolphins found stranded on the Co. Mayo coast in 1994 were found to contain blubber chlorobiphenyl concentrations of 773-63,400μg/kg with concentrations of the organochlorine pesticide DDT of 160-54,600 μg/kg. The concentrations were found to be highly dependent on the age, sex, reproductive state and nutritional condition of the animals in addition to the intake via the food web (McKenzie *et al*. 1997). One of the main factors determining body burden was the selective transfer of less lipophillic contaminants, such as the lower chlorinated chlorobiphenyls (CBs) and hexachlorobenzene (HCB) from lactating females to calves (McKenzie et al. 1997).

2.5.3 Data gaps

There are significant data gaps regarding the extent of contamination of the deep water environment to the west of Ireland. Comparisons with the Atlantic Frontier to the north suggest that contamination levels are low. However, there is limited information on anthropogenic inputs to the area and there are large gaps in survey coverage both spatially and temporally.

The OSPAR Quality Status Report for the wider Atlantic (OSPAR 2000a) identified a number of data gaps (uncertainties) related to contaminants in the region. Those of relevance to the present study include:

- A lack of adequate baseline data against which contaminant levels can be evaluated and changes detected;
- The pathways whereby the majority of the contaminants (organic and inorganic) reach the deep ocean and the dynamics of their fluxes;
- The dynamics of many of the chemical transformations that occur in the biota, water column and sediments;
- The relative contributions of anthropogenic and natural inputs for many substances;
- Adequate quantification of atmospheric inputs of contaminants,
- The impact of long-term chronic exposures to low doses of contaminants.

The major sources of contaminants associated with offshore oil and gas activities are drill cuttings, produced water and flaring; with relatively minor inputs via drainage and other discharges. Given the low level of oil and gas activity in the region, the control and mitigation measures in place, and the nature of the receiving environment, significant contamination from the oil and gas industry in the waters west of Ireland is very unlikely.

3 ECOLOGY

3.1 Regional overview

The ecology of the deep water area to the west of Ireland is poorly understood in comparison to shelf and coastal waters. The scale of the region and the technical challenges involved in survey and sampling have meant that information on the structure and functioning of deep water ecosystems has lagged behind our understanding of their shallow water counterparts. The expansion of human activities (e.g. fishing, oil and gas exploration) into the deep water area over the last 30 years has facilitated the gathering of ecological information but may also have impacted upon these as yet poorly understood ecosystems.

In general, biological productivity is lower in the cold deep water compared to shelf and coastal waters. Without light the deep water has no primary productivity except in the nutrient poor surface waters. Food availability is therefore extremely limited and often associated with oceanographic or physical features such as frontal systems and upwellings associated with seabed features. Energy transfer pathways from the surface to deeper waters include the overlapping food chains of organisms which occupy specific depths or depth ranges as well as the daily vertical migrations of many organisms which transfer energy directly and quickly down to the seabed. Otherwise the deep-sea ecosystem is fuelled mainly by a rain of dead plants and animals from surface waters and, in some cases, by chemotrophic utilisation of hydrothermal and hydrocarbon seeps.

The distribution of organisms within the deep water area whilst generally not well described is determined by a range of physical and biological factors. Temperature and depth are particularly important with some species able to tolerate a range of temperatures and depths whilst others have a more restricted distribution. Movements between deep water and shelf areas are common with a range of pelagic cephalopods, fish, turtles and marine mammals, as well as planktonic species, found across the shelf as well over deeper waters. A number of organisms also undertake migratory movements through the area to feed or spawn and are generally present seasonally. Surface currents are important determinants of the distribution of many species particularly plankton and fish whilst bottom currents may determine the distribution of many benthic species.

Recent PIP-funded cetaceans and seabirds at sea surveys have highlighted the importance of the region for a wide variety of cetacean and seabird species. Particular areas appear to be of importance for seabirds and cetaceans (as defined by species richness and abundance indices) and work to define these further is ongoing (CMRC 2005). Nature conservation initiatives at both national and European level are currently identifying a network of marine habitats and species which may be protected in the future. It is likely given the ecological significance of many aspects of the region's environment that particular sites and species may be designated as areas of conservation in the future (see Section 5.1.3 for details).

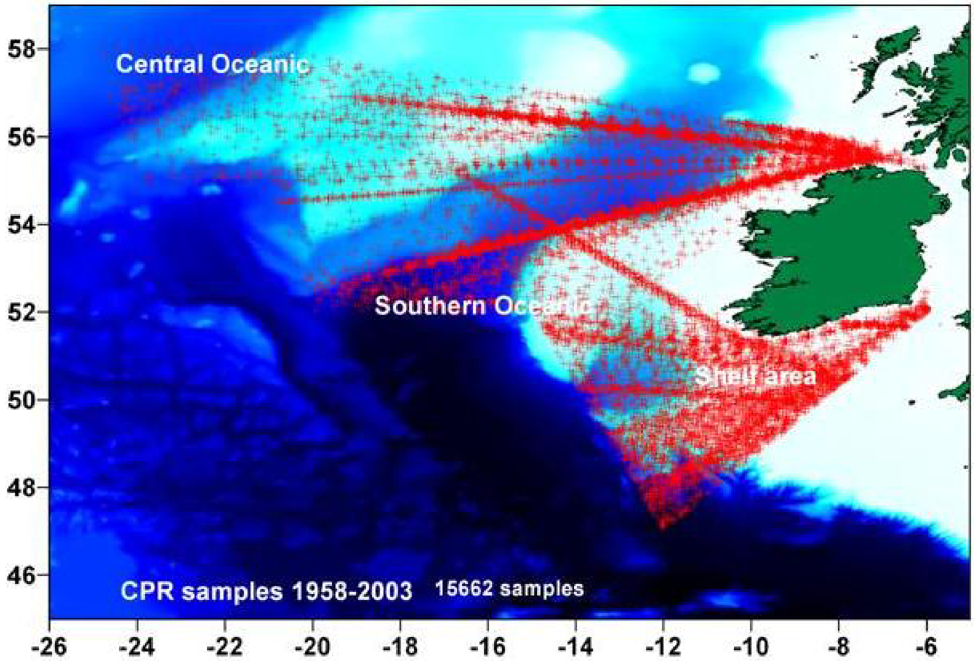
3.2 Plankton

3.2.1 Overview

Marine plankton comprises predominantly microscopic organisms, with some larger organisms such as jellyfish, which drift with the surrounding water. They include plants (phytoplankton), animals (zooplankton) and bacteria (bacterioplankton) with the majority ranging in size from 0.2µm to >20mm. In general, planktonic organisms form the basis of marine food webs and constitute a major food resource for many commercial fish species. Changes in plankton populations may therefore have important ecological and economic consequences (DTI 2003b).

Plankton distribution and abundance in the North Atlantic and North Sea has been monitored for almost 70 years using the Continuous Plankton Recorder. CPR coverage of the area to the west of Ireland is described in Figure 3.1. From this long-term dataset, changes in abundance and long term trends can be distinguished.

Figure 3.1 – CPR samples in the region (1958-2003)



Source: pers. comm., D Johns, SAHFOS

The Sir Alister Hardy Foundation for Ocean Science (SAHFOS) were commissioned to provide an analysis of CPR data on the phyto- and zooplankton communities found to the west of Ireland. Given the scale of the region, data were collected for three different areas; central oceanic, southern oceanic and shelf. Central and southern oceanic areas were split along the 52°N line of latitude as in Edwards *et al*. (2001) who identified differences between the long term plankton dynamics of these two areas. The shelf included the area landward of the 200m contour. Reference to the CPR Plankton Atlas (2004) provided further information as to the abundance and distribution of plankton species in the region. Whilst the CPR survey records over 400 taxa of plankton it does not record very small picoplanktonic organisms (0.2-2µm) which in many areas are thought to be responsible for the bulk of primary production (Iriarte & Purdie 1993).

3.2.2 Plankton communities and dynamics

Phytoplankton

Phytoplankton communities can be divided into larger entities such as diatoms and dinoflagellates, and smaller flagellates. The latter are often referred to as pico or nano plankton because of their small size, but can at times make up a large proportion of the phytoplankton community. Diatoms are autotrophic (produce energy by photosynthesis) whilst dinoflagellates are usually heterotrophic (consume substances), but can also photosynthesize under certain conditions (SAHFOS).

Table 3.1 describes those phytoplankton taxa with a >5% occurrence in the CPR survey (pers. comm. D Johns, SAHFOS) from the three areas. Figure 3.2 highlights the long term abundance of the main phytoplankton taxa identified from each of the three areas.

Table 3.1 – Phytoplankton % occurrence in CPR survey (1958-2003)

Central oceanic	%	Southern oceanic	%	Shelf area	%
Ceratium fusus	41.5	*Ceratium fusus*	25.2	*Thalassiosira* spp.	17.
Ceratium furca	29.8	*Ceratium furca*	18.8	*Ceratium fusus*	15.1
Thalassiosira spp.	22.2	*Thalassionema nitzschoides*	16.6	*Rhizosolenia alata alata*	14.8
Thalassionema nitzschoides	19.6	*Chaetoceros (Hyalochaete)* spp.	15.1	*Thalassionema nitzschoides*	13.7
Chaetoceros (Hyalochaete) spp.	17.7	*Thalassiosira* spp.	14.7	*Chaetoceros (Phaeoceros)* spp.	13
Chaetoceros (Phaeoceros) spp.	17.2	*Chaetoceros (Phaeoceros)* spp.	14.6	*Chaetoceros (Hyalochaete)* spp.	12
Pseudonitzscia pseudodelicatissima	16.9	*Pseudonitzscia pseudodelicatissima*	11.6	*Ceratium tripos*	10.5
Dactyliosolen mediterraneus	13.7	*Rhizosolenia alata alata*	9.9	*Ceratium furca*	8.8
Rhizosolenia styliformis	13.3	*Ceratium macroceros*	8.7	*Pseudonitzscia pseudodelicatissima*	8.4
Ceratium tripos	12.7	*Ceratium tripos*	8.5	*Nitzscia seriata*	6.4
Ceratium lineatum	12.5	*Nitzscia seriata*	7.6	*Rhizosolenia styliformis*	6.3
Nitzscia seriata	12.3	*Thalassiothrix longissima*	7.4	*Rhizosolenia imbrica shrubsolei*	6.1
Rhizosolenia alata indica	11.7	*Dactyliosolen mediterraneus*	6.8	*Rhizosolenia hebetata semispina*	6.1
Thalassiothrix longissima	10.5	*Rhizosolenia styliformis*	6.5		
Rhizosolenia alata alata	9.1	*Ceratium lineatum*	5.9		
Protoperidinium spp.	8	*Rhizosolenia imbrica shrubsolei*	5.2		
Rhizosolenia hebetata semispina	7.6	*Protoperidinium* spp.	5.1		
Rhizosolenia alata inermis	6.7	*Exuviella spp.*	5.1		
Ceratium horridum	6.2				
Rhizosolenia imbrica shrubsolei	5.5				
Ceratium macroceros	5				

Source: pers. comm., D Johns, SAHFOS

Figure 3.2 – Long term abundance profiles of the main phytoplankton taxa

Central oceanic area *Southern oceanic area*

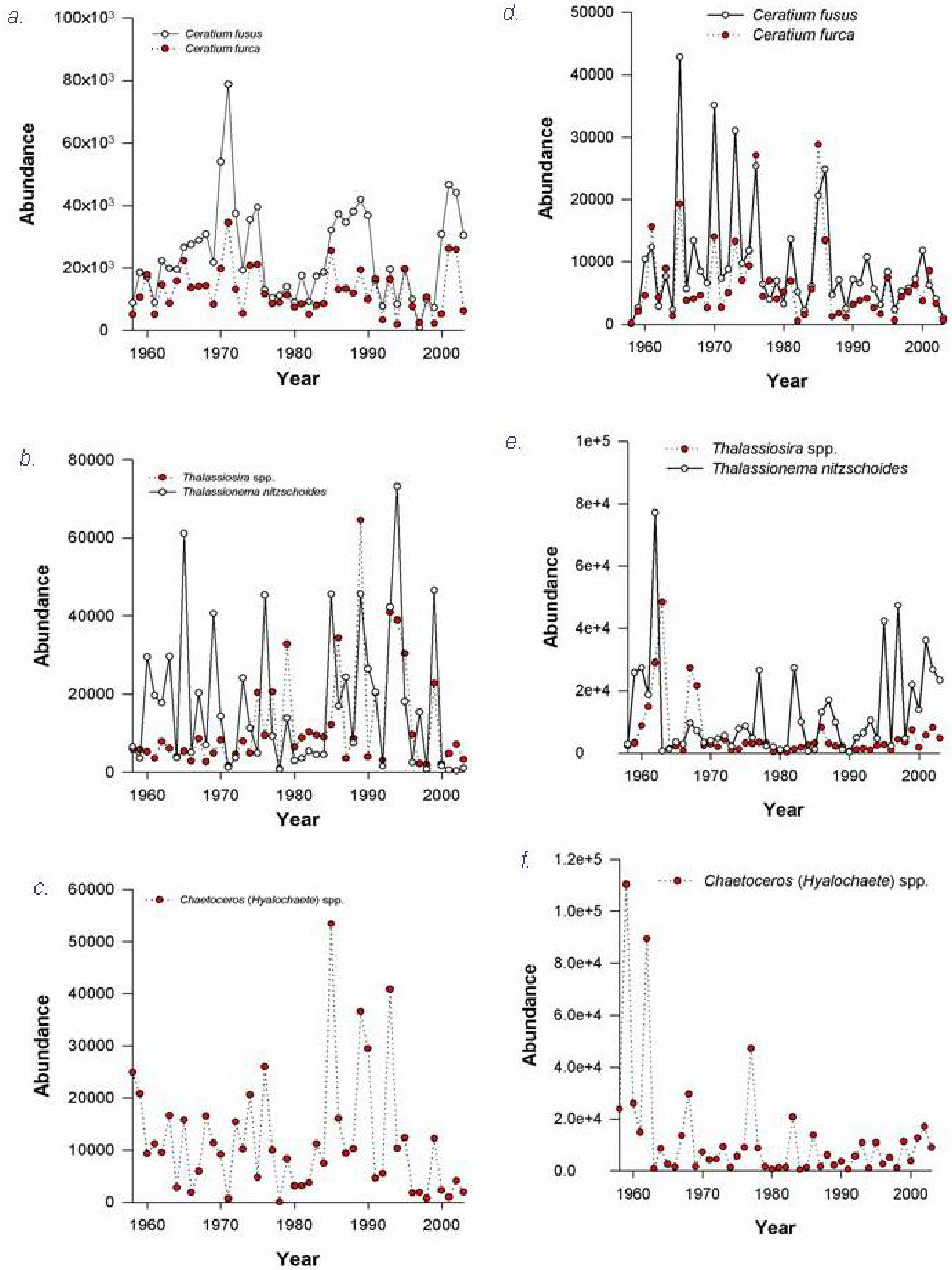
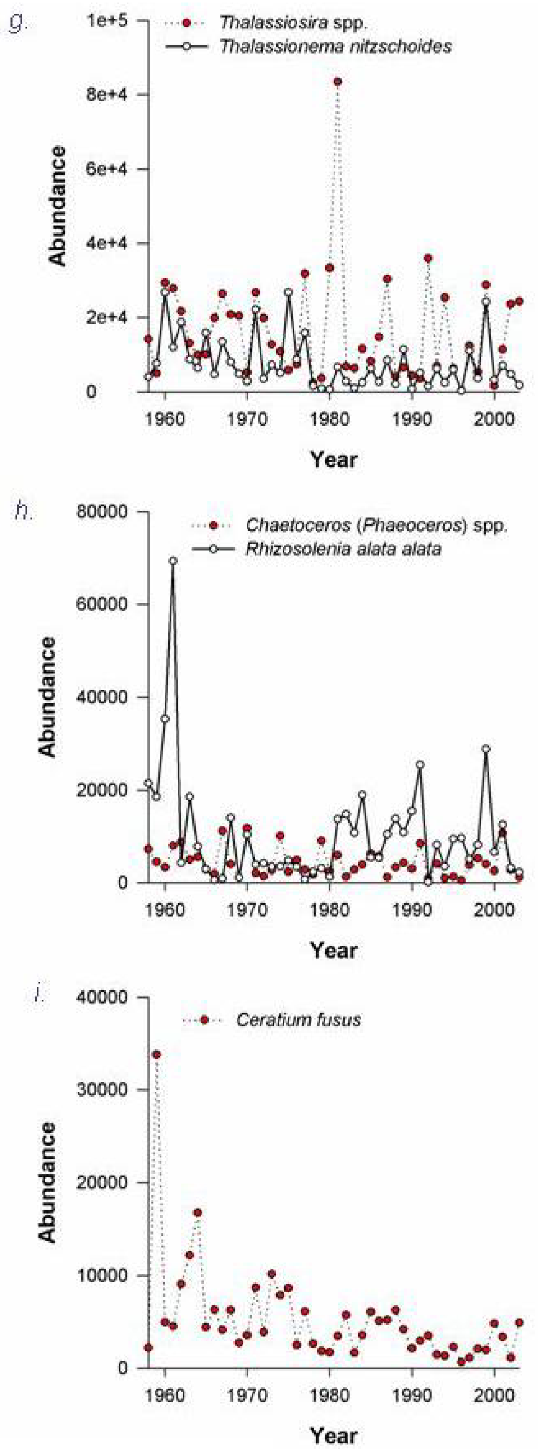


Figure 3.2 – Long term abundance profiles of the main phytoplankton taxa

Shelf area



Source: pers. comm., D Johns, SAHFOS

Oceanic phytoplankton

The dinoflagellates *C. fusus* and *C. furca* have the greatest occurrence in both central and southern oceanic areas with *C. fusus* occurring more frequently in central areas. Figure 3.2a and d indicate that there has been considerable variation in the abundance of both dinoflagellate species, particularly *C. fusus* over the CPR timecourse.

The majority of phytoplankton taxa recorded from oceanic areas were diatoms with *Thalassiosira* spp., *Thalassionema nitzschoides* and *Chaetoceros* spp. occurring frequently. All three diatom taxa showed considerable variation in abundance particularly *T. nitzschoides* and *Chaetoceros (Hyalochaete)* spp., especially in the central oceanic area (Figure 3.2b,c,e,f). *Thalassiosira* spp. were less variable and had lower abundance in southern waters. Higher abundances of the diatoms *Thalassiothrix longissima* and *T. nitzschoides* are associated with offshore rather than shelf waters. The central oceanic area contained the highest abundances of the diatom *Rhizosolenia alata indica* (CPR Plankton Atlas 2004).

Shelf phytoplankton

Fewer phytoplankton taxa were recorded as occurring in the shelf area than in either of the offshore areas (Table 3.1). The dinoflagellates *C. fusus* and *C. furca* were not dominant and *C. furca* occurred much less frequently than in offshore areas which accords with its more offshore distribution (CPR Plankton Atlas 2004). *C. fusus* has shown a steady decline in abundance in shelf waters (Figure 3.2i).

Diatoms make up the majority of shelf phytoplankton taxa recorded from the shelf with *Thalassiosira* spp., *Rhizosolenia alata alata* and *T. nitzschoides* the most frequently occurring. The distribution of *R. alata alata* and *R. hebetata semispina* is largely restricted to shelf and central oceanic waters (CPR Plankton Atlas 2004). *R. alata alata* abundance has varied considerably over the CPR timecourse (Figure 3.2h).

Zooplankton

Zooplankton communities are composed of a number of different organisms. The most common group are the copepods (small, arthropods which range from 0.5 to 6mm) which are known to reach large densities and form the main food source for higher trophic levels (Johns & Wootton 2003). Chaetognaths or 'arrow worms' are also an important component of the zooplankton community. Meroplankton are also present and represent the larval stages of benthic organisms (e.g. echinoderms, crabs and lobsters) that spend a short period of their lifecycle in the pelagic phase before settling in benthic habitats. The eggs and larvae of many fish species also form part of the zooplankton. Larger zooplankton, known as megaplankton, including arthropods such as euphausiids (krill), and gelatinous forms such as thaliacea (salps and doliolids), siphonophores and medusae (jellyfish) are also present (although not well sampled by the CPR) (DTI 2004c).

Table 3.2 describes those zooplankton taxa with a >5% occurrence in the CPR survey (pers. comm. D Johns, SAHFOS) from the three areas.

Table 3.2 – Zooplankton % occurrence in CPR survey (1958-2003)

Central oceanic	%	Southern oceanic	%	Shelf area	%
Acartia spp.	45.1	*Para-pseudocalanus* spp.	45.1	*Calanus helgolandicus*	70.7
Euphausiacea	37.2	Euphausiacea	41.6	*Para-pseudocalanus* spp.	56.4
Para-pseudocalanus spp.	34.7	*Calanus helgolandicus*	35.1	Euphausiacea	48
Oithona spp.	29.2	*Acartia* spp.	34.8	Decapoda larvae	34.3
Hyperiidea	27.7	*Metridia lucens*	29	*Oithona* spp.	31.3
Metridia lucens	26	Chaetognatha	28.8	*Acartia* spp.	30.8
Chaetognatha	17.9	Hyperiidea	27	Chaetognatha	29.5
Calanus finmarchicus	16.5	*Oithona* spp.	26.9	*Calanus finmarchicus*	27.1
Calanus helgolandicus	16.3	*Pleuromamma robusta*	16.9	Thecosomata	26.7
Evadne spp.	15.2	Decapoda larvae	16.4	*Pseudocalanus* spp.	23.1
Pleuromamma robusta	14.3	*Centropages typicus*	16.2	*Centropages typicus*	22.6
Decapoda larvae	10.7	*Clausocalanus* spp.	13	Echinodermata larvae	21.6
Thecosomata	10.5	Larvacea	12.8	Hyperiidea	18.1
Centropages typicus	10.2	*Evadne* spp.	12.5	Fish larvae	15.2
Larvacea	8.6	Fish larvae	9.8	Larvacea	14.7
Fish larvae	7.8	*Calanus finmarchicus*	9.2	*Candacia armata*	10.2
Pseudocalanus adult	7	*Pseudocalanus* spp.	9	*Evadne* spp.	8.8
Euchaeta norvegica	6.3	Thecosomata	8	*Euchaeta hebes*	7
Pleuromamma borealis	6	Echinodermata larvae	7.2	*Podon* spp.	7
Podon spp.	5.9	*Podon* spp.	7	*Clausocalanus* spp.	6.4
		Pleuromamma gracilis	6.8		

Source: pers. comm., D Johns, SAHFOS

Figure 3.3 highlights the long term abundance of the main zooplankton taxa identified from each of the three areas.

Figure 3.3 – Long term abundance profiles of the main zooplankton taxa

Central oceanic area *Southern oceanic area*

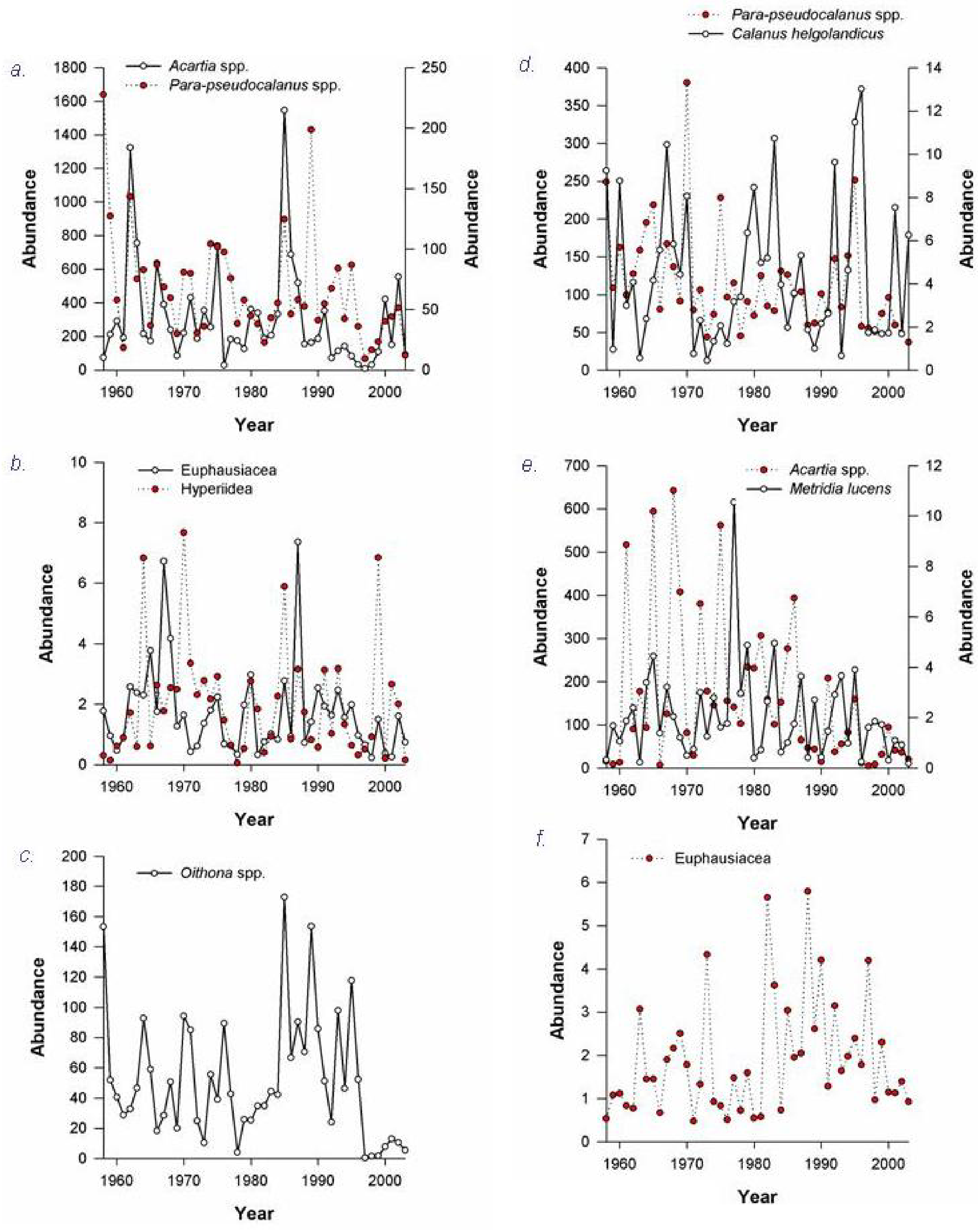
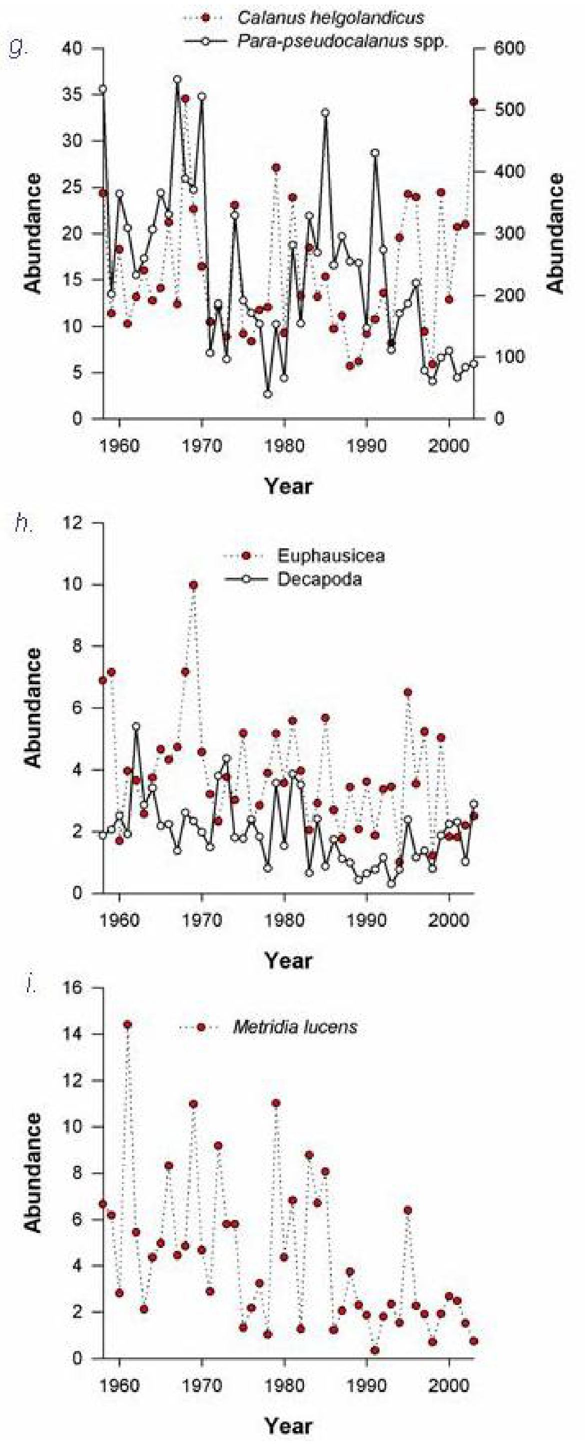


Figure 3.3 – Long term abundance profiles of the main zooplankton taxa

Shelf area



Source: pers. comm., D Johns, SAHFOS

Oceanic zooplankton

The zooplankton taxa which occur in the central and southern oceanic areas are similar although there frequency of occurrence may differ. For example, the calanoid copepod *Acartia* spp. occurs more frequently in the central oceanic area reflecting its greater abundance in central and northern waters (Figure 3.3a,e). The abundance of calanoid copepod *Para-pseudocalanus* spp. are greater (although variable) in shelf and southern oceanic waters (Figure 3.3g,d) . *Clausocalanus* spp. (Table 3.2) are southerly copepods with a high abundance in the Bay of Biscay. The amphipod suborder Hyperiidea has a greater abundance in offshore rather than shelf waters (CPR Plankton Atlas 2004).

Of considerable ecological interest in the NE Atlantic given their importance as a food resource for fish are the distributions and abundances of *Calanus finmarchicus* and *C. helgolandicus* (e.g. Planque & Batten 2000, Beaugrand 2003, Heath *et al.* 2000, Planque & Taylor 1998). *C. finmarchicus* is a more northern species (hence its increased occurrence in the central oceanic area) and is generally not abundant in Irish waters. *C. helgolandicus* on the other hand is more abundant in southern areas especially over the Celtic Sea shelf (CPR Plankton Atlas 2004). Changes in the relative abundances of these two species have been noted particularly in the northern North Sea which may be related to climate change (e.g. Beaugrand 2003).

Shelf zooplankton

C. helgolandicus is the most frequently occurring zooplankton species in shelf waters reflecting the importance of the Celtic Sea as a centre for its distribution. Figure 3.3g highlights the considerable variation in its abundance over the CPR timecourse. Similarly, *Para-pseudocalanus* spp. abundance is greatest on the shelf (CPR Plankton Atlas 2004) although there has been a general decline in its abundance (Figure 3.3g). Other species or groups that occur more frequently or are distributed mainly in shelf waters include Decapoda and Echinodermata larvae, and the calanoid copepods *Candacia armata* and *Euchaeta hebes* (CPR Plankton Atlas 2004).

In general, the main oceanic and shelf zooplankton taxa are characterised by considerable variations in annual abundance over the CPR timecourse.

Seasonal abundance and blooms

In arctic and temperate waters, a 'bloom' of phytoplankton occurs every spring as a result of increased light and temperature, often followed by a smaller peak in the autumn. During the winter months, in periods of low light, phytoplankton growth is inhibited allowing the build up of nutrients. Coincident with the onset of spring stratification, diatom species increase rapidly in abundance. As the spring progresses to summer, surface waters warm and a stronger thermocline develops. Colder, nutrient-rich waters are isolated from the photic zone; primary production slows and tends to be largely confined to deeper layers in the pycnocline. Silicate (essential for diatom growth) eventually becomes limited and other groups, such as flagellates, bloom, followed later by the dinoflagellates. With the onset of autumn, and the increase in wind strength, the sea becomes mixed once again. The resulting secondary bloom is limited by the amount of nutrients left after the initial diatom bloom (Johns & Wootton 2003).

Edwards *et al*. (2001) described long term (1960-1995) variability of phytoplankton biomass in six regions of the NE Atlantic (Table 3.3). The central and southern oceanic divisions utilised in the present study are comparable to the 'Central oceanic' and 'Southern oceanic' areas described by Edwards *et al.* (2001).

Table 3.3 – Summary of phytoplankton colour and hydrography of six regions of the NE Atlantic

Regions	Annual colour[1]	Spring bloom	Hydrographic regime
Offshore northern North Sea	0.62	April	Neritic (100-200m) summer stratified
Central and British coastal North Sea	1.1	March-April	Neritic (0-100m) summer stratified
Southern continental North Sea	1.65	March-April	Neritic (<50m) permanently mixed
Northern oceanic	0.41	May-June	Oceanic (>200m) seasonally stratified
Central oceanic[2]	0.85	April-May	Oceanic (>200m) seasonally stratified
Southern oceanic[2]	0.55	May	Oceanic (>200m) seasonally stratified

Note:

1. *Phytoplankton colour index annual mean – a measure of phytoplankton biomass*
2. *Central oceanic and Southern oceanic regions of most relevance to deep water area west of Ireland. Geographic boundaries described in Edwards et al. (2001).*

Source: Edwards et al. (2001).

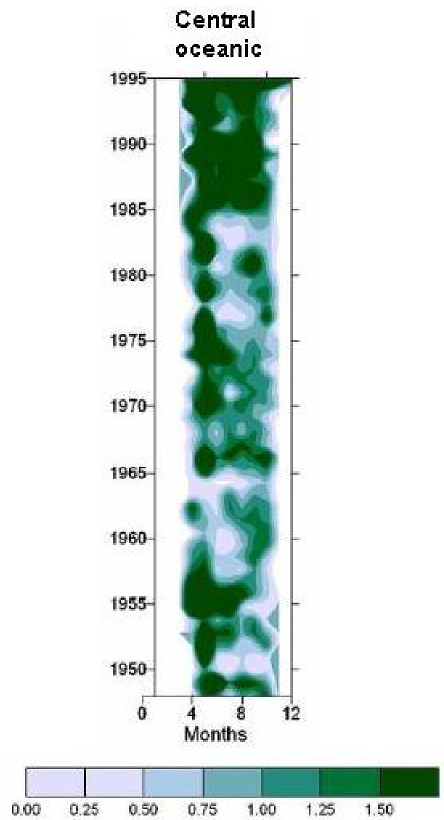


Figure 3.4 – Seasonal contour plot of mean monthly phytoplankton colour for the central NE Atlantic (1948-1995)

Source: modified from Beare et al. (2003).

Phytoplankton colour values (an indicator of phytoplankton biomass) in the central and southern oceanic regions have generally been above the 35-year average over the last decade. This increase has been particularly apparent for the central oceanic region (Figure 3.4) where since the mid-1980s, the seasonal growth period has intensified with no distinguishably clear break between the spring and autumnal blooms and an increase in colour during the summer months (Edwards *et al.* 2001). The potential causative agents of these changes are discussed in Section 3.2.3.

Higher levels of phytoplankton production are often associated with oceanographic features such as fronts. Longhurst (1998) noted that the dynamic processes which produce thermal fronts along the shelf edge of north west Europe from May to October (particularly in the Celtic Sea), also induce a continuous supply of nutrients leading to high levels of algal biomass at the front (Longhurst 1998). This enhanced shelf edge primary production is demonstrated by a SeaWiFS satellite image of chlorophyll-a concentrations to the west of Ireland at the peak of the spring bloom (Figure 3.5).

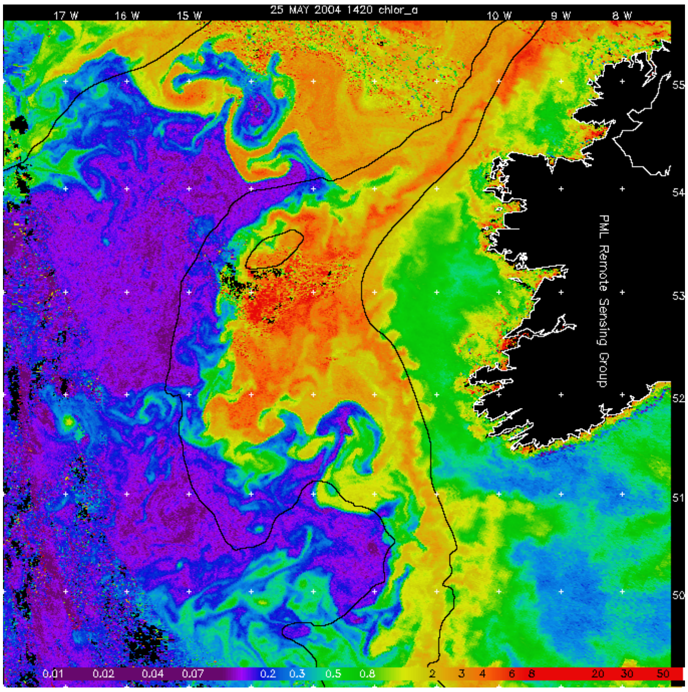


Figure 3.5 - SeaWiFS satellite image of chlorophyll-a concentrations (25 May 2004)

Notes: Chlorophyll-a (mg.m^{-3}) scale at bottom of image.
Source: Satellite image was received by the NERC Dundee Satellite Receiving Station and processed by Peter Miller at the Plymouth Marine Laboratory Remote Sensing Group (www.npm.ac.uk/rsdas/). Copyright Plymouth Marine Laboratory

Detailed analysis of the seasonal production of phytoplankton and zooplankton in surface waters across the Celtic Sea shelf edge, including sampling stations on the shelf, shelf edge (500-1,000m water depth), and at depths of 1,400m and >3,000m, was undertaken as part of the OMEX I project (1993-1996) (Joint *et al.* 2001). Data was combined over the timecourse of the project although the authors noted considerable annual variation (Joint *et al.* 2001).

The Celtic Sea shelf area showed the earliest increase in phytoplankton biomass in the spring, with a bloom that lasted over 2 months in April and May. The spring bloom was of much shorter duration at the shelf edge and over deeper oceanic waters although the largest peak in phytoplankton biomass was observed at the shelf edge in May. Over the Goban Spur, phytoplankton biomass declined from June to August before a smaller autumn bloom which was most pronounced on the shelf and in water depths of 1,500m (Joint *et al.* 2001).

Primary production at the Celtic Sea edge in the winter was dominated by small phytoplankton cells. From November to March, cells <5µm were responsible for 70–86% of the primary production, which was not insignificant at ca. $0.2gCm^{-2}d^{-1}$. The spring bloom was dominated by larger (>5mm) phytoplankton cells, particularly diatoms (*Nitzschia delicatissima*, *N. seriata*, *T. nitzschiodes* and *Chaetoceros* spp.) with total primary production increasing to $>1gCm^{-2}d^{-1}$. A number of dinoflagellate species (e.g. *Ceratium lineatum, Heterocapsa minima* and *Prorocentrum compressum*) were also present but at much lower densities. The production of the >5µm fraction declined steadily after the spring bloom and by July small unidentified flagellates dominated with large cells responsible for less than 50% of the total phytoplankton production. In the autumn, picoplankton (<2mm) were the most productive fraction although diatoms and a diverse assemblage of dinoflagellates including *C. furca, C. fusus, C. lineatum, Gonyaulax polygramma* and *Prorocentrum dentatum* were also present (Joint *et al.* 2001).

Upwelling along the Celtic Sea shelf break was responsible for bringing nutrients into the surface mixed layer which were utilised by phytoplankton and enhanced phytoplankton production (Joint *et al.* 2001). The highest primary production recorded during the OMEX I project was found at La Chapelle Bank to the south east of the Goban Spur where the steeper continental slope may have induced greater vertical mixing and nutrient supply (Joint *et al.* 2001).

Zooplankton biomass increased in April from winter minima (0.1-0.4mgC m^{-3}) in both shelf and offshore areas of the Celtic Sea with highest biomass recorded on the shelf in May ($12mgCm^{-3}$). Biomass was lower at the shelf edge ($7mgCm^{-3}$) and in deeper water ($3.3mgCm^{-3}$) (Joint *et al*. 2001). There was an autumn increase in biomass in October at the shelf edge and over water depths of 1,500m but none was apparent over the shelf region or the deepest water (Joint *et al*. 2001).

3.2.3 Other issues and data gaps

Hydro-climatic changes

As mentioned above, there has been a considerable increase in phytoplankton colour over the last decade in certain areas of the north east Atlantic and North Sea. Particularly high increases were seen after the mid-1980s in the central oceanic area between 52-58°N (Reid *et al*. 1998, Edwards *et al.* 2001). Over the same period of time there have been large scale changes in the spatiotemporal patterns of sea surface temperature (SST) in the Northeast Atlantic (Edwards *et al.* 2001).

These different regional responses can be partly explained by trends in the North Atlantic Oscillation (NAO). A high NAO index increases the degree of westerly winds, and consequently milder temperatures, over northern Europe whereas a low NAO index is usually associated with weaker westerly winds, allowing colder northerly winds to dominate over northern Europe. Edwards *et al.* (2001) suggested that the NAO has positive correlations with SST and phytoplankton colour in the central oceanic area although the exact mechanisms are poorly understood (Edwards *et al*. 2001).

Recently, a large-scale reorganisation in the calanoid copepod biodiversity has been detected in the north eastern North Atlantic and adjacent seas (Beaugrand *et al*. 2002). Strong biogeographical shifts in all copepod assemblages were found with a northward extension of more than 10° in latitude of warm-water species associated with a decrease in the number of colder-water species. These changes have been attributed to regional sea surface temperature warming (Beaugrand 2003).

During the past 40 years, the biomass of total copepods in the north east Atlantic has generally declined. In 1958 the mean total copepod biomass per CPR sample was twice that collected in 1997. This decline mostly results from a decrease in *C. finmarchicus* biomass. In 1964, *C. finmarchicus* accounted for 53% of the total copepod biomass; in 1997 the relative biomass was down to the lowest value ever recorded, 20%. Whether this decline in copepod biomass reflects a decline in zooplankton production or whether it has been compensated by an increase in the biomass of other zooplankton groups is not yet known (Planque & Batten 2000). *C. finmarchicus* abundance in the area to the west of Ireland is low, being restricted to more northern areas (Continuous Plankton Recorder Survey Team 2004).

Whilst recent changes in the region's primary productivity and plankton may be associated with climate variability, the lack of direct evidence and linkages between the two represents a significant data gap. The CPR represents one of the longest ecological datasets available however, in terms of the large scale climatic processes which it is being linked to, it is in fact very short. Studies of terrestrial tree rings and ice cores have allowed millennial-scale comparisons and associations to be made between productivity and climate.

Similarly, deep sea cores allow long term analysis of productivity through for example describing historic phytodetrital inputs to sediments. A number of megacores have been taken from the Goban Spur, the western Irish margin (west of Clew Bay, County Mayo), as well as from the Barra Fan to the north of the PIP area as part of the IMAGES programme. The objective of this international project is to understand the mechanisms and consequences of climatic changes using oceanic sedimentary records (IMAGES website – http://www.images-pages.org/start.html). Core analysis is ongoing and may allow better characterisation of the sequence of ocean-ice-climate interactions in the North East Atlantic with important consequences for our understanding of natural climate variability (IMAGES website). Similarly, shallow borehole cores have been taken on the eastern flank of the Rockall Trough as part of the PIP-funded RSG project 97/34 (Harrington et al. 2000). Through examination of the preserved micro-organisms and spores from different sediment layers within the cores, Harrington et al. were able to determine the paleo-depositional environment at the time.

Phytodetritus

Phytodetritus, commonly referred to as 'marine snow' (Alldredge & Gotschalk 1990) is derived from various sources, such as by-products of primary production (cellular fragments, tests etc.), faecal matter and terrestrial run-off. It contains a large source of carbon, which can be utilised in sub-surface primary production (Richardson *et al*. 2000).

Short-term, seasonal changes in deep-sea benthic populations are known to occur (e.g. Smith *et al.* 1996, Lauerman & Kaufmann 1998), and have been attributed to seasonal variations, such as in the deposition of phytodetritus (e.g. Rice *et al.* 1994, Smith *et al.* 1996). Of relevance to the present study is a 10 year benthic monitoring study of the Porcupine Abyssal Plain (Billett *et al.* 2001) which has suggested that inter-annual variability and long-term trends in organic matter supply to the seabed may be responsible for significant changes in abundance, species dominance and size distributions in deep sea benthic communities. Billett *et al.* (2001) noted that the flux of organic matter to the seabed varied both quantitatively and qualitatively in relation to surface productivity, and hence through biophysical coupling to long-term climatic change. Therefore, the aforementioned changes in plankton distribution and abundance may have significant effects on the benthic communities of the deep water area.

Foreign species and ballast water

Ballast water is a recognised vector for the introduction of non-indigenous and potentially harmful organisms into distant areas with resting stages of plankton easily transported in the fine sediments at the bottom of ballast water tanks. For example, the non-indigenous diatom *Coscinodiscus wailesii,* is suspected of being introduced to European waters via ballast water. From its initial appearance in 1977 in the English Channel the species has spread throughout European shelf seas to become an established and significant member of the planktonic community (Edwards *et al.* 2001, DTI 2004c, Johns 2004).

There is a growing concern of the risk of alien species and the importance of protecting native biodiversity. Raised awareness of this problem has resulted in the introduction of a variety of operational and technical innovations to reduce the risk of organism transfer via ballast water (DTI 2004c).

Harmful algal blooms

Some bloom forming species of phytoplankton produce toxins that can lead to direct mortalities of wild and farmed fish. Others cause excessive mucus secretion on fish gills, interfering with oxygen transfer and sometimes leading to fish mortalities. In sheltered coastal areas with weak circulation mortalities of fish and other marine organisms can occur when a bloom decays and bacterial decomposition leads to deoxygenation of the water (Boelens *et al.* 1999). The highest incidence of recorded toxic bloom events in the region is generally along the south west coast of Ireland, many of which are blooms of the dinoflagellate *Karenia mikimotoi*. There is now considerable evidence to show that many exceptional dinoflagellate blooms recorded at coastal sites do not develop in situ but result from physical advection of offshore populations suggesting a non-anthropogenic cause (Raine & McMahon 1998).

This year there have been reports of red/brown seawater discoloration (so called “red tides”) and mortalities of marine organisms such as oysters, cockles and lugworms along the west and northwest coasts of Ireland. Samples analysed by the Marine Institute (MI) in June 2005, identified an algal bloom of *K. mikimotoi* as responsible (Marine Institute website – http://www.marine.ie).

Water from around the Irish coast is routinely sampled and analysed by the Marine Institute to identify harmful or nuisance phytoplankton. In addition, the MI, in association with NUI Galway, are carrying out a three year research programme (BOHAB – Biological Oceanography of Harmful Algal Blooms) to better understand the development and movement of harmful algal blooms (HABs) along the west coast of Ireland. A simple model has been developed which predicts the onset of shellfish toxicity based on information on currents, forecasted meteorology and the time of year. At present this model only applies to the south west of Ireland although the potential of adopting this approach around Ireland is being researched (Marine Institute website - http://www.marine.ie/scientific+services/monitoring/phytoplankton/bohab.htm).

3.3 Benthos

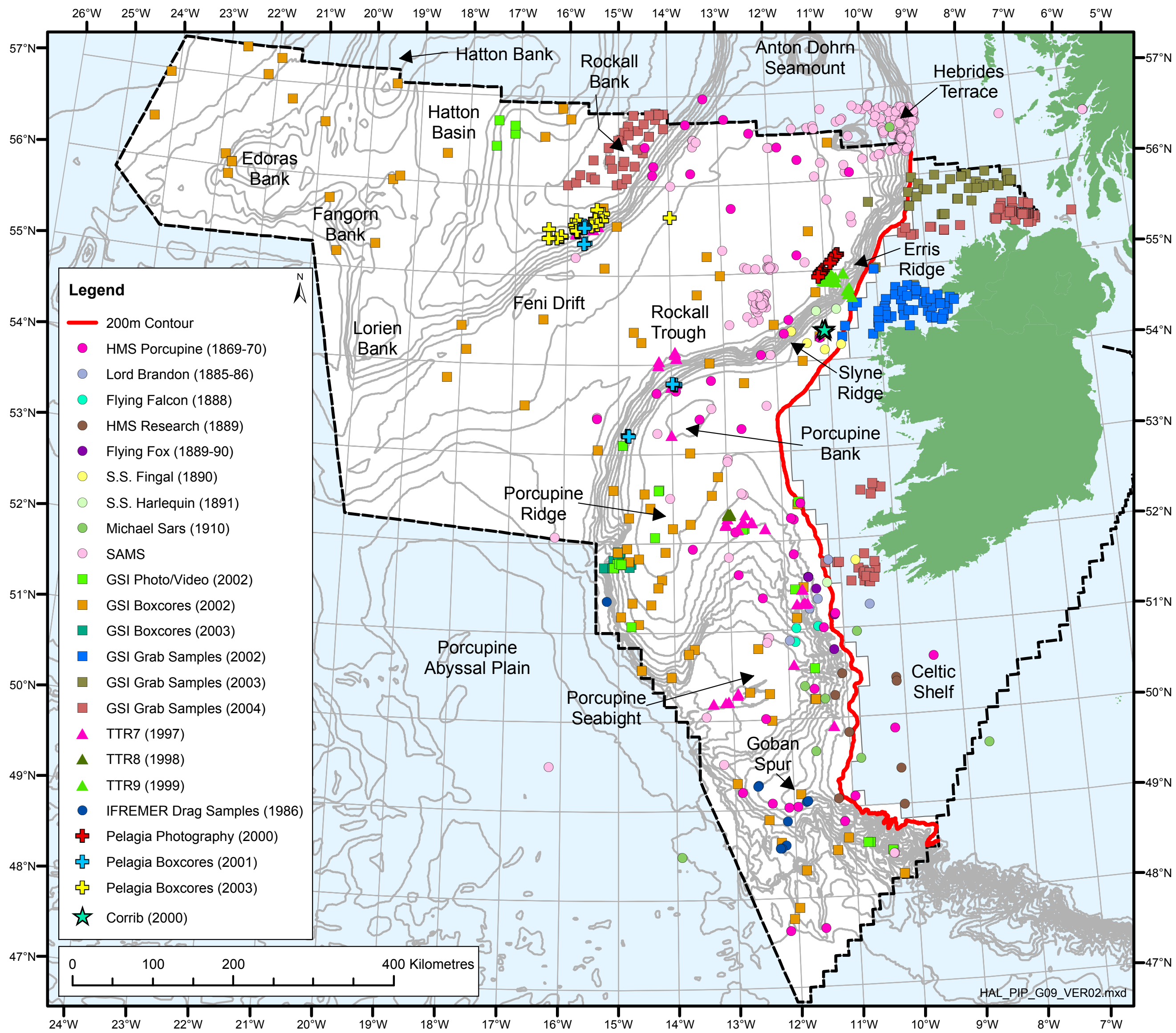
3.3.1 Overview and history of study

The waters to the west of Ireland have a long history of scientific study, stemming from the pioneering work from *HMS Porcupine* in 1869 (which discovered among other things, the Porcupine Bank). These cruises were for scientific exploration of the area and included bathymetric, oceanographic and biological investigations. Benthic sediment and animals were collected with a variety of dredges and concentrated on the deeper waters (down to some 4500m) although some material was also collected on the continental shelf. The cruises resulted in a series of papers and a classic marine biological text “The Depths of the Sea” (Wyville Thomson, 1874), which established the major water masses of the region and the vertical zonation of many species in relation to temperature.

A useful summary of the history of marine biological exploration of offshore Irish waters from the earliest days to recent studies of coldwater coral ecosystems is given in Greenwood *et al.* (undated).

The sampling positions of the major seabed investigations are shown in Figure 3.6 which allows a spatial appreciation of coverage and gaps in information. Gage and Tyler (1991) used many photographs of the seabed and representative larger animals from various depths in the Porcupine Seabight and Bank to illustrate their textbook "Deep-sea biology". The geophysical mapping carried in the area through PIP, GSI and others has provided a fairly comprehensive view of seabed topography and texture over the area. This has allowed the identification of benthic habitats of broad distribution as well as discrete features of geological, ecological and conservation importance such as carbonate mounds.

Figure 3.6 - Location of historic and recent seabed sampling stations



Rice (undated) prepared a report on behalf of the RSG entitled the Benthic Fauna of the Continental Slope to the West of Ireland (RSG Report R00_15). This report gave particular emphasis to the mobile and attached megabenthos[1] and includes a range of photographs of these benthic species and community types together with

[1] Animals which are large enough to be seen in seafloor photographs and caught by trawls.

species lists of depth zoned megabenthic assemblages. This report also includes a narrative on the history of scientific exploration of the area.

3.3.2 Benthic communities and dynamics

Biogeographic zones

Biogeographic zones are distinguished by patterns of overlapping occurrence of species, which in turn reflect major ecological influences such as water temperature. Generally, there are not sharp boundaries between biogeographic zones since individual species tolerances to ecological factors are different. The dividing lines can be further blurred where long term changes in conditions occur.

Work carried out on behalf of OSPAR (Dinter 1999) indicates that Ireland lies at the junction of three biogeographical zones (Provinces):

- Boreal Province including the North and Irish Seas
- Lusitanian-Boreal Province comprising the Celtic Sea and west coasts of Ireland and Scotland
- Atlantic Deep-Sea Province, a deep water zone to the west of northeast Europe

Each biogeographical province can be further subdivided into regions according to physical and biological features. For the Atlantic deep-sea province the prime variable is water depth to which several other factors controlling faunal distributions are linked. These include water temperature (which declines from between 8-11ºC near the shelf break to about 2ºC below 2500m), sediment type (which typically becomes finer with increasing water depth) and organic input (variable depending on location).

Soft sediments

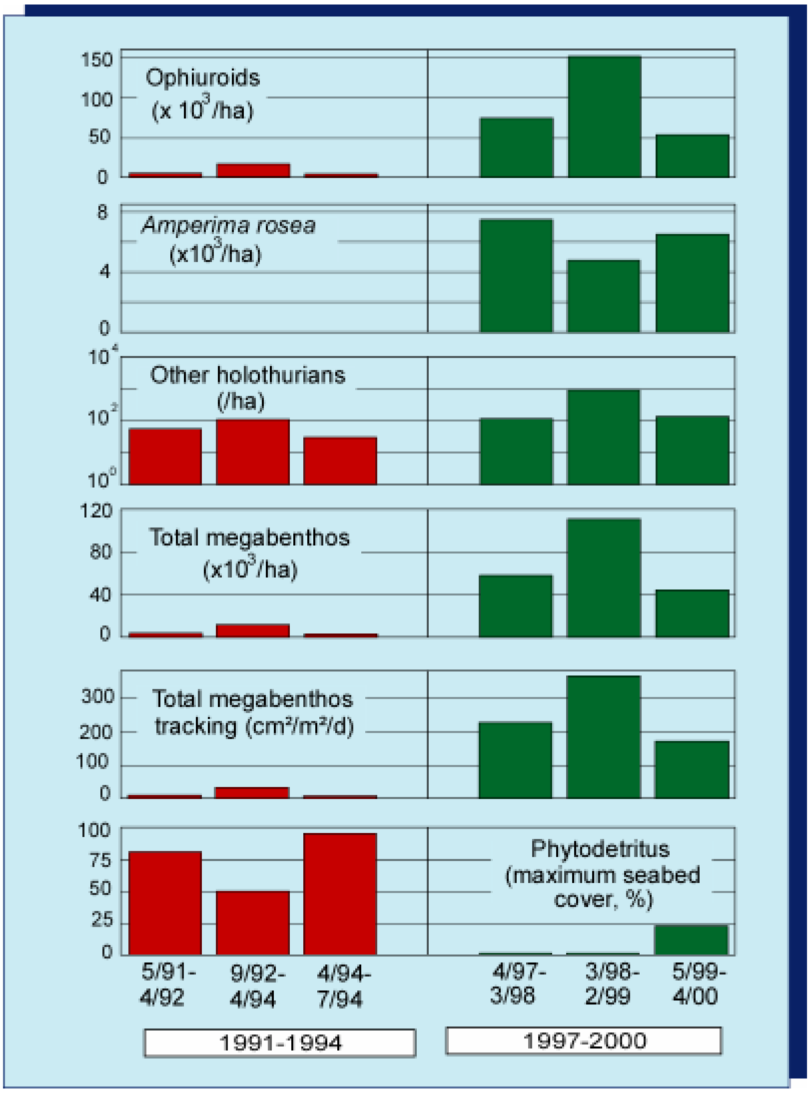
In continental shelf depths, a series of faunal communities have been distinguished inhabiting specific sediment types and water temperature ranges. In the deep sea where the vast majority of the seabed consists of soft sediments, the extent of sampling is insufficient to draw such community distinctions although it is clear that various species occupy discrete zones. For example the ecologically important bird's nest sponge *Pheronema carpenteri* occur in densities of up to 5/m^2 in a band between 1000-1300m depth with sharp upper and lower limits of distribution (Rice *et al.* 1990). Hughes and Gage (2004) sampled the range of benthic metazoa at 3 contrasting soft sediment sites to the west of the British Isles in water depths of 1100m, 1920m and 3580m. Each site had a range of characteristic animals in each of the size categories investigated (megafauna, macrofauna, meiofauna). The 1100m site included specimens of *Pheronema carpenteri*, indicating some constancy with earlier results in terms of repeatable patterns of faunal occurrence. The identity of most megafaunal species (larger animals visible in seabed photographs) of the deep waters of the Rockall Trough and adjacent areas is now comparatively well understood with many species photographed, collected and described in the scientific literature in recent years (see for example Gage *et al*. 1983 and 1985). In contrast, although the checklist of benthic invertebrates (Greenwood *et al.* and Leahy *et al.* undated) includes several hundred species names, it is known that there are many other undescribed animals in the macrofauna and meiofauna. For example in tanaid crustaceans it is estimated that some 30% of the species from the Atlantic Margin are new to science, with more regularly revealed by further surveys. Some progress in being made in describing these animals without names e.g. Bird (2004) named 3 new species and 2 new genera, but much remains to be done in many faunal groups. The lack of scientific names and descriptions hinders environmental monitoring, the appreciation of the biodiversity of an area and the drawing different datasets together into a regional synthesis.

The *Amperima* event

Until recently the deep sea seabed fauna was viewed as comparatively stable, with similar species and abundances found over long periods of time. New evidence from long term datasets from the abyssal eastern Pacific and the Rockall Trough challenge this perspective.

Major changes in the megafauna were found during a long-term study of a site on the Porcupine Abyssal Plain at roughly 48º50'N 16º30'W and a depth of some 4840m (Billett *et al*. 2001). In the early part of this study, which extended from 1989 to 1999, the benthic megafauna as sampled by semi-balloon otter-trawl and epibenthic sledge remained more or less constant in species composition and biomass. But between September 1994 and September 1996, a period during which no samples were taken, while the overall biomass remained fairly stable there was a marked change in the species composition, with a range of animal groups from worms to holothurians (sea cucumbers) all increasing significantly in abundance (Figure 3.7).

Figure 3.7 - Illustration of megafaunal changes on the Porcupine Abyssal Plain known as the "Amperima *event*"



After Billett et al. 2001.

Although statistically significant, most changes were relatively minor except in the case of the small holothurian *Amperima rosea* (Figure 3.8) which changed from being a minor constituent of the catches prior to 1994 to a numerically dominant element from 1996 to at least 1999. At the same time, the average size of some of the other species present decreased significantly, particularly some of the larger holothurians (Figure 3.9). The changes were not restricted to the immediate vicinity of the main sampling site but seem to have occurred over a wide area of the Porcupine Abyssal Plain and the phenomenon has become known as the "*Amperima* event" (Billett *et al*. 2001).

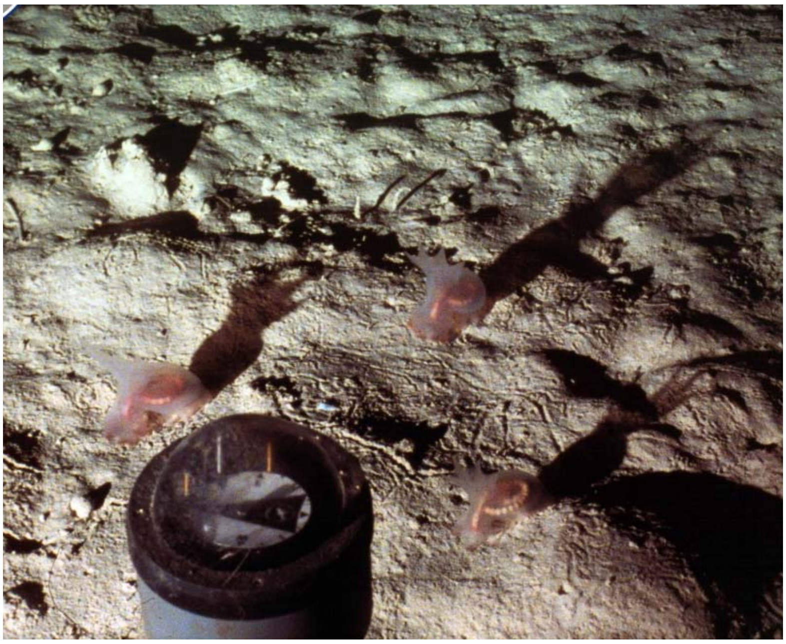


Figure 3.8 - The holothurian Amperima rosea*.*

This species previously uncommon on the Porcupine Abyssal Plain became abundant in the 1990s.

Image: Courtesy and copyright Southampton Oceanography Centre

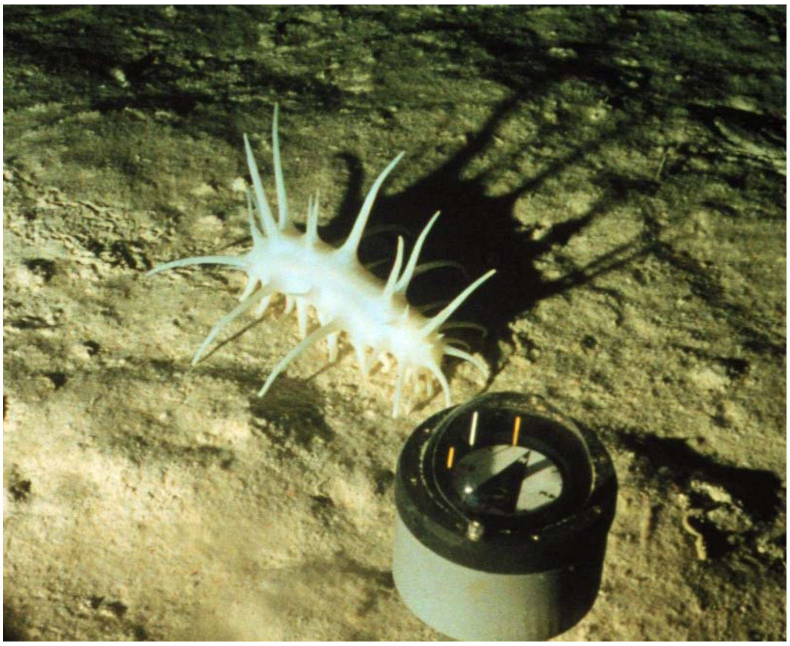


Figure 3.9 - The holothurian Oneirophanta mutabilis

One of the dominant megafaunal organisms on the Porcupine Abyssal Plain before the "*Amperima* event".

Image: Courtesy and copyright Southampton Oceanography Centre

The reason for this major change is suspected to be related (in some way) to the availability of food supply (Billett *et al*. 2001) which is now known to be variable seasonally and interannually (Billett *et al*. 1983). The This new perspective on deepsea faunal stability over time means that the results of a single survey at a deep-sea site are just a "snap shot" of the situation at that time and should not be assumed to represent the locality over the long term.

Mounds and reefs

Le Danois (1948) investigated the benthic fauna and sediments of the shelf and upper slope of the Celtic Sea and adjacent areas and had identified four main areas of cold water coral (mainly *Lophelia pertusa* and *Madrepora oculata*) reef along the continental slope break to the west of Ireland. Geophysical mapping of the seabed to the west of Ireland has shown the extent of steep-sided canyons (some with areas of exposed rock) and also the presence of a number of carbonate mound provinces across the region, especially on the flanks of the Porcupine Ridge and Rockall & Hatton Banks. These coral reefs and carbonate mounds have become a major focus of scientific research and a recent book (Freiwald and Roberts 2005) includes 8 papers describing aspects of the morphology, formation, dynamics etc of such features in the waters to the west of Ireland. These reefs and mounds are of major significance and a number are expected to be afforded protection through designation as European Special Areas of Conservation. The coral reefs are particularly vulnerable to physical damage for example by demersal trawling or rig anchoring and potentially to the effects of drilling discharges. Oilfield operations in the vicinity of such reefs will require careful environmental management e.g. such as implemented around the Flower Garden reefs in the Gulf of Mexico.

Internal wave linked communities

The occurrence of various filter feeding communities has been linked to internal waves impinging on the upper continental slope. When the angle of the ray slope is similar to the angle of the seabed (if convex) energy is imparted to the seabed from the internal wave (Huthnance, 1989; Ivey and Noakes, 1989). This energy input resuspends some bottom material, providing enhanced supply of food particles for suspension feeding animals in the immediate vicinity. Such a mechanism has been suggested to explain the distribution of coral *Lophelia pertusa* and large sponges round the Faroes (Frederiksen *et al*. 1992; Klitgaard *et al*. 1997) and the distribution of *Pheronema* sponges in the Porcupine Seabight (Rice *et a*l., 1990).

Data gaps

The following data gaps have been identified:

- Long term datasets in deep water areas to understand temporal variability in the seabed fauna.
- Basic scientific information on the identity and life history of many species – needed for understanding of likely sensitivity to disturbance, prediction of effects and use in environmental monitoring.
- Wider sampling coverage particularly in deeper water areas to provide assurance of anticipated uniformity (ideally undertaken as part of groundtruthing geophysical surveys).
- Understanding of the effects of past drilling operations in deep waters (through monitoring studies or the conduct of field experiments).

3.4 Cephalopods

3.4.1 Overview

Cephalopods are molluscs (squids, octopus and cuttlefish), often characterised by rapid growth rates and ranging in size from 1.5cm in pygmy squid (Sepiolidae) to 20m in giant squid (Architheutidae). In contrast to other molluscs, most cephalopods lack an external shell, are highly mobile as adults and occupy similar ecological niches to predatory fish. They are active predators at all stages of their life-cycle and generally regarded as opportunistic, taking a wide variety of prey. Cephalopods also sustain a number of marine top predators such as fish, birds and marine mammals (e.g. Lordan *et al*. 1998). Many species are powerful swimmers and carry out feeding and spawning migrations, thus influencing prey and predator communities strongly on a seasonal and regional basis (DTI 2004d, Stowasser *et al.* 2004).

Information regarding the distribution and abundance of cephalopod species in the deep water area to the west of Ireland is limited. The main source of data comes from fisheries records where cephalopod species are directly targeted or more often taken as bycatch in demersal trawls. These records provide useful qualitative information; however, given that the mesh size of most commercial trawls is probably too large to catch the majority of squid species, the data must be treated with caution. There have been a number of demersal survey programmes over both shelf and deep water areas utilising finer mesh trawls which probably better sample squid species. The presence of marine predators which specifically target squid may also provide indirect evidence of squid abundance and dynamics. Other sources of information include Massy (1928), Collins *et al.* (2001), and Lordan *et al.* (2001a).

3.4.2 Distribution and abundance

Cephalopod fisheries

The most recent assessment of cephalopod fisheries comes from the ICES Working Group on Cephalopod Fisheries and Life History (WGCEPH) (ICES 2004a) which provides details of cephalopod landings by ICES Divisions. The Divisions of most relevance to the present study are highlighted on Figure 4.3 (Section 4.3) and include VIa (NW coast of Scotland and North Ireland), VIb (Rockall), VIIb,c (West of Ireland and Porcupine Bank) and VIIg-k (Celtic Sea and SW of Ireland).

The majority of cuttlefish (Sepiidae) landings in 2002 were made from Division VIIg-k, predominantly by France (609.1t) and the UK (excluding Scotland) (101.8t). A small amount (3.3t) was landed from the west of Ireland and Porcupine Bank mainly by Spain. Similarly, the largest fishery for common squid *(Loligo forbesii, L. vulgaris, Alloteuthis subulata* and *A. media)* in 2002 was in the Celtic Sea and SW of Ireland by France (737.6t) and UK (excluding Scotland) (116.1t). Common squid were also taken in lesser amounts from Divisions VIa (mainly by Scotland and France), VIb (Scotland), and VIIb,c (Spain, UK (excluding Scotland), and Scotland). The main fishery for short-finned squid *(Illex coindetti* and *Todaropsis eblanae),* European flying squid *(Todarodes sagittatus)* and neon flying squid *(Ommastrephes bartrami)* was by Spain (411t) in Divisions VIIb, c, with Ireland and the UK (excluding Scotland) also involved (ICES 2004a). Divisions VIIg-k also supported an important fishery for these species.

Of relevance to the present study is the considerable amount of information that has been gained from analysis of *L. forbesii* fishery data from Scottish waters (e.g. Pierce & Boyle 2003, Pierce *et al.* 1998). *L. forbesii* is widely distributed on the Scottish continental shelf and also occurs on offshore banks, notably Rockall. The *Loligo* fishery has shown a consistent seasonal pattern, with peak landings from Rockall in June–August and from coastal waters in October and November (Pierce *et al.* 1998).

A notable feature of the Scottish fishery, common to many cephalopod fisheries, is the marked interannual fluctuation in landings, especially from Rockall, presumed to reflect changes in local abundance (Pierce & Boyle 2003). Like most squid species, *L. forbesii* has a short life-span, non-overlapping generations and rapid growth. Annual stock size depends almost entirely on recruitment success and is therefore expected to be strongly affected by environmental conditions (e.g. Boyle & Boletzky 1996, Brodziak & Hendrickson 1999).

Recruitment of *L. forbesii* occurs throughout the year in Scottish waters (Lum Long *et al.* 1992), with peaks in April and November (Collins *et al*. 1997). Spawning shows a single annual peak around December, but extends well into the following year (Collins *et al.* 1997). This pattern is similar to that observed for *L. forbesii* in Irish waters (Collins *et al.* 1995). The mismatch between recruitment and spawning periods remains difficult to explain (Boyle *et al.* 1995) and environmental conditions in virtually every month of the year may be important in terms of effects on spawning, hatching success, the early life of hatchlings or recruitment (Pierce & Boyle 2003).

Pierce *et al.* (1998) found that the spatial pattern of catch rates for *Loligo* in trawl survey hauls in the North Sea in February could be related to sea bottom temperature (SBT) and sea surface temperature (SST). Similarly, Waluda & Pierce (1999) showed that the spatial pattern of *Loligo* fishery catch per unit effort (CPUE) in the North Sea in winter was strongly (positively) related to both SST and SBT and, to a lesser extent, sea surface salinity (SSS). Modelling suggested that local abundance of *L. forbesii* was highest at around 11°C (Bellido *et al.* 2001). Sea bottom and surface temperatures have also been found to have a significant effect on survey catches of juvenile and adult *Loligo pealei* in the northwest Atlantic (Brodziak & Hendrickson 1999).

However, squid abundance in the Rockall fishery does not share a similar close correlation with temperature or salinity (Pierce & Boyle 2003). Instead, modelling indicates that large-scale oceanographic processes operating over longer timescales may be more important in determining squid abundance at Rockall. In the southwest Atlantic for example, time-lagged effects of El Niño events 2–5 years previously have been detected in squid fisheries (Waluda *et al*. 1999). Sims *et al.* (2001) have described temporal variations in the peak abundance of *L. forbesii* in the English Channel which they associated with the North Atlantic Oscillation (NAO).

Water circulation at local and meso-scales may have a strong influence on cephalopod distribution and abundance. Wang *et al.* (2003) described the strong influence that Atlantic inflow into the Celtic Sea and English Channel had on the annual migration of cuttlefish in that region. The nature and extent of inflow varied seasonally affecting the extent and location of frontal zones in the English Channel and further west. The increase in primary and secondary productivity in these frontal zones (e.g. Grioche & Koubbi 1997) attracts many species such as squid and fish species (e.g. Turrell 1992, Waluda *et al.* 1999, Reid 2001, Zheng *et al.* 2001). Wang *et al.* (2003) suggested that cuttlefish may stay within the frontal zone (an area of enhanced food availability) and migrate westward with the frontal zone.

Cephalopod surveys

The results of a series of demersal survey programmes in the area west of Ireland were analysed by Lordan *et al*. (2001b). Data was presented on cephalopod species caught from three surveys; the CEFAS March Celtic Sea Groundfish Survey covering the years 1994-1998 and a depth range of 57-580 m, and two Marine Institute surveys, one to the west and south west of Ireland between depths of 27-328m, and the other conducted in deepwater (520-1,174m) on the eastern slopes of the Rockall Tough to the west and northwest of Ireland. Both the Marine Institute surveys were conducted October-November 1997.

Eleven cephalopod species (14,981 individual cephalopods) were caught during the five CEFAS surveys of the Celtic Sea. The most numerous species caught was *Loligo forbesii* (n=6,803), with highest catches taken close to the shelf break between 50-51°N. Given that the largest catches were of squid around 90mm mantle length (ML) (recruitment to the commercial fishery is approximately at ML 100mm (Collins *et al*., 1995), Lordan *et al.* (2001b) suggested that the area may be an important feeding and probable nursery area for this species in March. Pierce *et al*. (1998) presented data from Scottish demersal trawl surveys during November (1990-1994) which showed that highest catches of *L. forbesii* occurred north of Ireland near the Stanton Bank area (~3,200/hr in one haul). In the CEFAS surveys, no *L. forbesii* were caught deeper than 400 m. The ommastrephid squid *Illex coindetii* represented the highest biomass taken (418.3kg), with highest catches at or beyond the shelf break (200m) south west of Ireland. Catches of the ommastrephid *Todaropsis eblanae* were also concentrated close to the shelf break in most years and *Todarodes sagittatus* catches were restricted to deeper water (>400m) on the slope between 48-51°N. Catches of cuttlefish and sepiolids were rarer and largely restricted to shelf and coastal areas (Lordan *et al.* 2001b).

Ten cephalopod species (estimated 8,712 individuals) were caught during the Marine Institute survey to the west and south west of Ireland with the results showing broadly similar patterns in species composition, distribution and abundance to the CEFAS surveys. *Loligo vulgaris* and *Sepia officinalis* were not caught in the Marine Institute survey probably as a result of the more northern range of the survey (Lordan *et al.* 2001b).

The range of cephalopods species caught in the deepwater survey was completely different from the shallower surveys. Six species were recorded (n=196) with *Todarodes sagittatus* replacing *L. forbesii* as numerically the most common species with highest catches recorded on the slope north west of Donegal between 55-56°N and west of the Hebrides. Catches of other species were very low. Deepwater octopods including *Benthoctopus piscatorum*, *Benthoctopus ergasticus* and *Opisthoteuthis massyae* were recorded from the northern slope of the Porcupine Bank (Lordan *et al.* 2001b).

Lordan *et al.* (2001b) suggested that for both *Illex coindetii* and *Todarodes sagittatus*, larger individuals were caught in deeper waters indicating that there may be an ontogenic migration down the slope. Similarly, surveys in the Northwest Atlantic have highlighted a bathymetric pattern of larger sized individuals with increasing depth (Brodziak & Hendrickson 1999).

Other relevant sources

Information on the distribution of predators which target cephalopods provides useful indirect evidence of cephalopod distribution. Within the deep water area to the west of Ireland, cephalopods are an important prey species for a number of marine predators including marine mammals and seabirds some of which are thought to specifically target cephalopods (e.g. sperm whales and long-finned pilot whales).

Information on the distribution and abundance of cetaceans and seabirds in Irish waters has been significantly advanced by the recent completion of a three year *Cetacean & Seabirds at Sea* project (Mackey *et al.* 2004a, Ó Cadhla *et al.* 2004, Aguilar de Soto *et al.* 2004). Undertaken by the Coastal & Marine Resources Centre at University College Cork on behalf of the Rockall Studies Group (RSG) and Porcupine Studies Group (PSG) under the Petroleum Infrastructure Programme, the project surveyed both visually and acoustically a large part of the Irish Atlantic frontier for cetacean and seabird species.

The diet of sperm whales consists almost entirely of cephalopods, and appears to vary from region to region. Santos *et al*. (1999) reported that *Gonatus* was the most commonly reported cephalopod species recovered from the stomach contents of sperm whales in the North Sea. In contrast, sperm whales from the north east Atlantic showed a more diverse diet, including the octopus *Haliphron atlanticus*, a *Gelatinus* octopus normally found in depths of up to 3,180m, the squid *Histhioteuthis bonnelli*, which are found in depths ranging from 100-2,000m and the giant squid species, *Architeuthis* (Santos *et al.* 2002).

Results from the Cetaceans & Seabirds at Sea project (Ó Cadhla *et al.* 2004, Aguilar de Soto *et al.* 2004) indicate that the waters of Ireland's Atlantic frontier may be important for sperm whales in spring and early summer with whales recorded in deeper offshore waters, particularly the Hatton-Rockall region. Limited survey coverage during the autumn and winter months prevented interpretation of year-round abundance patterns.

Long-finned pilot whales were the most commonly recorded of the larger odontocete species (686 individuals) in the Cetaceans & Seabirds at Sea survey (Ó Cadhla *et al.* 2004, Aguilar de Soto *et al.* 2004). The distribution of these deep-water squid feeders may be related to the occurrence of their prey (Bloch *et al*. 1993). Long-finned pilot whales were recorded throughout the Irish Atlantic Margin with additional sightings from the westernmost Hatton and Rockall Banks, predominantly from waters exceeding 1,000m depth and between the months of April and September. Reduced survey coverage in autumn and winter did not permit effective interpretation of true seasonal distribution patterns. The species has also been recorded with relatively high frequency in previous studies in the Atlantic Margins of Britain and Ireland (e.g. Pollock *et al*. 1997, Pollock *et al*. 2000).

Cephalopods have also been noted as an important element in the diets of blue sharks south and west of Ireland (MacNaughton *et al.* 1998).

3.4.3 Data gaps

Information on the cephalopod resource in the deep water to the west of Ireland is limited. Records from fisheries and survey programmes suggest that cephalopod abundance and distribution is patchy, highly variable and sensitive to environmental conditions. Whilst commercially important species such as *Loligo forbesii* have attracted significant research effort, the ecology of deep water and oceanic species remains relatively unknown. For all cephalopod species there is very little information on the locations of spawning grounds.

Of relevance to potential oil and gas activities is the suggested role that cephalopods play in the transfer of pollutants up the food chain (see Section 2.5.2). The significance of this role and its importance within deep water environments has yet to be determined.

3.5 Fish & shellfish

3.5.1 Introduction

The nature and dynamics of the fish species and communities of the deep water area to the west of Ireland are as yet not fully understood. The knowledge of central biological characteristics such as stock identity, migration, recruitment, growth, feeding, maturation, and fecundity of most deep-sea species still lags considerably behind that of shelf-based species (FSS 2004).
Given the focus of this report, this section will concentrate principally on deep water fish species. However, for context it also provides an overview of the fish species and communities present in shelf and coastal waters.

The main sources of information include the Marine Institute's Fisheries Science Services Stock Book (FSS 2004), the ICES Advisory Committee on Fishery Management/Advisory Committee on Ecosystems Report (ACFM 2004), the Report of the Working Group on the Biology and Assessment of Deep-Sea Fisheries Resources (ICES 2004b) and various fisheries research programmes.

3.5.2 Fish species and communities

Shelf and coastal waters

Overview

Shelf and coastal waters are very productive and support a diverse fish and shellfish fauna. Demersal fish species including many of commercial importance such as cod, haddock, whiting, sole, and plaice are present over much of the shelf with hake, anglerfish and megrim often also associated with the shelf edge. The distributions of many of these species are dynamic with feeding, spawning or migratory movements between coastal waters, the shelf and upper parts of the continental slope. Hake for example belongs to a very extended and diverse community of commercial species including megrim, anglerfish, *Nephrops*, sole, seabass, ling, blue ling, greater forkbeard, tusk, whiting, blue whiting, *Trachurus spp*, conger, pout, cephalopods, rays etc. (Lucio *et al.* 2003 cited by ACFM 2004).

Time series of the spatial distribution of abundance indices are available for hake (*Merluccius merluccius*), anglerfish (*Lophius piscatorius* and *L. budegassa*) and megrim (*Lepidorhombus whiffiagonis*) in the Celtic Sea area (Tidd & Warnes, in prep., cited by FSS 2004). The abundance of 2+ hake is highest along the shelf edge to the west and south-west of southern Ireland and south west of Brittany. The distribution of juvenile (age 1) hake tends to be less associated with the shelf edge, with highest abundance often to the south of Ireland. The distribution of megrim is similar to that of hake, with highest abundance along the shelf edge to the west and southwest of southern Ireland. The distribution of anglerfish (*L. piscatorius*) is widespread with fish sometimes occurring in high abundance from the shelf edge into the Celtic Sea and western Channel, while anglerfish (*L. budegassa*) are much more concentrated along the shelf edge (FSS 2004).

Water temperature is a major factor in limiting the overall distribution of species in the area. Cold water species such as cod and herring reach the southern limit of their distribution in the Celtic Sea, whilst the northward penetration of warm water species such as bass, sardines and anchovies varies periodically according to sea temperature. Seasonal temperature variations also influence the near-shore distribution of many species, with inshore movements of cold water species during winter and of warm water species in summer. Other physical factors including depth, tidal flow and sediment characteristics lead to considerable variation in the distribution of each species within its normal geographic range (Boelens *et al.* 1999).

Generally, gravelly sediments of the shelf are characterised by communities dominated by elasmobranchs, gurnards, cod, large whiting and only a few flatfish species with populations of scallops and queen scallops also present in such areas. Soft muddy sediments provide a habitat for burrowing crustacean, particularly *Nephrops* which support important commercial fisheries. These areas have higher incidence of gadoids and lower densities of plaice and dab than found in shallower sandy areas. Sandy or muddy sand sediments which cover a large area of the shelf support fisheries for cod, whiting, haddock, anglerfish, hake and saithe (Boelens *et al.* 1999).

The seasonal distributions of pelagic species such as mackerel, horse mackerel and herring are associated generally with the distribution and properties of the relatively warm surface waters in the north east Atlantic (ACFM 2004). These species are present within Irish waters largely on a seasonal basis, migrating between spawning and feeding grounds. Mackerel spawn over much of the shelf and migrate to feed in the northern North Sea during the second half of the year (FSS 2004, ACFM 2004). Recent declines in the herring stock have meant an almost complete absence of autumn-spawning herring from traditional spawning grounds off Galway and Mayo with selected spawning grounds off the coast of south west Ireland closed each year to protect spawning herring shoals (FSS 2004). Other widely distributed species such as bluefin and albacore tuna and pelagic sharks may be present over shelf or deeper waters although there is little information available on their distribution.

Fish communities present within coastal areas include juvenile flatfish and sandeels over sandy sediments, with seasonal influxes of sprat, herring, juvenile gadoids, mullet and in southern areas, bass. Rocky shore fish assemblages are diverse and dominated by small species such as wrasses, gobies and blennies, as well as juvenile pollack and saithe. Exploited coastal shellfish species include scallop, lobster, crawfish, spider crabs, brown crabs, green crabs and velvet crabs, whelks, periwinkles, surf clams and razor clams (FSS 2004).

Shelf and coastal areas support important spawning and nursery grounds for a range of demersal and pelagic species. This importance was recognised by the recent establishment of a “biologically sensitive area” (or Irish Conservation Box) off south west Ireland by the European Commission (see Section 4.3). Areas of importance include major spawning areas for mackerel, horse mackerel and blue whiting off the west coast; major spawning areas for hake, megrim and herring off the south coast, and very important nursery areas for herring, haddock, hake, whiting and megrim off the south and west coasts (Marine Institute website – http://www.marine.ie). Most species spawn in late winter, spring or early summer with peak spawning in early spring (*Boelens et al*. 1999).

Deep water

Overview

Without light the deep water has no primary productivity via the photosynthesis of plants and algae except in the surface waters. Furthermore, the nutrient concentrations in surface waters are low, and overall there is very little food compared to shelf and coastal waters. This, together with low temperatures results in very low productivity of the organisms living there. Energy transfer pathways include overlapping food chains of organisms which occupy specific depths or depth ranges as well as daily vertical migrations of many mesopelagic organisms which transfer energy directly and quickly down to the seabed (Mauchline & Gordon 1991). Otherwise the deep-sea food web is fuelled by a rain of dead plants and animals from surface waters (FSS 2004).

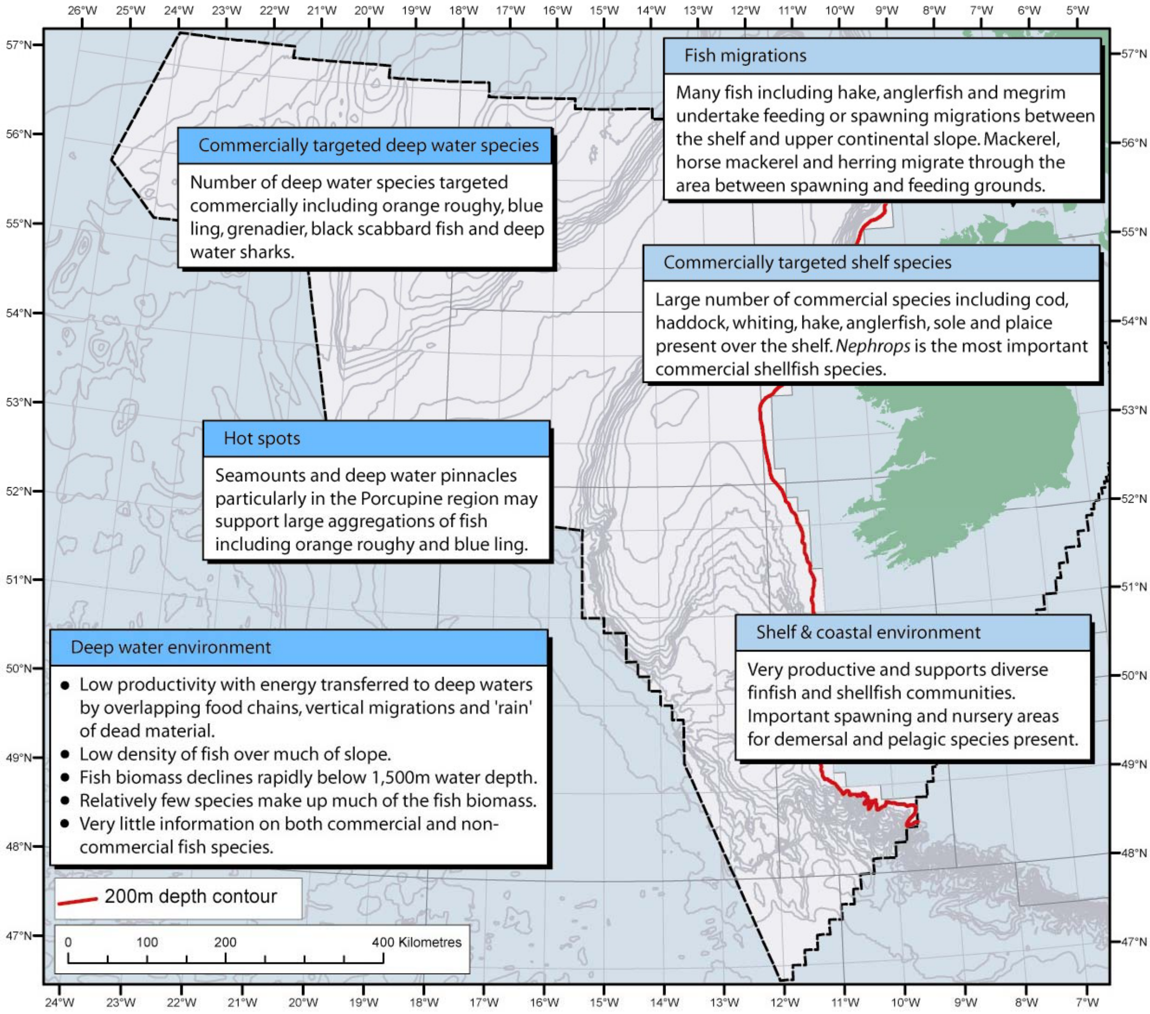
The diversity of deep-sea life history strategies is considerable, but many species of fish targeted by fisheries and their communities are particularly vulnerable to disturbance because they grow slowly, mature late in life, and form aggregations easily accessible to fisheries. Recovery rates are much slower than in shallower waters. Examples are the archetypal long-lived fish species orange roughy and grenadiers (FSS 2004).

The number of demersal fish species present in the Rockall Trough at any given depth is relatively high (ca. 40–50) on the upper and mid-slopes with total abundance and biomass of all species (caught using bottom trawl) maximal at depths between about 1,000 and 1,500m. Thereafter, fish abundance and biomass decline rapidly with depth (Gordon 2001).

A number of deep water species including ling *(Molva molva)* and tusk *(Brosme brosme)* inhabit a wide depth range from relatively shallow shelf waters into slope waters beyond 400m (ACFM 2004). Semi-pelagic blue whiting and argentines are also found on the upper slope and in deeper waters. Surveys of bluemouth rockfish *(Helicolenus dactylopterus)* from the Rockall Trough described a “bigger deeper” trend suggesting that small fish found at shallow depths may migrate down the slope as they become older and larger (Kelly *et al*. 1999). This trend is not uncommon for deep water fish species. Similarly, young anglerfish are thought to migrate from shallower areas into deeper waters to spawn (ACFM 2004).

Key environmental considerations and an overview of the fish communities found in both the deep water area and on the shelf are highlighted on Figure 3.10.

Figure 3.10 – Deep water and shelf environment and associated fish communities



Commercial deep water species

A wide variety of deep sea fish are commercially targeted or taken as bycatch from the deep water region to the west of Ireland. Table 3.4 provides a brief ecological summary of fish either targeted by deep water fisheries or occurring as bycatch (ACFM 2004).

Table 3.4 –Commercial deep sea fish from the North East Atlantic region

Deep water species	Depth range (m)	Ecology
Bony fish		
Roundnose grenadier *(Coryphaenoides rupestris)*	180-2200	Form large schools at 600-900m depth. Feed on a variety of fish and invertebrates, but primarily shrimps, amphipods, cumaceans; and cephalopods.
Black scabbardfish *(Aphanopus carbo)*	200-1700	Migrates to midwater at night and feeds on crustaceans, cephalopods and fishes.
Orange roughy *(Hoplostethus atlanticus)*	180-1800	Inhabits deep, cold waters over steep continental slopes, ocean ridges and sea-mounts. Dispersed over both rough bottoms and steep, rough grounds where it feeds on crustaceans and fish. Grows very slowly and is one of the longest lived fish species known.

Deep water species	Depth range (m)	Ecology
Mora *(Mora moro)*	450-2500	Feeds on fishes, crustaceans, molluscs and other invertebrates.
Greater forkbeard *(Phycis blennoides)*	10-800	Found over sand and mud bottoms. Young more coastal and found on the continental shelf while adults migrate along the slope. Feeds mainly on crustaceans and fishes.
Ling *(Molva molva)*	100-1000	Occurs mainly on rocky bottoms in fairly deep water. Found more commonly from 100-400m. Feeds on fish (cod, herring, flatfish), lobsters, cephalopods and echinoderms.
Blue ling *(Molva dypterygia)*	150-1000	Found mostly from 350-500m depth on muddy bottoms. Feeds on crustaceans and fish.
Argentine *(Argentina silus)*	140-1440	Probably form schools close to bottom. Feeds on planktonic invertebrates including euphausiids, amphipods, chaetognaths, squids and ctenophores, also small fishes. Spawns from April to July.
Rabbitfish *(Chimaera monstrosa)*	40-1000	Found generally between 300-500m depth. Feeds mainly on bottom-living invertebrates.
Tusk *(Brosme brosme)*	20-1000	Found in small shoals on rough, rock, gravel, or pebble bottoms, mostly between 150-450m Feeds on crustaceans and shellfish, benthic fishes and echinoderms.
Roughhead grenadier *(Macrourus berglax)*	100-1000	Commonly found in about 300-500m depth. Amphipods predominate in the diet, although polychaetes and various crustaceans also important.
Red (=blackspot) seabream *(Pagellus bogaraveo)*	-700	Inshore waters to 700m, young near the coast, adults on the continental slope. Feeds mainly on crustaceans, molluscs, worms and small fish.
Shark species		
Gulper shark *(Centrophorus granulosus)*	100-1200	Common deepwater dogfish of the outer continental shelves and upper slopes. Feeds mainly on fishes.
Leafscale gulper shark *(Centrophorus squamosus)*	140-2400	Found on or near the bottom of continental slopes; also found pelagically in the upper 1,250m of water 4,000m deep. Presumably feeds on fish and cephalopods.
Black dogfish *(Centroscyllium fabricii)*	180-1600	Found on outer continental shelves and upper slopes, mostly below 275m. Feeds on crustaceans, cephalopods, jellyfish and small fishes.
Portugese dogfish *(Centroscymnus coelolepis)*	270-3680	Found on continental slopes and abyssal plains. Feeds mainly on fish and cephalopods.
Longnose velvet dogfish *(Centroscymnus crepidater)*	230-1500	Fairly common on continental slopes on or near the bottom. Feeds mainly on fish and cephalopods.
Kitefin shark *(Dalatias licha)*	40-1800	Found on outer continental shelves and slopes. Mainly on or near the bottom but occurs pelagically. Feeds mainly on deepwater fish, but also skates, other sharks, cephalopods and crustaceans.
Birdbeak dogfish *(Deania calceus)*	60-1490	Found on outer continental shelves and slopes. Mainly on or near the bottom but occurs pelagically. Feeds on pelagic bony fish, squid, octopus and shrimp
Velvetbelly *(Etmopterus spinax)*	70-2000	Found on the outer continental shelves and upper slopes. Feeds on small fishes, squids and crustaceans.
Knifetooth dogfish *(Scymnodon ringens)*	200-1600	A rare species inhabiting continental slopes. Usually mesopelagic although taken most often near the bottom.

Sources: Fishbase website – http://www.fishbase.org, ACFM 2004, Gordon 2001.

Massutí *et al*. (2004) compared the deep sea fish assemblages of the Mediterranean and Atlantic (Rockall Trough and Porcupine Seabight) using data from standard research trawls between 1978 and 1998 including 39 trawls between 530-1955m depth (Rockall Trough) and 77 trawls between 407 and 1993m depth (Porcupine Seabight). Analysis of these trawls provides valuable information of the species assemblages present in the deep water area to the west of Ireland.

The number of species captured during these surveys was 80 in the Rockall Trough and 104 in the Porcupine Seabight. For both areas, the family Macrouridae (e.g. *Coryphaenoides rupestris*, *Nezumia aequalis* and *Coryphaenoides guentheri*) was the most important in terms of biomass throughout the whole depth range surveyed, although other important families included Gadidae and Chimaeridae on the upper slope, Moridae and Alepocephalidae on the middle slope and Synaphobranchidae on the lower slope. Synaphobranchidae and Macrouridae were the most important families in terms of abundance at all depth strata (Massutí *et al*. 2004). In both areas, fish biomass had maximum values at mid-slope depths which is probably related to the depth range of greatest potential vertical and horizontal impingement of epi- and mesopelagic fauna on the slope (Mauchline & Gordon 1991).

Massuti *et al*. (2004) suggested that the reason for the lower number of species in the Rockall Trough was its semi-enclosed nature, with the relatively shallow sills to the north and west creating a physical barrier to the movement of deep water species. Whilst the two areas were found to have many species in common, the Porcupine Seabight also has affinities with the northwest African slope with the presence of some species *(e.g. Holostethus mediterraneus*) attributed to the presence of a Mediterranean influence. Mediterranean water has been clearly identified in the Porcupine Seabight (Rice *et al.* 1991) but its presence in the Rockall Trough has been questioned (New & Smith-Wright 2001).

Results from the Bord Iascaigh Mhara's deep water observer programme suggest marked differences between the deep water fish assemblages to the west of Ireland and those to the west of Shetland. Blue ling, redfish and Greenland halibut dominated the catches in the colder waters off Shetland, whereas roundnose grenadier, siki shark (Portuguese dogfish) and black scabbard dominated the more southerly stations. Orange roughy were found in greatest abundance over seamounts within the North Porcupine and West Porcupine areas (BIM 2002).

Species such as orange roughy, blue ling, red sea bream and alfonsinos aggregate in shoals often associated with seamounts, and fisheries have high catch rates once shoals are located. Orange roughy are known to reach very old ages (highest estimated age of an individual is 187 years), and experience in other areas (e.g. South Pacific) has shown that this species is especially vulnerable to exploitation with newly discovered aggregations often overexploited before enough information is available to provide advice on management (ACFM 2004).

A comparative study of trawl and longline catches of deep water elasmobranchs (Clarke *et al.* 2005) provides further information on the fish assemblages of the Rockall Trough and Porcupine Seabight.

Table 3.5 provides details of the species composition of comparable trawl and longline surveys of the Rockall Trough in 1997. Longline catches from deeper than 500m were dominated by squalid sharks, particularly birdbeak dogfish *(D. calceus),* Leafscale gulper shark *(C. squamosus)* and the Portugese dogfish *(C. coelolepis)*. Elasmobranch dominance increased with depth, with catches deeper than 1,300m almost totally composed of squalid sharks (98%). In contrast, trawl catches displayed a greater diversity of species although the roundnose grenadier *(C. rupestris)* dominated at depths greater than 700m. The large commercial squalids, the leafscale gulper shark and Portugese dogfish, were the most abundant elasmobranchs in trawl catches (Clarke *et al.* 2005).

Table 3.5 –Species composition (%) of longline and trawl catches from the Rockall Trough

500-699m	700-899m	900-1099m	1100-1299m	1300-1499m
Longline				
D. calceus 43	*C. squamosus* 34	*C. squamosus* 60	*C. coelolepsis* 41	*C. coelolepsis* 61
B. brosme 24	*D. calceus* 30	*M. moro* 10	*C. squamosus* 40	*C. squamosus* 23
P. blennoides 8	*B. brosme* 25	*D. calceus* 9	*D. calceus* 7	*E. princeps* 10
C. monstrosa 7	*M. moro* 5	*C. coelolepsis* 8	*E. princeps* 4	*P.microdon* 2
M. moro 7	*P. blennoides* 4	*B. brosme* 6	*C. crepidater* 3	*C. crepidater* 1
C. squamosus 5	*M. dypterygia* 1	*E. princeps* 3	*M. moro* 3	*C. fabricii* 1
M. molva 2		*M. dypterygia* 2	*M. dypterygia* 1	
H. dactylopterus 2		*C. crepidater* 2		
M. dypterygia 1				
Trawl				
C. monstrosa 39	*C. rupestris 40*	*C. rupestris* 47	*C. rupestris 52*	
A. silus 16	*C. squamosus* 19	*A. bairdii* 8	*C. coelolepsis* 8	
C. rupestris 11	*C. monstrosa* 10	*C. squamosus* 8	*C. squamosus* 6	
M. merluccius 10	*A. carbo* 8	*A. carbo* 7	*A. bairdii* 5	
P. blennoides 4	*L. piscatorius* 8	*D. calceus* 6	*M. dypterygia* 5	
M. dypterygia 4	*M. merluccius* 4	*C. coelolepsis* 5	*H. atlanticus* 4	
B. brosme 4	*M. dypterygia* 3	*M. dypterygia* 4	*L. eques* 4	
L. eques 3	*C. coelolepsis* 2	*L. eques* 3	*A. carbo* 4	
L. piscatorius 2	*P. blennoides* 2	*C. monstrosa* 3	*C. crepidater* 3	
S. squamosus 2	*H. dactypopterus* 1	*H. atlanticus* 2	*D. calceus* 3	
D. calceus 1	*A. silus* 1	*C. crepidater* 2	*T. murrayi* 1	
H. dactypopterus 1	*C. crepidater* 2	*L. piscatorius* 1	*L. piscatorius* 1	
G. melastomus 1	*L. eques* 1	*M. moro* 1	*C. monstrosa* 1	
	D. calceus 1		*M. moro* 1	

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

The species composition of longline catches from similar depths on the Porcupine Seabight differed from those of the more northerly Rockall Trough (Clarke *et al.* 2005). For example, catches of birdbeak dogfish dominated over a greater range of depths and there were a larger number of species caught at most depths.

The absence of small specimens of the large squalid sharks from west of Ireland and Britain has been well documented (Clarke *et al.* 2002, Girard & DuBuit 1999). In the case of *D. calceus* and *C. squamosus* this is probably explained by migratory behaviour. Smaller *D. calceus*, absent from the area west of Ireland, are present off continental Portugal (Machado & Figueiredo 2000). Gravid *C. squamosus,* totally absent from west of Ireland, are found in Madeira and off Portugal (N. R. Hareide and G. Garnes, pers. comm.; M. J. Figueiredo, pers. comm. cited by Clarke *et al.* 2005). Smaller specimens of *C. coelolepis* may have a more pelagic distribution, out of range of bottom trawls but attracted to baited longline hooks (Clarke *et al.* 2005).

At present, no shellfish species from the deep water area to the west of Ireland are commercially exploited. Whilst there have been a number of exploratory surveys for the deep water crab *Chaceon* *affinis* in the Rockall Trough no fishery has developed (Hastie 1995). *Nephrops* are taken from areas of suitable muddy sediment on the upper slope, particularly on the Porcupine Bank (see Section 4.3).

Non-commercial species

A high proportion of the fish biomass is accounted for by relatively few species. However the remainder, approximately 20% constitute an important component of the ecosystem (Gordon 2001). Research surveys in the Rockall Trough using fine meshed trawls have shown that at any given depth there may be 40–50 different fish species in the catch (Gordon & Swan 1993).

Bycatch data gives an indication of the abundance of some non-commercial species although depending on quantity and market demand bycatch species may be exploited. Hall-Spencer *et al.* (2002) noted a range of non-commercial fish species from a 3 hour bottom trawl in the Rockall Trough (54°4'N 10°5'W) at approximately 1,250m depth (Table 3.6). Baird's smoothhead made up the largest component of the catch.

Table 3.6 – Catch composition of a Rockall Trough bottom trawl

Species	Number of fish	Weight (kg)
Roundnose grenadier[1]	480	400
Roundnose grenadier (small discards) [1]	902	407
Orange roughy[1]	80	200
Leafscale gulper shark[1] Portugese dogfish[1]	27	150
Baird's smoothhead	750	2,400
North Atlantic codling	50	18
Smalleyed rabbitfish	37	16
Spearnosed chimaera	4	24
Roughnose grenadier	325	80
Spearsnouted grenadier	125	31
Dogfish sharks	216	351
Risso's smoothhead	6	-
Pallid sculpin	2	-
Pudgy cuskeel	1	-

Note: [1]Species landed commercially.
Source: Hall-Spencer et al. (2002)

Clarke *et al.* (2005) found discards from trawling on the Rockall Trough were high, and composed of up to 30 different species, while species diversity of discards from longlining was lower, but dominated by sharks (Connolly & Kelly 1996). Trawl discards were composed of small individuals of commercial species such as *Coryphaenoides rupestris, Molva dypterygia* and *Phycis blennoides* as well as a large range of non-commercial species, such as blue antimora *(Lepidion eques)*, Murray's longsnout grenadier *(Trachyrhynchus murrayi)* and Baird's smoothhead *(Alepocephalus bairdii)*. In contrast, longline discards were mainly composed of non-commercial shark species such as blackmouth dogfish *(Galeus melastomus),* greater lanternshark *(Etmopterus princeps)*, *D. calceus* and *C. crepidater* (Clarke *et al.* 2005).

During the BIM observation period, the percentage of the catch discarded was relatively high, varying between 25% in the north to approximately 45% in southern areas. The composition of the discarded catch was dominated in the south and west by Baird's smoothhead (33-49%). Birdbeak dogfish also formed a significant component of the discards (14-33%) in all areas other than off the west of

Shetland. The predominant discard species in this area was argentine (64%) with eelpouts (11%) and rays (12%) constituting the bulk of the remainder (BIM 2002).

The relatively high percentage of discards noted during the BIM 2001 survey (and from other studies e.g. Connolly & Kelly 1996, Blasdale & Newton 1998) indicate that non-commercial species make up a significant component of the catch. The bulbous heads and elongate bodies of many deep-water fish means that bottom trawls are more likely to retain a higher proportion of juvenile fish or species of small adult size (Gordon 2001).

Threatened and protected species

OSPAR have identified an Initial List of Threatened and/or Declining Species and Habitats (OSPAR 2004d) which will inform the identification of Marine Protected Areas in the OSPAR maritime area. A number of fish species which may be present to the west of Ireland have been included on the OSPAR list including basking shark, common skate, cod, orange roughy and salmon. Atlantic bluefin tuna may also be present at certain times of the year although fishing effort tends to be concentrated to the south in the Bay of Biscay.

In general, the primary reason for inclusion of these species on the OSPAR list is related to their vulnerability to directed or by-catch fishing as a result of their biology or historical exposure to overfishing. For example, all lamniform sharks (including basking sharks) have a very low fecundity and late age at maturity, and are likely to be sensitive to additional mortality (OSPAR 2004d). Many deep sea fishes have life cycles which make them particularly vulnerable to over-exploitation and the status of the main commercially exploited species is described in Section 4.3. Detailed information relating to the distribution of most of these fish species is not available.

Ireland contains a number of important salmon rivers which support important spawning populations and fisheries (see Section 4.3). Salmon returning to these rivers from feeding grounds around the Faroe Islands and West Greenland pass through Irish waters. Other diadromous fish species present in the area include European eel, sea lamprey, allis and twaite shad with some of these populations receiving protection through the European Union Habitats Directive. Information on the distributions of these species in the marine phase of their life cycles is limited. Halliday & Mott (1991) described a size dependent sea lamprey distribution in the north west Atlantic with fish less than 390mm long captured in bottom trawls on the shelf or in coastal nets, whereas animals more than 560mm long were captured in mid-water trawls along the shelf edge or over the continental slope. The Irish National Museum's collection of lamprey material includes a sea lamprey taken on the Porcupine Bank (Kelly & King 2001).

As mentioned, basking sharks are also present with their distribution associated strongly with zooplankton rich fronts in shelf and coastal waters. Previously these fish were targeted by fisheries and 12,360 basking sharks were taken by the Achill Island fishery between 1947 and 1975 (Sims & Reid 2002). Tracking and zooplankton sampling studies have shown that basking sharks actively select areas along thermal fronts containing high densities of large calanoid copepods (Sims & Quayle 1998). Recent satellite tracking of basking sharks in the north east Atlantic (Sims *et al.* 2003) has indicated that sharks undertake extensive horizontal (up to 3,400km) and vertical movements (>750m) to utilise productive continental shelf and shelf-edge habitats during summer, autumn and winter. Basking sharks did not undertake prolonged movements into open ocean regions away from the continental shelf and remained active year round in the same productive shelf areas (Sims *et al.* 2003).

3.5.3 Data gaps

There are significant data gaps in relation to the ecology and status of deep water fish species in Irish waters. Landings data from deep water fisheries and independent surveys of fish stocks have provided limited information (primarily from the Irish continental slope) on commercial species but there remains very little information on species which are not targeted by fisheries.

3.6 Marine reptiles

3.6.1 Overview

Marine turtles, most commonly the leatherback turtle (*Dermochelys coriacea*), are the only species of marine reptile found in waters around Ireland. Most migrate over long distances between nesting beaches in the tropics and feeding grounds which include temperate waters. . Turtles predominantly feed on jellyfish, tunicates, sponges, soft corals, crabs, squid and fish although some also feed on seagrasses and algae. Species distribution and abundance data in Irish waters comes largely from the records of turtle sightings, strandings and bycatch, held in the database 'TURTLE' (Pierpoint & Penrose 2002, Penrose 2002, 2003, 2004, 2005) and from the JNCC bycatch report (Pierpoint 2000), as well as a number of studies (Hays *et al*. 2001, 2003, 2004, Godley *et al.* 1998 and Spotila *et al.* 1996).

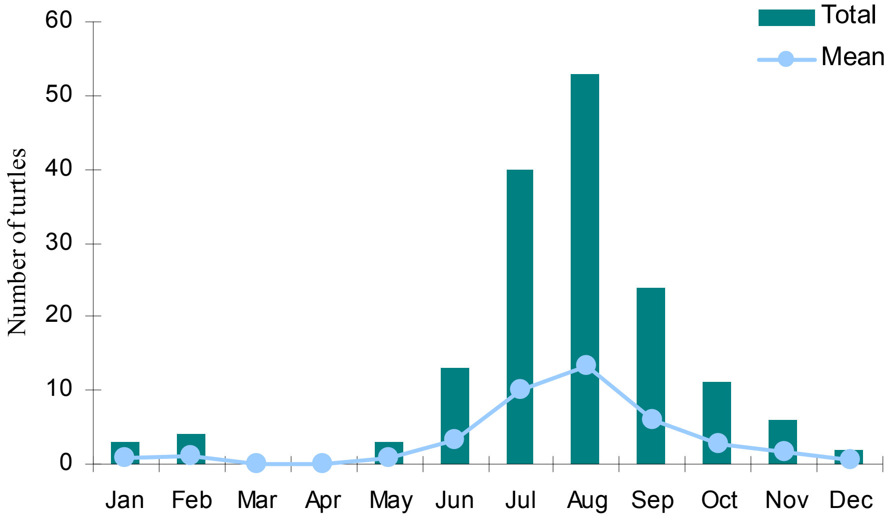
3.6.2 Distribution and abundance

It has been well documented that marine turtles, particularly the leatherback range widely in European Atlantic waters. Penrose (2005) indicates that a total of 59 marine turtles were reported around the UK and Ireland (live and dead animals) in 2004; 47 of which were leatherbacks, six were loggerhead turtles *(Caretta caretta)* and six were unidentified. Loggerhead and Atlantic ridley *(Lepidochelys kempii)* turtles are reported off the coast of Ireland but far less frequently than leatherbacks.

Leatherback turtle

The leatherback is reported annually and individuals from Caribbean and eastern US breeding sites are considered a regular and normal member of Ireland's marine fauna (Godley *et al.* 1998). Data from annual sightings reports (Penrose 2002, 2003, 2004, and 2005) highlighting the total numbers of reported leatherback turtle sightings around Ireland and the UK are presented in Figure 3.11. Leatherbacks are reported in every month with sightings peaking in August. Strandings peak slightly later in September and October (Pierpoint & Penrose 2002).

Figure 3.11 – Leatherback turtle sightings[1] for Ireland and the UK (2001-2004)



Note: [1]Total sightings include live and dead turtles. Source: Penrose (2002, 2003, 2004, and 2005)

Sightings data imply that leatherbacks move into Irish waters from the south and west, and pass northwards up western coasts and the Irish Sea. Records of dead leatherbacks are distributed widely throughout the region, with most being found in southern Ireland and south western coasts of the UK. Long-term satellite tracking studies of leatherbacks have provided significant information as to their movements in the North Atlantic. For example, five turtles tracked by Hays *et al*. (2004) travelled northeast from the Caribbean, reaching northerly latitudes between the Azores and Ireland.

Ongoing studies of leatherbacks during the nesting period have used satellite linked time-depth recorders to track their movements (Hays 2003). Leatherbacks have been shown to spend more time diving at night and at shallower depths than during the day when less time was spent diving but to greater depths. These dive patterns have been linked to the vertical movements of their prey, specifically scyphozoan jellyfish and other species of gelatinous plankton which reside in cold water by day and in warm water at night. Turtles spend more than half of their time diving to depths below 10m and very rarely deeper than 250m, although anomalies have been recorded that include depths of over 2,000m (Hays *et al.* 2004).

Other turtle species

A number of other marine turtles are occasionally recorded in Irish waters. Loggerhead and Atlantic ridley turtles are sometimes found on Irish coasts during the winter and spring, most are juvenile animals which have stranded on west and south west coasts following periods of stormy weather (Pierpoint & Penrose 2000). The majority of stranded individuals of both species are thought to originate from northwest Atlantic populations. Rarer visitors are hawksbill and green turtles.

Much more is known about the migration patterns of the loggerhead than that of the more pelagic species e.g. leatherbacks (Luschi *et al*. 2003). It is widely believed that ocean currents carry loggerhead hatchlings from eastern USA (principally Florida) to the seas around Ireland. Not all hatchlings reach European waters as drift patterns are highly variable and while some loggerheads will remain in circulation in the Sargasso Sea others will be carried on to the Azores. Hays and Marsh (1997) have estimated that juveniles are between 2-4 years old when they reach Irish and UK waters. It is possible that juvenile loggerheads, which reach these waters, would not however become part of the breeding population due to the low winter sea temperatures.

3.6.3 Conservation issues

The loggerhead and leatherback turtles are both included on the OSPAR Initial List of Threatened and/or Declining Species and Habitats as both species are in serious decline throughout their range (OSPAR 2004d).

Fisheries bycatch is regarded as one of the main threats to marine turtle populations (Hays *et al.* 2003) although the significance of bycatch in Irish waters is not fully known. The threat of bycatch encompasses many fishing methods both close inshore (e.g. set nets and entanglement in buoy ropes used in pot-based fisheries) as well as in deep-water (e.g. longlines, pelagic drift nets) and affects marine turtles throughout their range (Pierpoint 2000). On the basis of bycatch rates in the northwest Atlantic, Spotila *et al.* (1996) suggested that present levels of bycatch may be unsustainable. Many leatherbacks observed in Irish waters appear to be adult or large immature animals and in declining populations these size/age classes are thought likely to make the greatest contribution to the maintenance of the population. Therefore, even the present bycatch rates of leatherbacks in Irish waters may be important to their general decline.

The IUCN Red List is recognised as the most authoritative guide to the status of biological diversity. Loggerhead, leatherback, green, hawksbill, and Atlantic ridley turtles are all included on the IUCN

Red List. In particular, the leatherback, hawksbill and Atlantic ridley species are considered to be critically endangered (IUCN Red List website - http://www.redlist.org/).

Marine turtles are protected by a number of legislative agreements including the EC Habitats and Species Directive 1992 (Annex IV; loggerheads are also listed under Annex II); the Bern Convention on the Conservation of European Wildlife and Habitats 1979 (Appendix II), and the Bonn Convention on the Conservation of Migratory Species of Wild Animal 1980 (Appendix I & II).

3.6.4 Data gaps

Generally, there is very little information or data regarding the distribution and abundance of marine turtles in the north east Atlantic. For example, the overall extent of habitat use by leatherback turtles in the North Atlantic is poorly known and consequently potential interactions with fisheries are not fully understood (Hays *et al*. 2004). There is also no information on leatherback dive patterns in temperate waters such as around Ireland.

In relation to oil and gas activities, there is very little information available on the sensitivity of marine turtle species to acoustic disturbance from seismic surveys. Turtle hearing is most sensitive in the frequency range of 100–700Hz, and therefore overlaps with the most common sound frequencies produced by seismic air guns. It is likely therefore that turtles would be able to hear seismic activities for a considerable distance and would experience some disturbance. Threshold noise levels that are likely to cause either pathological damage or disturbance are not known (Western Australian Department of Industry and Resources 2002).

3.7 Seabirds and cetaceans

3.7.1 Study area

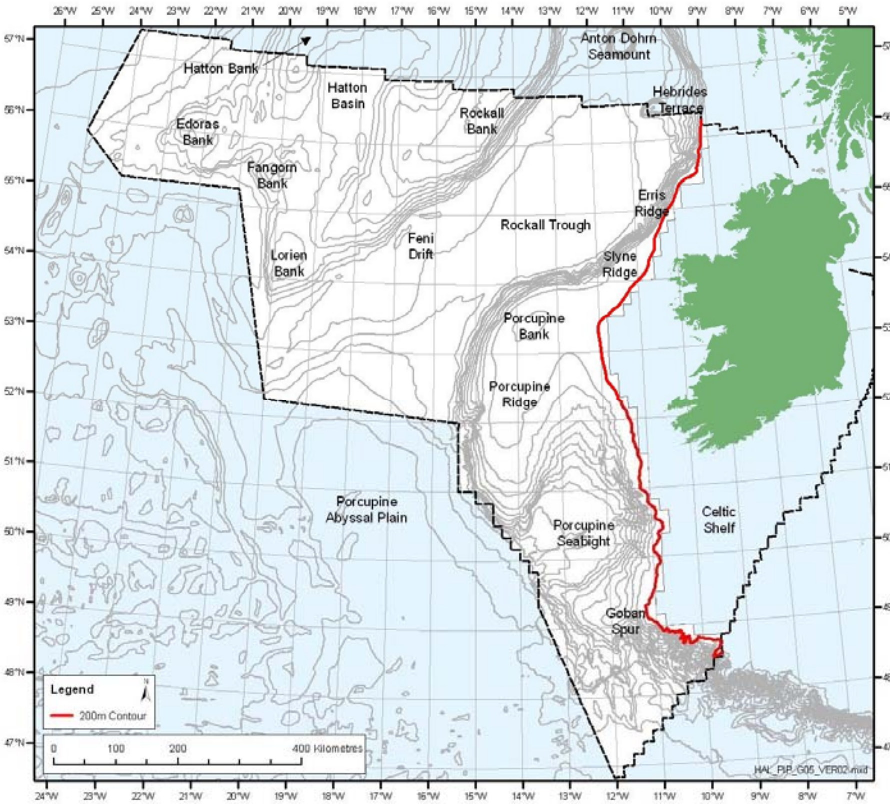
Several reports on seabird and cetacean distribution have been compiled for the waters around Ireland (e.g. Pollock *et al* 1997, Mackey *et al.* 2004a, Ó Cadhla *et al.* 2004, Mackey *et al*. 2005, CMRC 2005). In this report, data for the offshore waters greater than 200m deep, west of Ireland are summarised. Figure 3.12 shows the study area.

The shelf break west of Ireland is generally characterised by a steep drop off from a depth of 200m to 3000m over a short distance. The main exception to this is a relatively shallow area around Porcupine Bank. South-west of the continental slope is the Porcupine Abyssal Plain which reaches depths greater than 4000m and is outside the current study area. North-east of this area is the Rockall Trough. West of this area are several banks, including Rockall Bank and Hatton Bank.

The prevailing wind is south-westerly and there is almost always a swell. This can make conditions difficult for surveying cetaceans. The North Atlantic Current is the main current west of the shelf. Offshore currents are separated from shelf currents by the Irish Shelf front (Huang *et al.* 1991). Warmed by the North Atlantic Current, mean surface temperatures in winter are around 10°C (Lee & Ramster 1981).

Seabird and cetacean activity may be linked to water depth, most likely due to prey distribution. Upwelling of nutrient rich water along the shelf break may result in high productivity, thus concentrating prey for seabirds and cetaceans.

Figure 3.12 - Study area west of Ireland



3.7.2 Data sources

Seabirds

The Seabirds at Sea Team (SAST) of the Joint Nature Conservation Committee has been studying the distribution and abundance of seabirds and marine mammals in the waters around Britain since 1979 using both ship and aerial survey techniques (e.g. Pollock *et al.* 1997). Data from these surveys, and from other European countries, have been incorporated into the European Seabirds at Sea (ESAS) database (e.g. Stone *et al.* 1995).

Surveys of seabirds and cetaceans west and north of Ireland were carried out by JNCC between 1980 and 1999 (Pollock *et al.* 1997, Pollock *et al.* 2000) and by CMRC from 1999 to 2003 (Mackey & Perales i Giménez 2004, Mackey *et al.* 2004a). The Petroleum Infrastructure Programme has funded equipment and research into the distribution of cetaceans and seabirds in Irish waters over the period 1999-2005. This work is ongoing and the current CMRC project (IS03/22) is exploring relevant approaches within GIS and statistical modelling frameworks useful for examining the relationship between various environmental descriptors and the distribution of marine mammals and seabirds.

Cetaceans

During ESAS surveys, cetaceans were also recorded and several reports include data for the study area between 1980-2003 (Pollock *et al.* 1997, Pollock *et al.* 2000, Ó Cadhla *et al.* 2004, Mackey *et al.* 2004b).

Reid, Evans & Northridge (2003) used several data sources to summarise cetacean distribution in north-west European waters. Cetacean observations from seismic vessels are reported in Stone (2000, 2003).

Passive acoustic monitoring using bottom mounted hydrophone arrays operated by the US navy has recorded blue, fin and humpback whale in the study area (Clark & Charif 1998, Charif & Clark 2000). Dedicated acoustic surveys have also been conducted in the study area (Gordon *et al.* 2000, Aguilar de Soto *et al.* 2004).

Stranding records of cetaceans along the Irish coast have been reviewed by Berrow & Rogan (1997). Mackey *et al.* (2004b) outlines a comprehensive bibliography for cetacean publications in the waters around Ireland.

3.7.3 Seabirds

Twenty-one species of seabird were considered in this review. There were 6 species of petrel, gannet, 4 species of skua, 5 gull species, 2 tern species and 3 species of auk.

Northern fulmar (*Fulmarus glacialis)*

The northern fulmar is one of the commonest seabirds around Ireland and was one of the most frequently recorded and widespread species in recent offshore marine surveys (Pollock *et al.* 1997, Pollock *et al.* 2000, Mackey *et al.* 2004a). Studies have shown that fulmars make up a major proportion of seabirds found in deeper oceanic water beyond the shelf edge (Reid *et al*. 2001).

Great shearwater (*Puffinus gravis)*

Great shearwaters are generally recorded in offshore areas between July and November, with the majority of sightings between September and October. During late summer, birds are widespread and numerous along the shelf edge west of Ireland, particularly around the Porcupine and Rockall Banks, and the Rockall Trough (Pollock *et al.* 1997, Mackey & Perales i Giménez 2004).

Sooty shearwater (*Puffinus griseus)*

Like great shearwaters, sooty shearwaters are regular migrants from the south Atlantic in summer and autumn months, and it is thought that the waters west of Ireland are important feeding grounds for non-breeding birds (Warham 1996). The main concentrations in offshore areas were recorded around Rockall and birds were widespread over the Rockall Bank and Porcupine Shelf in August (Mackey *et al.* 2004a).

Manx shearwater (*Puffinus puffinus*)

Most of the world population of Manx shearwaters breed in Britain and Ireland (Mitchell *et al.* 2004). In recent surveys in offshore waters west of Ireland, Manx shearwaters were found beyond the 200m contour between February and September, with a peak in numbers in August (Mackey *et al.* 2004a). Offshore areas such as the Rockall Bank, the northern slope of the Porcupine Bank and the Hatton Bank appeared to be important feeding areas during spring and summer.

European storm-petrel (*Hydrobates pelagicus)*

The European storm-petrel is a pelagic species that feeds on plankton and is found mostly on oceanic waters greater than 100m in depth with salinity greater than 35‰ (Stone *et al.* 1995, Harrison *et al.* 1994). Ireland holds the largest known breeding colonies of European storm-petrels in the world, with 18-30 colonies supporting between 72,753 – 128,188 apparently occupied sites (Mitchell *et al.* 2004).

Recent offshore surveys recorded highest numbers of European storm-petrels along the shelf break and around the Porcupine shelf area in summer, when numbers of foraging breeding birds may be swelled by non-breeding immature birds in the area. Low densities were recorded over the Rockall Trough and Rockall Bank. Very few were recorded in winter months, as the species winters off southern Africa (Pollock *et al.* 1997, Mackey *et al.* 2004a). This species tends to be under-recorded by dedicated "at sea" surveys, due to its small size.

Leach's storm-petrel (*Oceanodroma leucorhoa)*

The only colony of Leach's storm-petrel in Ireland is on the Stags of Broadhaven in County Mayo, which hold an estimated 310 apparently occupied sites (Mitchell *et al.* 2004). On recent offshore surveys, highest numbers of Leach's storm-petrels were recorded north-west of Ireland, over the Rockall Trough during July and August (Pollock *et al.* 1997, Mackey *et al* 2004a). Leach's storm-petrel generally had a more offshore and northerly distribution than European storm-petrel (Pollock *et al.* 1997).

Northern gannet (*Morus bassanus)*

Colonies in Britain and Ireland support approximately 67.5% of the world population of northern gannet (Mitchell *et al.* 2004). On the west coast of Britain, major colonies are found on St Kilda, the Flannan Isles and Sula Sgeir while three colonies, Clare Island, Little Skellig and Bull Rock, are located off the west coast of Ireland.

Pollock *et al.* (1997) recorded highest densities of northern gannets in offshore waters between spring and early summer, and a similar distribution pattern was recorded by Mackey *et al* (2004a), with low to moderate numbers recorded over the Rockall and Hatton Banks and in the deeper waters of the Rockall Trough in spring and summer.

Pomarine skua (*Stercorarius pomarinus)*

Pomarine skuas are passage migrants in Irish waters, with adults moving north through the area to breeding colonies in north-east Russia and Siberia in spring and returning with juveniles in autumn. Recent offshore surveys recorded pomarine skuas between April and November, with the Hatton and Rockall Banks highlighted as a potentially important area during spring migration. A total of 340 birds were recorded during a 5 week survey in this area in May 2002 (Mackey *et al.* 2004a). The majority of summer records were from the Rockall Trough area.

Arctic skua (*Stercorarius parasiticus)*

As well as Arctic skuas being regular spring and autumn passage migrants on all Irish coasts (Hutchinson 1989), recent offshore surveys have also recorded birds over the Rockall and Hatton Banks, the Rockall Trough, the Porcupine Seabight, and the Porcupine Shelf (Pollock *et al.* 1997, Mackey *et al.* 2004a). Mackey *et al* (2004a) suggests that the Rockall and Hatton Banks and the Rockall Trough regions may be important routes during both spring and autumn migrations. Only two birds were recorded during surveys between December and February (Pollock *et al.* 1997).

Long-tailed skua (*Stercorarius longicaudus)*

Long-tailed skuas were the least common of the three small skua species recorded on offshore surveys west of Ireland, and were recorded between May and September. Over 270 were recorded during a 5 week survey in the Hatton–Rockall region in May 2002, suggesting that this area may be important on migration (Mackey *et al* 2004a).

Great skua (*Stercorarius skua)*

Great skuas have a restricted breeding range limited to the north-east Atlantic, with largest numbers nesting on Shetland, Orkney and Iceland (Mitchell *et al* 2004). However, one pair recently bred at a site in Connacht in 2002, which may be the beginning of colonisation of Ireland (Hillis 2004). Great skuas were the most common skua species encountered on offshore surveys, and were recorded throughout the year.

Peaks in March and April indicate birds migrating northwards to breeding grounds, with the Rockall and Hatton Banks and the northern sector of the Rockall Trough being important, along with the Porcupine Seabight and Goban Spur on the shelf edge (Mackey *et al* 2004a). Pollock *et al.* (1997) recorded highest numbers during November and December, in particular around the continental slope west of Brittany.

Sabine's gull (*Larus sabini)*

This pelagic species migrates southwards in autumn from Greenland to wintering areas off South Africa, passing off the west coast of Ireland (Stone *et al.* 1995). Sightings from offshore surveys were widely dispersed, with small numbers recorded over the Hatton and Rockall Banks, the Porcupine Bank and along the shelf edge, with concentrations over the Celtic Shelf in August (Pollock *et al.* 1997, Mackey *et al.* 2004a).

Herring gull (*Larus argentatus)*

Although this species shows a predominantly coastal distribution, small numbers of herring gulls were recorded from the Hatton and Rockall Banks in June (Mackey *et al.* 2004a).

Lesser black-backed gull (*Larus fuscus)*

Surveys west of Ireland have shown that lesser black-backed gulls are found in offshore areas, primarily between January and September. Pollock *et al.* (1997) found lesser black-backed gulls along the shelf edge to the south-west of Ireland at low densities between February and April, with a more coastal distribution for the rest of the year. During and after the breeding season, the deep waters of the Rockall Trough, the Rockall–Hatton region and the Porcupine Seabight also held variable concentrations (Mackey *et al* 2004a).

Great black-backed gull (*Larus marinus)*

In the winter months, great black-backed gulls were found at low to moderate densities on the continental shelf north-west of Ireland, with occasional records along the shelf break west of Ireland during the rest of the year (Pollock *et al.* 1997). Occasional sightings were recorded over the Rockall, Hatton and Porcupine Banks during the breeding season, and over the Rockall Trough in autumn (Mackey & Perales i Giménez 2004).

Black-legged kittiwake (*Rissa tridactyla)*

Offshore surveys recorded highest densities of black-legged kittiwakes around the shelf break south-west and north-west of Ireland, and over the Rockall Trough, the Hatton Bank and Porcupine Bank/Seabight region during spring (Mackey *et al.* 2004a). Densities of up to 100 birds per km^2 were recorded over the 500m contour south-west of Ireland in February (Pollock *et al.* 1997). High concentrations of black-legged kittiwakes associated with the shelf break at this time of year have also been recorded by other studies (Webb *et al.* 1990, Bloor *et al.* 1996). Low to moderate densities were recorded in offshore deep waters during the rest of the year.

Common tern (*Sterna hirundo)*

Common terns are summer visitors to the UK and Ireland, breeding at both coastal and inland colonies. There were a few sightings of common terns in offshore waters during surveys west of Ireland, in May and June (Pollock *et al.* 1997, Mackey *et al.* 2004a).

Arctic tern (*Sterna paradisaea)*

Arctic terns were recorded in higher numbers than the very similar common tern on offshore surveys west of Ireland (Mackey *et al.* 2004a). Birds were recorded between May and September, with numerous sightings over the Rockall Trough and Rockall and Hatton Banks.

Common guillemot (*Uria aalge)*

Common guillemots were virtually absent from deep offshore areas throughout the area. However low concentrations were recorded over the northern sector of the Rockall Trough and the western Porcupine Shelf between April and June, with birds occasionally noted as far west as the Rockall and Hatton Banks (Mackey *et al.* 2004a).

Razorbill (*Alca torda)*

Razorbills were largely found in coastal and shelf waters although they were occasionally recorded over the northern sector of the Rockall Trough in spring and north-west of County Mayo in June, when birds were also recorded over the Rockall and Hatton Banks (Mackey *et al.* 2004a).

Atlantic puffin (*Fratercula arctica)*

The Atlantic puffin is the most pelagic of the three auk species considered here, and was recorded at low to moderate densities in the Rockall Trough and over the Rockall and Hatton Banks during spring and summer. Birds were also recorded on the continental slope over the Porcupine Ridge and west of the Goban Spur between April and July (Pollock *et al.* 1997, Mackey *et al.* 2004a). Puffins were also recorded in low densities here between October and December (Mackey & Perales i Giménez 2004).

3.7.4 Marine Mammals

Of a total of twenty species of cetacean reviewed, 6 were baleen whales.

Northern right whale (*Eubalaena glacialis)*

This species is the rarest whale species that occurs in the north-east Atlantic. Sporadic sightings have been recorded from the Canaries, Madeira, Spain, Portugal, the UK, Norway and Iceland. Three records from 52^{o} north, 19^{o} west, off Ireland are shown in the Atlas of cetacean distribution (Reid *et al*. 2003).

Humpback whale (*Megaptera novaeangliae)*

In the north-east Atlantic, humpback whales are mainly concentrated around Iceland and the Barent's Sea. In winter they breed in tropical waters, while spending the summer in temperate and polar waters (Reid *et al*. 2003).

Humpback whales are uncommon migrants to the study area with JNCC & CMRC surveys between 1980 and 2003 yielding only one animal (Reid *et al*. 2003, Ó Cadhla *et al.* 2004). CMRC surveys recorded a humpback whale in September 2001 along the continental slope off the north-west coast of Ireland, close to the Erris Ridge (Ó Cadhla *et al.* 2004).

Passive acoustic monitoring in the study area has revealed that singing males are present mainly between October and late March. They appear to migrate south over this period, although fewer animals were detected in the deep waters south of Ireland (Clark & Charif 1998, Charif & Clark 2000). During the summer months, humpback whales are recorded in inshore waters off the south coast of Ireland (Berrow *et al.* 2002).

Minke whale (*Balaenoptera acutorostrata*)

Although abundant in shelf waters particularly during the summer months, minke whales are also recorded in deeper waters west of Ireland (Pollock *et al.* 1997). Just over 4% of sightings in the IWDG database were of offshore animals (Berrow *et al*. 2002).

There have been sightings over the Rockall Bank, Rockall Trough and Porcupine Ridge in spring and summer. No animals were recorded during the winter months (Mackey *et al*. 2004b, Stone 2003).

Sei whale (*Balaenoptera borealis*)

Sei whales are a deep water species preferring water depths of 500-3000m, with a more offshore distribution than fin whales (Reid *et al.* 2003). CMRC recorded sei whales in summer and autumn east of Edoras Bank, on the western & eastern slopes of the Porcupine ridge, Porcupine Seabight, west and south-west of the Goban Spur (Ó Cadhla *et al.* 2004).

Fin whale (*Balaenoptera physalus*)

Annual movements of fin whales in the study area are not well known. The area may be a migration route for animals moving between northern waters in summer to southern breeding grounds in winter (Evans 1987, Pollock *et al.* 2000). Some animals over-winter and may breed (Evans 1992). Fin whales are frequently recorded in the summer and autumn in coastal waters off the south coast of Ireland (Berrow *et al*. 2002).

In north-west European waters, fin whales are mostly recorded in waters in waters greater than 200m deep (Reid *et al.* 2003). Five of six sightings of fin whales recorded by JNCC were in offshore waters in July and August (Pollock *et al.* 1997). CMRC surveys similarly recorded most animals in offshore waters over the summer (Mackey *et al.* 2004b). Overall most animals in the study area were seen in the Rockall Bank and Trough and Porcupine Seabight and Goban Spur (Reid *et al*. 2003, Mackey *et al.* 2004b).

In contrast, acoustic surveys have recorded fin whale vocalisation in all months of the year with a peak in the winter months (Clark & Charif 1998, Charif & Clark 2000).

Blue whale (*Balaenoptera musculus*)

A single animal observed in the Rockall Trough in May 2001 represents the first sighting in these waters since whaling ceased in the region (Mackey *et al.* 2004b). The Atlas of cetacean distribution shows a second blue whale record in the Porcupine Seabight (Reid *et al.* 2003). In 1998 a blue whale was recorded over the Hebrides Terrace just outside the study area (Stone 2000).

Passive acoustic monitoring has revealed that blue whales are in fact present throughout the year with a peak in vocalisation between October and December (Clark & Charif 1998, Charif & Clark 2000).

Sperm whale (*Physeter macrocephalus*)

The sperm whale is a relatively common deepwater species generally preferring waters greater than 1000m (Pollock *et al.* 2000, Ó Cadhla *et al.* 2004). While sightings in the study area are mainly during the summer months, it is thought that some males remain at high latitudes during the winter (Reid *et al*. 2003, Mackey *et al.* 2004b).

Sperm whales have been recorded over the Rockall Trough and Rockall-Hatton Bank region, Porcupine Seabight and west and south-west of the Goban Spur (Mackey *et al*. 2004b). Most sightings were over the Rockall Trough in spring (Ó Cadhla *et al.* 2004).

Acoustic surveys have confirmed the importance of the Rockall Trough (Aguilar de Soto *et al.* 2004).

Cuvier's beaked whale (*Ziphius cavirostris)*

There have been 3 sightings of Cuvier's beaked whale in the study area in August. A single animal was recorded in waters 500m deep east of the Porcupine Seabight, while two individuals were observed in the Rockall Trough (Mackey *et al.* 2004b). This species may be a summer visitor to the area (Reid *et al.* 2003, Mackey *et al*. 2004b). Of a total of 21 stranded animals along the Irish coast in the last century, 18 were on the western seaboard (Berrow & Rogan 1997).

Northern bottlenose whale (*Hyperoodon ampullatus)*

Northern bottlenose whales are found in deep waters and was the most frequently observed beaked whale species in the study area. Animals were recorded south-west of Lorien Bank and along the shelf break north-east of the Porcupine Bank between June and August (Pollock *et al.* 1997, Mackey *et al.* 2004b).

Sowerby's beaked whale (*Mesoplodon bidens)*

A group of 5 animals including a juvenile were recorded in the Rockall Trough in August (Ó Cadhla *et al.* 2004). Although the distribution of Sowerby's beaked whale is thought to be centred in the North Sea, this species has been recorded in deep waters to the north of the study area (Pollock *et al.* 2000, Mackey *et al.* 2004b).

True's beaked whale (*Mesoplodon mirus)*

The first record of this species in the Study Area was a group of 5 animals over the Rockall Trough in May 2001 (Ó Cadhla *et al.* 2004). There have been six strandings of this species along the west coast of Ireland (Berrow & Rogan 1997).

Long-finned pilot whale (*Globicephala melas)*

This is the most common toothed whale species in the study area and is usually found in deep waters between 200 & 1000m (Pollock *et al.* 1997). While pilot whales were recorded in all months except October and January (Pollock *et al.* 1997), most animals were observed in spring and summer (Mackey *et al.* 2004b).

Most animals were recorded in the Rockall Trough and along the shelf break at its steepest, from south-west Ireland to the Bay of Biscay (Reid *et al.* 2003), as well as the shelf break off the north and west of Ireland (Gordon *et al.* 2000, Stone 2003).

Killer whale (*Orcinus orca)*

Killer whales are widely distributed in the deep North Atlantic and in coastal northern European waters but also occur west and south of Ireland (Reid *et al.* 2003). Offshore surveys west of Ireland recorded 4 small groups of killer whales between June and October around the shelf edge, east and south of the Porcupine Bank (Pollock *et al.* 1997).

False killer whale (*Pseudorca crassidens)*

This pelagic species has a worldwide distribution, and has mostly been recorded in the north-east Atlantic around the Canary Islands north to the Bay of Biscay (Reid *et al*. 2003). Offshore surveys north-west of Ireland recorded seven groups of false killer whales between July 1999 and September 2001.

All sightings were in the deep waters of the Porcupine Seabight/Goban Spur region and in the northern margins of the Rockall and Hatton Banks, in depths >720m (Ó Cadhla *et al.* 2004). Six of these records were in June or early July, with the seventh in November.

Risso's dolphin (*Grampus griseus)*

Risso's dolphins are mainly found over the continental shelf in north-west Europe, with only a few records from the shelf break and one sighting of 10 animals in continental slope waters to the north of the Porcupine Shelf (Reid *et al.* 2003, Pollock *et al.* 1997, Ó Cadhla *et al.* 2004).

Bottlenose dolphin (*Tursiops truncatus)*

Bottlenose dolphins occur in large numbers off western Ireland and around the shelf break to the south-west of Ireland. The species also occurs further offshore in deep waters of the North Atlantic, for example around the Rockall Bank (Reid *et al*. 2003). Records from offshore surveys also suggest that the Porcupine Seabight, Porcupine Bank and the adjacent continental shelf and slope habitats may be an important area for bottlenose dolphin, at least in the spring and summer months (Ó Cadhla *et al.* 2004).

White-beaked dolphin (*Lagenorhynchus albirostris)*

White-beaked dolphins are usually found over the continental shelf in waters of 50-100m depth (Reid *et al.* 2003). The species was rarely recorded in waters deeper than 200m on offshore surveys, with a few sightings in the Rockall Trough and Porcupine Seabight, where waters exceed 1,500m in depth (Pollock *et al.* 1997, Ó Cadhla *et al.* 2004).

Atlantic white-sided dolphin (*Lagenorhynchus acutus)*

This species was most abundant north-west of Ireland, with peak numbers offshore recorded around the Rockall and Hatton Banks and in the deeper waters in the Rockall Trough in July. Animals were also recorded along the shelf edge south-west of Ireland (Pollock *et al.* 1997, Ó Cadhla *et al.* 2004). There is a suggestion from bycatch data that white-sided dolphins may range much further into the open Atlantic than previously thought (Reid *et al.* 2003).

Common dolphin (*Delphinus delphis)*

Limited survey effort achieved in deeper Atlantic waters suggests that common dolphins are widespread in offshore waters west of Ireland (Reid *et al*. 2003). Common dolphins were recorded in all months and was the most abundant cetacean species recorded (Pollock *et al.* 1997, Ó Cadhla *et al.* 2004).

Common dolphins were recorded in moderate numbers in the Rockall Trough in winter and in moderate to high densities along the shelf break (Pollock *et al.* 1997, Ó Cadhla *et al.* 2004). Between January and May, common dolphins were recorded over the Porcupine Bank and Porcupine Seabight in low numbers (Pollock *et al.* 1997).

In the summer months, common dolphins were widespread and abundant over the Rockall Bank and Hatton Basin areas (Pollock *et al.* 1997). Groups including newborn calves were recorded over the Rockall Bank at this time (Ó Cadhla *et al.* 2004).

Striped dolphin (*Stenella coeruleoalba)*

Striped dolphin is a deep water oceanic species, occurring mainly offshore west of the Iberian Peninsula and France, and in the Bay of Biscay (Reid *et al.* 2003). Offshore surveys recorded striped dolphins in the Goban Spur and Porcupine Seabight areas during the summer, as well as along the southern margin of the Rockall Bank (Pollock *et al.* 1997, Ó Cadhla *et al.* 2004). These northerly records together with increased numbers of strandings suggest that this species may be extending its range northwards, at least during the summer months (Ó Cadhla *et al.* 2004).

3.7.5 Conclusions and data gaps

The deep waters west of Ireland are important for several species of seabirds and cetaceans. Studies have shown that fulmars make up a major proportion of seabirds found in deeper oceanic water beyond the shelf edge. Species such as great, sooty and Manx shearwaters are also widespread and numerous along the shelf edge west of Ireland, particularly around the Porcupine and Rockall Banks, and the Rockall Trough during late summer. The Hatton and Rockall Banks may be a potentially important area for skua species during spring migration.

The Rockall-Hatton Banks, Rockall Trough, Porcupine Seabight and Goban Spur regions have been highlighted as important for cetacean species such as fin whale, sperm whale, and long-finned pilot whale and for several species of dolphins.

In general there has been less survey work in offshore waters than in shelf waters, particularly during the winter months where existing survey coverage is poor. Further survey work is necessary to elucidate the seasonal distribution of cetaceans in the region. Ongoing PIP-funded work (CMRC 2005) relating the distribution of cetaceans and seabirds to various oceanographic parameters and features may provide greater understanding and facilitate identification of important areas for these animals.

4 HUMAN USERS OF THE AREA

4.1 Regional overview

Historically, the deep water area to the west of Ireland has not been subject to significant levels of human usage or exploitation, other than transit of shipping. However recent years have seen an expansion of fisheries into deep water areas targeting a range of fish species. Technology advances have also allowed oil and gas exploration activities to target deeper water areas.

Oil and gas activity in Irish waters is limited by comparison to the North Sea province. Exploration and development activity has focussed in the Celtic Sea basin with a number of gas fields currently under production. Largely due to the technical challenges and costs involved, exploration activity in the deep water area has been relatively low and the Irish government has sought to encourage further exploration through a series of licensing rounds. The Corrib gas field in the Erris basin represents the first major development in the deep water area. A range of oil and gas initiatives in particular the formation of the joint industry/government Petroleum Infrastructure Programme has promoted research into a range of relevant environmental issues in the area.

Fisheries in the area are important nationally and internationally. A wide range of fish and shellfish species from shelf waters are targeted by demersal and pelagic fishing fleets from a number of countries. Deep water fisheries have developed over the last 30 years and much of the effort has concentrated on the continental slope to the north and west of Ireland. Important deep water fisheries include directed trawl fisheries for demersal species including blue ling, grenadier, orange roughy and deepwater sharks; directed longline fisheries for ling, tusk and hake, and gillnetting for ling. There is a significant lack of information on the status of most deep water stocks. In general, advice from ICES highlights the vulnerability of deep water stocks to fishing and indicates that fishing effort should be significantly reduced or stopped until more information is gathered.

4.2 Oil and gas activity

4.2.1 Overview

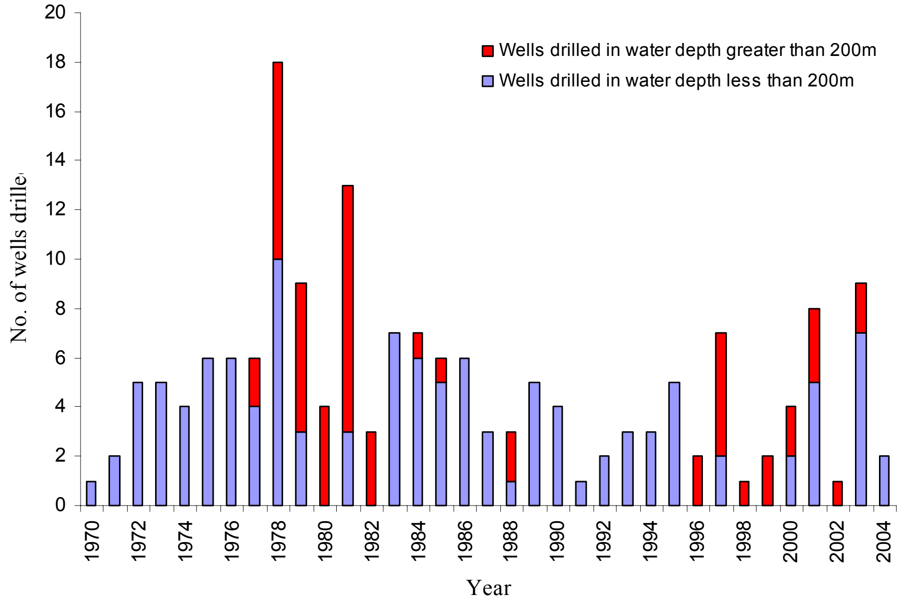
The deep water area to the west of Ireland is subject to some of the most extreme metocean conditions in the world, with respect to wind and waves (see Section 2.2). Water depths in the region range from 200m to over 3,500m. These adverse environmental conditions have historically restricted oil and gas drilling activities in offshore waters to between April and October.

The first well was drilled in Irish waters in 1970 and in the 35 years since this date only 187 wells have been drilled including appraisal and development wells. Of these wells, 121 were exploration wells. Currently Ireland's exploration success rate is viewed as very low. Drilling in Irish deepwater regions is also a costly operation. An estimation of the cost associated with drilling a deepwater well is in the vicinity of €30 million. Cost and success rate of exploration activities contribute to drilling in offshore Irish waters being a high risk business and have further compounded by low levels of activity in the region.

4.2.2 Exploration and development

May 1970 saw the first well to be drilled in Irish waters. The well was drilled by Marathon in the North Celtic Sea Basin and did show gas although it was later plugged and abandoned. To this date a total of 187 wells have been drilled in Irish waters, 55 of which were drilled in water depths greater than 200 metres (Figure 4.1). An estimated €2 billion, in today's terms, has been invested in Irish drilling operations in the past 35 years.

Figure 4.1 – Wells drilled in Irish waters (1970-2004)



Note: Does not include 14 Kinsale Head wells drilled by Marathon during 1978-1979.
Source: PAD website – http://www.pad.ie.

A total of 30 companies have engaged in exploration activities in Irish waters since 1970. The most prolific operator in the area is Marathon Oil who are responsible for drilling 30% of all wells (Table 4.1). As would be expected some of the major oil companies such as BP, Esso and Shell have also been active in the area, although to a lesser extent. Most recent drilling operations took place in 2004 during which time Providence Resources Plc drilled two exploration wells in the North Celtic Sea Basin.

Table 4.1 - Main operators in Irish waters

Operator	Wells drilled	Period of activity
Marathon	56	1970-2003 (activity concentrated 1978-79)
BP	18	1976-1989
Esso	15	1972-85
Enterprise Oil	12	1986-2001 (activity concentrated 1996 onwards)
Gulf	10	1979-1986
Elf	9	1976-1983
Chevron	6	1979-1981, 1995
Ramco Seven Heads Ltd	6	2003 (also 2 wells drilled in 2001 by Ramco Oil Ltd)
Amoco	5	1977-1979, 1988
Shell	6	1977-2002
Statoil	5	1997-2003

Source: PAD website – http://www.pad.ie

There are currently two companies operating offshore developments in Irish waters, Marathon Ireland Petroleum Inc and Ramco Seven Heads Ltd.

Marathon was the first company to produce natural gas in Ireland from the Kinsale Head field, located off the south coast of Ireland in the Celtic Sea, which came on stream in 1978 (www.marathon.com/Our_Business/Marathon_Oil_Company/Exploration_Production/Europe/Ireland). The Ballycotton subsea satellite was added in 1991, while the Southwest Kinsale field became operational in 1999. Ireland's first offshore gas storage service began in 2001 from the Kinsale Head area. The Kinsale Head gas is produced to two platforms, the Alpha and the Bravo. Gas is exported from the Alpha platform to a terminal near Cork for distribution. Kinsale Head was further developed in 2003 by adding an additional subsea gas well in 2003. The Greensand subsea gas well is designed to enhance the productivity of the main Kinsale Head natural gas producing Greensand reservoir and has been tied back to Marathon's existing Kinsale Head Bravo platform.

Ramco Seven Heads Ltd are operators of the Seven Heads development which is situated in the Celtic Sea, about 47km south of the Co. Cork coastline and 39km southwest of the existing Kinsale Head field Alpha platform. First gas was achieved from Seven Heads in December 2003. Once processed through the Kinsale Head facilities, gas is exported to shore through the existing pipeline to the Inch Onshore Terminal from where it is distributed. Initial production from the Seven Heads development has fallen short of predictions. Currently the field is producing only 4mmscf/d (Ramco website) however a programme of work to add new perforations to two wells and additional drilling is expected to open up further sources of gas.

The Corrib Field, located off the coast of Co. Mayo is in the process of being developed by Shell E&P Ireland (SEPIL, formerly Enterprise Oil Ireland Limited) along with co-venturers Statoil Exploration (Ireland) Limited and Marathon International Petroleum Hibernia Ltd. Natural gas will be produced from a number of wells and flowed through a pipeline to a terminal at Bellanaboy Bridge, Co. Mayo (Enterprise Energy Ireland 2001, SEPIL website - http://www.shell.com/home/Framework?siteId=ie-en&FC2=/ie-en/html/iwgen/leftnavs/zzz_lhn6_2_0.html&FC3=/ie-en/html/iwgen/exploration_and_production/corrib/SEPIL_corrib_home.html).

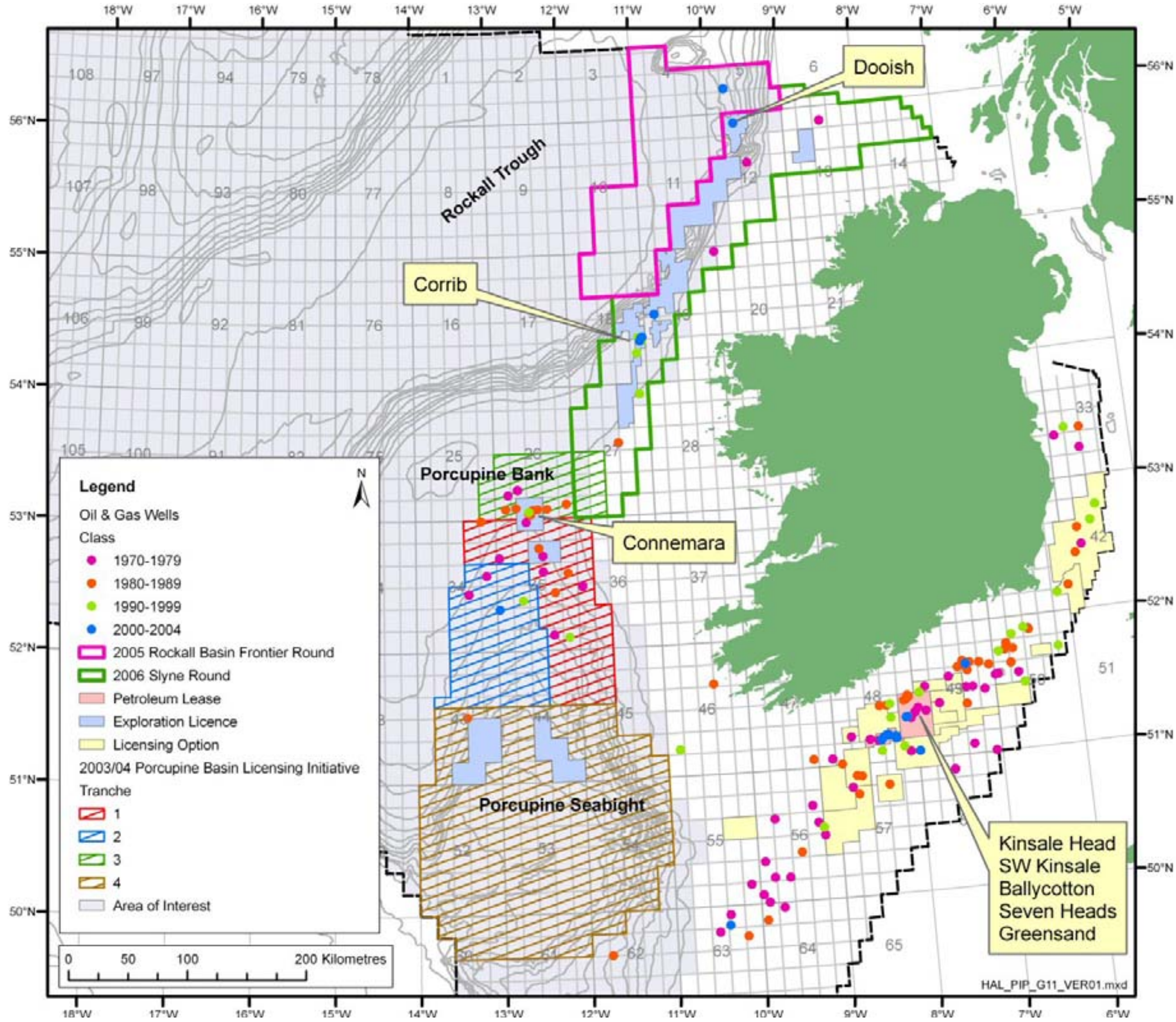
4.2.3 Licensing

The Department for Communications, Marine and Natural Resources has embarked on a structured series of licensing rounds of offshore areas in recent years aimed at rejuvenating exploration activity. The new licensing rounds are an attempt to reduce the over-dependence on imports to meet growing Irish energy requirements.

Since 2002 three licensing rounds have been announced; the 2003/2004 Porcupine Basin licensing initiative, 2005 North East Rockall Basin frontier licensing round and the 2006 Slyne/Erris/Donegal frontier licensing round (Figure 4.2).

Announced in November 2002, the Porcupine Basin licensing initiative encompassed 241 whole blocks to be released in four tranches (excluding the two areas currently held under Frontier Exploration Licence). Applications for Frontier Exploration Licences involving blocks in the four Tranches were considered in turn at approximately 6-month intervals: Tranche 1 (March 2003), Tranche 2 (and 1) (October 2003), Tranche 3 (and 1 & 2) (March 2004), and Tranche 4 (and 1, 2 & 3) (October 2004).

Figure 4.2 - Exploration and development in Irish waters



Source: PAD website – http://www.pad.ie

The 2005 North East Rockall Basin frontier licensing round was announced in July 2004 with the express aim of promoting areas with exploration potential. The acreage on offer during this licensing round covered 65 full blocks and 12 part-blocks - an area of approximately 15,800km^2. The region was classified as Frontier because of the deep water and challenging environment. Successful applicants will be offered Frontier Exploration Licences which have a duration of 16 years. The closing date for applications for this round was 31st May 2005.

The 2006 Slyne/Erris/Donegal frontier licensing round was announced in January 2005, as the second phase of a policy to successively open areas with exploration potential. The acreage on offer covers unlicensed blocks in an area of approximately 25,000km^2. Successful applicants will again be offered Frontier Exploration Licences, applications for which must be submitted by 15 March 2006. The Corrib gas field has already illustrated the hydrocarbon potential of this area and the infrastructure associated with Corrib could significantly reduce the development cost of any further commercial discoveries in the vicinity.

4.2.4 Initiatives

Petroleum Infrastructure Programme (PIP)

PIP was set up by the Petroleum Affairs Division (PAD) in 1997 and comprises a consortium of oil and gas exploration companies and government with the overall aim of promoting hydrocarbon exploration and development activities through:

- Strengthening of local support structures
- Funding of research data gathering and 'land-based' research in Irish offshore areas
- Providing a forum for co-operation amongst explorationists and researchers

PIP presently comprises two sub-programmes:- the active Petroleum Exploration and Production Promotion and Support (PEPPS) and the now completed PIP (1997 - 2002) sub-programmes.

The three Groups of the PIP Sub-Programme were:

- The Offshore Support Group (OSG)
- Rockall Studies Group (RSG)
- Porcupine Studies Group (PSG)

The OSG was established in June 1997 to assist in developing local support structure for hydrocarbon exploration and development offshore Ireland. RSG was also formed in June 1997 in conjunction with the award of licences under the Rockall Frontier Licensing Round. This group completed its term in June 2001 with a total of 58 projects receiving RSG funding. The PSG was established in March 1999 in conjunction with the award of licences under the South Porcupine Frontier Licensing Round. Both RSG and PSG have actively promoted and commissioned research and data gathering projects to improve understanding of common industry problems within the respective areas.

The two Groups of the active Petroleum Exploration and Production Promotion and Support (PEPPS), established in 2002, are:

- Expanded Offshore Support Group (EOSG)
- Irish Shelf Petroleum Studies Group (ISPSG)

The EOSG was set up in 2002 and continues the work of the PIP Offshore Support Group (OSG), concentrating mainly on infrastructure support, but also with the flexibility to conduct other work as deemed necessary. The ISPSG Group, the successor to RSG and PSG was also established in 2002 and concentrates on the regional exploration elements of the PEPPS objectives. The aim of the ISPSG is to address common industry problems anywhere in the Irish offshore environment. The four technical sub-groups covering the various work strands of the ISPSG are geology and geophysics, environment, engineering and data management and support services (PIP website – http://www.pip.ie).

Irish Offshore Operators Association (IOOA)

Formed in 1995, the IOOA is an umbrella organisation which represents the oil and gas companies with operating interests in Ireland's offshore hydrocarbon industry. It provides a forum for representatives of member companies to work together in identifying and tackling common issues (e.g. safety, environment, legislation and employment) facing Ireland's growing off shore industry. The IOOA also provides information on operations that may affect fishing or navigation on their website (http://www.iooa.ie).

Iniatives in adjacent areas

AFEN (Atlantic Frontier Environmental Network) is a joint industry/government group set up in 1995 with participation by over 20 Operators, the UK Department of Trade and Industry (DTI) and the UK Joint Nature Conservation Council (JNCC). Between 1996 and 2000 AFEN commissioned a wide range of environmental studies in the north east Atlantic to the north and west of Scotland with the aim of generating environmental information to facilitate environmental management decisions about oil and gas activities (AFEN 2001). To a large extent the work of AFEN has been superceded by the DTI-funded Strategic Environmental Assessment (SEA) programme.

Previous and parallel to AFEN, similar co-operative initiatives have included the North West Approaches Group (industry and Health and Safety Executive) to collect and synthesise weather and oceanographic information, and the Western Frontiers Association (industry and the British Geological Survey, BGS, WFA website – http://www.bgs.ac.uk/wfa) to study seabed geology and geotechnical conditions (AFEN 2001).

Through initiatives such as WFA and the UK Rockall Consortium, BGS have been actively involved in exploratory research and data collection in the Rockall and Hatton areas. This data, including seismic, seabed cores and cored boreholes has added greatly to the knowledge of this poorly explored area. Much of this data is in the area immediately north of the UK/Irish meridian line and some extends into Irish waters.

Other initiatives of interest include the Faroes Oil Industry Group, FOÍB. This association has been formed by the oil companies which have been granted license for exploration drilling on the Faroese continental shelf with the aim of improving the knowledge base of the area (FOÍB) website - http://www.foib.fo).

4.3 Fisheries

4.3.1 Introduction

Fisheries in the area are important nationally and internationally. A wide range of fish and shellfish species from shelf waters are targeted by demersal and pelagic fishing fleets from a number of countries. Deep water fisheries have developed over the last 30 years and much of the effort has concentrated on the continental slope to the north and west of Ireland. The lack of information on the status of many of the deep water commercial stocks is of considerable concern to regulators and conservationists.

The main sources of information include the Marine Institute's Fisheries Science Services Stock Book (FSS 2004), the ICES Advisory Committee on Fishery Management/Advisory Committee on Ecosystems Report (ACFM 2004), the Report of the Working Group on the Biology and Assessment of Deep-Sea Fisheries Resources (ICES 2004b) and various fisheries research programmes. Much of the information is presented by ICES Areas, Sub-areas or Divisions which are shown on Figures 4.3.1 and 4.3.2.

4.3.2 Fishing activity

Given that many fisheries on the continental shelf to the west of Ireland may extend out to the shelf edge and onto the continental slope it is difficult to describe them in isolation. An overview of relevant shelf and coastal fisheries is included to provide context and facilitate understanding. Figures 4.3.1 and 4.3.2 provide a summary of shelf and deep water fishing activity respectively.

Shelf and coastal fisheries

Overview

Most of the demersal fisheries on the shelf have a mixed catch and whilst possible to associate specific target species with particular fleets, various quantities of cod, whiting, haddock, hake, anglerfish, megrim, sole, plaice, and *Nephrops* are taken together, depending on gear type, sea area and countries involved (ACFM 2004). Some fleets, particularly those fishing coastal areas also take additional valuable species including squids, cuttlefish, and red mullet (FSS 2004). A wide range of shellfish species including lobster, crabs and scallops are taken from inshore areas.

Cod, haddock and whiting form the predominant roundfish catch in the mixed fisheries in Division VIa, with important bycatches of saithe and anglerfish in the deeper water and of *Nephrops* on the more inshore *Nephrops* grounds. Saithe are mainly taken in a directed trawl fishery in deeper water along the shelf in Subarea VI. Larger Scottish and Irish trawlers fish for haddock at Rockall (Division VIb).

A trawl fishery for anglerfish by Spanish and French vessels developed in the Celtic Sea, on the shelf edge around the 200m contour to the south and west of Ireland in the 1970s and expanded until 1990. This fishery used single and twin rig otter trawls in medium and deep water in Divisions VIIb,c,e-k. Although effort in most fleets appears to have declined since the early 1990s the increasing use of twin trawls may have increased the overall efficiency. Bycatch species include hake, megrim and to a lesser extent *Nephrops*. A gillnet fishery targeting anglerfish developed in the Celtic Sea on the shelf edge around the 200m contour to the south and west of Ireland in the 1990s (ACFM 2004).

Plaice and sole are taken as part of a mixed demersal fishery by otter trawlers mainly targeting hake, anglerfish, megrim and *Nephrops* in Division VIIb to the west of Ireland. Irish vessels from Rossaveal and the Aran Islands are the major participants in this fishery. To the south, plaice and sole are also taken by mixed otter trawling in Division VIIj. Ireland, UK, France and Belgium are the major participants in this fishery with Irish vessels operating from the ports of Castletownbere, Dingle, Union Hall, Baltimore and Schull. Beam trawlers and seiners are also involved to a lesser extent (ACFM 2004).

Celtic Sea whiting are taken in mixed species (cod, whiting, hake, *Nephrops*) fisheries with French trawlers accounting for about 60% of the total landings, Ireland 30%, and the UK (England and Wales) 7%, while Belgian vessels take less than 1%. The main Irish fleets in Divisions VIIf,g,h are inshore and offshore otter trawlers and seiners based in Dunmore East and Kilmore Quay. However, in recent years there has been an increase in the number of Irish beamers (+6 vessels) targeting anglerfish and megrim with whiting as by-catch, offshore in Division VIIg. Irish landings of whiting from Division VIIj-k are taken in both a mixed fisheries (cod/whiting/ anglerfish/megrim and *Nephrop*s) and in a directed fishery in the first quarter (FSS 2004).

There are two main *Nephrops* fisheries on the Porcupine Bank and in outer Galway Bay, off the Aran Islands. There are also very small inshore fisheries to the north and numerous small scattered inshore fisheries off the south west and south coasts. Landings from the Porcupine Bank are mainly by France, Ireland, Spain and the UK and have declined significantly over recent years. Irish otter trawlers and twin-rig vessels dominate the other fisheries with *Nephrops*-directed effort dependent on the availability of other species (FSS 2004).

In general, the pelagic fisheries in the area are targeted single species fisheries. In the past, the Celtic Sea herring fishery was principally an Irish "roe" fishery but in recent years the numbers of vessels mostly from south west coast ports has declined substantially and the fishery has changed to targeting herring for human consumption (FSS 2004). The herring stock to the north and west of Ireland has declined recently as has the associated mainly Irish fishery. The decline is particularly evident in

Division VIIb where there has been a complete absence of autumn-spawning herring from traditional spawning grounds off Galway and Mayo in recent years. The herring stocks and fisheries in the Celtic Sea and off northwest Ireland are managed by Irish Pelagic Advisory Committees and initiatives include a closed season from March to October in the north west and a series of spawning ground closures off the south and west coast (FSS 2004).

Mackerel which spawn over much of the Irish shelf are defined as the Western Component and comprise 85% of the entire North East Atlantic stock. The mackerel fishery takes place in the fourth and first quarter of the year when mackerel are returning from northern feeding areas to the spawning area. The western horse mackerel stock is fished mainly in the second half of the year over a wide area by directed trawl or purse seine fisheries from Norway, Iceland, UK, Ireland, Denmark, France, Netherlands and Germany. There are also fisheries for blue whiting in the area (FSS 2004).

The biological importance of Irish shelf and coastal waters was recognised by EC Council Regulation No 1954/2003 which established measures for the management of fishing effort in a "biologically sensitive area" (proposed Irish Conservation Box) in Subareas VIIb,j,g,h (Figure 4.3). The ICB covers major spawning and nursery areas for a number of commercially important fish species including mackerel, horse mackerel, herring, blue whiting, megrim, haddock and hake. Fishing effort exerted within this area by the vessels of each EU Member State may not exceed their average annual effort (calculated over the period 1998-2002) (ACFM 2004, Marine Institute website – http://www.marine.ie).

Deep water fisheries

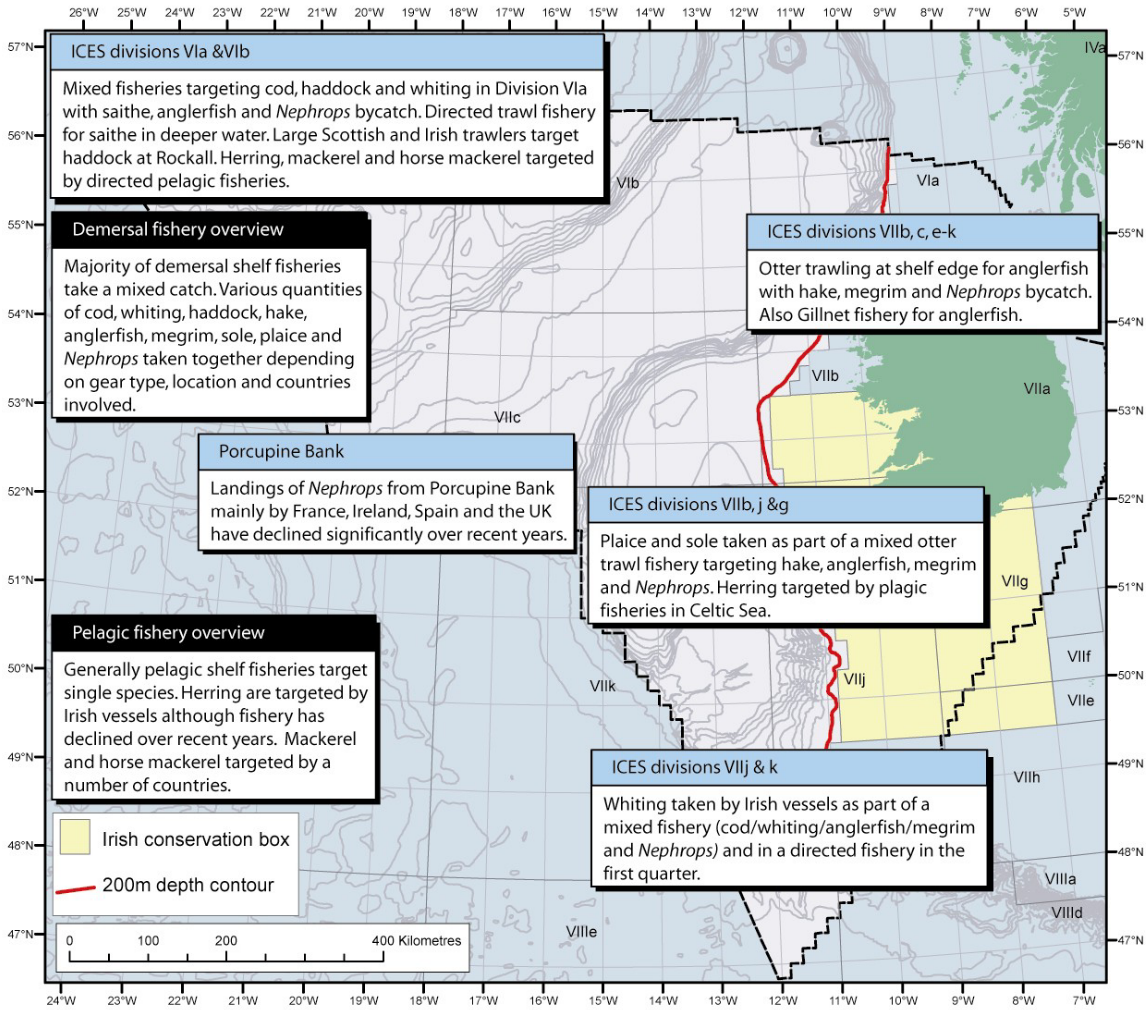
Overview

Since the 1980s, dwindling resources on the continental shelves have encouraged the development of fisheries in deeper waters. There has been a tendency for fisheries for species such as anglerfish to extend into deeper waters, and new fisheries have developed to target the deepwater species for which there is a commercial market. Deepwater species such as the argentine or greater silver smelt (*Argentina silus*) and roundnose grenadier (*Coryphaenoides rupestris*), which were previously bycatch species have been targeted within the ICES area for the last two decades. Orange roughy (*Hoplostethus atlanticus*) has been a target species since the early 1990s (FSS 2004).

Most fisheries in outer shelf and continental slope waters have more than one target species, and may thus be considered mixed fisheries exploiting communities or suites of species. Catches from most bottom trawl fisheries consist of 1-3 target species, a further few species that are marketable, and a variable unmarketable fraction that may eventually be discarded. Seamount fisheries or fisheries targeting aggregations (e.g. orange roughy, blue ling, alfonsino) may have catches that are less diverse than trawl fisheries targeting less aggregating slope species (e.g. grenadier, sharks). Longline fisheries for ling, tusk, and black scabbardfish, usually have more well-defined targets, but may also have a significant bycatch, some of which is unmarketable (ACFM 2004).

A further complication in defining fisheries is that several deep water species are actually only, or to a very high degree, exploited as bycatch in target fisheries for other species such as cod, hake, monkfish, and redfish. This is particularly the case for deepwater species that during their life history inhabit a wide depth range from relatively shallow waters of the shelf and coasts into slope waters beyond 400m. For example, while a high proportion of ling and tusk are landed from longline fisheries where ling is the target, a significant fraction stems from landings by trawl and longliner fleets targeting other species. Greater forkbeard *(Phycis blennoides)* is almost solely exploited as bycatch and is not landed consistently (ACFM 2004).

Figure 4.3 – Fishing activity on the shelf to the west of Ireland



Fishing activity

In ICES Subareas VI and VII there are directed trawl fisheries for blue ling, roundnose grenadier, orange roughy (*Hoplostethus atlanticus*), black scabbard fish and the deepwater sharks, Portuguese dogfish *(Centroscymnus coelolepis)* and Leafscale gulper shark *(Centrophorus squamosus)*. Bycatch species include bluemouth (*Helicolenus dactylopterus*), mora (*Mora moro*), greater forkbeard, argentine (*Argentina silus*), deepwater cardinal fish (*Epigonus telescopus*), and chimaerids, of which the rabbitfish *(Chimaera monstrosa)* is the most important. There are directed longline fisheries for ling and tusk and also for hake. Deepwater sharks are a bycatch of the longline fisheries, but there are also targeted fisheries for sharks in Subareas VI and VII. There is a gillnet fishery in Subarea VII for ling (FSS 2004).

In ICES Subarea XII (and VI) there is a multispecies trawl and longline fishery on the slopes of the Hatton Bank (primarily outside Irish waters) and effort may be increasing. Smoothheads which were previously discarded now feature in landings from this area (ACFM 2004).

In 2001 the Irish deep water fishery developed markedly. The largest fishery was the directed orange roughy trawl fishery, mainly based on aggregations on the continental slopes of the Porcupine Bank in Divisions VIIc and VIIk. Preliminary Irish landings of orange roughy in 2002 from these areas were 5,000t. Roundnose grenadier, black scabbardfish, blue ling and deepwater siki sharks were a small by-catch in orange roughy fisheries, but were also taken in the mixed species slope fisheries in these areas. Cardinal fish were discarded in large numbers in the orange roughy fishery but some quantities (55t) were landed. As in previous years, ling and forkbeard were landed in sizeable quantities from both deepwater and shelf-based fisheries. Irish longlining took place on the slopes west of Ireland and Scotland targeting sharks, mora and forkbeards (ICES 2004b). Table 4.2 and Figure 4.4 provide a summary of the main deep water fisheries in the area with information presented by ICES Division, area or Sub-area. Details of the status of the stocks as well as ICES advice for 2004 are also included.

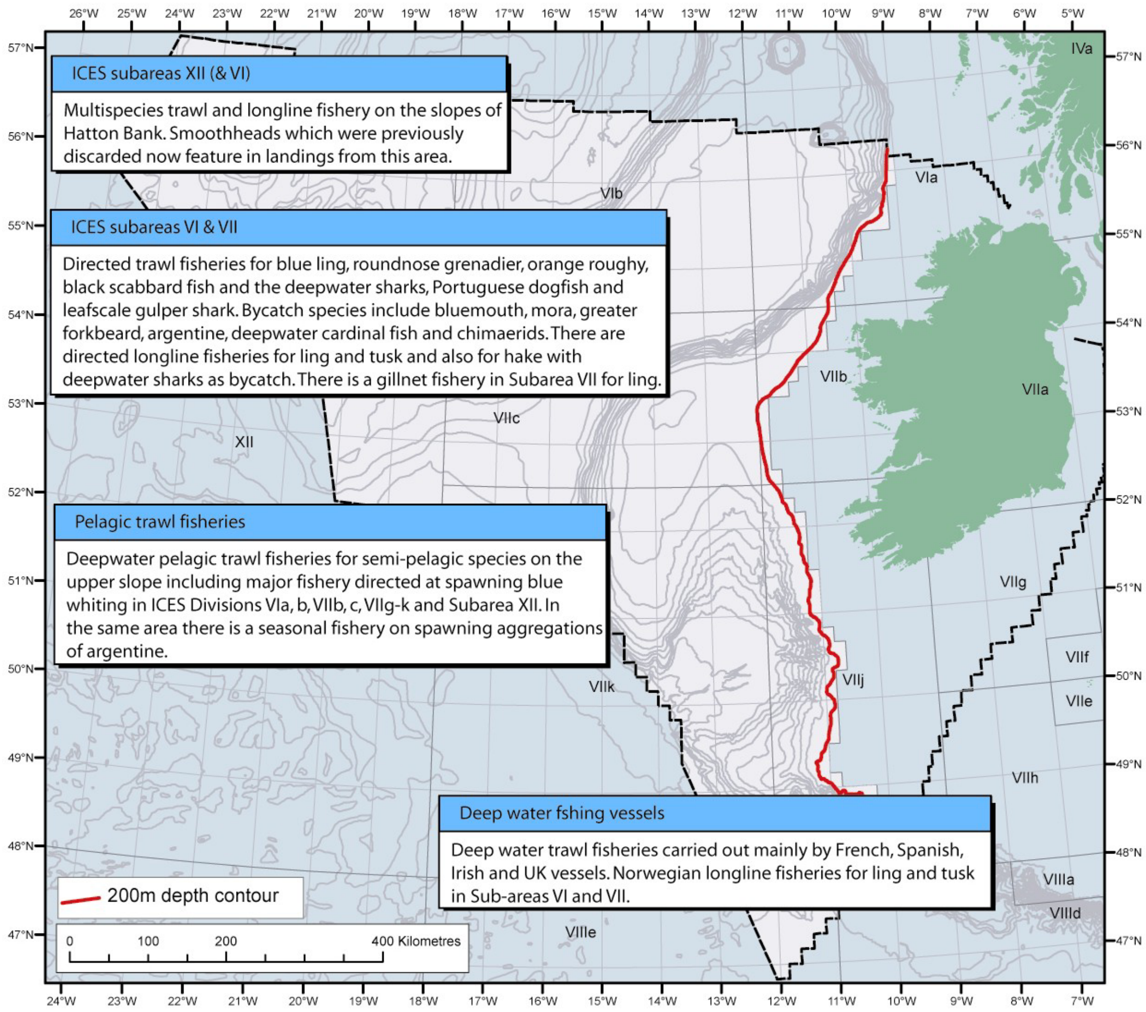
Table 4.2 – Status of the main deep water fisheries in Irish waters

Species	Description of main fisheries	Stock status & ICES advice
Blue ling	French trawl fisheries in VI and VII, targeting spawning fish in spring. Landings in VI and VII were 3,343t in 2003, with preliminary Irish landings of 340t.	Stock is outside safe biological limits. No directed fisheries for blue ling. Closed areas on spawning aggregations should be implemented.
Roundnose grenadier	French trawlers target grenadier in the mixed species deepwater fishery in VI and VII. Large scale Spanish fishery on the Hatton Bank in VIb and XII. Preliminary international landings in 2003 were 6,210t, with Irish landings of 224t.	Status uncertain but probably at low level. 50% reduction in effort from 2000-2002 levels in IIIa, Vb, VI and VII.
Orange roughy	Main fishery up to 2000 was conducted by French trawlers in VI and VII. In 2001, Irish fishery rapidly developed in Sub-area VII. 2003 landings in VI & VII reported as 559t, the lowest since fishery began.	Status unknown. No directed fishery in VI. Exploitation rate too high in VII.
Black scabbard fish	Taken in the mixed trawl fishery with roundnose grenadier, orange roughy, blue ling and sharks to the west of Ireland. Landings in VI, VII and XII declined to 4,000t in 2003 with preliminary Irish landings of 160t.	Status unknown. Significant effort reduction required. Management to take account of mixed fishery.
Portuguese dogfish & leafscale gulper shark (Siki sharks)	Main fishery in VI and VII as part of mixed trawl fishery mainly by France. In VII and VIII Spanish gillnetters and longliners target these species in some years. Landings of both species declined slightly to 5,175t in 2003. However does not include landings of "various sharks", including an unknown component of deepwater sharks.	Status unknown although evidence of strong decline. Can only sustain very low exploitation rate and overall exploitation should be reduced.
Ling	Norwegian long-liners (directed fishery) take the main catches in Sub-area VI and VII, west of Scotland, Donegal and Mayo. In Divisions VIIb,c,g,j,k, UK trawlers take most of the ling as by-catch. Total landings in VI and VII in 2003 were 9,932t, with preliminary Irish landings of 1,268t.	Status unknown. Fishing effort should be reduced by 30% (relative to 1998 levels) in Sub-Areas II, IV, VI, VII and VIII and Division Va.
Tusk	Tusk is taken as a by-catch of ling by Norwegian longliners in VI. New Russian and Norwegian fisheries for tusk on Hatton Bank. In 2003, landings were 7,137t in areas V, VI and VII with preliminary Irish landings (mainly from VI) of 47t.	Status uncertain but probably at low level. Fishing effort should be reduced by 30% relative to the 1998 level.

Source: FSS 2004, ACFM 2004

There are also two deep water pelagic trawl fisheries for semi-pelagic species on the upper slope including a major fishery directed at spawning blue whiting *(Micromesistius poutassou)* in ICES Divisions VIa,b, VIIb,c, VIIg-k and Sub-area XII. The fishery is mainly carried out by Norway, with Russia, UK and the Netherlands also catching significant amounts (Gordon 2001). In the same area there is a seasonal fishery on spawning aggregations of argentine *(Argentina silus)*. Until recently, the main catches of argentines were from Dutch freezer trawlers operating west and north-west of the Hebrides, from depths ranging from 600-700 m, and west of Ireland (Porcupine Bank). However, landings have declined significantly with preliminary landings of 2,280t for 2003. Argentines can be a very significant discard of the trawl fisheries of the continental slope of VI and VII (ICES 2004b).

Figure 4.4 – Fishing activity in the deep waters to the west of Ireland



4.3.3 Data gaps

There is a significant lack of information on the status of most deep water stocks. In general, advice from ICES and the Irish Fisheries Science Services of the Marine Institute highlights the vulnerability of most deep water stocks to fishing and indicates that fishing effort should be significantly reduced or stopped until more information is gathered as to the status of stocks.

There is very little information on the potential impact of these deep water fisheries on the deep water environment. There is evidence to suggest that deep water trawling is damaging areas of cold water corals on the North East Atlantic continental slope (Hall-Spencer *et al.* 2002). Deep water trawling has been excluded from an area of corals, known as the 'Darwin Mounds' to the north west of Scotland. The mounds have been designated recently as the UK's first offshore Special Area of Conservation. Whilst more information on the distribution and extent of cold water corals in Irish waters is becoming available (see Section 3.3), there are still significant data gaps and very little information on the potential disturbance by fisheries.

Given the physical scale of the region and the current low level of oil and gas activity within it, there are unlikely to be any significant interactions between the fishing and oil and gas industry.

5 OTHER OFFSHORE AND COASTAL SENSITIVITIES

5.1 Conservation sites

5.1.1 Data sources

Data regarding habitats and species of international and national importance have been taken from Ireland's National Parks and Wildlife Service (www.duchas.ie/), The Annotated Ramsar List (www.ramsar.org), Birdlife International (www.birdlife.org.uk/) and BirdWatch Ireland (www.birdwatchireland.ie/) while environmental descriptions of the coastal zone have been informed by Moore *et al.* (1997) and Wood *et al.* (1996). The EUNIS - European Nature Information System (www.eea.eu.int/), UNESCO (www.whc.unesco.org) and Heritage Council (www.heritagecouncil.ie) websites have provided further site-specific details, in particular World Heritage and Biogenetic Reserve information.

This section provides an overview of the international and national conservation sites of interest along the western coast of Ireland, from County Cork in the south to County Donegal in the north. The locations of these conservation sites are highlighted on Figures 5.1.1 and 5.1.2. It is to be noted that sites were marked on these maps using central points, as such; particularly large sites may appear to lie inland.

5.1.2 Coastal and nearshore

The west of Ireland has a long, highly indented and predominantly rocky coastline consisting of various cliff types, which include the highest in Europe at Achill Island (over 650m). Rocks range from ancient metamorphics and granites in the north to Carboniferous and Old Red Sandstone in the south. These rocky areas are interspersed with sweeping areas of soft shoreline, including the broad estuaries of Galway Bay and the complex outlet of the River Shannon. Small beach units, fjords and groups of islands also add variety to this Atlantic fringe of western Europe. The west Atlantic coastline also has three extensive upland areas of plateaux and ridges, with deep inlets.

The first area, the south-west of Ireland has a series of south-west facing bays (e.g. at the mouth of the Kenmare River and at Ballinskelligs Bay) and is typified by rounded, finger-like peninsulas and deep inlets. These inlets, and their associated reefs and bays, are generally more sheltered from wave action than the open coast. The second area is the west facing series of broad headlands and bays of Co. Galway and Co. Mayo with the unique islet-filled Clew Bay in the centre. North of Donegal Bay the north-west facing, intricate series of peninsulas and bays continue the resistant ancient uplands of Co. Donegal. Different types of bays, inlets and estuaries exhibit local differences in water depth, energy conditions and the influence of freshwater inputs; all of which create a wide range of marine and coastal environments.

All these different coastal landforms provide rich habitats for a variety of species. The high vertical Cliffs of Moher which stretch for 70km along Co. Clare are home to a very large colony of breeding seabirds, especially razorbills and puffins. Estuarine and more sheltered coastal environments support other species for example, black-throated divers in County Sligo and a population of harbour seals in Ballysadare Bay.

There are a number of habitats and species, found along the western Irish coast, which are afforded protection at an international level under the EU Habitats Directive. Natura 2000 is the European network of nature conservation sites comprising Special Areas of Conservation (SACs) designated under the EC Habitats Directive and Special Protection Areas (SPAs) classified under the EC Wild

Birds Directive. SACs are sites with outstanding examples of selected habitat types or areas important for selected non-avian species.

The west of Ireland is home to a wide range of Annex I coastal and marine habitats: from the large scale estuarine ecosystems of the Lower Shannon River SAC to the salt meadows found at Lough Swilly SAC. Many estuaries contain an extensive variety of habitats. For example, the Tralee Bay and Magharees Peninsula west to Cloghane – a single large SAC in County Kerry - is an estuary which contains a range of habitats of international importance including mudflats and sandflats, inlets and bays, reefs and coastal lagoons. A Biogenetic Reserve is found at Lough Hyne in Co. Cork. Biogenetic Reserves are designated by the Council of Europe to provide a network of reserves to conserve representative examples of European flora, fauna and natural habitats. In addition to areas that have been designated for ecological reasons, there is also a World Heritage Site, a 7th century monastic complex located on the steep sides of the rocky island of Skellig Michael, some 12km off the Kerry coast (Figure 5.1).

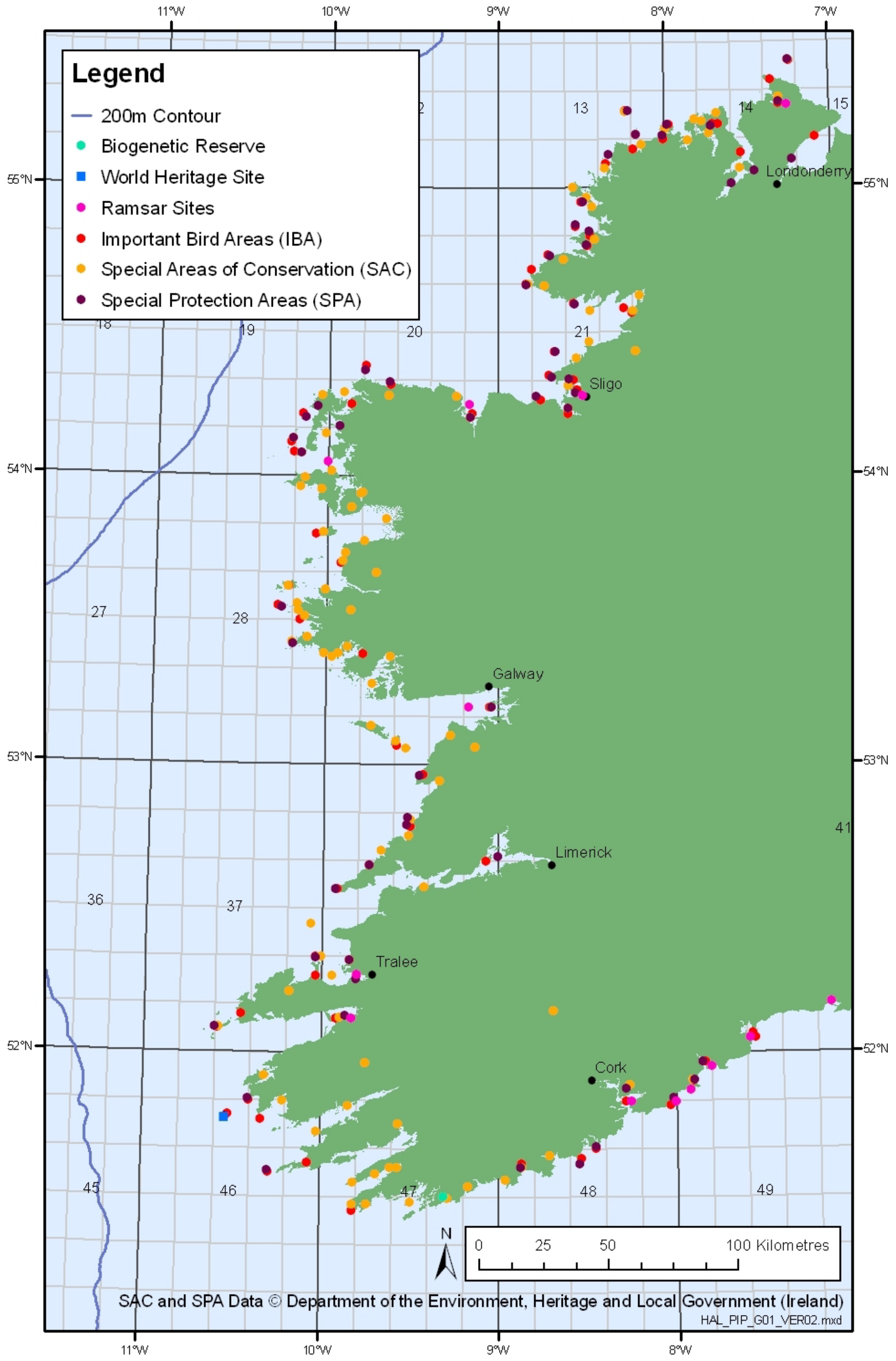
SPAs are designated by national government, under the EU Directive on the Conservation of Wild Birds, as requiring habitat conservation in order to protect bird species that visit or reside in the area. The Convention on Wetlands of International Importance, especially as Waterfowl Habitats (The Ramsar Convention, 1971) is an intergovernmental treaty that aims to stem the progressive encroachment on and loss of wetland habitat. Ramsar sites are designated for their important waterfowl populations and rare or endangered plant and animal species. Bird Life International identifies Important Bird Area (IBAs) for the conservation of the world's birds and whilst not a statutory designation, the majority of identified IBAs are protected by SPA/Ramsar designations. The region is important for shorebirds and for breeding seabird populations of shag, puffin, Manx shearwater, storm petrel, razorbill, great-black backed gull and storm petrel. Co. Donegal is particularly important for breeding auks and petrels, which nest in the numerous rocky cliffs and islands of the region.

Wetlands represent the dominant habitat type of IBA's found not only in this region, but throughout the whole of Ireland. These include estuaries and coastal lagoons and reflect the importance of the area for wintering waterbirds. Coastal lagoons are a scarce habitat in Europe and although they have a restricted distribution along the Atlantic coast of Ireland there are a sufficient number of such sites to make this habitat of singular importance in the conservational network of the Irish Republic.

Notable species of international conservation importance on the west coast of Ireland include populations of sea lamprey, Atlantic salmon, harbour porpoise, bottlenose dolphin, harbour and grey seals, and otters. Protected salmon and sea lamprey populations are found in a number of rivers and estuaries within the region including the lower reaches of the River Shannon and the Blackwater River in Co. Cork. Section 3.5 describes fish distribution and abundance in greater detail.

Internationally important otter populations are found in numerous riverine, lacustrine and coastal locations throughout western Ireland, including sites at Glangariff Harbour, Roaring Water Bay and Islands, Kenmare River, Lower River Shannon and Blackwater River. Grey seals feed on local inshore fish species, cephalopods and crustaceans, and come onshore to breed on exposed rocky shores. Several sites including Roaring Water Bay and Inishbofin and Inishark qualify as SACs for their populations of grey seals. Harbour seals are less widespread, inhabiting the shallow areas of estuaries, rivers, and places where sandbars and beaches are uncovered at lowtide (e.g. the Galway Bay Complex and Ballysadare Bay). Bottlenose dolphins occur in coastal waters and in large estuaries such as the Lower River Shannon SAC. There are also important populations of harbour porpoise and grey seal at Blasket Islands in Kerry. Further information regarding marine mammals can be found in Section 3.8.

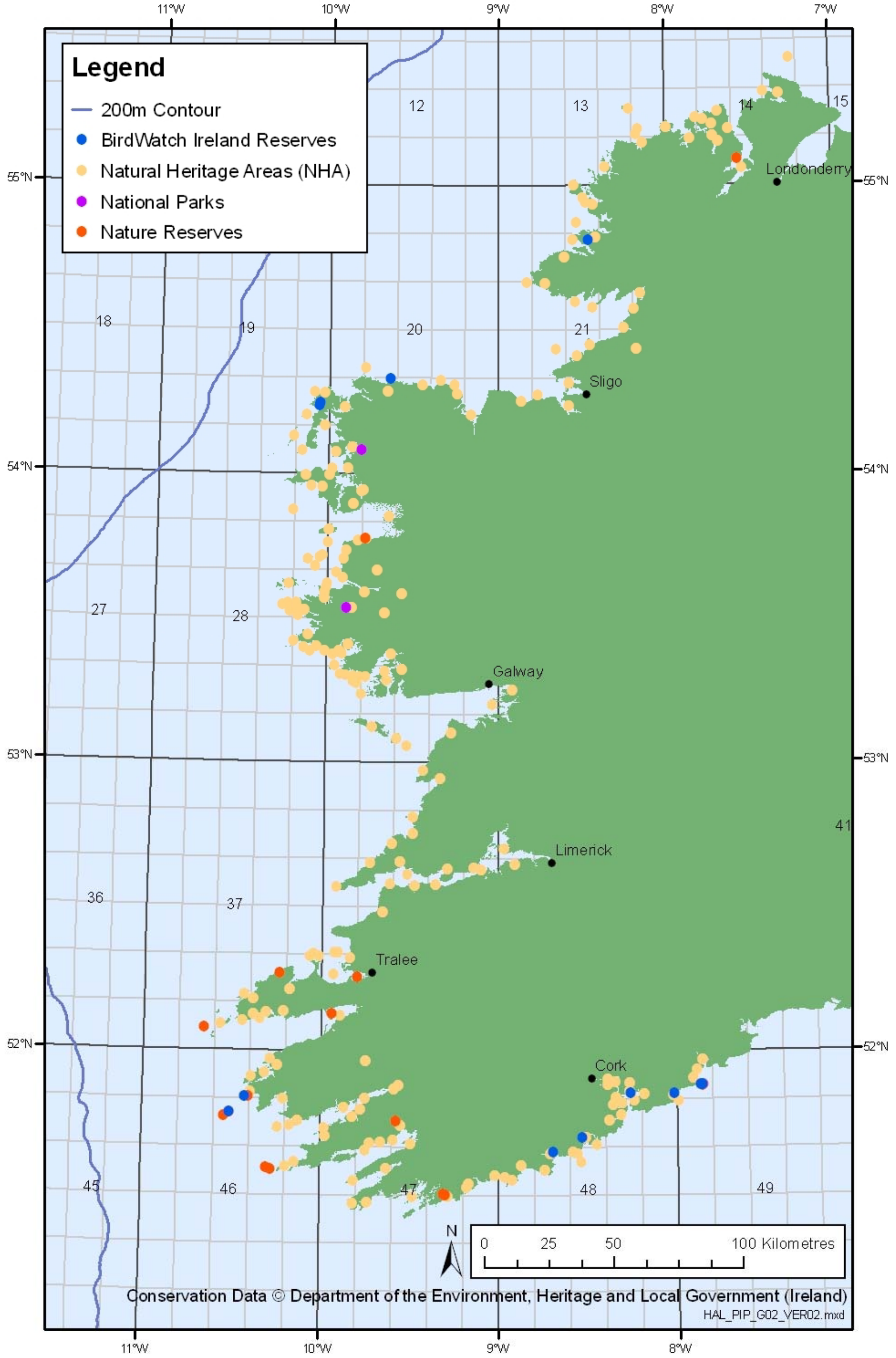
Figure 5.1 - Sites of international importance



The basic national designation for wildlife in Ireland is the Natural Heritage Area (NHA). Under the *Wildlife (Amendment) Act, 2000* NHAs are legally protected from damage from the date they are formally proposed. Statutory Nature Reserves are under the control of the Irish government and provide protection to habitats, flora and fauna. Most are owned by the State while others are owned by organisations or private landowners. Two of Ireland's six National Parks lie within the study area;

Connemara National Park in Co. Galway and Ballycroy National Park in Co. Mayo. BirdWatch Ireland is Ireland's largest voluntary conservation organisation and manages a series of nature reserves to conserve wild birds and their habitats (Figure 5.2).

Figure 5.2 - Sites of national importance



In summary, the coastal zone of the Atlantic seaboard of Ireland is intricate, highly indented and varied in form and orientation but always with an open maritime climate and oceanic characteristics. Bays, river mouths, inlets and 'fjord type' penetrations abound and there are several groups of small islands e.g. Aran Islands with historical and cultural importance at the western periphery of Europe. In general it is a rugged, cliff and rocky coastline but sandy bays and softer lowland shorelines are also found scattered along the lightly populated, scenic and mainly agricultural coastal zone. There is a tradition of local fishing communities, often combined with traditional farming but this, as elsewhere in Europe, is tending to disappear and tourism has become the main stay of the economy. The sheltered bays of Bantry and Cork are of great importance for commercial shipping and centres of regional tourism along with Galway in the north.

5.1.3 Offshore conservation

The protection of offshore marine habitats and species is currently being addressed at both national and European level. A brief summary of relevant initiatives are described below.

Offshore Natura 2000 network

The recent *Message from Malahide* (2004) which presented the conclusions of the Biodiversity and the EU – Sustaining Life, Sustaining Livelihoods Stakeholders' Conference 2004) agreed that the Natura 2000 marine site network be completed by 2008 with management objectives agreed and instigated by 2010. These conclusions have been endorsed by the European Council.

Ireland has made considerable progress towards the identification and designation of marine Natura 2000 sites. The National Parks and Wildlife Service have identified potential inshore sites (i.e. within 12 nautical miles of the coast) and a preliminary list of offshore sites (i.e. SACs and SPAs outwith 12 nautical miles of the coast) has been drawn up. Following discussion with the Department of Communications, Marine and Natural Resources, these will be finalised and sent to the European Commission for approval.

Ireland is required to designate SACs for habitats listed on Annex I to the Directive. Those Annex I habitats of relevance to the deep water area are likely to be *reefs* and *submarine structures made by leaking gases*. Information as to the exact locations of potential offshore sites is not publicly available at the present time. However, given the relative abundance of cold water coral within the deep water region (particularly associated with carbonate mounds, see Section 3.3) and the research and survey effort that has been directed at these features, there may be sufficient information available to allow site designation of some of these features. Ireland reported to the OSPAR Biodiversity Committee meeting in February 2005 that they had identified a number of areas under their jurisdiction where measures for the protection of cold-water coral reefs could be developed (BDC 2005). There is much less information available on habitats which may represent the habitat *submarine structures made by leaking gases* although pockmarks have been observed within the deep water area (see Section 2.2.5).

Offshore SACs sites may also be designated to conserve a number of species under Annex II to the Habitats Directive although given the present lack of information on the distribution and abundance of many of these species in the deep water area it is likely that further research will be required before potential sites are identified. Similarly, the identification of potential offshore SPAs may also require further survey work.

OSPAR

Initial OSPAR List of Threatened and/or Declining Species and Habitats

The Initial OSPAR List of Threatened and/or Declining Species and Habitats was first agreed at the OSPAR 2003 meeting with a number of further species and habitats added since. Those which have been specified as in decline and or threatened in OSPAR Region V (wider Atlantic) and may be of potential relevance to the deep water area to the west of Ireland are described in Table 5.1.

Table 5.1 – Potentially relevant OSPAR threatened and/or declining species and habitats

Species	Habitats
Fish	Carbonate mounds
Basking shark *(Cetorhinus maximus)*	Deep sea sponge aggregations
Common skate *(Dipturus (Raja) batis)*	*Lophelia pertusa* reefs
Orange roughy *(Hoplostethus atlanticus)*	Seamounts
Atlantic bluefin tuna *(Thunnus thynnus)*	
Marine turtles	
Loggerhead turtle *(Caretta caretta)*	
Leatherback turtle *(Dermochelys coriacea)*	
Marine mammals	
Blue whale *(Balaenoptera musculus)*	
Northern right whale *(Eubalaena glacialis)*	
Harbour porpoise *(Phocoena phocoena)*	

Source: OSPAR (2004d)

Currently, management measures required to protect the species and habitats on the Initial OSPAR List and the authorities or international bodies competent for taking such measures are being discussed. Recommendations will be developed and presented to OSPAR in 2007 (MASH 2004, BDC 2005).

Marine Protected Areas (MPAs)

A key element of OSPAR Annex V 'On the Protection and Conservation of the Ecosystems and Biological Diversity of the Maritime Area' is the development of an ecologically coherent network of Marine Protected Areas (MPAs).

The Bremen Statement (OSPAR 2003) adopted by the second Ministerial meeting of the OSPAR Commission included the commitment to, through working with HELCOM and the European Community, identify the first set of Marine Protected Areas (MPAs) by 2006, establish what gaps then remain and complete by 2010 a joint network of well-managed marine protected areas that, together with the NATURA 2000 network, is ecologically coherent..

Ireland are currently concentrating on identifying and designating sites under the Habitats and Birds Directives (Natura 2000 sites) and will consider sites for nomination as OSPAR MPAs in the latter half of 2005 (BDC 2005). Irish marine sites designated as part of the Natura 2000 network are likely to be proposed as MPAs.

5.2 Marine archaeological resource

5.2.1 Sources of information

A useful source of information regarding marine and coastal archaeology in Ireland is *BiblioMara* (http://bibliomara.ucc.ie), an annotated indexed bibliography on the cultural and built heritage of the

Irish coastal zone. The bibliography was commissioned by the Heritage Council in 2002 and compiled by a multidisciplinary team lead by the Coastal and Marine Resources Centre (CMRC) in Cork. The bibliography which contains 2,964 references is currently limited to references related to cultural and built heritage, with inclusion of references related to human activities in the coastal zone (Heritage Council website - http://www.heritagecouncil.ie/marine/index.html#completed).

A resource directory for marine and coastal heritage will be made available on the web through the Heritage Council website by mid 2005. Commissioned by the Marine and Coastal Committee of the Heritage Council the web-based directory will provide information on heritage issues in the coastal and marine area (Heritage Council website).

As part of the continuing UK Department of Trade and Industry's offshore SEA process, a series of prehistoric marine archaeology reviews (e.g. Flemming 2003, 2004) have been produced for a number of areas of the UK continental shelf (e.g. the North Sea and the area to the north and west of Scotland). These reviews describe existing coastal and marine prehistoric archaeology, the mechanisms by which submerged remains are preserved (or destroyed) and highlight potential submarine 'hot spots'.

PIP has published recently a consultation report on the application and interpretation of geophysical data for archaeological assessment during oil industry geophysical route surveys (Quinn 2005, ISPSG project ISO3/24). The report provides an authoritative review of relevant legislation and outlines a basic good practice that may be considered in the planning, data acquisition and interpretation stages of marine geophysical investigations used to support geo-archaeological assessment during the route selection phases for oil industry route surveys in Ireland. The recommendations concentrate on activities in water depths exceeding 50m (Quinn 2005).

5.2.2 Overview

Over recent years there has been a growing interest and awareness of Ireland's marine archaeological resource primarily through the work of a number of research institutes (e.g. the Centre for Maritime Archaeology, University of Ulster) and the development of survey technologies enabling easier identification of submarine remains.

The present Irish coastline contains a rich variety of archaeological remains some dating back to the Mesolithic (4-10,000 years BP). However, in general present sea level is higher than during prehistoric times and therefore there may be evidence of submerged prehistoric remains on the present seabed. Predicting potential locations is complicated as sea level since the last glaciation (approximately 14,000 years BP) has been influenced by regional variations in glacial rebound (i.e. uplifting of land following the removal of ice sheets) which have combined to produce a complex pattern of sea level and accompanying shoreline changes from late glacial to present times (Cooper *et al*. 2002).

Cooper *et al.* (2002) indicates that the relative paucity of coastal Mesolithic sites in Ireland compared to areas of Scotland (in particular, the island of Islay, Woodman 1978, cited by Cooper *et al.* 2002) may be due to the differing sea level histories experienced by the two areas. The northern Irish coast experienced a greater drop in late glacial/Holocene sea level (approximately 30m) compared to the Scottish coast (probably as a result of different responses to ice removal) and therefore during much of the Mesolithic, the northern Irish coast was located on what is now the seabed. Peat deposits recorded at 12m below present sea level date back to c.a. 9,000 years BP and represent the coastal Mesolithic land surface in Northern Ireland. Submerged peat deposits represent important indicators of potential areas which may contain archaeological remains (Flemming 2003, 2004).

Whilst much of the Irish mainland was covered by ice during the last glaciation, there is likely to be regional variation in the response to deglaciation. The extent of currently submerged areas that were previously dry land (and therefore available to humans) around the Irish coast has (to the knowledge of the author) not been quantified. However, potential areas of submarine archaeology are likely to be restricted to sheltered areas (e.g. estuaries, sheltered bays etc) relatively close to the coast. For example, submerged Mesolithic forests have also been recorded from intertidal archaeological surveys of the Shannon estuary, as has evidence of Mesolithic and Neolithic human occupation (e.g. a possible Mesolithic dugout canoe, worked wood, stone axe, animal bones etc) (O'Sullivan 2001, cited by Brunning). However, over much of the Irish continental shelf, archaeological remains are unlikely to be found due to the vigorous wave climate and strong currents.

The deep water area to the west of Ireland has not been exposed to significant human use and therefore is unlikely to contain a significant archaeological resource. Shipwrecks are likely to represent the main archaeological resource in this area.

5.2.3 Shipwrecks

Irish waters have a rich marine archaeological resource, much of which is yet to be discovered. Of particular relevance are the thousands of shipwrecks that are a legacy of past maritime activity. A national register of historic shipwrecks is maintained by the Department of the Environment, Heritage and Local Government (http://www.heritagedata.ie). The online shipwrecks database is currently in preparation and data is not available from the website.

However, an inventory series in four volumes listing the wrecks around the Irish coastline is currently in preparation by the Department's underwater archaeology unit. The number of wrecks has increased from an initial examination five years ago when about 7,000 wrecks were catalogued to an expected 10-12,000 and range from prehistoric dugout canoes to World War II wrecks (Irish Independent newspaper article, *Our ghostly seas – 12,000 shipwrecks litter coast*, 28th March 2005, http://home.eircom.net/content/unison/national/5277077?view=Eircomnet).

The first volume will cover Louth, Meath, Dublin and Wicklow. Wexford (which has the highest percentage of wrecks of any county) and Waterford will constitute the second volume with Cork, third and Kerry to Donegal, fourth (Irish Independent newspaper article, 28th March 2005).

The vast majority of wrecks around the Irish coast lie in inshore areas under 50m in depth. This reflects the fact that most vessels lost have been blown ashore by inclement weather, or have struck submerged rocks or hazards in inshore areas. Of those further off shore, especially north of Donegal to Antrim and south of Kerry and Cork most are associated with losses due to naval action along merchant shipping lanes in the Second World War. Most shipwrecks lie in the busy Irish Sea area reflecting trade routes with large ports. Eastern ports such as Dublin, Belfast and Drogheda have numerous wrecks in their vicinity as do other busy ports including Waterford, Cork, Galway and Derry. Other hot spots for wrecks include natural hazards, predominantly submerged rocks or sandbanks as well as around islands (Forsythe W, Centre for Maritime Archaeology, University of Ulster website – http://www.ulst.ac.uk).

A large number of wrecks, primarily in inshore waters have been identified by the ongoing Irish National Seabed Survey (INSS). In the 2003 survey of the Donegal Bay area, 104 wrecks were described (GSI website - http://www.gsiseabed.ie). Identification of potential wrecks in the deep water area to the west of Ireland is currently more difficult as survey resolution may limit the detection to very large wrecks. However, as the survey progresses and the results become more widely available, further interpretation and analysis may facilitate identification of deep water wrecks.

5.2.4 Data gaps

There are significant data gaps regarding Ireland's marine archaeological resource although it is expected that nearshore areas may contain evidence of early human settlement and usage. At present what information is available is limited primarily to the intertidal zone where a small number of surveys (e.g. Shannon estuary) have provided evidence of archaeological remains dating back to the Mesolithic. Historically, the deep water area to the west of Ireland has experienced little human usage and therefore archaeological remains are likely to be limited to wrecks associated with fishing, trade routes and war casualties. At present the ability to identify and quantify these deep water wrecks is very limited.

In relation to oil and gas activities, the identification of potential submarine archaeology forms part of the site survey process. In deep water areas this is likely to include ROV survey which would facilitate identification of seabed objects of potential archaeological interest.

5.3 Other offshore and coastal users

5.3.1 Overview

In addition to the offshore oil and gas industry, there are a number of industries/activities which utilise the deep water environment to the west of Ireland, including shipping and the telecommunication cables industry. As well as these, there are a small number of offshore sites to the northwest which have been used historically for munitions disposal.

The west coast of Ireland supports a mixture of sparsely populated rural areas and major centres of population including the major cities of Galway (65,832 persons, 2002) and Limerick (54,023 persons, 2002) (Central Statistics Office website - http://www.cso.ie). Coastal population densities vary from over 4,000 inhabitants/km^2 in major urban areas to less than 20 in parts of the west and north-west (Boelens *et al*. 1999). Commercial fisheries and aquaculture are important industries along this coastline, with the region also supporting a number of important industrial ports. The largely unspoilt nature of the coastline and the range of recreational opportunities it provides attract a large number of tourists, bringing employment and revenue to coastal communities. A summary of the main coastal industries and population centres are presented in Figure 5.3.

5.3.2 Shipping

Over the past twenty years the number of cargo and passenger vessel arrivals at Irish ports has increased steadily as has trade with non-EU countries and now major shipping routes traverse the waters off the west coast of Ireland. Although Ireland's Atlantic seaboard is less busy than the regions which fringe the Irish Sea (most notably the ports of Dublin, Dun Laoghaire and Rosslare), important shipping ports are still to be found at Galway, along the Shannon Estuary and at Cork.

Major trade routes between Europe, America and Asia cross the Atlantic (www.oceanatlas.com). Without precise data, however, it is impossible to tell how much of this traffic enters the PIP region to the west of Ireland. It can be assumed that cargo ships en route to major cargo ports in SE England, NW France and the North Sea region are likely to traverse the southern and northern limits of the PIP area respectively. An extensive search for such information has proven unsuccessful and this would point to a data gap in available information regarding trans-Atlantic shipping movements. Lloyds register (www.lloydslist.com), however, did reveal daily arrivals into Shannon Estuary ports, but these were generally vessels travelling from mainland Europe and although moving through Irish coastal waters the ships are unlikely to sail as far west as the PIP region. The densest shipping areas off the coast of Ireland appear to lie south of Ireland in the Celtic Sea, although it is highly probable that major routes also traverse the waters of the North Atlantic to the west (though the exact locations, frequency and type are unknown).

The majority of vessels operating in Irish coastal and shelf waters are involved in shortsea shipping between Ireland and Europe. The Irish Maritime Development Office (IMDO) is responsible for the preservation, expansion and development of these shortsea links and has recently produced an on-line interactive route map, which displays all LOLO (Lift On/Lift Off) and RORO (Roll On/Roll Off) services operating from Irish ports (www.imdo.ie/main.htm). Important shipping corridors exist between the ports of Shannon and Cork, in Ireland, and numerous, predominantly European ports. Traffic routes from Cork are much more diverse than those from Shannon (where the principal link is with Rotterdam) with busy routes between Cork and countries such as Portugal, France, Netherlands, Norway, Greece, Cyprus and Israel. Shortsea shipping routes, as described by the IMDO, do not traverse the PIP region but move south and southwest across the Celtic Sea and the English Channel.

Shannon Foynes Port Company is Ireland's largest bulk cargo handler. The Board of Shannon Foynes Port Company last year (2004) approved a Strategic Development Plan to invest €53.5 million over a five year period to create new shipping, industrial and commercial facilities along the Shannon estuary. It is envisaged that the proposed new facilities will capitalise on acute congestion at existing European container ports such as Rotterdam, Antwerp and Bremerhaven and will likely result in greater shipping densities in the area.

5.3.3 Cables

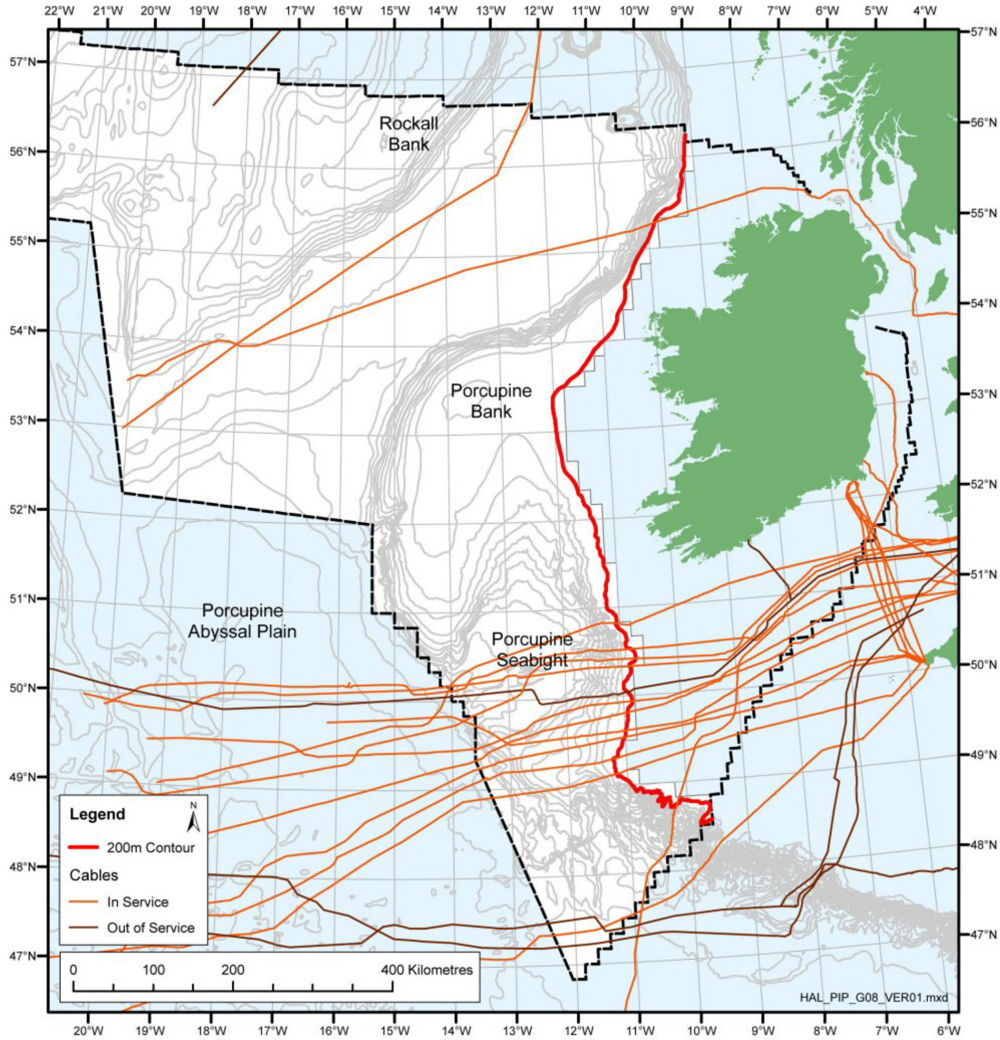
The submarine telecommunication cable industry represents another important user of the offshore area. An extensive network of subsea telecommunication cables is present on the sea floor ensuring reliable telephone and telegraphic communication between countries and continents. Cable and Wireless (C&W), Global Crossing and Flag Telecom are the major cable operators in the waters of the PIP region.

The majority of marine cables which traverse Irish waters head westwards, bisecting the Celtic Sea, out across the Atlantic and towards the US (Figure 5.3). As such, a high proportion of cable systems traverse the southern limits of the PIP region.

Information provided by company websites (i.e. Cable and Wireless, Global Crossing and Flag Telecom, see reference section for details) show that there are a number of looped systems in the area, connecting Ireland, the UK, Western Europe and the US; such as C&W's TAT-14 which makes landfall at Bude in SW England, traverses the Atlantic (south of Ireland) and onto Manasquan in the US before returning (at a higher latitude) back across the Atlantic towards Denmark. It is during the latter part of TAT-14s journey that it enters the PIP region. The majority of cables, however, pass through the southern limits of the region (for example the C&W Gemini system which connects the UK with the US). Global Crossing also operate in the area, running major lines of underwater communications (AC1 and Yellow/AC-2) from Kilmore Quay and Wexford in Ireland, via southwest England, across the Atlantic to Bellport USA. While Flag Telecom run the FLAG Atlantic-1 system from the UK to the US (via France).

In association with the Irish National Seabed Survey, geological researchers are working with cable companies to examine seabed geohazards in the Porcupine Seabight (P Mac Aodha, National University of Ireland Galway) and the properties and stability of seabed slopes in the Goban Spur region (M Cunningham, Southampton Oceanographic Centre). Outputs from the INSS may be of considerable benefit to the correct placement of seabed cables.

Figure 5.3 – Cables in the PIP region



Note. The halt in the cable to the northwest of the PIP area represents a lack of mapping data rather than a real-world termination in the cable route.
Source: Kingfisher Information Service website (http://www.kisca.org.uk/charts.htm)

5.3.4 Offshore munitions disposal

A considerable amount of arms and munitions were dumped at sea at the end of the Second World War ranging from scuttled vessels containing confiscated munitions, conventional munitions, phosphorus devices to mustard gases. The full extent of material dumped, their locations and present condition or stability is not fully known, however, a considerable amount is believed to have been disposed of within the OSPAR area. The majority of materials were dumped in areas which, at the time, were considered deep enough to be safe, with most material dumped in the Baltic and Skagerrak (OSPAR 2000a). There are, however, a number of disposal sites in and around the PIP region.

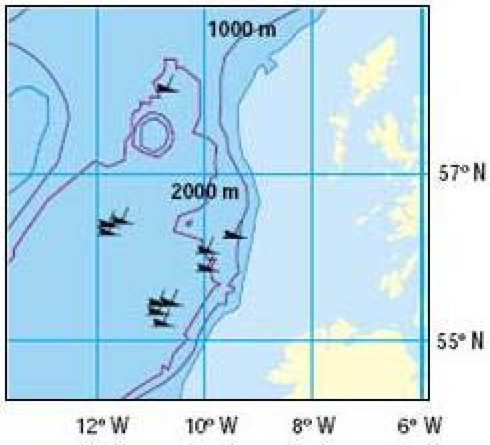


Figure 5.4 –Scuttled vessels in the Rockall Trough

Source: OSPAR (2000a).

Between 1945 and 1957, twelve redundant vessels loaded with confiscated German munitions were scuttled in the Rockall Trough, at depths ranging from 800 to 2500m (Figure 5.4, ACOPS 1988, cited in OSPAR 2000a).

In addition, there are also five sites to the north west of Ireland where chemical munitions have been dumped (Table 5.2).

Table 5.2 – Location and known details of munitions dumpsites in and around the PIP region (2004)

Latitude	Longitude	Type of munitions	Latitude	Longitude	Type of munitions
-12.08	56.52	Chemical	-10	56	Chemical
-12	56.5	Chemical	-11	55.5	Chemical
-9.45	56.37	Chemical			

Source: OSPAR (2004e)

5.3.5 Marine disposal and aggregate extraction

Dumping at Sea permits are granted for the disposal of dredged materials from ports, harbours and marinas, in the absence of suitable alternative reuse and disposal methods (Department of Communications, Marine and Natural Resources website - http://www.dcmnr.gov.ie). Two relevant sites have been granted dumping at sea permits as at March 2005. The Shannon Foynes Port Company, has been granted a permit to dredge spoil and dispose of 1,380,000 tonnes at the Foynes Harbour and Whelps sites. A small number of other sites on the west coast were granted permits in 2004.

Whilst most of the dredging and disposal of soil and the current interest in aggregates is in the Irish Sea and Celtic Sea it is by no means restricted to them. IMAGIN (Irish Sea Marine Aggregates Initiative) is a joint INTERREG/industry project led by the Marine Institute and managed by the CMRC with the Geological Survey of Ireland and Geoscience Wales as the other main partners (IMAGIN website - http://imagin-eu.org/). The project's main objective is to create a strategic framework, within which development and exploitation of marine aggregate resources from the Irish Sea may be managed sustainably with minimum risk of impact on marine and coastal environments, ecosystems and other marine users. The programme commenced recently and is surveying the Southern Irish Sea to define potential sand and gravel resources and characterise the seabed.

With increasingly severe constraints onshore, interest in offshore sand and gravel resources can only increase with time and IMAGIN-type surveys may be planned off the west coast of Ireland in the future (M Davies CSA, pers. comm.).

5.3.6 Ports

Commercial ports

There are a number of industrial shipping ports on the west and south west coast of Ireland. The two largest are the ports of Cork and Shannon Foynes Port. In 2003, Shannon Foynes handled in excess of 10 million tonnes of cargo (Shannon Foynes Port Company website, www.sfpc.ie), making it the second largest Irish port after Dublin (which handled 16,682 million tonnes in 2003). Cork is the third largest Irish port, handling in excess of 9 million tonnes of cargo in 2003 (Table 5.3) (CSO website - http://www.cso.ie).

Galway Harbour handled almost 1 million tonnes of cargo, principally liquid bulk (Galway Harbour Company website http://www.galwayharbour.com) and was the eighth largest Irish port in 2003. Galway is also used by a growing number of research and seismic survey vessels.

Table 5.3 – Traffic handled by the main commercial ports in the region (2003)

Port	Category of traffic ('000 tonnes)					
	Roll-on/ Roll-off	Lift-on/ Lift-off	Liquid bulk	Dry bulk	Break bulk & all other goods	Total
Galway	-	-	840	13	50	**903**
Shannon Foynes Port	-	-	1,583	8,332	187	**10,102**
Cork	130	1,140	5,879	1,707	319	**9,176**
Bantry Bay	-	-	376	453	-	**829**
Total all ports	**9,857**	**6,574**	**12,966**	**15,024**	**1,743**	**46,165**

Source: Central Statistics Office Ireland website (accessed March 2005) - http://www.cso.ie

There are also a number of locally important passenger and car ferries which run between: Galway and the Aran Islands; Cleggan and Inishbofin Island; Burtonport and Aran Island; Meenfaragh and Tory Island; and Fahan and Rathmullan, across Lough Swilly (Wood *et al.* 1996).

Fishing ports

Fishing is one of the most important coastal industries in Ireland and the west coast supports some of the largest fishing ports. Small scale inshore fisheries operate throughout coastal waters and target a wide range of fish and shellfish species (see Section 4.3), landing their catch at many of the small coastal fishing ports.

The larger fishing ports receive landings from the main offshore pelagic and demersal fisheries with shellfish landings generally distributed more evenly between the medium and smaller sized ports. Two of Ireland's most important fishing ports for pelagic and demersal landings, Killybegs and Castletownbere are located on the west coast (Table 5.4 and Figure 5.5).

Table 5.4 – Fish landings into main coastal fishing ports in the region (2000)

Port	Demersal		Pelagic		Shellfish	
	Landed wt (tonnes)	Value (IR£)	Landed wt (tonnes)	Value (IR£)	Landed wt (tonnes)	Value (IR£)
Moville	-	-	-	-	16,635.0	6,092,000
Greencastle	2,141.1	2,884,691	98.4	14,181	3,678.9	2,469,981
Malin Head	10.0	8,400	-	-	1,306.2	1,286,300
Rathmullan	0.1	60.0	15,260.7	2,972,321	108.6	191,846
Burtonport	99.6	169,756	16.4	5,412	1,097.1	1,765,710
Killybegs	4,307.6	5,911,864	80,449.0	14,520,425	95.3	218,804
Westport	-	-	-	-	2,775.1	2,786,349
Rossaveal	2,031.8	3,066,508	6,789.0	1,762,875	968.2	3,092,160
Dingle	2,385.8	3,227,717	3,229.7	2,410,937	396.6	860,520
Castletownbere	3,775.7	6,385,717	4,285.6	3,586,984	2,075	1,881,354
Schull	725.5	1,244,137	259.6	98,920	137.4	341,176
Total from all west coast ports	**16,770.9**	**24,745,511**	**113,277.7**	**25,883,723**	**33,274**	**28,219,254**
Total for all Irish ports	**32,956.3**	**51,449,797**	**210,950.2**	**52,106,477**	**65,301.0**	**67,989,189**

Source: Department of Communications, Marine & Natural Resources website - http://www.dcmnr.gov.ie

In 2000, pelagic landings at Killybegs were dominated by mackerel (25,197.5 tonnes, IR£7.5 million) and blue whiting (20,456.4 tonnes, value IR£0.9 million). Demersal landings were dominated by haddock (1,199.7 tonnes, IR£ 1.2 million), anglerfish (531.1 tonnes, IR£1.6 million) and whiting (398.6 tonnes, IR£0.2 million), while *Nephrops* (59.9 tonnes, IR£0.2 million) dominated shellfish landings. The dominant pelagic, demersal and shellfish species landed at Castletownbere in 2000 were albacore tuna (1,975.6 tonnes, IR£3.2 million), whiting (697.3 tonnes, IR£ 0.5 million) and edible crab (1,956.7 tonnes, IR£ 1.5 million) respectively.

5.3.7 Aquaculture

The aquaculture industry has grown significantly since initial developments in the 1970s. It has become an important contributor to the national economy and provides employment and associated economic growth in coastal areas (Wood *et al.*1996). There has been a steady and in some cases exponential increase in both output and value, in job creation and in the diversity of sites used and species farmed (Marine Institute website - http://www.marine.ie).

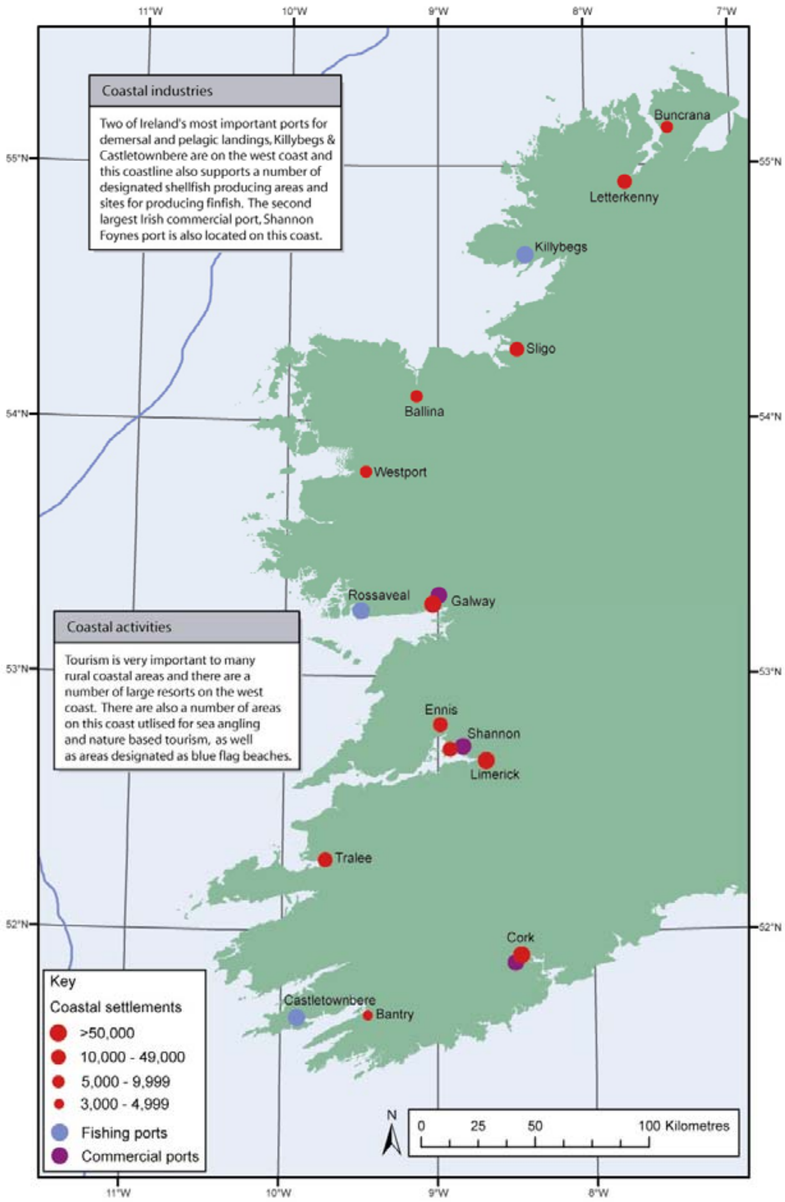
In 2002 the combined aquaculture production of shellfish and finfish species was 62,686 tonnes with a value of €117.4 million (Environment Protection Agency 2004). Atlantic salmon (*Salmo salar*) is the most important fish species farmed, valued at €71.7 million, representing 61% of the total value of aquaculture production. The mussel (*Mytilus edulis*) and the Pacific oyster (*Crassostrea gigas*) are the most important shellfish species and their combined value of €31.6 million in 2002, represented 89% of the total cultivated shellfish production (Environment Protection Agency 2004).

There are currently 20 finfish farms in operation on the west coast of Ireland and shellfish farming is carried out in all of the coastal counties to some extent (Marine Institute website, accessed March 2005). As well as the three core species (salmon, mussels and oysters) which account for the majority of output in Ireland, a range of new species have entered the sector including turbot, scallops, abalone, clams, char and perch.

There are a number of areas along the west and south west coast of Ireland which are utilised for the cultivation of shellfish species such as mussel, Pacific oyster, razor clam and surf clam. These include Greencastle, McSwynes Bay, Drumcliff Bay, Achill, Killary, Carrigaholt, Kenmare River, Castletownbere and Roaring Water Bay. The Food Safety Authority of Ireland website (http:///fsai.ie) provides a complete list of shellfish production areas.

There is a seaweed processing plant at Kilkieran, Co. Galway, which was established in 1947 and is a semi-state body, with the Irish Government holding 82% of the company shares. The plant utilises the large resource of seaweed available along the west coast of Ireland (Arramara Teoranta website http://www.arramara.ie).

Figure 5.5 – Coastal industry and population within the region



5.3.8 Tourism and leisure

Tourism has become increasingly important to Ireland's economy and an estimated 70% of all tourism activity is accommodated on the coast (Wood *et al.* 1996). Tourism is very important to many of the rural coastal areas in the region.

Many areas on the west and south west coast have been designated as amenity areas and the coastline includes a number of major tourist resorts including Donegal, Rosses Point, Enniscrone, Ballybunnion, Tralee, Dingle and Waterville. The coastline also supports a number of smaller resorts including Kilrush, Castlegregory, Kenmare and Castletownbere Haven.

Coastal activities

The varied character of coastal landscape, the extensive number of sandy beaches, the notable surfing areas and the areas sea-angling, sailing and other water sport opportunities are all important tourism resources for the west and south west coast.

There are a large number of blue flag beaches including sites at Ballyheigue in Co. Kerry and the sheltered, cliff-fringed beach at Old Head in Co. Mayo (Blue Flag Beach website http://www.blueflag.org).

Nature based tourism is growing rapidly, with coastal walking holidays and wildlife watching popular. Dolphins in Kerry and the Shannon estuary have generated local tourism enterprises based around dolphin watching.

5.3.9 Data gaps

Although data on the number and type of ship arrivals at major ports on Ireland's west coast is available, there is a lack of available data on shipping routes, movements and densities within the PIP region.

Whilst there is a large amount of data available describing the nature and extent of coastal industries, this can often be in a form which does not allow accurate regional or coastal trends to be determined. For example, the Central Statistics Office does not provide details of the number of visitors to coastal areas or towns. Similarly, data pertaining to the volume and revenue of aquaculture production is not broken down to values for coastal counties.

6 SUMMARY AND RECOMMENDATIONS

6.1 Summary

This report describes broadly the physical, chemical and biological environment of the deep water area to the west of Ireland. The region is a challenging, often extreme environment in terms of its scale, depth, weather, and waves. These factors have hindered exploration of the area and our knowledge of many aspects of the deep water region is very limited. Research funded through initiatives such as the Petroleum Infrastructure Programme, the Irish government and European agencies amongst others continues to broaden our understanding of the environment. However, significant gaps in our knowledge remain and the process of drawing together this environment description of the region has highlighted a number of these.

6.2 Significant data gaps

The following section does not provide an exhaustive list of data gaps but rather highlights particular areas or themes that may require further research. They are listed to reflect the format of the report rather than in any order of importance.

Physical and chemical environment

A number of significant data gaps relating to the physical and chemical environment of the deep water area have been identified. In general, these relate to the large scale of the area and the paucity of information at a local scale.

Geology, seabed substrates and features

1. Large scale seabed mapping projects have highlighted particular features (e.g. seabed mounds, pockmark fields) which require further local scale survey and sampling in order to better understand their formation and geological and ecological importance.

Oceanography and hydrography

2. Much of current understanding results from large-scale modelling work and there is a need for significant survey work to verify and strengthen these models further. Details of local currents and water conditions extremely limited.

Climate and meteorology

3. It is generally accepted that the North Atlantic Oscillation (NAO) plays an important role in determining the region's climate and weather but mechanisms which drive the NAO between positive and negative states are not yet fully defined.

4. Potential effects of climate change on physical, chemical and ecological environment.

Contamination

5. Limited information on contaminant inputs to the area and large gaps in contaminant survey coverage (e.g. levels in sea water, sediments, biota) both spatially and temporally.

Ecology

6. Generally there are significant data gaps for every aspect of the region's biological environment. Information is very limited or lacking on the distribution and abundance of the majority of species and detailed information on the ecology and life cycle of most species is not available. The capacity of deep water ecosystems to cope with disturbance is poorly known.

Other users and conservation

7. Accurate information on the extent of deep water fishing in the region is not available. The ecological effect of fisheries on both target and bycatch species is largely unknown and there is very little information available on the extent of damage caused by trawling on the deep water benthic environment.

8. There is a general lack of information on shipping routes and densities across the region.

9. At present, potential offshore conservation areas which support important habitats and/or species are in the process of being identified as part of the Irish government's European and OSPAR commitments. Until these are made publicly known, they represent a significant data gap.

6.3 Recommendations for future PIP research

The Petroleum Infrastructure Programme has been very successful in funding research directed at enhancing our understanding of the region's environment and in so doing facilitating environmental management of potential oil and gas activities within the deep water area. The review process inherent within this environment description has highlighted a number of key areas and themes which would benefit significantly from future PIP funded research whilst fulfilling necessary PIP criteria.

Recommendations for future PIP research are listed below. They are again listed to reflect the format of the report rather than in any order of importance.

Geology, seabed substrates and features

- Utilise data from Irish National Seabed Survey (INSS) to characterise in more detail deep water sediments and bedforms. Use this information to gain a better understanding of sediment processes and bottom water dynamics.

- Review and combine historical seabed survey information collected as part of PIP with information from INSS and others to characterise potential areas of EU Habitats & Species Directive Annex I habitat within the deep water area. Draw up recommendations/guidelines for potential oil and gas operations within or close to these areas.

- Analyse INSS information with respect to the identification of potential seabed hazards such as evidence of slope instability, archaeological wrecks etc.

Oceanography and hydrography

- At present oil and gas operations are likely to be restricted to the upper continental slope. Given the importance of the shelf edge current in this region as a transporter of water (and organisms) through the area, further research required to better characterise potential spill trajectories and likely destination of potential water-borne contaminants.

Contamination

- Improve the current lack of adequate baseline data against which contaminant levels can be evaluated and changes detected.
- Better characterise the pathways by which the majority of potential contaminants from oil and gas operations reach the deep ocean and the dynamics of their fluxes.
- Examine the uptake of contaminants by cold water corals and other deep water benthic organisms.
- Characterise the impact of long-term chronic exposures to low doses of contaminants.

Ecology

- Review paleoenvironmental information gained from previous PIP-funded coring projects in association with data from other coring projects (e.g. IMAGES) to better characterise long term changes in marine productivity and climate in the region.
- Better characterise important areas and migration routes for marine species within the region. Encourage and facilitate research examining all aspects of ecology of marine species.
- Characterise the existing levels of ambient and anthropogenic noise present within the marine environment to facilitate the assessment of the potential environmental impact of noise from oil and gas operations in the region.
- Undertake biological ground truthing by photography and sampling of areas geophysically mapped but not previously sampled.

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ABBREVIATIONS

Term	**Expansion**
ACES	Atlantic Coral Ecosystem Study
ACFM	(ICES) Advisory Committee on Fishery management/Advisory Committee on Ecosystem Report
AFEN	Atlantic Frontier Environmental Network
AIRS	Atlantic Irish Rockall Survey
BGS	British Geological Survey
BIM	Bórd Iascaigh Mhara
CAMP	(OSPAR) Comprehensive Atmosphere Monitoring Programme
CMRC	Coastal and Marine Resource Centre (UC Cork)
DCMNR	Department of Communications, Marine and Natural Resources
DTI	(UK)Department of Trade and Industry
ECOMOUND	Environmental Controls on Mound Formation along the European Margin
ENAM	European North Atlantic Margin
EOSG	Expanded Offshore Support Group
ESAS	European Seabirds At Sea
EUNIS	European Nature Information System
FOÍB	Faroes Oil Industry Group
GEOMAR	Research Centre for Marine Geoscience
GEOMOUND	Research project supported by the European Commission and forms part of the Ocean Margin Deep-Water Research Consortium (OMARC)
HADES	Hatton Deep Exploration Seismic
ICES	International Council for the Exploration of the Sea
IMAGES	International Marine Past Global Changes Study
IMAGIN	Irish Sea Marine Aggregates Initiative
IMDO	Irish Maritime Development Office
INSS	Irish National Seabed Survey
INTERREG	A European Community initiative aimed at stimulating interregional cooperation in the European Union.
IOOA	Irish Offshore Operators Association
ISPSG	Irish Shelf Petroleum Studies Group
IUCN	International Union for the Conservation of Nature and Natural Resources
IWDG	Irish Whale and Dolphin Group
JNCC	(UK) Joint Nature Conservation Committee
MI	Marine Institute
NODC	National Oceanographic Data Centre

NUI Galway	National University of Ireland Galway
OMEX	Ocean Margin Exchange project
OSG	Offshore Support Group
OSPAR	Oslo and Paris Commission
PAD	Petroleum Affairs Division
PEPPS	Petroleum Exploration and Production Promotion and Support
PIP	Petroleum Infrastructure Programme
PSG	Porcupine Studies Group
RSG	Rockall Studies Group
SAHFOS	Sir Alister Hardy Foundation for Ocean Science
SeaWiFS	Sea-viewing Wide Field-of-view Sensor Project
TRR	Training Through Research
TURTLE	Database of information on turtles in UK and Irish waters
UKMO	United Kingdom Meteorological Office
UNESCO	United Nations Educational, Scientific and Cultural Organisation
WFA	Western Frontiers Association
WGCEPH	(ICES) Working Group on Cephalopod Fisheries and Life History
WGDEC	(ICES) Working Group on Deep-Water Ecology

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