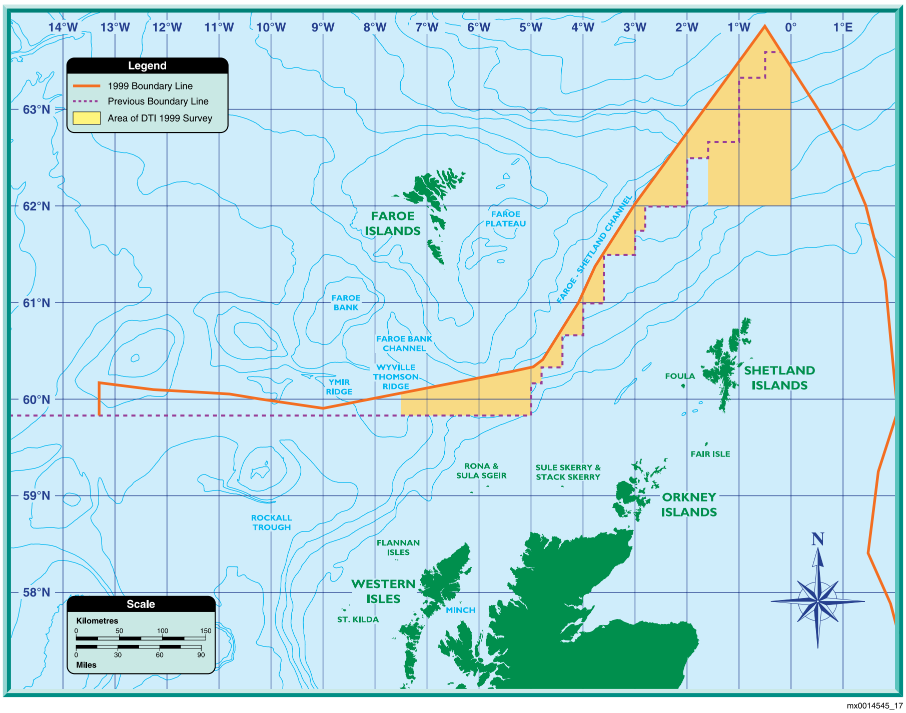
Report to the Department of Trade and Industry

Strategic Environmental Assessment of the Former White Zone

Volume 3 – Assessment



Consultation Document

AUGUST 2000

Prepared by
Hartley Anderson Limited
hartleyanderson@ha-an.demon.co.uk

CONTENTS

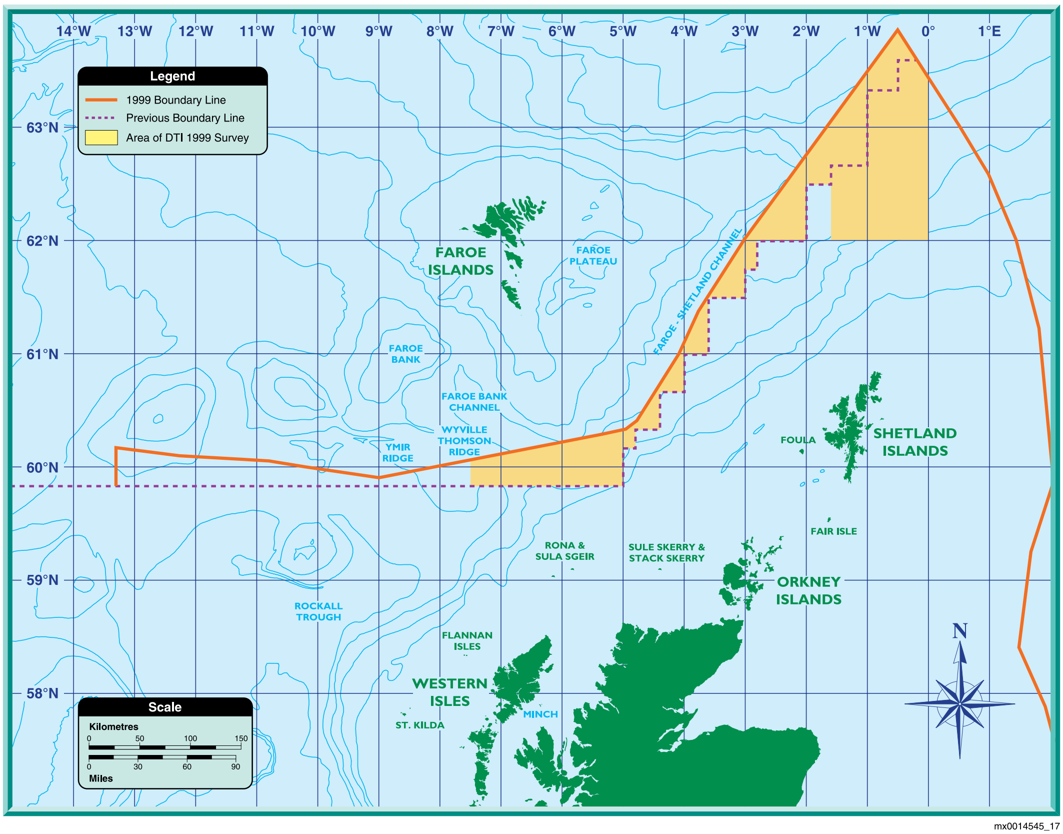
This page is intentionally blank

1 INTRODUCTION

In 1996 the European Commission proposed a Council Directive on the assessment of the effects of certain plans and programmes on the environment (Com (96) 511) to provide a strategic complement to the Council Directive 85/337/EEC which required Environmental Impact Assessments of specific developments and activities. The Strategic Environmental Assessment Directive as the proposed Directive is colloquially known, was amended in 1999 (Com (99) 73) following discussion within the Commission and is currently awaiting adoption.

In the interim, the UK government, as part of its "Greening Government" initiative, decided to follow the intent of the Strategic Environmental Assessment Directive in its consideration of major policy, plan and programme decisions. In May 1999, the location of the boundary to the north-west of Scotland between UK and Faroese waters (the "White Zone" see Figure 1 below) was formally agreed and consideration on both sides turned to licensing for hydrocarbon exploration. The UK government set in train various actions to allow the intent of the SEA Directive to be met. These actions included the commissioning of a seabed survey and of a Strategic Environmental Assessment (SEA) of the implications of licensing. The seabed survey aimed to map, photograph and sample the seabed in parts of the UK sector of the former White Zone, to identify potentially sensitive features and areas which could qualify as European sites under the Council Directive 92/43/EEC (the "Habitats and Species Directive").

Figure 1 – Location of the UK sector of the former White Zone



The purpose of the SEA was to consider the strategic and environmental implications of a 19^{th} UKCS licensing round covering parts of the area formerly known as the White Zone between the UK and Faroese waters. The SEA aimed to consider the following:

- The environmental protection objectives, standards etc established for the area relevant to the approval and subsequent implementation of the proposed action
- Any existing environmental problems in the area which may be affected by the proposed action
- Potential activities in the area
- The main mitigatory measures and alternatives investigated
- An assessment of the likely significant environmental consequences of the proposed action and its alternatives
- Proposed arrangements for monitoring the environmental effects of the proposed action and post decision analysis of its environmental consequences
- Difficulties encountered in compiling the information and a discussion of uncertainty of impact predictions

The SEA is part of a clear process by which government can demonstrate that before licensing decisions were taken, policy level consideration had been given to the environmental implications of oil and gas activity in the area and linked to subsequent decisions and proposals for the area, in particular in the:

- choices of blocks to offer
- conditions attached, including temporal and exploration/ development activity constraints, requirement to gather more information etc
- broad scale environmental monitoring

There is general agreement on the high level objectives and approach to SEA. However, in the absence of the final Council Directive on SEA, and with no agreed methodology for the conduct of a Strategic Environmental Assessment at an academic, European or international level, the approach taken here draws heavily on studies commissioned by the European Commission and other strategic assessments conducted of potential oil and gas licensing, in particular:

- European Commission 1998. Strategic Environmental Assessment Legislation and Procedures in the Community Volumes 1 & 2
- European Commission 1998. Case Studies on Strategic Environmental Assessment Volumes 1 & 2
- European Commission 1998. Strategic Environmental Assessment - Existing Methodology Volumes 1 & 2
- Thomassen *et al.* 1993. Åpning av Trøndelag I Øst, Nordland IV, V, VI og VII, Mørebassenget, Vøringbassenget I og II for letevirksomhet
- Minerals Management Service 1998. Gulf of Mexico OCS oil and gas lease sales 171, 174, 177 and 180. Western planning area. Final environmental impact statement

The SEA is documented in three volumes the first a stand alone summary of the process, key issues and findings the second a synthesis of environmental information for the former White Zone and immediately adjacent areas, and this volume a more detailed discussion of the nature of oil and gas exploration and production, potential impacts and prevention and mitigation measures.

2 PROPOSED ACTIVITY

The maritime boundary agreement between the UK and Faroes was signed in May 1999. Subsequently, the UK sector of the former White Zone was designated a part of the United Kingdom Continental Shelf by means of a Statutory Instrument No. 2031 (under the Continental Shelf Act, 1964) which entered into force in August 1999.

The Petroleum Act 1998 which consolidated among other issues, the Petroleum (Production) Act 1934 and the Petroleum and Submarine Pipe-lines Act 1975, became effective in February 1999. The Act provides the basis for granting onshore (Landward) and offshore (Seaward) Licences. There are two types of Seaward Licence:

- Exploration Licences - are non-exclusive and permit the holder to conduct non-intrusive surveys (e.g. seismic) on any area of the UKCS not covered by a Production Licence
- Production Licences - grant exclusive rights to the holders to "search and bore for, and get, petroleum" in specific blocks.

The proposed activity is to offer Production Licences covering part of the former White Zone as the 19th Round of offshore licensing. The licence round process normally involves the following steps:

- Nomination of blocks of interest by companies
- Consideration of nominated blocks for shipping, fisheries, conservation and other sensitivities
- Offer of selected blocks by government
- Application for blocks of interest by companies, detailing proposed work programme, environmental management controls etc
- Interview of prospective licence holders by the DTI
- Offer of licence to successful applicant company, subject to its acceptance of a number of conditions

The alternatives to the proposed activity are few, namely:

1. not to offer any blocks for Production Licence award
2. to restrict the area licensed by offering only a proportion of the blocks nominated
3. or to stagger the timing of block offer (or licence award) so that initially there is staged activity in the area

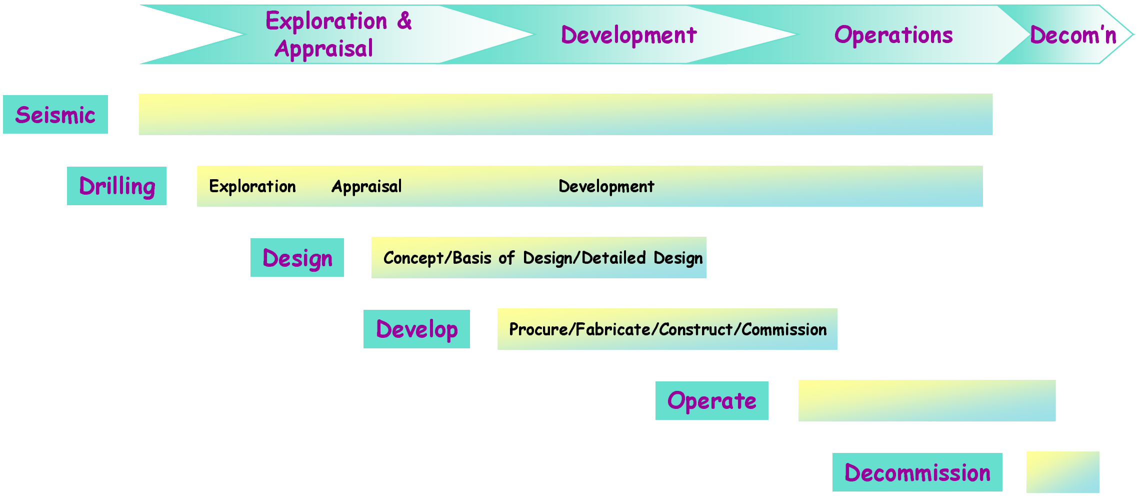
This page is intentionally blank

3 EXPLORATION AND PRODUCTION OPERATIONS

3.1 Introduction

This section provides an overview of the main stages of offshore exploration and production and key associated activities which are illustrated in Figure 2 below.

Figure 2 – Oil and Gas Exploration and Development Stages and Activities



3.2 Exploration and appraisal

The purpose of exploration activity is to identify commercially viable reserves of oil and gas. The conditions necessary for such reserves to have accumulated are complex and largely dependent on past geological history and present geological formations and structures. Identifying the necessary combinations of potential source and reservoir rocks together with migration pathways and trap structures, and estimating the likelihood of such reservoirs containing oil and gas is a technically complex process requiring the use of a range of techniques. Such techniques include deep and shallow geophysical (seismic) surveys, shallow drilling and coring, aero-magnetic/gravity surveys and exploration and appraisal drilling.

Based on a general geological understanding, broad areas of the earth have been identified as prospective areas with potential to contain reserves of oil and gas. Prospective areas are further defined using surface/shallow mapping techniques and geophysical (seismic) surveys to aid understanding of deeper, subsurface geology. Aero-magnetic and gravity surveys are useful in defining general structure such as sedimentary basins but not for pinpointing areas with potential oil and gas. Areas of potential interest are subjected to further geophysical study, which may involve reinterpretation of existing seismic data or necessitate conducting new surveys. The only reliable way to determine whether the identified formations contain hydrocarbons is to drill into them. However, the decision to drill is not taken solely on geological grounds. Government requirements, economic factors (drilling costs, transport costs, market opportunities, relative merit/financial risk) and technical feasibility (including safety and environmental considerations) are all factored into the decision.

3.3 Geophysical surveys

Surface techniques do not allow reliable extrapolation as to the subsurface geology. Although other methods may be used as a reconnaissance tool, seismic survey techniques remain the most effective method of developing an understanding of the deep geology of an area. Seismic surveys are based on the same principles used to record data on subsurface geology during earthquakes but utilise a much smaller man-made energy source to generate energy waves which are directed into the earth's crust. Some of these energy waves are reflected or refracted back from geological structures deep beneath the surface and picked-up by sensitive detectors (geo- or hydrophones). Geophones are deployed at the ground or sediment surface and detect surface particle velocity whilst hydrophones are used principally in marine seismic and detect pressure (sound) waves in water. The strength and speed with which the waves return is affected by the nature of the formations and other media through which they have travelled. The data are recorded and interpreted using a combination of computer software and experienced judgment to produce geological maps.

Marine seismic surveys are conducted from survey vessels which deploy a seismic source, normally an array of air guns, beneath the sea surface to generate pressure (sound) waves which transmit through the sea and sediment and through the subsurface geological structures. Pressure waves reflected from subsurface structures are recorded by a series of hydrophones, typically arranged at intervals along buoyant streamers towed just beneath the sea surface behind the vessel. See Figure 3. Where floating streamers are used, corrections have to be calculated to compensate for the drift induced by currents (feathering effect).

One or more guard vessels, whose role is to liaise with fishermen and other small vessels and prevent collisions with the streamers etc normally accompany marine seismic survey vessels.

On occasion a multi-component system involving a combination of geophones and hydrophones may be deployed on the surface of the seabed arranged along cables which may be towed along behind the vessel (dragged array) or lifted and replaced in a new location as the survey progresses. Such surveys normally involve two vessels, one attached to and processing the data from the sensors and one from which the source is deployed. Multi component systems are considered to be better at penetrating through basalt structures (such as those encountered in the western parts of the former White Zone) which are opaque to traditional towed seismic survey techniques. This method of hydrophone deployment is presently uncommon in deep water and not usually used in initial seismic survey. There are two types, a dragged array involving up to 750m of cable which can be used down to water depths of 2000m, or a dual sensor ocean bottom cable where up to 72km of cable is laid on the seabed but only in waters of less than 200m (Gulland and Walker, 1998). The deployment and retrieval of the cables is intended to be along straight lines, and without lateral dragging although tidal and other currents can cause this to occur.

Seismic surveys may use 2-dimensional or 3-dimensional methodologies:

- **2-D seismic** utilises a single hydrophone streamer towed behind the survey vessel together with a single source. The reflected pressure waves are assumed to lie directly beneath the streamer and hence the nomenclature of 2-D. Repeated parallel lines are typically run at intervals of several kilometres (minimum *ca.* 0.5km) and a second set of lines at right angles to the first to form a grid pattern. 2-D seismic provides a broad understanding of the geology of the area, however its weakness lies in the interpretation of what is between the grid lines.
- **3-D seismic** utilises one or more hydrophone streamers towed behind a vessel. A series of closely spaced (some 25 or 30 metres apart) parallel lines are run in a "race

track" pattern to allow adjacent lines to be run in the same direction. Unlike 2-D no cross over lines are run. In simple terms, 3-D seismic collects a series of 2-D slices at very close intervals which can be interpreted to produce a 3-D understanding of the geology of the surveyed area.

2-D seismic surveys can be conducted relatively quickly and inexpensively but the data produced, though valuable, does not give as accurate an understanding as 3-D surveys. As a result, the majority of marine seismic surveys now conducted to identify oil and gas reserves are 3-D.

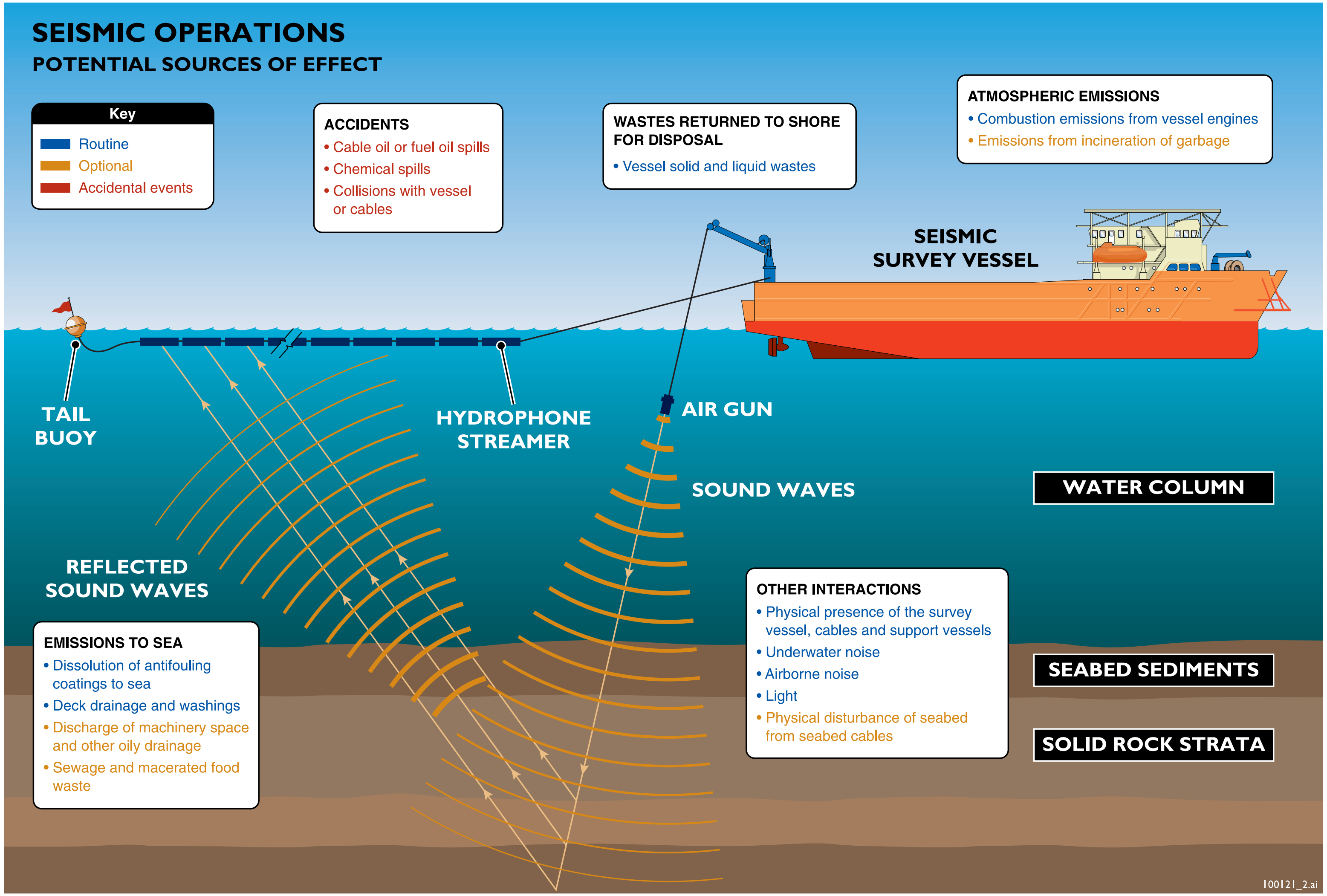
Data from seismic surveys may be reinterpreted as the result of information from other sources including exploration drilling. Seismic survey should not be viewed only as an exploration tool. Surveys are frequently conducted in areas which have been developed to provide continuing information on the reservoir and input to the information base used to determine the ongoing development drilling programme. In some developed areas, (e.g. the Foinaven Field), fixed arrays of seismic receivers (multi-component system) have been deployed on the seabed connected by a series of parallel cables to allow repeated surveys to be conducted over precisely the same area. Such data is as detailed as 3-D seismic and in addition, shows the temporal changes as oil is produced, and referred to as 4-D seismic.

On occasion, vertical seismic profiles (VSP) may be generated through the deployment into a well of a number of geophones spaced on a cable. The seismic source is deployed in the water column either suspended from the rig or platform (zero offset VSP) or from a source vessel at some distance from the well (offset VSP). VSP allows data from the rocks/structures encountered during drilling to be correlated with seismic data. Such surveys are usually of short duration (1-2 days) and utilise sources with volumes intermediate between those used in rig site and typical seismic surveys. 3-D VSP may, uncommonly be generated by making multiple passes with the source vessel.

3.3.1 Potential sources of effect

Potential sources of effect from seismic survey are shown on Figure 3 and considered in more detail in Section 4.

Figure 3 – Sources of potential environmental effects from seismic operations



3.4 Exploration and appraisal drilling

3.4.1 Well objectives and planning

As described above, the target structures to be drilled (bottom hole location) are identified principally from the interpretation of seismic survey information. Well specific objectives are defined at an early stage of the planning cycle for the well and in many respects define the nature and cost of the well to be drilled. The simplest objective for a first exploration well in an area may be to determine whether the structure identified contains oil and/or gas. The more complex the objectives, the longer the well may take and the greater the range of tests which will be conducted. Objectives will define the information to be gathered during the drilling including well logs and possible well test, and whether the well would be plugged and abandoned on completion of the programme or suspended for re-entry at a later date. On occasion, the well objectives may include provision for a sidetrack to the main well in the event that hydrocarbons are encountered.

Surface hole locations (and therefore rig position) are normally chosen to achieve the shortest well consistent with avoiding surface hazards and sensitivities. Before a well is drilled from a mobile drilling unit, information on the stability of surface sediments and potential subsurface hazards (e.g. shallow gas formations) must be gathered to ensure that the rig will not encounter problems when positioning anchors or drilling the surface hole. Rig site surveys utilise seismic techniques similar to those for a 2-D survey although with a smaller energy source and shorter hydrophone streamer. The rig site survey vessel may also be used to gather baseline information on the seabed sediment, fauna and background contamination. The rig site seismic data can further refine the understanding of surface features obtained from regional mapping surveys (e.g. the AFEN 1996 and 1998 surveys).

In scheduling a drilling operation, the metocean conditions, seasonal environmental conditions and licence conditions, availability of rigs, commitments made to government and other company internal constraints are taken into account. The well design including the length and diameter of the various hole sections and casings, mud types (see Section 3.4.3) to be used and contingencies allowed for is dependent on the nature of the formations to be drilled, the length of the well and the well objectives. The well design and plan is subject to external review and approval.

3.4.2 Drilling rigs

Exploration wells are drilled from mobile drilling rigs. Rigs are basically of three types:

- **Jack-up rigs** which are based on a buoyant steel hull with 3 or more lattice legs up and down which the hull can be "jacked". The rig is towed to location by 2 or more tugs with the legs jacked up so the hull floats. On reaching the drilling location the rig jacks its hull up the legs until the base of the legs are firmly in contact with the sea floor and its deck positioned above wave height. The rig's position is maintained by the legs which are in firm contact with the sea floor. No anchors are deployed, although in areas of strong seabed currents where sediment scour may be expected, gravel or rock may be dumped around the base of the legs to stabilise the sediments. Jack-up rigs are depth limited and can only operate in water depths of around 100m or less and would not be expected to be used in the former White Zone.

- **Semi-submersible rigs** which float at all times on pontoons are the most likely rig type to be used in the former White Zone. The rig is towed to location by two or more tugs.

The pontoons contain ballast tanks, and the height of the deck above the sea surface can be altered by pumping ballast (sea) water in or out of the pontoons. During drilling operations, the deck is lowered but still kept above wave height. Rigs used in deep water, harsh environments maintain position over the drilling location either by anchors (and where fitted, with rig thruster assistance as necessary) or by dynamic positioning using a series of computer controller thrusters. Rig anchoring typically involves the deployment by anchor handler vessel, of eight or more 12 tonne high efficiency seabed penetrating anchors. The anchors are attached to the rig by cable and near the anchor by chain, of which a proportion and a minimum of 100m lies on the seabed (the catenary contact). Hauling in of the cables by the rig “sets” the anchors in the seabed after which minor adjustments to the rig position can be made by hauling or paying out cable. The precise arrangement of anchors around a rig is defined by a mooring analysis which takes account of factors including water depth, tidal and other currents, winds and seabed features. The relationship between water depth and lateral extent of the anchor pattern is not linear and typical radii of anchor patterns for semi-submersible drilling rigs operating in the Faroe Shetland Channel are 2,400m in 700m water depth and 2,800m in 1500m of water. Anchors are retrieved by anchor handler vessels by means of pennant wires which slide down the cable towards the anchor allowing a more or less vertical retrieval, facilitating anchor breakout from the seabed.

- **Drill-ships** are based on a conventional ship’s hull adapted with a moon pool to allow the deployment of the drill though the hull. They typically have their own motive power and are not dependent on tugs, maintaining position with DP and/or anchors. Drill-ships can operate in deep water and are the platform from which the academic Ocean Drilling Programme is conducted. However because of the hull shape, they are more affected by wind and wave movement than semi-submersible rigs, and as a consequence would be more likely to suffer from weather down time in the former White Zone.

Exploration rigs are self-contained with their own power generation, utilities and accommodation facilities. Supplies are brought to the rig and wastes returned to shore by supply boat. Crew are transferred on and off the rig by helicopter. A stand by vessel is deployed in the field for the duration of the drilling programme. A drilling derrick above the drill floor bears the weight of the drillstring, which is a series of 9m long sections of hollow drill pipe, screwed together and to the bottom of which the drill bit is attached. The lower part of the drill string, adjacent to the drill bit, is comprised of a series of heavy drill collars to give added weight to the drill bit. The drill bit is rotated either by rotating the whole drill string by means of a rotary table on the drill floor/topdrive system or by a downhole turbine powered by the flow of mud pumped down the hollow drill pipe.

3.4.3 Drilling operations

Once the rig is fixed in position the well is commenced. A temporary guide base is deployed on the seabed and a wide conductor (typically 30” or 36”) is installed through the guide base (spudded) into the surface of the seabed either by piling or using a water jet. The well is drilled in a series of steps with the hole sizes and casing getting progressively smaller. The upper section(s) of oil and gas wells is normally drilled “open” without a riser so that displaced sediments and rock are discharged directly around the wellbore. The uppermost section of the well is sometimes made by water jetting rather than drilling, and can result in a plume of sediment in the water column. The methods used and the depths to which a surface hole is drilled are dependant on several factors, particularly well design and intended function and the surface and shallow sediment and rock type. Examples of exploration wells drilled in the Faroe Shetland Channel and adjacent areas indicate the weight of surface hole material generated ranges between 214 and 875 tonnes (Conoco 1998, Mobil 1998) although the typical figure is towards the upper end of this range. Side scan sonar and ROV inspection around exploration wells indicate that surface hole cuttings form a low mound with a radius of 5 to 10m around the wellhead. The riser is fitted with devices to maintain it under tension whilst compensating for heave.

Drilling muds are a combination of a weighting agent and other materials suspended in a fluid (the base fluid). The choice of mud weight (specific gravity) and base fluid type (water, synthetic "oil" or low-toxicity oil) is dependent on the nature of the formations to be drilled. The weighting agent most commonly used is the dense mineral barites. However in certain circumstances, including where local environmental sensitivities require this (e.g. where scallop beds are present), alternatives such as calcium carbonate may be used. The function of the mud is to provide a circulation to remove cuttings from the hole, to cool the drill bit and to provide a hydrostatic head exerting a greater pressure than that expected from any formation which may be encountered, to maintain well control. Other chemicals are included in the mud formulation to aid its performance. Muds may be premixed onshore and transported in the mud tanks of the rig, or via supply vessel, or alternatively they can be made on the rig.

The contaminant composition of drilling wastes has changed significantly over the last few decades, in response to technical and regulatory developments. Previous widespread and substantial discharges of oil-based muds, and later synthetic oil muds, have been superseded by alternative disposal methods (either containment and onshore treatment, or reinjection) or by water-based muds. The major environmental effects of development of the North Sea in the 1970s and 1980s, i.e. the formation of cuttings piles beneath platforms and zones of benthic effects surrounding the platforms, are therefore unlikely to be repeated west of Shetland.

Base fluids are chosen based on knowledge of the formations to be drilled since certain rock types, such as shales, absorb water and expand, thereby potentially causing the drill pipe to stick and disrupting the drilling operation. If formations such as these are expected, then a non-water base fluid, either a synthetic or low-toxicity oil, may need to be used in those sections of the well.

Muds and cuttings are returned via the riser to the rig for treatment. Firstly cuttings and muds are separated on shale shakers (vibrating screens) and the mud returned to the mud tanks for re-use. Cuttings from the shale shakers are normally either discharged, in the case of water based muds or in the case of synthetic or low toxicity oil based muds, contained for shipment to shore for further treatment and disposal. The opportunity to re-inject cuttings is not normally available for exploration and appraisal wells. The cuttings are monitored for evidence of hydrocarbons by the mudlogger.

3.4.4 Cementing

As each section of the well is drilled, the drill string is removed from the well and steel casing lowered into the well and cemented into place to prevent the well from caving in. A measured amount of quick drying cement slurry is pumped into the casing and a plug inserted above it. The cement is forced down to the bottom of the casing and then up the annulus (i.e. the space between the outside of the casing and the wall of the well) by pumping mud on top of the cementing plug. Pumping ceases once some cement is observed returning with the mud returns indicating that all the mud in the annulus has been replaced with cement. Drilling activity is suspended for a variable length of time, until the cement has set, the actual time being dependent on the cement additives used.

3.4.5 Logging and coring

Dependent on the original objectives, readings and sampling may be conducted in the lower sections of the well, particularly in potential reservoir rocks. Cores are taken by replacing the drillbit with a core barrel which can cut rock cores several metres long. Other measurements, including porosity/permeability, electrical resistivity and formation density may be made using electronic/radiographic instruments lowered into the uncased, lower sections of the well using a wireline unit (wireline logging). If hydrocarbons are found, then a downhole tester is lowered into the well by wireline. This instrument measures fluid pressures and takes samples of the fluids.

3.4.6 Well testing

Where significant hydrocarbons are encountered the well may be tested by installing a section of production liner in the lower hole and flowing the well to the surface for a short period to measure pressures and flow rates and take samples of well fluids (well test or drill stem test). Prior to a well test, the well is cleaned up using a combination of high-density brines and clean-up chemicals to remove all traces of mud and cuttings debris from the bore. The brines are circulated to the rig via the riser and may be contained for reuse/disposal or discharged overboard. The liner is then perforated in the reservoir section and a gravel pack may be installed to prevent production of unconsolidated sand from the reservoir with the fluids. The well fluids are flowed to the rig, through a surge tank and into a test separator, to provide information on the relative proportions of gas, oil and water. The hydrocarbons produced during a well test are either burned in a high efficiency burner or in the case of oil produced during extended well tests, contained typically in a specialist storage vessel for transport to shore for treatment.

3.4.7 Well suspension and abandonment

Following completion of the drilling programme the well may either be plugged with cement and abandoned by cutting off the casing below the surface of the seabed, (using a circular metal cutting tool attached to the bottom of the drill string or explosive charges) or suspended to allow re-entry by plugging it with cement and capping the top hole casing. Following this operation, a video debris survey is conducted using a remotely operated vehicle (ROV) and any dropped objects recovered.

3.4.8 Abnormal operations

On occasion a mechanical failure of the tools down the hole may occur, for example a fracture of the drill pipe. A range of “fishing” techniques and tools may be used to recover the equipment to the surface so that drilling can recommence. Should this be unsuccessful then the well may be plugged with cement and a (mechanical) sidetrack well drilled from just above the plug and down to the target location.

The drill pipe may become stuck in some formations. The first approach is to attempt to carefully jolt the pipe free. If this approach fails then a small amount (a "pill") of synthetic or oil base fluid may be used to help free the pipe, with the fluid recovered for disposal when circulated to the rig.

Whilst drilling through porous formations, the drill mud may be lost into the pore spaces in the rock resulting in a dramatic reduction in the amount of mud returned to the rig. Mud returns are constantly monitored to aid early identification of such lost circulation. Lost circulation is remedied by loading the mud with various materials to plug the porous rock e.g. cellulose strips, ground walnut shells.

In the event that gas, oil or water pressures exceed the hydrostatic head and invade the well (a kick) the back pressure is detected on the rig. Normally, the mud weight is increased through the addition of weighting material to the point where downhole pressures are balanced and contained. In extreme circumstances the blow-out preventer (a series of hydraulic rams which can close off the well) is operated.

3.4.9 Appraisal wells

If a hydrocarbon bearing reservoir is discovered during exploration drilling, one or more appraisal wells may be drilled. Appraisal wells are used to delineate the physical dimensions of the field and calculate its development potential. Such information is important in determining:

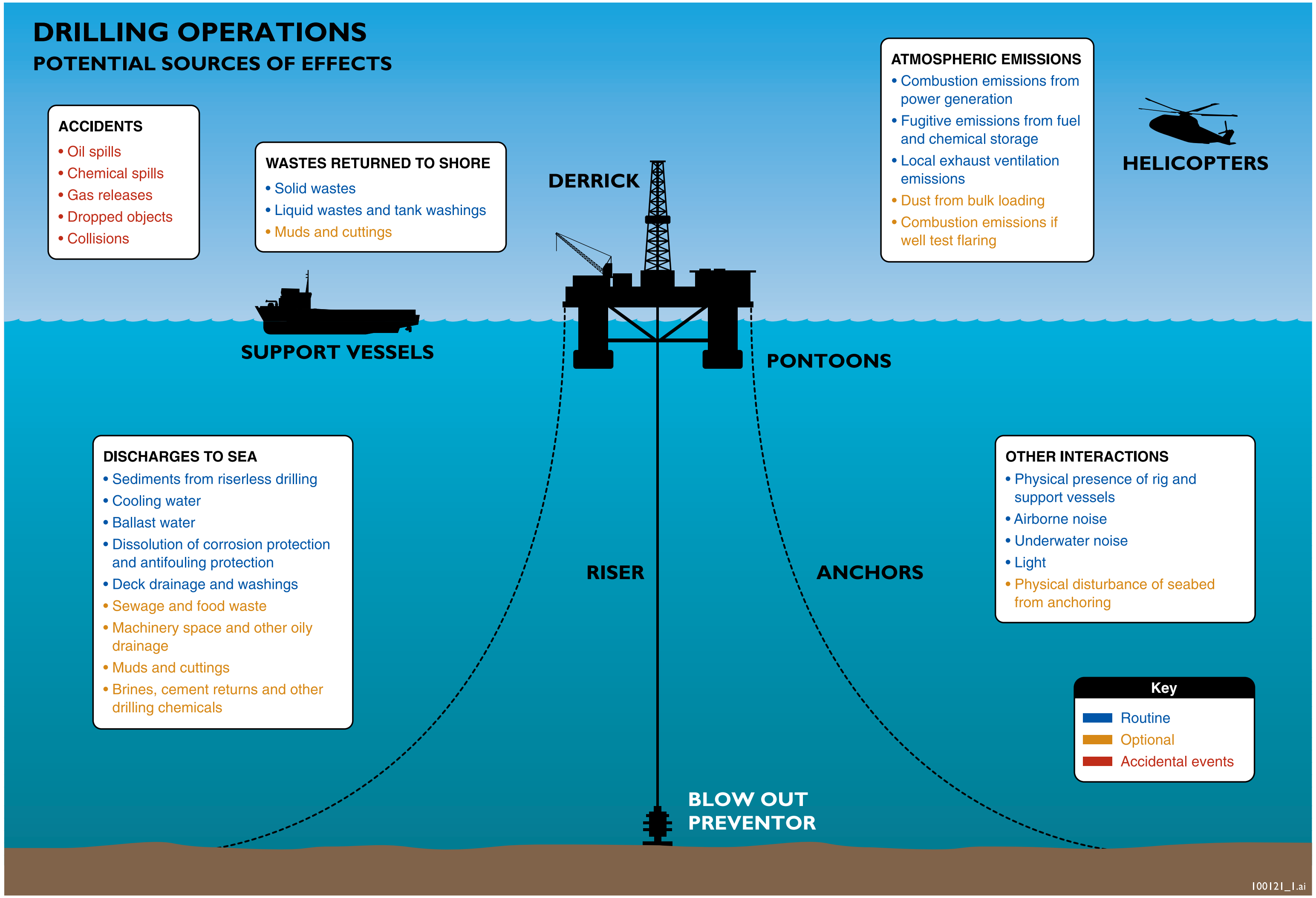
- whether it would be economically viable to develop the field
- likely hydrocarbon production rates
- appropriate process and export facilities

Most appraisal wells would normally include extensive logging and involve a well test. Because of the cost, as few appraisal wells as possible would be drilled, the actual number being dependent on the particular circumstances of the field. Some appraisal wells are drilled as future potential production wells and suspended following completion for future re-entry.

3.4.10 Potential sources of effect

Potential sources of effect from exploration and appraisal drilling are shown on Figure 4, and discussed in more detail in Section 4.

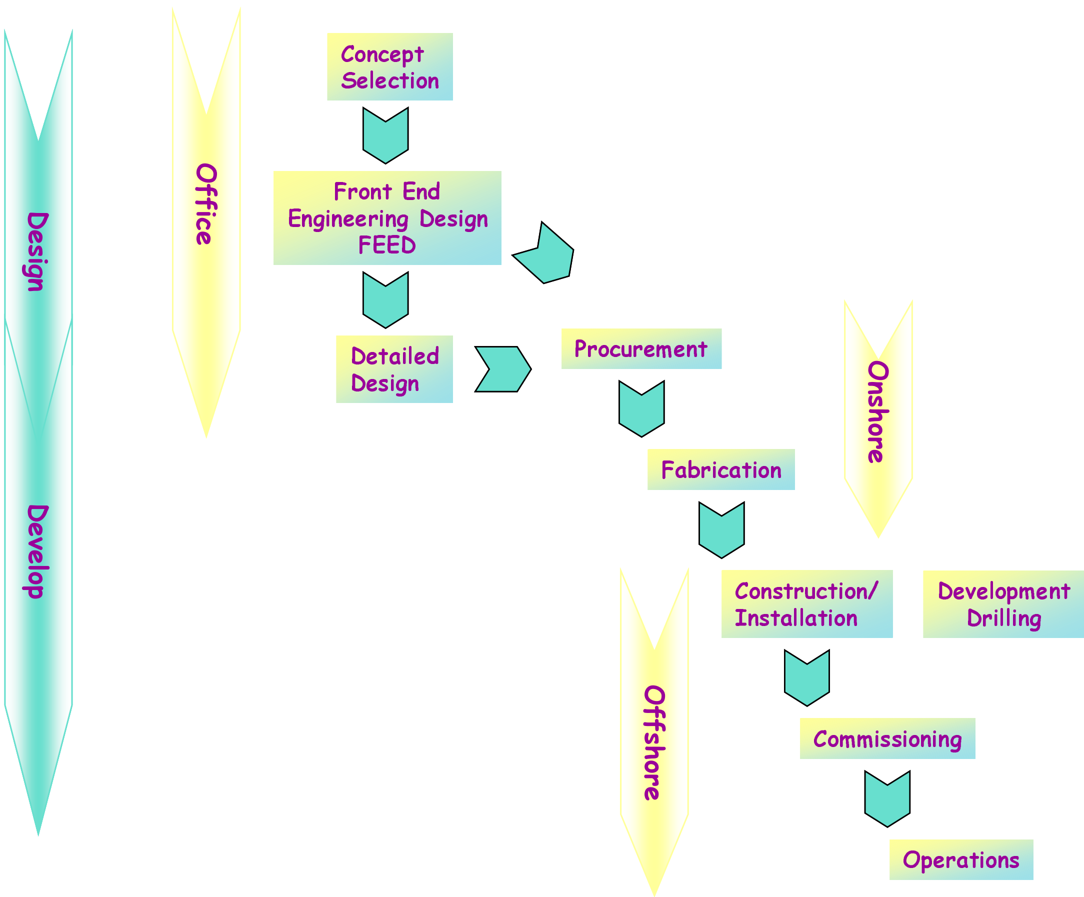
Figure 4 – Sources of potential environmental effect from semi-submersible drilling operations



3.5 Field development

A number of factors including field economics, availability of export routes, technical feasibility and environmental sensitivities are brought to bear on the decisions as to whether, when and how to develop a field for production. The development of a field is a staged process (see Figure 5 below) with a great deal of activity taking place prior to the commencement of construction work offshore.

Figure 5 – Offshore Design and Development Process



The summary description below focuses on the nature of the key potential field activities:

- Drilling of development wells
- Construction and installation of production and export facilities
- Commissioning of the systems

3.6 Development drilling

The objective of a development drilling programme is to access as efficiently as possible the recoverable reserves from the field. The number of wells and locations from which they are drilled are dependent on the size and nature of the reservoir. Development wells are often drilled over a period of time and both the temporal and areal spacing of the wells are dependent on the reservoir properties and field economics. The function of the wells that may be drilled during the life of a field would fall into the three broad categories listed below, although it is sometimes possible to convert wells from one function to another as the need changes:

- Production wells
- Injection wells (water or gas)
- Disposal wells (cuttings, produced water or gas)

In terms of operations and activities, development drilling is similar to exploration and appraisal drilling. The surface locations of development wells are normally centred at the main production facility and directional drilling techniques are used to access the different parts of the reservoir. The drill string incorporates assemblies to weight and deflect the drill bit to the desired angle from vertical. Electronic/radiographic instruments are incorporated in the string to relay to the surface information on location and angle of deviation of the drill bit and porosity and density of the formations. Because the frictional coefficient increases with the angle of deviation, turbo drills or jet bit drills are used rather than rotary drills and particularly where shales may be expected, the rheological properties of an oil based or similar mud may be required to prevent stuck pipe in these sections of the well. The reservoir section of the well may be drilled more or less horizontal. In such cases one or more horizontal sidetracks may be drilled from the same well to maximise access to the reservoir.

Where it is not technically feasible to drill to the target location from the main facility then development wells may be drilled at one or more satellite locations. However, to minimise footprint and maximise use of infrastructure deviated drilling techniques are also used.

To reduce delay between the installation of the main facility and commencement of production, some development wells may be predrilled from a mobile rig and temporarily suspended. Where a number of wells are to be drilled from the same surface location a steel template may be deployed on the seabed rather than a series of individual guide bases. Templates are normally fixed on the seabed with two or more piles and also provide for accurate subsequent positioning of the jacket relative to the template. Cuttings reinjection facilities are often not available at this stage and cuttings contaminated with synthetic or low-toxicity oil based muds are contained and would be shipped to shore for treatment.

Subsequent development wells at the main facility are either drilled from a drill rig permanently installed on the facility or from a mobile drilling rig adjacent to a floating installation or cantilevered over a fixed platform. The conductors for wells drilled from a fixed platform extend from the seabed through slots on the facility with the wellhead and blow out preventer located on deck. With floating facilities, the wellheads and blow out preventers are on the seabed and connected to the installation by flexible risers (see Figure 6). Following completion of a production well, a valve assembly (Christmas tree) is installed on the wellhead, production tubing installed in the well and the well cleaned up using a combination of heavy brines and clean-up chemicals which are either discharged or contained and shipped to shore for reuse/disposal dependent on type. Once all debris and mud has been cleaned from the well, well fluids will be flowed for a short period. Where clean-up operations are being conducted on the platform, the well fluids will normally be processed. Satellite wells may be cleaned-up via a mobile rig and in these cases, the well fluids may be disposed of via a high efficiency burner. Subsea wellheads are typically fitted with various trawl protection structures.

Past development drilling using oil based muds has resulted in significant accumulations of contaminated cuttings under some platforms in the central and northern North Sea. Since only cuttings from the surface hole and sections drilled with water based muds would be discharged, significant accumulations of contaminated cuttings would not be expected from development drilling in the former White Zone.

3.7 Construction and installation

3.7.1 Possible types of production facility

A range of different structures have been used to support offshore oil and gas production on the UKCS including fixed, floating and subsea facilities, see Figure 6.

Fixed
Fixed steel jackets are normally 4 or 6 leg structures, constructed of a welded steel tubular framework. The jackets are normally towed out to the development location and manipulated into position by a heavy lift barge. Piles are driven into the seabed at each leg to fix the jacket into place and the topsides lifted into place by in one or more lifts. Fixed steel jackets are deployed in water depths of up to 450m. In some instances, to achieve separation of accommodation and hydrocarbon processing, 2 or more platforms may be installed in proximity and bridge linked.

Concrete gravity base platforms are constructed out of concrete reinforced with steel and have been used in locations where the seabed is too hard to permit piling. The platform is supported on concrete legs, at the base of which are ballast and storage tanks. Having been towed out to the development location, the ballast tanks are flooded and the structure settled on the seabed. Concrete structures have been used in water depths of up to 350m.

Because of the water depths in the area, fixed steel and concrete structures may have limited application in the former White Zone.

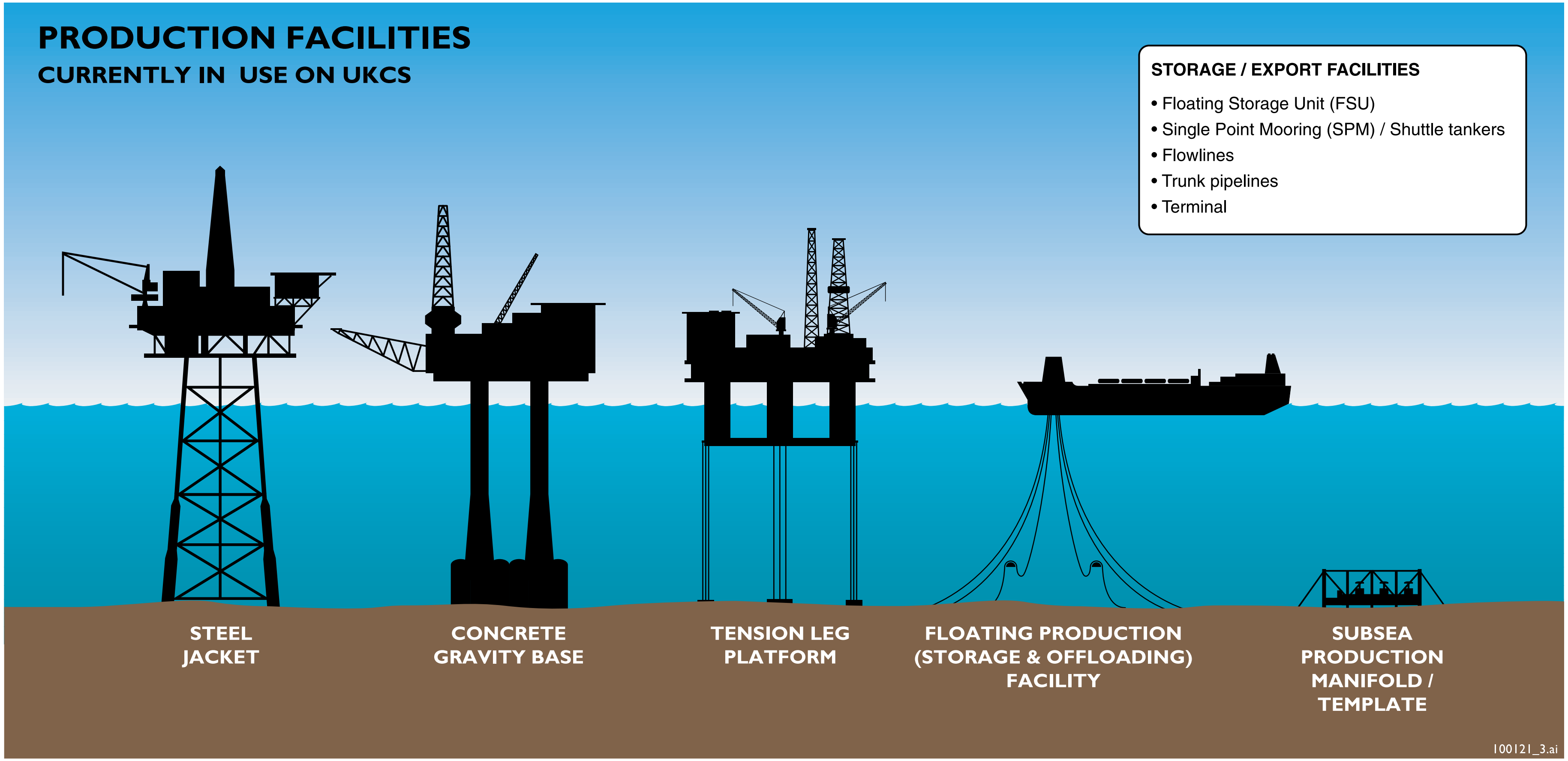
Floating
Tension Leg Platforms (TLP) are floating structures, ballasted and anchored by tensioned steel tendons to templates piled to the seabed. TLPs are relatively stable and can operate in a wide depth range (up to *ca.* 2,100m).

Floating Production Systems (FPS) and Floating Production, Storage and Offloading Systems (FPSO) are facilities based either on ships' hulls or semi-submersibles. They are ballasted and anchored to the seabed, can accommodate vertical movement and operate in a wide depth range. Wells are normally fitted with subsea completions and produced to the facility via flexible risers with built in compensation for vertical movement.

Both types of structures can operate in relatively deep water and are normally towed out to the development location with the topsides already pre-commissioned onshore.

Subsea
Smaller fields or parts of the reservoir, which cannot be successfully accessed by directional drilling from the main facility location, are developed using a combination of subsea completions, manifolds and pipelines tying the development back to a surface facility for fluids processing and export (host facility). Umbilicals with multiple cores are used to inject chemicals at the wellhead/manifold as necessary (e.g. to prevent the formation of hydrates or protect the pipeline from corrosion) and to support electric and hydraulic control of the wellhead and/or manifold valves from the main facility.

Figure 6 – Types of offshore facility



Other
Deepwater developments elsewhere in the world e.g. the Gulf of Mexico, have production facilities based on alternative structures e.g. compliant towers (a narrow flexible tower piled to the seabed) and spars (a cylindrical ballasted structure which floats vertically in the water and is anchored to the seabed).

It is not possible to be definitive as to which structures would be used for developments in the former White Zone, although it is likely that they would be based on a combination of floating and subsea structures. A number of issues affect the selection of production facility including expected field life, reservoir fluid type and flow rates and location. It should be noted that deep water production technologies continue to develop rapidly.

Offshore installations are self contained units with all the facilities needed to support the main processes and export including power generation, pressure relief, water treatment, utilities, drains, helideck, cranes and crew accommodation. Drilling facilities may or may not be permanently installed depending on the type of development. Structures are fitted with corrosion protection in the form of sacrificial anodes and/or impressed current systems.

3.7.2 Export facilities

Oil may be exported by tanker offloading or pipeline. Currently gas is only exported by pipeline, although technologies in development may allow the conversion of gas into liquids (gas to liquids) and therefore export via tanker or oil pipeline. In fields with no economically viable export route gas surplus to fuel gas requirements is either injected into the reservoir for future recovery or other rock formations via disposal wells. The disposal of surplus gas by routine flaring is unlikely to be approved for any developments in the former White Zone.

Tanker offloading requires both oil storage and offloading facilities. These may be provided by the main facility as, for example, in the case of FPSOs. Where insufficient storage is available on the main facility, a separate storage facility may be permanently anchored in the field. Where the main or storage facility design does not permit safe approach by tanker then an alternative mooring, for example, a single point mooring, is located a safe distance (up to several kilometres) away. Oil is transported by short infield pipeline(s) from the host facility to the storage and/or offloading units.

There are currently no available oil or gas export pipelines in the immediate vicinity of the former White Zone and oil production from the existing west of Shetland fields is exported by shuttle tanker to Sullom Voe Terminal on Shetland or Flotta Oil Terminal on Orkney. Only very large reserves would justify the establishment of new terrestrial reception facilities.

Marine oil and gas pipelines are laid either by anchored or dynamically positioned pipelay barges, where sections of steel pipe are welded together to form the pipeline as the barge progresses along the pipeline route. Alternatively, a prefabricated pipeline is laid from a large reel mounted on a dynamically positioned ship, although this technique has limitations in terms of the size of pipeline that can be accommodated. Anchored pipelay barges usually have an array of 12 anchors which are redeployed in sequence during pipelaying. The anchor type is selected according to sediment and metocean conditions of the area and are normally either 12 tonne high efficiency seabed penetrating anchors or 20 to 25 tonne stockless general marine anchors. The anchors are attached to the barge by steel cables (typically 75mm in diameter) of which about a third to a half forms a catenary contact on the seabed. The anchors are repositioned by anchor handler vessels and dropped in a corridor between 2 and 3km wide centred on the pipeline. Each anchor is advanced about 650m which results in a total of 24 anchor drops being made within the pipelay corridor for each 1300m advanced (24 drops in an area of 2.8km^2). Once dropped, the anchor cable is hauled in from the barge until a good hold is achieved. This normally drags the anchor along the seabed for between 5m and 50m depending on anchor type. The barge then uses the anchor spread to pull itself along as pipelaying progresses and during this process the catenary contact cable is dragged across the seabed surface, resulting in cable scrape. Mounds of sediment up to 2m high may be formed in clay and mud seabeds during the pulling against the anchors or when the anchors are retrieved for redeployment.

The degree and nature of seabed scarring or disturbance during pipelay barge operations is dependant on a range of factors including:

- Laybarge type
- The anchor type, size and weight
- The nature of the seabed sediments
- The load placed of the barge and hence the anchors by prevailing weather and current conditions
- Barge and anchor handler crew skill

Dynamically positioned vessels normally have no contact with the seabed other than the pipeline being laid.

Large diameter (greater than 16 inches) pipelines are typically laid directly onto the surface of the seabed while smaller ones are normally trenched into it to a depth of about 1m. The pipeline trench is either cut by plough where displaced sediment is sidecast or made by water jet which disperses the removed sediment more widely as a plume in the water column. Trenches are either backfilled with sidecast material or allowed to fill naturally over time with sediments transported by tidal and other currents. Umbilical cables for the control of subsea facilities are either placed alongside a buried pipeline in its trench or buried separately, normally using a marine version of the agricultural mole plough. The trenching is typically undertaken using equipment deployed from the laybarge or other support vessel.

Pipelines and subsea structures are fitted with corrosion protection in the form of sacrificial anodes, normally of aluminium.

3.7.3 Potential sources of effect

Potential sources of effect from construction and installation of facilities are discussed in more detail in Section 4.

3.8 Commissioning

In this summary, commissioning is taken to include offshore activities and covers only pipeline testing and dewatering.

Pressure testing of pipelines and subsea equipment with seawater is carried out to detect leaks prior to use. The seawater includes a small quantity of a dye and is normally chemically treated to prevent internal corrosion of the pipeline. The treated seawater is normally discharged. The pipeline is dewatered/dried prior to use using a quantity of glycol and/or methanol or by using air drying or vacuum drying techniques.

Much of the topsides process and utility equipment may be pre-commissioned onshore. Once the wells are brought on stream final commissioning will be completed. As systems are being fully commissioned and fine-tuned, some process trips normally occur, resulting in shut down of part or whole systems and sometimes necessitating the disposal of gas to flare for a period.

3.8.1 Potential sources of effect

Potential sources of effect from facility commissioning are discussed in more detail in Section 4.

3.9 Production operations

The main function of the process system is to separate well fluids into the oil and gas phases and condition them for transport by removing any water and solids.

The principal production systems and options for export and disposal of emissions and discharges are shown in Figure 7 overleaf.

3.9.1 Atmospheric emissions

The major sources of emissions to atmosphere are internal combustion for power generation by installations, terminals, vessels and aircraft, flaring for pressure relief and gas disposal, cold venting and fugitive emissions.

Power requirements for the offshore industry are dominated by production installations (typically >50MW per platform), with substantially smaller contributions from mobile drilling units (typically 10MW per unit) and vessels. The major energy requirement for production is compression for injection and export, with power generated by gas or dual-fuel turbine. Fuel gas accounted for 59.5% of total CO_2 emissions from the UKCS in 1998 (UKOOA 1999).

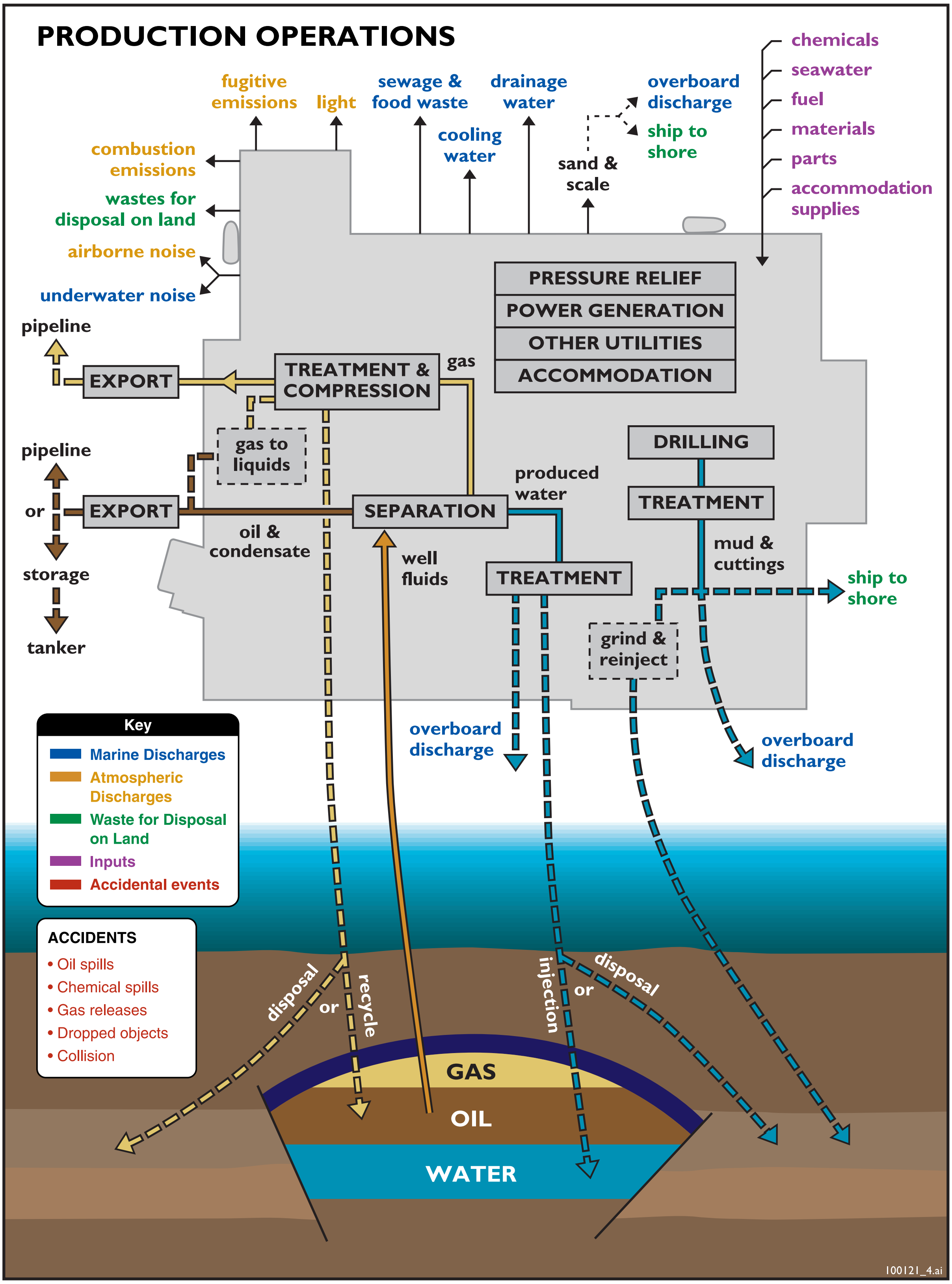
Flaring from UKCS installations has been substantially reduced relative to historic levels, largely through development of export infrastructure and reinjection. New developments will generally flare in substantial quantities only for pressure relief, with “zero routine flaring” now considered a realistic design target for planned developments.

3.9.2 Produced water and other aqueous discharges

Produced water is derived from reservoir (“fossil”) water and from breakthrough of treated seawater injected to maintain reservoir pressure, and is generally the largest single wastewater stream in oil and gas production (OLF 1998).

Other overboard discharges are generally of much lower volumes than produced water, and are unlikely to have significant effect, outside the immediate vicinity of fixed or mobile installations.

Figure 7 – Sources of potential environmental effects from production operations



3.9.3 Process and utility chemicals

A range of process and utility chemicals are used in the offshore production of oil and gas. Chemicals may be contained in closed systems e.g. as heating medium or dependent on function, partition in whole or part with the oil or water phase. Examples of some of the key functions of chemicals used offshore are to:

- Aid separation of fluids
- Prevent foaming in process vessels and piping
- Prevent the formation of hydrates
- Inhibit corrosion of equipment and piping
- Inhibit the build up of scale in equipment and piping
- Treat and dry gas
- Treat seawater

3.9.4 Logistics and support

Supplies to the facility (chemicals, diesel, parts, consumables, food and other supplies) and returns from the facility (wastes, unused parts and chemicals etc) are transported to and from land by supply boat. Personnel are carried by helicopter.

A stand-by vessel is normally located in the vicinity of the main facility to provide safety cover and for oil spill response.

3.9.5 Well workover

During the life of a field, wells may be worked over to remedy faults or to improve performance. Workovers are conducted either from the main facility, if a drilling rig is permanently installed, or from a mobile rig brought into the field. The term workover covers a range of well intervention techniques including wireline and coiled tubing operations and often involves the use of chemicals.

3.9.6 Potential sources of effect

Potential sources of effect from production operations are shown in Figure 7 and discussed in more detail in Section 4.

3.10 Decommissioning

At the end of field life (less than 10 to more than 25 years) production and export facilities will be decommissioned.

Facilities will be decommissioned according to the requirements of UK, EU, OSPAR and other international regulations and agreements in force at the time. The methods used to decommission individual facilities would be selected on a case-by-case basis. Wells will be plugged with concrete and the conductors cut off below seabed level. Floating installations would be towed away, potentially to a new location for reuse and associated risers and seabed anchor points removed. Similarly subsea manifolds will be removed. Pipelines would be considered for removal on a case-by-case basis.

This page is intentionally blank

4 ASSESSMENT

4.1 Introduction

Scoping is a key initial aspect in the assessment of the environmental implications of a policy, programme or plan. A literature search (and consultation) was undertaken to identify potential hazards and the nature and scale of potential environmental effects of the consequences of licensing all or part of the UK sector of the former White Zone. The environmental effects of oil and gas exploration and production have been extensively researched and reviewed over the last 30 years. Reviews of effects usually attempt to be comprehensive or address a specific topic, such as drilling wastes, the effects of oil on marine mammals etc. The general reviews and position papers considered during this assessment are listed below:

Title	Reference
Environmental effects of offshore oil production. The Buccaneer gas and oil field study	Middleditch BS (1981)
Long-term environmental effects of oil and gas development	Boesch DF and Rabelais NN (1987)
North Sea oil and the environment: developing oil and gas resources, environmental impacts and responses	Cairns WJ (1992)
North Sea quality status report 1993	NSTF (1993)
Åpning av Trøndelag I Øst, Nordland IV, V, VI og VII, Mørebassenget, Vøringbassenget I og II for letevirksomhet	Thomassen *et al.* (1993)
Environmental implications of offshore oil and gas developments in Australia	Swan JM *et al.* (1994)
Likely impacts of oil and gas activities on the marine environment and integration of environmental considerations in licensing policy	Hailey N (1995)
Polluting the offshore environment	Joint Links (1995)
Environmental trends in the Gulf of Mexico in the twentieth century: The role of offshore oil and gas industry.	Gallaway *et al.* (1997)
Gulf of Mexico OCS oil and gas lease sales 171, 174, 177 and 180. Western planning area. Final environmental impact statement	MMS (1998)
The Atlantic Frontier Britain's last wilderness	Murray and Simmonds (1998)
Oil and gas in the environment	Environment Agency (1998)

In addition, a wide range of papers, topic specific reviews, reports and environmental statements have been consulted in the preparation of this section and considered in the assessment of effects. These are referenced as appropriate in each section and listed in the bibliography.

Clearly, not all of the potential sources of effect identified in Section 3 are of equivalent importance. The potential sources of effect were screened on the basis of the reviews and position papers listed above and only those considered as important or with a potential to result in cumulative, synergistic or transboundary effects are assessed below. Consequently, discharges such as drainage water, cooling water and sewage are not addressed further in detail in this assessment.

The distinction between sources of effects and effects on receptors is not clear-cut. For example contamination of water is both an effect in itself and a potential cause of ecological or socio-economic effects. For convenience, the assessment of effects which follows is grouped:

- firstly into those effects resulting from a range of potential sources, specifically contamination of water, sediments and atmosphere (Sections 4.2-4.4)
- secondly, a consideration of oil spill risks (Section 4.5)
- thirdly, assessments of potential effects on individual receptors both ecological and anthropogenic (Sections 4.6-4.14)
- fourthly consideration of cumulative, synergistic and transboundary effects (Sections 4.15-4.17)

It should be noted that in order to allow an assessment of the implications of licensing, possible development and activity scenarios have been developed for consultation purposes by the DTI and these are outlined and considered in Volume 1.

4.2 Contamination of water

4.2.1 Importance

Potential contamination of the water column by exploration and production activities may be caused by discharges of produced water, sewage, cooling water, drainage and surplus drilling muds, which in turn may contain a range of hydrocarbons in dissolved and suspended droplet form, various production and utility chemicals, metal ions or precipitates (including Low Specific Activity (LSA) radionuclides) and salts. In addition to these mainly platform-derived discharges, a range of discharges is associated with operation of subsea developments (hydraulic fluids), pipeline testing and commissioning (treated seawater), support vessels (sewage, cooling and drainage waters) and terminals (predominantly ballast water from tankers).

Potential effects of discharges include direct toxicity, organic enrichment, contaminant bioaccumulation and dissolution of particulates and precipitates. Some slight elevation in the sea temperature may occur in the immediate vicinity of the discharge. These effects are of potential significance in terms of:

- Chronic accumulation of persistent contaminants in the marine environment
- Acute or chronic effects on biota, including effects on productivity, within the human foodchain (i.e. indirect effects on human health and commercial interests)
- Acute or chronic effects on other biota (i.e. indirect effects on biodiversity)

4.2.2 Effects

Produced water is derived from reservoir ("fossil") water and from breakthrough of treated seawater injected to maintain reservoir pressure, and is generally the largest single wastewater stream in oil and gas production (OLF 1998). Discharges of produced water in the North Sea were predicted to peak at about 340 million m^3/year in 1998 (E&P Forum 1994), followed by a levelling in discharge volumes. A more recent survey carried out by UKOOA concluded that total UKCS produced water discharges in excess of 300 million tonnes/year would probably be sustained to 2010 and beyond (UKOOA unpublished). The latest reported total produced water discharge from UKCS oil production was 253 million tonnes in 1998 (UKOOA 1999).

Chemical composition and effects of produced water discharges have been reviewed previously (e.g. Middleditch 1981, 1984, Davies *et al*. 1987, Ray and Engelhardt 1992, E&P Forum 1994, Reed and Johnsen 1996, OLF 1998). Chemical composition is strongly field-dependent, with generally no correlation between the oil-in-water content (which is used as the standard for environmental regulation) and the aromatic content. Studies of acute and chronic toxicity of produced water in Norway (OLF 1998) concluded that Polycyclic Aromatic Hydrocarbons (PAH) and alkylated phenols were the major contributors, with immunotoxic, carcinogenic and teratogenic effects in the former, and oestrogenic effects in the latter case.

The toxic effects of produced water are influenced by bulk dispersion and dilution processes following discharge, and by bioaccumulation and biomagnification of individual contaminants. Direct measurement of dispersion and dilution is extremely challenging from a technical viewpoint, and most studies have focused on the use of computer models (e.g. Rye *et al*. 1998, OLF 1998). Most studies have considered single sources, although the OLF (1998) model simulates discharges from all North Sea installations (Norwegian, British, Danish and Dutch) simultaneously. Field measurements have confirmed predicted concentration fields (Johnsen *et al*. 1998). Dispersed oil and PAH concentrations in the northern North Sea were predicted to be increased approximately tenfold over background concentrations. Uptake of selected PAH and phenol compounds from water in a marine planktonic food chain was rapid, with significant bioaccumulation at the lower level of the food chain (flagellate and dinoflagellate micro-zooplankton), and to a lesser extent in *Calanus finmarchicus*. The levels of PAHs observed in organisms were all much lower than literature reported No Effect Concentration (NEC) of PAH or phenolic compounds, suggesting (although final proof is lacking) that no adverse or chronic effects on marine organisms would be expected except for areas very close to the discharge points (less than 100-500m) (OLF 1998). The earlier studies reviewed by E&P Forum (1994) also concluded that the necessary dilution would be reached at 10 to 100m from the discharge point, and therefore that biological impacts would be confined to the seafloor or platform fouling community at the discharge site.

Other components of produced water include organic compounds (mainly volatile fatty acids), metals and residual process chemicals. None of these are considered likely to have significant effects (OLF 1998), with the possible exception of alkylated phenols which may have oestrogenic properties (see below).

In contrast to the intensively developed North Sea areas considered above, produced water discharges west of Shetland are, to date, relatively limited. Produced water discharges from Foinaven are currently around 20,000 bpd (1.2 million m^3/year) and are forecast to increase (including production from East Foinaven) to 142,000 bpd (8.1 million m^3/year) over ten years (BP Amoco 2000a). Produced water from Schiehallion will largely be reinjected, with a target availability for the reinjection equipment of 93% (BP Amoco 2000b).

In theory, wider dispersion of discharge effluents in the possible licence area will be influenced by the hydrographic regime, which for much of the area is characterised by vertical current shear, large temperature gradients and relatively little mixing between water masses. In practice, noting the dilution ranges necessary to achieve NECs for individual produced water components, such considerations will be of minor relevance as extremely low contaminant concentrations are achieved in close proximity to the discharge.

4.2.3 Understanding

The volume and composition of potential produced water and the proportion reinjected rather than discharged to sea from any field developments in the possible licence area cannot be predicted. However, the range of composition is unlikely to vary significantly from that produced in the North Sea and existing west of Shetland developments. Produced water chemistry and anticipated chemical use would generally be known from well testing prior to development of production facilities, and would be considered on a project-specific basis. Overall produced volumes in the possible licence area are unlikely to exceed produced volumes in the East Shetland Basin, which is one of the most intensively developed offshore areas in the world. Cumulative produced water effects are therefore considered unlikely to exceed those observed previously in the UKCS.

As noted above, direct measurement of dispersion and dilution of produced water components is extremely difficult, due to the low concentrations involved. Model development (e.g. PROTEUS in the UK, DREAM in Norway) has therefore concentrated on simulation of physical dispersion processes, in addition to more sophisticated chemical risk assessment methods than the Hazard Quotient (PEC/NEC) method used currently. However, further development and validation of dispersion modelling, including better understanding of the chemical partitioning of residual process chemicals (many of which have surfactant properties) would improve confidence in risk assessment.

The potential effects of endocrine disrupting compounds (e.g. alkylated phenols present in many produced waters) require further investigation (OLF 1998). An ongoing study of potential reproductive effects of alkylated phenols in cod reproduction is due to be completed later in 2000. In addition, current understanding of cumulative and synergistic effects of produced water components is inadequate. Improved understanding will require research on both chemical behaviour and toxicological effects.

Produced water management and alternative disposal techniques, including reinjection, improved treatment (“polishing”), downhole separation and shut-off all tend to have significant energy requirements and therefore increase combustion emissions from power generation. At present, there are no reliable and robust approaches to comparative assessment of the relative effects of air emissions and discharges to water, and selection of the preferred disposal option is judgemental.

The eventual fates of produced water discharges are poorly known. Although it might be expected that volatile hydrocarbon fractions, including some PAHs, will evaporate to atmosphere or be metabolised by marine organisms in the water column, surface adsorption onto biogenic or inorganic particulates and subsequent incorporation into sediments is a more likely fate for more persistent organic compounds and metals. At present, however, quantitative understanding of these processes is lacking.

However, the above issues are primarily of concern in relation to intensively developed, mature oil producing areas (e.g. the North Sea) where cumulative effects of produced water are more likely. With regard to the proposed licensing activity in the former White Zone and the known effects of produced water discharges, current understanding is considered adequate to support the Environmental Assessment process.

4.2.4 Control and mitigation

Produced water discharges are regulated under the Prevention of Oil Pollution Act 1971 with limits set for the proportion of oil in water (currently 40 mg per litre) and the daily flow which may be discharged. Chemical use and discharge is currently managed through the Offshore Chemical Notification Scheme, and in the near future will be controlled through regulations under the Integrated Pollution Prevention and Control Act 1999.

The management of produced water and chemical discharges will continue to be a key issue addressed through the environmental assessment process for planned developments (under The Offshore Petroleum Production and Pipe-lines (Assessment of Environmental Effects) Regulations 1999).

Current technical approaches to the minimisation and management of produced water discharges include reinjection (to reservoir, or more usually to a receiving formation via a dedicated well), and improved treatment. Produced water reinjection is a well established technology, and although requiring significant energy consumption, is likely to be a preferred option for many new field developments. Future technology, including downhole separation and improved reservoir management, may also substantially reduce produced water discharges in comparison to previous oilfield practice.

4.2.5 Conclusion

Wastewater discharges from production operations are likely to be dominated in terms of volume, and potential effect, by produced water. Potential effects include accumulation of persistent contaminants, and toxic or other disruptive effects on biota.

It is likely that, in the event of development within the possible licence area, a substantial proportion of produced water would be reinjected. Produced water discharges in intensively developed, mature areas of the North Sea have not resulted in significant effects, and it is considered unlikely that effects would result from developments in the former White Zone.

Other wastewater discharges from exploration, development and production activities, are of much lower volume than potential produced water discharges, and are not likely to have effects. Existing regulatory controls are adequate to prevent, minimise and mitigate potential effects of discharges to water.

4.3 Contamination of sediments

4.3.1 Importance

Seabed sediments act as a sink for contaminants discharged as solid phase particulates, and from dissolved discharges where these are adsorbed onto particulates or precipitate following discharge, and also for accidental spills. Potential sources of sediment contamination therefore include discharges to water reviewed above, in addition to discharges of solids from drilling wastes, sand and scale. Sediment disturbance through construction operations may also re-mobilise existing sediment contaminants.

The fate of sediment contaminants is strongly influenced by sediment transport and geochemical processes, and is therefore dependent on local environmental characteristics at the point of sedimentation. Although most sources of seabed contaminants can be considered as point-sources, the area of sedimentation may be considerable, with further spread as a result of sediment re-mobilisation. Much of the possible licence area is relatively deep water, with active sediment transport and sediment contamination is therefore likely to be relatively widespread, but low severity (in contrast to the central and northern North Sea, where sediment contamination by development drilling is characterised by localised piles of oil contaminated cuttings).

Potential effects of sediment contamination include direct toxicity to benthic communities, organic enrichment and subsequent modification of community structure and productivity, and contaminant bioaccumulation through the food chain. Benthic communities have complex interactions with planktonic, pelagic and demersal biota including commercial fish species. Sediment contaminants may therefore be of potential significance in terms of:

- Chronic accumulation of persistent contaminants in the marine environment
- Acute or chronic effects on biota, including effects on productivity, within the human foodchain (i.e. indirect effects on human health and commercial interests)
- Acute or chronic effects on other biota (i.e. indirect effects on biodiversity)

In many cases, the ecological effects of sediment contamination are similar to those resulting from physical disturbance of benthic biotopes, considered in Section 4.8.

4.3.2 Effects

Drilling wastes are a major component of the total waste streams from offshore exploration and production, with typically around 1,000 tonnes of cuttings resulting from an exploration or development well.

The major insoluble component of water-based mud discharges, which will accumulate in sediments, is barite (barium sulphate). Barite is known to accumulate in sediments following drilling (e.g. Hartley 1996), including development drilling in relatively deep water (400-600m) west of Shetland (ERT 1998). Barium sulphate is of low bioavailability and toxicity to benthic organisms (e.g. Starczak *et al*. 1992). Barite formation has been shown to be intimately related to settling biogenic material (decaying phytoplankton and faecal pellets) and accumulates in sediments (above the depth of barite dissolution) forming a useful proxy for past productivity of the overlying waters (Francois *et al*. 1995, Torres *et al.* 1996). Barium sulphate crystals are also known to be present within the protoplasm of xenophyophores (Tendal 1972), one species of which (*Syringammina fragilissim*a) is widely distributed in the Rockall Trough and was recorded in substantially elevated densities on the Darwin Mound tails (Bett 2000). The role of barite in xenophyophore metabolism is questionable, its formation (if it is indeed formed within the protoplasm) may simply be a defence mechanism, providing protection against the toxic effects of soluble barium compounds (Bett 2000).

Other metals, present mainly as salts, in drilling wastes may originate from formation cuttings, from impurities in barite and other mud components or from other sources such as pipe dopes. Although a variety of metals (especially chromium) are widely recorded to accumulate in the vicinity of drilling operations (e.g. Engelhardt *et al*. 1989, Kroncke *et al.* 1992), limited experience to date suggests that cuttings dispersion (due to water depth and current regime) prevents detectable accumulation of metals around drilling sites on the west Shetland slope. Following the drilling of ten development wells at the two Foinaven drill centres, the distribution of nitric acid extractable metals (excluding barium) indicated marginal variation across a sampling grid with no discernable patterns of distribution around the Foinaven location (ERT 1998).

Modelling of drilling waste dispersion is frequently carried out in support of environmental assessment of specific projects under the The Offshore Petroleum Production and Pipe-lines (Assessment of Environmental Effects) Regulations 1999. Dispersion modelling usually focuses on physical accumulation of cuttings (see Section 4.8), although contaminant concentration can also be simulated. To date, limited calibration and validation of dispersion models has been carried out for deep water locations west of Shetland.

As noted above, contaminants in aqueous discharges may accumulate in sediments following adsorption or precipitation. In the absence of organic phase drilling fluids and oil spills, produced water is likely to be the major source of hydrocarbons in sediments from offshore exploration and production. Hydrocarbons in produced water plumes have been shown to adsorb onto particulates in the water column and settle to the seafloor or contaminate the seafloor directly through bottom impact of the plume (MMS 1998) although the latter is unlikely in water depths characteristic of the possible licence area. Widespread, low-concentration accumulation of hydrocarbons in sediments of the East Shetland Basin has been attributed to produced water discharges (Davies and Kingston 1992). A significant effect is unlikely in view of anticipated produced water discharge volumes (see above) and dispersion in the possible licence area.

Sand, sludge and scale from production facilities may be discharged, as an alternative to onshore disposal, subject to regulatory controls. Hydrocarbon and metal contaminants may be present, but discharge quantities are generally low and no significant effects in the North Sea have been attributed to these sources. LSA scale, removed from pipework and vessels, has been routinely discharged from North Sea installations with no detectable accumulation in sediments.

Oil spills may also result in accumulation of sediment hydrocarbons through particulate adsorption and deposition, for example following the *Tsesis* (Boehm *et al.* 1980) and the *Braer* spills. The extent of deposition would depend on oil characteristics, the spill location and the local concentration of suspended particulate material. It is possible that a subsea spill in deep water would result in higher deposition rates than a comparable surface spill, since other processes (e.g. evaporation and photo-oxidation) would be limited.

4.3.3 Uncertainty

The fate and effects of sediment contaminants, in terms of geochemical processes and toxicology, are active research areas, with sufficient understanding for strategic environmental assessment purposes. However, in relation to the possible licence area, limited understanding of a number of specific environmental characteristics and processes would restrict confidence in project-specific assessments:

- To date, there have been few multiwell developments west of Shetland, and little validation of predictive dispersion modelling. Understanding of the area potentially affected by drilling waste discharges, and resulting contaminant concentrations, under the range of conditions prevalent in the possible licence area is therefore limited. In addition, sediment (and associated contaminant) sinks associated with sediment transport in the area have not been identified.

- The influence of seasonal phytodetrital deposition, in terms of adsorption and deposition of water column contaminants, is not known.

- The potential for deposition of hydrocarbons following a subsea oil spill is not known.

4.3.4 Control and mitigation

Solid and aqueous waste discharges containing oil from exploration and production operations are regulated under the Prevention of Oil Pollution Act 1971 and the Merchant Shipping (Prevention of Oil Pollution) Regulations 1996. Chemical use and discharge is currently managed through the Offshore Chemical Notification Scheme, and in future will be regulated through regulations under the Integrated Pollution Prevention and Control Act 1999.

Potential sediment contamination associated with specific exploration drilling or development projects in the possible licence area would require to be assessed under The Offshore Petroleum Production and Pipe-lines (Assessment of Environmental Effects) Regulations 1999.

Alternative disposal methods for cuttings, including onshore treatment and reinjection as currently implemented for oil and synthetic-based muds, may also be feasible for drilling with water-based mud (for example, if particular benthic biotope sensitivities were identified). However, the environmental benefit of these approaches would require detailed assessment.

4.3.5 Conclusion

Discharge of water-based mud and cuttings is identified as the major potential source of sediment contamination from exploration and production in the possible licence area. In comparison to existing North Sea development areas, sediment contamination is likely to be relatively widespread, but of low severity. Potentially toxic concentrations of contaminants are unlikely to occur. Significant sediment contamination by hydrocarbons, as occurred previously in the North Sea, will be prevented by regulation.

4.4 Atmospheric emissions

4.4.1 Importance

Gaseous emissions from the combustion of hydrocarbons and other releases of hydrocarbon gases contribute to atmospheric concentrations of greenhouse gases, acid gases and reduction in local air quality.

Global atmospheric concentrations of greenhouse gases include carbon dioxide (CO_2), methane (CH_4), and oxides of nitrogen (NO_X). Man-made emissions of greenhouses gases (particularly CO_2) are implicated in amplifying the natural greenhouse effect resulting in global warming and potential climate change (IPCC 1995).

Regional atmospheric concentrations of acid gases include sulphur dioxide (SO_2) and oxides of nitrogen (NO_X). These gases react with water vapour forming acids, and increasing the acidity of clouds and rain which can result in vegetation damage, acidification of surface waters and land, and damage to buildings and infrastructure. In addition these gases can transfer directly to terrestrial surfaces through dry deposition (close to the source) causing similar damage to acid rain (UKTERG 1988).

Reduction in local air quality through inputs of contaminants such as oxides of nitrogen (NO_X), volatile organic compounds (VOCs) and particulates, which contribute to the formation of local tropospheric ozone and photochemical smogs. Ozone impairs lung function and NO_X causes irritation of the airways and is particularly problematic for people with asthma (EPAQS 1996).

4.4.2 Effects

Indicative emissions from west of Shetland developments are available from environmental reporting by Foinaven and Schiehallion (Golar-Nor undated, BP Amoco 2000b). Flaring from the Schiehallion FPSO accounted for approximately 78 million m^3 in 1999, with 45 million m^3 burned in gas turbines on the FPSO for power generation. Also in 1999, 37,512 tonnes of diesel were consumed on two drilling rigs in the Schiehallion field, and 11,213 tonnes of heavy fuel oil was burned by the shuttle tanker Loch Rannoch. Resulting CO_2 emissions were estimated as 152,173 tonnes from flaring, 81,000 tonnes from diesel combustion and 88,310 from fuel gas combustion. CO_2 emissions from the Foinaven FPSO from January-October 1998 were 192,422 tonnes from flare (above target because of poor performance of the gas disposal well) and 126,179 tonnes from fuel (annual pro rata 230,906 and 151,415 tonnes respectively).

Venting and fugitive emissions account for a substantial proportion of hydrocarbon production methane and VOC emissions. Crude oil storage on FPSOs results in methane and VOC emissions. Tank venting during tanker loading has been a particular area of concern with VOC losses from a typical shuttle tanker, with a carrying capacity of 120,000 tonnes, of the order of 85-240 tonnes per load (OLF 1993), i.e. emission factor in the range 0.0007 to 0.002 tonnes VOC / tonne oil. BP studies indicate lower storage and emission factors for the Foinaven FPSO, with methane and VOC storage emissions of 0.0001375 and methane and VOC loading emissions of 0.00003 and 0.00006 respectively, in part due to the heavy biodegraded oil with low gas to oil ratios (GORs) (BP 2000a). Potential discoveries in the possible licence area may be similar, or may be of much lighter oil or condensates, which would tend to result in higher emission factors, although improved emissions control technologies are currently under development.

Significant VOC emissions are also associated with tanker loading and offloading at terminals, such as Sullom Voe, Flotta, Nigg and Hound Point. Onshore emissions mainly from terminals accounted for 56% of total VOC emissions from UKCS exploration and production in 1998 (UKOOA 1999), and development of the possible licence area would be expected to contribute to this source.

Short-term trends in emissions from exploration and production are variable – from 1996-1998, CO_2 emissions increased slightly (by 5%), methane emissions decreased by more than 10%, and NOx emissions have increased by 14% (UKOOA 1999). However, in the longer term it is likely that increased contribution from the Atlantic Frontier would (at least partially) offset reduced emissions from mature areas of the UKCS, in which production is expected to decline over the next few decades. Regardless, emissions from hydrocarbon exploration and production will be included in the UK efforts to meet its Kyoto and any subsequent commitments on atmospheric inputs.

4.4.3 Uncertainty

In addition to the uncertainty regarding the scale of potential emissions from the possible licence area, major uncertainties remain in the assessment of long-term environmental effects associated with greenhouse and acid gas emissions (UKTERG 1988, IPCC 1995).

4.4.4 Control and mitigation

Gas flaring is regulated through consenting under the model clauses included in production licences. Draft Offshore Combustion Installations (Prevention and Control of Pollution) Regulations 2000, at present out to consultation but expected to come into force by the end of 2000, would require permitting of all new offshore combustion processes with a thermal rated input greater than 50MW. High efficiency, low emission turbines are likely to be required for permit approval.

Vapour control during tanker loading and offloading is a developing technology, and would be a key issue in assessment of proposed developments involving tanker export, under The Offshore Petroleum Production and Pipe-lines (Assessment of Environmental Effects) Regulations 1999. Recycling of recovered vapour in the process, with disposal by gas export, reinjection or gas-to-liquids processing, is likely to be a preferred option.

4.4.5 Conclusion

Potential environmental effects of acid gas and greenhouse emissions are, respectively, regional and global in nature, and local environmental effects of atmospheric emissions are not expected to be significant, in view of the high atmospheric dispersion associated with offshore locations.

Significant combustion emissions from flaring are not expected from potential development in the possible licence area, in view of regulatory controls and commercial considerations, and combustion emissions from power generation are unlikely to represent a major contribution to industry or national totals. VOC emissions resulting from tanker loading are, potentially, an issue for consideration of mitigation in the event of further developments involving this export option.

4.5 Oil spill risk

Environmental risk is generally considered as the product of probability (or frequency) and consequence. The environmental consequences of oil spills are considered individually for environmental sensitivities in Sections 4.6 to 4.13. The sources, frequency and scale of hydrocarbons spills are considered below.

4.5.1 Spill scenarios and frequency

Hydrocarbon spills have been reported from exploration and production facilities on the UKCS since 1974 under PON1 (formerly under CSON7), with annual summaries published in the “Brown Book” series. This data – the DTI PON1 database – has been widely used for risk assessment in the preparation of Environmental Statements and Oil Spill Contingency Plans for exploration wells and developments in licensed areas west of Shetland and elsewhere on the UKCS. A geographically wider database, collated by SINTEF, includes reported well control incidents (i.e. “blowouts” involving uncontrolled flow of fluids from a wellbore or wellhead) from the North Sea and Gulf of Mexico from 1957 (Holand 1996). A risk assessment of oil spill events is currently being prepared for the Faroese sector by the GEM group of Operators. This assessment has considered sources, magnitudes and durations of spill scenarios associated with exploration activities on the Faroese side of the Faroe Shetland Channel.

Blowouts are extremely rare in modern drilling, with a range of historical frequencies quoted by Environmental Statements (indicative examples are reviewed below). Recommended blowout frequencies as input basis data for risk analysis of North Sea installations are provided by Holand (1996, Table 12.2), based on the SINTEF database. These vary from 0.0049 shallow gas blowouts/well for exploration drilling, to 0.00005 blowouts per production well-year (equivalent to 0.00075 assuming a typical 15 year well life). The recommended frequencies do not distinguish between gas and oil, which makes application to spill risk assessment difficult. The frequency of deep blowout for exploration drilling is given as 0.00196 per well by Conoco (1999, citing HSE data) and likely frequency of occurrence per development well is cited as 0.000046 by BP Amoco (2000b). Mobil (1998) quote a figure of 1 in every 660,000 exploration wells as causing severe pollution through blowout (i.e. frequency of 0.0000015). A range of exploration blowout frequencies, derived from safety risk assessment (DNV Technica 1991), is given by Conoco (1998) based on a worldwide frequency of 0.00049 per well. This figure is halved for UK operations, further reduced by an order of magnitude for large (>35kg/s) blowouts, and halved again for oil blowouts to give a frequency of 0.000123 large oil blowouts per well (8,130 wells per blowout). The range in quoted blowout frequencies is partly due to differences in the definition of blowout (e.g. exclusion of shallow gas events), and to difficulties in comparing risk units (e.g. events per well, events per workover, events per wireline job, events per well-year). It should also be noted that the historical blowout frequency databases are dominated by conventional (overbalanced, jointed pipe) drilling, in which hydrostatic pressure from the mud column and the blowout preventer (BOP) form primary and secondary barriers respectively. Coiled tubing and underbalanced drilling are more recent technical developments, mainly used in production and workover situations, which may involve significantly different barrier philosophies and therefore different risk scenarios. However, it is very likely that conventional methods would be used in exploration and development drilling in the possible licence area.

The only significant blowouts on the UKCS to date have been from *West Vanguard* (1985) and *Ocean Odyssey* (1988), both involving gas. The April 1977 Ekofisk blowout in the Norwegian sector released about 25,000 tonnes of oil, but killed relatively few birds due to the fortuitous timing (Mehlum 1980). The UK Health and Safety Executive's Offshore Safety Division (OSD) records well kicks, involving an unexpected but controlled flow of formation fluids into the wellbore, including "serious" kicks defined as those that posed a safety hazard to personnel on the installation or had the potential to cause a significant safety hazard (Hinton 1999). Between 1988 and 1998, 52 serious kicks have been recorded from 3,668 UKCS wells (an occurrence rate of 1.4%), none of which resulted in pollution (most kicks involved gas).

Seabed blowout flow rates in deep water will be limited by the high seabed hydrostatic pressure from the overlying water column. Qualitative analysis and preliminary modelling carried out for Faroese exploration suggests that high flow rate blowout scenarios (e.g. to surface via drillpipe) will tend to bridge relatively quickly, however, sustained well flow at low rates can be simulated under some circumstances, which could result in a prolonged release in the absence of intervention.

DTI PON1 data indicates that topsides and infield flowlines and risers are the most frequent sources of spills from production operations, with most spills being <1 tonne. A large proportion of reported oil spills in recent years (since about 1990) have resulted from process upsets (separation and/or produced water treatment), causing sheens from oil in produced water discharges and from oily drainage (usually via caisson discharges). For example, in 1998 there were 362 reports of spills of less than one tonne from the UKCS, representing 92% of all reports (DTI 1999). In contrast, major spill events from UKCS production facilities include the Claymore pipeline leak, 1986 (estimated 3,000 tonnes), Piper Alpha explosion, 1988 (1,000 tonnes) Captain spill, 1996 (685 tonnes). Although significant, these volumes are negligible in comparison to other anthropogenic sources of oil in the marine environment (e.g. 85,000-209,000 tonnes per year to the North Sea, including oil-based drilling fluids, NSTF 1993).

Since 1986 the UK has carried out unannounced surveillance flights over offshore installations in accordance with international obligations under the Bonn Agreement. In 1998, 3,641 surveys of installations were undertaken and the total amount of oil observed by unreported (via PON1) spills was estimated at just over 1 tonne (total reported spills were 137 tonnes) (DTI 1999). The Scottish Fishery Protection Agency also undertakes its own routine overflights of the UKCS.

Subsea oil spills pose particular problems, both in terms of detection and reporting of actual events, and in terms of consequence prediction. Chronic leaks from pipelines, manifolds and risers may not result in surface oil, and may be very difficult to quantify. This issue will become an increasing challenge with further deepwater development.

Oil spill risks associated with development of, and production from existing facilities west of Shetland, i.e. Foinaven, Schiehallion and associated tie-back developments, have been considered in a series of Environmental Assessments, Progress Reports and Statements (e.g. BP Exploration 1994, 1995, 1996, 1997, BP Amoco 1999, 2000a, 2000b). Export by shuttle tanker was assessed as a specific source of oil spills, with combined (all sizes) spill frequency from export pipelines considered to average about one spill in 15 platform years, and tanker offloading averaging about one spill in 9 platform years (BP 1997). Actual reported oil spillage totals from Schiehallion, and associated drilling rigs and vessels were 590 litres in 1998 and 106 litres in 1999, and <3 litres from Foinaven in Jan-Oct 1998 (BP Amoco 1999, 2000a, Golar-Nor undated).

The Environmental Statement for the East Foinaven development west of Shetland (BP Amoco 2000b) provides a recent comprehensive review of the DTI PON1 database in the context of development drilling, subsea completion, production via FPSO and tanker export west of Shetland. The major types of spill from mobile drilling rigs have been organic phase drilling fluids (and base oil), diesel and crude oil. There has been a correlation between the number of reported spills and number of wells drilled, but no consistent trend in the volume of hydrocarbons spills from mobile rigs since 1984 (a marked increase between 1986-1993, with a subsequent decrease to <100 tonnes/year). Estimated spill risk from UKCS subsea facilities averaged just over 0.11 spills per year (equivalent to a risk of one spill in any one year of 0.003 from an individual facility), with almost all reported spills <5bbl in size. Offshore loading spill risk from *Petrojarl Foinaven*, including incremental production from East Foinaven, was estimated as 0.034 incidents per year (or 1 spill every 29 years, based on historical incidence data for shuttle tankers operating on UKCS from Lloyds Maritime Information Service and BP Shipping Casualty databases). Predicted shuttle tanker scenario-specific risks ranged from an estimated 100-220 bbl (12.7-25.4 tonnes) loading hose spill (1 in every 260 liftings, or 2.6 years) to major structural failure resulting in a 450,000bbl (57,240 tonne) spill (1 in every 8772 tanker years).

Overall, the wide range in estimated risk quoted in Environmental Statements and elsewhere indicates the difficulty of deriving reliable predictions of potential spill frequency for future exploration and production operations (in part due to the low number of significant spills that have occurred under comparable circumstances). In view of uncertainty over activity levels following the proposed licensing, it would be misleading to attempt a quantitative assessment of cumulative oil spill risk associated with licensing in the former White Zone. Oil spill risk is best assessed and managed on an individual project basis. However, from previous exploration activity and numbers of developments west of Shetland, it is reasonable to conclude that the incremental frequency of a major oil spill (>1,000 tonnes) is low and is dominated by tanker offloading incidents. Credible scenarios for hydrocarbon releases on this scale (e.g. blowouts, major process failures, shuttle tanker casualties) involve multiple failures of management and control systems. Minor spills, <5 tonnes, are more likely, and could result from a wide variety of sources including subsea flowline and flange failures.

4.5.2 Spill fate

The fate of oil spills to the sea surface is relatively well understood, in contrast to subsea spills in deep water. Following a surface oil spill, there are eight main oil weathering processes:

- **Evaporation –** Lighter components of oil evaporate to the atmosphere. The amount of evaporation and the speed at which it occurs depend upon the volatility of the oil and the ambient temperature. An oil with a large percentage of light and volatile compounds will evaporate more than one predominantly composed of heavier compounds. Rough seas, high wind speeds and high temperatures tend to increase the rate of evaporation and thus the proportion of oil lost by this process.

- **Dispersion –** Waves and turbulence at the sea surface can cause a slick to break up into fragments and droplets of varying sizes which become mixed into the upper levels of the water column. Some of the smaller droplets will remain suspended in the sea water while the larger ones will tend to rise back to the surface, where they may either coalesce with other droplets to reform a slick or spread out to form a thin film. Small droplets have a greater surface area which facilitates other natural processes such as dissolution, biodegradation and sedimentation. The speed at which an oil disperses is largely dependent upon the nature of the oil and the sea state, and occurs most quickly if the oil is light and of low viscosity and if the sea is very rough. The use of chemical dispersants can accelerate the process of dispersion.

- **Emulsification –** Emulsification occurs as a result of physical mixing promoted by wave action. The emulsion formed is usually very viscous and more persistent than the original oil and formation of emulsions causes the volume of the slick to increase between three and four times and slows and delays the other processes which cause the oil to dissipate. Emulsions are not normally amenable to chemical dispersants. Oils with an asphaltene content greater than 0.5% tend to form stable emulsions which may persist for many months after the initial spill has occurred. Oils with a lower asphaltene content are less likely to form emulsions and more likely to disperse. Emulsions may separate back into oil and water again if heated by sunlight under calm conditions or when stranded on shorelines.

- **Dissolution –** Some compounds in an oil are water soluble and will dissolve into the surrounding water. The proportion dissolving depends on the composition and state of the oil, and occurs most quickly when the oil is finely dispersed in the water column. Components that are most soluble in sea water are the light aromatic hydrocarbons compounds such as benzene and naphthalene. However, these compounds are also those first to be lost through evaporation, a process which is 10-100 times faster than dissolution. In contrast to diesel, crude oil contains only small amounts of these compounds making dissolution one of the less important processes.

- **Oxidation –** Oils react chemically with oxygen either breaking down into soluble products or forming persistent tars. This process is promoted by sunlight. This process is very slow and even in strong sunlight, thin films of oil break down at no more than 0.1% per day. The formation of tars can form an outer protective coating of heavy compounds that results in the increased persistence of the oil as a whole. Tarballs, such as found on shorelines, have a solid outer crust surrounding a softer, less weathered interior and are a typical example of this process.

- **Sedimentation/Sinking –** Sinking is usually caused by the adhesion of sediment particles or organic matter to the oil. In contrast to offshore, shallow waters are often laden with suspended solids providing favourable conditions for sedimentation. Oil stranded on sandy shorelines often becomes mixed with sand. If this mixture is then washed off the beach into the sea it is likely to sink. In addition, if the oil is burned after it has been spilled, the tarry residues may be sufficiently dense to sink.

- **Biodegradation –** Sea water contains a range of micro-organisms that can partially or completely breakdown the oil to water soluble compounds (and eventually to carbon dioxide and water). Many types of hydrocarbon bacteria exist and each tends to degrade a particular group of compounds in crude oil. However, some compounds in oil are very resistant to attack and may not degrade. The main factors affecting the efficiency of biodegradation, are the levels of nutrients in the water, temperature and the level of oxygen present. The creation of oil droplets, either by natural or chemical dispersion, increases the surface area of the oil and thus increases the area available for biodegradation to take place.

- **Combined processes –** The processes of spreading, evaporation, dispersion, emulsification and dissolution are most important early on in a spill whilst oxidation, sedimentation and biodegradation are more important later.

The behaviour of crude oil releases at depth will depend on the immediate physical characteristics of the release, and on subsequent plume dispersion processes.

In qualitative terms, if associated gas is released from a wellhead, manifold, flowline, pipeline or riser along with crude oil, the mixing conditions at the release point will be very intense. The pressure differential between the source and hydrostatic pressure at the release point will be a critical factor in determining the form of the oil as it is released. If the release pressure is high and the size of the escape orifice is small, the oil will be converted almost instantly into a jet or plume of small oil droplets by the effect of its escape velocity and gas expansion. The crude oil will be mechanically dispersed into the sea. These very small oil droplets will have a low buoyant ascent velocity, but will be propelled towards the sea surface by the sea water entrained by the buoyant gas plume. Because the water from the deeper layers in the possible licence area is relatively cold, the plume will tend to collapse as it mixes into warmer surface water. The entrained oil droplets may therefore be distributed into a huge volume of the water column without ever having reached the sea surface.

The normal sea surface oil weathering sequence of spreading, evaporation, natural dispersion, emulsification and drifting will be compressed into a single event of mechanical dispersion for the vast majority of the oil volume. The more volatile (and more toxic) oil components will not be able to be evaporated into the air; they will partition into the surrounding water at a very rapid rate. The extent of emulsification and hydrate formation is dependent on conditions at the spill site. There will be little resultant oil on the sea surface and all environmental consequences (if any) will occur in the water column (Rye and Brandvik 1997).

If there is limited or no associated gas production, the oil will be released less energetically, with less shear and immediate dispersion resulting in a larger droplet size. However, a lack of gas will also result in a less buoyant plume, and there remains a high probability of dispersion within the water column.

4.5.3 Spill trajectory

Oil spill trajectory modelling can be carried out deterministically (i.e. with defined arbitrary metocean conditions, usually "worst case") or stochastically (i.e. using statistical distributions for wind and current regimes). Spill trajectory modelling has not been carried out for the possible licence area, although modelling has supported Environmental Assessments and Oil Spill Contingency Planning for exploration wells and developments in adjacent licensed acreage (e.g. BP Exploration 1995, 1996, Conoco 1998, 1999, Mobil 1998).

In general, stochastic modelling predicts oil spill trajectories from the west Shetland shelf break and slope towards the northeast, most probably to the north of Shetland. Most modelling has assumed Foinaven oil characteristics. For persistent oils, such as Foinaven, there is a moderate probability of surface oiling in coastal waters and beaching around Shetland, with lower probabilities for the Faroes, Orkney and northwest Scotland. Model simulations for diesel spills do not predict coastal oiling.

4.5.4 Uncertainty

A number of uncertainties relate to the assessment of oil spill risks associated with exploration and development in the possible licence area. Although reservoir characteristics of potential discoveries cannot be predicted, existing developments (Foinaven and Schiehallion) and proposed developments (Clair) all involve relatively persistent oils, and are closer to land (in the most probable trajectory) than the former White Zone. Previous risk assessments are therefore considered to be precautionary in relation to the proposed area.

The behaviour and fate of subsea oil spills is not well understood. In particular, the influence of hydrate formation, and subsequent dissolution, in buoyant plumes is not predictable. Ongoing work in Norway, including experimental releases, will increase understanding.

The approach to stochastic modelling generally used in the UK (i.e. the proprietary models OSIS and OILMAP), incorporates statistical distributions of historical wind direction and velocity, but does not allow for wind shifts within individual model runs. In contrast, the approach used in Norway uses historical wind data sequences. These approaches are complementary, and generic modelling of spills from the west of Shetland UKCS using the Norwegian approach would be useful.

4.5.5 Conclusion

Overall, incremental risk of oil spills associated with exploration and development in the possible licence area is low. In the event of a spill of persistent oil, and in the absence of an effective response, there is a moderate probability of coastal oiling around Shetland.

Significant uncertainty remains in relation to the behaviour and fate of subsea oil spills.

4.6 Plankton

4.6.1 Importance

Primary productivity by phytoplankton is the major source of carbon and energy supporting the offshore marine ecosystem. In general, there is extensive vertical flux of fixed material to meso-pelagic and benthic communities. Primary and secondary consumption by zooplankton (and associated faecal production) was previously thought to be the major route of utilisation and vertical flux (e.g. Raymont 1983) although phytodetrital deposition is now recognised to be a significant process for the direct transfer of phytoplankton biomass to the seabed (Billett *et al.* 1983, Rice *et al.* 1986).

The herbivorous copepod *Calanus finmarchicus* can represent up to 75% of zooplankton populations in the North Atlantic by number and more by weight (e.g. Pipe and Coombs 1980, Krause and Martens 1990, Gaard 1996, Heath 1999). *Calanus finmarchicus* is of particular importance to the ecosystem of the North Atlantic and North Sea, as it represents an important food source for the young of many fish species and is therefore an important element in the recruitment of fish stocks over the continental slope and shelf. The Faroe Shetland Channel is recognised is being an important over-wintering area (Heath and Jónasdóttir 1999) with substantial populations of *C. finmarchicus* transported into the North Sea in spring, primarily by the Norwegian Trench Atlantic Inflow and to a lesser extent the East Shetland Atlantic Inflow (Heath 1999, Madden *et al.* 1999).

The macrozooplankton of the Faroe Shetland Channel is much less understood. The most abundant macrozooplankton are the krill species (mainly *Meganyctiphanes norvegica* and (probably) *Thysanoessa inermis* while amphipods are expected to occur in somewhat lower abundances. There may also be some small mesopelagic fish species, mainly *Benthosema glaciale*. Krill are known to be abundant in the North-east Atlantic and the Nordic Seas (Mauchline and Fisher 1969, Lindley 1982). Macrozooplankton are an important component of the plankton ecosystem, providing an important source of food for redfish and other pelagic carnivores including seabirds, basking shark and baleen whales.

Many benthic species, and most commercial fish species have a temporary planktonic larval development phase, with generally predictable timing of occurrence.

4.6.2 Effects

Potentially significant sources of effect on plankton include physical effects of seismic noise, direct toxicity of discharges, bioaccumulation of contaminants with potential transfer to higher trophic levels of the food chain, eutrophication and oil spills. Negligible effects are possible from (for example) entrainment in abstracted seawater, and thermal stress due to heated discharges. Indirect effects on predators of plankton are also possible, for example dispersion of krill swarms could affect feeding efficiency of baleen whales although this is considered unlikely to be significant (no such effects have been noted in studies of feeding arctic whales).

The effects of seismic exploration on plankton are due to direct effects of sound pressure in close proximity to airguns and are considered to have negligible cumulative effect on planktonic populations (McCauley 1994, Turnpenny and Nedwell, 1994). Norwegian studies of commercial fish egg and larval mortality support this conclusion (Gausland 1996).

Potential sources of toxicity and contamination are reviewed in Sections 4.2 – 4.3, with produced water considered to be the most important source. Toxicity of individual produced water components is not significant except in the immediate vicinity (<100m) of the discharge. Although the toxicity of whole produced water is less well characterised, available data indicates detectable toxicity only at low dilutions (API 1996, Gamble *et al.* 1987).

Eutrophication from sewage and produced water discharges could cause increased primary productivity through the availability of nutrients which otherwise limit phytoplankton production. The scale of inputs and available dispersion indicates that no detectable effects are likely.

In the context of the biogeographical area, potential oil spills at the sea surface (see Section 4.5) would be relatively local and are extremely unlikely to have a significant effect on plankton populations. No significant effects have been detected following major tanker spills (e.g. Ritchie and O'Sullivan 1994). Effects from a prolonged subsea blowout are difficult to study experimentally and to predict, although a study commissioned through the Faroes GEM group should inform these uncertainties. In addition, the results of field work planned for summer 2000 on the actual behaviour of deepwater spills of part of the DEEPSPILL programme should help to validate models.

4.6.3 Conclusion

Although localised effects of sound pressure and toxicity are possible, these will be limited to ranges of a few metres (seismic) and tens of metres (produced water) and no other significant cumulative effects on a population or ecosystem scale are predicted.

4.7 Deep sea fish and cephalopods

4.7.1 Importance

Comparatively little is known about the biology and distribution of deeper water fish populations. What is known is that in general terms, a higher species diversity is seen on the continental shelf than on the slope, although commercially exploited deep-sea species remain a small proportion of the total species richness. Some deep water fish species are thought to migrate to surface layers at night to feed. This behaviour therefore means a link between surface pollution and deep water populations is feasible (Gordon *et al.* 1995).

Concerns about the sustainability of deep water fisheries are based on these fish species having late sexual maturity, a long-life span, low fecundity and slow growth; all these factors are thought to be biological adaptations to low food availability (Atkinson 1994, Gordon *et al.* 1995, Merrett and Haedrich 1997). Some larger deep water fish species are known to exhibit semelparity (reproduce only once in a lifetime) (Gordon *et al.* 1995). Work on breeding biology of deep water demersal species has been undertaken by Merrett (1994) (cited in Gordon *et al.* 1995). This work was limited to commercially exploited species, which represented only 19% of the known demersal species in the North Atlantic Basin, and results from the study supported the generally held belief of late sexual maturity, with only large adults spawning. All the species examined produced small eggs, presumably indicative of a planktonic larval phase. Such reproductive behaviour makes deep-sea fish populations especially vulnerable to exploitation through harvesting and slow to recover from disturbances.

The cold Norwegian Sea water of the Faroes Shetland and Faroe Bank Channels supports a very impoverished and distinct fish fauna of little commercial value (Gordon *et al.* undated). Very few of the Atlantic deep water species are found on the upper slopes of the Faroe Shetland Channel, which are typically inhabited by species with a limited depth span over their whole life cycle (i.e. limited to upper warmer layer of Atlantic water). Of note are those species that are found at the transition zone between cold Norwegian Sea water and upper layer of warm Atlantic water, species such as the Greenland halibut (*Reinhardtius hippoglossoides*), roughhead grenadier (*Macrourus berglax*) and the redfish (*Sebastes mentella*). These species are only rarely found to the south and west of the Wyville Thomson Ridge (Gordon *et al.* undated).

Mesopelagic cephalopods, mainly teuthoid squid and sepioids (cuttle-fish) are known to be abundant and diverse in the deep North Atlantic west of the former White Zone (Lu and Clarke 1975). The commonest mesopelagic species are relatively small, rarely exceeding 30cm in overall length, including *Abraliopsis affinis*, *Histioteuthis* spp., *Pyroteuthis margaritifera* and *Mastigoteuthis schmidti*. Two small sepioids, *Spirula* and *Heteroteuthis*, and the octapods *Vitreledonella richardi* and *Japetella diaphana* are also common at mesopelagic depths. However, it is known from cetacean (especially sperm whale) stomach contents that larger squid must also be abundant (Clarke 1977). Some species of mesopelagic cepalopods undertake diurnal vertical migrations and occur at epipelagic levels during the night (Clarke and Lu 1974, 1975). Ontogenetic migrations are also known, and it is thought that most deep sea cephalopods have epipelagic larval stages.

At present, mesopelagic cephalopods are not commercially exploited in the former White Zone. They are known, however, to be a key food source for cetaceans particularly sperm and beaked whales (e.g. Benjaminsen and Christiansen 1979, Desportes and Mouritsen 1989), and seabirds (Hunt *et al*. 1996).

4.7.2 Effects

Potentially significant sources of effect on deep sea fish include physical and behavioural disturbance effects of seismic noise, direct toxicity of discharges, bioaccumulation of contaminants with potential transfer to higher trophic levels of the food chain and oil spills. Behavioural or distributional disturbance is possible through attraction to physical structures, as noted for shallow water demersal species (mainly gadoids) where aggregation rather than overall increase in numbers is thought to occur. Aggregations of saithe and redfish have also been noted around *Lophelia* reefs (Mortensen *et al*. 1995) A further possible effect is physical damage or behavioural disturbance by the presence of lights on ROVs or subsea equipment, although the numbers of individuals potentially affected will be negligible in population terms.

The potential physiological and behavioural effects of seismic noise on shallow water fish species have been widely reviewed (e.g. Turnpenny and Nedwell 1994, McCauley 1994), although virtually nothing is known specifically concerning deep water species. Assuming that the anatomy, physiology and acute behavioural (e.g. startle) responses are comparable to those in shelf species, qualitatively similar effects might be expected in deep water mesopelagic and demersal species, mitigated by vertical distance from surface airgun sources and by a relatively low population density. Conversely, since airgun arrays are designed to focus sound vertically, and minimise side lobe propagation, it could be speculated that deep water fish are exposed to relatively high intensity noise.

Most studies of fish in response to seismic have focused on catchability (e.g. Skalski *et al*. 1992, Engås *et al*. 1993). It is not known whether behavioural effects on commercial catchability also apply to predation by seabirds and cetaceans. Behavioural studies have investigated the effects of seismic sound in experimental systems (Pearson *et al*. 1992) and in the field (Wardle *et al*. 1998). The former study (together with Skalski *et al*. 1992) considered the redfish *Sebastes* spp., species of which are also commercially exploited in the deepwater northeast Atlantic. The studies of Wardle *et al*. (1998) investigated fish and invertebrates around a reef in a Scottish west coast sea loch when exposed to airgun sound at various intensities and distances. Although fish showed a distinctive startle response, electronic tagging showed no change in the location of fish.

Cephalopods lack the gas-filled swim bladder and lateral line organs which make fish sensitive to sound pressure effects. However, they have a well-developed central nervous system and it can reasonably be assumed that some degree of behavioural disturbance of mesopelagic cephalopods by noise is likely.

Potential sources of toxicity and contamination are reviewed in Section 4.2, with produced water considered to be the most important source. Mesopelagic and demersal fish and cephalopods are unlikely to come in contact directly with discharge plumes. Bioaccumulation and transfer of contaminants via the food chain is possible, although under the OCNS chemicals used in exploration and production are screened for bioaccumulating substances. Cephalopods are known to accumulate very high concentrations of metals, especially copper (e.g. up to 15,000 µg/g dry weight in livers of *Loligo opalescens* from the Pacific, Martin and Flegal 1975 – one gramme of squid dry liver contains as much copper as 11.7 tonnes of Monterey Bay sea water). The physiological significance of this is unclear, but diet is assumed to be the source of high concentrations of metals (especially cadmium and mercury) in pilot whale tissues around the Faroes (Caurant *et al*. 1994). However, although metals are discharged in produced water and drilling wastes from offshore exploration and production, the potential incremental contribution to metal concentrations in sea water in the possible licence area is predicted to be negligible, and direct exposure pathways for mesopelagic fish, cephalopods and cetaceans are not expected.

Subsea oil spills could potentially affect mesopelagic fish and cephalopod populations through (in the worst case) dispersion of large quantities of hydrocarbons in the water column. Accumulation of hydrocarbons and toxic effects in shallow water fish are known to occur following surface oil spills (Stagg *et al*. 1997) with larval stages generally more sensitive and exposed to high oil concentrations in surface films. Adult fish tend to be more mobile and exhibit avoidance of hydrocarbon concentrations. Pelagic development is thought to be typical for most mesopelagic fish and cephalopods which would mitigate the effects of subsea spills. In view of the low probability of a major release (see Section 4.5), the risks to deep sea fish at a population level are considered to be low.

4.7.3 Conclusion

The potential effects of seismic noise on deep water fish and cephalopods are unknown, although extrapolation from shallow water fish suggests that ecological effects would not be significant at a population level. Commercial exploitation of mesopelagic and deep water demersal populations is not currently or predicted to be intensive, and economic effects of seismic activities on fisheries would not be expected. Significant contamination of fish, cephalopods and their predators is not considered likely, and oil spill risk to populations is low.

4.8 Benthic biotopes

4.8.1 Importance

The former White Zone area includes the interface of five marine biogeographic zones and has a wide variety of substratum types from rock outcrop, mixed sediments to mud. While most sediments are inhabited by a range of species which are known to be or can be expected to be widely distributed, a range of rare or uncommon benthic species and biotopes (a physical habitat and its associated biological community) occur in the area. These include carbonate mounds (the Darwin Mounds) with colonies of the cold water coral *Lophelia pertusa* and dense populations of xenophyophores in the immediately adjacent area. Such mounds are currently only known from two discrete areas on the Wyville Thomson Ridge, although both *Lophelia* and xenophyophores are widespread in surrounding areas. These mounds may be regarded as reefs under the EC Council Directive 92/43/EEC and could be designated as Special Areas of Conservation. Other important seabed biotopes known from the area or which could be present, include areas dominated by large sponges, rough ground with extensive epifauna, gas hydrates, seeps of hydrocarbons or sulphidic water

The seabed fauna is important as a major food source for demersal fish and other predators. The seabed also acts as a sink for contaminants derived from terrestrial and marine sources through atmospheric fallout, solid phase and aqueous discharges (where these become adsorbed onto particulates). The seabed is thus a potential route for the transfer of contaminants into the food chain, either directly, or if biogeochemical processes in sediments alter the state of metals or organic contaminants making them available for uptake by benthic animals. Benthic fauna and microflora are instrumental in the rapid metabolism of the periodically deposited phytodetritus. Seabed animals also form a major reservoir of marine biodiversity although the full extent of this or its relative importance has not been fully explored, either in the former White Zone or globally.

4.8.2 Effects

Physical damage to seabed individual organisms or colonial animals can be caused by several routine activities. These are:

- Seismic survey
- Drilling from a mobile rig
- Surface hole sediments and cuttings
- Pipelay and trenching

The physical disturbance of the seabed from anchoring, pipeline trenching and other hydrocarbon exploration and production activities can result is a range of effects at various scales. Crushing or physical damage of biota through direct impact or dragging of cables, anchors etc is likely to be the most important source of significant effect from physical disturbance to large, long lived fragile species. The spatial extent of effects will be operation specific but even small scale disturbance of a unique or sensitive feature may result in effects considered as significant. The duration of effects is related to the life history of the species involved or to the timescale required for a biotope to become developed. The majority of seabed species recorded from the former White Zone area are known or believed to have short lifespans (a few years or less) and relatively high reproductive rates, indicating the potential for rapid recovery, typically between 1 to 5 years (Jennings and Kaiser 1998). The lifespans of only a proportion of deeper water species found in and around the area are known, but the general conclusion of the studies is that growth and mortality may not be markedly different from shallow water species (Gage and Tyler 1991). There are several long lived benthic species recorded from adjacent areas which may be present in parts of the former White Zone e.g. the bivalve *Arctica islandica* which can live for over 200 years (Ropes 1985), and the largest colonies of the cold water coral *Lophelia pertusa* are believed to be several thousand years old (Bruntse and Tendal, 2000). The growth rates and ages of large sponges present in the area are essentially unknown.

In addition to potential damage to biotopes or individual species, a range of physical effects at the seabed may occur from anchor deployment (impact depressions), tensioning or dragging of anchors and attached cables (scars, mounds and displacement), retrieval (depressions and mounds) and pipeline trenching (spoil mounds). The creation of mounds or scars on the seabed can affect demersal fishing by snagging trawls or dredges and by contaminating the catch with clay, blocks of which can be picked up in the nets and mixed with fish in the cod end. The duration of such effects varies from short to long term depending on the nature of sediments and the durability of the cohesive masses at the seabed surface (Dunaway and Schroeder, 1988).

The longevity of surface hole cuttings mounds will be dependant on the rate of erosion, which is a function of the nature of the material and current speeds in the area. This suggests that in the majority of the former White Zone area, surface hole material mounds will be short lived, being eroded and widely dispersed by currents.

Lethal effects may result from smothering by sediment of sessile and mobile animals, if the depth of burial is beyond their powers of escape or clearance. This smothering can be direct or indirect (from winnowing disturbed material) and effects on infauna are normally short lived and similar to those from severe nearshore storms and dredge spoil disposal where recovery is normally well underway within a year (Rees *et al*. 1977, SOAEFD 1996). Benthic storms can generate substantially elevated suspended sediment loads in deep waters, for example at the HEBBLE site on the Nova Scotia rise during a 10 week period several elevations in sediment concentrations occurred (lasting days), peaking at over 10mg/l (Hollister *et al*. 1984). Bedforms in many areas of the former White Zone indicate active sediment erosion and transport (Jacobs and Masson 2000) and nepheloid layers are known to occur in the region. There is limited information on the sediment clearance abilities of continental shelf and slope sessile epifauna or the effects of sedimentation on them, especially on long lived species such as scleractinian and other corals. Work on tropical reefs indicates that excessive sedimentation can adversely affect the structure and function of the coral reef ecosystem by altering both physical and biological processes (Rogers, 1990). Tropical reef corals are particularly susceptible to sedimentation effects as they contain symbiotic algae and are dependant on light for photosynthesis. While cold water corals do not have such symbioses, Rogers (1999) conjectured that *Lophelia pertusa* may be even more susceptible to sedimentation than its shallow water counterparts on the assumption that sediment loads in deep-water habitats are generally lower than on the shelf (but see Hollister *et al.* 1984). The strong currents found the general area (Turrell *et al*. 1999) and in areas of *Lophelia* occurrence (Frederiksen *et al*. 1992) may both cause sediment suspension and transport and alleviate the effects of increased sediment load (Rogers 1999). Bett (2000) notes evidence of active sediment transport (rippled sand) in the area of the Darwin Mounds and suggests that the corals present are normally subject to particulate deposition and to sediment scour from particle laden bottom waters. It is noteworthy that *Lophelia* has recently been found growing on various oil installations in the northern North Sea (Bell and Smith 1999), suggesting greater larval dispersive ability and adult tolerance to oilfield drilling solids and other discharges than has been hitherto recognised.

In addition to the potential lethal effects of sedimentation, sediment plumes in the water column and settling to the seabed from surface hole jetting and pipeline trenching activities can result in sub-lethal effects on biota through clogging of feeding mechanisms, temporarily altering the nature of the seabed sediments or in near surface waters, reduction of light for photosynthesis (Newell *et al*. 1998). The extent of effects will vary according to the frequency of occurrence and the tolerance of the species involved, itself a function of the average and extreme natural levels of sediment transportation/deposition experienced in an area.

Inversion of boulders at the seabed causes damage or death of epifauna living on the boulder surface. Some of the species involved, especially those in deeper waters can be long-lived and fragile. Physical damage to rock outcrops can occur through anchoring on or anchor cables dragging across fractured or friable rocks (the crushing of biota effects are considered above).

Localised biological effects may result from changed sediment type. Mixing of sediments can occur through anchoring and trenching activities and result in an alteration to the nature of the seabed surficial sediments and therefore the type of seabed biological community it can support. Naturally infilled depressions may have a different sediment (e.g. muddier or more uniform) to the surrounding area, resulting in detectable faunal differences. The scale of such effects is minor while the duration can vary from short to long term depending on the durability of the material deposited at the seabed surface (e.g. indurated clays).

Dropped objects and construction debris if left on the seabed would form a hard substratum which would in time become colonised by a range of animals. The significance of this is minor since the former White Zone and adjacent areas are rich in glacigenic boulders, cobbles etc. providing ample hard surfaces.

The past discharge to sea of drill cuttings contaminated with oil based drill mud resulted in well documented acute and chronic effects at the seabed (e.g. Davies *et al*. 1989, Olsgard and Gray 1995, Daan and Mulder 1996). These effects resulted from the interplay of a variety of factors of which direct toxicity (when diesel based muds were used) or secondary toxicity as a consequence of organic enrichment (from hydrogen sulphide produced by bacteria under anaerobic conditions) were probably the most important. However, through OSPAR and other actions, the discharge of oil based and other organic phase fluid contaminated material is now effectively banned and the effects of such discharges are not considered further.

In contrast to oil based mud discharges, the effects on the seabed fauna of the discharge of cuttings drilled with water based muds and of the excess and spent mud itself are subtle or undetectable, although the presence of drilling material at the seabed is normally detectable chemically (e.g. Cranmer 1988, Neff *et al*. 1989, Hyland *et al*. 1994, Daan and Mulder 1996). Water based muds are of low inherent toxicity (see Ray *et al*. 1989) and most studies using the major individual constituents have reported limited or no effects (e.g. Tagatz and Tobia 1978, Starczak *et al.* 1992). However, in contrast to the general picture of limited effects, Cranford and Gordon (1992) reported low tolerance of dilute bentonite clay suspensions in sea scallops (*Placopecten magellanicus*). Cranford *et al*. (1999) found that used water based mud and its major constituents, bentonite and barite caused effects on the growth, reproductive success and survival of sea scallops, which were attributed to chronic toxicity and physical disturbance. It may be that *Placopecten* is especially sensitive to drill muds (or fine sediments in general) or that in the field, water based drilling discharges very rapidly disperse to below effective concentrations. Alternatively, certain filter feeding organisms may be sensitive to water based mud materials. Studies of the effects of water based mud discharges from 3 production platforms in 130-210m off California found significant reductions at the high flux stations in the mean abundance of 4 of 22 hard bottom taxa investigated using photographic quadrats (Hyland *et al*. 1994). Hyland *et al*. (1994) concluded that these reductions reflected possible negative responses to drilling discharges. During the study period some 11,200 tonnes of drill mud solids were discharged and as the mud constituents in the suspended particulates were below the toxicity threshold, the effects were attributed to the physical effects of particulate loading, namely disruption of feeding or respiration of the burial of settled larvae. It is noteworthy that 3 of the 4 potentially affected taxa were sessile suspension feeders and also that the coral *Lophelia prolifera* (=*pertusa*) was present but apparently not significantly affected. The consideration of potential smothering effects on fauna of natural seabed sediments (above) is believed to be applicable to waterbased mud discharges.

4.8.3 Understanding

The combination of DTI 1999 and 2000 surveys of the former White Zone together with past information of the area and adjacent regions (notably the AFEN 1996 and 1998 surveys and the BIOFAR programme), has provided a good initial picture of seabed topography, biotopes and species. It is likely that some small scale biotopes and large, potentially vulnerable species have yet to be identified in the area. Similarly, while adequate for the purposes of this assessment, a full appreciation of the benthic biodiversity of the area and its relationship with adjacent areas can only be achieved following further scientific study of the taxonomy, biogeography and general ecology of the benthic fauna of the region. Several UK and international initiatives and research programmes are underway which will help to fill these gaps in understanding.

4.8.4 Control and mitigation

The environmental implications of any proposed wells, developments and pipelines (above defined thresholds) in the possible licence area would require to be given due consideration before being consented under UK regulations implementing the European Directives on integrated pollution prevention and control (IPPC) and on the assessment of the effects of certain public and private projects on the environment. Major or important reefs or selected other seabed features may be designated as Special Areas of Conservation under the European Directive on the conservation of natural habitats and of wild fauna and flora. If so, under the terms of the Directive, an Appropriate Assessment would be required if a plan or project would be likely to have a significant effect on the SAC (unless directly connected with the management of the site for nature conservation purposes).

Understanding the location and extent of sensitive seabed features is key to their protection. Surveys of rig or development sites and of a pipeline route typically involve side scan sonar and swathe bathymetry which allow the detection of the majority of localised biotopes. Through altered location(s) and control of discharges, in most cases potential seabed damage resulting from the operation could be mitigated to acceptable levels.

The United States approach to such areas provides a useful context. A number of banks and elevated topographic features within the Gulf of Mexico are shallow enough to receive sufficient light to allow hermatypic coral growth (i.e. corals with commensal algae) (Rezak *et al*. 1985). These sites are protected by licence conditions (Topographic Features Stipulations as part of leases) which include no activity zones (defined by the 85m bathymetric contour) and shunt zones where drilling discharges are to be made close to the seabed. A number of sites (e.g. Flower Garden Banks) are US National Marine Sanctuaries and receive similar protection but with more precautionary depths and distances for the zones. The US lease stipulations are intended to protect hermatypic corals from physical damage, reductions in light intensity and smothering.

4.8.5 Conclusion

The area for possible licensing contains a known area of coral mounds (the east Darwin Mounds) which are susceptible to physical damage, for example from anchor impact or cable scrape, and potentially to solid (particularly drill muds and cuttings) and aqueous discharges. Adverse effects can be avoided through controls on the proximity of such activities and the discharge of effluents.

4.9 Seabirds

4.9.1 Importance

Seabird populations within the possible licence area are dominated by breeding birds originating mainly from major colonies in the Faroe, Shetland, and Orkney Islands and more northerly breeding areas such as Norway and Iceland. In addition, a number of species migrate through the area in late summer and autumn (skuas and shearwaters), or are present as winter visitors (gulls and little auk). The Atlantic Frontier region – west and north of Scotland – contains substantial proportions of the biogeographic (i.e. north-east Atlantic) breeding populations of some species, in particular great skua (64.6%), gannet (49.8%), puffin (49.5%) and black guillemot (45.3%). Shetland and Orkney support a major proportion of the regional populations of these species. The Faroe Islands support further biogeographically significant breeding populations.

A total of 40 seabird species have been recorded in slope and oceanic waters of the Atlantic Frontier, during systematic surveys incorporated in the ESAS database. Petrels (mainly fulmar) were the most abundant taxon, followed by auks and gulls. Eight species were present over the deep waters throughout the year. In order of decreasing abundance, they were: fulmar, gannet, kittiwake, puffin, great black-backed gull, guillemot, herring gull and razorbill. Apart from fulmar, all species were found in greater numbers over the shelf. Seven species were summer visitors: European storm-petrel, lesser black-backed gull, great skua, Leach's storm-petrel, Manx shearwater, Arctic tern and Arctic skua. Three species were winter visitors: Iceland gull, glaucous gull and little auk, and four were transiting migrants: great shearwater, long-tailed skua, Pomarine skua and sooty shearwater.

Recorded densities of some seabird species over the possible licence area are relatively high, with up to 9 fulmars/km^2 over Atlantic Frontier slope/oceanic waters recorded by Pollock *et al*. (in press) and 24.7 fulmars/km^2 for north-west oceanic waters recorded by Stone *et al*. (1995). The next most abundant species were gannets (0.8 birds/km^2 , Pollock *et al*. in press, 4.8 birds/km^2 , Stone *et al*. 1995) and kittiwakes (0.75 birds/km^2 , Pollock *et al*. in press, 4.1 birds/km^2 , Stone *et al*. 1995). Auks were recorded at densities of ca. 0.5 birds/km^2 (combined guillemots, razorbills and puffins), European storm-petrels at 0.2 birds/km^2 (Pollock *et al*. 1995) and great skua at 0.05 birds/km^2. (NB. The north-west oceanic area considered by Stone *et al*. 1995, extends north of 54ºN).

In comparison, densities of up to 12.1 fulmars/km^2 and 7.3 kittiwakes/km^2 have been recorded from the Shetland, Orkney and Moray Firth shelf, 6.7 storm-petrels/km^2 and 1.39 gannets/km^2 from the shelf slope south-west of Ireland, and 14.4 guillemots/km^2 from the western North Sea (Stone *et al*. 1995).

In terms of relative population density, therefore, the slope and oceanic areas including some of the possible licence area are considered among the most important offshore areas in north-west European waters for fulmar and gannet (which have a widespread distribution). European and Leach's storm-petrels have a predominantly oceanic distribution and internationally important breeding populations utilise the area during summer, although higher densities of European storm-petrels are known to occur off south-west Ireland (Pollock *et al*. 1997). Great skua densities, although relatively low, are of international importance.

Seabird distribution at sea is strongly influenced by food availability, with more birds found in hydrographic frontal areas, and over shallower continental shelves than the deeper oceanic waters (Stone *et al.* 1994). Although much information exists on the diet of seabirds during the breeding season, suggesting a high degree of reliance on sandeels *Ammodytes* spp. and clupeids, there is a lack of information on diet away from the coast and in winter (Jensen *et al*. 1994). In general, the Faroe Shetland Channel and north of Shetland areas, and to some extent the Wyville Thomson Ridge, are less important for birds than the adjacent shelf areas and shelf break. Food availability is variable both geographically and temporally, and the foraging ranges of individual species (e.g. Hamer *et al*. 1993, Uttley *et al*. 1994) and distribution (e.g. Blake *et al*. 1984, Tasker *et al*. 1987) of seabirds is known to vary significantly from year-to-year.

The seasonal importance of the shelf edge and deep water Atlantic Frontier was considered to be greatest during summer (Pollock *et al*. in press), due especially to the presence of European and Leach's storm-petrels from June to August, and great skua in April and May.

Factors which influence seabird numbers, and therefore population status of individual species, are comprehensively reviewed by Lloyd *et al*. (1991), who concluded that food quality and abundance were probably the most important factors currently affecting seabird numbers. Commercial fishing has resulted in major, but complex changes in seabird food stocks (Furness 1987) including removal of food source (especially herring), reduction in competition (by removal of predatory fish), and availability of fishing discards. In addition, entanglement in nets is a major cause of seabird mortality. Using evidence from ringing recoveries, Mead (1989) considered that modern fishing techniques, particularly the use of monofilament nets, are now the main cause of unnatural death among auks, especially in the seas around Britain and off Iberia.

Pollution of the sea by oil, predominantly from merchant shipping, can also be a major cause of seabird mortality. Chronic pollution resulting from illegal dumping or tank washing probably has a greater impact on seabirds than accidental spills from shipping casualties (e.g. Andrews and Standring 1979).

4.9.2 Effects

Potential effects on seabirds, associated with exploration and production in the possible licence area, include direct disturbance effects of noise and physical presence, direct mortality and sub-lethal effects associated with surface oil pollution and indirect effects related to disturbance or contamination of prey species.

Direct effects, due to noise or physical presence of installations and support vessels, will extend over limited ranges and will influence seabirds which are foraging over wide areas (in contrast to disturbance of coastal breeding sites). The likely ranges of effect of light and noise is of the order of a few kilometres, within which total seabird numbers (assuming a total seabird density <10 birds/km^2) will be limited. Attraction of seabirds to installations and support vessels is likely to influence distribution at a local scale, particularly for fulmars, gulls and skuas which frequently scavenge around vessels. In a regional or population context, however, the scale of such effects associated with the hydrocarbon industry is negligible in comparison to that resulting from fishing activities, which are known to have a significant influence on seabird distributions (e.g. Camphuysen *et al*. 1993, 1995). Seabirds, especially gulls, may also make opportunistic use of fixed installations as a resting place or regular roost (Tasker e*t al*. 1986).

Opportunistic use of vessels and facilities by migrant or vagrant land birds is also well known (e.g. North Sea Bird Club records), although such use may be less frequent west of Britain than in the North Sea, where installations are located conveniently for birds on passage between Scandinavia, continental Europe and the UK.

Direct effects on seabirds because of seismic exploration noise could occur through physical damage, or through disturbance of normal behaviour. Diving seabirds (e.g. auks) may be most at risk of physical damage. The physical vulnerability of seabirds to sound pressure is unknown, although McCauley (1994) inferred from vocalisation ranges that the threshold of perception for low frequency seismic in little penguins would be high, hence only at short ranges would penguins be adversely affected. Mortality of seabirds has not been observed during extensive seismic operations in the North Sea and elsewhere. A study has investigated seabird abundance in Hudson Strait (Atlantic seaboard of Canada) during seismic surveys over three years (Stemp 1985). Comparing periods of shooting and non-shooting, no significant difference was observed in abundance of fulmar, kittiwake and thick-billed murre (Brünnich's guillemot).

Direct mortality of seabirds in the event of oil spill is undoubtedly the most significant aspect associated with the proposed licensing and subsequent activities. Spills affecting waters near major colonies during the breeding season could be catastrophic (Tasker 1997). The sources, sizes and characteristics of potential spills resulting from exploration and production in the possible licence area are reviewed in Section 4.5. Seabirds are affected by oil pollution in several ways, including oiling of plumage and loss of insulating properties, and ingestion of oil during preening causing liver and kidney damage (Furness and Monaghan 1987).

The vulnerability of bird species to oil pollution is dependant on a number of factors and varies considerably throughout the year. The Offshore Vulnerability Index (OVI) developed by JNCC and used to assess the vulnerability of bird species to surface pollution, considers four factors:

- the amount of time spent on the water,
- total biogeographical population,
- reliance on the marine environment,
- potential rate of population recovery (Williams *et al.* 1994).

Vulnerability scores for offshore areas are determined by combining the density of each species of bird present with its vulnerability index score. Of the species present over deep water in the possible licence area (see above), gannet and puffin are considered to be the most vulnerable to oil pollution due to their ecology (Webb *et al*. 1995). Both species are heavily reliant on the marine environment, have low breeding output with a long period of immaturity before breeding, and the region contains a large percentage of the biogeographic population of each (Pollock *et al*. in press). In contrast, the aerial habits of the fulmar, together with its large population and widespread distribution, reduce its vulnerability.

The latest vulnerability data for the UKCS were issued in 1999 (JNCC 1999b). Limited data are available for the area north of Shetland and generally, no data are available for some areas of the Faroe Shetland Channel and Wyville Thomson Ridge. Data are available for adjacent areas of the UKCS and these can be used to provide an indication of the times of year that seabirds will be most vulnerable to surface pollution, including oil. High or very high vulnerability occurs north of Shetland from May through September, in some areas of the Faroe Shetland Channel during the post-breeding season (May through to the end of July) and again in September, and over the Wyville Thomson Ridge throughout the breeding and post breeding seasons, particularly in May and August.

Spills of persistent oil originating in the possible licence area could also have a significant impact inshore, in the event that natural weathering and oil spill response measures are ineffective, and the spill trajectory approaches coastal waters. Coastal oil spills could also result directly from export facilities (pipelines and tankers) and from shipping associated with offshore activities. Shelf waters adjacent to the possible licence area hold important concentrations of seabirds throughout the year, and a high number of species utilise only this habitat (Pollock *et al*. in press). Coastal seabird vulnerability to oil pollution is therefore high or very high throughout the year.

The overall risk to seabirds associated with oil spills resulting from the proposed licensing is difficult to quantify. Clearly, the level of activity will have a major influence on the cumulative spill likelihood (see Section 4.15). Under existing regulations, proposed exploration drilling, production and oil pipeline developments must undertake specific oil spill risk assessments. To date, oil spill risk assessments for exploration wells and oilfield developments west of Shetland and west of Hebrides have concluded that risk is acceptable, based on the very low historic frequency of spill events involving significant quantities of oil (see Section 4.5).

Exploration and production activities in the possible licence area would be subject to similar regulatory requirements, and local seabird vulnerability will be similar to, or lower than, existing licensed areas in the Atlantic Frontier. In relation to existing licensed areas in nearshore waters, for example in the Moray Firth, Irish Sea and St George's Channel, risk to seabirds in the possible licence area is comparable or lower both in terms of overall vulnerability and exposure of species with internationally important populations. (For example, licensed areas in the St George's Channel are in close proximity to internationally important Manx shearwater breeding sites on the Pembrokeshire islands.)

Beached bird surveys around the UK (Stowe and Underwood 1983), and elsewhere in Europe (e.g. Vauk 1984), provide useful data on the risks to seabirds of oil pollution. Although a high proportion of seabirds and coastal birds recovered dead from beaches show signs of oiling (e.g. up to 64% of divers, Stowe 1982 cited in Pollock *et al*. in press), most of the oil samples taken from bird plumage suggest that bunker oils from shipping discharges are predominantly involved (Cormack 1984). It is also likely that a proportion of oiled bird carcasses were dead prior to coming in contact with oil. Recorded seabird mortalities resulting from specific tanker incidents around the UK have been relatively limited – 4572 from *Amoco Cadiz* (Clark 1997), 3702 from *Esso Bernicia* (Richardson *et al*. 1981), 1542 from *Braer* (Ritchie and O'Sullivan, 1994), ca.7000 from *Sea Empress* (MPCU 1996). Some of these incidents had locally significant effects on seabird populations, e.g. the *Esso Bernicia* spill in Sullom Voe during December 1978 almost wiped out the breeding colonies of black guillemots in Yell Sound (Heubeck and Richardson 1980). It is also important to note that reported mortality may significantly underestimate actual mortality. In contrast, seabird mortality attributed to upstream oil and gas exploration and production activities on the UKCS has been low, with few significant incidents (Ekofisk blowout, Claymore pipeline leak, Piper Alpha, Captain spill) resulting in very few reported casualties. Oiled birds beaching on the west coasts of Shetland have been attributed to liquid carry-over from drill stem testing of an exploration well.

Indirect effects of exploration and production on seabirds are potentially associated with effects on prey species, principally (in deep water) zooplankton, clupeid and gadoid fish and cephalopods (reviewed by Pollock *et al*. in press). Conceivable effects will be limited to transient disturbance of prey populations by seismic noise, and are considered negligible at a seabird population level. Contamination of prey species is thought to be the major source of toxic chemical residues found in almost all seabirds and seabird eggs examined (NERC 1983, cited in Lloyd *et al*. 1991). However, the contaminants involved are mainly agricultural pesticide residues, or historic land-based industrial discharges (e.g. halogenated hydrocarbons including Polychlorinated Biphenyls, PCBs), and not associated with oil and gas activities. Use and discharges of PCBs and other toxic, bioaccumulating chemicals from exploration and production facilities are either prohibited or controlled under existing controls and proposed regulations.

4.9.3 Understanding

Limited coverage by systematic sightings surveys within the possible licence area is the major limitation on reliable evaluation of potential effects on seabirds, although the available data is considered adequate for this assessment. As noted in Section 4.9.1, priority areas in the former White Zone have been identified and will be the focus of surveys during 2000 (JNCC 1999a). However, if the area is licensed, continued survey effort would increase coverage, together with understanding of variability in seabird distribution and this is considered desirable.

The cumulative level of oil spill risk associated with exploration and development is the other major uncertainty in prediction. As noted above, risk assessments including fate modelling are routinely carried out for specific exploration wells and developments, and spill likelihood and consequences for these activities are relatively well characterised (with individual project risk considered to be relatively low). The overall level of activity that would follow licensing, and therefore the cumulative risk, is unknown (see Section 4.15.).

The direct effects of seismic noise on seabirds are largely unknown, although as noted above, circumstantial evidence suggests that seismic activity to date has had little effect on the UKCS and elsewhere.

4.9.4 Control and mitigation

Currently implemented control and mitigation measures relating to potential effects of exploration and production on seabirds, are primarily aimed at prevention and clean-up of oil spills. As noted above, development of the UKCS to date has resulted in little direct impact on seabirds. Recent legislative developments (The Merchant Shipping (Oil Pollution Preparedness, Response and Co-operation) Regulations 1998) have strengthened regulatory control over oil spill risk assessment and response arrangements. Consequently, specific consideration of oil spill prevention and response provisions would be required of operators before exploration wells or production activities were undertaken in the possible licence area. Offshore oil spill response measures are normally structured as Tier 1 (locally available, sufficient for small spills), Tier 2 (available within a short period, usually defined in terms of beaching times, to deal with moderate sized spills) and Tier 3 (to deal with major spills). Existing response arrangements and times for Tier 2 and Tier 3 measures in the North Sea may need to be reviewed, in view of the geographical location of the possible licence area, although there is unlikely to be a significant practical difference between response operations in the former White Zone and existing licensed areas in the northern North Sea and west of Shetland. At present, Tier 1 oil spill response arrangements are primarily based on the provision of dispersant on standby vessels. Proposed changes to personnel recovery and evacuation methods (i.e. replacement of standby vessels by helicopters), if applied in the possible licence area, would necessitate alternative Tier 1 response provision.

Restriction of the timing of certain activities, considered to involve increased risks of oil spills (e.g. well tests), has also been implemented as a control mechanism in areas of high seabird vulnerability. This measure has been implemented through licence conditions, the existing Environmental Assessment Regulations and oil spill contingency planning. Timing restrictions are area and project-specific. The preferred operational period for exploration, construction and installation activities in the possible licence area (summer) coincides with the highest seabird vulnerability in most of the possible licence area, and this would be reflected in the performance standards for oil spill response required by Government under the OPRC Regulations.

In some parts of the possible licence area, seabird survey coverage is inadequate for comprehensive Environmental Assessment and Oil Spill Contingency Planning of exploration, development or production activities, notably in winter months. In these cases, additional survey work is likely to be necessary in advance of operations.

4.9.5 Conclusion

The possible licence area is clearly important for seabirds, in particular for high densities of fulmar and gannet throughout the year and for summer utilisation by storm-petrels and great skua which have internationally important breeding populations in the region. Although seabird densities vary within the area, there are no specific local areas which are considered to be sufficiently important to justify exclusion from licensing.

Direct mortality of seabirds in the event of oil spill is undoubtedly the most significant aspect associated with the proposed licensing and subsequent activities. However, review of the historical effects of exploration and production on the UKCS, and comparison with existing licensed areas (notably in nearshore locations) indicates that the proposed licensing would be consistent with previous practice. Risk to seabird species at a population level is very low.

4.10 Marine mammals

4.10.1 Importance

Marine mammal distribution, and the importance of Atlantic Frontier deep water and shelf water north and west of Scotland for marine mammals, are discussed by Pollock *et al.* (in press).

In terms of distribution and feeding, marine mammals in the possible licence area and adjacent waters can be broadly distinguished into nine groups:

- **Deep water baleen whales** (blue, fin, sei and humpback) – recorded in deep water (>1000m), north and south of the Wyville Thomson Ridge and not associated with the shelf edge. Pelagic feeders, with considerable specialisation in terms of prey selection and feeding method. Extensive migrations, although some individuals may utilise the region throughout the year.

- **Shelf baleen whales** (minke) – summer visitor to shelf areas. Winter distribution unknown.

- **Deep water, squid-eating whales** (sperm, beaked and pilot) – found along the 1000m contour. Sperm and beaked whales concentrated on eastern flank of Rockall Trough, southern flank of Wyville Thomson Ridge and along eastern side of Faroe Shetland Channel. Northern bottlenose whale possibly have a more westerly distribution.

- **Deep water dolphins** (Atlantic white-sided, common) – widely distributed in deep water, not associated with shelf break. Pelagic feeders, with differing species-specific geographical distributions (not directly related to water temperature).

- **Shelf dolphins** (white-beaked, Risso's) – concentrated in shelf waters, with occasional records at shelf edge. White-beaked predominantly piscivorous, Risso's may also feed on cephalopods. Both species show localised distribution centres.

- "**Generalist cetaceans**" (killer whale, bottlenose dolphin, harbour porpoise) – widely distributed over deep and shelf waters. Killer whales have a broad diet, probably mainly piscivorous offshore, with seals, small cetaceans and birds nearshore. Harbour porpoise probably present in higher densities in deep water, than visual sightings suggest.

- **Breeding seals** – common and grey seals associated with defined haul-out and breeding locations, predominantly coastal foraging. Grey seals forage over considerable distances, although deep water sightings are rare.

- **Deep water seals** – hooded seals utilise deep water in the Faroe Shetland Channel and north of the Faroes, throughout the year. Deep diving (1000m).

- **Vagrants** – striped dolphin, beluga, narwhal, false killer whale, bearded seal, harp seal, ringed seal and Atlantic walrus are probably vagrants to the area.

No marine mammal species are restricted to the possible licence area. Using the 1% of biogeographical population criterion used for seabird populations (e.g. Lloyd *et al*. 1991, see Section 4.9), the Atlantic Frontier would be considered important for most species present, a view which is qualitatively reflected both by NGOs (e.g. Hughes *et al*. 1998, Moscrop 1997) and by industry (e.g. AFEF 2000). However, the application of importance criteria generally used for discrete breeding sites, to large sea areas (e.g. 104,087 km^2 combined survey area, Hughes *et al*. 1998) is of doubtful merit. For offshore areas, even the highest population density estimates (0.05 animals/km^2, Hughes *et al*. 1998) of the most abundant species (Atlantic white-sided dolphin) are low in absolute terms, and density estimates for other species (e.g. baleen whales) are at least an order of magnitude lower. Population density estimates may be biased by the distribution of survey effort together with clumped distribution of animals, and it is difficult to reconcile the findings of different studies. For example, fin whale encounter rates recorded by Hughes *et al*. (1998) are much higher than those recorded by SAST/ESAS surveys (29 fin whale sightings in 48,221 km^2 survey effort with 33% effort in deep water >200m) (Pollock *et al*. in press), or suggested by SOSUS monitoring (minimum numbers of 6 to 20 vocalising fin whales in Region A during 1996-1997, Clark and Charif 1998).

In terms of utilisation by marine mammals, four areas within and adjacent to the former White Zone can be distinguished:

- **Deep water channels** (Faroe Bank and Faroe Shetland Channels, Rockall Trough) – used by deep water, pelagic baleen whales and dolphins (principally Atlantic white-sided, common dolphin more prevalent in Rockall Trough). Flanks used by sperm, beaked and pilot whales. Also used (pelagically) by killer whale and harbour porpoise.

- **North Sea Fan** – as above, with hooded seals also present. Arctic vagrants (beluga, narwhal, bearded seal, harp seal, ringed seal) may be present.

- **Shelf break, Wyville Thomson and Ymir Ridge flanks** – Main centre of distribution of sperm, beaked and pilot whales. Also used by pelagic baleen whales and dolphins and by killer whale (spring) and bottlenose dolphins (winter), and occasionally by grey seals.

- **Shelf areas** – main centre of distribution for minke whale (summer), white-beaked and Risso's dolphin, harbour porpoise, common and grey seals. Other species as occasional (blue, fin, sei, humpback, sperm and beaked whales) or regular visitors (minke, killer and pilot whales, Atlantic white-sided, common and bottlenose dolphin).

Although sightings frequencies are higher in summer than at other times, marine mammals are present within the possible licence areas throughout the year.

4.10.2 Effects

Potential effects of offshore exploration and production on marine mammals result primarily from noise (e.g. McCauley 1994, Richardson *et al*. 1995, Evans and Nice 1996, Moscrop 1997, Gordon *et al*. 1998, Stone 1998) and oil spills (Geraci and St. Aubin 1990).

In general, environmental assessment of the effects of UKCS offshore operations (in particular, seismic surveys) has been characterised by a lack of relevant, reliable data and by considerable speculation. Gordon *et al*. (1998) provide a comprehensive and well-balanced review of seismic effects studies worldwide but with reference to the UKCS, and including pinnipeds. They consider potential effects in terms of physical damage, noise-induced hearing loss (temporary and permanent threshold shifts), behavioural responses (auditory masking, disruption of behaviour, habituation, sensitisation and individual variation in responsiveness), zones of influence (*sensu* Richardson *et al*. 1995), chronic effects and stress, long term behavioural responses and exclusion, and indirect effects. The conclusions reached are that the most likely physical/physiological effects are shifts in hearing thresholds and auditory damage, that behavioural responses including fright, avoidance and changes in behaviour and vocalisation have been observed in baleen whales, odontocetes and pinnipeds, in some cases at ranges of tens or hundreds of kilometres.

Various studies have considered potential effects of seismic surveys on cetaceans in the Atlantic Frontier including observations from seismic and support vessels (e.g. Stone 1997, 1998, 2000, Chappell 1996) and long-term acoustic monitoring of regional cetacean distribution during seismic operations (Clark and Charif 1998). Cetacean observations during seismic surveys (Stone 1998), mainly west of Britain, indicate that dolphins are more strongly affected by seismic activity than other species, with sightings rates of both white-beaked and Atlantic white-sided dolphins lower during periods of shooting. No significant differences were found in sightings rates of sperm and fin whales between periods of shooting and not shooting, although sperm whales were observed to dive more frequently when airguns were firing. Pilot whales showed an inconsistent response to seismic shooting, with some indications that pilot whales may be attracted to low power airguns used for site surveys. There were indications that in deeper water the effects of seismic activity may be reduced, with relatively more cetaceans seen during periods of shooting in deeper waters than during those periods in shallow waters. Stone (1998) also notes that more subtle effect may exist than the short-term behavioural responses recorded by visual observations from seismic vessels, and recommends caution with regard to the interpretation that the continued presence of cetaceans is evidence that seismic disturbance is not excessive.

The effects of non-seismic noise, including drilling, are reviewed by Richardson *et al*. (1995), with most evidence from locations where mobility of grey, bowhead and humpback whales is restricted by ice or by defined migration routes. Evidence of behavioural disturbance is inconsistent, as are experimental studies of bowhead whale and beluga responses to recorded noise. Sorensen *et al*. (1984) observed distributions of a similar small cetacean species range to that in the possible licence area (mainly common, Risso's, bottlenose and *Stenella* dolphins), in the vicinity of drilling activities off New Jersey, and reported no difference in sightings per unit effort with and without the presence of rigs.

BP Amoco has recently commissioned a study of local whale acoustic activity and levels of industrial noise in the vicinity of Foinaven and Schiehallion (Charif and Clark, in prep), using autonomous acoustic recording devices ("pop-up" hydrophones). Five pop-up units, each consisting of a microprocessor, hard disks for data storage, and batteries sealed in a 43cm glass sphere, were deployed for approximately two months from late January 1999. One unit was damaged during deployment, and a further unit was destroyed by an internal fire during recovery. The three successful deployments were at distances of 6.9 to 12.6 km from Foinaven FPSO, and 7.1 to 22.0 km from Schiehallion FPSO.

Ambient acoustic intensity level measurements from all three pop-ups have been processed by automated "powermeter" software that averages received acoustic intensity levels in specified frequency bands over successive one-minute intervals (Charif and Clark, in prep). At all sites, the low frequency noise band (1-10Hz) was on average the noisiest overall, with the high frequency noise band (30-100Hz) being the least noisy. However, acoustic intensity in all frequency bands was highly variable, and at any particular time, any one of the bands may have been the most or least noisy. The ranks of average spectrum levels at the three sites were inversely related to their relative mean distances from industrial activity sites (i.e. FPSOs, drill centres, and wells), indicating that Foinaven and Schiehallion facilities are the predominant source of ambient noise in the area. 90^{th} percentile values of the distribution of one-minute average spectrum levels range from 92 to 121 dB re 1µPa / $\sqrt{}$Hz for all three frequency bands.

Qualitatively, the noise recorded by the pop-ups was extremely variable both in temporal and spectral characteristics. Individual noise events lasted from a few seconds to many hours. The short duration transient noises were sometimes isolated occurrences, and at other times were repeated at either regular or irregular intervals. Many sounds were stationary or slowly varying broadband rumbles or grinding sounds. Others were more tonal whines. Further investigation of the operational sources of noise, by correlation of times with operational records, is ongoing at Aberdeen University.

In 429 hours (47.9% of total), the level of industrial noise in the frequency ranges used by fin and blue whales was so high that recognition of whale call sequences would have been impossible or highly unlikely. During periods when whale vocalisation was detectable over ambient noise, several events were observed in which fin whales ceased calling as levels of industrial noise increased. However, the available data set permits no conclusions regarding the possible responses of whales to industrial noise because of the small sample size and uncertainties regarding the received noise levels experienced by individual whales.

Further deployments of pop-ups in the Foinaven area are planned for Q3/Q4 2000, funded by AFEN.

Propagation of sound fields in water is complex, and is dependent on depth, seabed topography and reflectivity, and water column structure (i.e. velocity profile). Logarithmic relationships between distance from source and received sound pressure, with empirical estimates of decay models ranging from 15 logR to 25 logR, corresponding to several orders of magnitude in the radius of predicted noise intensities from a given source. Topographic and water column characteristics of the Faroe Shetland Channel will complicate sound propagation, and simple sound field models will be indicative at best.

Several reviewers have noted that a number of adjacent seismic surveys within a short period of time could act as a barrier to migration, for example Gordon *et al.* (1998) considered that sound fields from planned seismic surveys in 1997, assuming a spherical propagation model and a threshold intensity of 160dB re 1 µPa, would form a "virtually unbroken barrier to any marine mammal wishing to move north-south along the shelf edge". Recent acoustic monitoring (Clark and Charif 1998, Charif and Clark in prep) has indicated that fin whales in particular do not all follow the previously assumed migration, and the "acoustic barrier" concept may be simplistic and available evidence suggests that neither previous seismic activity nor more recent increases in activity have had a catastrophic effect. Nevertheless, there is little doubt that successive seismic surveys could have a cumulative effect.

Oil spill risks to marine mammals are reviewed by Geraci and St. Aubin (1990) who consider that in ice-free offshore habitats, cetaceans are not at risk to prolonged exposure of oil. In the same volume Würsig (1990) concludes that as a group, baleen whales are the most vulnerable cetaceans in view of their generally low numbers, peculiar feeding strategy and their dependence on selected, localised habitats for feeding and reproduction (the latter criterion relating mainly to Bowhead whales in the Pacific). Most odontocetes are considered "too mobile and wide-ranging for oil to present much of a threat". Physiologic and toxic effects are reviewed by Geraci (1990) and Moscrop (1997), including observational studies following spill events and experimental studies on detection and avoidance, skin contact, inhalation, baleen fouling, ingestion and accumulation. In spite of numerous observations of cetaceans in spills, mainly in US waters, none of the above effects has been detected, or at least recorded with any certainty (Geraci 1990).

4.10.3 Uncertainty

Major areas of uncertainty remain concerning the distribution of cetaceans in the possible licence area (especially beaked whales), the sensitivity of marine mammals to noise disturbance and the propagation of sound fields. In particular, the incremental effects of successive seismic surveys in a limited area (usually following a licence round with an emphasis on "fast-track" development) are unknown.

Acoustic monitoring of cetaceans remains at a relatively early stage of development, with significant limitations imposed by species-specific vocalisation behaviour (or lack of – see Clark and Charif 1998), security restrictions (for SOSUS), range (particularly for medium and high frequency ranges) and various technical issues regarding interpretation. Nevertheless, SOSUS and hydrophone monitoring during seismic surveys have dramatically increased knowledge of baleen whales and harbour porpoise distributions respectively, and have highlighted some inconsistencies with the interpretation of seasonal distribution from visual sightings data. Further work on automated detection systems, and on species which have received little attention in the study area (especially sperm and beaked whales), would be particularly valuable.

4.10.4 Control and mitigation

Although seismic surveys must be carried out under the terms of an exploration or production licence, notified to Government and consultations with JNCC carried out, in general the degree of assessment carried out prior to seismic is much less than is the case for exploration drilling or development. In particular, non-exclusive surveys are carried out by contractors without involvement of oil companies, and Environmental Management System requirements have not been consistently applied.

Guidelines have been issued to minimise acoustic disturbance to marine mammals from seismic surveys, which also cover the reporting of marine mammal observations, and UKOOA has indicated that its members will comply with the guidelines. However, JNCC has expressed concerns regarding the level of compliance, both of “soft-start” procedures and of reporting.

Drilling noise has been considered in Environmental Statements for exploration and development wells, although noise from production facilities has not received consideration in Environmental Statements for west of Shetland developments. Recent observations suggest that significant noise intensities may occur, and this issue is likely to be assessed in more detail in future Environmental Statements. Assessment will, however, continue to be limited by the uncertainties noted above.

Conclusion
Seismic noise is clearly the potential effect of most concern regarding marine mammals in the possible licence area, particularly where successive surveys may be carried out in adjacent areas. Noise from production facilities may also be a source of chronic disturbance. Major areas of uncertainty remain concerning the distribution of cetaceans (especially beaked whales), the sensitivity of marine mammals to noise disturbance and the propagation of sound fields.

Most of the former White Zone is considered to be important for cetaceans, notably large baleen, sperm, pilot and beaked whales. There is no clear variation in seasonal sensitivity which would allow significant mitigation through operational timing.

This issue is considered to be a key factor in the overall assessment of proposed licensing. In the absence of conclusive data, which is unlikely to be forthcoming for technical and ethical reasons, a precautionary approach is justified. This should emphasise the minimisation of incremental noise disturbance, both temporal and spatial.

4.11 Other users offshore

4.11.1 Importance

Deep-water vessels from Scotland, France, Spain and Norway dominate fishing in the area, with fishing vessels from England, Faroe, Germany, Netherlands, Denmark, and Ireland also present (SFPA 2000). The main demersal gears employed are otter trawls and long-lines, with some gill netting also being used.

Demersal fishing effort in the area is relatively low compared to other areas of the UKCS (Coull *et al.* 1998 and SFPA 2000) with greatest effort being seen over the area of the Wyville Thomson Ridge. Demersal effort along the continental shelf break and upper slope is classed as moderate by Coull *et al.* (1998) and effort decreases rapidly beyond the continental shelf break and upper slope (Coull *et al.* 1998 and SFPA 2000). Pelagic effort over the upper slope is at similar levels to that seen in other areas of the UKCS (Coull *et al.* 1998). An area of increased effort is seen in ICES Rectangles 48E5 and 49E5 to the south of the White Zone area. This appears to coincide with mackerel migration routes through the area.

The waters of the former White Zone area are of minor importance for shipping, being crossed by two comparatively minor shipping routes (although with no defined lanes or separation zones) with traffic primarily consisting of cargo vessels, tankers and fishing vessels. A limited number of seasonal ferries and cruise liners transit between Scotland, Norway, the Faroes and Iceland during in the summer months. Vessels associated with hydrocarbon exploration and production activities UK, Faroese or Norwegian waters may cross the area but at present the numbers are low and future trends will be dependent activity levels.

The former White Zone is crossed by two telecommunications cables one from Torshavn to Shetland and one from Streymoy to Norderney (Germany). Both of these cables are disused.

The former White Zone area does not contain any designated military exercise or training areas, although military use of the area does occasionally occur during NATO and other training exercises. Such exercises can involve aircraft and surface or submarine craft. Seabed mounted hydrophones (the SOSUS array operated by the US Navy) used for tracking submarines are present in the region although the precise location of the hydrophones and cables is confidential.

4.11.2 Effects

Potential interactions between offshore exploration and production and fishing can result from exclusion, noise disturbance, ecological effects on commercially exploited stocks, seabed obstructions and contamination of catch.

In order to ensure the safety of fishing vessels and installations, limited exclusion of fishing activities from potential fishing grounds would be necessary near exploration drilling and production locations. This exclusion has theoretical potential for an economic impact on the fishing industry. Exclusion would be achieved through the establishment of defined exclusion zones, usually 500m radius around an installation and either temporary (during construction and commissioning) or permanent (around fixed installations including subsea manifolds). In addition, the presence of unburied pipelines could result in potential interference with fishing activities in the area.

Although exclusion can represent a significant conflict between fishing and production in intensively developed areas within established fishing grounds, such as the central North Sea, the likely level of oil industry activity coupled with the low fishing intensity is unlikely to cause significant problems. The oil industry and UK fishing industry maintain consultation, liaison and compensation mechanisms, which should serve to mitigate and resolve any conflicts.

Temporary reduction in catchability of commercial fish stocks has been reported as a result of seismic surveys by Engås *et al*. (1993), presumably as a result of behavioural disturbance. However, the scale of the affected area (if any) and the economic significance of the effect have been disputed by both sides of the debate. Anticipated levels of seismic activity and fishing intensity are such that significant effects are not foreseen within the former White Zone.

Ecological effects on commercial stocks, through habitat alteration, attraction / aggregation to shelter or food, toxicity, reproductive effects or indirect effects on prey (e.g. *Calanus*) are unlikely. The possible licence area is distant from the major fishing grounds, migration routes and breeding and nursery areas of important commercial species. Only blue whiting and Norway pout spawn in significant numbers in the area and a mackerel migration route passes the extreme southeastern part of the area. Natural stock variability in commercial species is large, and significant effects from oil industry activity would be much more likely (but have not been observed) either in the North Sea or the Gulf of Mexico.

Obstructions on the seabed, associated with pipelines, suspended wellheads, anchor mounds and debris, can have safety implications for fishing, especially demersal trawling. The intensity of demersal trawling in the possible licence area is low to very low compared to other areas of the UKCS, and routine mitigation measures involving consultation, debris surveys and recovery, and notification of obstructions would minimise interference risks posed.

Oil and certain chemicals have the potential to introduce taint (defined as the ability of a substance to impart a foreign flavour or odour to the flesh of fish and shellfish following prolonged and regular discharges of tainting substances (Guidelines for the UK Revised Offshore Chemical Notification Scheme, CEFAS 2000). Possible effects on human consumers of seafood are also an issue of concern in relation to accidental spills and industrial discharges. Government may issue exclusion orders preventing marketing of seafood from areas considered to be contaminated following a spill or other incident, resulting in economic impacts on local fisheries and associated processing. Historical experience (e.g. the *Braer* spill) indicates that irrespective of actual contamination levels, spills may result in significant loss of public confidence in seafood quality from the perceived affected area, and therefore in sales revenue. Either perceived or actual contamination of target species with hydrocarbons or other chemicals may therefore result in economic damage to the fishing industry (and associated industries).

Significant interaction between offshore exploration and production, and merchant shipping, telecommunications and military activity is not anticipated. In addition to normal navigational aids, it is likely that, as a precautionary measure, fixed installations will require to be equipped with submarine warning beacons.

4.11.3 Conclusion

Overall, potential effects or conflict with the fishing industry is considered unlikely, and not significant particularly in comparison with existing activities on the North Sea shelf. Significant interactions with other users are not anticipated.

4.12 Coastal other users

4.12.1 Importance

Coastal industry and activities in adjacent areas to the former White Zone (the Faroe, Shetland, Orkney and Western Isles and northwest Scotland) include fishing, aquaculture, tourism and recreation. All are of considerable importance to local economies.

4.12.2 Effects

Potential adverse effects of exploration and development in the possible licence area are dominated by oil spill risks, although export and support activities could also have environmental effects. The latter, however, would be incremental on existing effects and significant expansion of onshore activities is not foreseen. Construction of new trunk pipeline infrastructure west of Shetland is under consideration at present (the BP Amoco Magnus EOR project) and major discoveries in the former White Zone or Faroese sector could justify further pipeline development. The likelihood or consequences of this cannot be predicted in advance of exploration, but would most probably involve incremental development of existing terminals at Sullom Voe and Flotta.

Oil spill risk is considered in Section 4.5, in terms of sources, frequency and scale of hydrocarbons spills. It is concluded that the incremental risk of oil spills associated with exploration and development in the possible licence area is low. In the event of a spill of persistent oil, and in the absence of an effective response, there is a moderate probability of coastal oiling around Shetland and lower probabilities for other coastal areas.

The environmental consequences of oil spills are dependent on the quantity and type of oil spilled, the spill location, the nature of the receiving environment, the time of year and the success of oil spill response measures.

As discussed in relation to the effect of spills on the offshore fishing industry (Section 4.11), possible effects on human consumers of seafood are also an issue of concern in relation to accidental spills. Perceived or actual contamination of target species with hydrocarbons or other chemicals may therefore result in economic damage to the inshore fishing industry, aquaculture and associated processing and support industries.

Impact on the tourism and amenity “appeal” of Shetland, Orkney and other coastal areas in the event of a major oil spill, primarily in terms of tourist numbers, would be influenced primarily by the extent, duration and tone of media reporting, and by public perception of the severity of the event. These factors cannot be reliably predicted. Medium and long-term influences of the *Esso Bernicia* and *Braer* tanker spills have not been quantified, but have not been catastrophic (although both spills occurred in winter, with low numbers of visitors expected).

Spill prevention measures and mitigation proposed for all phases of offshore exploration and production include spill prevention and containment measures, risk assessment and contingency planning. Minimum beaching times from the possible licence area with sustained 30 knot winds, are of the order of 70-150 hours (depending on location and trajectory) allowing sufficient time for appropriate response measures. Tier 3 response resources, available through industry and Government contingency arrangements, include facility for large-scale aerial application of dispersants within 2.5 – 3 hours, if consultation with regulatory agencies judges this to be appropriate (see Section 4.5 for definition of Tiered response strategy). Coastal oil spill risks would be a key issue in assessment and risk management of proposed developments, under the The Offshore Petroleum Production and Pipe-lines (Assessment of Environmental Effects) Regulations 1999 and The Merchant Shipping (Oil Pollution Preparedness, Response and Co-operation) Regulations 1998.

Coastal oil spill contingency response arrangements are currently the responsibility of local authorities. Operators with west of Shetland or west of Hebrides exploration and production activities have consulted and co-operated with local authorities on contingency planning, and in some cases have trained local authority personnel and provided response equipment. Coastal Protection Plans have been developed by individual Operators and later by AFEN in three phases which on completion in 2000 will cover Scottish, Hebridean, Orkney and Shetland coastlines.

4.12.3 Conclusion

In summary, a large oil spill associated with exploration or development of the possible licence area could result in substantial effects on private or public finance in adjacent coastal areas. However, taking the probability of such an event into consideration, the incremental risk associated with licensing some or all of the former White Zone is low.

4.13 Coastal conservation

4.13.1 Importance

The Faroe, Shetland, Orkney and Western Isles and northwest Scotland all have conservation sites considered important on international, European and national scales (see Volume 2).

In general, all coastlines adjacent to the former White Zone are characterised as wave-exposed, with dramatic geomorphology ranging from high west-facing vertical cliffs (St Kilda and the Faroes providing the most spectacular examples) to sheltered bays at heads of narrow inlets (fjords, fjards, voes and sea lochs). Numerous rock stacks and islands lie offshore. Orkney's coastline includes lower relief around Scapa Flow and east coast areas, with shores predominately composed of bedrock or boulders, and sand in the bays. There are extensive shallow sublittoral areas and varied degrees of wave exposure, particularly around the Orkney and the Western Isles. Sand dune systems and machair are typical of western coasts of the Western Isles, with machair considered globally unique to the Western Isles and Ireland. There are three large inlets on the north Scottish mainland, Kyle of Durness, Kyle of Tongue and Loch Eriboll, which display contrasting features, and a large break in cliffed coast at Dunnet Bay. The Faroe Islands form part of a thick basaltic plateau, and in terms of overall morphology, open coasts account for much of the shoreline. The narrow sounds between islands and fjords provide more sheltered waters, but features such as bays, estuaries and lagoons are uncommon or absent. Consequently, and also as a result of biogeographic isolation, the fauna and flora of the Faroese coastline are restricted in terms of diversity in comparison with other analogous land-masses. Nevertheless, the position of the Faroe Islands at a boundary between colder Arctic water masses and the temperate Atlantic flow provides biogeographic variety to the biota of the area.

Designated conservation sites are listed in Volume 1, and include World Heritage Sites (St Kilda and parts of Orkney), Biosphere Reserves, Special Protection Areas (SPAs), candidate Special Areas for Conservation (cSACs), and Ramsar sites. These have variously been designated for importance in relation to breeding seabirds, wildfowl and moorland birds, seals, otters, vegetated sea cliffs, submerged caves, reefs, lagoons and archaeology. Seabird breeding colonies are undoubtedly the principal ecological sensitivity, with the area holding biogeographically important numbers of great skua, gannet, puffin and black guillemot (see Section 4.9).

4.13.2 Effects

Potential effects of exploration and development in the possible licence area are dominated by oil spill risks, although export and support activities could also have local environmental effects. The latter, however, would be incremental on existing effects and significant expansion of onshore activities is not foreseen.

Oil spills pose both direct and indirect risks to breeding seabirds (Section 4.5). Direct mortality of seabirds is the most significant, and spills affecting waters near major colonies during the breeding season could be “catastrophic” (Tasker 1997). Seabirds are affected by oil pollution in several ways, including oiling of plumage and loss of insulating properties, and ingestion of oil during preening causing liver and kidney damage (Furness and Monaghan 1987). Seabird and wildfowl vulnerability in coastal waters, particularly around Shetland and Orkney, is high throughout the year. In addition to seabird species considered in Section 4.9, coastal populations of divers, cormorant, shag, gulls, terns, seaduck and waders are vulnerable.

Other coastal habitats and species are also vulnerable to surface oil pollution, or to windblown oil in the case of onshore maritime habitats (e.g. machair). After seabirds and wildfowl, seals and otters are probably the most obvious potential casualties (and certainly the most emotive in terms of press coverage), with vulnerability of intertidal habitats also high, particularly in the event of oiling of sheltered coastlines (e.g. Gundlach and Hayes 1978). Subtidal habitats are probably more at risk of the effects of oil spill response (i.e. dispersant application) than surface oiling.

Sources, sizes and characteristics of potential spills resulting from exploration and production in the possible licence area are reviewed in Section 4.5, where it was concluded that the incremental risk of oil spills associated with exploration and development in the possible licence area is low. In the event of a spill of persistent oil, and in the absence of an effective response, there is a moderate probability of coastal oiling around Shetland and lower probabilities for other coastal areas.

The conclusion of low incremental risk is, in part, based on the existing level of risk associated mainly with commercial shipping. Shetland, Orkney and the Western Isles in particular are exposed to high levels of tanker traffic in the Fair Isle Channel and deep water route west of Lewis (Lord Donaldson 1994). These routes are close to shore and upwind of vulnerable coastlines, and limited time is available for effective response measures in the case of accidents. It is generally accepted (e.g. Ritchie and O’Sullivan 1994) that natural dispersion (with some chemical dispersion) of spilled oil from the *Braer* was exceptionally rapid, due to prevailing weather conditions, and far greater ecological effects could have resulted from a similar event in summer weather.

It can also be noted that military casualties over the course of two world wars resulted in unquantified, but substantial release of crude and heavy fuel oils in the region within relatively short timescales, apparently without catastrophic environmental consequences. Naval wrecks in Scapa Flow continue to be a source of chronic oil pollution.

In contrast, offshore spills of comparable volume to those resulting from tanker casualties are very unlikely (see Section 4.5). Minimum beaching times from the possible licence area with sustained 30 knot winds, are of the order of 70-150 hours (depending on location and trajectory) allowing sufficient time for appropriate response measures. Tier 3 response resources, available through industry and Government contingency arrangements, include facilities for large-scale aerial application of dispersants within 2.5 – 3 hours, if consultation with regulatory agencies judges this to be appropriate (see Section 4.5 for definition of Tiered response strategy).

Tanker export of oil is associated with higher oil spill risks than pipeline export (e.g. BP 1997), although most risk assessments consider only tanker loading offshore. Tanker transit to coastal terminals is incremental to the risks associated with subsequent transport of crude oil and refined products by tanker, which has accounted for most historical (large) oil spills in coastal waters (see Section 4.9 for review of associated bird mortality). Coastal oil spill risks would therefore be a key issue in assessment of proposed developments involving tanker export, under the The Offshore Petroleum Production and Pipe-lines (Assessment of Environmental Effects) Regulations 1999.

4.13.3 Conclusion

A large oil spill associated with exploration or development of the possible licence area could have major effects on coastal conservation sensitivities. In the context of existing oil spill risks from tanker traffic however, the incremental risk is low. Although many coastal conservation sites are recognised as of international importance, a large number of sites are distributed throughout the Faroe, Shetland, Orkney and Western Isles and northwest Scotland. Specific risk to individual sites, and the consequences of a major spill event in conservation terms, are thus substantially reduced.

4.14 Wilderness value

4.14.1 Definitions

The intrinsic value of “wilderness” is frequently alluded to with reference to the Atlantic Frontier (e.g. “Britain’s last ocean wilderness”, Murray and Simmonds 1998) although generally without specific definition or justification. For example, on behalf of Greenpeace and the Whale and Dolphin Conservation Society, Murray and Simmonds (1998), under the above subtitle, described ecological diversity, whales and dolphins, other biodiversity, and threats to whales and dolphins (focusing on seismic activity, oil spills and climate change) of the Atlantic Frontier without further mention of wilderness or any related concept.

Anderson and Moore (1996) have reviewed criteria for wildlife sensitivity assessment in relation to marine oil and gas exploration on the UKCS. A number of complementary approaches to categorising and evaluating marine wildlife sensitivities have been developed by statutory and voluntary conservation agencies in the UK. These approaches have generally been developed to support statutory site designation, although they also have more general relevance in natural resource management. The reviewed approaches included the Marine Nature Conservation Review site selection rationale specified by Mitchell (1987), Critical Environmental Capital / Constant Natural Assets developed by English Nature, sensitivity criteria developed by Holt *et al*. (1995) on behalf of the Countryside Commission for Wales, Limits of Acceptable Change, and the Sensitivity Index of MacDonald *et al*. (1996). Of the above, only the first considered any quality of a site resembling “wilderness”.

Mitchell (1987) reflected general terrestrial conservation thinking in developing selection criteria for comparative evaluation of marine "biocoenoses" as the fundamental units for marine conservation. Biocoenoses are roughly equivalent to communities, McLeod 1996, and the term has largely been replaced by the more pragmatic concept of biotopes as physical habitats with characteristic assemblages of conspicuous species (see Section 4.8). Four criteria were defined – species richness, representativeness, naturalness and rarity – with naturalness assessed by considering the proportion of natural substrata, the extent of modification by human activities (e.g. length of modified coast, changes to water flow and natural freshwater input), the degree of pollution and the level of disturbance to the natural communities present (from fishing, dredging and other uses). The more natural areas are most highly rated for conservation. "Naturalness" can be considered to approximate to a measure of how close to "wilderness" an area or biotope is.

Other countries have taken a more qualitative approach to conserving wilderness. In New Zealand, for example, EIAs for major projects should "reflect values of all the people affected by a project", with values defined as "a personal frame of reference encompassing beliefs, thoughts, feelings and attitudes that influence judgements, setting of goals, identification of needs and discriminating among competing demands" (Morgan and Memon 1993). It is also noted that "technical experts have no special claim to superior values".

Pepper (1984) traces the ideological roots of modern "environmentalism", from medieval cosmology through eighteenth century European Romanticism, nineteenth century American Transcendentalism to modern "Ecocentrism". He notes the radical shift in the value of wilderness as "sacred/sublime" over little more than a century, from eighteenth century perception of unproductive Scottish mountains as "hopeless sterility" to the "love of wilderness" evident in the writings of American transcendentalists such as Muir, Thoreau and Emerson. This tradition is explicitly fostered in the work of NGOs such as the John Muir Trust, and implicit in campaigns such as that conducted by Greenpeace over development of the Atlantic Frontier. "Wilderness", however, remains undefined in terms relevant to an assessment of the former White Zone.

A further difficulty in defining "threats" to "wilderness", such as anthropogenic climate change, is associated with timescales, or precisely which wilderness should be conserved? Petroleum geologists consider the Atlantic Frontier over timescales of ca. 100 million years. Sedimentological studies (see Volume 2) and archaeological studies of Neolithic remains both consider Holocene timescales of ca. 10,000 years. Ecological studies tend to consider environmental conditions as stable, or at most, consider changes in species distributions over a few decades in relation to possible environmental factors (see for example, Lloyd *et al.* 1991, and the classic study of Fisher 1952 on fulmar distribution in the north Atlantic).

In fact, the Holocene marine environment of the Atlantic Frontier has experienced rapid, major changes in sea level, water temperatures and hydrography associated with postglacial isostatic uplift and the location of the polar front (Peacock and Harkness 1990). Around 13,000 years ago, the North Atlantic oceanic polar front rapidly moved northwards of Scotland (Ruddiman and MacIntyre 1973, Duplessey *et al.* 1981). A warm period was followed by the Loch Lomond Stadial glaciation, 11,000 to 10,000 years before present, when the Scottish climate was similar to that of modern Spitzbergen and the marine environment was characterised by a restricted molluscan fauna, the principal elements of which are now found in arctic regions (Peacock *et al.* 1978). These climatic changes occurred over relatively short periods (tens or hundreds of years), against which the stability (and conservation) of biotopes, species and individuals must be considered. A colony of *Lophelia pertusa*, which may live for several thousand years (Bruntse and Tendal 2000) may or may not survive an event like the Loch Lomond Stadial.

4.14.2 Assessment

In contrast to virtually all terrestrial habitats in the UK (and elsewhere in northern Europe), large areas of the marine environment, particularly in deep waters, can be considered to be natural. Some aspects of the "naturalness" criterion of Mitchell (1987), see above, can be applied to the former White Zone:

- **the proportion of natural substrata** – with the negligible (in terms of area and effect) exceptions of shipwrecks and telecommunications cables, natural substrate is present. This is largely derived from glacigenic material with a veneer of Holocene deposition. In addition to glacial transgressions, sediment habitats have been modified during the Holocene period by along-slope and downslope sediment transport (including significant slide events) and possibly by diapir formation (Jacobs and Masson 2000).

- **the extent of modification by human activities** – there has been no deliberate modification of the marine environment of the area (comparable with, for example, management of intertidal sediment transport through the erection of groynes or beach replenishment).

- **the degree of pollution** – existing contaminant concentrations are considered to be at, or close to baseline (see Sections 4.2 – 4.3), although pesticide and halogenated hydrocarbon residues in seabirds and cetaceans indicate chronic contamination from terrestrial sources. Localised contamination is likely in the vicinity of shipwrecks.

- **the level of disturbance to the natural communities present** (from fishing, dredging and other uses) – fishing represents the principal current source of disturbance to the area. Physical disturbance of the seabed by trawling is extensive and destructive in shelf and slope depths (see Section 4.8, also Bett 2000) and exploited fish stocks are significantly modified with associated indirect ecological effects on predation and potentially on ecosystem functioning. Disturbance of cetacean and seabird populations is ongoing, through the Faroese drive fishery and seabird harvest (and a small harvest of gannets on Sula Sgeir), although this is of minor importance in comparison to past seabird harvests on the north Atlantic islands and catches of baleen and bottlenose whales (Section 4.10) which are thought to have dramatically affected population status and dynamics. Until recently, substantial subsistence harvesting of seabirds was carried out throughout the area, with significant "sporting" mortality in the late nineteenth century (Lloyd *et al*. 1991) although the extent of population disturbance is unclear. In historic times, great auk, Atlantic grey whale, Atlantic populations of bowhead whale and probably northeast Atlantic populations of northern right whale have been hunted to extinction. The ecological implications of these population modifications to top predators are unknown. No significant introductions of marine species are known to have occurred in the area, although eggs and chicks of some seabird species may be eaten by introduced rats on many islands and in some locations by American mink (Lloyd *et al*. 1991).

Although substrate, habitat modification and pollution aspects are essentially unchanged from natural conditions, the overall level of historic and ongoing disturbance to natural populations and communities represents a significant change from natural conditions over approximately 500 years (i.e. from commencement of large scale Basque whaling, Mowat 1984). In ecological terms therefore, the former White Zone cannot be considered to be "wilderness".

In this context, the potential cumulative and incremental effects identified by this assessment are not considered likely to result in significant modifications, as defined by Mitchell (1987).

In value terms, the visual appearance of the open sea area of the former White Zone is little changed from a natural state. Wilderness or not, there is little doubt that conservation of the oceanic environment, and in particular remnant populations of baleen and other whales is judged to be important by much of the general public.

Determining the identity of people "affected", who might have "beliefs, thoughts, feelings and attitudes" (Morgan and Memon 1993) concerning potential developments, is not straightforward in the absence of a significant resident population or regular recreational use of the area. Greenpeace has successfully argued that it has a *locus* (in legal terms) to challenge Government policy regarding development and conservation in the Atlantic Frontier, and this is presumably to represent people with a belief that the area is, and should remain, "pristine". Taking due consideration of the wider public interest will be a political, rather than environmental assessment, concern, and something which will be addressed through the public consultation proposed by the DTI as part of the SEA process.

4.15 Cumulative effects

The consideration of cumulative effects is one of the requirements of the proposed EU Council Directive on the assessment of the effects of certain plans and programmes on the environment (Com (96) 511 and Com (99) 73). Guidance on the range of techniques for assessing cumulative impacts (and indirect impacts & impact interactions) has been prepared on behalf of the EU by Hyder (1999) although this was primarily targeted at Environmental Impacts Assessments and Integrated Pollution Prevention and Control. The following assessment of the likely occurrence and magnitude of cumulative effects is based on available past experience of oil and gas exploration and production in the North Sea, the Gulf of Mexico and elsewhere (see Section 4.1).

The sources and mechanisms of direct and indirect effects are considered in Sections 4.2 – 4.15. While all sources of emission, discharge and disturbance contribute to local, regional and global concentrations, levels or loads, only the following are considered to have the potential to result is significant cumulative effects:

- Seismic surveys
- Drilling discharges
- Produced water discharges
- Underwater noise from production facilities and support vessels

Seismic survey is an intermittent activity, with a trend towards co-operative surveys funded by several companies covering larger areas. In the summers following the 16th and 17th UK offshore licensing round block awards there were numerous seismic surveys on the Atlantic Margin. This raised the concern that the areal extent, intensity and duration of insonification might result in significant disturbance of cetaceans using or moving through the area (Gordon *et al*. 1998). An area of uncertainty is whether exposure to sufficiently intense noise from seismic survey, either once or repeatedly, will result in behavioural effects or physiological responses in terms of reduced hearing sensitivity in cetaceans through temporary or permanent threshold shifts (see Section 4.10).

Power generation and other activities on production platforms and their support vessels represent continuous or semi-continuous sources of underwater noise and vibration in an area. Studies on such noise and its effects, particularly on cetaceans, are few although the results of the pop-up hydrophones deployed around the Foinaven field are relevant to consideration of the issue in the context of the former White Zone (see Section 4.10). The importance of the deeper waters to the west of Scotland for large and small cetaceans is clear from past whaling records, recent sightings surveys and hydrophone studies. These studies are building a general picture of the occurrence of the different species in the area. What is much less clear is the extent to which the area is used as a migration route, exemplified by recent hydrophone records throughout the year of vocalisations of fin whales, previously thought to be migratory in the area. However, some species do appear to be migratory in the area e.g. humpback whales. Also unclear are many aspects of the ecology of most of the cetacean species in the area including feeding grounds, food resources and fidelity, and how the resources are partitioned between species. Cetacean vocalisations are used for prey location and communication, and while there is no evidence for oilfield operational noise interfering with either of these functions in cetaceans, the possibility of a cumulative masking effect exists. The cumulative noise from a series of production installations along the Faroes Shetland Channel and adjacent areas could be conjectured to introduce a level of disturbance such that it interfered with cetacean communication or feeding. However, the ocean is a noisy environment and cetacean noise discrimination is acute, allowing extraneous noise to be ignored. Consequently, cumulative effects from operational noise are not predicted although as a precautionary measure, noise and vibration abatement should be included in new installation design.

Drilling discharges
The effects of drilling discharges are considered in Sections 4.3 and 4.8. The spatial extent of acute and chronic effects from discharges of drill cuttings and mud have been the subject of considerable debate (contrast Davies *et al*. 1989 and Reiersen *et al*. 1989). This debate has centred on effects from oil based mud drilling, and since the routine discharge of such material is no longer permitted in the UKCS, it is not considered further. Drilling discharges involving water based drill muds are normally permitted in the OSPAR area, Gulf of Mexico and elsewhere, with the effects of such discharges generally held to be minor and insignificant.

The possibility of sublethal and eventually lethal effects from water based drill muds on some filter feeding benthic species has been raised by Canadian laboratory studies (see Section 4.8). It is unclear if these effects will occur in field conditions or if the test species exhibits extreme sensitivity to suspended particulates. However, studies of multiple well development drilling off California found possible field effects on some filter feeding epifauna (Hyland *et al*. 1994). If further study indicates that certain suspension feeders are sensitive to the size fractions and specific gravities of water based muds drilling materials, then drilling discharges from a series of wells in the former White Zone area could result in cumulative effects. Drilling discharges from adjacent UKCS areas and potentially from the Faroes area may also contribute to the possibility of cumulative effects in the area. However, in view of the uncertainty about the occurrence of field effects, the substantial water depths over the area (promoting wide dispersion) and the progressive trend towards reinjection of drill muds and cuttings during field development, it is concluded that significant cumulative effects are unlikely.

Around 200 exploration, appraisal and development wells have been drilled on the existing licensed areas to the north west of Scotland. If the drilling wastes from the wells were transported and accumulated in seabed “sinks” a potential for cumulative effects could be seen. No evidence of areas of elevated concentrations barium in sediment (a useful tracer of drilling discharges) was found during the AFEN 1996 and 1998 or the DTI 1999 surveys (although slight elevations have been noted around field development sites west of Shetland, see Section 4.3). This suggests that past drilling discharges in the area have been very widely dispersed by the energetic and directionally diverse currents rather than accumulating in discrete sinks in the area.

Produced water discharges

There is no evidence from the North Sea or elsewhere of cumulative acute or chronic toxicity effects resulting from produced water discharges (see Section 4.2). A progressive raising of "background" levels of sediment hydrocarbon concentrations in some areas of the North Sea has been recorded although it is unclear if this is a result of oil based mud drilling discharges, oil spills, shipping, atmospheric fallout or produced water discharges. For the former White Zone, cumulative effects of produced water discharges either in the water column or at the seabed are unlikely in view of a progressive shift towards reinjection of produced water (including at the existing Schiehallion and Loyal fields development west of Shetland). In addition, where produced water discharges are made, the performance treatment equipment has been improved over time resulting a progressive reduction in the average oil in water concentration of UK produced water discharges.

4.16 Synergistic effects

Cumulative and synergistic effects from exploration and production activities with those of other activities in the area are not predicted. One possible exception would be the physical effects of drilling discharges and commercial demersal trawling on benthic biotopes (specifically, the Darwin Mounds) although this would be mitigated through the assessment and consenting processes for wells (see Section 4). The individual sources of potential significant effect identified in Volume 3 affect only one sensitivity and conversely major receptors are predicted to be significantly affected by only one major source of impact. Therefore, significant negative synergistic effects in relation to existing uses of the area, in particular fishing and potential future oil and gas activities in the area are not expected.

4.17 Transboundary effects

One of the objectives of the proposed EU Council Directive on the assessment of the effects of certain plans and programmes on the environment (Com (96) 511 and Com (99) 73) is to promote adequate consideration of, and consultation between the relevant governments, on transboundary effects where a plan or programme in one Member State may have significant effects on the environment of another.

The Convention on Environmental Impact Assessment in a Transboundary Context was signed in 1991, and is known as the Espoo Convention. This applies to various major activities with the potential to cause transboundary effects and includes offshore hydrocarbon production and large diameter oil & gas pipelines. Projects need to be screened for the potential transboundary effects and an Environmental Impact Assessment and international consultation by government conducted if necessary.

The area under consideration for licensing under the UK 19th offshore licensing round abuts the international boundaries with the Faroe Islands and Norway. Norway is a corresponding rather than full member of the EU and the Faroes is a self governing territory of Denmark, but not a full member of the EU.

The activities likely to occur following a decision to licence some or all of the UK sector of the former White Zone are summarised in Section 3 with their potential environmental effects discussed in Sections 4.2 – 4.16. Of the potential effects from oil and gas exploration and production, the following have the potential to be detected in the adjacent countries:

- Seismic noise
- Light
- Drilling discharges

- Combustion emissions
- Underwater noise from vessels and operations
- Produced water discharges
- Oil spills
- Chemical spills

Many of the above aspects may be able to be detected physically or chemically in adjacent States, particularly from activities on the international boundary. However, only oil spills are regarded as having the potential to result in significant environmental effects.

5 CONTROL, MANAGEMENT AND MONITORING

5.1 Existing controls

The DTI as licensing authority and offshore environmental regulator has at its disposal a range of powerful legislation and other environmental control mechanisms. The principal controls are as follows:

- Through the licensing mechanism and Model Clauses under the Petroleum Act, 1998, the DTI can introduce additional environmental controls without primary legislation. These controls can be UKCS wide or Block specific. In addition, Petroleum Operations Notices (PONs) outline further requirements of Licensees in relation to certain activities under their licences.

- With the exception of seismic survey, all major activities which could result from the issue of Production Licences are subject to a staged consenting process and the requirements of The Offshore Petroleum Production and Pipe-lines (Assessment of Environmental Effects) Regulations 1999.

- Under the Merchant Shipping (Oil Pollution Preparedness, Response and Co-operation) Regulations 1998, drilling from a mobile rig, oil pipelines and producing facilities are required to have in place an approved oil spill contingency plan, underpinned by oil spill risk assessment and demonstration of adequate response capability.

- The discharge to sea of oil is an offence under the Prevention of Oil Pollution Act, 1971 unless an exemption has been obtained, for example those issued by the DTI permitting and controlling the discharge of produced water.

- The implementation of the European Directive (96/61/EC) on integrated pollution prevention and control (IPPC) is being staged for offshore facilities and will in the near future result in rigorous control of operational emissions and discharges through assessment and permitting.

In addition, several aspects of offshore oil and gas operations in Scottish waters are regulated by other bodies, notably:

- Radioactive sources and wastes (including naturally occurring radioactive materials) by the Scottish Environment Protection Agency under the Radioactive Substances Act, 1993

- Oily drainage water by the Marine and Coastguard Agency under the Merchant Shipping (Prevention of Oil Pollution) Regulations, 1996

- Wastes returned to land for treatment, recycling or disposal, by the Scottish Environment Protection Agency under the Environmental Protection Act, 1990 and the Special Waste Regulations 1996

- Non operational discharges to sea (such as rock dumping) by the Scottish Executive Rural Affairs Department under the Food and Environment Protection Act, 1985

In addition, major or important reefs, selected other species/groups or seabed features may be designated as Special Areas of Conservation under the European Directive on the conservation of natural habitats and of wild fauna and flora. If designated, under the terms of the Directive, an Appropriate Assessment would be required if a plan or project would be likely to have a significant effect on the SAC (unless directly connected with the management of the site for nature conservation purposes).

The above controls, together with those implementing the International Convention for the Prevention of Pollution from Ships, 1983 as modified by the Protocol of 1978 (Marpol 73/78), provide a sound basis for the regulation of potential oil and gas activities in the former White Zone.

The following sections highlight area specific considerations.

5.2 Further controls

Seismic surveys may be conducted under Exploration or Production Licences. As a licence condition, the licence holder conducting the survey must comply with the terms of Petroleum Operations Notice No 14 Notification of Geophysical Surveys, with respect to consultation, prior notification and application of the DETR Guidelines for Minimisation of Effects of Seismic on Small Cetaceans. More detailed assessment of the implications of individual surveys and the possibility of cumulative effects should be considered for seismic surveys in and around the former White Zone area, in recognition of the importance of the area for cetaceans, the difficulties of visual observation in the vicinity of seismic vessels and uncertainties about the potential for disturbance effects.

5.3 Site specific controls

The Darwin Mounds are regarded as vulnerable to physical damage and potentially to smothering by particulates. However, there are alternatives to exclusion from licensing which could involve activity exclusion zones, the extent of which would require further understanding of the occurrence and ecology of these features.

5.4 Information gaps

Gaps in information and understanding relevant to potential operational activities are:

- The spatial and temporal distribution of seabirds (particularly the winter months) and their use of the area, required for oil spill risk assessment and response planning
- Further information on cetacean distribution and use of the area
- Information on cephalopod distribution and abundance (as a major food resource for some cetaceans)
- High resolution topographic and biotope surveys of specific areas selected for drilling or development

- The ecological importance and susceptibility to disturbance of large sponges (although this is of limited importance to most potential activities in the possible licence area)
- Propagation of seismic noise in the area
- Background noise levels in the area
- Operational noise levels from the range of potential activities and identification of low noise technologies
- The occurrence and ecology of the Darwin Mound features (if the area is considered for licensing)

It is noted that a number of the above gaps can be filled most efficiently through co-operative action.

5.5 Monitoring

The routine monitoring and reporting of the major sources of emissions and discharges from exploration and production activities is a legal requirement and the information would be publicly available. In addition, performance monitoring is a prerequisite of a company's EMAS or ISO 14001 environmental management system.

Depending on the nature of the activity and the potential sources of significant effect, a selective programme of monitoring and review should be required to assess the accuracy of model outputs and other predictions made in Environmental Statements. In particular, the predictions made regarding noise levels from drilling and production operations should be tested and coupled with observation of cetacean behavioural responses. Similarly, visual observation (and where appropriate, acoustic monitoring) of cetaceans should be conducted during all seismic surveys.

Programmes for the monitoring of contamination and sediment recovery from physical disturbance resulting from licensed activities should be linked to the scale of activities and nature of discharges. It is recognised that some installation designs will incorporate reinjection technologies and so result in limited marine discharges.

This page is intentionally blank

6 GLOSSARY

Term	Definition
Amphipods	Marine crustaceans (“sandhoppers”)
Annulus	The space between the drill string and well bore
Aqueous discharges	Watery discharges to the sea
Barite	Barium sulphate – a heavy mineral added to drilling mud as a weighting agent to increase its specific gravity and thus the hydrostatic head of the mud column
Base fluid	The liquid component of drilling mud
Bathymetry	Measurement and study of ocean depth and floor
Benthos	Organisms living in or on the seabed
Bioaccumulation	The uptake of elements or compounds within organisms
Biocoenoses	Association of organisms forming a closely integrated community
Biodiversity	Diversity of species
Biogeographic	Relating to the geographical area characterised by distinctive flora and fauna
Biomagnification	The transfer of increasing concentrations of elements or compounds up the trophic levels in the food web
Biosphere Reserves	Sites designated for the long-term study of ecosystems and the monitoring of environmental change
Biota	The total flora and fauna of a given area
Biotope	A physical habitat and its associated biological community
Blow-out preventor	Hydraulically operated device used to prevent uncontrolled releases of oil or gas from a well
Carcinogenic	Compounds inducing cancer
Cephalopods	Marine molluscs including cuttlefish and octopus
Cetaceans	Aquatic mammals including whales, dolphins and porpoises
Christmas tree	Valve assembly at the top of a well used to control flow of oil or gas
Clupeid	Family of fish including herring, sprat and anchovy
Combustion emissions	Emissions of gases including carbon dioxide and oxides of nitrogen and sulphur, from the burning of fossil fuels such as oil or gas

Term	Definition
Condensate	Liquid hydrocarbons, sometimes produced along with natural gas
Contaminants	Substances which may cause impurity or pollution
Copepod	Small crustaceans, usually planktonic
Corrosion protection	Use of chemicals or sacrificial anodes to protect a structure from progressive breakdown by chemical attack (or rusting)
Cuttings pile	Pile of mainly rock chips deposited on the seabed as a result of drilling
Darwin Mounds	Seabed features found on the southern flank of the Wyville Thomson Ridge, with coral colonies
Demersal	Living at or near the bottom of the sea
Drill bit	A drilling tool used to cut through rock
Drill casing	Steel pipe cemented into a well to prevent cave-in and stop fluids from leaking to or from surrounding rock into the hole
Drill cuttings	Rock chips produced as a result of drilling
Drill string	Lengths of steel tubing roughly 10m long screwed together to form a pipe connecting the drill bit to the drilling rig. It is rotated to drill the hole and delivers drilling fluids to the bit
Drilling mud	Mixture of clays, water and chemicals used to cool and lubricate the drill bit, return rock cuttings to the surface and to maintain hydrostatic pressure to maintain well control
Dynamic Positioning	Use of thrusters instead of anchors to maintain the position of a vessel
Endocrine disrupting compounds	Compounds which have an effect on the hormonal systems of organisms
Environmental Impact Assessment	Systematic review of the environmental effects a proposed project may have on its surrounding environment
Environmental Management System	System established to manage an organisation's processes and resultant environmental impacts
Environmental Statement	Formal document presenting the findings of an EIA process for a proposed project. Issued for public consultation in accordance with The Offshore Petroleum Production and Pipe-lines (Assessment of Environmental Effects) Regulations, 1999
Epipelagic	Relating to towards the surface of the water column
Flare	Controlled burning of gas for pressure relief (or during well testing to disposal of excess gas)
Formation	An assemblage of rocks or strata

Term	**Definition**
Fugitive emissions	Very small chronic escape of gas and liquids from equipment and pipework
Gadoid	Fish of the cod family
Geology	Physical structure and substance of the earth
Glacigenic	Relating to glacial activity
Greenhouse effect	Rise in the earth's temperature due to infra-red radiation being trapped in the atmosphere by water vapour, carbon dioxide and other gases
Greenhouse gases	Gases believed to contribute to the greenhouse effect, including carbon dioxide, water vapour and methane
Hermatypic	Reef-forming corals containing symbiotic algae
Hydrocarbon	Compounds containing only the elements carbon and hydrogen, including oil and natural gas
Immunotoxic	Having a toxic effect on the immune system
ISO 14001	International standard for environmental management systems
Licence block	Area of the sea which has been sub-divided and licensed to a company or group of companies for exploration and production of hydrocarbons
Licensing round	An allocation of licences made to oil companies
Liner	Small diameter casing placed within a well to carry hydrocarbons back to the surface
Low Specific Activity	Low dose, naturally occurring radiation
Macrozooplankton	Larger free-floating microscopic animals
Manifold	Assembly of pipes, valves and fittings which allows fluids from more than one source to be directed to various alternative routes
Mattresses	Concrete structures used to protect pipelines or other subsea structures
Meso-pelagic	Relating to the middle section of the water column
Micro-zooplankton	Smaller free-floating microscopic animals
NEC (No Effect Concentration)	Concentration at which no detrimental effects are expected to occur
Odontocetes	Toothed whales
Oestrogen	Female hormone
Oestrogenic	Acting as an oestrogen

Term	Definition
OILMAP	Computer model used to predict oil spill trajectories
Ontogenetic	Relating to the development of an individual organism
Organic compounds	Materials containing carbon combined with hydrogen, often with other elements
OSIS	Oil Spill Information System
Ozone	A gas formed naturally in the atmosphere containing three atoms of oxygen
PEC (Predicted Environmental Concentration)	Concentration of a chemical predicted to occur in the environment
Pelagic	Organisms living in the water column of the sea
Permeability	Degree to which a solid allows the passage of fluid through it
Photosynthesis	Process by which plants convert carbon dioxide into organic compounds using the energy of light absorbed by chlorophyll
Phytodetrital deposition	Particulate material derived from dead phytoplankton which settles to the seabed
Phytoplankton	Free-floating microscopic plants
Plankton	Free-floating microscopic organisms
Porosity	Degree to which a substance allows movement of fluids through its pores
Produced water	Water removed from the reservoir along with oil and natural gas
Ramsar Sites	Areas designated by the UK under the Ramsar Convention (Convention on Wetlands of International Importance especially as waterfowl habitat)
Rheological	Relating to flow or current
Riser	Pipe connecting a rig or platform to a wellhead or pipeline
Sacrificial anodes	Metal plates placed on underwater structures to prevent corrosion. The seawater attacks the anodes rather than the structure
Satellite wells	Wells a considerable distance from the main development, connected via pipelines
Sediments	Loose material, such as sand and mud, laid down at the bottom of the sea, river or lake

Term	Definition
Seismic	Survey technique used to determine the structure of underlying rocks by passing acoustic shock waves into the strata and detecting and measuring the reflected signals. Depending on the spacing of survey lines, the seismic is referred to as either 2 or 3-D
Sepioids	Cephalopods of the cuttlefish family
Shale	Mud or claystone rocks
Shallow gas	Gas accumulation present near the surface of the seabed
Sidetrack well	Creation of a new section of well to detour around an area or to reach another area
Special Area of Conservation	Areas designated as European Sites (Natura 2000) under the Habitats and Species Directive
Special Protection Areas	Areas designated as European Sites under the Wild Birds Directive
Strategic Environmental Assessment (or Appraisal)	An appraisal process through which environmental protection and sustainable development is considered in decisions on policy, plans and programmes
Tank washings	Effluent as a result of cleaning tanks on rigs or vessels
Target location	Position within a reservoir which is the target at the start of drilling the well
Teratogenic	Causing birth defects
Trenching	Excavation of a trench into the seabed for a pipeline or umbilical
Umbilical	Narrow, reinforced, flexible pipeline containing several different cores, which are used to carry electrical power, chemicals and control fluids to the wellhead or other subsea equipment
Volatile organic compounds	Organic compounds such as ethylene and benzene which evaporate readily and contribute to air pollution directly or indirectly
Wellhead	Control equipment fitted at the top of a well
White Zone	The formerly disputed area of sea between the UK and the Faroes
Xenophyophores	Giant single celled seabed animals
Zooplankton	Free-floating small animals

7 ACRONYMS, SYMBOLS AND ABBREVIATIONS

µg	Micrograms
µPa	Micropascal
2D	2 Dimensional
3D	3 Dimensional
AFEF	Atlantic Frontier Environmental Forum
AFEN	Atlantic Frontier Environmental Network
bbl	Barrel (= $0.1589m^3$)
BOP	Blow Out Preventor
BP	British Petroleum
cm	Centimetres
cSAC	Candidate Special Area of Conservation
CSON	Continental Shelf Operations Notice
dB	Decibel
DETR	Department of Environment, Transport and the Regions
DP	Dynamic Positioning
DTI	Department of Trade and Industry
E&P	Exploration and Production (See References)
EC	European Community
EEC	European Economic Community
EMAS	Eco Management and Audit Scheme
EPAQS	Expert Panel on Air Quality Standards (See References)
ESAS	European Seabirds At Sea
EU	European Union
FPS	Floating Production System
FPSO	Floating, Production, Storage and Offloading Facility
g	Grams
GEM	Faroes Geophysical Environmental and Metocean Group
GOR	Gas Oil Ratio
HEBBLE	High Energy Benthic Boundary Layer Experiment
Hz	Hertz

ICES	International Council for the Exploration of the Sea
IPCC	Intergovernmental Panel on Climate Change (See References)
IPPC	Integrated Pollution Prevention and Control
JNCC	Joint Nature Conservation Committee
km	Kilometres
LSA	Low Specific Activity
m	Metres
MARPOL	International Marine Pollution Convention
mg	Milligrams
MMS	U.S. Minerals Management Service
MW	Megawatt
NATO	North Atlantic Treaty Organisation
NEC	No Effect Concentration
NERC	Natural Environment Research Council
NGO	Non Governmental Organisation
OLF	The Norwegian Oil Industry Association
OPRC	International Convention on Oil Pollution Preparedness, Response and Co-operation
OSD	Offshore Safety Division
OSPAR	Oslo and Paris Commission
OVI	Oil Vulnerability Index
PAH	Polycyclic Aromatic Hydrocarbons
PCB	Poly Chlorinated Biphenyls
PEC	Predicted Environmental Concentration
PON	Petroleum Operations Notice
ROV	Remotely Operated Vehicle
SAC	Special Area of Conservation
SAST	Seabirds At Sea Team
SEA	Strategic Environmental Assessment or Appraisal
SFPA	Scottish Fisheries Protection Agency (See References)
SINTEF	The Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology
SOAEFD	Scottish Office Agriculture, Environment and Fisheries Department (See References)

SOSUS	US Navy Sound Surveillance System
SPA	Special Protection Area
TLP	Tension Leg Platform
UK	United Kingdom
UKCS	United Kingdom Continental Shelf
UKOOA	United Kingdom Offshore Operators Association
UKTERG	United Kingdom Terrestrial Effects Review Group (See References)
VOC	Volatile Organic Compounds
VSP	Vertical Seismic Profile

8 REFERENCES

AFEF (2000). Atlantic Frontier Environmental Forum. Working together to protect the environment.

Anderson SJ and Moore J (1996). Guidance on assessment of seabed wildlife sensitivity for marine oil and gas exploration. Report to JNCC. 69pp.

Andrews JH and Standring KT (eds) (1979). *Marine pollution and birds*. Royal Society for the Protection of Birds, Sandy.

API (1996). Summary of Produced Water Toxicity Identification Evaluation Research. American Petroleum Institute Health and Environmental Sciences Department. Publication Number 4641.

Atkinson DB (1994). The biology and fishery of roundnose grenadier (*Coryphenoides rupestris* Gunnerus, 1765) in the northwest Atlantic. In: Hopper AG (Ed). *Deep-Water Fisheries of the North Atlantic Oceanic Slope.* NATO ASI Series E: Applied Sciences **296**: 51-111.

Bell N and Smith J (1999). Coral growing on North Sea oil rigs. *Nature*, London **402**: 602.

Benjaminsen T and Christensen I (1979). The natural history of the Bottlenose Whale, *Hyperoodon ampellatus* (Forster). In, *Behaviour of Marine Animals, Vol 3: Cetaceans*, ed. HE Winn and BL Olla, 143-164. Plenum Press, New York.

Bett BJ (2000). Comparative Benthic Ecology of the Rockall Trough and Faroe-Shetland Channel. In, *Atlantic margin environmental surveys of the seafloor 1996 & 1998*. CD Atlantic Frontier Environmental Network and UKOOA.

Billett DSM, Lampitt RS, Rice AL and Mantoura RFC (1983). Seasonal sedimentation of phytoplankton to the deep-sea benthos. *Nature*, London **302**: 520-522.

Blake BF, Dixon TJ, Jones PH and Tasker ML (1984). Seasonal changes in the feeding ecology of guillemots (*Uria aalge*) of the north and east of Scotland. *Estuarine, Coastal and Shelf Science* **20**: 559-568.

Boehm PD, Barak J, Fiest D and Elskus A (1980). The analytical chemistry of *Mytilus edulis*, *Macoma balthica*, sediment trap and surface sediment samples. In: The *Tsesis* Oil Spill. JJ Kineman, R Elmgren and S Hansson eds. US Department of Commerce, National Oceanic and Atmospheric Administration, 296 pp.

Boesch DF and Rabelais NN (1987). Long-term environmental effects of oil and gas development. Elsevier Applied Science, London.

BP Amoco (1999). Schiehallion Business Unit Interim Environmental Statement. Environmental Performance Update 1998.

BP Amoco (2000a). Schiehallion Delivery Unit Environmental Statement 1999.

BP Amoco (2000b). East Foinaven Development Environmental Statement.

BP Exploration (1994). Foinaven Phase 1 Development Environmental Progress Report.

BP Exploration (1995). Foinaven Phase 1 Development Environmental Assessment.

BP Exploration (1996). Schiehallion Stage II Environmental Statement.

BP Exploration (1997). Schiehallion Development and the Environment. BP Exploration, December 1997.

Bruntse G and Tendal OS (2000). *Lophelia pertusa* and other cold water corals in the Faroes area. In: *Marine biological investigations and assemblages of benthic invertebrates from the Faroe Islands*. Bruntse G and Tendal OS (eds).

Cairns WJ (1992). North Sea oil and the environment: developing oil and gas resources, environmental impacts and responses. Elsevier, Cambridge

Camphuysen CJ, Ensor K, Furness RW, Garthe S, Huppop O, Leaper G, Offringa H and Tasker ML (1993). *Seabirds feeding on discards in winter in the North Sea*. EC DG XIV research contract 92/3505. NIOZ Rapport 1993-8. Netherlands Institute of Sea Research, Texel.

Camphuysen CJ, Calvo B, Durinck J, Ensor K, Follestad A, Furness RW, Garthe S, Leaper G, Skov H, Tasker ML and Winter CJN (1995). *Consumption of discards by seabirds in the North Sea*. EC DG XIV research contract BIOECO/93/10. NIOZ Rapport 1995-5. Netherlands Institute of Sea Research, Texel.

Caurant F, Amiard JC, Amiard-Triquet C and Sauriau PG (1994). Ecological and biological factors controlling the concentrations of trace elements (As, Cd, Cu, Hg, Se, Zn) in delphinids *Globicephala melas* from the North Atlantic Ocean. *Marine Ecology Progress Series* **103**: 207-219.

CEFAS in consultation with FRS, DETR and DTI (2000). Guidelines for the UK Revised Offshore Chemical Notification Scheme. 27pp.

Chappell O (1996). Report on Field Trials to Investigate the use of Hydrophone Systems to Monitor for Cetaceans during Seismic Operations. 1.12.96

Clark CW and Charif RA (1998). Acoustic monitoring of large whales to the west Britain and Ireland using bottom-mounted hydrophone arrays. October 1996-September 1997. JNCC Report, No. 281

Clark RB (1997). *Marine Pollution*. Fourth Edition. Clarendon Press, Oxford. 161pp.

Clarke MR (1977). Beaks, nets and numbers. In, Nixon M and Messenger JB (eds) *The Biology of Cephalopods*. Symposium of the Zoological Society of London. 615pp.

Clarke MR and Lu CC (1974). Vertical distribution of cephalopods at 30°N, 23°W in the North Atlantic. *Journal of the marine biological Association of the UK* **54**: 969-984.

Clarke MR and Lu CC (1975). Vertical distribution of cephalopods at 18°N, 25°W in the North Atlantic. *Journal of the marine biological Association of the UK* **55**: 165-182.

Conoco (1998). Environmental Statement of proposed drilling operations for exploration well 204/14-C. Conoco (U.K.) Limited, November 1998.

Conoco (1999). Environmental Statement for the proposed operations on well 204/14-1 and drilling of exploration well 204/14-D. Conoco (U.K.) Limited, February 1999.

Cormack D (1984). Seabirds and Oil. *Marine Pollution Bulletin* **15**: 345-347.

Coull KA, Johnstone R and Rogers SI (1998). Fisheries sensitivity maps in British waters. UKOOA, London.

Cranford PJ and Gordon DC Jr (1992). The influence of dilute clay suspensions on sea scallop (*Placopecten magellanicus*) feeding activity and tissue growth. *Netherlands Journal of Sea Research* **30**: 107-120.

Cranford PJ, Gordon DC Jr, Lee K, Armsworthy SL and Tremblay GH (1999). Chronic toxicity and physical disturbance effects of water- and oil-based drilling fluids and some major constituents on adult sea scallops (*Placopecten magellanicus*). *Marine Environmental Research* **48**: 225-256.

Cranmer G (1988). Environmental survey of the benthic sediments around three exploration well sites. Aberdeen University Marine Studies Ltd. Report No 88/02 to the United Kingdom Offshore Operators Association, 33pp plus figures and appendices.

Daan R and Mulder M (1996). On the short-term and long-term impact of drilling activities in the Dutch sector of the North Sea. *ICES Journal of Marine Science* **53**: 1036-1044.

Davies JM and Kingston PF (1992). Sources of environmental disturbance associated with offshore oil and gas developments. In, Cairns WJ (ed) *North Sea oil and the environment: developing oil and gas resources, environmental impacts and responses*. University Press, Cambridge.

Davies JM, Bedborough D, Blackman RAA, Addy JM, Appelbee JF, Grogan WC, Parker JG and Whitehead A (1989). The environmental effect of oil-based mud drilling in the North Sea. In *Drilling Wastes* (FR Engelhardt, JP Ray and AH Gillam eds), pp. 59-89. Elsevier Applied Science, London.

Davies JM, Bedborough D, Blackman RAA, Addy JM, Appelbee JF, Grogan WC, Parker JG and Whitehead A (1989). The environmental effect of oil-based mud drilling in the North Sea. In *Drilling Wastes* (FR Engelhardt, JP Ray and AH Gillam eds), pp. 59-89. Elsevier Applied Science, London.

Davies JM, Hay SJ, Gamble JC and Dow K (1987). The ecological effects of produced water discharges from offshore oil platforms in the northern North Sea. *Marine Environmental Research* **25**:

Desportes G and Mouritsen R (1989). Diet of the pilot whale, *Globicephala melas*, around the Faroe Islands. Paper SC/41/SM13, Reports of the International Whaling Commission.

DNV Technica (1991). Blowout Database.

DTI (1999). Development of the Oil and Gas Resources of the United Kingdom 1999. HMSO.

Dunaway ME and Schroeder P (1988). Minimising anchoring impacts during construction of offshore oil and gas facilities. *Oceans '88* Conference and Exhibition, Baltimore.

Duplessey JC, Delibrias G, Turon JL, Pujol C and Duprat J (1981). Deglacial warming of the north-eastern Atlantic Ocean; correlation with the palaeoclimatic evolution of the European continent. *Paleogeography, Palaeoclimatology and Palaeoecology* **35**: 121-144.

E&P Forum (1994). North Sea Produced Water: Fate and effects in the marine environment. Exploration and Production Forum Report No. 2.62/204. May 1994. 48pp.

Engås A, Løkkeborg S, Ona E and Soldal AV (1993). Effects of seismic shooting on catch and catch availability of cod and haddock. Institute of Marine Research, Fisken og Havet, No. 9. 117pp.

Engelhardt FR, Ray JP and Gillam AH (eds) (1989). *Drilling Wastes*. Elsevier Applied Science, London. 867pp.

Environment Agency (1998). Oil and gas in the environment. Environmental Issues Series, The Stationery Office, 104pp.

EPAQS (1996). Expert Panel on Air Quality Standards, Nitrogen Dioxide. HMSO.

ERT (1998). BP Foinaven seabed environmental survey UKCS Blocks 204/19 and 24a. Final data assessment report. Environment & Resource Technology Ltd.

Evans PGH and Nice H (1996). Review of the Effects of Underwater Sound Generated by Seismic Surveys on Cetaceans. Sea Watch Foundation, Oxford. (Report commissioned by UKOOA.)

Fisher J (1952). *The Fulmar*. Collins, London.

Francois R, Honjo S, Manganini SJ and Ravizza GE (1995). Biogenic barium fluxes to the deep sea: Implications for paleoproductivity reconstruction. *Global Biogeochemical Cycles* **9**:268-303.

Frederiksen R, Jensen A and Westerberg H (1992). The distribution of the scleractinian coral *Lophelia pertusa* around the Faroe Islands and relation to internal tidal mixing. *Sarsia* **77**: 157-171.

Furness RW (1987). *The skuas*. T&AD Poyser, Calton.

Furness RW and Monaghan P (1987). *Seabird ecology*. Blackie & Son, Glasgow.

Gaard E (1996). Life cycle, abundance and transport of *Calanus finmarchicus* in Faroese waters. *Ophelia* **44**: 59-70.

Gage JD and Tyler PA (1991). *Deep sea biology*. Cambridge University Press, 504pp.

Gallaway BJ, Senner RGB, Fechhelm RB and Hubbard GF (1997). Environmental trends in the Gulf of Mexico in the twentieth century: The role of offshore oil and gas industry. Report to the American Petroleum Institute, 110pp. Available at www.api.com

Gamble JC, Davies JM, Hay SJ and Dow FK (1987). Mesocosm Experiments on the Effects of Produced Water Discharges from Offshore Oil Platforms in the Northern North Sea. *Sarsia*, **72**:383-386

Gausland I (1996). The effects of underwater sound generated by seismic surveys on marine life. Internal report, Statoil.

Geraci JR and St. Aubin DJ (eds) (1990). *Sea Mammals and Oil: Confronting the Risks.* Academic Press. 282pp.

Golar-Nor (undated). Petrojarl Foinaven Environmental Statement. January-October 1998.

Gordon JCD, Gillespie D, Potter J, Frantzis A, Simmonds M and Swift R (1998). The effects of seismic surveys on marine mammals. In, Seismic and Marine Mammals Workshop, 23-25 June 1998 (sponsored by AMJIG and IAGC).

Gordon JCD, Gillespie D, Potter J, Frantzis A, Simmonds M and Swift R (1998). The effects of seismic surveys on marine mammals. In, Seismic and Marine Mammals Workshop, 23-25 June 1998 (sponsored by AMJIG and IAGC).

Gordon JDM, Harrison EM and Swan SC. (undated). *A guide to the deep-water fish of the north-eastern Atlantic.* Scottish Association for Marine Science.

Gordon JDM, Merrett NR and Haedrich RL (1995). Environmental and biological aspects of slope-dwelling fishes of the North Atlantic. In: Hopper AG (Ed). *Deep-Water Fisheries of the North Atlantic Oceanic Slope.* NATO ASI Series E: Applied Sciences **296**: 1-26.

Gulland J and Walker C (1998). Marine seismic overview. In, Seismic and Marine Mammals Workshop, 23-25 June 1998 (sponsored by AMJIG and IAGC).

Gundlach ER and Hayes MO (1978). Vulnerability of coastal environments to oilspill impacts. *Marine Technology Society Journal* **12**: 18-27.

Hailey N (1995). Likely impacts of oil and gas activities on the marine environment and integration of environmental considerations in licensing policy. English Nature Research Reports No 145, 29pp.

Hamer KC, Monaghan P, Uttley JD, Walton P and Burns MD (1993). The influence of food supply on the breeding ecology of kittwakes *Rissa tridactyla* in Shetland. *Ibis* **135**: 255-263.

Hartley JP (1996). Environmental Monitoring of Offshore Oil and Gas Drilling Discharges – A Caution on the Use of Barium as a Tracer. *Marine Pollution Bulletin* **32**(10): 727-733.

Heath MR (1999). The ascent migration of *Calanus finmarchicus* from overwintering depths in the Faroe-Shetland Channel. *Fisheries Oceanography* **8 (suppl. 1)**, 84-99.

Heath, MR and Jónasdóttir, SH (1999). Distribution and abundance of overwintering *Calanus finmarchicus* in the Faroe Shetland Channel. *Fisheries Oceanography* **8** (suppl 1):, 40-60.

Heubeck M and Richardson M (1980). Mortality following the 'Esso Bernicia' oil spill, Shetland, December 1978. *Scottish Birds* **11**: 97-108.

Hinton A (1999). An analysis of OSD's well incident database; results can improve well design and target well control training. SPE 56921. Presented at the 1999 Offshore Europe Conference held in Aberdeen, Scotland 7-9 March 1999.

Holand P (1996). Offshore blowouts, causes and trends. Doctoral Dissertation, Norwegian Institute of Technology Department of Production and Quality Engineering, Trondheim, Norway.

Hollister, CD, Nowell ARM and Jumars PA (1984). The dynamic abyss. *Scientific American* **259**: 42-53.

Holt TJ, Jones DR, Hawkins SJ and Hartnoll RG (1995). The Sensitivity of Marine Communities to Man-Induced Change - A Scoping Report. Report No. 65, Countryside Council for Wales, Bangor.

Hughes K, Arnold H, De Boer M, Irish R, Mackins C, Murray L, Norris K, Pert J, Simmonds M and Stanley M (1998). Results and analyses of Greenpeace/WDCS cetacean survey of the Atlantic Frontier: July-August 1998. In: *The Atlantic Frontier; Britain's last ocean wilderness*, ed. L Murray and M Simmonds, 18-36. Greenpeace and the Whale and Dolphin Conservation Society Report.

Hunt GL Jr, Barrett RT, Joiris C and Montivecchi WA (1996). Seabird/fish interactions: an introduction. In, Hunt GL Jr and Furness RW (eds) *Seabird/fish interactions with particular reference to seabirds in the North Sea*. ICES Cooperative Research Report No 216.

Hyland J, Hardin D, Steinhauer M, Coats D, Green R and Neff J (1994). Environmental impact of offshore oil development on the outer continental shelf and slope off Point Arguello, California. *Marine Environmental Research* **37**: 195-229

IPCC (1995). Climate Change 1995 The science of climate change. Contribution of working group 1 to the second assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, 572pp.

Jacobs CL and Masson, DG (2000). Section 3 Preliminary Surface Geology Interpretation from TOBI Sidescan Sonar, 3.5KHz Profiles and WASP Camera. In: White Zone DTI marine surveys 1999. Preliminary report, January 2000, Southampton Oceanography Centre.

Jennings S and Kaiser MJ (1998). The effects of fishing on marine ecosystems. *Advances in Marine Biology* **34**: 210-352.

Jensen H, Tasker ML, Coull K and Emslie D (1994). *A comparison of distribution of seabirds and preyfish stocks in the North Sea and adjacent areas*. JNCC Report No. 207 / Final report to EC DGXIV PEM 92/3501.

JNCC (1999a). Progress report for the Atlantic Frontier Environmental Network, March to September 1999. Seabirds and Cetacean Team, Joint Nature Conservation Committee.

JNCC (1999b). Vulnerability data for the UKCS. Unpublished data from the Seabirds and Cetacean Team, Joint Nature Conservation Committee.

Johnsen S, Røe TI and Durell GS (1998). Dilution and bioavailability of produced water compounds in the northern North Sea. A combined modelling and field study. SPE paper 46269. SPE International Conference on health, safety and environment in oil and gas exploration and production, Caracas, Venezuela, 7-10 June 1998.

Joint Links (1995). Polluting the offshore environment. The practices and environmental effects of Britain's offshore oil and gas industry. Report to the Jont Links' Oil and Gas Consortium, 15pp.

Krause M and Martens P (1990). Distribution patterns of mesozooplankton biomass in the North Sea. *Helgolanders Wiss Meeresuntersuchungen* **44**: 295-327.

Kroncke I, Duineveld GCA, Raak A, Rachor E and Daan R (1992). Effects of a former discharge of drill cuttings on the macrofauna community. *Marine Ecology Progress Series* **91**: 277-287.

Lindley JA (1982). Continuous plankton records: geographical variations in numerical abundance, biomass and production of Euphausiids in the North Atlantic Ocean and the North Sea. *Marine Biology* **71**: 7-10.

Lloyd C, Tasker ML and Partridge K (1991). *The Status of Seabirds in Britain and Ireland*. Published for The Nature Conservancy Council and The Seabird Group. T&AD Poyser, London. 355pp.

Lord Donaldson (1994). Safer Ships, Cleaner Seas. Report of Lord Donaldson’s Inquiry into the Prevention of Pollution from Merchant Shipping. HMSO, London.

Lu CC and Clarke MR (1975). Vertical distribution of cephalopods at 40°N, 53’N and 60°N at 20°W in the North Atlantic. *Journal of the marine biological Association of the UK* **55**: 143-164.

MacDonald DS, Little M, Eno NC and Hiscock K (1996). Disturbance of benthic species by fishing activities: a sensitivity index. *Aquatic Conservation* **6**: 257-268.

Madden H, Beare D, Heath MR, Fraser JG and Gallego A (1999). The spring/early summer distribution of *Calanus* spp. In the northern North Sea and adjacent areas. *Fisheries Oceanography* **8** (suppl. 1): 138-152.

Martin JH and Flegal AR (1975). High copper concentrations in squid livers in association with elevated levels of silver, cadmium and zinc. *Marine Biology* **30**: 51-55.

Mauchline J and Fisher LR (1969). The biology of euphausiids. *Advances in marine Biology* **7**: 1-454.

McCauley RD (1994). Seismic surveys. In, Swan, JM, Neff, JM and Young, PC (Eds) *Environmental implications of offshore oil and gas developments in Australia. The findings of an independent scientific review*. Australian Petroleum Exploration Association, Sydney, NSW. 696pp.

McLeod CR (1996). Glossary of marine ecological terms, acronyms and abbreviations used in MNCR work. Joint Nature Conservation Committee, Peterborough.

Mead CJ (1989). Mono-kill and Auk netfax. *BTO News* **163**: 1 & 8.

Mehlum F (1980). Seabirds and the Bravo blow-out at Ekofisk, North Sea. *Polska Akademia Nauk: Acta Ornithologica* **XVII**: 119-126.

Merrett N R (1994). Reproduction in the North Atlantic oceanic icthyofauna and the relationship between fecundity and species sizes. *Environmental Biology of Fishes.*

Merrett NR and Haedrich RL (1997). *Deep-sea demersal fish and fisheries.* Chapman and Hall, London.

Middleditch BS (1984). Ecological effects of produced water effluents from offshore oil and gas production platforms. *Ocean Management* **9**: 1091-316

Middleditch BS (ed) (1981). Environmental effects of offshore oil production, the Buccaneer gas and oil field study. Plenum Press. 446pp.

Mitchell R (1987). Conservation of marine benthic biocoenoses in the North Sea and Baltic. Council of Europe. Nature and Environment series No. 37, Strasbourg.

MMS (1998). Gulf of Mexico OCS Oil and Gas Lease Sales 171, 174, 177 and 180. Western Planning Area. Final Environmental Impact Statement. US Department of the Interior Minerals Management Service, Gulf of Mexico OCS Region. New Orleans.

Mobil (1998). Environmental Statement. Exploration Well 214/4-EA. Mobil North Sea Limited, May 1998.

Morgan RK and Memon A (1993). Assessing the Environmental Effects of Major Projects. A practical guide. Environmental Policy and Management Research Centre Publication No 4. University of Otago, Dunedin, New Zealand.

Moscrop A (1997). Cetaceans of the north-east Atlantic Fringe. Report to Greenpeace UK.

Mowat F (1984). *Sea of Slaughter*. Bantam Books Inc. 438pp.

MPCU (1996). *The Sea Empress Incident*. A report by the Marine Pollution Control Unit. The Coastguard Agency, Southampton. 128pp.

Murray L and Simmonds M (1998). The Atlantic Frontier; Britain's last ocean wilderness. Greenpeace and the Whale and Dolphin Conservation Society Report.

Neff JM, Bothner MH, Maciolek NJ and Grassle JF (1989). Impacts of exploratory drilling for oil and gas on the benthic environment of Georges Bank. *Marine Environmental Research* **27**: 77-114.

NERC (1983). Contaminants in marine top predators. NERC report series C, No 23.

Newell RC, Seiderer LJ and Hitchcock DR (1998). The impact of dredging works in coastal waters: A review of the sensitivity to disturbance and subsequent recovery of biological resources on the sea bed. *Oceanography and Marine Biology: An Annual Review* **36**: 127-178.

NSTF (1993) North Sea Quality Status Report 1993. North Sea Task Force. Oslo and Paris Commissions. International Council for the Exploration of the Sea. Olsen & Olsen, Fredensborg. 132pp.

OLF (1993). OLF Environmental Programme Phase II: Project B06 Reduction in Emissions from Offshore Loading. OLF March 1993.

OLF (1998). Produced water discharges to the North Sea: Fate and effects in the water column. Summary Report. 39pp.

Olsgard F and Gray JS (1995). A comprehensive analysis of the effects of offshore oil and gas exploration and production on the benthic communities of the Norwegian continental shelf. *Marine Ecology Progress Series* **122**: 277-306.

Peacock JD and Harkness DD (1990). Radiocarbon ages and the full-glacial to Holocene transition in seas adjacent to Scotland and southern Scandinavia: a review. *Transactions of the Royal Society of Edinburgh. Earth Sciences* **81**: 385-96.

Peacock JD, Graham DK and Wilkinson IP (1978). Late-glacial and post-glacial marine environments at Ardyne, Scotland, and their significance in the interpretation of the history of the Clyde sea area. *Reports of the Institute of Geological Sciences* 78/17.

Pearson WH, Skalski JR and Malme CI (1992). Effects of sounds from a geophysical survey device on behaviour of captive rockfish (*Sebastes* spp.). *Canadian Journal of Fisheries and Aquatic Science* **49**: 1357-1365.

Pepper D (1984). The Roots of Modern Environmentalism. Routledge. 246pp.

Pipe RK and Coombs SH (1980). Vertical distribution of zooplankton over the northern slope of the Wyville Thomson Ridge. *Journal of Plankton Research* **2**: 223-234.

Pollock CM, Mavor R, Weir CR, Reid A, White RW, Tasker ML, Webb A and Reid JB (in press). The distribution of seabirds and marine mammals in the Atlantic frontier, north and west of Scotland. Joint Nature Conservation Committee.

Pollock CM, Reid JB, Webb A and Tasker ML, (1997). The distribution of seabirds and cetaceans in the waters around Ireland. JNCC Report No 267.

Ray JP and Engelhardt FR (eds) (1992). *Produced Water: Technological / Environmental Issues and Solutions*. Plenum Press.

Ray JP, Fucik KW, O'Reilley JE, Chai EY and LaMotte LR (1989). Drilling fluid toxicity test: Variability in US commercial laboratories. In *Drilling Wastes* (FR Engelhardt, JP Ray and AH Gillam eds), pp. 731-755. Elsevier Applied Science, London.

Raymont JEG (1983). Plankton and Productivity in the Oceans. 2nd edition. Volume 2 Zooplankton. Pergamon Press. 824pp.

Reed M and Johnsen S (eds) (1996). *Produced Water 2: Environmental Issues and Mitigation Technologies*. Plenum Press.

Rees EIS, Nicolaidou A and Laskaridou P (1977). The effects of storms on the dynamics of shallow water benthic associations. In *Biology of Benthic Organisms*. Proceedings of the 11th European Symposium on Marine Biology, Galway, Ireland, October 5-11, 1976 (BF Keegan, PO Ceidigh and PJS Boaden eds), pp 465-474. Pergamon Press, Oxford.

Reiersen L-O, Gray JS, Palmork KH and Lange R (198). Monitoring in the vicinity of oil and gas platforms; results from the Norwegian sector of the North Sea and recommended methods for forthcoming surveillance. In *Drilling Wastes* (FR Engelhardt, JP Ray and AH Gillam eds), pp. 91-117. Elsevier Applied Science, London.

Rezak R, Bright TJ and McGrail DW (1985). *Reefs and banks of the northwestern Gulf of Mexico: their geological, biological and physical dynamics*. John Wiley & Sons, New York.

Rice AL, Billett DSM, Fry J, John AWG, Lampitt RS, Mantoura RFC and Morris RJ (1986). Seasonal deposition of phytodetritus to the deep-sea floor. *Proceedings of the Royal Society of Edinburgh* **88B**: 265-279.

Richardson MG, Dunnet GM and Kinnear PK (1981). Monitoring seabirds in Shetland. *Proceedings of the Royal Society of Edinburgh* **80B**: 157-179.

Richardson WJ, Greene CR Jr, Malme CI and Thomson DH (1995). *Marine Mammals and Noise*. Academic Press.

Ritchie W and O'Sullivan M (eds) (1994). *The environmental impact of the wreck of the Braer*. The Ecological Steering Group on the oil spill in Shetland. The Scottish Office Environment Department.

Rogers AD (1999). The biology of *Lophelia pertusa* (Linnaeus, 1758) and other deep-water reef-forming corals and impacts from human activities. *Internationale Revue de Hydrobiologie* **84**: 315-406.

Rogers CS (1990). Responses of coral reefs and reef organisms to sedimentation. *Marine Ecology Progress Series* **62**: 185-202.

Ropes JW (1985). Modern methods to age oceanic bivalves. *Nautilus* **99**: 53-57.

Ruddiman WF and MacIntyre A (1973). Time-transgressive deglacial retreat of polar waters from the North Atlantic. *Quaternary Research* **3**: 117-130.

Rye H and Brandvik PJ (1997). Verification of subsurface oil spill models. Proceedings of the 1997 International Oil Spill Conference, pp 551-557.

Rye H Reed M, Ekrol N, Johnsen S and Frost T (1998). Accumulated concentration fields in the North Sea for different toxic compounds in produced water. SPE paper 46621. SPE International Conference on health, safety and environment in oil and gas exploration and production, Caracas, Venezuela, 7-10 June 1998.

SFPA (1999). SFPA surveillance coverage 1998-1999. Scottish Fishery Protection Agency Annual Report 1999. SFPA, Edinburgh.

Skalski JR, Pearson WH and Malme CI (1992). Effects of sounds from a geophysical survey device on catch-per-unit-effort in a hook-and-line fishery for rockfish (*Sebastes* spp.). *Canadian Journal of Fisheries and Aquatic Science* **49**: 1343-1356.

SOAEFD (1996). Monitoring and assessment of the marine benthos at UK dredged material disposal sites. Scottish Fisheries Information Pamphlet, No. 21 35pp.

Somerville HJ, Bennett D, Davenport JN, Holt MS, Lynes A, Mahieu A, McCourt B, Parker JG, Stephenson RR, Watkinson RJ and Wilkinson TG (1987). Environmental effect of produced water from North Sea oil operations. *Marine Pollution Bulletin* **18**: 549-558.

Sorensen PW, Medved RJ, Hyman MAM and Winn HE (1984). Distribution and abundance of cetaceans in the vicinity of human activities along the continental shelf of the northwestern Atlantic. *Marine Environmental Research* **12**: 69-81

Stagg RM, McIntosh AD, Moffat CF, Robinson C, Smith S, Bruno DW and Secombes CJ (1997). The sub-lethal effects of the Braer oil spill, Shetland Isles, Scotland, on farmed Atlantic salmon (*Salmo salar*) and the common dab (*Limanda limanda*). In, Davies JM and Topping G (eds) *The impact of an oil spill in turbulent waters: the Braer*. The Stationary Office, London.

Starczak VR, Fuller CM and Butman CA (1992). Effects of barite on aspects of the ecology of the polychaete *Mediomastus ambiseta*. *Marine Ecology Progress Series* **85**: 269-282

Stemp R (1985). Observations on the effects of seismic exploration on seabirds. In, Greene GD, Engelhardt FR and Paterson RJ (eds) *Proceedings of the Workshop on Effects of Explosives Use in the Marine Environment*. Jan 29-31, 1985. Halifax.

Stockil P (Ed.) (1977). Our Industry Petroleum. The British Petroleum Company Limited, London. 600pp

Stone CJ (1997). Cetacean observations during seismic surveys in 1996. JNCC Report, No. 228

Stone CJ (1998). Cetacean observations during seismic surveys in 1997. JNCC Report, No. 278

Stone CJ (2000). Cetacean observations during seismic surveys in 1998. JNCC Report.

Stone CJ, Webb A and Tasker ML (1994). The distribution of auks and procellariiformes in north west European waters in relation to depth of sea. *Bird Study*, **42**: 50-56.

Stone CJ, Webb A, Barton C, Ratcliffe N, Reed TC, Tasker ML, Camphuysen CJ and Pienkowski MW (1995). An Atlas of Seabird Distribution in North-West European Waters. JNCC, Peterborough.

Stowe TJ (1982). Beached bird surveys and surveillance of cliff-breeding seabirds. Unpublished report to NCC. Royal Society for the Protection of Birds.

Stowe TJ and Underwood LA (1983). Oil spillages affecting seabirds in the United Kingdom, 1966-1983. *Marine Pollution Bulletin* **15**: 147-152

Swan JM, Neff JM and Young PC (1994). Environmental implications of offshore oil and gas development in Australia - the findings of an independent scientific review. Australian Petroleum Exploration Association, Sydney, 695 pp.

Tagatz ME and Tobia M (1978). Effect of barite ($BaSO_4$) on development of estuarine communities. *Estuarine and Coastal Marine Science* **7**: 410-407.

Tasker ML (1997). Seabirds. In, Barne JH, Robson CF, Kaznowska SS, Doody JP, Davidson NC and Buck AL (eds) *Coasts and Seas of the United Kingdom, Region 1 Shetland.* Joint Nature Conservation Committee, Peterborough.

Tasker ML, Hope Jone P, Blake BF, Dixon TJ and Wallis AW (1986). Seabirds associated with oil production platforms in the North Sea. *Ringing & Migration* **7**: 7-14.

Tasker ML, Webb A, Hall AJ, Pienkowski MW and Langslow DR (1987). Seabirds in the North Sea. Final report of phase 2 of the Nature Conservancy Council Seabirds at Sea Project. November 1983-October 1986. Nature Conservancy Council.

Tendal OS (1972). *A monograph of the Xenophyophoria (Rhizopodea, Protozoa*). Danish Science Press Ltd, Copenhagen.

Thomassen J, Bamstedt U, Munro Jensen B, Mariussen, A Moe KA and Reiersen JE (1993). Åpning av Trøndelag I Øst, Nordland IV, V, VI og VII, Mørebassenget, Vøringbassenget I og II for letevirksomhet. Konsekvensutredning for miljø, naturressurser og samfunn. Naerings- og energidepartementet, Oslo, 132 pp.

Torres ME, Brumsack HJ, Bohrmann G and Emies KC (1996). Barite fronts in continental margin sediments: A new look at barium remobilization in the zone of sulfate reduction and formation of heavy barites in diagenetic fronts. *Chemical Geology* **127**:125-139.

Turrell WR, Slesser G., Adams RD, Payne R and Gillibrand, PA (1999). Decadal variability in the composition of Faroe Shetland Channel bottom water. *Deep-Sea Research 1* **46**: 1-25.

UK Offshore Operators Association and the Natural History Museum. Britain's Oil and Gas. Second Edition. 55pp.

UKOOA (1999). 1998 Environmental Performance Report. http://www.oilandgas.org.uk

UKTERG (1988). The Effects of Acid Deposition on the Terrestrial Environment in the United Kingdom. United Kingdom Terrestrial Effects Review Group, First Report. HMSO.

Uttley J, Walton P, Monaghan P and Austin G (1994). The effects of food abundance on breeding performance and adult time budgets of Guillemots *Uria aalge*. *Ibis* **136**: 205-213.

Vauk G (1984). Oil pollution dangers on the German coast. *Marine Pollution Bulletin* **15**: 89-93.

Wardle CS, Carter TJ, Urquhart GG, Johnstone ADF, Ziolkowski AM, Hampson G and Mackie D (1998). Seismics and fish. Abstract presented at Atlantic Frontier Environmental Conference, 6th and 7th October 1998.

Webb A, Stronach A, Tasker ML and Stone CJ (1995). Vulnerable concentrations of seabirds south and west of Britain. Joint Nature Conservation Committee, Peterborough.

Würsig B (1990). Cetaceans and Oil: Ecologic Perspectives. In, Geraci JR and St. Aubin DJ (eds) (1990). *Sea Mammals and Oil: Confronting the Risks*. Academic Press. 282pp.