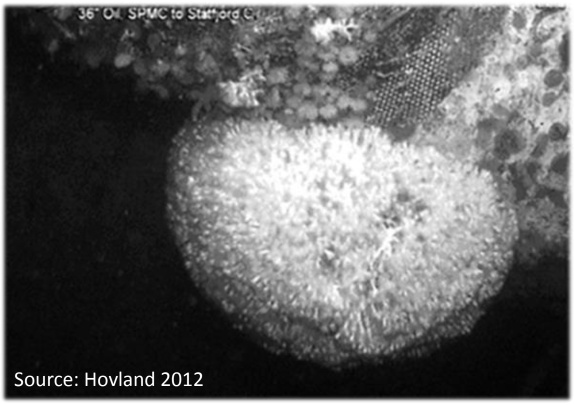
Cold-water corals and offshore hydrocarbon exploration operations on the Irish Atlantic Margin

A knowledge exchange workshop

Irish Offshore
Operators'
Association


Source: IOOA 2014


Source: Hovland 2012

Report from the workshop

1st December 2014

Dublin, Ireland

Client:	Irish Offshore Operators’ Association (IOOA)
Project Title:	Cold-water corals and offshore hydrocarbon operations on the Irish Atlantic Margin – Workshop Report

Rev.	Status	Date	Author(s)	Reviewed By	Approved By
F01	Final (Rev0)	13th March 2015	Dr James Forde Dr James Massey	Dr James Massey	Gareth McElhinney

EXECUTIVE SUMMARY

A knowledge exchange workshop was hosted by the Irish Offshore Operators' Association (IOOA) on 1st December 2014. Workshop participants included national and international representatives from the oil and gas industry, academia, government departments and non-government organisations. The aim of the workshop was to gain expert insight and opinion on the potential impacts from, and controls/mitigations for, exploration seismic surveys and drilling operations on cold-water coral (CWC) reef systems. The key objectives of the workshop were;

- identification of potential receptors associated with CWC reefs including reef-forming coral species (e.g. *Lophelia* sp. and *Madrepora* sp.) and reef-associated invertebrate and fish species;
- potential interactions with CWC receptors by exploration seismic surveys and drilling operations and determination of potential impacts;
- likely receptor tolerance and thresholds to O&G exploration activities; and
- potential mitigation measures and degree of confidence in their success.

The workshop included presentations on the state of knowledge on CWC, and industry case studies, followed by a collaborative ENVID style review and impact assessment session for a seismic and drilling scenario. The purpose of the sessions was to discuss, and achieve consensus on, all possible interactions between the seismic and drilling operation scenarios and CWC. Each interaction was then assessed in detail by the group and a general accord reached on potential impacts, options to eliminate or mitigate these and any residual impacts or uncertainties. The following conclusions were determined:

- The distribution of CWC carbonate mounds in the Irish Atlantic margin is relatively well mapped through a combination of direct observational data (e.g. drop-down camera/video, ground truth/grab records) and interpretation of geophysical and acoustic survey and predictive habitat suitability modelling. This mapping is based on data collected by the hydrocarbon industry, academia and during the INSS (Irish National Seabed Survey), and its successor INFOMAR (Integrated Mapping for the Sustainable Development of Ireland's Marine Resources). With the exception of a few, small areas of sustained CWC research effort, less is understood across the Irish Atlantic margin about the distribution of small stands of CWC (Wheeler, 2014). The coverage of high-resolution seabed mapping over the Irish offshore is limited;
- Further directed sampling is required to improve the understanding of the relative distribution and current condition of high quality, high conservation value CWC reefs;
- There was recognition among participants that there are case studies where hydrocarbon exploration activities have been carried out in locations adjacent to areas of high-conservation value CWC and tropical coral, particularly in Norwegian and Australian offshore waters, with no detectable impact on these ecosystems;
- It is highly improbable that the interaction of seismic survey employing airgun arrays less than 4,450 in^3 with Irish CWC and reef-associated species would cause any short- or long- term adverse biological or ecological impacts. This conclusion is based on the modelled sound exposure levels being below the thresholds for any biological and ecological impacts for tropical scleractinian coral and fish species established by detailed research in offshore Australia;
- Management and mitigation controls do exist to eliminate or significantly reduce potential impacts of drilling activities on CWC and associated species. There are case studies from around the world which demonstrate numerous best practice options to eliminate impacts to CWC;
- Australian and Norwegian case studies demonstrated that, should a potential exploration project require it, it would be relatively easy and, given the advances in high-resolution mapping sensors and platforms, not prohibitively expensive to secure suitable data to determine the spatial extent and condition of local CWC reef prior to operations; and
- There are internationally-accepted scientific thresholds for potential impacts of drilling discharges on CWC reef that can be used for exploration drilling planning, impact assessment and engineering option selection to ensure the risk of any impacts are minimised or eliminated.

TABLE OF CONTENTS

APPENDICES

LIST OF FIGURES

LIST OF TABLES

1 WORKSHOP SUMMARY

1.1 WORKSHOP RATIONALE

A workshop, investigating the potential interaction between cold-water coral (CWC) reef and offshore hydrocarbon exploration operations on the Irish Atlantic margin, was held in Dublin on 1st December 2014. The workshop, hosted by the Irish Offshore Operators' Association (IOOA), was initiated to provide a forum for the exchange of scientific and operational knowledge and experience from other European mature hydrocarbon provinces which co-occur with, or are adjacent to, areas supporting CWC. The workshop programme is provided in **Appendix A**.

Invited workshop participants included national and international representatives from the oil and gas industry, academia, government departments and non-government organisations (a full list of participants is presented in **Appendix B**). The aim of the workshop was to gain expert insight and opinion on the potential impacts from, and controls/mitigations for, exploration seismic and drilling operations on CWC on the Irish Atlantic margin. Overall objectives of the workshop included:

- identification of potential receptors associated with CWC reefs including reef-forming coral species (e.g. *Lophelia* sp. and *Madrepora* sp.) and reef-associated invertebrate and fish species;
- potential interactions with CWC receptors by exploration seismic surveys and drilling operations and determination of potential impacts;
- likely receptor tolerance and thresholds to O&G exploration activities;
- potential mitigation measures and degree of confidence in their success; and
- consideration of monitoring plan/scheme requirements against baseline data.

1.2 WORKSHOP PROCESS

A list of key topics (see **Section 1.3.2** below) was identified. The workshop approached each topic area in terms of briefing and case studies, and discussion on the current state of knowledge followed by ENVironmental aspects IDentification (ENVID) style review and impact assessment. In each case, the purpose was to discuss, where possible, achieve a consensus on the potential interactions between petroleum exploration, CWC reefs and the keystone or reef-forming species. This included impact assessment methodologies and discussion as outlined below.

The ENVID review was followed by an assessment of the level of impact and consideration of techniques to eliminate or mitigate potential impacts of drilling activities on CWC and associated species (**Figure 1.1**). Descriptions of the scenarios used for the ENVID review and impact assessments of seismic and drilling operations are outlined in **Section 2.4** and **Section 2.6** respectively. Conclusions of discussions for seismic operations are in Appendix **C** and **Section 4.1**. Conclusions of discussion for drilling operations are in **Appendix D** and **Section 4.2**.

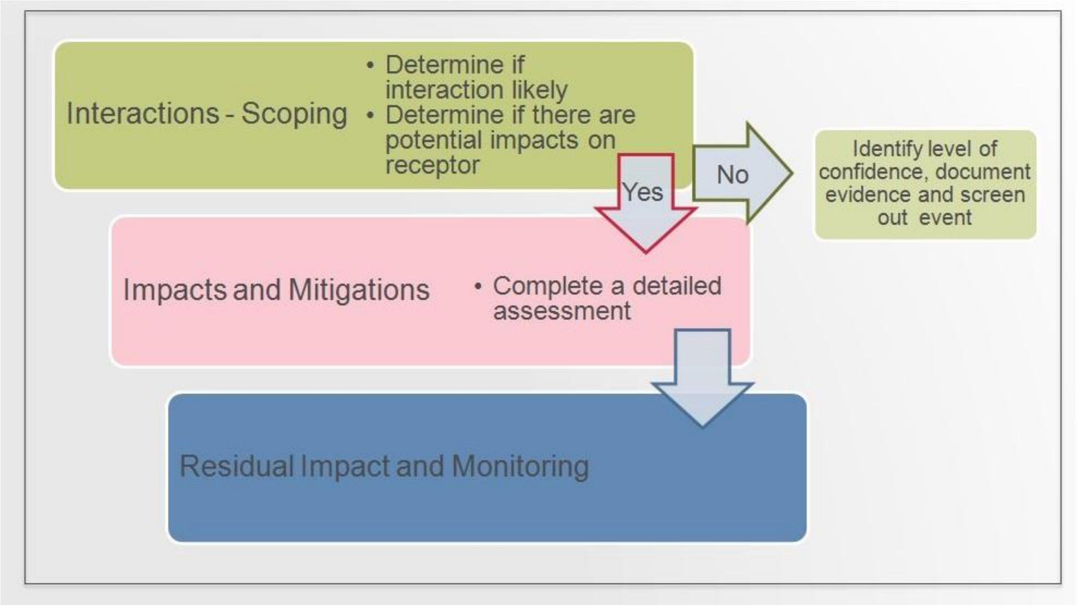


Figure 1.1 Workshop ENVID and Impact Assessment Process

Potential interactions between exploration activities and marine mammals, fish, and other invertebrate species potentially associated with the CWC reef were acknowledged. However, it was agreed that generally these species are subject to their own assessments within current Strategic Environmental Assessment (SEA), Environmental Impact Assessment (EIA), Habitat Regulations (HR) and Appropriate Assessment (AA) processes. Consequently, assessment of potential impacts generally focused on major CWC reef-forming species found in Irish waters (*Lophelia* sp., *Madrepora* sp.) and, to lesser extents, reef-associated fish and invertebrates.

1.3 WORKSHOP ACTIVITIES

Section 1.3.1 below briefly outlines presentation topics while **Section 1.3.2** outlines the main subject matter discussed during break-out/plenary sessions.

1.3.1 Workshop Presentations

- A review of historical, current and projected oil and gas exploration/production activities in Irish waters including a brief introduction to the regulatory framework for hydrocarbon activities [Professor Pat Shannon (IOOA)];
- A review of European legislation affording protection to CWC reef ecosystems, and a state-of-play account of Ireland's existing and proposed network of offshore marine protected areas (MPAs) that, either directly or indirectly, provide protection to CWC reef ecosystems [Dr David Lyons (Irish National Parks and Wildlife Service)(NPWS)];
- A description of the spatial distribution, ecology, biology and connectivity of key CWC provinces in the Porcupine and Rockall basins, recent developments with respect to broad-scale reef mapping and a description of future directed research opportunities with respect to biodiversity hotspots [Dr Anthony Grehan (NUI Galway) (NUIG) and Professor Andy Wheeler (University College Cork) (UCC)];
- Ecology and biology of CWC and the success of Joint Industry Programmes (JIPs) in the UK sector [Professor Murray J Roberts (Heriot-Watt University) (HWU)];

- Laboratory-measured threshold/tolerance of *Lophelia* sp. to drill cuttings exposure and knowledge gaps. Discussion on knowledge gaps for gorgonians and sponges [Dr Thierry Bassant (International Research Institute of Stavanger) (IRIS)];
- Description of Woodside Energy Ltd three-dimensional marine seismic survey ('Maxima' 3D MSS) at Scott Reef, Australia and world-first field research on quantifying impacts of seismic activities on tropical corals and site-attached fish [Dr Luke Smith (Woodside Energy Ltd) and Professor Chris Battershill (University of Waikato) (UW)];
- Understanding potential physical and chemical O&G related impacts to CWC species, and quantifying relevant environmental thresholds. Identification of controls, monitoring standards and mitigation measures using examples from Norway [Lars Petter Myhre and Rune Weltzien (Statoil)];
- A review of the noise modelling results of a theoretical seismic survey in the Porcupine Basin using a large seismic array and sound models to calculate sound exposure levels at three CWC provinces [Dr Luke Smith (Woodside Energy Ltd)].

1.3.2 Main Workshop Discussion Topics

- State of knowledge of the distribution, ecology and biology of CWC in Irish waters;
- Potential physical and non-physical impacts of seismic exploration surveys on CWC reef. Discussions included a review of Australian research on the impacts of seismic surveys and a critical evaluation of the relevance of research findings to CWC in Irish waters;
- Review of information regarding the sensitivity and tolerances of *Lophelia* sp. published in the MarLIN/JNCC guidance (Tyler-Walters, 2005) and group evaluation of possible mitigation measures and monitoring of potential seismic impacts;
- Potential impacts of exploration drilling on CWC reef, taking into account existing research conducted on CWC and tropical coral reef habitats. Discussion included a critical assessment of the applicability of existing industry guidelines for the regulation of exploration activities in the Irish offshore. Potential mitigation measures with respect to CWC along the Irish Atlantic margin were also discussed; and
- Although not fully explored during the workshop, there were discussions on the identification of ecologically suitable, yet economically and technically feasible, period(s) of time that monitoring should be conducted following seismic/drilling operations.

1.4 WORKSHOP DELIVERABLES

This report summarises the workshop process, major discussions and key conclusions of the participants. This report is intended to highlight the state-of-knowledge for CWC and potential management and mitigation approaches to exploration seismic and drilling operations in the Irish offshore. The preparation and review of this report has been a collaboration between workshop participants, the RPS group and the IOOA environment subcommittee.

2 WORKSHOP SESSIONS

The workshop programme comprised presentations and break-out group/plenary session discussions (**Appendix A**). Overviews of presentations are provided in **Sections 2.1, 2.2, 2.3** and **2.5**. Full presentations are available on the IOOA website (http://iooa.ie/) or on request from the IOOA environment subcommittee. **Section 2.4** and **Section 2.6** summarises group discussion from the ENVID review sessions for the seismic and drilling scenarios.

2.1 ABSTRACTS - IRISH CONTEXT

2.1.1 Historical, current and future oil & gas activity in offshore Ireland [Professor Pat Shannon (IOOA)]

The Department of Communications, Energy and Natural Resources (DCENR) administers Ireland's regime of licensing for oil and gas exploration and production. The principal relevant statute is the Petroleum and Other Minerals Development Act 1960 applied to the Irish offshore, comprising the territorial waters of the State and offshore areas designated by Order from time to time under the Continental Shelf Act.

The acquisition of seismic data in Irish offshore waters started in 1965 and the first licensing authorisations were granted in 1970. A total of 158 exploration and appraisal wells have been drilled in offshore Irish waters between 1970 and 2014 (DCENR, 2015; Naylor and Shannon, 2011).

The 2015 Atlantic Margin Licensing Round will involve acreage in all of Ireland's major Atlantic basins: Porcupine, Goban Spur, Slyne, Erris, Donegal and Rockall. As in the 2011 Licensing Round, the form of petroleum authorisation on offer will be a two year "licensing option". The entire Irish offshore area is currently subject to an Irish Offshore Strategic Environmental Assessment (IOSEA) process.

The last three years have seen a significant increase in exploration seismic operations along the Irish Atlantic margin, with the expectation that proposals for exploratory drilling will also be made. This is likely to facilitate an increase in the number of exploration drilling operations in the medium term.

Sharing the state-of-knowledge for any fragile ecosystems in offshore Ireland ahead of any sustained increase in exploration operations in the Irish offshore will ensure hydrocarbon exploration operations in offshore Ireland are designed and executed with an evidence-based, best-in-region approach.

2.1.2 Current protection of Cold-Water Coral and future designations [Dr David Lyons (NPWS)]

The Irish Government and the NPWS recognise offshore areas as likely to contain 'Reef' as defined under Annex 1 of the Habitats Directive. Reefs can be either biogenic concretions or of geogenic origin. They are hard compact substrata on solid and soft bottoms, which rise from the sea floor as distinct structures and habitats in the sublittoral and littoral zone.

Reefs may support a zonation of benthic communities of algae and animal species as well as corallogenic concretions. CWC can form reef habitat and occur in association with geogenic reef in the same site. There are six Special Areas of Conservation (SACs) designated for biogenic or geogenic reef in the Irish offshore . The NW Porcupine Bank cSAC[1], Hovland Province SAC Belgica Mounds SAC and SW Porcupine Bank cSAC[1] are designated for biogenic reef. SE Rockall Bank SAC is designated for geogenic reef and the Porcupine Bank Canyon SAC is designated for geogenic reef.

In Ireland, the NPWS is responsible for the management and reporting of the favourable conservation status (FCS) of reef habitats under the Habitats Directive. The conservation status of a habitat is considered 'favourable' when: (i) its natural range and area it covers within that range are stable or increasing; and (ii) the species structure and functions which are necessary for its long term maintenance exist and are likely to continue to exist for the foreseeable future.

Any exploration activities in these areas are subject to full assessment for potential impacts. All exploration activities are subject to screening against the EIA and Habitat Regulations AA.

2.2 ABSTRACTS - UNDERSTANDING COLD-WATER CORALS

2.2.1 Distribution of Cold-Water Coral in Irish Waters. Structure of key provinces in the Porcupine and Rockall Basins [Professor Andy Wheeler (UCC)]

CWC reefs are aggregation of azooxanthallate corals (corals without photosynthetic symbionts) which include calcareous frameworks of corals that provide habitat for other species. The reef habitats support communities with high levels of biodiversity and biomass. In Irish waters CWC are not rare but are slow growing and slow colonising.

CWC occurrence (distribution) and sensitivity to change is identified by their tolerances to changes in (in order of priority) temperature, food supply, hydrodynamics, substrate and acidification (Roberts et al., 2009). In Irish waters CWC is typically found between 200 – 1,000 m water-depth but some examples have been recorded at 80 – 100 m and where they occur their distribution can be extensive. There are three distinct recognised CWC bedforms: reef, carbonate mounds and small stands of corals (Roberts et al., 2009), which produce different habitats with variable amounts of live corals associated and exhibit differing sensitivities. They occur as habitat complexes or aggregations with other megafaunal communities such as deep water sponges and rocky reef habitats, as well as sedimentary habitats.

While CWC is present throughout the ridge areas of the Irish continental shelf their distribution is particularly concentrated into a number of areas (or provinces) which exhibit differing environmental conditions. CWC is present in the Rockall Bank and Ray Keary Mounds, Porcupine Bank (including the Hovland mounds), Porcupine Seabight and Moira mounds. Their distributions are varied however, with the Logachev and Belgica Mounds (including the Moira Mounds) provinces having the most "vibrant" coral reef habitats, with patch reef, rubble and sediment filled mounds present in the Porcupine Bank provinces (Hovland and Megallan Mound Provinces). Most of these areas are underexplored and mapping of CWC reef distribution and condition within SACs and exploration licenses would benefit researchers and industry alike.

---

[1] A candidate Special Area of Conservation (cSAC) is an SAC pending finalisation of the designation process. A cSAC is afforded conservation status equal to a fully designated SAC.

2.2.2 Cold-Water Coral understanding and management. Current stresses to Cold-Water Corals on the Irish Atlantic margin and the status of the Irish MPA network [Dr Anthony Grehan (NUIG)]

CWC habitat complexes along the Atlantic margin are comprised of *Lophelia* sp*., Madrepora* sp*., Desmophyllum* sp., black corals (*Antipatharia*), sponges, erect sponges, *Hexactinellid* sponges, gorgonians, hydrozoan (e.g. *Stylasteridae*) and crinoids. The principal reef forming corals are *Lophelia* perusa and *Madrepora oculata.* Invertebrate species associated with CWC including barnacles, squat lobsters (*Mundidae*), crabs (e.g. *Bathynectes* sp*, Paramola* sp, *Chaceon* sp) and echinoderms; urchins, starfish and holothurians (e.g. *Psolus* sp).

The EU FP7 multinational 'CoralFISH' project (www.eu-fp7-coralfish.net) provides information and tools for the management of coral habitats:

- It was a four-year study to assess the interaction between corals, fish and fisheries, in order to develop monitoring and predictive modelling tools for ecosystem based management in the deep waters of Europe and beyond. As part of the programme of work a CWC Habitat Catalogue has been compiled listing more than 80 different coral habitats. Much of the research output from the project will be reported in a Deep-Sea Research Special Issue: The CoralFISH project: supporting ecosystem based management and monitoring of the deep Mediterranean & North-East Atlantic (due the end of 2015).
- One of the main outputs of the project was the development of habitat suitability modelling to enable the predictive distribution maps of species and habitats to be created. Habitat suitability modelling addresses the paucity of biological data available to resource managers in the offshore. Further mapping and assessment (inventory) of the condition of our ecosystems and valuing the provision of ecosystem services is underway as part of the national contribution to the EU Biodiversity Action Plans - 2020). Habitat suitability modelling allows the mapping of potential coral areas to assist the management of activities and support the development of a coherent national marine spatial planning strategy (MSP Directive). Specifically this allows the facilitation of a move from 'precaution' to 'evidence based' adaptive management.

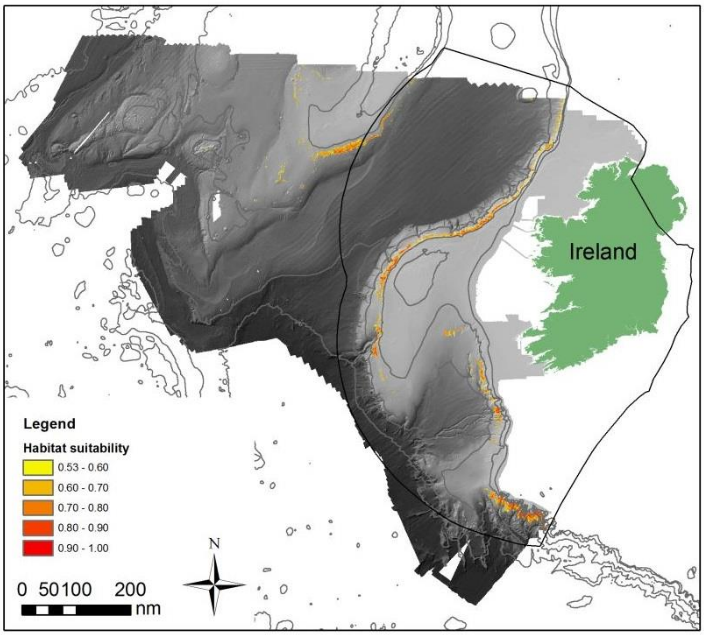


Figure 2.1 Habitat suitability model for cold water corals (GeoHAB) (from Rengstorf et al., 2013)

2.2.3 Ecology and biology of Cold-Water Coral and success of Joint Industry Programmes in the UK Sector [Professor Murray Roberts (HWU)]

Joint Industry Programmes (JIPs) have supported a long history of petroleum exploration research in the UK. Currently programmes are focusing on:

- Acute pollution issues: identification of the major groups of bacteria that contribute importantly to the degradation of oil;
- Chronic issues: Cuttings, with research now focusing on spatial and temporal trends in benthos analysing and identifying the effects of cuttings piles examined versus effects of oceanographic regimes; and
- Long-term issues: Ocean Acidification, which is a particular concern to coral reefs and may affect the process reef/mound development. Ongoing collaboration includes monitoring trends in global ocean acidification.

Assessment of the potential interactions with coral reefs should employ the best available integrated high resolution acoustic mapping and visual survey to ascertain not only distribution, but habitat types and an evaluation of the presence (and condition) of live corals.

Development of measurement techniques for biodiversity and ecosystem function will provide future monitoring potential in relation to identifying any potential interaction with drilling activity.

2.3 ABSTRACTS - SEISMIC EXPLORATION AND COLD-WATER CORALS

2.3.1 Introduction to seismic survey operations [Gareth Parry (IOOA)]

Seismic operations are conducted to identify sub-surface structures that might trap oil and gas deposits. The geophysical method commonly used in surveying is called ‘seismic reflection profiling’. The technique involves releasing pulses of acoustic energy along designated lines. The energy penetrates the sub-surface rocks and is reflected back to the surface where it can be detected by acoustic transducers (hydrophones). Analysis of seismic reflections provides a profile of the underlying rock strata and identification of any configurations that are favourable to hydrocarbon accumulations. In some cases, it is possible to record anomalies that may correspond to actual hydrocarbon deposits. Over water, seismic surveys are usually conducted with ship-borne airguns as the acoustic energy source. A streamer of hydrophones is towed behind the vessel, usually extending for several kilometres (**Figure 2.2**). There are three main aspects in the delivery of a seismic survey, these are the;

- seismic vessel;
- seismic acquisition equipment; and
- guard vessel and when necessary, support vessel, to be deployed.

A survey is usually based on a grid pattern of lines, along each of which are ‘shot points’, where the sound is released. Two-dimensional (2D) seismic lines are normally acquired on a 500 m or greater line spacing whereas three-dimensional (3D) seismic is acquired at a much closer spacing, between 25-50 m, such that the data can be processed to give a continuous image of the reflections between, as well as along the line. Offshore, survey activities are confined to a self-contained survey vessel together with (a) ‘guard vessel(s)’, which will warn off other vessels/ maritime users.

Most surveys use an airgun source, which comprises of an array of individual and varied size, highly pressurised air chambers that, when simultaneously released by electronically-controlled solenoid valves, produce an energy impulse sound wave containing a range of low frequencies, typically 3 - 200 Hertz, which is the frequency bandwidth of most interest in seismic surveying (Gulland and Walker, 1998; MacGillivray and Chapman, 2005). Approximately 98% of all the acoustic energy in a seismic pulse is within this band (IAGC, 2014; IOGP, 2008). The source array consists of several strings of airguns forming a towed grid that provides several advantages over a single source, including increased sound pressure levels, broader frequency spectrum and a more downward focused beam.

The tail buoy helps the crew locate the end of the streamers. The seismic source is activated periodically, typically every 25 m (approximately 8-12 seconds apart). The resulting sound wave travels into the seabed and is reflected back by the underlying rock layers to the hydrophones and relayed to the recording vessel. The reflectivity of the sound wave is then analysed to provide information on the geological structures in the seabed.

A suitable scenario was developed for the workshop representing a larger and intense operation (3D survey with large source) to provide a likely worst case scenario for assessment. A likely worst case represents an operation that could occur in Irish waters with a specification above the levels most commonly conducted.

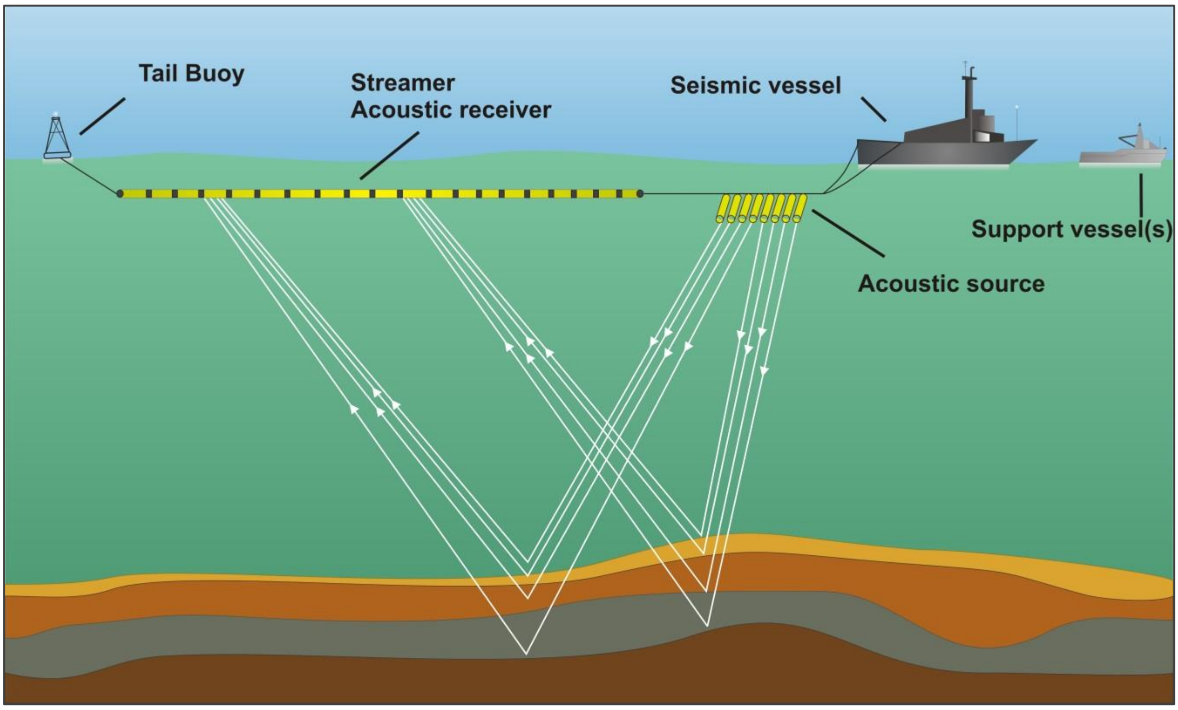


Figure 2.2 Typical Seismic Array Survey

2.3.2 Case Study – Maxima 3D seismic experiments [Professor Chris Battershill (UW)]

The Browse Development is located approximately 425 km north of Broome, Western Australia, and comprises three gas fields in water depths up to 600 m. The proposed development is a joint venture involving Woodside (operator) with Shell, BP, MIMI and PetroChina. One of the gas fields is partially overlaid by Scott Reef, a unique coral atoll with 237 km^2 of corals (max depth 60 m), and high biodiversity value.

In 2007, Woodside Energy Ltd conducted a three-dimensional (3D) marine seismic survey (Maxima 3D MSS) at Scott Reef. Before this seismic survey could proceed in this sensitive environment a world-first independent field study was undertaken to understand the impact of seismic noise on shallow-water scleractinian corals and site-attached fishes. The field study was a major research project involving, at its peak, 120 people and eight vessels operating in a remote offshore location (Colman et al., 2008). The research was undertaken by Australian Institute of Marine Science, Centre for Marine Science and Technology (Curtin University) and Pennsylvania State University and included many scientists who are leaders in their fields.

The key potential impacts Woodside needed to assess included:

- Individual benthic animals (such as hard and soft corals, sponges);
- Coral community as a whole (benthos and fish);
- Non-hearing physiological effects on site-attached fish;
- Physiological ‘hearing’ impacts (Temporary Threshold Shift, Permanent Threshold Shift, ear (otolith) damage on site-attached fish; and
- Population-level effects on fish communities.

The project included significant multi-disciplinary monitoring as there was little literature available on the impacts of seismic noise on scleractinian corals. These studies identified:

- Control sites recorded a maximum cSEL of 168dB re 1µPa^2 (RMS 150dB re 1µPa);
- ‘Impact’ sites recorded a maximum cSEL of 204dB re 1µPa^2 (RMS 220dB re 1µPa);
- No immediate nor sublethal effects on corals;
- No long term effects on corals; and
- No medium or long term effects on coral reef fishes (Miller and Cripps., 2013).

Significantly this represents an exploration seismic operation over a major scleractinian coral reef. It should be noted that this research was measured against 15-years of benthic and fish community baseline data including ongoing post activity monitoring (that continues today). The work represents the first of its type to examine the possible effects of seismic on scleractinian coral reef communities *in situ*, with a full commercial seismic array and over multiple time periods following seismic exposure (days to months).

With the correct mitigation measures and controls the project recorded:

- No short term damage or observed stress in coral assemblages;
- No impact on fish hearing or physiology (Hastings and Miksis-Olds, 2012);
- No long term impact on fish populations (Miller and Cripps., 2013) or coral communities (Battershill et al., 2007, 2008, 2015);
- No evidence of any immediate physiological damage as would be observed by mucous streaming from plate and branching corals and no evidence of polyp withdrawal or flaccidity in soft corals (Battershill et al., 2007, 2008, 2015);
- No detectable differences in the variables measured before and after seismic; and
- No fish mortality (Miller and Cripps, 2013).

2.3.3 Predicted sound exposures in an Irish context [Dr Luke Smith (Woodside Energy Ltd)]

A desktop 3D seismic survey sound modelling study was completed in 2014 for the Porcupine Basin in offshore Ireland (Austin et al., 2014). The study compared modelled sound levels at the seabed with thresholds for impacts on scleractinian corals and associated species.

The seismic acquisition modelled is the same as the scenario assessed in the workshop ENVID assessment (see **Section 2.4)**. The modelled acquisition used a large air gun array (total 4,450 in^3 over 26 individual guns) towed at 7 m depth. It should be noted that usual array size in Irish waters is between 3,500 and 3,900 in^3. The maximum array size used in offshore Ireland was 5,000 in^3 for the national Atlantic 2D long offset survey in 2013-2014 by ENI and DCENR.

Three areas were modelled (Magellan Mound Province, Hovland Mound Province; Belgica Mound Province) in water depths between 662 and 1,025 m. Multiple seismic lines were modelled to determine maximum ($SEL_{single\ pulse}$)[2] and cumulative sound exposure levels (SEL_{Cum}) received at resident coral mounds.

Using scleractinian coral exposure levels from the Maxima 3D research project (see **Section 2.3.2)** Austin et al. (2014) set a precautionary threshold of:

- SEL of 197 dB re 1 µPa^2·s for potential long-term effects on cold-water scleractinian corals; and
- SEL of 204 dB re 1 µPa^2·s for potential immediate impacts on cold-water scleractinian corals.

Table 2.1 Maximum modelled sound exposure levels (SEL) at CWC sites based on the workshop scenario

Site	Mound	Maximum SEL (single pulse) (dB re 1 µPa^2·s)	Maximum 24-hour Cumulative SEL (dB re 1 µPa^2·s)	Maximum Peak – Peak SPL (dB re 1 µPa)
A–MMP	Magellan	175.2	190.1	205.1
F–HMP	Hovland	172.9	189.2	202.8
I–BMP	Belgica	171.4	188.3	201.3

In relation to cold-water scleractinian corals Austin et al. (2014) found:

- The **maximum single-pulse SEL** at the seafloor was 175.2 dB re 1 µPa^2·s which is 22 dB **below the no long-term effect** maximum SEL of 197 dB re 1 µPa^2·s based on the Maxima 3D research project;
- The **maximum 24-hour SEL** was 190.1 dB re 1 µPa^2·s when accumulated over a suite of airgun pulses. This is 7dB below the **below the no long-term effect** maximum SEL of 197 dB re 1 µPa^2·s based on the Maxima 3D research project;

---

[2] Sound Exposure Level (SEL) according to Southall et al. (2007) is a Received Level (RL) measure of energy as the "dB level of the time integral of the squared-instantaneous sound pressure normalised to a 1-s period". Units are dB re 1 µPa^2-s.

- Under the assumption that all scleractinian corals have a similar response to seismic-related noise:
  - it is **highly unlikely CWC would be impacted** by the significantly lower received sound exposure levels from an Irish offshore seismic survey.

The maximum peak-peak (pk-pk) SPL[3], at the seafloor, from a single airgun pulse, modelled by Austin et al. (2014) was 205.1 dB re 1 µPa which is:

- 65 dB below the level at which Hastings et al. (2008) predicted there is likely to be skeletal damage to scleractinian corals (270 dB re 1µPa pk-pk); and
- 55 dB below the level at which Hastings et al. (2008) predicted there is likely to be damage to coral polyps (260 dB re 1µPa pk-pk).

The conclusion of the modelling is that no physical or physiological disturbance is expected to CWC reefs as a result of a large 3D seismic survey. In addition the modelling indicated that any physical or physiological disturbance to associated fish species was unlikely.

2.4 POTENTIAL STRESSORS FOR EXPLORATION SEISMIC AND COLD-WATER CORALS (GROUP DISCUSSIONS)

The workshop group considered a seismic survey scenario in an area of CWC. The assessment followed an ENVID style workshop and focussed on completing impact assessment summary tables.

Once the scenario was outlined the plenary was split into two groups. Within each group planned and unplanned events and potential interactions were discussed and rated. Consensus was reached on each point and the two groups then returned to plenary to discuss and agree the results.

The scenario outlined was the same as used in the Austin et al. (2014) modelling study, namely a 90 m survey vessel and guard vessel and support vessel with approximately 1,500 m^3 of marine diesel fuel conducting a 3D survey with a 4,450 in^3 airgun array in waters 700 m deep. The potential for bunkering at sea was also considered in the review. The vessel was determined to be running 10 streamers, each 12 km long. This represents a more extensive and powerful array than has been used in offshore Ireland recently, but remains a possible specification for a high-end seismic survey.

The groups then assessed possible interactions across two categories:

1) Planned, such as noise from airguns, noise from vessels and normal discharges from vessels; and
2) Unplanned, such as hydrocarbon spills, chemical spills, streamer breakages and dropped objects.

---

[3] Sound Pressure Level (SPL)or peak to peak according to Southall et al. (2007) is a Sound Level (SL) as it would measure 1m from the source in units of dB re 1 µPa

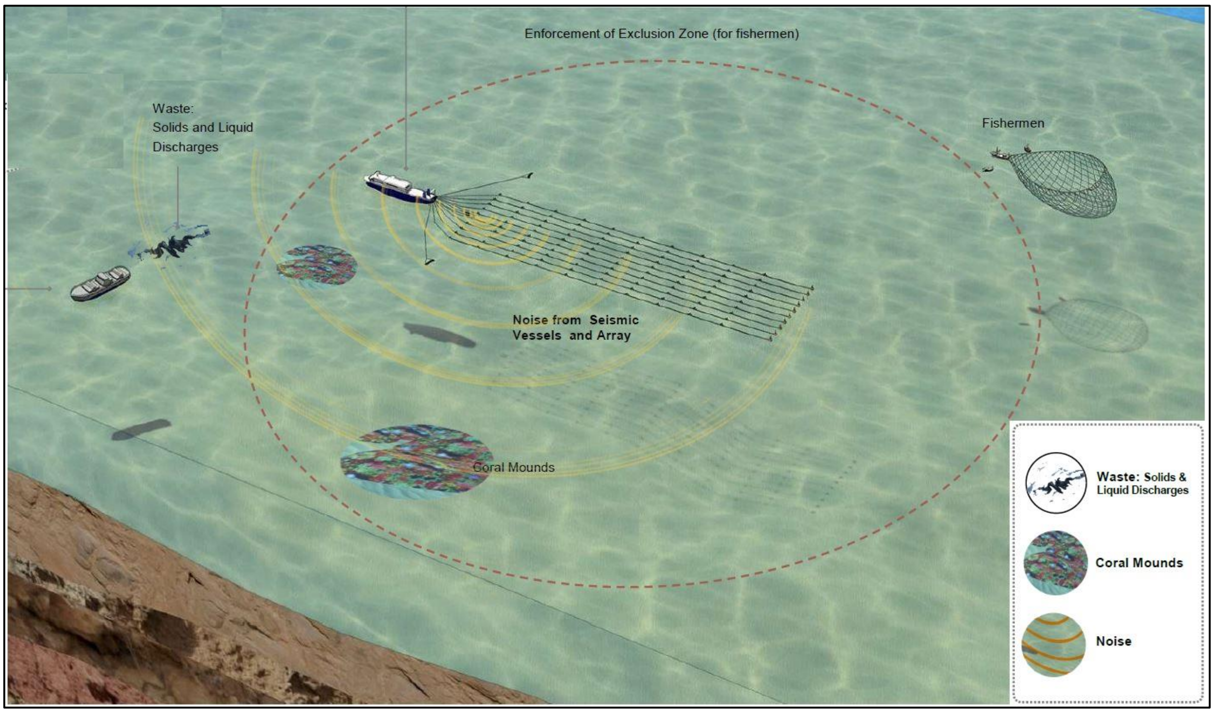


Figure 2.3 Seismic Survey potential interactions with the environment. (ERM & CMRC, 2014)

The results of the impact assessment are presented in compiled tables in **Appendix C** and **Section 4.1** and **Section 4.3**. For each potential impact the confidence in the assessment was recorded.

In general there was little interaction anticipated between normal seismic operations and CWC species and CWC reef habitats. This agreement included three important caveats:

- The interactions with CWC were thought to be minimal and there was clear evidence from tropical reef examples that with suitable controls no impacts on CWC would be anticipated. Whilst the group accepted that the information presented provided suitable background for survey planning and management, peer-reviewed or expert analysis comparing tropical and cold-water scleractinian corals was not presented and further evidence was required to show that they were comparable with respect to potential impacts from seismic airgun noise. However, the groups generally agreed that the case histories demonstrated best practice and that the activity could be conducted without impact;
- For protected areas, any proposed operations would be subject to suitable assessment (under the Environmental Impact Assessment (EIA) and Habitat Regulations(HR)) though in general these interactions would be likely to be screened out; and
- That the assessment and agreements were undertaken in the assessment of CWC and CWC reef or reef habitat complex. Associated species, in particular fish, sharks and cetaceans would all be subject to their own assessments within a SEA, AA or EIA process.

2.5 ABSTRACTS – EXPLORATION DRILING AND COLD-WATER CORALS

2.5.1 Introduction to exploration drilling operations [Gareth Parry (IOOA)]

A prospect is a potential trap which geologists believe may contain hydrocarbons. The prospect is identified from interpreting the results of seismic surveys. A significant amount of geological, structural and seismic investigation must first be completed to redefine the potential hydrocarbon drill location from a lead to a prospect.

Once a prospect is identified, the only way to determine if hydrocarbons are present is to drill a well. The well is created by drilling a hole into the seabed with a drilling rig that rotates a drill string with a bit attached. After the hole is drilled, sections of steel pipe (casing), slightly smaller in diameter than the borehole, are placed in the hole. Cement is placed between the outside of the casing and the borehole.

Drilling fluid, generally referred to as “drilling mud” is pumped down the inside of the drill pipe and exits at the drill bit. The principal components of drilling fluid are usually water and clay, but it also typically contains a complex mixture of fluids, solids and chemicals that must be carefully tailored to provide the correct physical and chemical characteristics required to safely drill the well. These fall into two general descriptors: Water Based Muds (WBM) which are predominantly water and clays, and Non Aqueous Drilling Fluids (NADF) which use an alternative component (often a hydrocarbon). Particular functions of the drilling mud include cooling the bit, lifting the rock chips or “cuttings” to the surface, preventing destabilisation of the rock in the wellbore walls and overcoming the pressure of fluids inside the rock so that these fluids do not enter the wellbore. The generated rock cuttings are swept up by the drilling fluid as it circulates back to surface outside the drill pipe. The pipe or drill string to which the bit is attached is gradually lengthened as the well gets deeper by screwing in additional sections of pipe.

This process is all facilitated by a drilling rig which contains all necessary equipment to circulate the drilling fluid, hoist and turn the pipe, control downhole, remove cuttings from the drilling fluid, and generate on-site power for these operations.

Where NADF are used the cuttings and drilling fluids are recovered to the surface and separated. The fluids can be reused in the process and the remaining cuttings must be disposed of. The cuttings are often transported to a processing facility back onshore in a process called ”skip and ship”. It is becoming increasing common to process NADF to environmentally safe standards offshore and then discharge them at the sea surface.

An offshore drilling operation can be broken in a number of phases:

1. Prospect selection – the determination of a drilling location via seismic survey and analysis.
2. Drill site and shallow drilling hazard assessment - this can be completed by a desktop review using existing data or by acquiring new data from (seismic, magnetometer, Sub Bottom Profilers (SBP), Side Scan Sonar (SSS) MultiBeam Echo Sounder (MBES), drop-down video, grab samples and shallow boreholes). The assessment considers:
    - Debris;
    - Shallow gas assessment and shallow geohazards;
    - Metocean;

- Archaeology;
- Environmental; and
- Anchor locations (holding ground).

3. Pre-lay anchors – if the rig is to be anchored to the seabed, the anchors can be pre-laid to allow controlled placement.
4. Mobilise rig – rig is brought to site either under its own steam or towed. This includes siting of the rig – i.e. hooking up the anchors if used, In the case of jack up rigs this includes 'jacking up' on the legs to setting the dynamic position location.
5. Drill, log and test – the well is drilled usually over a period of 30-120 days dependant on conditions and depth. The well may then be tested (Vertical Seismic Profiling (VSP) for example the use of a seismic source down the well to assess the surrounding rock strata). In the case of exploration and appraisal wells this may include recovering product (gas or oil) for testing the components of the hydrocarbon. In the case of appraisal wells tests are also done in terms of the likely rates of production from a well.
6. Plug and abandonment - in Ireland this generally consists of sealing the well by injecting cements to seal it. The well head is then usually cut off below the level of the seabed so that there is no residual impact from the wellhead.
7. Demobilise (recover anchors) and leave the site. Post-drill surveys are often required including drop down video and benthic samples for comparison with the site assessment samples.

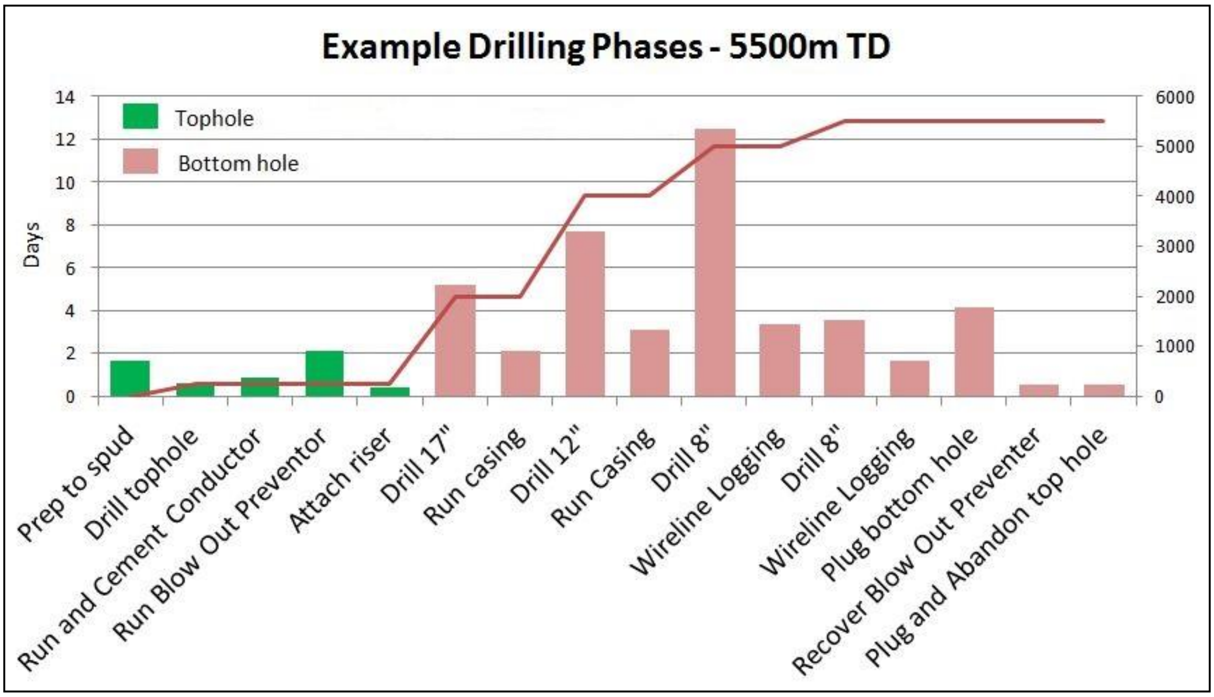


Figure 2.4 An indicative drilling timeline. (from Woodside, 2014).

2.5.2 Summary of current understanding of laboratory measured threshold/tolerance of *Lophelia* sp. to drill cuttings exposure [Dr Thierry Baussant (IRIS)]

The distribution of deepwater CWC in the Norwegian continental ridge area is extensive, as is the current and historic extent of oil and gas exploration and production in the region. Drilling occurs in vicinity of CWC regularly, and through operation planning, monitoring and assessment detailed procedures have been developed to ensure any impact is minimised. In addition laboratory research and in-situ observations have been undertaken to provide evidence to support CWC tolerance and sensitivity assessments.

The research currently undertaken is focussed on:

- Investigating the sensitivity of CWC to drilling discharges, with emphasis on the coral *Lophelia pertusa*;
- Using the generated data to enhance decision-making for the management and mitigation actions by the oil industry;
- Enhancing our basic understanding of CWC physiology;
- Implementing early diagnosis of coral biology changes: emphasis on non-invasive measurements; and
- Determining thresholds and effects (acute and chronic) to exposure from drilling cuttings particulates and drilling muds.

Laboratory assessment of the exposure of CWC to drilling fluids has been conducted. Key physiological sub-lethal indicators were used to assess the corals sensitivity to drilling cuttings and fluids. The experiments particularly looked at indicators for markers of mucus production and using time lapse photography analysis of polyp behaviour to detect affects and recovery rates. They determined that at 10 ppm of drilling particulates there were no discernible effects, at 50 ppm some acute physiological effects were detected such as mucus production and changes in polyp behaviour. These levels provide thresholds for activity planning and dispersion modelling (**Appendix E**).

2.5.3 Case Study – Scott Reef Torosa-6 appraisal well [Dr Luke Smith (Woodside Energy Ltd)]

The Browse development is located approximately 425 km north of Broome, Western Australia, and comprises three gas fields in water depths up to 600 m. The proposed development is a joint venture involving Woodside (operator) with Shell, BP, MIMI and PetroChina. One of the gas fields (Torosa) is partially overlaid by Scott Reef; a unique coral atoll with 237 km^2 of highly diverse corals spread over two reefs, North and South Reefs.

The Torosa-6 appraisal well was drilled in 2008 in a sensitive marine setting. The drilling occurred in an area of very low coral cover and diversity in the lagoon (60 m depth) of the South Reef. The site selection inputs and zone of influence modelling were particularly important to minimise any potential impact on the reefs. In order to drill the well with minimal environmental impacts it was determined that there should be no loss of cuttings and muds to the environment. This required the development of a system to capture all cuttings and muds from the well. As this also included the tophole section a riserless collection and recovery system was designed, constructed and installed on the rig.

In order to develop a process to depose of these cuttings, three options were evaluated and considered:

1. Slurrification on rig and transfer by vessel to deepwater disposal site
    - Riserless Mud Recovery (RMR) system
    - Rig based equipment similar to package used for cuttings re-injection
    - Required least amount of additional fabricated equipment
    - Could be done with one dedicated vessel.
2. Skip and ship to onshore disposal site
    - Require fabrication of a number of skips
    - Increased safety risk handling skips offshore
    - Require three dedicated vessels due to distance to shore base
    - Land disposal requirements onshore
3. Cutting transfer by pipeline away from reef
    - No history of having been done before
    - Would require considerable design and fabrication work
    - Risk of hose failure creating sedimentation on reef

Following an internal Woodside assessment based on environmental risk, safety and cost the Torosa-6 well was drilled and cuttings slurrified and disposed in deepwater. No cuttings were disposed at the well location.

The Torosa-6 well was successfully drilled with the following significant achievements:

- World first application of Riserless Mud Recovery (RMR) unit from a jack-up rig.
- No loss of drill cuttings and fluids to Scott Reef as a result of the cuttings collection, containment and disposal system.
- No impact to water quality at the location (all <50 m).
- Minimal footprint of less than 500 m^2 in area of relatively low sensitivity.
- No impact to any deepwater coral community.
- Appraisal objectives met.

Environmental monitoring prior, during and after the drilling program confirmed no short or long term impacts to the coral reef from the activity.

Figure 2.5 The Riserless mud recovery system developed for the well (from Woodside, 2014)

2.5.4 Case Study – Norwegian Sea Development [Lars Petter Myhre and Rune Weltzien (Statoil)]

A significant proportion of the Norwegian Continental Shelf (NCS) has coral reefs *L. pertusa, c*oral gardens, *Paragorgia arborea* and sponge grounds present. These interact with exploration and production areas, particularly in the Haltenbanken area and in the area of the Morvin field development which was used as a case study.

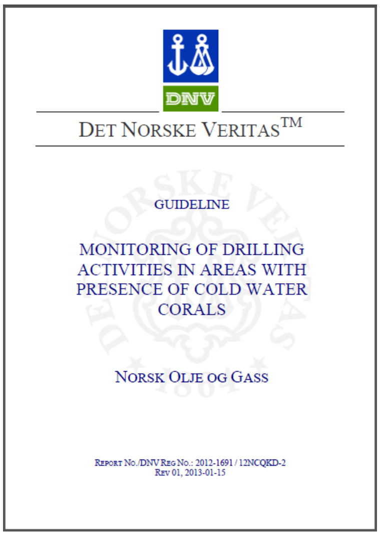
In addition to detailed survey to identify CWC location, condition and facilitate the positioning of the drill location to eliminate physical impacts, in the case of the Morvin field development detailed dispersion modelling was used to locate suitable discharge points via a specialised Cutting Transport System (CTS). These CTS transported the cuttings away from sensitive areas and, using detailed dispersion modelling, enabled a high level of confidence that discharges would be a suitable distance from mapped CWC.

A monitoring programme was enacted to monitor the rates and distribution of the particulates from the discharge, and analyses of the corals was conducted looking for physiological effects. The study showed that lipid class and fatty acid analyses of corals that had been exposed to drill cuttings and of corals that had not been exposed **showed no significant differences**. Hence, the exposed corals did not have decreased amount of storage lipids compared to corals from the unexposed control area and this suggests that there is no differences in the feeding rate between the two.

Image **analyses revealed no significant behavioural differences** between corals that were exposed to drill cuttings and unexposed corals. Detailed analyses of the time series from the exposed coral reef revealed that changes in current direction and speed were the main reasons for changes in coral polyp behaviour.

In conclusion, while the plume of mud and drill cuttings did reach the coral reefs in the downstream direction our **analyses do not reveal any immediate damage to the corals**. The coral reefs will be revisited at a later stage to assess whether there are any long-term effects of having been exposed to mud and drill cuttings.

In addition the development of these fields provided methodologies and risk assessments for anchor placement.



DNV

DET NORSKE VERITAS™

GUIDELINE

MONITORING OF DRILLING
ACTIVITIES IN AREAS WITH
PRESENCE OF COLD WATER
CORALS

NORSK OLJE OG GASS

REPORT NO./DNV REG NO.: 2012-1691 / 12NCQKD-2
REV 01, 2013-01-15

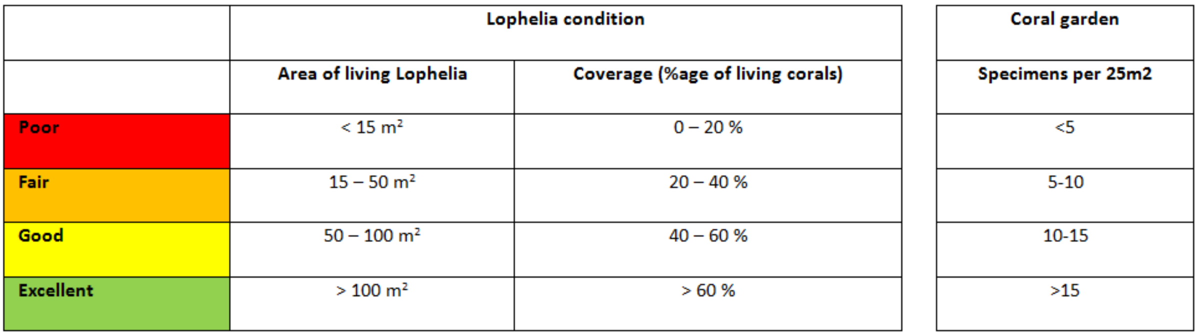
As a result of the work conducted in these areas, guidelines have been produced for drilling in areas where CWC are present (Ulfsnes et al., 2015). These were circulated prior to the workshop.

Key recommendations include the detection of potential coral structures >1m above sea floor, early identification of CWC with detailed survey, using ROV mounted MBES, at <0.5x0.5m resolution. A detailed survey of 4x4 km area should be covered (possible anchor spread + contingency) and provide a complete coral map based on the survey.

The guidelines include risk assessment and impact assessment provisions include coral condition assessment. Extracts from this guideline are shown in **Tables 2.2** and **2.3.**

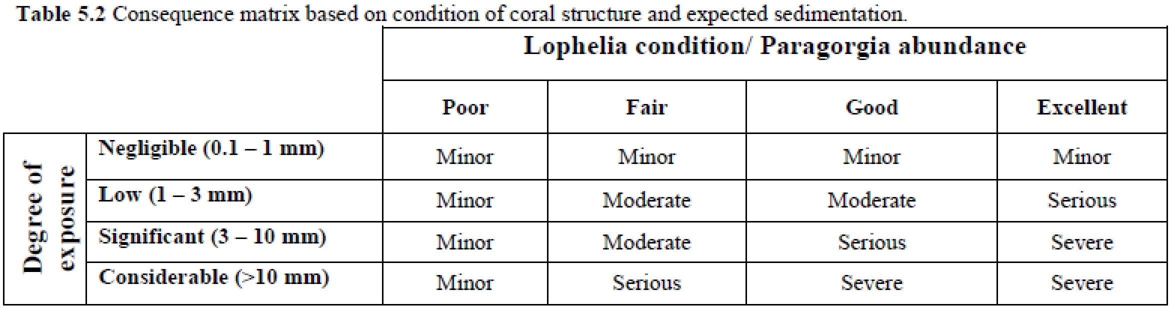
Table 2.2 and Table 2.3 Extract from (Ulfsnes et al., 2015) Guidelines for Monitoring of Drilling Activities in Areas with presence of Cold-water Corals

Table 1.1 Criteria for coral conditions.



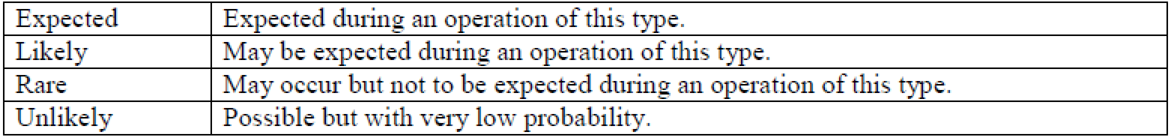
	Lophelia condition		**Coral garden**
	Area of living Lophelia	**Coverage (%age of living corals)**	**Specimens per 25m2**
Poor	< 15 m²	0 – 20 %	<5
Fair	15 – 50 m²	20 – 40 %	5-10
Good	50 – 100 m²	40 – 60 %	10-15
Excellent	> 100 m²	> 60 %	>15

Table 5.2 Consequence matrix based on condition of coral structure and expected sedimentation.



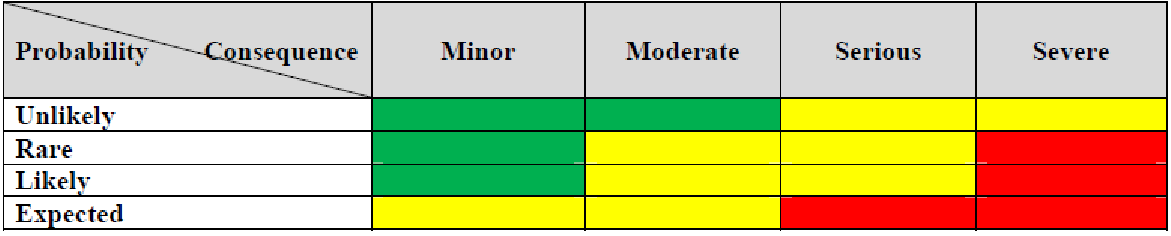
		Lophelia condition/ Paragorgia abundance			
		Poor	**Fair**	**Good**	**Excellent**
Degree of exposure	**Negligible (0.1 – 1 mm)**	Minor	Minor	Minor	Minor
	Low (1 – 3 mm)	Minor	Moderate	Moderate	Serious
	Significant (3 – 10 mm)	Minor	Moderate	Serious	Severe
	Considerable (>10 mm)	Minor	Serious	Severe	Severe

Table 5.3 Probability scale for expected impact on corals.



Expected	Expected during an operation of this type.
Likely	May be expected during an operation of this type.
Rare	May occur but not to be expected during an operation of this type.
Unlikely	Possible but with very low probability.

Table 5.4 Risk matrix based on consequence above and the probability of the expected sedimentation.



Probability \ Consequence	**Minor**	**Moderate**	**Serious**	**Severe**
Unlikely	🟩	🟩	🟨	🟨
Rare	🟩	🟨	🟨	🟥
Likely	🟩	🟨	🟨	🟥
Expected	🟨	🟨	🟥	🟥

The assessment tables are shown in **Appendix E**.

2.6 POTENTIAL STRESSORS FOR EXPLORATION DRILLING AND COLD-WATER CORALS (GROUP DISCUSSIONS)

The assessment followed an ENVID style workshop and focussed on completing impact assessment summary tables. The plenary was conducted in a single group once the scenario was outlined. Consensus was reached on each point and the tables populated during the discussions. The scenario used is outlined in this section. These were considered a likely worst case, as conducted for the seismic survey.

As Non-Aqueous Drilling Fluids (NADF) cannot be discharged in Irish waters, Water-Based Muds (WBM) were used for the scenario. The scenario discussed was for a semisubmersible or drillship, moored with eight anchors, which were not pre-laid, covering an area 4 km in diameter. It included two support vessels and a 90-day operation timeline (included 25% weather downtime). The tophole section was drilled using WBM and returned to seabed and the bottomhole sections drilled using WBM and returned to the rig then discharged at the sea surface.

The groups assessed possible interactions across two categories:

1) Planned, such as anchor placement, drilling, cuttings piles; and
2) unplanned, such as hydrocarbon spills, collision, blowout and dropped objects.

The results of the impact assessment are presented in compiled tables in **Appendix D** and in **Section 4.2** and **Section 4.3**. For each potential impact the confidence in the assessment was recorded.

3 EXPLORATION ACTIVITIES AND COLD-WATER CORAL IN OFFSHORE IRELAND - A SYNTHESIS OF CURRENT KNOWLEDGE

The following sections synthesise knowledge discussed during the workshop and from published literature relating to the state-of-knowledge for CWC on the Irish Atlantic margin and potential impacts from, and mitigations for, seismic and drilling exploration activities on coral habitats and associated species. Conclusions for seismic and drilling discussions are in **Section 4.1** and **Section 4.2** respectively.

3.1 DISTRIBUTION OF COLD-WATER CORALS IN IRISH WATERS

L. pertusa and, to a lesser extent, *M. oculata* are CWC species common throughout the North Atlantic. These reef-forming CWC species create a complex 3-dimensional structure and provide a habitat for many other species which live both on live and dead coral and/or in the spaces between the coral branches (Roberts et al., 2009).

The reef-forming *L. pertusa* is classed as a threatened species under IUCN classification, and forms priority habitat, as a framework-building coral, afforded protection under Irish and EU legislation (OSPAR, 2008; Frost, 2014). CWC reefs and associated communities are recognised globally as vulnerable marine ecosystems that functions as biodiversity hotspots and are likely to be more biologically diverse than surrounding benthic habitats (ICES, 2002). As these reefs are physically fragile, complex ecosystems and are often very long-lived, they are susceptible to anthropogenic pressures including climate change, ocean acidification, commercial fishing practices and offshore hydrocarbon exploration operations including seismic survey and drilling activity (Nilsen et al., 2010).

There was consensus on the distribution and forms of CWC reef and assemblages along the Irish Atlantic margin. In Irish waters CWC are typically found between 300 – 1,000 m water-depth but some examples have been recorded at 80 – 100 m. CWC occurs in three distinct bedforms: reef, carbonate mounds and small stands of corals (Wheeler et al., 2007). The distribution of CWC carbonate mounds in the Irish Atlantic margin is relatively well known. With the exception of a few, small areas of sustained CWC research effort, less is understood across the Irish Atlantic margin about the distribution of small stands of CWC (Wheeler, 2014). The coverage of high-resolution seabed mapping over the Irish offshore is limited.

Workshop participants agreed that the primary controls for CWC reef distribution and condition include water temperature, sedimentation rates, current-driven recruitment and food supply. It was further agreed that existing data would permit regional level risk assessment on the likelihood of an exploration operation encountering high densities of good quality high conservation value CWC. However, there was discussion around how further directed sampling would improve the current understanding of where high-quality high conservation value CWC reefs occur, their current condition and how these CWC areas may be interconnected.

3.2 EXPLORATION SEISMIC OPERATIONS ON THE IRISH ATLANTIC MARGIN

A description of a typical seismic operation is included in **Section 2.3.1**. A description of the seismic operation scenario used in the ENVID is included in **Section 2.4**.

3.2.1 Potential interaction between seismic operations and Cold-Water Corals in Irish waters

The vast majority of studies investigating the potential impact of seismic exploration activity on coral and reef-associated species have been conducted in tropical environments, while in contrast research on CWC, typical of temperate environments, is relatively sparse. As a result, assessment of the potential impacts of seismic exploration activities on CWC and reef-associated species have been largely based on the findings of research conducted in tropical reef ecosystems. While tropical corals and CWC can be considered similar in terms of their vulnerability to sedimentation and physical disturbance e.g. demersal trawling (Grehan et al., 2005), the comparability of tropical and cold-water scleractinian corals in terms of their potential vulnerability to noise from seismic airguns is less clear. In light of this knowledge gap, further expert opinion is needed to determine the level of confidence in assessments of potential impacts of seismic airgun noise, on CWC and associated species, that are based on responses observed for similar functioning groups found in tropical environments. As proposed by the precautionary principle, the lack of scientific certainty should not preclude the adoption of cost-effective measures to control environmental risks. Activities should proceed only with appropriate checks and risk reduction in place. Consequently, measures to mitigate noise from seismic airguns in tropical coral ecosystems should be adopted for CWC.

In recent reviews of interactions of high intensity seismic waves on fish species, Popper et al. (2014) and Battershill et al. (2008, 2015) indicated that reported findings of the interaction of seismic exploration activity on fish species varied widely from no perceivable effects/impacts to temporary behavioural changes and, in some extreme cases, extensive tissue damage. McCauley et al. (2003) showed that seismic air guns, with a measured source level or Sound Pressure Level[4] (SPL) of 222.6 dB re 1 µPa, caused extensive physical damage to sensory hair cells in the pink snapper pink (*Pagrus auratus*) with no recovery apparent 58 days after exposure. Fish behavioural studies conducted by Wardle et al. (2001) at a shallow rocky reef habitat (water depth 20 – 30 m) in Loch Ewe, Scotland indicated that, with the exception of an immediate and transient startle response to air-gun emission, which measured 210 dB re 1 µPa at 16 m from the source and 195 dB re 1 µPa at 109 m, there was no perceivable change in fish behaviour. As noted by Gausland (2003), the findings of Wardle et al. (2001) are based on observation of a local group of fish in an inshore area. Consequently, findings may not be directly transferable to fish species found in deeper waters. Popper et al. (2014) presented sound exposure thresholds below which fish species are unlikely to exhibit short or long-term adverse effects (**Table 3.1**).

Popper et al. (2014) also proposed exposure thresholds for injury to eggs and larvae based on work by Bolle et al. (2012) and also concluded that based on work by Saetre and Ona (1996) the rate of mortality for eggs and larvae due to noise form seismic airguns is insignificant compared to natural mortality (**Table 3.1**).

---

[4] Sound Pressure Level (SPL)according to Southall et al. (2007) is a Sound Level (SL) as it would measure 1m from the source in units of dB re 1 µPa

Table 3.1: Seismic sound exposure level (SEL) thresholds for fish species, and eggs and larvae (modified from Popper et al., 2009).

Type of animal	Mortality and potential mortal injury	Recoverable injury	Behaviour
Fish: no swim bladder	>219 dB SEL cum or >213 dB peak	>216 dB SEL cum or >213 dB peak	(N) High (I) Moderate (F) Low
Fish: swim bladder is not involved in hearing	210 dB SEL cum or >207 dB peak	203 dB SEL cum or >207 dB peak	(N) High (I) Moderate (F) Low
Fish: swim bladder involved in hearing	207 dB SEL cum or >207 dB peak	203 dB SEL cum or >207 dB peak	(N) High (I) High (F) Moderate
Eggs and larvae	>210 dB SEL cum or >207 dB peak	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low

* Relative risk categories (high, moderate, low) is given for animals at three distances from the source defined in relative terms as near (N), intermediate (I), and far (F).

In 2007 a major research project investigated the potential impact of noise from seismic airguns on coral species and reef-associated fish at Scott Reef, on Australia's north-western continental shelf (max water depths of 60 m) (Battershill et al., 2007, 2008, 2015). The 2007 study measured sound exposure levels up to 210 dB at the seafloor. These levels exceeded sound guideline thresholds proposed by Popper et al. (2014) but had no detectable effect on fish physiology, hearing overall, fish biodiversity and abundance. Furthermore the Scott Reef study indicated that, with the exception of a short-lived startle response to air-gun emissions, seismic activity had no significant effect on the behaviour of coral-associated fish species (Miller and Cripps, 2013) while Battershill et al. (2008, 2015) reported no significant impacts of seismic sound on benthic invertebrate communities. Hastings et al. (2008) calculated that received sound levels would need to exceed 260 dB re 1µPa to affect coral polyps and 270 dB re 1µPa to affect hard structures in scleractinian corals.

Austin et al. (2014) conducted an acoustic modelling study on a representative exploration seismic survey in the Porcupine Basin in water depths between 662 and 1025 m to investigate the potential effects on CWC and reef-associated fish at three CWC provinces. The CWC provinces investigated included the Belgica Mound Province, the Hovland Mound Province and Magellan Mound Province and comprise part of the Irish offshore SACs designated for the protection of CWC biogenic reef. The Austin et al. (2014) modelling study employed a 4,450 in^3 air-gun array to evaluate the peak sound pressure levels and exposure at the seafloor for a single air-gun emission and a 24-hour series of airgun emission. The maximum sound levels at the seafloor was 175.2 dB re 1 $\mu\text{Pa}^2\cdot\text{s}$, well below the biological effects sound thresholds proposed by Popper et al. (2014) for fish. Similarly, the maximum sound levels reported in the Austin et al. (2014) study were considerably lower than levels recorded in the 2007 Scott Reef studies with no measured impacts on reef-associated fish, soft or hard corals or benthic invertebrates. In addition, the sound exposure threshold level investigated by Andriguetto-Filhoa et al. (2005) far exceeded those reported by Austin et al. (2014). Consequently, it is concluded that it is highly unlikely that seismic survey would have any long-term adverse impacts on CWC and reef-associated fish species in deep waters of the primary Irish offshore basins[5].

---

[5] This woud include all of the basins covered by the Irish Offshore Strategic Environmental Assessment 5 (IOSEA5)

There were discussions during the plenary sessions regarding the potential impact of noise from seismic airguns on CWC larvae and reproduction. There is little known about spawning periods for CWC on the Irish Atlantic margin (Larsson et al., 2014). Reef-building CWC are predominantly broadcast spawners, with a dispersive larval stage, but also have the capacity to reproduce asexually (Waller and Tyler, 2005; Jackson, 1986). Studies show *L. pertusa* is an annual reproducer with spawning starting late-January in the NE Atlantic and, based on histoligical studies by Waller and Tyler (2005), January/February in the western Atlantic (Waller and Tyler, 2005; Larsson et al., 2014; Brooke and Järnegren, 2013). It has been suggested by Kostyuchenko (1973) and Booman et al. (1996) that underwater noise from seismic airguns could be fatal or damaging to larvae at very close range (<5m). Given planktonic larvae are designed to disperse rapidly and potentially damaging noise from seismic airguns is highly localised, it is likely that mortality rates due to noise exposure would be insignificant when compared to natural mortality (Morrisson et al., 2011; Booman et al., 1996; Dalen and Maestad, 2008; Saetre and Ona, 1996);

There was discussion in the workshop that a better understanding of CWC larval biology and behaviour would allow modelling of larval dispersal, which forms the basis for predictions of connectivity among populations. Such a study in Irish waters was identified as potentially underway.

With respect to activities near or within conservation areas (SACs), national and European regulators require clear scientific reasoning in order to evaluate their potential impacts on protected features. Where there is significant doubt around potential impacts, the precautionary principle is applied. The evidence presented at the workshop, in the form of studies on the impacts of noise from exploration seismic airguns, was based on tropical scleractinian corals. This research would be considered an acceptable analogue for CWC by regulators if accompanied by peer-reviewed or expert analysis assessing if different scleractinian corals could be expected to have a similar response to noise from seismic airguns. The regulators and participants agreed that there was no overriding scientific reason for seismic to be excluded from any areas where CWC occur but that suitable mitigation must be in place to minimise potential impacts in areas where they do occur. For CWC and reef within SACs further assessment (under existing systems such as EIA regulations, the Habitat Regulations and AA) would need to be conducted.

Based on the workshop information and discussions impact assessments of the interactions between CWC and seismic activities have been tabulated and are included in **Appendix C**.

---

http://www.dcenr.gov.ie/Natural/Petroleum+Affairs+Division/Irish+Offshore+Strategic+Environmental+Assessment+(IOSEA+5)/

3.3 EXPLORATION DRILLING OPERATIONS ON THE IRISH ATLANTIC MARGIN

A description of a typical drilling operation is included in **Section 2.5.1**. A description of the drilling operation scenario used in the ENVID is included in **Section 2.6**.

During the plenary sessions the type of Mobile Offshore Drilling Unit (MODU) selected for a particular drilling activity was one of the key factors in determining options to manage potential interactions with CWC. MODUs fall into three main categories:

- Semi-submersible: have hulls (columns and pontoons) of sufficient buoyancy to cause the structure to float, but of weight sufficient to keep the structure upright. Semi-submersible platforms can be moved from place to place; can be ballasted up or down by altering the amount of flooding in buoyancy tanks. These platforms are generally anchored by combinations of chain, wire rope or polyester rope, or both, during drilling operations, though they can also be kept in place by the use of Dynamic Positioning (DP) systems (Hyne, 2014). Semi-submersibles can be used in water depths from 60 to 3,000 m, and as such are the most likely rig type to be used for the areas where CWC occur in Ireland.
- Jack-up: rigs that can be jacked up above the sea using legs that can be lowered, much like jacks. These units are typically used in water depths up to 120 m, although some designs can go to 170 m, depth (Hyne, 2014). They are designed to move from place to place, and then anchor themselves by deploying the legs to the ocean bottom using a rack and pinion gear system on each leg. Whilst sometimes used to drill shallow water Irish prospects these are unlikely to be used in areas containing deep water CWC.
- Drillship: a maritime vessel that has been fitted with a drilling apparatus. It is most often used for exploration drilling in deep water. Most drillships are outfitted with a DP system to maintain position over the well (Hyne, 2014). They can drill in water depths up to 3,700 m.

In order to asses potential impacts from drilling activities a scenario was developed representing a ‘worst case’ (least favourable option’) from discussion of potential interactions and impacts. This scenario is described in **Section 2.6**.

3.3.1 Potential interactions between drilling operations and Cold-Water Corals in Irish waters

The workshop outlined successful projects of exploration drilling in close proximity to tropical and CWC reefs in other jurisdictions. Lessons learned from these jurisdictions, over the last 40 years of petroleum exploration, have provided guidelines and targeted mitigation to enable drilling in close proximity to these habitats without long term discernible effects.

In Norway, assessment of site suitability, and mitigation for drilling operations has enabled the exploration industry to operate in areas where CWC occur. As physical damage from operations has been minimised by better well planning, research has identified suitable mitigation for discharges and other interactions. Laboratory research has identified levels at which sub lethal and behavioural changes may occur, as well as acceptable thresholds at which CWC are tolerant to exposure from drilling operations. In an Australian example, the Torosa-6 appraisal well at Scott Reef clearly showed how suitable mitigation can avoid impact even in sensitive tropical coral reef areas with no significant or detectable acute or long term effects to the habitat or associated species.

Potential impacts of drilling activity on CWC and reef-associated species include structural damage to coral due to physical disturbance by drilling and mechanical abrasion of rig anchors and chains while physiological impacts include stress-induced changes in rates of respiration, growth and mortality due to exposure to drill cuttings (e.g. Larsson et al., 2013).

Exposure and effects potential of drill cuttings on CWC were considered in terms of concentrations of particles and distance from drilling source. Potential impacts on CWC were broadly categorised as physical or physiological. In laboratory experiments, the primary reef-building CWC *L. pertusa* was exposed to settling particles. The effects of reef sediment, petroleum drill cuttings and a mix of both, on the development of anoxia at the coral surface were studied using O_2, pH and H_2S microsensors and by assessing coral polyp mortality. Photography of polyp movement was used to detect behavioural sub lethal responses. Due to the branching morphology of *L. pertusa* and the release of coral mucus, accumulation rates of settling material on coral branches were low. Microsensors detected H_2S production in only a few samples, and sulfate reduction rates of natural reef sediment slurries were low (<0.3 nmol S cm^{-3} d^{-1}).

When *L. pertusa* was exposed to suspended particles (<63 µ) of drill cuttings for 12 weeks. Skeletal growth was significantly lower under exposure concentrations of similar to 25 mg/l than similar to 5 mg/l and there was a trend of lower growth rates when exposed to water-based drill cuttings than to natural benthic sediment. Polyp extension was less in corals exposed to higher material concentrations, which provides a possible explanation for observed skeletal growth differences between particle concentrations. Particle exposure had no significant impact on respiration or proportions of tissue and fatty acids in corals. The volume of additional cleaning mucus released by exposed corals was low and release did not significantly affect coral energy expenditure. Results indicate that *L. pertusa* polyps can deal comparatively well with enhanced particle deposition rates and suspended matter concentrations (Larsen et al., 2013).

While the exposure to significant concentrations of sediment clearly reduced the coral's accessibility to oxygen, *L. pertusa* tolerated both partial low-oxygen and anoxic conditions without any visible detrimental short-term effect, such as tissue damage or death, and may be exposed to similar conditions seasonally. However, complete burial of coral branches for >24 h in reef sediment resulted in suffocation (Allers et al., 2013).

A summary of CWC thresholds use for planning drilling activities on some areas in the NCS is included in Appendix E based on laboratory studies by Larsson et al. (2011, 2013), Smit (2008) and Cranford et al. (1999) and is considered in conjunction with the recognised industry guidelines (Ulfsnes et al., 2015).

Based on the case studies presented, it was concluded that, in areas with high quality CWC, it would be relatively easy and not prohibitively expensive to secure suitable data to determine the extent and condition of CWC reef prior to operations. In addition, there was acknowledgement among participants that there are areas of extensive high-conservation value CWC (Norwegian offshore) and tropical coral (Australian offshore) ecosystems where extensive hydrocarbon exploration (including seismic operations) operations had been carried out with no detectable impact on reef ecosystems.

Based on the workshop information and discussions impact assessments of the interactions between CWC and drilling activities have been tabulated and are included in **Appendix D**.

4 SUMMARY OF WORKSHOP CONCLUSIONS

The workshop outlined and discussed the current state of knowledge of CWC in Irish waters and the potential interactions from petroleum exploration operations. There was a clear consensus that, although there is a knowledge gap in the extent of small stands of CWC in offshore Ireland, there is a sound understanding of the processes which control CWC distribution and the impact of anthropogenic activities.

4.1 CONCLUSIONS ON SEISMIC OPERATIONS AND COLD-WATER CORALS

Discussion of the potential interaction of planned seismic activities with CWC focused predominantly on the impact of sound pressure waves on coral polyps, CWC reef and associated species. A number of other planned and unplanned events were discussed (e.g. loss of acoustic gear). However, given the depth of CWC, the potential for significant interaction with reef habitats and associated species was assessed as low and the likelihood of potential emergency events such as ship loss was deemed extremely unlikely. Impact assessments of the interactions between CWC and seismic activities have been tabulated and are included in **Appendix C**. The key conclusions were:

- The Maxima 3D field verification study investigating potential impacts of noise from seismic airguns at Scott Reef, Australia presented robust evidence to support the findings of no significant or adverse effects of noise from airguns on coral communities and associated species (Battershill et al., 2007, 2008, 2015; Miller and Cripps, 2013). A data gap was identified as to the comparability of the physiology and biology of tropical and cold-water scleractinian corals in relation to potential impacts from seismic airgun noise. It was suggested that the lack of significant or adverse effects of noise from seismic airguns on scleractinian tropical corals in the Scott Reef study could be considered similar to those expected for cold-water scleractinian corals;
- Based on acoustic modelling by Austin et al. (2014), sound levels at the seabed from a typical large seismic survey received at CWC provinces in the Porcupine Basin are below levels measured during the Maxima 3D field verification study. The modelled sound levels were also significantly below the levels predicted by Hastings et al. (2008) to cause physical damage to scleractinian coral polyps or skeletal structures;
- The Maxima 3D field verification study showed no significant physical impacts either short- or long- term to coral reef or reef-associated species after exposure to sound levels greater than those modelled by Austin et al. (2014) for a typical seismic survey in Irish waters;
- There is little known about spawning periods for CWC on the Irish Atlantic margin (Larsson et al., 2014). Reef-building CWC are predominantly broadcast spawners, with a dispersive larval stage, but also have the capacity to reproduce asexually (Waller and Tyler, 2005; Jackson, 1986). Using histological studies Waller and Tyler (2005) suggested that *L. pertusa* spawns around January/February in the western Atlantic. It has been suggested by Kostyuchenko (1973) and Booman et al. (1996) that underwater noise from seismic airguns could be fatal or damaging to larvae at very close range (<5m). Given planktonic larvae are designed to disperse rapidly and potentially damaging noise from seismic airguns is highly localised, it is likely that mortality rates due to noise exposure would be insignificant when compared to natural mortality (Morrisson et al., 2011; Booman et al., 1996; Dalen and Maestad, 2008; Saetre and Ona, 1996);
- Discussion concluded that it is highly improbable that seismic survey interaction with Irish CWC and reef-associated species would cause short- or long- term adverse biological impacts. This conclusion was based on the potential peak level of sound received at CWC

reefs (Austin et al., 2014) being below thresholds for physical and physiological impacts reported for tropical coral (Hastings et al., 2008) and fish species (Popper et al., 2009,2014), (Miller and Cripps, 2013); and

- Other species typically associated with Irish CWC are also unlikely to be affected as modelled sound levels received at the seabed are significantly below levels reported in Battershill et al. (2008, 2015) which resulted in no significant impact on benthic communities. Similarly, based on the findings of Andriguetto-Filhoa et al. (2005) and sound levels modelled for Irish CWC by Austin et al. (2014), impact on invertebrates such as shrimp species are deemed unlikely.

4.2 CONCLUSIONS ON DRILLING OPERATIONS AND COLD-WATER CORALS

Impact assessments of the interactions between CWC and drilling operation have been tabulated and are included in **Appendix D**. The discussion in the drilling interactions session covered various management and mitigation controls and examples whereby potential impacts on CWC could be eliminated. These management and mitigation controls were grouped into two broad categories:

- Avoidance: all drilling operations are conducted (and discharges released) a suitable distance from CWC reef to ensure no potential interaction; and
- Engineering: the conclusion of the drilling interactions session was that there are numerous engineering solutions to completely eliminate or reduce interactions with CWC reefs which have been used effectively in other European jurisdictions, including the Norwegian Continental Shelf (NCS).

It was agreed that management and mitigation controls could require the following;

- Site survey followed by a detailed survey to carry out high-resolution mapping of CWC reef within the drill site area. Mapping survey techniques include MultiBeam Echo Sounder (MBES), Side-Scan Sonar (SSS), Sub-Bottom Profiling (SBP) and Remotely Operated Vehicle (ROV) camera/video (e.g. Nichol et al., 2012; Przeslawski et al., 2011; Ulfsnes et al., 2015);
- Modelling of the dispersion of routine drilling operation discharges (e.g. drill cuttings). Modelling would require determination analysis of major or prevailing bottom-boundary, sub-surface and sea surface currents;
- Zone of influence for drilling operations based on thresholds from CWC laboratory studies [e.g. laboratory studies Larsson et al. (2011,2013), Smit (2008) and Cranford et al. (1999) into the Norwegian regime (**Appendix E**)]; and
- Appropriate monitoring programs to validate modelling predictions, impact threshold and assessments (Ulfsnes et al., 2015).

It was also considered that the collection and analysis of bottom boundary and sea surface currents may facilitate an assessment of connectivity between CWC reef systems on the Atlantic margin. It was noted that the extensive baseline current and coral recruitment work completed at Scott Reef, in the 15-years prior to the Torosa-6 appraisal well, was extremely valuable in defining the connectivity and coral recruitment dependence between regional emergent tropical coral atolls.

There is clear evidence that drilling can be safely and environmentally-sensitively undertaken in CWC areas and protected areas with the correct mitigations and solutions. In order to evaluate the best option, the DNV Guidelines (Ulfsnes et al., 2015) provide a robust and tested process for assessing the impacts and selecting the most appropriate site locations and mitigation.

Table 4.1: Output from workshop discussion

Activity	Interaction	Engineering Mitigation
Anchoring	▪ Physical impact ▪ Secondary sediment impacts	▪ Use dynamically positioned (DP) MODU or drillship (no anchoring) ▪ Anchoring plan to avoid any potential impacts from anchors using a precautionary approach – best-fit approach to ensure safe distance to every potential CWC (Morvin) ▪ Anchor chain/wire corridor to avoid physical abrasion during drilling operations (DNV example 50m) ▪ Minimise anchor chain/wire touchdown distance using flotation (e.g. use of larger chain diameter and/or heavier anchor) ▪ Anchoring retrieval plan to avoid impacts (e.g. ROV retrieval) ▪ Pre-lay anchors (ROV assisted)
Rig skidding	▪ Physical impact ▪ Secondary sediment impacts	▪ Limitations/requirements on skidding of drilling rig during operation due to lateral movement of chain at seafloor (example – max. 50 m and in only one specified direction)
Wellhead	▪ Physical impact	▪ Directional drilling – moving wellhead location away from any sensitivities ▪ Well location plan - survey and plan wellhead to be a suitable distance from CWC
Drill cuttings (Tophole - Riserless)	▪ Smothering / Burial ▪ Chemical toxicity ▪ Turbidity	▪ Minimise length of tophole section ▪ Cuttings collection and transport away from sensitivities (Statoil example – Morvin). Multiple discharge locations for variable dispersion. ▪ Selection of low toxicity chemicals and drill cuttings (WBM) ▪ Introduce heavy brine to replace more harmful barite as weighting material drill/well fluids ▪ Directional drilling – moving wellhead location and tophole discharges away from any sensitivities ▪ Consideration of a slim hole well design to reduce the volume of muds and cuttings produced
Drill cuttings (Bottom hole – Riser installed)	▪ Smothering / Burial ▪ Chemical toxicity ▪ Turbidity	▪ Directional drilling – moving wellhead location and therefore drill cuttings away from any sensitivities ▪ Cuttings collection via the riser, processed and transport away from sensitivities (open water disposal - Scott Reef example) ▪ Drill mud and cuttings returned to drill rig, 'slurrify' and transported to shore (skip and ship Exxon example) ▪ Consideration of a slim hole well design to reduce the volume of muds and cuttings produced ▪ Cuttings collection and 'slurrify' before discharge at sea surface to achieve wider dispersion and dilute to concentration and sedimentation below threshold levels
Waste water discharge, noise emissions,	No interactions	

4.3 WORKSHOP SUMMARY

The following conclusions were determined:

- The distribution of CWC carbonate mounds in the Irish Atlantic margin is relatively well mapped through a combination of direct observational data (e.g. drop-down camera/video, ground truth/grab records) and interpretation of geophysical and acoustic survey and predictive habitat suitability modelling. This mapping is based on data collected by the hydrocarbon industry, academia and during the INSS (Irish National Seabed Survey), and its successor INFOMAR (Integrated Mapping for the Sustainable Development of Ireland's Marine Resources). With the exception of a few, small areas of sustained CWC research effort, less is understood across the Irish Atlantic margin about the distribution of small stands of CWC (Wheeler, 2014). The coverage of high-resolution seabed mapping over the Irish offshore is limited;
- Further directed sampling is required to improve the understanding of the relative distribution and current condition of high quality, high conservation value CWC reefs;
- There was recognition among participants that there are case studies where hydrocarbon exploration activities have been carried out in locations adjacent to areas of high-conservation value CWC and tropical coral, particularly in Norwegian and Australian offshore waters, with no detectable impact on these ecosystems;
- It is highly improbable that the interaction of seismic survey employing airgun arrays less than 4,450 in^3 with Irish CWC and reef-associated species would cause any short- or long- term adverse biological or ecological impacts. This conclusion is based on the modelled sound exposure levels being below the thresholds for any biological and ecological impacts for tropical scleractinian coral and fish species established by detailed research in offshore Australia;
- Management and mitigation controls do exist to eliminate or significantly reduce potential impacts of drilling activities on CWC and associated species. There are case studies from around the world which demonstrate numerous best practice options to eliminate impacts to CWC;
- Australian and Norwegian case studies demonstrated that, should a potential exploration project require it, it would be relatively easy and, given the advances in high-resolution mapping sensors and platforms, not prohibitively expensive to secure suitable data to determine the spatial extent and condition of local CWC reef prior to operations; and
- There are internationally-accepted scientific thresholds for potential impacts of drilling discharges on CWC reef that can be used for exploration drilling planning, impact assessment and engineering option selection to ensure the risk of any impacts are minimised or eliminated.

5 ACKNOWLEDGMENTS

The IOOA would like to thank all of the workshop participants for attending in their own time with a special thanks to those who travelled internationally and presented their research and case studies. The authors acknowledge workshop funding from IOOA and the Joint Venture Participants (JVPs) for FEL 5/14. The preparation and review of this report has been a collaboration between workshop participants, the RPS group and the IOOA environment subcommittee.

6 REFERENCES

Allers, E., Abed, R.M.M., Wehrmann, L.M., Wang, T., Larsson, A.I., Purser, A. and de Beer, D., 2013. Resistance of *Lophelia pertusa* to coverage by sediment and petroleum drill cuttings, Marine Pollution Bulletin 74, 132-140.

Andriguetto-Filho, J.M., Ostrensky, A., Pie, M.R., Silva, U.A. and Boeger, W.A. 2005. Evaluating the impact of seismic prospecting on artisanal shrimp fisheries. Continental Shelf Research Volume 25, 1720–1727. doi:10.1016/j.csr.2005.05.003.

Austin, M., McPherson, C., O'Neill, C., Warner, G. and Zeddies, D. 2014. Impacts of Seismic Surveys near Coldwater Coral Carbonate Mounds: Acoustic Modelling Study – Offshore Ireland, JASCO Document 00889, Version 1.0. Technical report by JASCO Applied Sciences for Woodside Energy (Ireland) Pty Ltd.

Battershill, C., Cappo, M., Colquhoun, J., Cripps, E., Jorgensen, D., McCorry, D., Stowar, M. and Venables, W. 2007. Environmental Report for Seismic 3-D effects on deep water corals for Woodside Petroleum and EPA. Scott Reef Australian Institute of Marine Science.

Battershill, C., Cappo, M., Colquhoun, J., Cripps, E., Jorgensen, D., McCorry, D., Stowar, M. and Venables, W. 2008. Final Report. Towed Video and Photoquadrat Assessments for Seismic 3-D effects on deep water corals for Woodside Petroleum and EPA. Scott Reef, May 2008.

Battershill, C., Cappo, M., Colquhoun, J., Cripps, E., Jorgensen, D., McCorry, D., Stowar, M., Radford, B., Miller, I., Venables, B. and Heyward, A. 2015. Coral community response to a 3D marine seismic survey. In prep Marine Ecology Progress Series.

Bolle, L.J., C.A.F. de Jong, S.M. Bierman, P.J.G. van Beek, O.A. van Keeken, PW. Wessels, C.J.G. van Damme, H.V. Winter, D. de Haan, and R.P.A. Dekeling. 2012. Common Sole Larvae Survive High Levels of Pile-Driving Sound in Controlled Exposure Experiments. PLoS One. 2012; 7(3):e33052. Published online 2012 March 14.

Booman C., Dalen J., Leivestad H., Levsen A., van der Meeren T. and Toklum K. 1996. Effects of seismic air-gun shooting on fish eggs, larvae and fry. Institute of Marine Research, Fisken og Havet, 3: 83 pp.

Brooke, S. and Järnegren, J. 2013. Reproductive periodicity of the scleractinian coral Lophelia pertusa from the Trondheim Fjord, Norway. Marine Biology 160:139–153

Cranford, P.J., Gordon, D.C., Lee, K., Armsworthy, S.L. and Tremblay, G.H. 1999. Chronic toxicity and physical disturbance effects of water and oil-based drilling fluid and some major constituents on adult sea scallops (Placopecten magellanicus). Marine Environmental Research. 48:225-256.

Colman, J.C., Grebe, C.C., and Hearn, R.L. 2008. The challenges and complexities of impact assessment for a seismic survey in a remote coral reef system. Proceedings from the International Association for Impact Assessment (IAIA) 2008, Perth Western Australia. [on-line] . Available at http://www.iaia.org/iaia08perth/pdfs/concurrentsessions/CS1-7_sectoral_marine_Colman.pdf

Dalen, J. and Maestad, K. 2008. The impact of seismic surveys. [on-line]. A marine research news circular from the Institute of Marine Research, Norway. Volume 5, 2008. Available at http://www.imr.no/publikasjoner/andre_publikasjoner/havforskningsnytt/2008/HI_News_5_ENG.pdf/en

Dalen, J., and Knutsen, G. M. 1987. Scaring effects in fish and harmful effects on eggs, larvae and fry by offshore seismic explorations. In: Merklinger, H. M. ed. Progress in Underwater Acoustics. New York: Plenum Publishing Co.:93–102.

Department of Communications, Energy and Natural Resources. 2015. Historical exploration and production data. [on-line]. Available from: http://www.dcenr.gov.ie/NR/rdonlyres/F926AFB6-BA5A-45EB-97BA-B8B456289D73/0/OffshoreIrelandWellListing.xls

Environmental Resource Management and Coastal and Marine Research Centre. 2014. Review and Collation of Existing Information on the Distribution and Abundance of Deepwater Coral Mounds (Surface) in Offshore Irish Waters. A technical report for Woodside Energy.

Frost, T.K., Myrhaug, J.L., Ditlevsen M.K. and Rye, H. 2014. Environmental Monitoring and Modelling of Drilling Discharges at a Location with Vulnerable Seabed Fauna: Comparison between Field Measurements and Model Simulations, Paper for presentation at the SPE International Conference on Health, Safety and Environment, Long Beach, California, USA, 17-19 March 2014.

Gausland, I. 2003. Seismic Survey Impact on Fish and Fisheries. Stavanger: Norwegian Oil Industry Association.

Grehan, A.J., Unnithan, V., Olu-Le Roy, K. and Opderbecke, J. 2005. Fishing impacts on Irish deep-water coral reefs: making the case for coral conservation. In: Barnes PW, Thomas JP (eds) Benthic habitats and the effects of fishing. American Fisheries Society Symposium 41, Bethesda, MD, USA, pp 819–832

Gulland, J. A. and Walker, C. D. T. 1998. Marine Seismic Overview. In: Seismic and Marine Mammals Workshop, London, UK.

Hastings, M. 2008. Effects of sound on shallow coral reefs and predicted effects for the Gigas seismic survey in and around north Scott Reef lagoon. Technical report for Woodside Energy / Sinclair Knight Merz Pty Limited WV03377.221.

Hastings, M.C. and Miksis-Olds, J. 2012. Shipboard assessment of hearing sensitivity of tropical fishes immediately after exposure to seismic air gun emissions at Scott Reef. Journal of Advances Experimental Medicine and Biology 730:239-243.

Hovland, M. 2012. Marine life associated with offshore drilling, pipelines, and platforms, Encyclopaedia of Sustainability Science and Technology.

Hyne, N. 2014. Dictionary of Petroleum Exploration, Drilling & Production. 2nd Edition, Penwell, USA ISBN-13: 978-0878143528.

ICES, 2002. Report of the Study Group on Mapping the Occurrence of Cold Water Corals. ICES CM 2002/ACE:05.

International Association of Geophysical Contractors. 2014. Fundamentals of sound in the marine environment. [on-line] A technical report for the IAGC. Available at http://www.iagc.org/media/files/page/177239f2/IAGC_1_Pager_Sound_101_Formatted_FINAL_2014_09_24.pdf

International Oil and Gas Producers Association. 2008. Fundamentals of underwater sound. [on-line] A technical report for the IOGP. Report No. 406. Available at http://www.ogp.org.uk/pubs/406.pdf

Jackson, J. B. C. 1986. Modes of dispersal of clonal benthic invertebrates: consequences for species' distributions and genetic structure of local populations. Bulletin of Marine Science 39:588–606

Kostyuchenko, L.P. 1973. Effects of elastic waves generated in marine seismic prospecting of fish eggs in the Black Sea. Hydrobiolica Journal 9 (5): 45-48.

Larsson, A.I. and Purser, A. 2011. Sedimentation on the cold-water coral Lophelia pertusa: Cleaning efficiency from natural sediments and drill cuttings. Marine Pollution Bulletin 62: 1159-1168.

Larsson, A.I., van Oevelen, D., Purser, A. and Thomsen, L. 2013. Tolerance to long-term exposure of suspended benthic sediments and drill cuttings in the cold-water coral Lophelia pertusa. Marine Pollution Bulletin 2013 May 15;70(1-2):176-88. doi: 10.1016/j.marpolbul.2013.02.033. Epub 2013 Mar 16.

Larsson, A.I., Järnegren, J., Strömberg, S.M., Dahl, M.P., Ludälv, T. and Brooke, S. 2014. Embryogenesis and Larval Biology of the Cold-Water Coral Lophelia pertusa. 2014. PLoS ONE 9(7): e13636. doi:10.1373/journal.pone.010222

Le Goff-Vitry, M. C., Pybus, O. G. and Rogers, A. D. 2004 Genetic structure of the deep-sea coral Lophelia pertusa in the northeast Atlantic revealed by microsatellites and internal transcribed spacer sequences. Molecular Ecology 13:537–549

MacGillivray, A.O. and Chapman, N.R. 2005. Results from an acoustic modelling study of seismic airgun survey noise in Queen Charlotte Basin. [on-line] Technical report submitted to the BC Offshore Oil and Gas Team. Available at http://www.offshoreoilandgas.gov.bc.ca/reports/reports.htm

McCauley, R.D., Fewtrell, J. and Popper, A.N. 2003. High intensity anthropogenic sound damages fish ears. Journal of the Acoustical Society of America 113, 638–642.

Miller, I. and Cripps, E. 2013. Three dimensional marine seismic survey has no measurable effect on species richness or abundance of a coral reef associated fish community. Marine Pollution Bulletin 2013 Dec 15;77(1-2):63-70.

Morrison, C. L., Ross, S. W., Nizinski, M. S., Brooke, S. and Järnegren, J. 2011. Genetic discontinuity among regional populations of Lophelia pertusa in the North Atlantic Ocean. Conservation Genetics 12:713–729.

Naylor, D. and Shannon, P.M. 2013. Petroleum Geology of Ireland. Dunedin Academic Press, Scotland

Nichol, S.L., Anderson, T.A., Battershill, C. and Brooke, B.P. 2012. Submerged reefs and Aeolian dunes as inherited habitats, Point Cloates, Carnarvon Shelf, Western Australia. IN: Harris PT; Baker EK (eds). Seafloor Geomorphology as Benthic Habitat. Ch 27: 397-406.

Nilsen, M., Godal, B., Bechmann, R and Bassant, T. 2010. Cold-water corals in relation to oil and gas operations. International research Institute Stavanger (IRIS) Report 2010.

OSPAR. 2008. OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic. OSAR List of Threatened and/or Declining Species and Habitats (Reference Number: 2008-06, Replaces agreement 2004-6).

Popper, A.N. and Hastings, M.C. 2009. Effects of anthropogenic sources of sound on fishes. Journal of Fish Biology 75, 455–498

Popper, A.N., Hawkins, A.D., Fay, R.R., Mann, D.A., Bartol, S., Carlson, T.J., Coombs, S., Ellison, W.T., Gentry, R.L., Halvorsen, M.B., Løkkeborg, S., Rogers, P.H., Southall, B.L., Zeddies, G.D. and Tavolga, W.N. 2014. Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI. ASA S3/SC1.4 TR-2014. Springer and ASA Press, Cham, Switzerland. doi: 10.1007/978-3-319-06659-2.

Przeslawski, R., Daniell, J., Anderson, T., Barrie JV, Battershill C, Heap A, Hughes M, Li J, Potter A, Radke L, Siwabessy J, Tran M, Whiteway T, Nichol S. 2011. Seabed habitats and hazards of the Joseph Bonaparte gulf and Timor sea, Northern Australia. Record 2011/40, Geoscience Australia, Canberra. 69pp. www.ga.gov.au

Roberts, J.M., Wheeler, A.J., Freiwald, A. and Cairns, S.D. 2009. Cold-Water Corals: The Biology and Geology of Deep-Sea Coral Habitats. Cambridge University Press.

Saetre, R. and E. Ona, 1996. Seismic investigations and damages on fish eggs and larvae; an evaluation of possible effects on stock level. Fisken og Havet 1996:1-17, 1-8.

Smit, M.G.D. 2008. SSD parameters for the nontoxic stressors; temperature, suspended matter, oxygen depletion and nitrogen. A Technical Report for Statoil ASA.

Southall, B.L., Bowles, A.E., Ellison, W.T., Finneran, J.J., Gentry, R.L., Greene, C.R. Jr., Kastak, D., Ketten, D.R., Miller, J.H., Nachtigall, P.E., Richardson, W.J., Thomas, J.A., and Tyack, P. (2007). Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations. Aquatic Mammals 33: 411-521.

Tyler-Walters, H. 2005. Lophelia reefs. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. Available from: http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=294&code=2004

Ulfsnes, A., Haugland, J.K. and Weiltzien, R. 2015. Monitoring of drilling activities in areas with presence of cold-water corals. A report for Norsk Olje og Gass.

Waller, R. G. and Tyler, P. A. 2005. The reproductive biology of two deep-water, reef-building scleractinians from the NE Atlantic Ocean. Coral Reefs 24:514–522

Wardle, C. S., Carter, T. J., Urquhart, G.G., Johnstone, A.D.F, Ziolkowski, A.M., Hampston, G. and Mackie, D. 2001. Effects of seismic air guns on marine fish. Continental shelf research 21:1005-1027.

Wheeler, A. J., Beyer, A., Freiwald, A., de Haas, H., Huvenne, V.A.I., Kozachenko, M., Olu-Le Roy K. and Opderbecke, J. 2007. Morphology and environment of cold-water coral carbonate mounds on the NE European margin. International Journal of Earth Science Volume 96:37–57

Wheeler, A.J. 2014. *Per comms*. Feedback form a workshop on cold-water corals and offshore hydrocarbon exploration operations on the Irish Atlantic margin. In preparation

APPENDIX A

WORKSHOP PROGRAMME

Irish Offshore Operators' Association
Suite No. 2119, Fitzwilliam Business Centre, 26, Upper Pembroke Street, Dublin 2, Ireland
Tel: +353 1 637 3996 Fax + 353 662 0365 Email: iooa.chairman@gmail.com Website: www.iooa.ie

Irish Offshore
Operators'
Association

Workshop: Cold-water corals and offshore hydrocarbon exploration operations on the Irish Atlantic margin

Monday 1 December 2014
Venue: DoubleTree by Hilton Dublin – Burlington Road, Dublin 4
1st Floor business centre – Room 7
Contact: Gareth Parry – IOOA
+353 (0) 86 074 7420

TIME	ITEM	SPEAKER
08:30	Housekeeping and introductions	Prof. Pat Shannon - IOOA Chairman
08:45	Agenda and objectives	Prof. Pat Shannon
	Irish context	
09:00	Historical, current and future O&G activity in offshore Ireland	Prof. Pat Shannon
09:15	Current protection of cold-water corals and future designations	Dr David Lyons National parks and Wildlife Service - NPWS
	Understanding cold-water corals	
09:30	Distribution of cold-water corals in Irish waters. Structure of key provinces in the Porcupine and Rockall basins	Prof. Andy Wheeler University College Cork - UCC
09:50	Cold-water coral understanding and management. Current stresses to cold-water corals on the Irish Atlantic margin and status of the Irish MPA network	Dr Anthony Grehan National University of Galway - NUIG
10:10	Ecology and biology of cold-water corals and success of Joint Industry Programmes (JIPs) in the UK sector	Prof. Murray J. Roberts Heriot-Watt University - HWU
10:35 -	11:00 **MORNING TEA – 1st Floor reception**	
	Seismic exploration and cold-water corals	
11:00	Seismic survey operations	Gareth Parry - IOOA
11:05	Case Study – Maxima seismic experiments	Prof. Chris Battershill University of Waikato - Environmental Research Institute
11:25	Predicted sound exposures in an Irish context	Dr Luke Smith Woodside Energy Ltd
11:45	Potential stressors for exploration seismic and cold-water corals	ALL
12:45	Conclusions on seismic operations	Prof. Pat Shannon
12:55 -	13:40 **LUNCH - B-Bar Ground Floor**	
	Exploration drilling and cold-water corals	
13:40	Exploration drilling operations	Gareth Parry
13:45	Summary of current understanding of laboratory measured threshold / tolerance of *Lophelia* sp. to drill cuttings exposure	Dr Thierry Baussant International Research Institute Stavanger
14:05	Case Study – Scott Reef Torosa 6 appraisal well	Dr Luke Smith
14:25	Case Study – Norwegian Sea development	Lars Myhre (Statoil) Rune Weltzien (Statoil)

14:45	Overview of afternoon objectives and agenda	Prof. Pat Shannon
14:55	Potential stressors and mitigation strategies for exploration drilling	ALL
15:15 -	15:40 **AFTERNOON TEA – 1st Floor reception**	
15:40	Potential stressors and mitigation strategies for exploration drilling	ALL
17:00	Summary on exploration drilling operations	ALL
17:30	**CONCLUSION**	

Pre-read

Norsk Olje og Gass. 2013. *Report Monitoring of Drilling Activities in Areas with Presence of Cold-Water Corals*. Guidelines REPORT NO./DNV REG NO.: 2012-1691 / 12NCQKD-2 REV 01, 2013-01-15

Norwegian Oil and Gas' intention has been to produce a guideline which summarises the most relevant matters regarding drilling activities in areas with presence of cold water corals. This guideline presents specific requirements on coral mapping using SSS/MBES and visual techniques in order to identify whether there are corals present in the planned drilling area or not, estimation of value of coral structures, risk assessment, monitoring alternatives and mitigation measures to avoid negative impacts on corals.

https://www.norskoljeoggass.no/Global/2013%20Dokumenter/Publikasjoner/Monitoring%20of%20drilling%20activities%20-%20Areas%20with%20Cold%20Water%20Corals.pdf

APPENDIX B

LIST OF PARTICIPANTS

Name	Organisation
Professor Pat Shannon	Irish Offshore Operators' Association (Facilitator)
Professor Andy Wheeler	University College Cork
Professor Chris Battershill	University of Waikato - Environmental Research Institute
Professor Murray Roberts	Heriot-Watt University
Dr Anthony Grehan	NUI Galway
Dr David Lyons	Irish National Parks and Wildlife Service
Dr Luke Smith	Woodside Chief Environmental Scientist
Dr Thierry Baussant	International Research Institute Stavanger
Aaron Lim	University College Cork
Gareth Parry	Irish Offshore Operators' Association
Dr James Forde	RPS
Dr James Massey	RPS
Lars Petter Myhre	Statoil
Margot Cronin	Marine Institute
Michael Hanrahan	Department of Communications Energy and Natural Resources
Natalia Lopez	Orbis Energy
Nick O'Neill	SLR Consulting
Orla Ryan	Department of Communications Energy and Natural Resources
Rune Weltzien	Statoil
Xavier Monteys	Geological Survey of Ireland

APPENDIX C

SEISMIC ACTIVITY - WORKSHOP SESSION OUTPUTS - IMPACT ASSESSMENT TABLES

Activity	Seismic
Receptor	CWC reef

Seismic operation assumptions:
- 90m seismic vessel.
- 1500m3 marine diesel.
- 45 day campaign.
- 3D survey with 4450 in3 airgun array.
- 700m water depth.
- 10 streamers 12 km long.
- Two support vessels.
- Bunkering at sea.

	INTERACTIONS - SCOPING					IMPACTS - DETAILED ASSESSMENT						Residual and Monitoring	
	1	2	3	4	5	6	7	8	9	10	11	12	13
	Likelihood of element of operation occurring Certain / Likely / Possible / Unlikely / Remote	Potential Interaction	Potential Impacts Yes / No	Raw Interaction Major / Moderate / Negligible / None	Evidence Confidence High / Medium / Low	Potential impact mechanism	Intolerance * Benchmark level	Recoverability	Sensitivity	Evidence Confidence High / Medium / Low	Mitigation	Residual Impact Major / Moderate / Negligible / None	Monitoring
Noise from air guns	Certain	Sound pulse causing damage to coral structure	yes	none	medium	physical damage	intolerant	low	high	high	noise attenuation levels should be below Hastings 2008 and Maxima studies threshold at seabed	none	
Noise from air guns	Certain	sound pulse causing physiological damage to coral	yes	none	medium	physiological damage	intolerant	unknown	unknown	low	seabed levels at seabed expected below 175dB. No effects likely at this level but must be confirmed	negligible	Further evidence/expert opinion required to confirm no significant or adverse effects found in Australian tropical coral research is comparable
Noise from air guns	Certain	sound pulse causing ecological function response to coral	yes	negligible	low	behavioural / functional	tolerant	unknown	unknown	low	Noise attenuation modelling for source level below reported thresholds	negligible	
Noise from air guns	Certain	sound pulse causing ecological function response to associated species	yes	negligible	low	behavioural / functional	tolerant	high	low	medium	Noise attenuation modelling for source level below reported thresholds	negligible	
Vessel noise	Certain	none	no	none	high	none	tolerant			high	▨	▨	▨
Physical presence	Certain	none	no	none	high	none	tolerant			high	▨	▨	▨
Surface discharge	Possible	none	no	none	high	none				high	▨	▨	▨

Table C6.1: Seismic Activity Interactions with cold-water coral reef

Activity	Seismic
Receptor	CWC reef

Seismic operation assumptions:
- 90m seismic vessel.
- 1500m3 marine diesel.
- 45 day campaign.
- 3D survey with 4450 in3 airgun array.
- 700m water depth.
- 10 streamers 12 km long.
- Two support vessels.
- Bunkering at sea.

	INTERACTIONS - SCOPING					IMPACTS - DETAILED ASSESSMENT						Residual and Monitoring	
	1	2	3	4	5	6	7	8	9	10	11	12	13
	Likelihood of element of operation occurring Certain / Likely / Possible / Unlikely / Remote	Potential Interaction	Potential Impacts Yes / No	Raw Interaction Major / Moderate / Negligible / None	Evidence Confidence High / Medium / Low	Potential impact mechanism	Intolerance * Benchmark level	Recoverability	Sensitivity	Evidence Confidence High / Medium / Low	Mitigation	Residual Impact Major / Moderate / Negligible / None	Monitoring
Dropped object	Unlikely	Physical damage	yes	moderate	high	Physical	intolerant	low	high	high	SOPs	negligible	▨
Dropped object	Unlikely	Chemical	yes	moderate	high	Chemical	intolerant	low	high	high	SOPs	negligible	▨
Surface spill	Unlikely	Chemical	yes	negligible	high	Chemical	intolerant	low	high	high	marine notices, AIS, guard vessels	negligible	▨
Vessel sinking / collision	Unlikely	Physical and chemical	yes	major	high	Physical and chemical	intolerant	low	high	high	marine notices, AIS, guard vessels	negligible	▨
Loss of array	Unlikely	Physical and chemical	yes	major	high	Physical and chemical	intolerant	low	high	high	Maintenance, neutral buoyancy	negligible	▨

Table C6.1 cont: Seismic Activity Interactions with Cold-water Coral Reef

Activity	Seismic	Seismic operation assumptions: - 90m seismic vessel. - 1500m3 marine diesel. - 45 day campaign. - 3D survey with 4450 in3 airgun array.	.- 700m water depth. - 10 streamers 12 km long. - Two support vessels. - Bunkering at sea.
Receptor	CWC species		

INTERACTIONS - SCOPING						IMPACTS - DETAILED ASSESSMENT						Residual and Monitoring		COMMENT
	1	2	3	4	5	6	7	8	9	10	11	12	13	
	Likelihood of element of operation occurring Certain / Likely / Possible / Unlikely / Remote	Potential Interaction	Potential Impacts Yes / No	Raw Interaction Major / Moderate / Negligible / None	Evidence Confidence High / Medium / Low	Potential impact mechanism	Intolerance * Benchmark level	Recoverability	Sensitivity	Evidence Confidence High / Medium / Low	Mitigation	Residual Impact Major / Moderate / Negligible / None	Monitoring	
Airguns	Certain	larval	yes	negligible	Medium	physical damage	intolerant	low	low	medium	Feb. likely spawning event, very near field impacts only (7-10m likely)	negligible		Spawning in Feb, Lethal of physically damaging noise would only occur in very close proximity to the source. Interaction unlikely
Noise from air guns	Certain	sound pulse causing damage to coral structure	yes	none	Medium	physical damage	intolerant	low	high	high	noise attenuation levels should be below Hastings threshold at seabed	none		Seismic sources do not operate at the levels which Hastings 2008 models physical damage can occur. Seabed sources operating at over 270 dB would be required to cause physical damage.
Noise from air guns	Certain	sound pulse causing physiological damage to coral	yes	none	Medium	physiological damage	intolerant	unknown	unknown	low	seabed levels at seabed expected below 175dB. No effects likely at this level but must be confirmed	negligible		Further evidence/expert opinion required to confirm no significant or adverse effects found in Australian tropical coral research is comparable
Noise from air guns	Certain	sound pulse causing ecological function response to coral	yes	negligible	Low	behavioural / functional	tolerant	unknown	unknown	low	Noise attenuation modelling for source level below reported thresholds	negligible		
Noise from air guns	Certain	sound pulse causing ecological function response to associated species	yes	negligible	Low	behavioural / functional	tolerant	high	Low	medium	Noise attenuation modelling for source level below reported thresholds	negligible		
Noise from air guns	Certain	Tissue damage (rupture)	yes	negligible	Medium	Physical	n/a	intolerant	Low	medium	Noise limits set at threshold level determined by Austin 2014 and Scott Reef tropical coral work	negligible		
Noise from air guns	Certain	Dislodged tentacle	yes	negligible	Medium	Physical	n/a	intolerant	Low	medium	Noise limits set at threshold level determined by Austin 2014 and Scott Reef tropical coral work	negligible		
Noise from air guns	Certain	Skeletal damage	yes	negligible	Medium	Physical	n/a	intolerant	Low	medium	Noise limits set at threshold level determined by Austin 2014 and Scott Reef tropical coral work	negligible		
Noise from air guns	Certain	Behavioural response (reduced feeding respiration, mucous secretion)	yes	Moderate	Medium	Physiological	Unknown	high	Low	Medium		negligible		
Noise from air guns	Certain	Larvae release mechanism	yes	Moderate	Low	Physical	Unknown	high	Low	Medium	Survey timed to avoid spawning season	negligible		Histology studies of larvae indicate 4-6 week spawning event from Feb (high confidence).Survey should be planned outside of spawning period. Coral and fish larvae are similarly in structure, no hearing structures. Positive locomotive response of larvae to noise of reef (crashing surf). Spawning cold water coral effect on locomotion. Gap in knowledge. Negligible and medium confidence. Or moderate with low confidence. N.B spawning and feeding aggregations of orange roughy during coral spawning events may be coincidental
Noise from air guns	Certain	Larvae (buoyancy / locomotion)	yes	Moderate	Low	Physical	Low	high	Low	Medium	Survey timed to avoid spawning season	negligible		Gap in knowledge. Negligible and medium confidence. Or moderate with low confidence. See comment above
Noise from air guns	Certain	Symbionts	yes	Moderate	Low	Physiological	Unknown	high	unknown	Low	Unknown but given no hearing structures in majority of symbionts unlikely to impact	negligible		Unknown but given no hearing structures in majority of symbionts unlikely to impact

Table C2: **Seismic Activity Interactions with cold-water coral species**

APPENDIX D

DRILLING ACTIVITY - WORKSHOP SESSION OUTPUTS - IMPACT ASSESSMENT TABLES

Activity	Drilling	Drilling operation assumptions: • Semisubmersible or drillship. • Moored with 8 anchors – not pre-layed. 4km diameter. • Debris and shallow gas survey completed (SSS, SBP, magnetometer). • Tophole drilled using WBM and returned to seabed. • Bottom hole drilled using WBM and returned at sea surface. • Two support vessel. • 90 days onsite (25% weather downtime).
Receptor	CWC reef	

	INTERACTIONS - SCOPING					IMPACTS - DETAILED ASSESSMENT						Residual and Monitoring	
	1	2	3	4	5	6	7	8	9	10	11	12	13
	Likelihood of element of operation occurring Certain / Likely / Possible / Unlikely / Remote	Potential Interaction	Potential Impacts Yes / No	Raw Interaction Major / Moderate / Negligible / None	Evidence Confidence High / Medium / Low	Potential impact mechanism	Intolerance * Benchmarklevel	Recoverability	Sensitivity	Evidence Confidence High / Medium / Low	Mitigation	Residual Impact Major / Moderate / Negligible / None	Monitoring
Anchoring	Certain	anchor	Yes	Major	High	Physical damage	High	very low	Very high	High	Site survey, ROV, Prelaying, CPT - DP vessel	Negligible	
Anchoring	Certain	chains	Yes	Major	High	Physical damage	High	very low	Very high	High	Site survey, ROV, Prelaying, CPT, DP vessel	Negligible	
Anchoring	Certain	anchor handling	Yes	Major	High	Physical damage	High	very low	Very high	High	Subsurface buoys, don't do grapling, shorter larger chains to reduce length. DP vessel	Negligible	
Anchoring	Certain	anchor handling	Yes	Negligible	high	particulates	high	high	low	High	Pre-lay anchors, Site survey, ROV, acoustic release	Negligible	
Drilling footprint	Certain	seabed footprint	Yes	Major	High	Physical damage	High	very low	Very high	High	Site survey, ROV, positioning	None	Assumes avoidance
Drilling footprint	Certain	seabed footprint	No	Moderate	Medium	scour	High	Low	High	Medium	90 days duration so unlikely to result in scour	None	
Tophole	Certain	cuttings pile	Yes	Major	High	Physical damage	High	very low	Very high	Medium	Site survey, ROV, positioning, discharge point and cuttings retrieval / pumping	Negligible	Sediment traps and ROV stations
Tophole	Certain	cuttings pile	Yes	Major	High	Smothering	Intolerant	very low	Very high	Medium	Site survey, ROV, positioning, discharge point and cuttings retrieval / pumping	Negligible	Sediment traps and ROV stations
Tophole	Certain	cuttings pile	Yes	Moderate	High	chemical	Low	Low	High	Low	Site survey, ROV, positioning, discharge point and cuttings retrieval / pumping, chemical selection	Negligible	Chemical sampling, sediment traps and ROV stations
Tophole	Certain	Casings and cements	Yes	Moderate	High	chemical	Low	Low	high	Low	Site survey, ROV, positioning, discharge point and cuttings retrieval / pumping, chemical selection	Negligible	Chemical sampling, sediment traps and ROV stations

Table D6.1: Drilling Activity Interactions with cold-water coral reef

Activity	Drilling	Drilling operation assumptions: • Semisubmersible or drillship. • Moored with 8 anchors – not pre-laid. 4km diameter. • Debris and shallow gas survey completed (SSS, SBP, magnetometer). • Tophole drilled using WBM and returned to seabed. • Bottom hole drilled using WBM and returned at sea surface. • Two support vessel. • 90 days onsite (25% weather downtime).
Receptor	CWC reef	

INTERACTIONS - SCOPING						IMPACTS - DETAILED ASSESSMENT						Residual and Monitoring	
	1	2	3	4	5	6	7	8	9	10	11	12	13
	Likelihood of element of operation occurring Certain / Likely / Possible / Unlikely / Remote	Potential Interaction	Potential Impacts Yes / No	Raw Interaction Major / Moderate / Negligible / None	Evidence Confidence High / Medium / Low	Potential impact mechanism	Intolerance * Benchmark level	Recoverability	Sensitivity	Evidence Confidence High / Medium / Low	Mitigation	Residual Impact Major / Moderate / Negligible / None	Monitoring
Bottom hole	Certain	Cuttings pile	Yes	Major	High	Physical damage	High	very low	Very high	Medium	Site survey, ROV, positioning, discharge point, discharge type, modelling and cuttings retrieval / pumping, Skip and ship	Negligible	Sediment traps and rov stations
	Certain	Cuttings pile	Yes	Major	High	smothering	High	very low	Very high	Medium	Site survey, ROV, positioning, discharge point, discharge type, modelling and cuttings retrieval / pumping, Skip and ship	Negligible	Sediment traps and rov stations
	Certain	Cuttings pile	Yes	Moderate	High	chemical	Low	Low	High	Low	Site survey, ROV, positioning, discharge point, discharge type, modelling and cuttings retrieval / pumping, Skip and ship	Negligible	Chemical sampling, sediment traps and rov stations
	Certain	Casings and cements	Yes	Moderate	High	chemical	Low	Low	high	Low	Site survey, ROV, positioning, discharge point and cuttings retrieval / pumping, chemical selection	Negligible	Chemical sampling, sediment traps and rov stations
Surface discharges	Possible	cuttings	Yes	Moderate	High	smothering and chemical	High	Low	high	Medium	Site survey, ROV, positioning, discharge point modelling and cuttings retrieval / pumping, diluting?, chemical selection	Negligible	Chemical sampling, sediment traps and rov stations
	Possible	grey water	no	none	High	chemical	High	Low	High	Medium		None	
VSP	Possible	Noise from airgun	yes	Negligible	High	Physical and physiological damage	High	Low	High	High	Survey , planning, noise modelling and coral avoidance. Duration of activity is very short	Negligible	
Site survey damage	possible	physical damage rov tethers etc	yes	Major	High	Physical damage	high	low	high	High	Survey planning, rov operations	negligible	ROV stations
Abandonment	possible	cutting wellhead	yes	Major	High	Smothering	high	low	high	High	Leave wellhead intact	none	ROV stations

Table D6.1 cont: Drilling Activity Interactions with cold-water coral reef

Activity	Drilling
Receptor	reef

Drilling operation assumptions:

- Semisubmersible or drillship.
- Moored with 8 anchors – not pre-layed. 4km diameter.
- Debris and shallow gas survey completed (SSS, SBP, magnetometer).
- Tophole drilled using WBM and returned to seabed.
- Bottom hole drilled using WBM and returned at sea surface.
- Two support vessel.
- 90 days onsite (25% weather downtime).

INTERACTIONS - SCOPING						IMPACTS - DETAILED ASSESSMENT						Residual and Monitoring	
	1	2	3	4	5	6	7	8	9	10	11	12	13
	Likelihood Certain / Likely / Possible / Unlikely / Remote	Potential Interaction	Potential Impacts Yes / No	Raw Interaction Major / Moderate / Negligible / None	Evidence Confidence High / Medium / Low	Potential impact mechanism	Intolerance * Benchmarklevel	Recoverability	Sensitivity	Evidence Confidence High / Medium / Low	Mitigation	Residual Impact Major / Moderate / Negligible / None	Monitoring
Unplanned													
Anchoring	Unlikely	anchor loss - misplacement	Yes	Major	Medium	physical	High	Low	High	High	Site survey, ROV, Prelaying, CPT - DP vessel	negligible	ROV stations
	Unlikely	chains - loss drift mislay	Yes	Major	Medium	physical	High	Low	High	High	Site survey, ROV, Prelaying, CPT - DP vessel	negligible	ROV stations
Loss of rig / ship / equipment	Unlikely	Loss and collision with reef on seabed	Yes	Major	Medium	physical and chemcial	High	Low	High	High	marine notices, AIS, guard vessels, MSO inspections, Safety Cases	negligible	Long term montoring for chemcial in sediments and ROV stations
Blow out	Unlikely	Spillage of oil from equipment failure	Yes	Moderate	Medium	Chemcial	High	Low	High	Medium	Many targets are gas. Limited seabed interaction, oil moves to survface or is entrained. OSCP and blow out preventors. Provision of capping technologies within 24hrs transportation of the well is a common condition for wells likely to be oil finds.	negligible	Long term montoring for chemcial in sediments and ROV stations

Table D6.1 cont: Drilling Activity Interactions with cold-water coral reef

Interactions

1	Likelihood of element of operation occuring	Certain	Always occurs as a result of this operation
		Likely	Occurs frequently as a result of this operation
		Possible	Has occurred once or twice in O&G industry in offshore Ireland
		Unlikely	Has occurred many times in the O&G industry but never in offshore Ireland
		Remote	Has occurred once or twice in the industry

4	Raw Interaction	Major	Change in a sensitive receptor leading to long-term damage and poor potential for recovery to a normal state
		Moderate	Change in a sensitive receptor leading to damage but with a likelihood of recovery
		Minor or Negligible	Change which is within the range of existing variability but can be monitored and/or noticed
		None	No potential for significant interaction with receptor group or change markedly smaller than natural variability and immeasurable

5	Evidence Confidence	Low	There is limited or no specific or suitable proxy information on the sensitivity of the feature to the relevant pressure. The assessment is based largely on expert judgement.
		Medium	There is some specific evidence or good proxy information on the sensitivity of the feature to the relevant pressure.
		High	There is good information on the sensitivity of the feature to the relevant pressure. The assessment is well supported by the scientific literature.

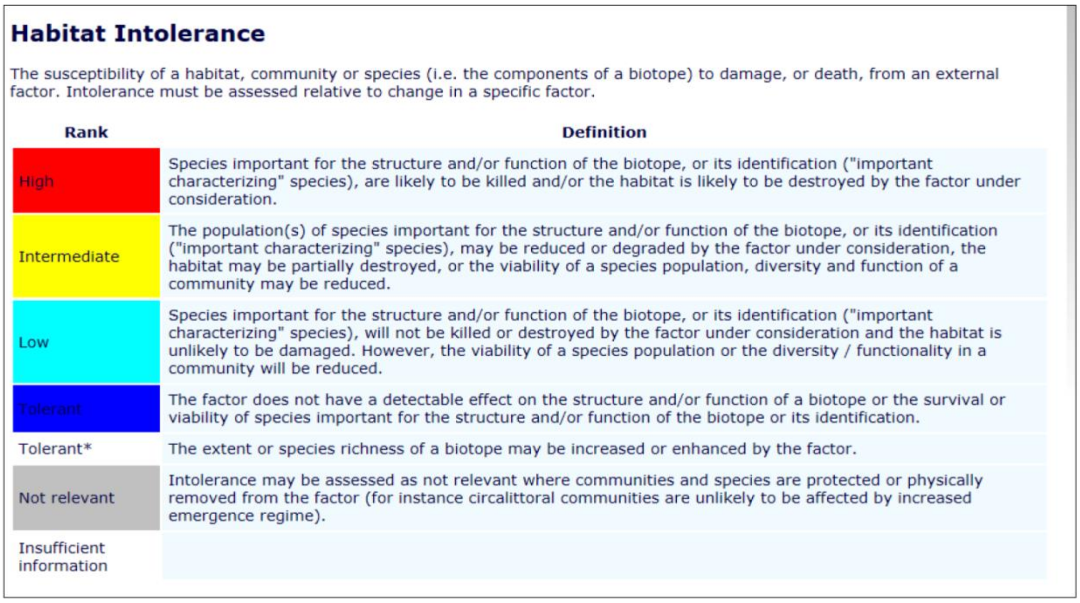
Table D2 : Interaction definitions – Likelihood of element of operation occurring, raw interaction and evidence/confidence

Impacts

6

Impact Mechanism	**Physical**
	Non-physical
	Biological
	Chemical

7 MarLIN

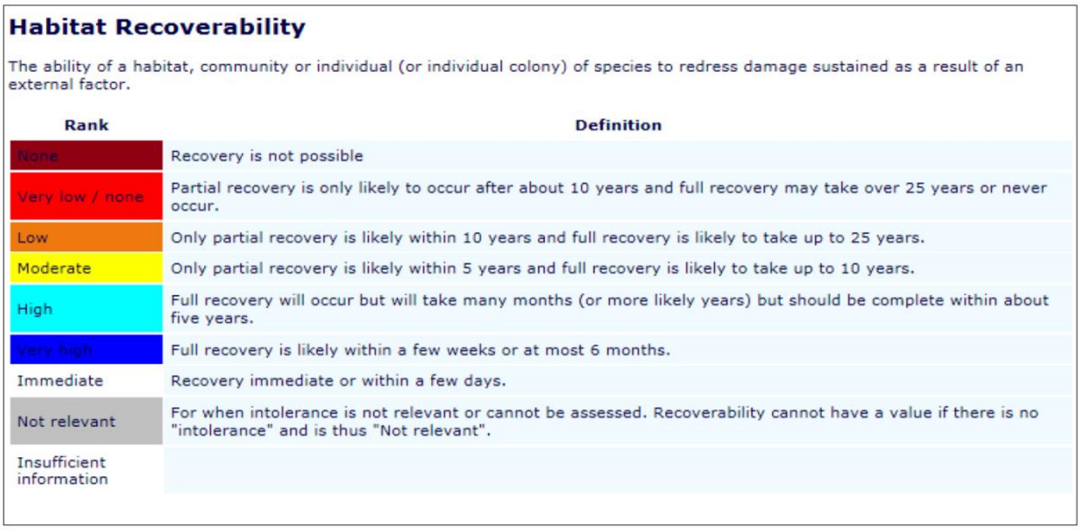


Habitat Intolerance

The susceptibility of a habitat, community or species (i.e. the components of a biotope) to damage, or death, from an external factor. Intolerance must be assessed relative to change in a specific factor.

Rank	Definition
High	Species important for the structure and/or function of the biotope, or its identification ("important characterizing" species), are likely to be killed and/or the habitat is likely to be destroyed by the factor under consideration.
Intermediate	The population(s) of species important for the structure and/or function of the biotope, or its identification ("important characterizing" species), may be reduced or degraded by the factor under consideration, the habitat may be partially destroyed, or the viability of a species population, diversity and function of a community may be reduced.
Low	Species important for the structure and/or function of the biotope, or its identification ("important characterizing" species), will not be killed or destroyed by the factor under consideration and the habitat is unlikely to be damaged. However, the viability of a species population or the diversity / functionality in a community will be reduced.
Tolerant	The factor does not have a detectable effect on the structure and/or function of a biotope or the survival or viability of species important for the structure and/or function of the biotope or its identification.
Tolerant*	The extent or species richness of a biotope may be increased or enhanced by the factor.
Not relevant	Intolerance may be assessed as not relevant where communities and species are protected or physically removed from the factor (for instance circalittoral communities are unlikely to be affected by increased emergence regime).
Insufficient information	

8 MarLIN



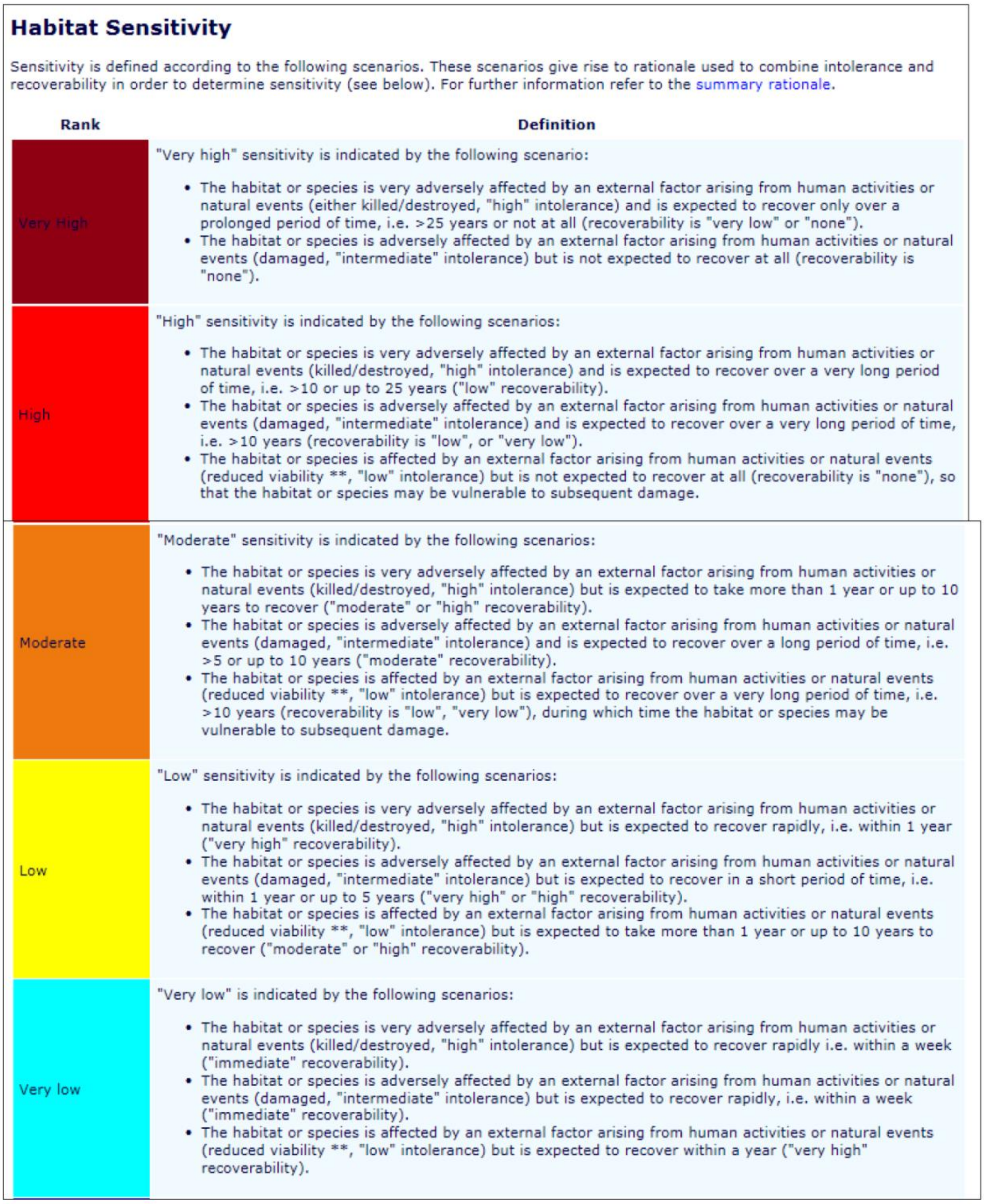
Habitat Recoverability

The ability of a habitat, community or individual (or individual colony) of species to redress damage sustained as a result of an external factor.

Rank	Definition
None	Recovery is not possible
Very low / none	Partial recovery is only likely to occur after about 10 years and full recovery may take over 25 years or never occur.
Low	Only partial recovery is likely within 10 years and full recovery is likely to take up to 25 years.
Moderate	Only partial recovery is likely within 5 years and full recovery is likely to take up to 10 years.
High	Full recovery will occur but will take many months (or more likely years) but should be complete within about five years.
Very high	Full recovery is likely within a few weeks or at most 6 months.
Immediate	Recovery immediate or within a few days.
Not relevant	For when intolerance is not relevant or cannot be assessed. Recoverability cannot have a value if there is no "intolerance" and is thus "Not relevant".
Insufficient information	

Table D3: Impact definitions – mechanisms, intolerance and recoverability

9



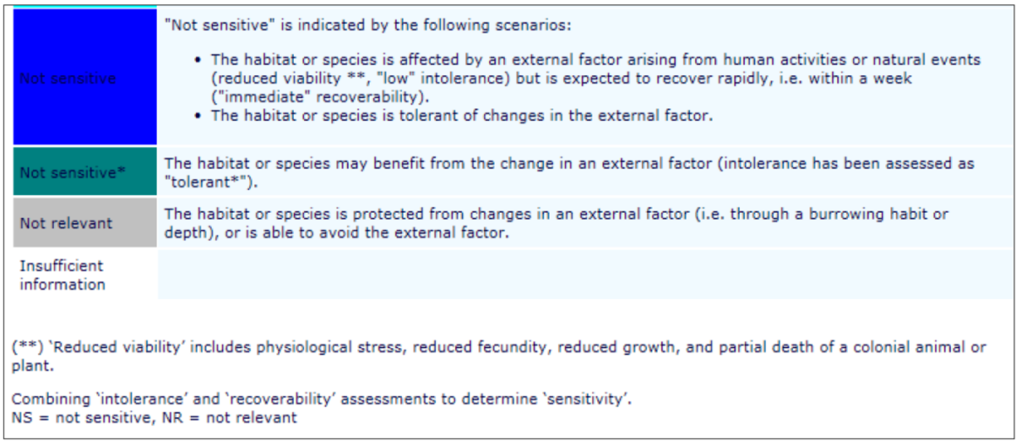
Habitat Sensitivity

Sensitivity is defined according to the following scenarios. These scenarios give rise to rationale used to combine intolerance and recoverability in order to determine sensitivity (see below). For further information refer to the summary rationale.

Rank	Definition
Very High	"Very high" sensitivity is indicated by the following scenario: • The habitat or species is very adversely affected by an external factor arising from human activities or natural events (either killed/destroyed, "high" intolerance) and is expected to recover only over a prolonged period of time, i.e. >25 years or not at all (recoverability is "very low" or "none"). • The habitat or species is adversely affected by an external factor arising from human activities or natural events (damaged, "intermediate" intolerance) but is not expected to recover at all (recoverability is "none").
High	"High" sensitivity is indicated by the following scenarios: • The habitat or species is very adversely affected by an external factor arising from human activities or natural events (killed/destroyed, "high" intolerance) and is expected to recover over a very long period of time, i.e. >10 or up to 25 years ("low" recoverability). • The habitat or species is adversely affected by an external factor arising from human activities or natural events (damaged, "intermediate" intolerance) and is expected to recover over a very long period of time, i.e. >10 years (recoverability is "low", or "very low"). • The habitat or species is affected by an external factor arising from human activities or natural events (reduced viability **, "low" intolerance) but is not expected to recover at all (recoverability is "none"), so that the habitat or species may be vulnerable to subsequent damage.
Moderate	"Moderate" sensitivity is indicated by the following scenarios: • The habitat or species is very adversely affected by an external factor arising from human activities or natural events (killed/destroyed, "high" intolerance) but is expected to take more than 1 year or up to 10 years to recover ("moderate" or "high" recoverability). • The habitat or species is adversely affected by an external factor arising from human activities or natural events (damaged, "intermediate" intolerance) and is expected to recover over a long period of time, i.e. >5 or up to 10 years ("moderate" recoverability). • The habitat or species is affected by an external factor arising from human activities or natural events (reduced viability **, "low" intolerance) but is expected to recover over a very long period of time, i.e. >10 years (recoverability is "low", "very low"), during which time the habitat or species may be vulnerable to subsequent damage.
Low	"Low" sensitivity is indicated by the following scenarios: • The habitat or species is very adversely affected by an external factor arising from human activities or natural events (killed/destroyed, "high" intolerance) but is expected to recover rapidly, i.e. within 1 year ("very high" recoverability). • The habitat or species is adversely affected by an external factor arising from human activities or natural events (damaged, "intermediate" intolerance) but is expected to recover in a short period of time, i.e. within 1 year or up to 5 years ("very high" or "high" recoverability). • The habitat or species is affected by an external factor arising from human activities or natural events (reduced viability **, "low" intolerance) but is expected to take more than 1 year or up to 10 years to recover ("moderate" or "high" recoverability).
Very low	"Very low" is indicated by the following scenarios: • The habitat or species is very adversely affected by an external factor arising from human activities or natural events (killed/destroyed, "high" intolerance) but is expected to recover rapidly i.e. within a week ("immediate" recoverability). • The habitat or species is adversely affected by an external factor arising from human activities or natural events (damaged, "intermediate" intolerance) but is expected to recover rapidly, i.e. within a week ("immediate" recoverability). • The habitat or species is affected by an external factor arising from human activities or natural events (reduced viability **, "low" intolerance) but is expected to recover within a year ("very high" recoverability).

Table D4: Impact definitions - Sensitivity

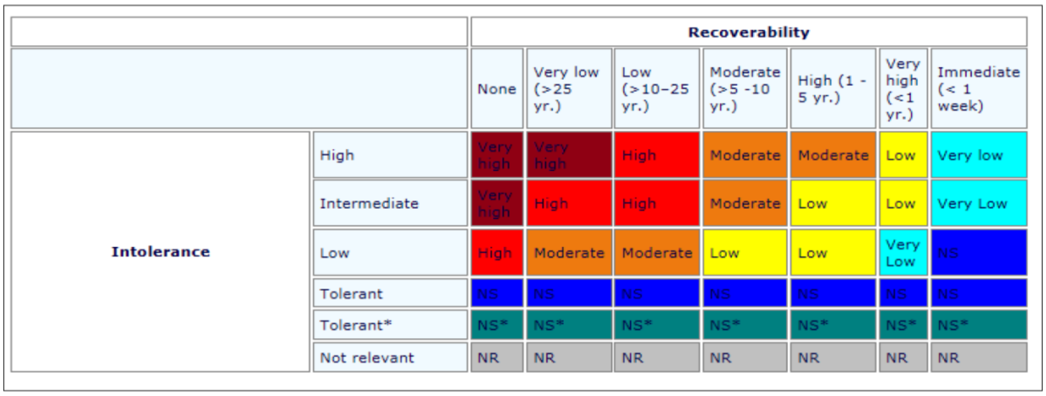
Impacts



Not sensitive	"Not sensitive" is indicated by the following scenarios: • The habitat or species is affected by an external factor arising from human activities or natural events (reduced viability **, "low" intolerance) but is expected to recover rapidly, i.e. within a week ("immediate" recoverability). • The habitat or species is tolerant of changes in the external factor.
Not sensitive*	The habitat or species may benefit from the change in an external factor (intolerance has been assessed as "tolerant*").
Not relevant	The habitat or species is protected from changes in an external factor (i.e. through a burrowing habit or depth), or is able to avoid the external factor.
Insufficient information	

(**) 'Reduced viability' includes physiological stress, reduced fecundity, reduced growth, and partial death of a colonial animal or plant.

Combining 'intolerance' and 'recoverability' assessments to determine 'sensitivity'.
NS = not sensitive, NR = not relevant

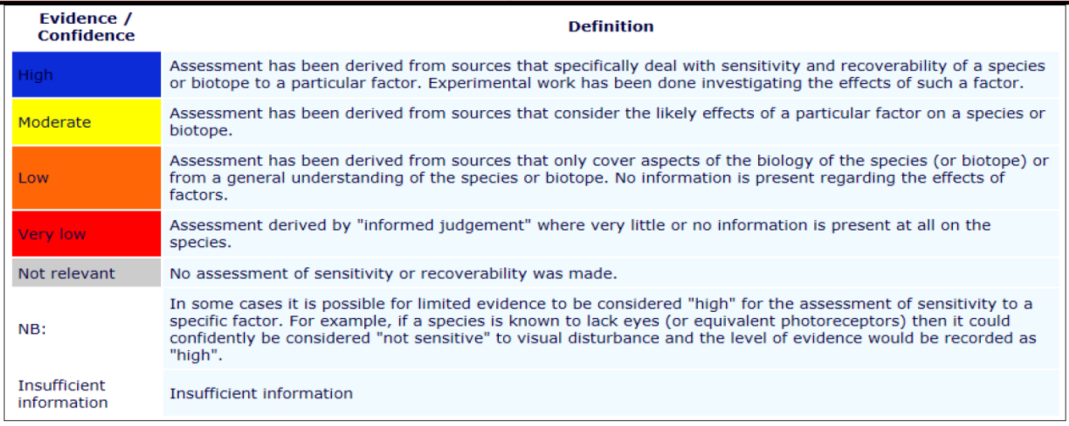


		Recoverability						
		None	Very low (>25 yr.)	Low (>10–25 yr.)	Moderate (>5 -10 yr.)	High (1 - 5 yr.)	Very high (<1 yr.)	Immediate (< 1 week)
Intolerance	High	Very high	Very high	High	Moderate	Moderate	Low	Very low
	Intermediate	Very high	High	High	Moderate	Low	Low	Very Low
	Low	High	Moderate	Moderate	Low	Low	Very Low	NS
	Tolerant	NS	NS	NS	NS	NS	NS	NS
	Tolerant*	NS*	NS*	NS*	NS*	NS*	NS*	NS*
	Not relevant	NR	NR	NR	NR	NR	NR	NR

Table D4 cont: Impact definitions – Sensitivity

Impacts

10



Evidence / Confidence	Definition
High	Assessment has been derived from sources that specifically deal with sensitivity and recoverability of a species or biotope to a particular factor. Experimental work has been done investigating the effects of such a factor.
Moderate	Assessment has been derived from sources that consider the likely effects of a particular factor on a species or biotope.
Low	Assessment has been derived from sources that only cover aspects of the biology of the species (or biotope) or from a general understanding of the species or biotope. No information is present regarding the effects of factors.
Very low	Assessment derived by "informed judgement" where very little or no information is present at all on the species.
Not relevant	No assessment of sensitivity or recoverability was made.
NB:	In some cases it is possible for limited evidence to be considered "high" for the assessment of sensitivity to a specific factor. For example, if a species is known to lack eyes (or equivalent photoreceptors) then it could confidently be considered "not sensitive" to visual disturbance and the level of evidence would be recorded as "high".
Insufficient information	Insufficient information

11 Residual Impact

Major	Change in a sensitive receptor leading to long-term damage and poor potential for recovery to a normal state
Moderate	Change in a sensitive receptor leading to damage but with a likelihood of recovery
Negligible	Change which is within the range of existing variability but can be monitored and/or noticed
None	No potential for significant interaction with receptor group or change markedly smaller than natural variability and immeasurable

Table D5: Impact definitions – evidence confidence and residual impact

APPENDIX E

THRESHOLD VALUES FOR LOPHELIA SP. – BASED ON EXPERIMENTAL DATA

Table E.1 Threshold values for consequences for deposition of discharges

Sediment load	Degree of impact	
0.1 - 1 mm	**No:**	**No detectable influence** (no effects identified for 2.4 mm).
1-3mm	**Minor:**	**Minor smothering of tissue** (42% of exposed coral fragments having 10% estimated smothered coensarc, potentially leading to coenocarc loss). Polyp mortality of 0.5 %. Good ability to shed sediments. No impact on growth rate compared to control (0 mm) and 19 mm.
3-10 mm*	**Moderate**	**Moderate smothering of tissue** (75% of exposed coral fragments having 10% estimated smothered coensarc, potentially leading to coenocarc loss). Polyp mortality of 3.7 %. Reduced ability to shed sediments. No impact on growth rate compared to control (0 mm) and 6.5 mm.
>10 mm **	**Considerable**	**Considerable smothering of tissue**

* Degree of impact is referring to sedimentation load of 6.5 mm in Larsson and Purser (2011).

** Degree of impact is referring to sedimentation load of 19 mm in Larsson and Purser (2011).

Table E.2 Suggested limit values due to effects of suspended barite/bentonite solids. (Please note that mg/l (thresholds) is equivalent to ppm (DREAM output.)

Suspended barite/bentonite particles	Degree of impact
0 – 0,5 mg/l	**No detectable effect:** Lowest effect level observed by Cranford et al., (1999)* confirmed by Bechmann et al., (2006)** (longterm exposure).
0,5 – 4 mg/l	**Minor effects:** Lowest effect value (4 mg/l) observed for growth on mussel larva by Bechmann et al., (2006)**. Threshold value of 1,8 and 0,8 mg/l is derived for barite and bentonite particle stress based on the Species Sensitivity Distribution (SSD)*** approach (longterm exposure).
4 – 40 mg/l**	**Moderate effects:** Lowest effect value (40 mg/l) observed for growth on mussels, scallops and cod, and mortality on scallops by Bechmann et al., (2006) (longterm exposure).
> 40 mg/l**	**Considerable effect:** Lowest effect value (40 mg/l) observed for growth on mussels, scallops and cod, and mortality on scallops by Bechmann et al., (2006) (longterm exposure).

*Cranford PJ, Gordon DC, Lee K, Armsworthy SL, 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). Mar. Environ. Res. 48:225-256.

Table E.3 Suggested threshold values for effects of suspended drill cutting solids. (Please note that mg/l (thresholds) is equivalent to ppm (DREAM output.)

Suspended cuttings particles	Degree of impact
0 – 5 mg/l*	**No detectable effect:** No detectable impacts on *Lophelia* polyp activity, respiration, skeleton growth and polyp mortality when exposed to 5 mg/l drill cuttings particles (< 63μm) in 12 weeks.
5 – 10 mg/l**	**Minor effects:** Threshold value of 10 mg/l is derived for particle stress based on the Species Sensitivity Distribution (SSD) approach (long term exposure).
10 – 25 mg/l *	**Moderate effects:** Reduced skeletal growth (33%) and polyp extension on *Lophelia* when continuously exposed to 25 mg/l drill cuttings particles (< 63μm) in 12 weeks. No effects of particle exposure on respiration or proportion of tissue and fatty acids were detected (longterm exposure).
>25 mg/l*	**Considerable effect:** Reduced skeletal growth (33%) and polyp extension on *Lophelia* when continuously exposed to 25 mg/l drill cuttings particles (< 63μm) in 12 weeks. No effects of particle exposure on respiration or proportion of tissue and fatty acids were detected (longterm exposure).

* Larsson A, D. Van Oevelen, A. Purser, L. Thomsen. (submitted). Tolerance to long-term exposure of suspended benthic sediments and drill cuttings in the cold-water coral *Lophelia pertusa*.

** Smit M.G.D. 2008. SSD parameters for the nontoxic stressors; temperature, suspended matter, oxygen depletion and nitrogen. Technical report Statoil ASA.

THIS PAGE HAS BEEN LEFT BLANK INTENTIONALLY