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Report from the Coral Workshop  
31<sup>st</sup> May-1<sup>st</sup> June 2010

## Cold-water coral ecosystems: Knowledge status, -gaps, research needs and strategy related to oil and gas operations

Report IRIS - 2011/054

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Project number: 7911860  
Project title: Coral Workshop  
Client(s): OLF  
Research program:  
ISBN: 978-82-490-0725-7  
Distribution restriction: Open

Stavanger, 31.03.2011

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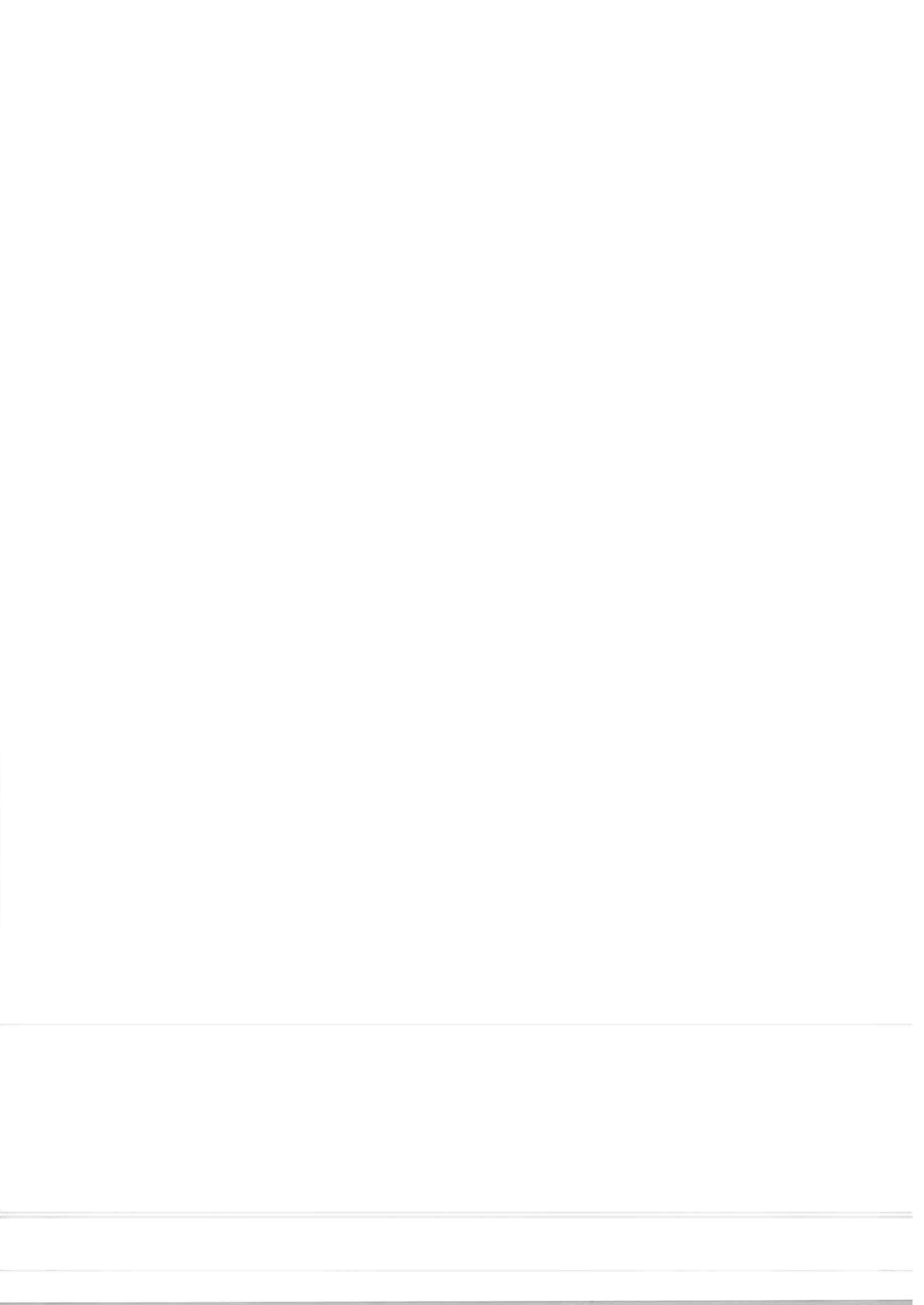
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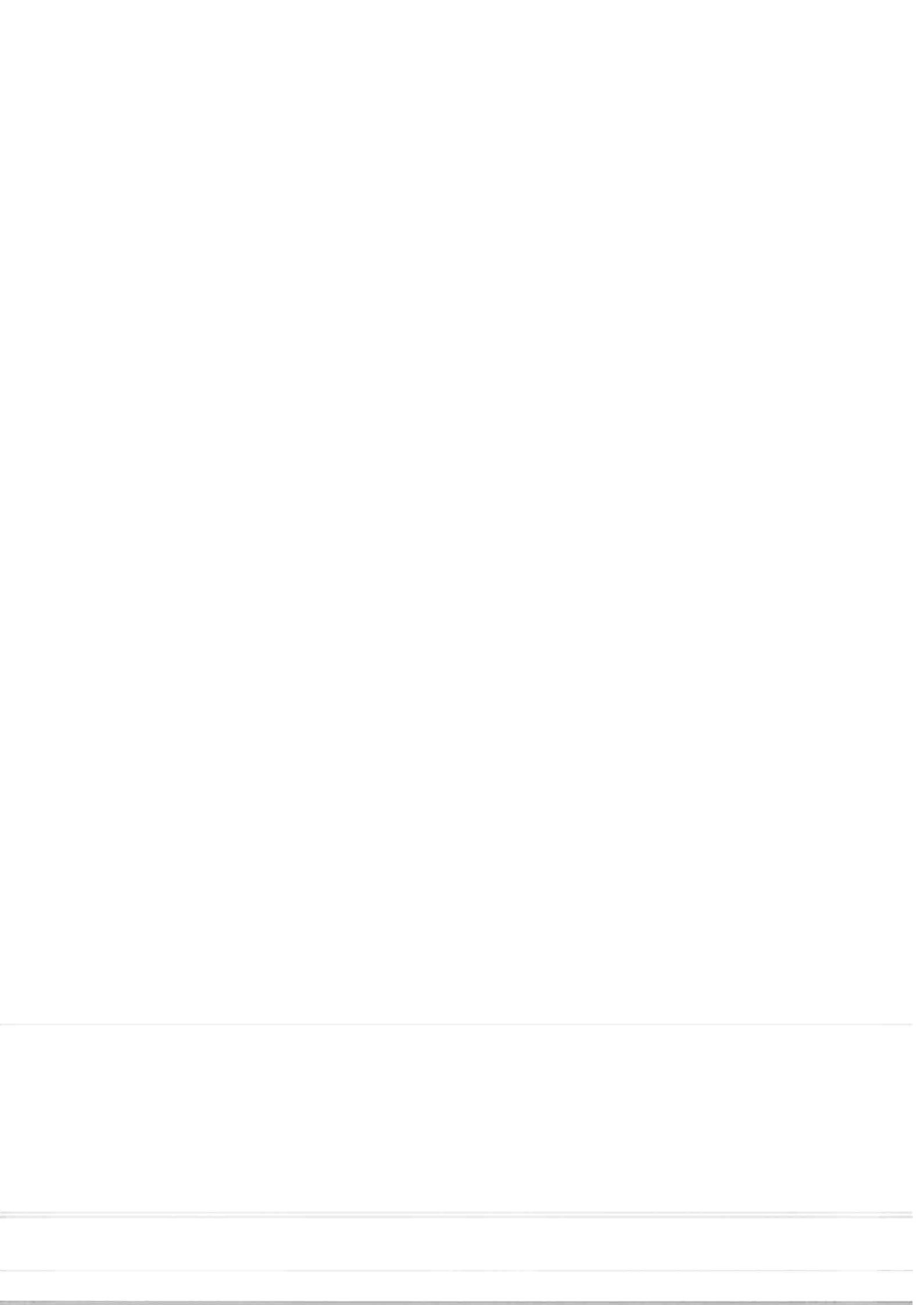
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Coral Workshop 31<sup>st</sup> May – 1<sup>st</sup> June 2010**

**“Cold – water coral ecosystems: knowledge status, gaps,  
research needs and strategy related to oil and gas  
operations. “**





**Thanks to contributors.**

We would like to thank the Norwegian Oil Industry Association (OLF) and the oil and gas companies for the opportunity to host this workshop and their financial support.

We are grateful for all invited participants who contributed with excellent presentations and constructive discussions.

Special thanks to Benedicte Jacobsen for her great efforts in planning and practical organization, and to Eivind Larssen, Anne Hjelle and Grethe Kjeilen-Eilertsen for their stand-by and contribution.

Stavanger 03. March 2011

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Thierry Baussant, Project Manager

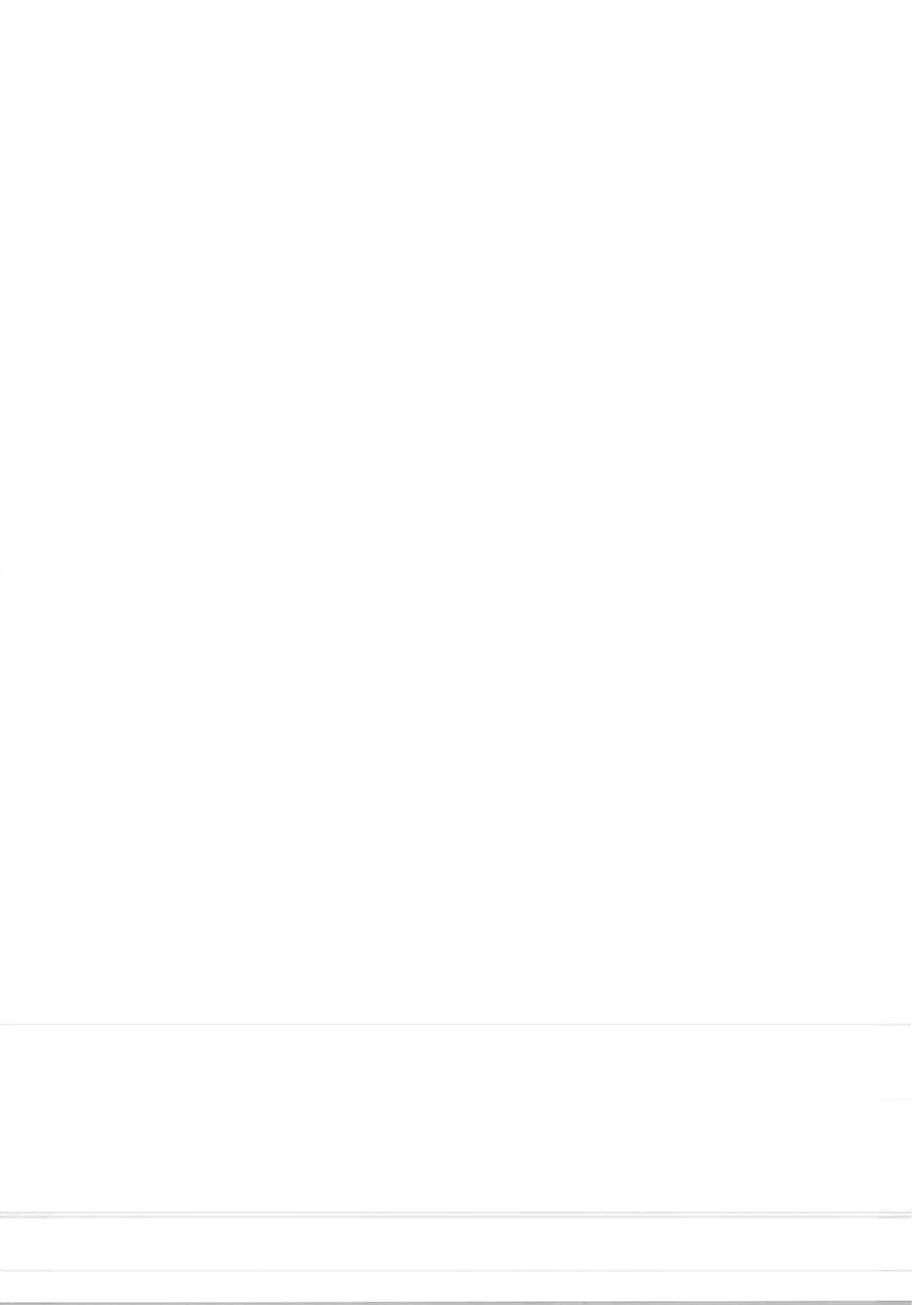
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## **Workshop overview**

Knowledge status and -gaps in coral biology and sensitivity to drilling operations of cold-water corals (CWC), as well as examples of mitigation actions taken by oil operators were presented at the “OLF coral workshop” held in Stavanger, Norway, 31<sup>st</sup> of May and 1<sup>st</sup> of June 2010. The workshop was organized by the Norwegian Oil Industry Association (OLF) and hosted by the International Research Institute of Stavanger (IRIS). Acona Wellpro has supported IRIS and OLF in the finalizing of this report from the workshop.

43 participants, representing the scientific community (researchers), the oil and gas (O&G) industry, governmental and non-governmental organizations, were present. Program, presentation and a min-review is available at the following website: <http://www.iris.no/coralworkshop2010>. The program and participants are presented in Appendix A. The mini-review covers some general aspects of CWC biology and ecology and the regular framework and legislation in relation to oil and gas activities and vulnerable ecosystems. Observed stress effects/responses in corals caused by these activities are reviewed.

This document summarizes the workshop by giving an overview of the recommendations and presentations in **Part I**, mainly with emphasis on coral sensitivity to drill cuttings (DC) and drilling mud (DM) exposure. **Part II** will contain knowledge on CWC obtained during the workshop and from published literature. Recommendations (**Chapter 1**) for future studies and common guidelines for the oil and gas operators to safeguard and manage these unique ecosystems are given.

### ***Summary of the workshop***

An overview of basic knowledge of CWC biology and ecology was provided by scientists Day 1 of the workshop. Generally, research indicates that CWCs are tolerant to environmental stress even in some extreme cases. More particularly, CWCs exposed to high discharge loads of DC/DM for short periods of time have high survival rates, although there appears to be a tipping point above which corals will not recover. The occurrence of live CWC colonies on oil installations may argue against detrimental effects caused by drilling activity and instead give favourable physical conditions to the

settlement of colonies, but may also reflect no / short-time exposure to DC/DM. Both live and dead corals favor habitats with high biodiversity and the highest diversity is encountered in reefs with a mixture of live and dead corals. Areas which need deeper insight are reproduction, including larval development/settlement, and possible long term effects caused by drilling activity. These are key measures to assess CWC vulnerability, and are important considerations in future CWC management. Additional mitigating actions taken by operators may be to restrict drilling activity during sensitive periods of reproduction and larval development.

On workshop Day 2, the regulative authorities presented their requirements and O&G operators exemplified their mitigating actions before and during drilling activity in CWC areas. O&G operators make great efforts to avoid (potential) impact of their activities, and their practices are in accordance with the requirements put forward by The Norwegian Climate and Pollution Agency (Klif). However, there is a need for a standardization and harmonization of the practices. A standard procedure proposed by Det Norske Veritas (DNV), on behalf of OLF, is under development. In the final discussion, the workshop participants raised the question whether today's monitoring practices are sufficient to reveal possible effects from drilling operations on corals, or if the current methods should be supplemented with other monitoring parameters. A scientific paper from the workshop, reflecting the content of the present report, from the workshop is planned for publication.

### *Abbreviations*

CWC – Cold water corals, mainly reef building corals like *Lophelia pertusa*.

CTS – Cuttings Transport System

Klif – Norwegian Climate and Pollution Agency

RMR – Riserless mud recovery, allows for cuttings and mud to be returned to rig.

OLF – Norwegian Oil Industry Association

O&G – Oil and Gas

DREAM - The Dose-related Risk and Effects Assessment model developed by Sintef

DC - Drill Cuttings

DM – Drilling Mud

OBM – Oil Based Mud

WBM – Water Based Mud

MRDB – Marine resource Database

MOD – Marine monitoring database

BAT – Best Available Techniques

EBM – Ecosystem based management

BOP – blow out preventer





**Part I:** Presentations and recommendations from the workshop

# 1 Workshop recommendations and key points

In the following, the workshops advices and recommendations are presented. The recommendations below are based on consensus by the OLF working group on corals, and the recommendations are not presented in prioritized order.

1) In general, the ultimate goal is to minimize or avoid discharge of DC/DM to cause harmful impact on coral habitats in the vicinity of the drilling operation. A necessary distance from the release of the discharge will depends on (i) the exposure of harmful discharge and (ii) the vulnerability of CWC. For appropriate management of CWC the following recommendations are given:

a. *Development of threshold levels.* Concerning exposure of harmful discharges; type, volume, duration and repeatability are of importance when possible biological effects are assessed. Research indicates that CWCs generally are organisms that tolerate relatively high discharge loads of DC/DM for short periods of time. However, there appears to be tipping points above which corals will not recover, and these points are important to define and to investigate further. The focus should be to define and develop threshold values for turbidity and sedimentation to guide both the authorities and O&G industry.

b. *Validation of particle distribution models.* Models provide a helpful supplement to the site surveys in deciding the placements of structures and disposal sites. The most advanced models predict and simulate the concentrations of DM particles (and chemicals and metals) in the free water-masses and deposition of DC (and chemicals and metals) on the seafloor. Further validation studies (based on recently monitoring studies results) of the prediction in depositions to models will increase the robustness of the models and a tool for assessment of mitigation measures.

2) *Collect and review information.* Comprehensive studies, monitoring programs and mitigation methods were presented by the operators. The results should be systematic collected and made available for the authorities, institutes, industry and the public.

a. Information regarding corals and their environment should be coordinated and made available to existing programs e.g. MAREANO, MOD-database, MRDB, Arctic web and electronic fishery charts.

b. Experiences regarding mitigation measures and technology. It is recommended to continuously collect and review information regarding best available technology (BAT) based on experiences from O&G activities. Currently several mitigation measures has been used or evaluated in drilling operations in CWC areas:

- Reducing or avoid the discharges to the recipient (well design, RMR, re-injection, slurring, recycling etc.).
- Controlling the release point in relation to the CWC (rig position, cutting transport system, CTS).
- Dilution of the discharge (water column versus sea bottom).
- Anchor handling (anchor analysis, lifting-equipments and procedures).

3) *Development of harmonized guidelines.* Legal requirements have been given on monitoring and investigations for drilling activities in CWC areas in Norway. The requirement includes normally specified conditions before, during and after drilling. It is therefore identified a need for harmonized guidelines for the relevant activities for drilling operations based on state-of the art knowledge, experiences, monitoring practices. Developing guidelines for site surveys and monitoring program for drilling activities is in progress by OLF and DNV.

A monitoring guideline should address the following main questions:

- a. When should monitoring of CWC be performed?
- b. The scope of the monitoring and how extensive program?
- c. Which parameters are applicable for measuring the effects?
- d. Design of the monitoring program (e.g. distance, location of stations, use of predicted modeling results)?
- e. How to assess the results gathered from the monitoring?

4) *Filling knowledge gaps.* The basic knowledge on CWCs is increasing, particularly on *Lophelia pertusa*. The workshop identified several knowledge gaps for further research and investigation, and briefly presented below:

- a. *Basic ecology and biology.* Knowledge on reproduction cycle, larval development, settlement, distribution is limited and therefore should be further investigated. Research institutes and scientists are further requested to continue in collaborate and share experiences on cultivating CWC, field investigations, measure biological responses and other relevant information.
- b. *Effects.* Knowledge of possible effects, in particular for long-term effects, on corals caused by drilling activity is limited. More research should be performed e.g including other potential indicators than visual mapping for more in depth monitoring of coral health.

- c. *Reproduction.* Studies indicate that reproduction and larvae development along the Norwegian coast takes place during December to April. Further research is needed on reproduction, larvae distribution and possible effects caused by O&G activities during this critical period.
- d. *Other relevant investigations.*
- CWC communities found on O&G installations in areas without natural occurrence should be further investigated. CWC on installations indicates the robustness towards O&G activities. It is recommended to evaluate the exposure regime for these CWC communities, and whether other aspects than growth may have been affected.
  - Monitoring of CWCs could be assessed to be included in the current regional monitoring programs O&G fields on the Norwegian Continental Shelf.
  - The use of biological indicators as supplementary parameters to monitoring and mapping of CWC should be considered for further research.
  - The use of ecosystem indicators as a tool for impact assessment when implementing ecosystem based management (EBM) of maritime areas is considered as a possible approach. Further research is needed in this area.
  - It should be further considered if knowledge from studies and experiences on tropical corals can be transferred to CWC.

## 2 Abstracts from workshop presentations

Prior to the workshop, a status of available knowledge on CWC, mainly *Lophelia pertusa*, was provided (Nilsen et al., 2010). The mini-review included selected aspects of CWC biology and ecology, focusing on stress responses to sedimentation. An introduction to legal requirements and mitigating actions of O&G activities in CWC areas in Norway was also provided. The mini-review and the presentations are available at <http://www.iris.no/coralworkshop2010>.

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## 2.1 Abstracts Day 1

### **Ecophysiology and Ecology of *Lophelia pertusa* in the Northeast Atlantic**

Laura Wicks & J. Murray Roberts

Heriot Watt University, Edinburgh, United Kingdom

Cold-water corals (CWC) are widespread in all oceans of the world, with *Lophelia pertusa* the most common species. They form important structural habitats in the form of large reefs and carbonate mounds; to date more than 2000 species have been found associated with CWC (Roberts et al., 2006), including commercially important fish species. Studies of the growth rates of the carbonate skeletons of CWC have found a wide range of values. Initial estimates of the linear growth of coral came from man-made structures, firstly from trans-Atlantic cables (Duncan, 1877) (8mm/yr) and then from North Sea oil platforms (Gass and Roberts, 2006) (26-34 mm/yr). Recently isotopic dating studies have also been conducted to assess growth rates, with values ranging from 3-5 mm/yr with uranium-thorium isotopes (Thresher et al., 2004). However, to date there is still very little data on CWC growth rates in nature or experimental systems. Additionally, little is known of the environmental conditions which CWC experience, due to the expense and difficulty associated with collecting such data. In this presentation we focused on the Mingulay Reef Complex, which lies off the west coast of Scotland. Dense colonies of *L. pertusa* dominate this site, with recent studies examining their physiology and ecology both in the field and in an aquarium. CWC at the site experience what has been termed a hydraulic jump (Davies et al., 2009), where downwelling of warm nutrient rich water occurs once every tidal cycle, bringing an abundant food supply. The respiratory physiology of *L. pertusa* from Mingulay was recently examined in an aquarium environment. *L. pertusa* was found to be an oxyregulator, surviving periods of extreme hypoxia. Additionally, although *L. pertusa* has been found at a range of temperatures (4-12°C), experiments found that it is sensitive to temperature, with a 5°C temperature increase causing a three-fold increase in energy demand (Fig. 1) (Dodds et al., 2007).

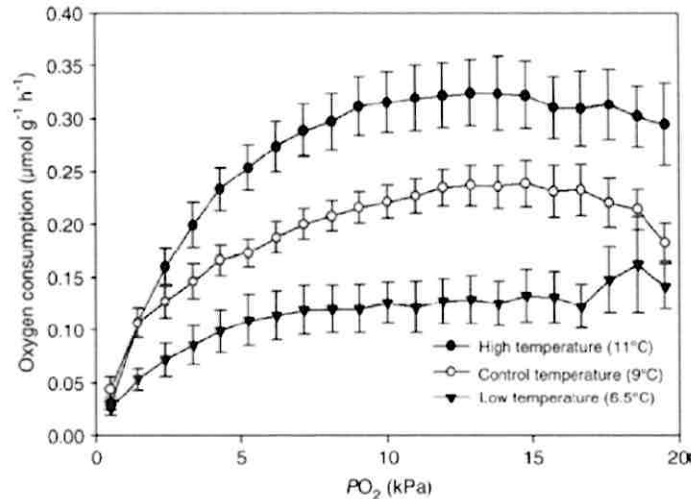


Figure 1. The relationship between the mean rate of oxygen consumption of *Lophelia pertusa* and oxygen partial pressure ( $pO_2$ ) at three different temperatures. Data normalised to live coral buoyant weight (Dodds et al., 2007).

As it is projected that temperature will increase by 1-3°C by the end of the century (IPCC, 2007), these findings have implications for the survival of CWC. The question arises; will food supply be enough to meet this increase energy demand associated with increased temperature? As little is known of CWC diet and energy requirements it is hard to speculate. In addition to global warming, the IPCC predict that CO<sub>2</sub> in the atmosphere will increase from present day values of 380 ppm up to 750-1000 ppm by the end of the century (IPCC, 2007). This equates to an oceanic pH reduction of 0.4 units, or 30 % increase in hydrogen ions (Caldeira and Wickett, 2003), and is termed ‘ocean acidification’. Ocean acidification will affect the availability of compounds that form the skeletal structures of many marine organisms via calcification, including CWC. The slow skeletal growth and sensitivity of deep-sea reefs makes them particular vulnerable to environmental perturbation, but without any understanding of how these species may respond to changing environmental conditions, we are entering a period of uncertainty just as our baseline knowledge of cold-water corals is starting to develop. It has also been suggested that the CO<sub>2</sub> related changes in seawater chemistry could change the depth below which coral skeletons dissolve (the aragonite saturation horizon; ASH) to become shallower by several hundred meters (Orr et al., 2005). Many cold-water coral habitats are found at high latitudes and deeper depths, which exhibit lower saturation state of calcium carbonate (Guinotte et al., 2006). However, it is anticipated that more than 70 % of the cold-water coral biotherms known today will be



exposed to waters undersaturated with respect to aragonite by the end of the century (Guinotte et al., 2006). Therefore, not only might calcification of cold-water corals be hampered but the crucial balance between processes that promote reef framework growth and processes that degrade the structure (bioerosion and dissolution) may be altered.

Much remains to be learnt of CWC physiology and ecology. Some key questions include:

1. What is the chemical and biological variability of their natural habitat?
2. What are the physiological responses of CWC to ocean acidification, temperature rise and the combination of both phenomena?
3. How can we examine this in aquaria, to reflect the natural environment?

#### **Aspects on cold-water coral biology and calcification. Lessons learned from perturbation and on board experiments.**

Cornelia Maier

Laboratoire d'Océanographie de Villefranche sur Mer, Villefranche sur Mer, France

Feeding experiments with *Lophelia pertusa* and *Madrepora oculata* in natural seawater, virus and bacteria free seawater, virus concentrate and bacteria concentrate showed no indication of uptake of bacteria and viruses by corals. However, growth of bacteria and viruses were stimulated in the presence of corals and/or zooplankton. It is hypothesized that this growth is stimulated by deteriorating tissue and/or organic nutrients release, and hence the potential uptake of bacteria by corals may be masked by simultaneous stimulation of growth. To validate this, experiments with fluorescently labeled bacteria showed stimulated bacterial growth in the presence of CWC and revealed a concentration-dependent uptake of bacteria by *L. pertusa*. Experiments with radioisotope labeled *L. pertusa* showed increased chemo- and heterotrophic activity in the corals.

Growth of *L. pertusa* is fastest in young polyps, but there is also high variability in growth within polyp age, which may indicate a sporadic growth pattern. With respect to ocean acidification it is interesting to observe reduced growth with lower pH for short term responses in Skagerrak corals, whereas longer-term exposures of Mediterranean



corals show no effect of higher CO<sub>2</sub> concentrations. The results also indicate that *L. pertusa* can continue calcification at  $\Omega_{\text{arag}} < 1$ .

### **Results from *Lophelia pertusa* experiments performed by Sandra Brooke et al.**

Sandra Brooke<sup>1</sup>, Craig M. Young<sup>1</sup>, M.W.Holmes<sup>2</sup>

<sup>1</sup>Marine Conservation Biology Institute, Bellevue, United States.

<sup>2</sup>Oregon Institute of Marine Biology, Oregon, United States

Presented by Thierry Baussant, IRIS Biomiljø, Stavanger, Norway

*In situ measurement of survival and growth of Lophelia pertusa in the northern Gulf of Mexico* (Brooke and Young, 2009)

This study represents the first direct measurement of in situ growth of *L. pertusa*. Stained branches were transplanted and recovered after one year. The polyp survival was >90 % for all transplant units, the average annual linear growth rate were in the lower range of published rates; ~3.8 and 2.4 mm. The stain bands on the corals illustrated double growth centers, which introduces an additional level of complexity when assessing growth through lateral banding patterns.

*Sediment tolerance of two different morphotypes of the deep-sea coral Lophelia pertusa from the Gulf of Mexico* (Brooke et al., 2009)

In the Gulf of Mexico there are two structural morphotypes of *L. pertusa*, the very heavy calcified “brachycephala” and the more fragile “gracilis”. These morphotypes were exposed to a range of suspended sediment concentrations for 14 days, and although they tolerate relatively heavy concentrations, mortality increased rapidly with higher sediment loads. Also, when buried in sediments for 1-4 days, the corals tolerated relatively heavy sediment conditions, but mortality increased with longer burial. Relatively small differences were observed between the morphotypes in both experiments.

## Cold-water corals in Norway –an overview

Pål Buhl-Mortensen

Institute of Marine Research, IMR, Bergen, Norway

Cold-water Anthozoa includes soft-, black-, stone- and horny corals. Of the >700 species found worldwide, 26 are recorded in Norway. CWCs are mainly distributed between 100 and 2000 m depth. In Norway the deepest known coral reef is recorded at around 500 m depth. The unique CWC reefs off Norway are primarily built from the stone coral *Lophelia pertusa* (L.). *L. pertusa* colonies may reach 2 m in height, and reefs 35 m in height and 1 km in length. More than 3000 reefs are recorded along the Norwegian coast, with reef complexes up to 45 km. CWCs are normally located at hard bottoms with oceanic water (6-10°C and >35 PSU) and strong tidal driven currents (0.25-0.50 cm/s) and are mostly found in fjords, at edges and ridges on the continental shelves and at seamounts. Although CWCs have been known to fishermen from by-catch in trawls, new technologies brought on by the offshore petroleum activities, such as ROVs, multibeam and side scan sonars, have revealed a high number of CWC habitats formerly unknown to science. In today's monitoring, towed video cameras, video-grabs and still photos are additional valuable methods.

Knowledge of basic CWC biology is limited. Most knowledge exists on *L. pertusa*, whereas the biology of other habitat forming corals (gorgonians) is largely unknown. Colonies of *L. pertusa* have separate sexes, and fertile colonies most commonly occur during late autumn/winter. Larvae have only been observed under laboratory conditions, and the occurrences of colonies on platform legs in areas with no "natural" colonies suggest that they are long-lived. *L. pertusa* feed on copepods, krill, fish and detritus. Reported skeletal growth of *L. pertusa* is between 0.72 and 2.6 cm/yr, and for other CWCs growth rates are between 0.06-4.0 cm/yr.

CWCs support unique ecosystems with a high biodiversity of associated fauna. In *L. pertusa* there are microhabitats in soft tissues and mucus at the surface of living corals, in the soil/detritus at the surface of dead corals, in cavities within dead coral skeletons and in the free space between coral branches. *Lophelia* reefs are an important habitat for many species. Distinct communities are found in different zones of the reefs; in live colonies, dead colonies or in (*Lophelia*) rubble, where the mixture zones of live and

dead corals are most diverse. Over 800 associated species, many of which are rare in other habitats, have been recorded on *Lophelia* reefs. Comparing inshore and offshore reefs, the former are more diverse. The four most common phyla of associated fauna are Mollusca, Crustacea, Bryozoa and Polychaeta.

CWCs face a number of threats, including physical disturbance (and sedimentation) from fisheries, physical disturbance, sedimentation and potential pollution from petroleum activity, eutrophication, sedimentation, pollution/poison from sewage and other outlets, possible changes in temperature, current patterns and pH resulting from atmospheric emissions. So far, it is expected that 30-50 % of the reefs present along the Norwegian coast have been impacted by trawling. Some of these have been completely crushed, with no signs of live colonies. Six reefs, or reef areas are so far included in marine protection areas, and bottom trawling is prohibited in all known coral reef areas. To manage the CWCs better more knowledge is needed on their distribution, what the area is used for, how sensitive the corals are to different exposures, the possibility to restore damaged coral habitats and how local communities appreciate CWCs.

### **The microbiology of *Lophelia pertusa* – Summary**

Sven Christopher Neulinger

Leibniz Institute of Marine Sciences IFM-GEOMAR, Kiel, Germany

#### *Specificity*

Several molecular-biological studies demonstrated that most *L. pertusa*-associated bacteria are not present in the surrounding environments (i.e., seawater, sediments, and dead corals), that the bacterial composition differs between coral fractions (e.g. coral mucus and skeleton), and that this composition alters considerably once the coral is transferred from its natural habitat into an artificial environment (aquarium). Moreover the composition of *L. pertusa*'s bacterial community differs significantly from that of other cold-water corals. The bacterial community of this coral can thus be called 'specific'. Since on the other hand several bacterial groups found on *L. pertusa* also live on other corals, these groups can be considered typical for cold-water corals in general.

### *Variability*

The bacterial composition of *L. pertusa* varies significantly with sampling location (even within the same geographic region) and with coral color. Possible control mechanisms for this variability are environmental factors as well as growth-mediating substances produced by the coral.

### *Dominant bacterial groups*

The most dominant bacterial ribotypes in *L. pertusa*-derived clone libraries belong to the *Roseobacter* clade, to Gammaproteobacteria, and to representatives of the genus *Mycoplasma*. Members of the *Roseobacter* clade might contribute to the nutrition of *L. pertusa* by degradation of dimethylsulfoniopropionate (DMSP). The Gammaproteobacteria found on *L. pertusa* are related to sulfur-oxidizing symbionts of mussels from deep-sea vent and seep systems and might use organic sulfides (e.g., DMSP or derivatives) as an energy source. A new mycoplasma species, “*Candidatus Mycoplasma corallicola*” lives firmly attached to the nematocyst batteries of the coral. Closely related mycoplasma phylotypes were found on *L. pertusa* in the Gulf of Mexico, which supports the picture of an exclusive association between these bacteria and the coral. The mycoplasmas are probably commensals that benefit from haemolymph leaking by “sloppy feeding” of *L. pertusa* during prey capture.

### *Caveats and prospects*

There are currently only a few microbiological studies on *L. pertusa*, and their comparability is restricted by differing sampling and analysis methodologies. The ecology of *L. pertusa*-associated bacteria has so far only been inferred from comparison with closest relatives through ribosomal sequence data. Future research in this field would therefore profit from better geographic coverage and a concerted action on microbiological sampling, from cultivation experiments and functional genomics, and from the identification of secondary metabolites controlling host-microbe interactions.

## **Microbial Ecology of *Lophelia pertusa* and the Potential for Using Coral-Associated Bacteria as a Diagnostic of Coral Stress**

Christina Kellogg

U.S. Geological Survey, St. Petersburg, United states

Recent research has determined that like shallow-water corals, *Lophelia pertusa* maintains conserved bacterial symbionts in spite of its global distribution (Kellogg et al., 2009). Prior work already demonstrated that *Lophelia*-associated microbial communities are distinct from those of the surrounding seawater and sediments (Neulinger et al., 2008; Yakimov et al., 2006). Coral-associated microbial communities in shallow-water species have been shown to shift in response to coral stress, such as bleaching or disease (Bourne et al., 2008; Pantos et al., 2003) and there is evidence that long-term heat stress resulted in a similar shift in the bacterial associates of *Lophelia* in the Gulf of Mexico (Kellogg et al., 2009). Based on this background, we anticipate using microbial community shifts as a diagnostic tool to detect impacts of DM on *L. pertusa*.

## ***Lophelia pertusa* on oil and gas structures in the British North Sea**

Susan Gass

Dalhousie University, Halifax, Canada

This presentation covered results from a study which examined the occurrence of *Lophelia pertusa* on northern North Sea oil infrastructure and its environmental sensitivity to oil and gas activities (Figure 1). Underwater videos from industry platform surveys were examined to identify *L. pertusa*, detail its occurrence at two sites (Heather and North Alwyn A (NAA)), the reproductive status of colonies on the platforms, and to look for evidence of exposure to DM and DC (discharges). In addition, laboratory experiments were carried out on live corals. Corals in the lab were exposed to 4-h sedimentation events of increasing rates and to single doses of 30, 60 and 120 mg/cm<sup>2</sup> to examine clearing rates and mechanisms used for sediment removal.

The results showed a newly established sub-population of *L. pertusa* in the northern North Sea. *L. pertusa* was identified on 14 platforms and 947 colonies were recorded on Heather and NAA between 59 to 132 m depth coinciding with the presence of year round Atlantic water. Original larvae recruits were likely from the northeast Atlantic

and are now annually self-recruiting to the platforms. Additional video from Tern in 1993, 1994, 1998, and 2002 provided the first *in situ* colony growth rate ( $26 \pm 5$  mm yr<sup>-1</sup>) for *L. pertusa*. Visual evidence of contamination from drilling discharges was limited to colonies close to drilling discharge points where partial and complete colonies were dead.

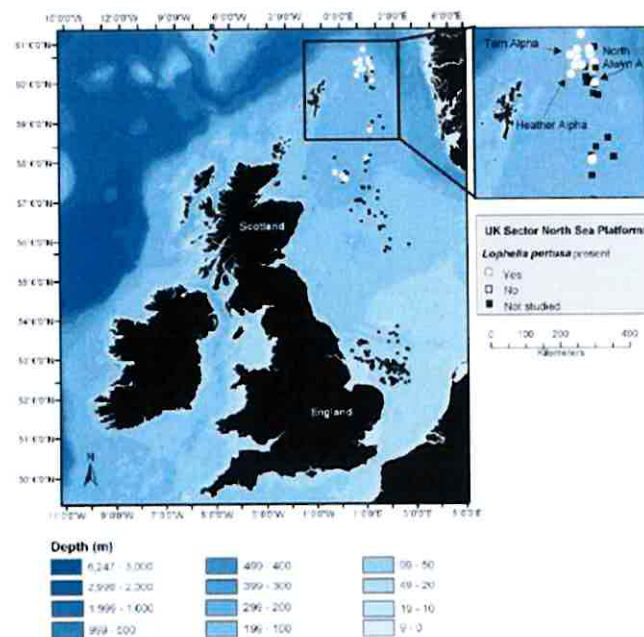


Figure 1. Oil and gas platforms in the UK sector of the North Sea. Those with confirmed presence of *L. pertusa* are in the northern North Sea.

Colonies sampled from platforms were examined for their reproductive status. 8 colonies were sampled in Spring/Summer season (2003 and 2004) and none were found to be reproductive. 8 colonies were sampled in December 2003 and two were found to be reproductive: one female and one male. The egg size of the female colony showed a similar reproductive cycle to other colonies of *L. pertusa* sampled from Porcupine Seabight in a previous study (Waller and Tyler, 2005). Reproduction is usually synchronous between colonies and thus further study with a larger sample size is required to investigate whether proximity to drilling discharges is related to the presence of non-reproductive colonies.

The results from the laboratory experiments showed that polyp behavior was negatively affected only at the highest sedimentation rates ( $12\text{-}19$  mg cm<sup>-2</sup> min<sup>-1</sup> and a single dose of 120 mg/cm<sup>2</sup>), which are likely to be significantly higher than *in situ* rates. Polyps



cleared sediment with ciliary currents and ingestion, which may be an indiscriminate feeding response.

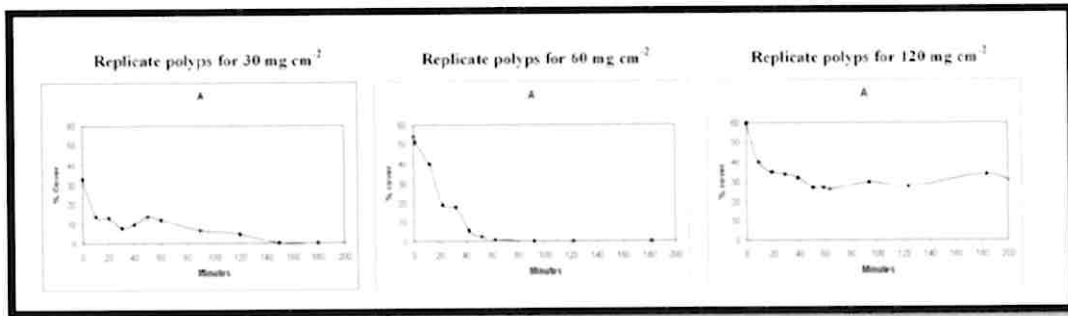


Figure 2. Example of results of coral clearing rates from a single dose of sediment.

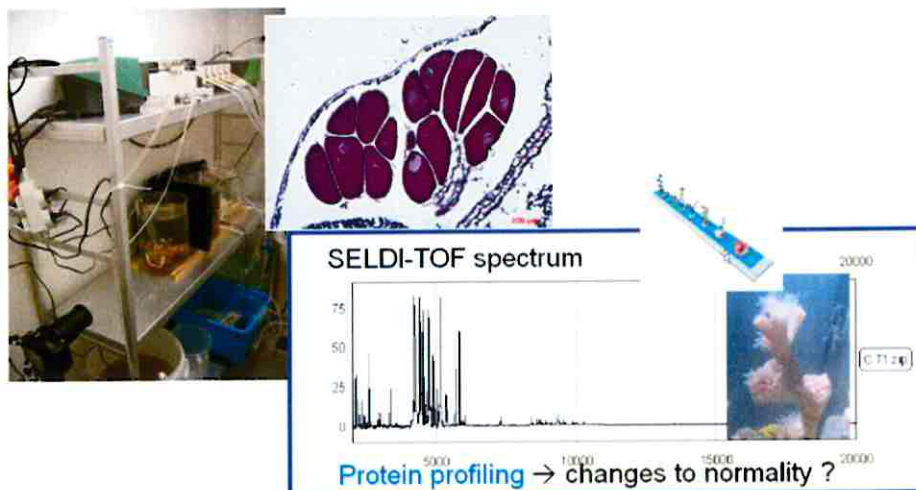
### Effects of drilling mud on the cold-water coral *Lophelia pertusa*

T. Baussant, C. Boccadoro, B. Godal, K. Kaster, E. Larssen, E. Lyng, A. Osland, F. Provan, M. Sydnes, S. Westerlund, K.B. Øysæd

International Research Institute of Stavanger (IRIS)

Today, there exists a gap in scientific knowledge and good documentation of impact supporting the risk-based management actions for drilling operations. Through funding by the Research Council of Norway (NRF project # 184699) and additional support from Total E&P Norge as, IRIS is developing several methodologies and diagnostic tools aiming at evaluating the health of the coral *Lophelia pertusa* and assessing their use in relation to operational discharges of DM. The methodologies implemented are based both on traditional measurements and innovative techniques bearing potential for field monitoring. Both need adaptation to corals. Polyp behavior is assessed by time-lapse camera picture analyses based on the scoring of the total coral area change reflecting the activity of each individual polyp. This parameter appears extremely relevant as particles in the discharges may disrupt the natural polyp activity and displace the energy flow. Preliminary DM exposure showed that polyp behavior was enhanced when ca. 8 mg/l DM was present. Assessments using histology allow to measure internal cell damages or disruption in physiological processes. One parameter we focused on is related to the change in number and size of mucocytes producing mucus. Image analysis is used to infer changes. So far, our results didn't indicate significant

change with DM. Coral pigmentation based on a method by NTNU (Trondheim) was tested but didn't provide clear evidence of DM effect. State-of-the-art techniques based on a combination of SELDI-TOF mass spectrometry (MS) and nano LC-orbitrap are evaluated to identify protein changes in whole polyp and in coral mucus. These methods bear great potential for understanding better how DM can impair corals through alteration of protein expression as well as developing specific tools for field monitoring. The results of this research with DM-exposed corals are currently under evaluation. Further, new investigations are related to the development of gene expression assay based on homology from other (tropical) corals and existing information for *L. pertusa*. Q-PCR of selected coral transcripts (catalase, superoxide dismutase, cytochrome P450 74A, Heat Shock Protein 70 and 90) are now implemented and will be tested on corals exposed to DM. New aspects related to coral-associated microbial fauna are also under study with the arising question "Can changes in the microbial community of coral mucus be connected to DM and be used as a diagnostic tool?" A combination of DGGE separation of PCR-generated DNA products and sequencing and identification of specific bands is used. The results of this research are under evaluation. The corals *L. pertusa* used in this study have been collected in Trondheimsfjord (NINA, Johanna Järnegren) and in Lophhavet, off Finnmark (IMR, Pål Buhl-Mortensen and R/V SARS).





## Experiments on *Lophelia pertusa* with emphasis on drill cutting exposure

Ann Larsson<sup>1</sup>, Autun Purser<sup>2</sup>, Dick van Oevelen<sup>3</sup>, Laurenz Thomsen<sup>2</sup>, Tomas Lundälv<sup>4</sup>

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<sup>4</sup>The Lovén Center Tjärnö, Sweden

Results from several experiments were presented. The experiments aimed at increasing the knowledge of basic physiology in *Lophelia pertusa* and assess the effects of exposure to natural benthic sediments and DC.

### *Long-term experiments of growth and respiration depending on zooplankton food density*

In a first experiment, corals were starved for 6 months resulting in a 40 % decrease in respiration rate but no visible effects on coral condition or survival. The decrease in respiration tended to be faster in sterile-filtered water than in sand-filtered water indicating possible uptake of detritus and smaller plankton from the sand-filtered water. In a second experiment, corals were fed during 15 weeks with nauplii of the brine shrimp *Artemia salina* at four densities with organic carbon provided corresponding to between 20 % and 300 % of the carbon turned over by initial respiration. The respiration was found to increase with high zooplankton food density but no effect on skeletal growth could be detected. Skeletal growth was maintained at a positive rate also under poor feeding with *A. salina*.

### *Coral cleaning efficiency from natural sediments and DC*

The rejection efficiency of deposited natural sediment particles and DC was evaluated in a series of laboratory experiments. Results show that tissue-covered coral surfaces were efficiently cleaned also after repeated exposure to settling particles (33 mg DW cm<sup>-2</sup> 23 times during 45 days) and that starved corals rejected sediments as efficiently as fed corals. In a second study with repeated exposure using fine-fraction DC (< 63 µm) focusing on burial of coral tissue, the coral surface area covered by sediments increased with time. DC was added in portions during 3 weeks to reach total sediment cover

thicknesses of 6.5 mm and 19 mm, respectively. DC accumulated mainly in areas where the coral skeleton initially lacked tissue (Fig. 1) resulting in smothering of adjacent tissue and polyps. The number of coral fragments with smothered tissue and the polyp mortality increased with sediment load. Conclusions are that the mechanisms used to remove deposited particles, i.e. mucus shedding and eventual ciliary action, are efficient and not easily exhausted. *L. pertusa* showed no difference in the ability to reject natural sediments and DC with similar grain size and proportion organic carbon. Burial at levels comparable to the threshold level currently used in the environmental risk assessment model for drilling discharges in Norway (max. 6.3 mm) may under certain circumstances result in damage to *L. pertusa*.



Figure 1.

#### *Effects of suspended sediments on larval survival and coral growth and respiration*

Fragments of living coral were exposed to natural sediments and DC at 5 mg/l and 25 mg/l for a period of 12 weeks. No effect on respiration as a response to stress from sediment exposure could be found. Rates of skeletal growth did not significantly differ between the control treatment with no sediment exposure and any of the sediment treatments. However, skeletal growth was significantly higher (by 50 %) in the low concentration exposures compared to the high concentration exposures (Fig. 2). Low levels of sediment exposure at the prevailing experimental conditions might actually have enhanced growth. A small pilot experiment was performed to assess the effect of suspended fine-fraction DC on larval survival. 23-day old planulae were exposed to 5 mg l<sup>-1</sup> and 25 mg l<sup>-1</sup> respectively. Transfer of larvae to experimental wells caused mortality in all treatments but during the following 3 days no mortality occurred in the

control treatments. Corresponding mortality in 5 mg l<sup>-1</sup> was 10 % and in 25 mg l<sup>-1</sup> as high as 70 %. Results gave the indication that moderately high levels of suspended DC might be harmful to the reproductive stage of *L. pertusa*. The significance of these findings must however be checked in dedicated properly designed experiments.

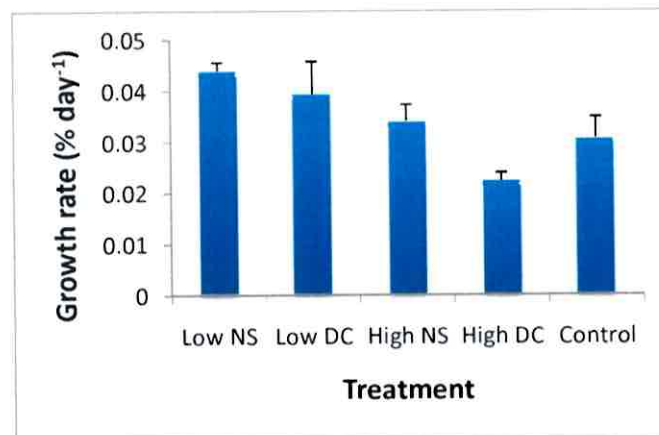


Figure 2.

### Reproduction of *Lophelia pertusa* - embryo and larval development

Johanna Järnegren<sup>1</sup>, Sandra Brooke<sup>2</sup>, Ann Larsson<sup>3</sup>, Susanna Strömberg<sup>3</sup>, Mikael Dahl<sup>3</sup>,

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<sup>2</sup> Oregon Institute of Marine Biology (OIMB), USA

<sup>3</sup> The Lovén Center Tjärnö, Sweden

For the very first time has embryo and larval development been documented for the deep living cold water coral *Lophelia pertusa*. Through coral collections over four years, time of spawning event was pinpointed through histological methods. Spawning occurred in February 2009 and was documented simultaneously at Trondhjem Biological Station (TBS), Norway and Tjärnö, Sweden. Extremely low fertilization rates with 68-85 % undeveloped eggs was evident and slow cell division rate was recorded. Spawmed eggs were 161 µm in size and very dense, while early larval stages were 220µm. The larvae were kept for 10 days at TBS and longer at Tjärnö. Time until bottom probing was noted as well as swimming speed. By using the histological cycle

recorded from samples in the Trondheimsfjord, time of spawning event in the Gulf of Mexico was estimated and later also confirmed through spawning .

### **The Coral Risk Assessment, Monitoring and Modelling (CORAMM) project: An overview of project results and a new monitoring technique**

Laurenz Thomsen<sup>1</sup>, Ræid Abed<sup>3</sup>, Elke Allers<sup>3</sup>, Melanie Bergmann<sup>5</sup>, Dirk de Beer<sup>3</sup>, Carlos Dias de Jesus César<sup>7</sup>, Ståle Johnsen<sup>7</sup>, Frederik de Laender<sup>4</sup>, Ann Larsson<sup>8</sup>, Tomas Lundälv<sup>2</sup>, Tim W. Nattkemper<sup>6</sup>, Ingunn Nilssen<sup>7</sup>, Dick van Oevelen<sup>4</sup>, Jörg Ontrup<sup>6</sup>, Katsia Pabortsava<sup>1</sup>, Autun Purser<sup>1</sup>, Ingeborg Rønning<sup>7</sup>, Mathijs Smit<sup>7</sup>, Vikram Unnithan<sup>1</sup>, Hannes Wagner<sup>1</sup>, Tao Wang<sup>3</sup>

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<sup>7</sup> Statoil, Statoil ASA Arkitekt Ebbels veg 10, Rotvoll, NO-7005 Trondheim, Norway

<sup>8</sup> Dept. of Marine Ecology-Tjärnö, University of Gothenburg, Sweden

The Coral Risk Assessment, Monitoring and Modelling (CORAMM) project was a 3.5 year initiative of Jacobs University Bremen. The overall aim of the project was two-fold. Firstly, to improve our understanding of the possible risks posed to cold-water corals (CWCs) by exposure to elevated levels of particulate material. Secondly, the project attempted to develop novel cold-water coral reef health assessment and monitoring techniques which could be used for reefs found at different locations and under different potentially stressful conditions (such as close to drilling operations or on the borders of fishing exclusion zones).

In contrast to the majority of cold-water coral investigations to date, the CORAMM project gathered together researchers from the biological sciences, image analysis experts, modellers and representatives from industry (Statoil) as key project partners. By having such a diverse group working together from day one, the CORAMM project could plan experimental work and design reef imaging systems which would be of use in the development of management strategies for these complex ecosystems.

Two types of particulate material were investigated in the project as representing possible hazards to *Lophelia pertusa*, the key scleractinian reef building coral at the majority of most European CWC reefs. The first of these was resuspended seabed sediments, as released by bottom trawling in the vicinity of reefs. The second material type was DC, the waste rock material (and attached DM) often discharged to sea during drilling operations. 103 different DC sample types (from 5 wells and a selection of drill depths, all cut with WBM) were provided to CORAMM by Statoil. The majority of samples originated from the 17.5" and 12.25" drill sections, with a lesser quantity from the 8.5" sections (some of which from substrates containing a percentage of hydrocarbons from the reservoir rocks).

#### *Drill cuttings: Particle size composition, aggregation and transport*

Particle size composition was assessed for all DC samples provided to CORAMM by Statoil. A great variability in size distribution and fluid content was observed across samples, even between samples separated by a few tens of meters originating from the same drill hole. We investigated the settling rates of the particles of various sizes and how these settling rates may change following aggregation with algal aggregate material naturally occurring in Norwegian in surface waters. In many DC samples we found a high percentage of material <63µm in diameter, and observed that this material aggregated quickly with algal material. We observed that such aggregations sank at a much faster rate than both the naturally occurring aggregates and the un-aggregated fine DC (figure 1). This observation we believe indicates that transport and arrival at the seafloor of DC released during drilling operations will be greatly influenced by both the size composition of waste material and amount of algal material in suspension in the upper water column.

#### *Automated reef health assessment*

One of the great successes of the CORAMM project was to develop an automated system to determine the percentage coverage by *Lophelia pertusa* of the seabed, from still images extracted from video stream data. By using neural network machine learning algorithms the automated system learns from an expert to identify regions of



seabed in a set of test images covered by living *Lophelia pertusa*. From these training images the automated system can then identify and quantify coverage area of living coral within further images automatically. The automated system attained a degree of accuracy comparable to that achieved by a human, following standard quantification methodologies (figure 2).

#### *Further CORAMM results*

Further results from CORAMM work are presented elsewhere in this document, with Larsson *et al.* reporting on the potential effects on *Lophelia pertusa* health following exposure to elevated concentrations of particles and by Van Oevelen *et al.* on the development of a dynamic energy budget model for CWC reefs. Many of these results and those of other CORAMM work are now published or in press, with details of publications found on the project website: <http://www.irccm.org/coram/>

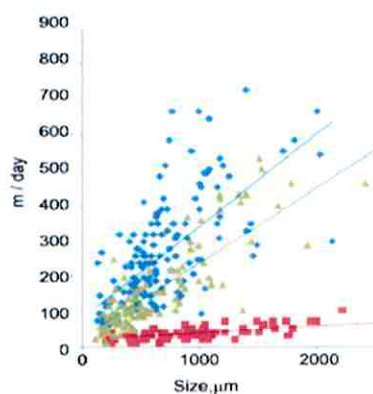


Figure 1. Settling rates of a selection of marine aggregates. RED – naturally occurring marine aggregates. BLUE – naturally occurring marine aggregates following aggregation with <63µm DC material from a 12.5” drill section from the Norwegian margin. GREEN - naturally occurring marine aggregates following aggregation with <63µm DC material from a 8.5” drill section from the Norwegian margin, a section containing a percentage of contaminant hydrocarbon material from the reservoir rock.

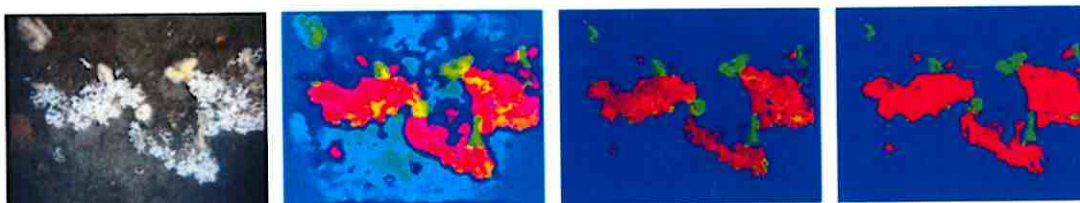


Figure 2. Sequence of result images from the automated analysis processing pipeline. The first image shows the original video frame. The second corresponds with the cluster colors the neural network has learned from the texture data. Note, that this image is generated without any expert labels - by the unsupervised training process only. For preparation of the third image expert labels were applied to the neural network. Depending on the number of coral or sponge labels within the clusters on the map, regions of the image are colored red or green respectively. The last image is the final categorised frame from which the coverage estimations are produced by counting the colored pixels (Purser et al., 2009).

### **Development of a DEB model of the cold-water coral *Lophelia pertusa* for the quantification of sedimentation stress**

Dick van Oevelen<sup>1</sup>, Ann Larsson<sup>2</sup>, Autun Purser<sup>3</sup>, Laurenz Thomsen<sup>3</sup>

<sup>1</sup> NIOO-KNAW, The Netherlands

<sup>2</sup> TMBL, Sweden

<sup>3</sup> Jacobs University, Germany

Cold-water coral reefs are arguably one of the most spectacular ecosystems on the continental shelves (Roberts et al., 2006), which are hotspots of carbon cycling and biomass (van Oevelen et al., 2009) that support enhanced levels of biodiversity (Henry and Roberts, 2007). Cold-water coral reefs are increasingly protected in marine protected areas. Drilling operations in the vicinity of cold-water coral reefs by the O&G industry may cause exposure to plumes of fine suspended sediment particles which may cause deleterious effects of the cold-water corals. Tropical corals are known to be sensitive to sedimentation stress (Bak and Elgershuizen, 1976) and impacts on cold-water coral may be expected as a result of 1) reduced feeding capability due to clogging of the feeding tentacles with particles, 2) energy loss due to the enhanced production of mucus sheets and 3) suffocation due to oxygen shortage. These effects manifest themselves at the physiological level and integration these effects requires the development of a physiological model. The Dynamic Energy Budget (DEB) theory describes the basic physiology of organisms across levels of organization (Kooijman, 2000). The strength of DEB is that the physiological effects measured in toxicity tests can be explained by changes in “parameter values”. In this way, the physiological effect

of a toxicant can be interpreted in terms of its fundamental effect on animal physiology, rather than on the output variable only.

Various experiments were conducted to parameterize the DEB model for *Lophelia pertusa*. These experiments included 1) feeding rates on *Artemia*, 2) respiration rates during prolonged starvation, 3) respiration rates at different levels of food density and 4) mucus production during DC exposure.

Preliminary simulations suggest that the capacity to store energy reserves is large for cold-water corals, implying that comparatively short (days – weeks) interruptions in feeding activity (e.g. due to drilling operations) have only limited impact on growth and reproductive output. Mucus production however proved to be more difficult to quantify and remains an uncertain component in the energy budget of cold-water corals. Current data for mucus production fall within the range of published values and are compatible with the present energy budget. If mucus production is however substantial, there are two factors that need to be taken into account. First, can available reserves be mobilized fast enough to produce the required mucus? Second, colonies in poor food condition prior to the exposure to DC may suffer disproportionately due to limited available energy reserves.

### **Biological and oceanographic studies at Scott Reef: highlights from 15 years of research**

Tim Cooper

Australian Institute of Marine Science, Crawley, Australia

The focus of this talk centered on Scott Reef, which lies on the North West Shelf of Australia, a region rich in oil and gas resources. Scott Reef is surrounded by deep clear oceanic water, over 1000 m deep to the seaward, and 450 m to landward. The reef system is unique in having a large deep open lagoon 20 km across and over 70 m deep. An oil and gas reservoir lies underneath Scott Reef, which is a deposit of significant value. The objectives of the Scott Reef Research Project can be summarized in the following questions:



- A. How significant is Scott Reef in a regional context?
- B. How resilient is the reef to disturbances?
- C. What is the significance of deep-water communities?
- D. What is the role of the lagoon and open ocean in the functioning of the reef?
- E. Can thresholds for sedimentation be developed to help mitigate any effects of dredging / drilling operations associated with the development?

These questions have been addressed through four integrated science projects:

1. Shallow-water coral and fish communities
2. Deepwater benthic communities (30-70 m)
3. Physical and biological oceanography
4. Dose / response experiments using Scott Reef sediments in the controlled aquarium facilities at AIMS

Of most relevance to the participants of the 'OLF Cold-water Coral Workshop' held in Stavanger were the approaches used and outcomes of research Projects 2 and 4, i.e. the deepwater coral communities and developing sedimentation thresholds.

Project 2 investigated the significance of deepwater coral communities in the Scott Reef lagoon. Specifically, we looked at questions such as: Are these deep corals (like their shallow counterparts) able to rely solely on light for all their energy needs? Since deeper corals do not experience bleaching or wave damage, do they act as sources of replenishment for disturbed shallow communities? Or do they live in functional isolation from shallow habitats? In Australia, there has been very little ecological and even less physiological work on deep water communities since they lie beyond safe scuba diving depths.

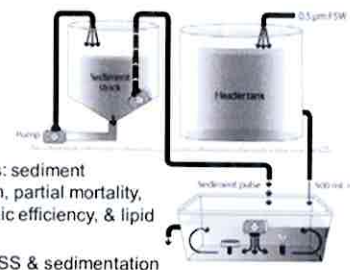
Important findings of Project 2 included the description of extensive areas of very high coral cover in the deep lagoon, dominated by flat plate growth forms. Scott Reef is unique in this region for possessing this type of deep coral environment. Several species were new records for Australia. The genetic connectivity component focused on the brooding hard coral *Seriatopora hystrix*, which is one of several coral species that span shallow to deep water habitats at South Scott Reef. The results of DNA analysis show

that depth is a dominant influence on the genetic composition of *S. hystrix*; corals collected from deep water were genetically highly distinct from their shallower counterparts, and genetic connections appear to be restricted over depths greater than 30 m. The implication is that recovery of shallow water populations, which are most susceptible to warm water bleaching, may be facilitated by input of new recruits produced from healthy colonies growing at 20 to 30 m depths, but reseeding of shallow water populations by corals from depths greater than 30 m is unlikely in this brooding hard coral. Finally, we also investigated a total of 12 physiological parameters in each of 2 species (the foliaceous *Pachyseris speciosa* and the branching *S. hystrix*) during 2 sampling events over a 60 m depth gradient at Scott Reef. Many of the photo-physiological parameters showed species-specific variability over the depth gradient. For example, *P. speciosa* showed a high affinity for a zooxanthellae belonging to clade C over its entire depth range, while shallow colonies of *S. hystrix* associated with clade D shifting to clade C around a depth of 25 m. As expected, the minimum saturating irradiance in both species decreased and light decreased with depth. Responses in the photosynthetic pigments were generally characterized by increases in chlorophyll-*a* as light decreased with depth. This demonstrates capacity of the symbionts for optimization of light capture and utilization under contrasting light regimes. This is considered good news as it suggests that zooxanthellate corals at Scott Reef should be able to acclimatize to any natural or anthropogenic changes in the light regime.

Project 4 comprised a laboratory dose/response experiment to examine responses in physiological variables (bioindicators) of offshore corals exposed to fine carbonate sediments, as might be associated with dredging / drilling operations during the development of the gas field. The aim was to develop thresholds for sedimentation that could be used to as management strategies to mitigate the effects of the development on Scott Reef corals. Responses in coral bioindicators included sediment accumulation, partial mortality, chlorophyll *a* fluorescence (i.e. photosynthetic efficiency), changes in photosynthetic pigments, and lipid content using this dosing system. We were able to control environmental factors such as light, temperature, water flow whilst at the same time exposing corals to various treatments of sediments 0 – 100 mg/l. Colony morphology was an important factor in the results. Sediment accumulation on foliaceous corals had an obvious effect on tissue condition, leading to partial mortality


and reduced photosynthetic efficiency even at moderate levels of sedimentation. Partial mortality and reduced photosynthetic efficiency was evident in the branching corals at the highest treatment levels. An important finding has been that a physiological threshold occurs between 30 – 100 mg/l and sublethal responses were detected after ~8 weeks of sediment exposure.

### Experimental exposure to reef sediment



Bioindicators: sediment accumulation, partial mortality, photosynthetic efficiency, & lipid content  
Consistent TSS & sedimentation rates

### Laboratory experiment



30 mg/L

100 mg/L

Physiological threshold is species-specific (10 – 100 mg/L), sublethal responses detected after ~8 weeks of sediment exposure

## 2.2 Abstracts Day 2

### **Regulation and legal requirements for drilling operations related to corals – 1: Regulations relating to pollution control.**

Mathilde Juel Lind

Norwegian Climate and Pollution Agency, Oslo, Norway

There are five general principles in environmental legislation that must be followed during drilling operations; The precautionary principle, The principle of risk reduction, Continuous improvement, The use of Best Available Techniques and The polluter pays principle. The Pollution Control Act states that all pollution is prohibited, but that planned discharges and emissions are allowed if covered by regulations or environmental license. There are four Health, Safety and Environment regulations for the petroleum industry to follow; Framework regulation, Management regulation, Technical and operational regulations, Facilities regulation and Activities regulation. The latter states that DC, sand and other solid particles shall not be discharged to sea if the oil content exceeds ten gram per kilo gram of dry matter. Framework for specific activities is also provided in White papers, as e.g. the Norwegian Sea management plan, which states that drilling or discharge of DC will not be permitted in areas where valuable or vulnerable resources might occur. Operators must use technology to deal with DCs and DM that prevents deposition of cuttings in areas with vulnerable benthic fauna, or in key spawning areas. In areas that may be included in the national marine conservation plan, activities should be evaluated in relation to the conservation value and purpose, and activities that may lead to sedimentation should be avoided on or near coral reefs. Operators should, in their applications, give an account of the presence of vulnerable resources such as corals, and assess if activity such as DC and anchors will affect these. Assessments on handling of DC should also be included. Some specific demands in permits when drilling in areas with corals can be: zero discharge, discharge from top hole section only, move the point of discharge of cuttings, environmental monitoring.

From the Climate and Pollution Agency's point of view there are several challenges when handling applications concerning drilling in areas where corals are present, such as: defining a significant coral occurrence, getting relevant measurements of sea

currents when accounting for topography and sea floor, and the present technology for zero discharge is considered challenging or impossible from a safety perspective.

## **Regulation and legal requirements for drilling operations related to corals – 2: Regulations relating to biodiversity.**

Erlend Standal

Directorate for nature management, Trondheim, Norway

The purpose of the Nature Diversity Act is to protect biological, geological and landscape diversity and ecological processes through conservation and sustainable use, in such a way that the environment provides a basis for human activity, culture, health and well-being, now and in the future, including a basis for the Sami culture. Stated management objectives are to maintain the diversity of habitat types within their natural range and the species diversity and ecological processes that are characteristic of each habitat type. The ecosystem structure, functioning and productivity should be maintained to the extent this is considered reasonable. This also includes species and their genetic diversity, and it should be ensured that species occur in viable populations within their natural ranges. If a species is endangered, the authorities have a duty to consider whether it is necessary and appropriate to designate it as a priority species. Endangered and vulnerable habitats should also be safeguarded through sustainable use. Any person should act with care and avoid causing damage to nature diversity, the ecosystem approach to management should be followed to avoid cumulative environmental effects. Official decisions that affect nature diversity shall be based on scientific knowledge, the precautionary- and user-pays principle should be followed for all activities and environmentally sound techniques and methods of operations should be used. Marine protected areas are introduced as a new protection category, and other categories such as natural parks and nature reserves may also be used. Any person that possesses or does anything that may have an impact on nature diversity has a duty to provide the supervisory authority with any information necessary to enable it to carry out tasks within this act.

On the continental shelf and the economic zone of Norway: Sections 1, 3 to 5, 7 to 10, 14 to 16, 57 and 58 apply to the extent they are appropriate. The Government will make

a thorough evaluation of whether and in what way any other provisions are to be made applicable outside the territorial limit

The Nature Diversity Act can be found here (English version):

<http://www.regjeringen.no/en/doc/Laws/Acts/nature-diversity-act.html?id=570549>

### **Mitigating measures.**

Rune Weltzien

Statoil, Bergen, Norway

The Top hole is the upper part of the well, the 36" and 26" hole sections. After completion of top hole, the 20" casing is installed, and BOP and riser are connected. Before the riser is installed, cuttings and mud are disposed on the seafloor. Drilling is not a continuous operation, discharge of fluids happen only during drilling. Drilling the 36" hole is approx 8 hours with a flow rate of 40 m<sup>3</sup>/hr and the 26" is approx 33 hours with a flow rate of 35 m<sup>3</sup>/hr. Techniques for handling top hole DC are reduction of cuttings and solids, transport and disposal of cuttings on seabed, and recovery of cuttings to rig. Cuttings transport systems (CTS) prior to riser installation are open systems, meaning that operational problems might lead to unplanned discharge. Robust techniques/operations will minimize risk.

Morvin A, the drilling of 4 production wells in a coral rich area in the Norwegian Sea. Using the SINTEF Dream-model, an environmentally optimal positioning of discharge for the CTS was chosen for each of the templates (North and South). Both were located around 500 m from the wells. To handle the cuttings a real time monitoring of the nearest corals was installed on the seafloor. This made it possible to monitor the particle plumes and sedimentation from the CTS. The results from Morvin was no sedimentation of cuttings on corals, nearest coral upstream (350 m) were exposed to "cutting plumes", an no observed stress behavior or other acute effects on corals. There will be a plan for monitoring long term effects. The CTS worked without problems.

Lessons learned were that monitoring technology needs development and standardization, and a monitoring strategy needs to be developed. Best Praxis in coral areas "might be" CTS combined with environmentally optimal disposal site, in combination with environmental monitoring

## **Will drill cuttings and drill mud harm cold water corals?**

Edgar Furuholt

Det Norske, Trondheim, Norway

The Trolla exploration well was surveyed with sidescan and multibeam echosounder and numerous potential corals were found. Five locations were selected for visual inspection, *Lophelia* and *Paragorgia* confirmed on four of these. The spud location was moved 1 km for geological reasons, there were no visual observations of corals in the vicinity, except for several single *Paragorgia* (35 m). Nearest potential coral was approx 220 m, nearest confirmed was 760 m away. Spreading simulations of cuttings in the main current direction was simulated with the SINTEF Dream-model.

Riserless Mud Recovery (RMR) was used when drilling the 36" and 26" hole sections. RMR allows for use of weighted mud when drilling top hole sections, is a safety measure against shallow gas, and allows for cuttings to be transported to rig or deposited on suitable seabed location with CTS. This was the first time commercial use for top hole section (36"). All cuttings from the drilling were transported up to the rig. Cuttings were sampled from shaker from several well depths, fine particle size fraction was analyzed in a laboratory ashore.

Monitoring was executed with ROV photo and video. Sediment from seabed was sampled before and after drilling, as well as in sedimentation traps. The sediment was analyzed for metals (particularly barium). Current direction and velocity as well as turbidity were measured. The measured sea currents generally supported the simulated currents. There were no clear trends in increased turbidity during drilling, neither 2 nor 10 m above the seabed. Sediment traps contained DM and natural sedimentation. Increased barium concentration was found in sediment close to the well, and traces of clay were found 100 m from the well. No obvious trends in change of sediment surface grain size composition at increasing distances from Trolla centre. The visual inspection found no signs of disturbance of corals 3 – 400 m from the well, nor at the *Paragorgia* 35 m from the well.

Lessons learned were to design site surveys to provide sufficient information on seabed habitats. Do Mooring pattern and anchor laying operations to avoid corals/vulnerable habitats (dynamic positioning?). Simulations of sea currents and cuttings spreading give valuable information. Assess the potential harm to coral habitats in the vicinity of the



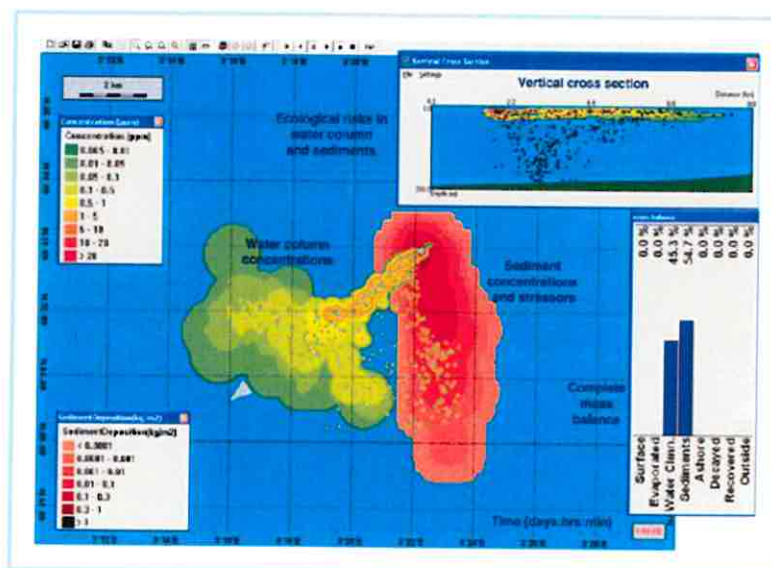
well. Technologies exist to recover all cuttings to rig, provided suitable sea bed Conditions. Each well will have selected optimal technologies and operational procedures, as well as open dialogue with authorities and scientific institutions. A well planned monitoring programme may provide valuable new information on the effects of DC on seabed habitats. Our experience from the Trolla well shows that drilling may be conducted without harming corals.

### Calculation of stresses (depositions and water column concentrations) at the sea floor caused by drilling discharges.

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In an environmental risk management system for the offshore petroleum activities, impacts from produced water and the drilling operations on the water column and the bottom sediments need to be assessed.



The Dose-related Risk and Effects Assessment model (DREAM) originally accounted for potential impacts from produced water discharges in the water column. Today the DREAM concept also embraces the Par Track model which simulates concentrations of particles in the water column (basically DM) as well as deposition of the releases at the sea floor (basically cuttings). The risk volumes/areas calculated for drilling discharges is based on the PEC/PNEC approach, accounting for chemical stress (toxicity) and particle



stress in the water column (volume), and for chemical stress (toxicity), burial, change in grain size and oxygen depletion at the sediment surface (area). Corals are today not included in the species sensitivity distribution functions used to derive PNEC values that is subsequently used to calculate the risk volumes.

In brief, model output describes the general deposition of cuttings on the sea floor, where larger particles are deposited near the drilling sites, whereas smaller particles drift further away before they are deposited. The inclusion of ocean current data into these models is an important factor to explain the direction and distance of this plume. Based on the spreading and settling of particles, placing of the plume release will play an important role for the possibility of coral exposure. With an outlet closer to the sea floor finer particles will remain in suspension in waters surrounding the corals for a relatively long period of time. An outlet higher in the water column will on the other hand produce a particle cloud closer to the surface, with less potential to stress the corals.

During the Trolla validation study, predictions on depositions calculated prior to the execution of the drilling program were compared with measurements carried out during drilling. The model input data were measured currents, actual discharge data and measured particle size distributions on the drilling rig. The model output data were seafloor depositions. The results show reasonably good correspondence between measured and simulated depositions of cuttings. Deviations in directions for dominant transport of cuttings should, however, be anticipated when simulations are carried out for different time periods prior to the actual drilling, and the results obtained are limited to be valid for discharges directly from the drilling rig.

## **Experiences from exploration drillings, investigation, mitigation measures and monitoring program.**

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The exploration wells Pumbaa and Caerus are located within the marine protected area “Sula korallvernområde”: Prohibited for all use of fishing gears that are dragged and may get in contact with the sea floor (as well as “all intentional destruction of coral reefs”). Each well had different challenges to the well due to different coral and environmental situation, well specific conditions, and rig specific or technical conditions. Legal requirements stated in the permit (Klif) and experience with the necessary risk reduction measures were presented.

In general, the time plan for exploration drilling explains that a rig contract is usually made 1.5-3 years in advance, while the environmental evaluation starts 15 months prior to drilling. Site surveys in areas with expected occurrence of corals, start approximately 12 months before drilling, with normally scanning an area of 5 km x 5 km. This is mandatory for shallow gas, geotechnical information and cultural monuments. Topography (iceberg plough marks, steep clefts and rocks) are typical habitat areas for corals. The side scan sonar creates precise images of the seafloor with structure resolution with a error margin of 5-20 cm vertically and 1-2 m horizontally. Some key experiences from drilling operations are presented below.

### *1) Pumbaa – GDF SUEZ (nearest coral 280 m)*

Actions taken to minimize the risk of harming the corals: rig with dynamic positioning, contact with both IMR and Klif to gain more knowledge on corals, hole sizes was optimized with the aim to minimize the volume of drill cuttings (DC) (some 55 % reduction), particle distribution simulation, evaluation of different technical solutions for reducing the discharges. According to the permit requirements DC from the two top hole sections were transported with Cuttings Transport System (CTS) 300 m away from the location of drilling, and about 500 m upstream from the nearest coral. The DC from the bottom sections were returned, grinded and collected in tanks for usage as spud mud in future drilling operations. The drilling mud (DM) was reused on the rig, or sent onshore for reuse or as slop. A relatively comprehensive monitoring program was

developed by DNV; measuring current and turbidity, deposition of cuttings from sediment traps and seafloor sampling, and visual inspection with ROV.

*II) Caerus (nearest corals 1341 m, nearest Lophelia 1539 m)*

Cuttings from the two deepest sections (WBM) were to be transported to land. Challenges related to waste handling of WBM; classified as non-hazardous waste, high content of salts and organic matter, metal contamination (Pb and Cu), logistic and emissions to air, safe handling for workers, and environmentally accepted treatment. For the last part, three scenarios were explored; waste landfill, storage and re-use. There are few waste landfills with permit for deposit of WBM and cuttings, the challenge is contents of salts and impact of drainage water to the environment. Use as “binding material” for safe and permanent storage of hazardous waste could be done in mines in Rana. A permit from Klif for treatment and handling of hazardous waste was needed, with the main challenge being organic matter (TOC < 5 %, technical stability). Treatment and re-use of cuttings: Requires thermo-mechanical treatment (TCC, energy demanding process at 300°C) similar to treatment of OBM, the end product would be dry recovered solids for re-use. Alternative re-use would be filling / layer for industrial construction, filling in asphalt production, or other evaluated re-uses.

The WBM used was Glydrill MC, two sections totaling 400 tons of DC and DM transported with about 50 containers to land (Mongstad). Chemical characterization executed before treatment with TCC. It was pre-mixed with OBM and cuttings. The end product was re-used as filling / layer in a local industrial construction area. The re-used product was analyzed and evaluated based on acceptance criteria, local environmental conditions etc.

**Guidelines for the methodology of coral monitoring during drilling activities – an empirical approach.**

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When drilling in areas where corals occur, it is important to both assess the potential effects on corals, and document any effects on the corals. There are different practices by the companies and it seems that there have been different practices by the authorities

with regard to grant permissions or the monitoring requirements in connection with the drilling. The questions are; when should monitoring of drilling be performed, how extensive should the monitoring program be, and what parameters are applicable for measuring effects on the corals?

Side scan sonar and multi-beam echo sounder are commonly used during site surveys in order to collect data of the seabed features. Data provided from the side scan sonar in a mosaic image create the basis for interpretation of potential coral structures within the surveyed area. The ROV has at a few instances during the visual mapping identified structures not present in the mosaic. Placement of structures in the mosaic may vary up to 20 m.

Currently, the visual mapping is performed with ROV or camera frame. There has been established a rough classification of *Lophelia* condition observed at the “potential” coral structures based on amount of apparently living polyps (used by Gardline, Fugro and DNV). These conditions are being accounted for by KLIF in their discharge permits, with special consideration to “moderate” and “good” coral targets. Use of ROV is recommended since it is maneuverable and very often equipped with sonar.

Oceanic current measurements are required for dispersion modeling, planning of potential discharge area, placement of monitoring equipment and interpretation of other data collected during the monitoring. Measuring oceanic current is usually required by KLIF. Velocities and directions may vary throughout a period, with more or less similar directions at different depths (2-60 m above sea floor), and decreasing velocities closer to the sea floor.

Sediment samples are used in order to identify background values and dispersion of DC, the samples are analyzed for grain size, TOM and metals. Barium (Ba) proves to be the most valuable parameter for measuring the dispersion of DC. Highest Ba concentration is usually registered in the immediate vicinity of the discharge area. One corer sample (0-1 cm) gives enough material to analyze on, making the method very efficient.

Turbidity, measured as FTU (Formazin Turbidity Units), is a relative measure of the permeability of water to UV radiation. It is typically increased in response to an increase in particulate matter. Changes in the FTU level do not provide information on

the quantity or quality of particles but may still serve as an indication of DC exposure. This is often required by KLIF.

Summary of applicable monitoring methods:

For each methodology, relevance has been graded to “high” (■) “medium” (■) and “low” (■) for the sampling periods before-, during- and after drilling operations, and reference station.

Method	Before	During	After	Reference
Current	Placement of equipment	Interpretation of other data Re-running of dispersion model	Could be relevant if there are further plans for the reservoir	Not very relevant, even though the current regime may varied within a area
Visual mapping	What to map and monitor?	NA	NA	NA
Turbidity	Natural particle loads on corals measured in FTU	Particle loads in the water masses	Natural particle loads on corals measured in FTU	Background
Sediment samples	Baseline data	Could be relevant in order to identify differences in discharges from different drilling sections	Dispersion pattern of Ba	Depending on other drilling activities in the area
Sediment traps	Reflecting natural variance	Suspended matter, Ba values	Could be important regarding re-suspension of discharges.	Background
Visual monitoring	NA	Missing a parameter to measure on?	Excessive sediments which visually can be seen	

**Part II: Background information: knowledge on CWC  
obtained during the workshop and published  
literature**

### **3 Cold-water corals in relation to oil and gas activities in Norway; a synthesis of knowledge**

The following chapter synthesizes the new knowledge on CWC obtained during the workshop and published literature.

#### **3.1 Mitigating actions in oil and gas operations**

As part of the permits for O&G activities on the Norwegian continental shelf environmental impacts assessments must be performed. The Pollution Control Act (Miljøverndepartementet, 1981) states that all discharges of importance should be given a special permit, and not cause any damage or inconvenience. Acute discharges should be prevented, detected, stopped, eliminated or reduced, and the use of best available techniques (BAT) is normally required. The Activity Regulations (Miljøverndepartementet, 2010) states that the O&G operators should carry out regular monitoring surveys of the water column and sea bottom sediments. This involves mapping of potential pollution and assessment of biological effects.

Drilling in CWC areas force additional requirements because of the vulnerability of these ecosystems. Although the overarching regulations are in place (mapping, top hole section discharge only, environmental monitoring, etc.), there are few real guidelines, and different practices regarding planning and environmental monitoring. Thus, there is a great need for a standardization of the management practices and requirements set forward to the O&G companies. In general, the authorities require actions taken prior to, immediately before and during drilling. So far, no requirements are set to assess possible long-term biological effects. The oil industry believe that mitigation measures taken during drilling is sufficient to avoid significant exposure to CWCs and that it is little reason to expect any long-term effects.

#### **3.2 Site survey/habitat mapping**

As a part of the environmental impact assessment, O&G companies are obliged to map coral reefs and other vulnerable seabed fauna in intended drilling areas. The mapping is necessary to plan and select drilling/spud location, place structures such as anchors, pipelines and cables, to evaluate disposal sites and to observe possible effects on CWC



caused by particles (Freiwald et al., 2004). If needed, mitigation measures related to change in original plans should be taken to avoid exposure to CWCs. Habitat mappings are generally made by the use of Side Scan Sonars and/or Multibeam Echo Sounders, followed by more detailed mappings of remotely operated vehicles (ROVs) (Moe & Kaland, Furuholt, Weltzien, presentations).

### **3.3 Particle distribution, dispersion modelling and current measurements**

The deposition of DC on the sea floor is of great concern for CWCs and dispersion modeling is normally required as a basis for impact assessment of the drilling operations. These dispersal models provide a helpful supplement to the site surveys in deciding the placements of structures and disposal sites.

In general, there is an immediate settling of large cutting particles near the release site, whereas finer particles are spread and distributed over longer distances. Dispersal models have shown that an essential part of the particles may remain in water suspension close to the sea floor, whereas an “outlet” for cuttings higher in the water column, with a particle cloud closer to surface, probably stresses corals less (Rye, presentation). Different models have been used separately to predict and simulate the deposition of DC/DM on the seafloor (DREAM), as well as the concentrations of DM and chemicals in the free water-masses (Par Track), but lately these have been combined in one DREAM model (Rye et al., 2006). Input data to these models are ambient currents and densities, chemical and physical properties of the effluent (incl. Particle Size Distribution, PSD) and details from the release scenario.

Together with data from the general environmental monitoring survey, the data obtained during the drilling operations can verify the numerical models made in advance (Rye et al., 2006; Furuholt/Rye 2010). One example is the Trolla validation, where predictions and depositions calculated prior to the drilling corresponded well to the actual measures of currents, discharges, particle size distributions and depositions on the sea floor (Rye, presentation). The results obtained so far, are limited to be valid for discharges from the drilling rig and can be altered for discharges near the seafloor. Deviations in the directions of dominant transport of cuttings could be expected when simulations are carried out for different time periods prior to the actual drilling (Rye, presentation). It is therefore important to use data representative in time and space.

### **3.4 Drill cuttings deposition**

DC with water based DM are normally allowed to be discharged in the marine environment, however, in areas with CWCs and in the Barents Sea, this is only permitted for the top-section (St. meld. nr. 38 (2003 - 2004)). In areas with valuable ecosystems, such as CWC reefs, there is likely to become a zero-discharge requirement also for DC, but the technology needed to meet this requirement is not fully developed. As a compromise, the operators are permitted to discharge DC from the top hole section but they must use technology for dealing with DC/DM that prevents deposition in areas where the benthic fauna is vulnerable, or in key spawning areas (Miljøverndepartementet, 2009). Awaiting safe technology to transport large volumes of DC/DM from rig to ship, the discharge point of cuttings have generally been recommended to be located 500 m away from the closest coral reef, but this is not set distance (Lind, presentation). Relatively coarse-grained sediments and barite crystals trapped in the skeleton structure of live coral polyps 500 m down-current from a drilling site in the Træna Deep indicating transport over this distance have, however, been observed (Lepland and Buhl-Mortensen, 2008).

There are several options for handling of DC; collection, deposition, transporting to land, slurrification and re-injection, recycling for usage as DM and collection in Sub Sea Bigbags (SSB) (Oljedirektoratet, 2008; SFT, 2009). Because of different limitations (e.g. SSB is today not a proven or accepted method), optimal technologies and operational procedures need to be selected for each well. Cuttings transport system (CTS) have successfully been used at Morvin and Sula (Weltzien, Moe & Kaland, presentations) and Riserless Mud Recovery (RMR) at Trolla (Furuholt, presentation).

### **3.5 Visual monitoring**

Visual monitoring with ROVs or cameras can be used to give a rough indication of the coral state before, during and after drilling. The “quality” of the corals is interpreted from pictures/videos. As an example, Gardline, Fugro and DNV “score” corals as good, moderate, poor and dead based on the amount of apparently living polyps (Jensen, presentation). However, interpretation of CWCs from pictures and videos have obvious limitations in being time consuming and dependent on image resolution, with still photos considered as the best alternative (Jensen, presentation).

### **3.6 Sediment traps and turbidity measurements**

Sediment traps can be placed at locations in different distances from the discharge point and at locations with down-current corals to measure the actual sedimentation rate before and during drilling operations. In addition, the suspended matter from the sediment traps can be analysed for dry weight, metals and total organic matter. The amount of particles in the water column is measured by turbidity measurements at different distances from the discharge point and at reference locations. Such data is implemented in models (Rye, presentation), but their interpretation and utility value alone is limited, as no threshold values are set for these measures.

## **4 Stress responses due to drill cuttings, drilling mud and natural sediments on cold-water coral ecosystems**

As surface attached animals, CWCs have no opportunity to escape possible threats. Cold water coral reefs are long lived, slow growing and fragile, which are generally believed to make them particularly vulnerable to physical disturbances and recovery of reefs from physical damage may take decades to centuries (Nilsen et al., 2010).

Corals use a number of mechanisms to remove sediments; ciliary movements, mucus production, tissue expansion, movements of tentacles and sediment ingestion (Riegl, 1995; Staffordsmith and Ormond, 1992). These mechanisms may affect the energy availability to processes such as growth, respiration, reproduction, resistance to disease and survival (Dallmeyer et al., 1982; Krone and Biggs, 1980; Riegl and Branch, 1995), and the physiological effects of diverting energy to sediment clearing is worth further attention.

Only a few studies have been published on stress responses caused by DC/DM and sedimentation in CWCs (Brooke et al., 2009; Gass, 2006; Gass and Roberts, 2006; Lepland and Buhl-Mortensen, 2008), but unpublished data from on-going projects such as "CORAMM" (funded by Statoil; Larsson, van Oevelen & Purser presentations) and "Effects of drilling mud on the cold-water coral *L. pertusa*" (funded by The Research Council of Norway; Baussant, presentation) were provided during the workshop. In the

following, observed stress responses in CWCs, mainly *L. pertusa*, caused by DM/DC and natural sediments are presented.

#### **4.1 Respiration, growth and mortality**

During a 12 week exposure to low (5 mg/L) and high (25 mg/L) levels of DC and natural sediments, no clear patterns were seen in respiration rate of *L. pertusa* between treatments (Larsson, presentation), which indicates that this exposure concentration and duration do not stress the corals. In the same experiment, there were no differences in skeletal growth or budding rate between groups, however, polyp mortality was observed in the highest DC exposure. Also, tissue covered surfaces of *L. pertusa* cleaned by mucus secretion showed that the fine fraction (<63 µm) of DC is more “sticky” than the coarser. It is suggested that this may cause oxygen depletion at coral surface which could lead to tissue damages (Larsson, presentation).

When *L. pertusa* were exposed to different concentrations (54 - 362 mg/L) of suspended sediments, the individuals showed a high survival rate after 14 days of exposure, and no differences were observed between the two “structural” morphs, “bracycephala” and “gracilis”. The mortality however, increased rapidly with longer exposure and subsequent burial, probably caused by the lack of oxygen. Survival seems to decrease in steps rather than showing a continuous linear decline, which implies that the corals have physiological thresholds beyond which they cannot compensate (Brooke et al., 2009).

#### **4.2 Reproduction and larvae development**

Due to slow development, embryonic larvae may be highly susceptible to pollutants. However, very few data on this are available. In a 5 days small pilot experiment where larvae were exposed to two concentrations of suspended DC (5 and 25 mg/L), larval mortality was high in the highest DC concentration (Larsson, presentation). There is a need to validate these findings in dedicated, properly designed experiments. That the lower levels of suspended DC did not lead to immediate death of larvae may indicate tolerance, or be explained by the short duration of the experiment.

A more indirect effect of DC/DM exposure could be related to the possibility of larvae to find suitable settling substrates in areas with a high sedimentation (exogenous substrate). This means that although existing colonies may grow, the lack of new

colonies may weaken the genetic diversity and therefore the tolerance of the CWCs in a given area.

### **4.3 Mucus production**

During an exposure study with natural sediment and DC, observations of an efficient cleaning of surfaces by mucus was done in *L. pertusa* (Larsson, presentation). However, when registering different sediment clearing mechanisms used by *L. pertusa*, Gass did not observe any mucus production, only behavioural changes (Gass, presentation). Methods based on the quantification of mucocytes by histological techniques and on the detection of protein markers using proteomics techniques are currently tested to possibly reveal physiological changes related to mucus production in stressed corals (Baussant, presentation).

### **4.4 Behaviour and feeding**

When testing the short-term (from instantaneous to some hours) effects of sedimentation on *L. pertusa*, polyp behaviour was recorded by picture analyses of polyp silhouettes (Gass, 2006). At medium sedimentation rates (6-10 mg/cm<sup>2</sup>/min<sup>-1</sup>) there were a significant increase in polyp expansion after the sedimentation event, whereas at higher doses (12-19 mg/cm<sup>2</sup>/min<sup>-1</sup>) there were a significant decrease. A similar technique is currently used to evaluate possible long-term (several days) effects of continuous DM exposure (Baussant, presentation).

In addition to feeding behaviour, food quantity and quality may also be affected by sedimentation. Settling rates between aggregates consisting of only phytoplankton and aggregates of phytoplankton and DC was compared in an experiment, and a higher settling rate was observed in the latter (Purser, presentation). This could have consequences for the feeding success of filtering animals such as *L. pertusa* since less food is available in the water column. Another consideration is whether the possible accumulation of DC in zooplankton or aggregates is of concern for *L. pertusa* when feeding on these.

#### **4.5 Bacterial community shifts**

The interaction between bacterial communities and their host is a relatively new research area for the CWCs. To date, no study of the effects of DM on bacterial community associated to *L. pertusa* is reported. However, a preliminary study has been made in aquaria-maintained DM exposed *L. pertusa* (Baussant, presentation). Also, by analogy to tropical corals, *Lophelia*-associated bacterial community shifts could possibly be used as early diagnostic tool of stress, and this is worth further attention. A key challenge when using bacteria associated to corals will be to distinguish natural variability from stress-related variability (Kellogg, presentation).

#### **4.6 DEB- modelling**

A biological DEB (dynamic energy budget) model is being developed for *L. pertusa* with two main objectives: (i) to be a basic model that describes the physiology of healthy corals and (ii) to append “modules” for sedimentation stress (van Oevelen, presentation). The model is limited by the lack of knowledge in basic biology of *L. pertusa* and in how they tolerate stress. However, the preliminary model has been tested, and results from the first simulations hardly show any change in feeding of *L. pertusa* when exposed to DC, or any change in mucus production in the presence of suspended barite. Mucus production is important but still difficult to parameterize in the model (van Oevelen, presentation).

#### **4.7 Colonization of artificial structures**

Observations of apparently healthy and relatively fast growing CWCs on platforms/installations in the North Sea and on the Brent-Spar oil-storage buoy, may indicate that the corals are not exposed to regular discharges or that they are unaffected by the activity (Bell and Smith, 1999; Gass and Roberts, 2006). However, analyses of footage from the oil platforms in the North Sea have shown that colonies of *L. pertusa* do not survive in close proximity to the actual discharges (Gass and Roberts, 2006; Roberts, 2000). Larval dispersion and settlement conditions need better insights, and an assessment of the health status of corals found on installations was proposed during the workshop.

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## Appendix A

Cold-water coral ecosystems: knowledge status, gaps, research needs and strategy related to O&G operations		
DAY 1 – 31st May 2010		
	Topic	Invited speaker
08:30-09:00	Registration, coffee and tea	
09:00-09:10	Welcome. Opening sessions “General objectives of the workshop”	Egil Dragsund OLF, Oslo (Norway)
09:10-09:20	General information - General introduction for the 1 <sup>st</sup> day	Thierry Baussant IRIS, Stavanger (Norway)
<b>Session 1 - State-of-knowledge of the biology and key features of cold-water corals</b>		
09:20-09:45	“Ecophysiology and ecology of <i>Lophelia pertusa</i> in the NE Atlantic”	Laura Wicks Heriot Watt University, Edinburg (United Kingdom)
09:45-10:10	“Aspects on cold-water coral biology and calcification. Lessons learned from perturbation and on board experiments”	Cornelia Maier Laboratoire d’Océanographie de Villefranche sur Mer, Villefranche sur Mer (France)
10:10-10:30	“Reproduction biology” ( <i>title to be updated</i> )	Sandra Brooke Marine Conservation Biology Institute, Bellevue (United States) Presented by Johanna Jarnegren, NINA, Trondheim (Norway)
10:30-10:50	<i>Coffee break</i>	
10:50-11:15	“Cold-water corals in Norway – an overview”	Pål Buhl-Mortensen Institute of Marine Research, IMR, Bergen (Norway)
<b>Session 2 - Coral ecosystems, ecology and specific associations</b>		
11:15-11:40	“The microbiology of <i>Lophelia pertusa</i> ”	Sven Christopher Neulinger Leibniz Institute of Marine Sciences IFM-GEOMAR, Kiel (Germany)
11:40-12:05	“Microbial ecology of <i>Lophelia pertusa</i> and the potential for using coral-associated bacteria as a diagnostic of coral stress”	Christina Kellogg U.S. Geological Survey, St. Petersburg (USA)
12:15-13:00	<i>Lunch break</i>	
13:15-13:45	Tour of IRIS Biomiljo experimental facilities	Anne Hjelle Adm. Manager IRIS Biomiljo
<b>Session 3 - Current state-of-knowledge of impacts on corals from natural and O&amp;G activities</b>		

13:45-14:10	" <i>Lophelia pertusa</i> on oil and gas structures in the British North Sea"	Susan Gass Dalhousie University Halifax (Canada)
14:10-14:35	"Study of effects of used water-based drilling mud on the cold-water coral <i>Lophelia pertusa</i> "	Thierry Baussant IRIS-bionuljo, Stavanger (Norway)
14:35-15:05	"Experimental studies on <i>Lophelia pertusa</i> with emphasis on drill cutting exposure"	Ann Larsson University of Gothenburg, Dept. of Marine Ecology, Strömstad (Sweden)
15:10-15:30	<i>Coffee break</i>	
15:30-15:55	(title to come later)	Johanna Järnegren Norwegian Institute of Nature Research (Norway)
<b>Session 4 - Current sampling methods, mapping and monitoring strategies from laboratory and field experience with cold-water corals (CWC)</b>		
15:55-16:20	"The Coral Risk Assessment, Monitoring and Modelling (CORAMM) project: An overview of a new reef monitoring technique and results"	Auttun Purser Jacobs University, Bremen (Germany)
16:20-16:45	"Development of a DEB model of the coldwater coral <i>Lophelia pertusa</i> for the quantification of sedimentation stress"	Dick van Oevelen NIOO-KNAW, Yerseke, (The Netherlands)
16:45-17:10	"Biological and oceanographic studies at Scott Reef: highlights from 15 years of research"	Tim Cooper Australian Institute of Marine Science, Crawley (Australia)
17:10-17:30	1 <sup>st</sup> day closing remarks and summary	IRIS & all
<b>19:30 – Welcome drink &amp; Workshop dinner at CITY BRASSERIE &amp; VINBAR –</b> <a href="http://www.citybrasserie.no/en/index.html">http://www.citybrasserie.no/en/index.html</a>		

<b>DAY 2 –1st June 2010</b>		
	Topic	Invited speaker
09:00-09:10	General information - General introduction for the 2nd day	Thierry Baussant IRIS, Stavanger (Norway)
<b>Session 5 – Management measures and strategies to protect coral ecosystems</b>		
09:10-09:30	Regulation and legal requirements for drilling operations related to corals – 1: "Regulations relating to pollution control"	Mathilde Juel Lind Norwegian Climate and Pollution Agency, Oslo (Norway)
09:30-10:00	Regulation and legal requirements for drilling operations related to corals – 2: "Regulations relating to biodiversity"	Erlend Standal Directorate for nature management, Trondheim (Norway)
10:00-10:30	"Mitigating measures"	Rune Weltzien StatOil, Bergen (Norway)
10:30-10:50	<i>Coffee break</i>	



10:50-11:15	“Will drill cuttings and drill mud harm cold water corals?”	Edgar Furuholt Det Norske, Trondheim (Norway)
11:15-11:40	“Calculation of stresses (depositions and water column concentrations) at the sea floor caused by drilling discharges.”	Henrik Rye SINTEF, Trondheim (Norway)
11:40-12:05	“Experiences from exploration drillings, investigation, mitigation measures and monitoring program.”	Jannecke A. Moe (GDF Suez) Toralf Kaland (Cetrice Energi) Stavanger and Oslo (Norway)
12:15-13:00	<i>Lunch break</i>	
<b>Session 6 –The way forward: identify current challenges, limitations and potential needs.</b>		
13:00-13:15	“Brief summary of workshop presentations: introduction to workshop discussion”	Thierry Baussant IRIS, Stavanger (Norway)
13:15-13:40	“Guidelines for the methodology of coral monitoring during drilling activities – an empirical approach”	Amund Ulfnes Det Norske Veritas, Oslo (Norway)
13:40-15:00	“Panel discussion: where do we go from here?”	IRIS & all participants
15:00-15:15	<i>Coffee break</i>	
15:15-16:30	Summary workshop discussion & conclusions	IRIS & all participants
16:30	Closing workshop	

**Cold Water Coral workshop****31.05 – 01.06.2010 in Stavanger****Email**

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