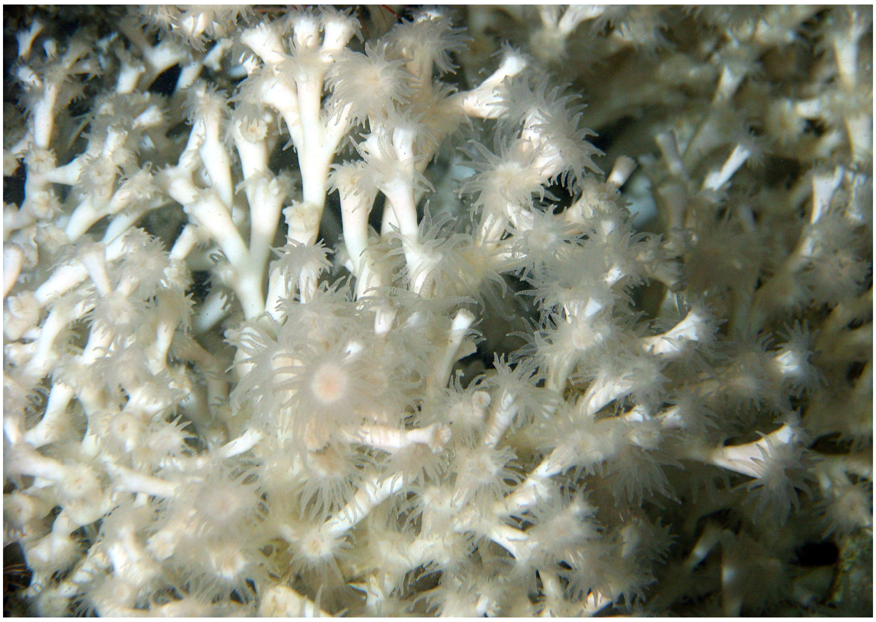
OFFSHORE NORGE

Handbook

Species and Habitats of Environmental Concern

Mapping, Risk Assessment, Mitigation and Monitoring. - In Relation to Offshore Activities



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PREFACE

This handbook has been developed by DNV with the participation of a reference group from the industry and consultants.

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Objective:

On the Norwegian continental shelf there are several legal requirements governing drilling and subsea activities, and how the negative impact on the biodiversity at the seabed should be minimised. This document describes key species and habitats such as corals and sponge grounds and how these can be impacted by drilling, anchoring and pipeline construction/ installation of infrastructure. The document gives recommended methods and requirements for visually assessing the habitats, impact assessment, mitigation and monitoring of effects. A summary of existing knowledge on impact from the various operations is given.

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FOREWORD

This document should be considered as a revision of the document "*Monitoring of drilling activities in areas with presence of cold-water corals*". DNV report nr.: 2012-1691. In 2019 the first version of the present document "*Handbook. Species and Habitats of Environmental Concern. Mapping, Risk Assessment, Mitigation and Monitoring. - In Relation to Oil and Gas Activities*" was published. The document has been revised in this Rev. 1 of the document.

The document is intended as a supplement to the Guidelines M300 and M408 (Miljødirektoratet, 2015 - revised 2021), the activities regulations; Requirements for Environmental Monitoring of the Petroleum Activities on the NCS (2017, §§ 53 and 54) and NS-EN 16260 (Standard Norge, 2012). The aim of the document is summarising relevant legislations, conservation status of species and habitats of concern and recommended best practices for mapping, impact assessment and mitigation of environmental impact where species or habitats of environmental concern (SHEC) can occur.

The basis for the revisions originates from the workshop on Seabed Habitats of Environmental Concern, held in 2013 (NOROG. 2014), work on sponges in NOROG (2013) and workshops held in 2019 and 2023.

Revision history:

Report/ revision	**Year**	**Significant updates**
Monitoring of drilling activities in areas with presence of cold-water corals". DNV report nr.: 2012-1691.	2013	First version
Present report. Rev 0	2019	- New name and report number - Literature review on impact from drilling operations. - Refined description on cold water coral reef mapping. - Inclusion of new habitat types in addition to corals. - Extension for pipeline operations and impact assessments.
Present report. Rev 1	2024	- Adjustment of title, …-"In relation to Oil and Gas Activities" changed to "In Relation to Offshore Activities" - Adjustments of mapping categories for sediment and corals. - Addition of risk assessment for suspended particles. - Extensions and updates for risk assessment for pipelaying operations

1 SUMMARY

On the Norwegian continental shelf there are several legal requirements governing drilling and subsea activities, and how the risk of impact on the biodiversity at the seabed should be minimised.

This document describes key species and habitats such as coral reefs, coral gardens and sponge grounds and how these can be impacted by drilling discharges, anchor handling and deployment of infrastructure in offshore development projects. The document provides recommended methods and best practices for mapping and classification of relevant habitats and species, impact and risk assessment, mitigation and monitoring of effects. A summary of existing knowledge on impact from the various operations is given.

Table 2.1 addresses source of impact, potential effects, and influence areas, which should be considered when planning for mitigating actions and monitoring regime. Suggestions for mitigation is provided in this document.

Table 1-1 The main sources identified as a possible threat to coral communities during drilling operations, its potential effects, and applicable methods for documenting the impact/influence.

Source		**Potential effect**	**How to document impact/influence**	**Potential influence area**
Deposition of discharges	Cuttings WBM Cementing Circulation	- Burial - Excessive particle loads - Exposure to toxic/ harmful components	Demarcation of the deposition area by: - sediment core samples using barium as tracer - visual assessment of the deposition area. - Turbidity, current measurements, and sediment traps	>10 mm: 0 - 100m 3 - 10 mm: 100 - 250m 1 - 3 mm: 250 - 500 m
Suspended solids	Suspended solids from drilling activities, incl. cementing and circulation, cuttings, WBM, and weight material in the **water column**	- Excessive particle loads - Exposure to sharp/ harmful particles -Proven negative effect on coral larvae from suspended solids. -Data deficiency on long term effects from exposure to particles	Demarcation of the plume by: - Sediment traps using barium as tracer for finer particles - Visual assessment of the plume. - Turbidity measurements - Current measurements / dispersion modelling - Turbidity, current measurements, and sediment traps	Suspended solids (particles) expected at least 1000m downstream. Suggested exposure thresholds (corals and sponges): Short term (<60 hours): 20 mg/L Long term (>60 hours): 10 mg/L Storm/burst: 100 mg/L
Pipelines and infra-structure	Laying of pipeline or infrastructure Placement of rocks Trenching	-Removal of habitats -Crushing -Smothering	- Visual assessment - Turbidity measurements	~25 m corridor for pipelines
Anchor operations	Anchor Anchor chains Grappling hooks Pennant wires	-Physical damage -Excessive particle loads	*Physical damage – Before/after:* - Visual mapping of the anchor – pennant - grappling corridors *Excessive particle loads:* - Turbidity measurements at coral structures	~25-80m corridor, increasing towards rig, depending on chain length
Other	Accidental spills and discharges	-Excessive particle loads -Exposure to toxic components	- Visual assessment - Sediment sampling – chemical analysis of relevant components - DGTs and POMs	

2 INTRODUCTION

On the Norwegian continental shelf (NCS), several red listed or potentially threatened seabed habitat types have been identified (referred to as "Species and Habitats of Environmental Concern" – SHEC in this document). Before drilling or planning other seabed activities in areas where SHEC might occur, several requirements must be fulfilled. The requirements are according to regulations and project specific demands from the government. In many cases several studies shall be performed, before final plans are decided upon, and a discharge permit is given.

This document describes best practices for performing offshore activities in areas where SHEC can be expected, and how to minimize impact to the seabed habitats. The document describes what species and habitat types should receive special attention, how to map the habitat types, impact and risk assessments, mitigation and monitoring of impact. Some of the relevant processes involved are summarized in Figure 2-1, giving an example for a case where e.g. coral reefs can be found on the seabed.

The first edition of this document (DNV, 2013a) covered only cold-water corals but has now been updated to cover other habitat types as well. A map summarizing relevant known occurrences of SHEC on the NCS is given in Figure 2-2.

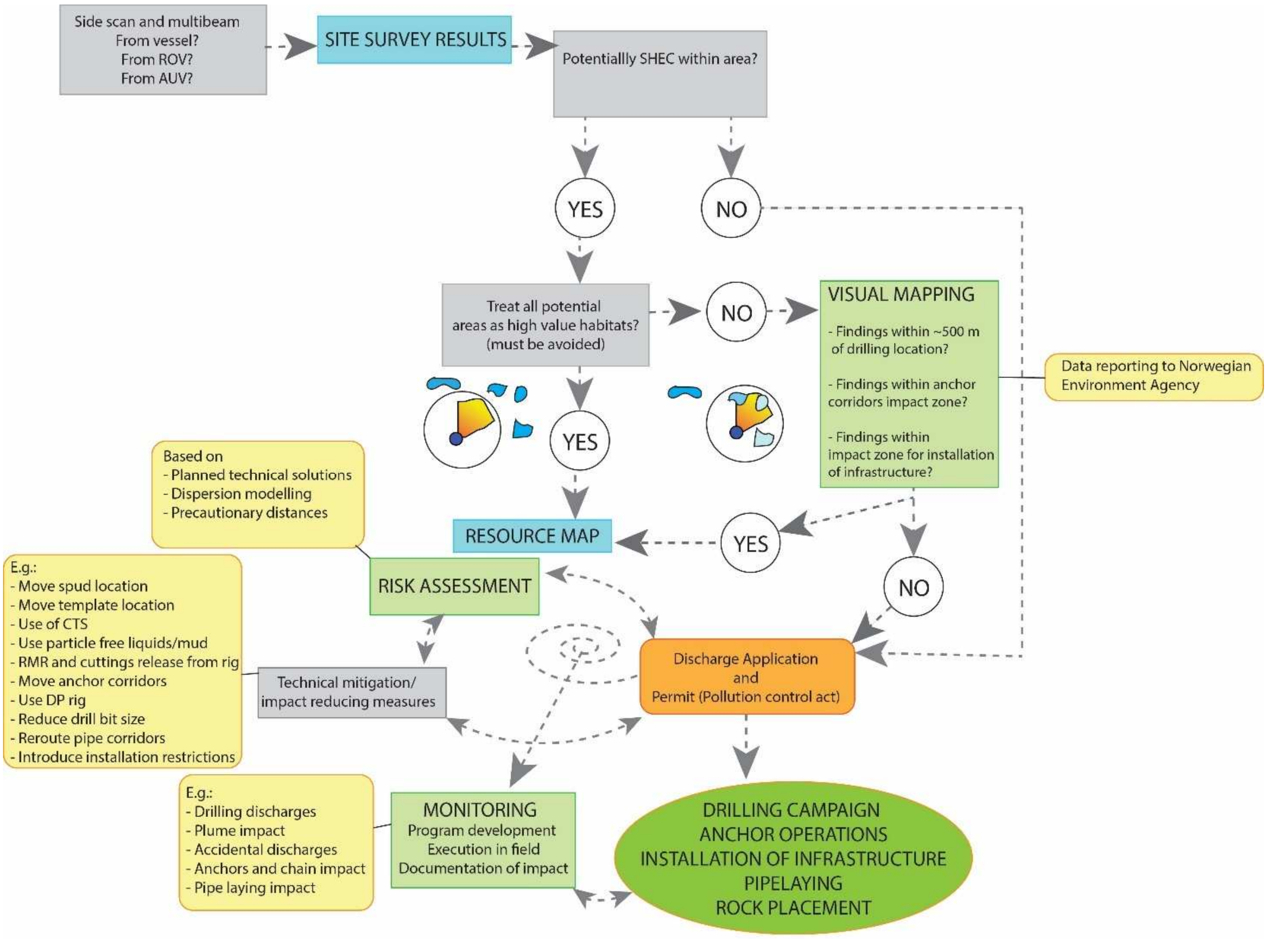


Figure 2-1 Flow chart summarizing some of the major processes involved prior to and during drilling, anchoring or installation of infrastructure and pipelaying in areas where species or habitats of environmental concern (SHEC) are known to occur. The diagram shows a typical decision three in cases where SHEC (e.g. coral reefs) can be revealed in the site survey data.

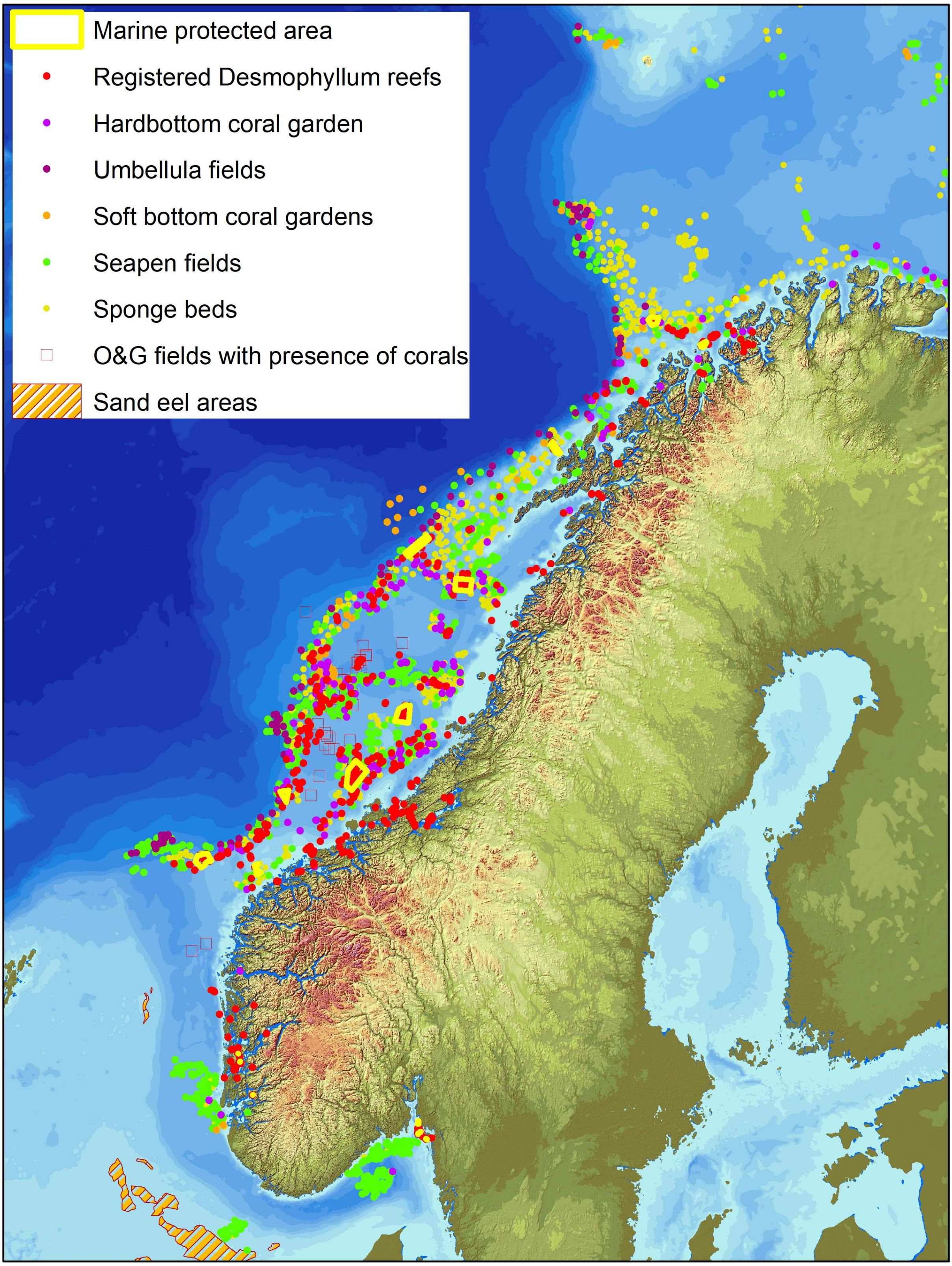


Figure 2-2 Map showing occurrences of relevant SHEC on the NCS. Data from MAREANO (www.mareano.no), sponge bed occurrences in the Barents Sea based on sites visually mapped (DNV). Oil and gas fields with known occurrences of corals (FUGRO, 2017 and DNV projects).

3 BACKGROUND

3.1 External framework

The biodiversity in Norway is protected by the Nature Conservation Act (Naturmangfoldloven, NML). The purpose of NML is to preserve nature and its biological, landscape and geological diversity and ecological processes through sustainable use and conservation (§ 1). According to NML (§ 6), everybody shall act with care and do what is reasonable to avoid harm to the biodiversity. If an activity is performed under a permit by a public authority, the duty of care is considered met. In the context of oil and gas exploration on the Norwegian continental shelf it is discharge permits from the Norwegian Environment Agency (Miljødirektoratet) that determines what is permitted under the duty of care concept. Furthermore, government decisions affecting biodiversity should as far as it is reasonable be based on scientific knowledge about the species' population status, habitat and ecological condition and the effect of impacts (NML § 8). When a decision without sufficient knowledge about the effects on the natural environment is made, the aim is to avoid possible significant harm to biodiversity. Lack of knowledge shall, according to § 9 in NML, not be used as a reason for postponing or failure to make management measures if there is a risk of serious irreversible damage to biodiversity (the precautionary principle). Costs related to obtaining broader knowledge will be covered by the operator (§ 11). However, there is a weighting between costs of acquiring the knowledge and the possible impact on the environment.

Permits for any activities that may cause pollution are issued according to the pollution control act. For oil and gas exploration and production on the Norwegian Continental Shelf (NCS) the discharge permits from the Norwegian Authorities (Norwegian Environmental Agency, NEA) determines what is permitted. When species or habitats of environmental concern (e.g. cold-water coral reefs) are identified or are likely to occur in the area planned for drilling operations, an extended site survey and visual mapping is required prior to exploration and production drilling, in accordance to the Activities Regulations; Requirements for Environmental Monitoring of the Petroleum Activities on the NCS (2017, §§ 53 og 54). In 2015 NEA released new guidelines for environmental monitoring of petroleum activities on the Norwegian continental shelf, M-300/M418 (Miljødirektoratet, 2015). The guideline provides more detailed requirements that supplement the more general regulatory requirements. Baseline studies and visual mapping operations and requirements are described in detail, and it is stated that visual baseline surveys must be performed prior to exploration drilling in areas potentially housing vulnerable fauna.

Environmental requirements for placement of subsea installations and routes for pipelines/ umbilicals as well as considerations regarding seabed fauna during anchoring operations is given in the framework regulations (§ 47 and § 47a).

What species and nature types should be considered declining or threatened and should be of particular concern on the NCS is inventoried by Norwegian Red Lists for species (Artsdatabanken, 2021) and nature types (Artsdatabanken, 2018), as well as OSPAR identified habitats that are classified as vulnerable and under threat of extinction (OSPAR, 2008).

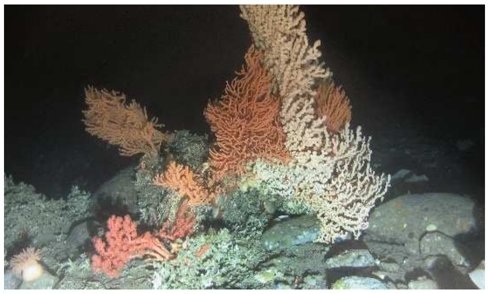
In Norwegian waters, species and habitats of environmental concern in relation to oil and gas activities (referred to as "SHEC" in the remainder of this document, see NOROG/DNV GL, 2013), is generally associated with cold water coral reefs (CWC), sponge bed communities and sea pen communities.

Several databases and internet pages present valuable information on seabed habitats. Of particular interest are the web portals of the national mapping programme MAREANO, mapping depth and topography, sediment composition, contaminants, biotopes and habitats in Norwegian waters (www.mareano.no). The Norwegian Environmental Agency's web page for visualization and reporting of data from visual surveys contains a lot of data from visual mapping campaigns for the petroleum industry dating back to 2006 (https://visuell.miljodirektoratet.no/). The web portal Barentswatch (www.barentswatch.no), www.yggdrasil.no (fisheries directorate) and Naturbase (https://kart.naturbase.no), showing relevant near-shore data. In addition, DNV has modelled the distribution of sponges in the Barents Sea, based on input data from >100 surveys. A brief description of relevant SHEC in Norwegian waters is given in the following section.

3.2 Species and Habitats of Environmental Concern (SHEC)

3.2.1 Cold-water coral reefs and hardbottom coral gardens

Coral reefs in Norwegian waters are in most cases situated at depths below 250 meters, in cold waters. The cold-water coral reef systems are compromised by the red listed species *Desmophyllum pertusum* (previously *Lophelia pertusa), Paragorgia arborea*, *Anthomastus grandiflorus* (Henriksen and Hilmo. 2015) as well as the habitat categories "Coral reef" and "Hardbottom coral garden" ("hardbunnskorallskog", Artsdatabanken, 2018) and OSPAR habitat type "Coral garden" (OSPAR, 2006). All species listed as nearly threatened should be prioritized for protection. Coral gardens are known to host rich and complex ecosystems and have been found in water as shallow as 30m (in Norwegian fjords) to several thousand meters on Open Ocean, and thrive between temperatures of 3 and 8°C. Densities of coral species in the habitat vary depending on taxa and abiotic conditions (depth, current, exposure, substrate), but may in some places reach densities more than 100 colonies per 100m^2.



According to OSPAR Recommendation 2010/9 on furthering the protection and restoration of coral gardens in the OSPAR Maritime Area, coral gardens are defined as a relatively dense aggregation of colonies or individuals of one or more coral species covering an area of at least 25m^2. Coral garden species includes leather corals (Alcyonacea), gorgonians (Gorgonacea), sea pens (Pennatulacea), black corals (Antipatharia), hard corals (Scleractinia) and, in some places, stony hydroids (lace or hydrocorals: Stylasteridae).

Desmophyllum pertusum is regarded as the most important reef-forming coral species in the North Atlantic Ocean. The Norwegian Continental Shelf holds the largest known *Desmophyllum* reef system in the world, covering an area up to of 60000 m^2. *Cold water coral* reef systems are regarded as a biodiversity hotspot, as the reef communities can be up to three times as biologically diverse as the surrounding soft sediment habitats (ICES, 2003), *D. pertusum* reefs are particularly vulnerable to physical damage. They are defined as slow growing species with annual growth rates of ~7 mm. Recent record indicate growth exceeding 29 mm the first years in warmer waters or on platform legs then reduced growth according to Gass and Roberts (2011), The structure is a colonial organism, which consists of many individuals/polyps. Living polyps build calcium carbonate skeletal and feeds by filtering plankton from water masses with extending tentacles. Carbonate skeleton from dead polyps remains and can form vast reef structures after growing for thousands of years. Desmophyllum usually grows towards the current creating a reef tail consisting of aggregations gorgonian corals with decreasing densities towards end tail which can be categorized as coral rubble.

In Norwegian waters the hard bottom coral gardens are characterised as being dominated by the Gorgonian corals *Paragorgia arborea*, *Primnoa resedaeformis* and *Paramuricea placomus* (OSPAR, 2009). The habitat is separate from the habitat type "coral reef", dominated by *Desmphyllum pertusum (Lophelia pertusa*) (Artsdatabanken, 2018). Gorgonian corals are not reef building (they don't develop external hard skeleton). *Paragorgia arborea*, the most common hard bottom coral garden species, is often found on coral rubble (dead coral reefs) and other hard substrates. For further details regarding coral garden definition in relation to OSPAR see section 3.2.5.

3.2.2 Sponge communities

Within Norwegian waters there are ~260 species of sponges, with the class Demospongia accounting for most of the species present. Sponges are filter feeding organisms. The water depths that sponges are usually found in are between 250 and 1300 m (Bett and Rice, 1992). Sponges occur on both hard substrata such as boulders and cobble or on soft substrate. Higher densities are usually found in higher aggregates on hard bottom substrata.

According to the Norwegian Red List for ecosystem types (Artsdatabanken, 2018) the nature type type "Svampspikelbunn i Barentshavet Sør" (sponge spicule seabed in Barentshavet south) is classified as "near threatened". The habitat type is characterised by having sediment with high densities of spicules originating from sponges in the genera *Geodia*, and other associated sponge species predominantly growing on soft sediments (e.g. *Aplysilla, Mycale, Stryphnus, Thenea*). The sponge habitats can form dense aggregations in the southern part of the Barents Sea.

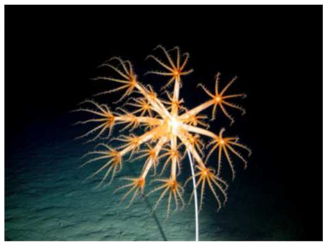
The OSPAR habitat type "Deepsea Sponge Aggregation" is threatened According to OSPAR (2010b). Background document for Deep Sea Sponge Aggregations describes the habitat as being dominated by primarily are composed of the classes Hexactinellida and Demospongia. Densities of 0.5-1 per m^2 of sponges in the class Demopongiae are reported to occur in areas typically characterized as "deepsea sponge aggregations".

3.2.3 Sea pen communities

According to OSPAR (2010c) the habitat type "Sea Pens and Burrowing megafauna" is recognised as being dominated by relatively dense occurrences any of the seapens species *Kophobelemnon stelliferum, Funiculina quadrangularis*, *Virgularia mirabilis* or *Pennatula phosforea*. The habitat type is considered by OSPAR to be under threat or/and in decline in OSPAR area "Greater North Sea" and "Celtic waters" but not in "Arctic waters" being comprised by the Norwegian sea and the Barents Sea. Norwegian lobster (*Nephrops norvegicus*), the squat lobster *Munida sarsi* and the sea cucumber *Parastichopus tremulus* is commonly found within the habitat.

MAREANO has given the habitat type the name "Sea pen communities". According to experience the OSPAR definition of the habitat suites well for the habitats encountered within fjords and in shallower waters in Norway where Norwegian lobster is commonly found. Offshore sea pen communities, however, do occur but not necessarily together with Norwegian lobster.

The large sea pen *Umbellula encrinus*, (reaching 2 meter in height) is not classified as threatened in the Norwegian Red List for species, but according to MAREANO occurrences of the species can represent OSPAR habitat "Sea Pen and Burrowing megafauna of the deep". The habitat has in some instances been mapped in deepwater field developments.



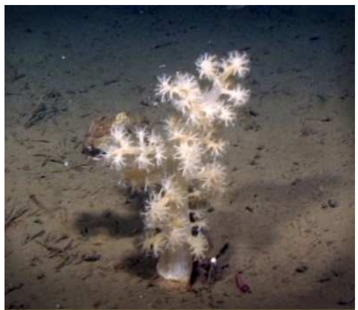
3.2.4 Bamboo coral forest

"Bambuskorallskog" – ("Bamboo coral forest"), is classified as a soft bottom coral garden characterized by being dominated by the bamboo coral *Isidella lofotensis*. The species is listed as Near threatened (NT) in Norwegian Red List for species and the nature type is regarded as endangered (EN) in the Red List for ecosystem types. The habitat type is rare, occurring in fjords and few locations offshore in the North Sea and Norwegian sea.

3.2.5 Other species or habitat types

In addition to the coral species above there are additional coral species categorized as "near threatened - NT" or "vulnerable - VU" in the Norwegian Red List for species (Artsdatabanken, 2021); *Anthelia fallax* (NT), *Anthomathus grandiflorus* (NT), *Anthothela grandiflora* (NT), *Swiftia pallida* (VU) and *Radicipes gracilis* (VU). The species *Radicipes gracilis* is rare, only registered south of Bjørnøya at 700-900 meters depth. Dense occurrences of the species is regarded as "grisehalekorallbunn" (soft bottom coral garden category together with *Isidella lofotensis*) and is regarded as endangered (EN) according to the Norwegian Red List for habitats (Artsdatabanken, 2018).

Aggregations of other coral species might be considered to fall in under OSPAR definition of coral gardens (OSPAR 2010a): "a relatively dense aggregation of colonies or individuals of one or more coral species". Or, by using the definition in OSPAR recommendation 2010/9 (OSPAR 10/23/1-E, Annex 31): "Coral gardens" means a relatively dense aggregation extending over at least 25m^2 of colonies or individuals of one or more coral species, such as leather corals (Alcyonacea), gorgonians (Gorgonacea), sea pens (Pennatulacea), black corals (Antipatharia), hard corals (Scleractinia) and, in some places, stony hydroids (lace or hydrocorals: Stylasteridae)." In Norwegian waters this might be the case for aggregations of e.g. carnation corals (*Drifa, Capnella or Gersemia*) or cup corals such as *Flabellum macandrewi*. A system for verifying coral garden species assemblages as true coral gardens or not, for UK waters has been proposed by Henry & Roberts (2014) and might be considered for Norwegian waters. However, "coral garden" definitions proposed by OSPAR are wide and not particularly well



suited for differentiating all truly vulnerable coral garden assemblages that might occur in the Norwegian waters, from coral garden assemblages that might be more common or might not fulfil the criteria for truly being recognized as coral gardens (being dense enough, having habitat forming capabilities, or support enhanced biodiversity.

Sand eels (*Ammodytes*) and their spawning grounds have sometimes been a cause for concern in some field developments, since their stocks have been depleting, and the Sand eels being stationary for parts of the year and having particular environmental requirements (sediment grain size). One species was regarded threatened in earlier versions of the Norwegian Red List.

3.3 Offshore activities of potential impact

Offshore seabed operations and drilling activities in areas where SHEC might occur on the seabed, represents a potential impact source especially from:

- mechanical damage such as crushing and removal of habitats
- sedimentation of drill cuttings/drill fluids and/or cementing material
- suspended particulates (solids)
- smothering by natural sediments

Mechanical damage can in most cases be avoided by carefully planning placement of drill hole, anchors, templates and in most cases pipelines and other infrastructure. Requirements for site surveys before drilling is granted will reduce the risk of mechanical damage and is described in M300/M408 (Miljødirektoratet, 2015 – revised 2021). Impacts on seabed communities from waste drilling products, is more complex, as the drilling is a multi-stage process consisting of a number of drilling events (Neff, 1987, Purser and Thomsen 2012). A general review of impacts is given in Cordes et al. (2016).

Environmental impact from noise and vibration can be important in relation to installation of infrastructure and particularly by aid of pile driving.

Impacts from accidental spills and seabed discharges of produced water will have potential for imposing several adverse effects on seabed habitats but is not discussed further in this document. Further information on impacts from produced water can e.g. be found in Neff et al. (2011).

In the sections below and Appendix A, B and C are summarised relevant knowledge and experiences made on the NCS. Focus is on drilling and impacts from smothering and mechanical damage from anchors, pipelines or installation of infrastructure. Relevant threshold levels for use in impact / risk assessments is presented in section 5.2.

3.3.1 Drilling

Release of particles, cuttings and mud chemicals are expected to directly impact the seabed habitats within the near zone of drilling, as well as suspended solids influencing nearby habitats for the duration of the drilling period via dispersal in the plume of the particles. The dispersion of particles will strongly depend on technical solutions, amount and type of drill mud, seabed topography and current regime at the seabed. On the NCS most discharges to the seabed come from the use of water-based mud (WBM) or particle free mud (spud mud). Oil based muds being released to sea have been phased out since 1993, and if used is generally shipped to shore for disposal. Oil based drill cuttings can be cleaned offshore (by use of TCC system, see e.g. Bilstad et al., 2013; IOGP, 2016) and is can be given a discharge permit if oil content is less than 1% dry weight of the material (Activities regulations § 68, https://www.ptil.no/en/regulations/all-acts/the-activities-regulations3/XI/68/). Note that in cases with relatively large discharges of cleaned cuttings to sea, limits for oil content (set by NEA) have been set to 0.3-0.5 % dry weight oil content.

General effects on seabed fauna from release of WBM and cuttings have been studied in a number of cases (e.g. Barlow and Kingston, 2001, Trannum et al., 2009; Trannum et al. 2011). Clear observable effects on many megafauna species because of settlement of WBM and drill cuttings appears to be often limited to distances of less than several hundred meters from point of release (Jones and Gates, 2010). In most cases WBM are considered to have environmental impacts on benthic communities generally within 100 meters from the drill site (Neff et al., 1987; Daan and Mulder, 1996; Montagna and Harper, 1996; Currie and Isaacs, 2005; Zuvo et al., 2005; Trannum al., 2006). WBM have a low organic content and low toxicity potential and can be regarded as only causing impacts on seabed habitats due to sedimentation. However, an impact study undertaken by Schaaning et al. (2008) indicated that changes in grain size and particle shape, toxicity effects and oxygen depletion are also of importance, within the limits of the near zone (some hundred metres away). Compared to natural sediments, WBM and drill cuttings are reported to contain more heavy metals (Neff. 2010), to be stickier, clinging to e.g. corals than natural sediments, thus having potentially more harmful effects than smothering by natural sediments (e.g. Trannum et al., 2010; Larsson and Purser 2011; Baussant et al., 2018; Larsson et al., 2013). Gorgonian corals have been shown to be adversely affected by sharper particles arising from anthropogenic activities (Liefmann, 2018), and it is expected that filter feeding organisms will be expected to be more sensitive towards excessive sedimentation than other fauna (Schaaning, 2008).

Changes in seabed water temperature is generally not expected but could occur depending on activities (discharges of water with higher temperature, compressors altering seawater temperature etc.). Increased temperatures together with increased sediment load has been shown to negatively impact sponges and corals (Knudby et al., 2013; Scanes et al., 2018). Use of particle free liquids (spud mud) containing salts as weight component should be considered in relation to potential negative impacts from increased salinity near the seabed.

Of relevance for offshore activities, and this handbook is expected effects on corals, particularly *Desmophyllum pertusum* (previously *Lophelia pertusa*) and sponges, particularly *Geodia* spp. Relevant knowledge is reported in detail in Appendix A and B where a summary of studies related to environmental impact on corals and sponges relevant for the NCS is given. Threshold criteria for impact on corals and sponges are also proposed. **The studies presented in Appendix A and B are basis for decision of threshold levels to be used in risk assessments of drilling activities, as presented in this handbook.**

3.3.2 Pipelaying and infrastructure

Mechanical damage and smothering from jetting or trenching or rock placement are expected effects from pipelaying and installation of infrastructure. The actual operation of laying down a pipeline may imply embedding by sediment jetting or covering by rock placement. Sediment jetting is performed by using tools similar to an ROV, but usually larger and with a skewer with nozzles that are about 1 meter below ground. The sediment is sucked out and washed out behind the tool, through an exhaust pipe. The mechanism of this technique is to fluidize the sediment making the pipeline to sink into the sediment. The different equipment types will have varying number of water jets, water pressure operating ranges, and arrangement of eductor tubes. Discharges from eductors will usually occur 2-5 meters above the seabed. Disturbance is expected to come from direct damage and removal of sediments in the trench and from smothering and sedimentation of seabed fauna communities due to sediments being dissolved and flocculated in water. Rock or gravel placement is done by deploying the gravel through a "fall-pipe" for accurate deployment. Physical damage to surrounding habitats can also arise from the pipeline buckling and moving along the seabed as temperature within the pipeline changes. Movements have been reported to be over 10 meter and can be controlled by placing rocks for locking the pipeline. The impact from any pipelaying operation will vary depending on diameter of pipe and planned operations.

Experiences have shown that installation of pipelines can adversely affect seabed sponge communities, with direct mortality occurring over a relatively small area (<10 m to each side of the pipeline. E.g. DNV, 2015b; DNV GL, 2016; DNV, 2019; DNV 2023a; DNV 2023b).

Rock placement results in direct removal of habitats usually in 5-10 meters wide corridors but can reach further depending on seabed topography and technical solutions. Outside this a transition area is generally seen, with moderate impact on the seabed communities. In large infill areas a substantial footprint on the seabed can be expected, and presence of SHEC should be considered specifically for each infill. A footprint 2 times as large as the infill area has been reported and pile size must also be taken into consideration when planning and mitigating the environmental impact.

Impact from jetting and trenching will vary depending on trenching depth and equipment used. The impact is expected to result in smothering over a short time period out to 5-25 meter, with discharges ranging from 2-20 kg/second, being dispersed 2-5 meters above the seabed (DNV, 2013b). Little environmental impact is expected outside 15 meters.

With regards to mapping, based on experience, and in order to minimise need for extra work, 50 meter to each side of the planned pipeline route is recommended mapped in areas with e.g. coral reefs. This area should be extended to 100 meters to each side of the planned route in areas with high density of corals.

In case of findings of SHEC within expected impact area, these should be avoided, or installation restrictions (such as minimising jetting, rock placement etc.) should apply. Se section 7.4 for mitigation alternatives.

3.3.3 Anchor operations

Anchor operations will affect seabed communities either directly by crushing due to the anchors, chains or grappling hooks, or indirectly, by being subject to excessive sedimentation.

Influence area from chains moving over the seafloor due to rig movements have been found to increase with distance from the anchors. DNV GL. (2015a) reported anchor chain impact increasing closer to the well location with chain marks being observed 40 meters apart. Scars in seabed was observed to be up to 2 meter wide and 1 meter deep. DNV (2012) reported how chains can create scars on coral reefs. In later years there have been stricter requirements for pre-laying and use of ROV assisted laying of anchors and use of fibre with buoys is more commonly used, thus reducing sideways movement of anchor chains.

It is suggested to use an influential area representing a cone shaped **~**20-80m corridor (depending on chain length), in addition up to ±15m position inaccuracies during pre-laying operations (ROV-assisted pre-laying may further improve the accuracy). These values are obtained from previous anchor handling operations and general information from anchor handling personnel with regards to accuracy during the pre-laying operations. The influence area should be adjusted depending on technical solutions being used.

Aassociated with both ends of the anchor chain is a pick-up system to help attaching the work wire from the anchor handling vessel, before winching in the anchor chain. Pick-up systems vary greatly but generally comprise one or more pennant wires with varying lengths and buoys linked to an ROV pick-up hook. There are two main types of anchor pick-up operations; pick-up by grappling and ROV pick-up. Grappling is less commonly used in the last years. What method is used can be specified according to how delicate the operation must be. A grappling approach on the pennant wire involves dragging a grappling anchor, usually 100-150 meters along the seabed, hooking on to the pennant, before hoisting up the anchor chain. On a site with known SHEC, like Haltenbanken, anchor handling by ROV pick-up is often preferred instead of pick-up by grappling. Such an arrangement can typically involve a short chain (~15m) for correcting the lay down and a longer pennant wire (60-70m) trailing behind the anchor. A buoy with ROV pick-up hook is attached to the pennant wire. An ROV hooks the work wire from the anchor handling vessel directly to the ROV pick-up system and pennant. In both types of pick-up operations, the anchor handling vessel will typically go backwards while hoisting the anchor chain straight up from the sea floor without dragging it.

Use of fibre instead of chain should be considered as an alternative, so that impact on seabed can be minimised. See section 7 for more information on mitigation alternatives.

During pipelaying in areas with corals, use of anchored barges will have a potential for severe mechanical damage to seabed communities, as the chains will be dragged along the seabed as the barge moved forward. Use of DP barges or other lay vessels should be considered.

4 MAPPING

4.1 Mapping techniques

Techniques and methods to be followed when performing visual mapping are given in the standard NS-EN 16260 (Standard Norge, 2013). The document deals with technical requirements for carrying out visual assessments but is not adapted for mapping specific targets such as corals.

Gathering of survey data relating to seabed bathymetry and sediment characteristics can be of great importance in relation establishing presence of SHEC or not. The starting point for resource mapping is site survey data obtained from multibeam echo sounder or side scan sonar, showing seabed bathymetry and topography, including additional data such as backscatter and thus hardness of the substrate and elevation of objects (Table 4-1). The data can be obtained from vessel, ROV or AUV, with increasing level of resolution (particularly if synthetic aperture sonar is utilised). Details regarding collection of these data are not described in further detail in this handbook, reference is made to relevant standards and guidelines for Offshore surveying.

For visual mapping purposes, it is highly recommended to use ROV (with sonar) that should be manoeuvred around/over the habitats or targets to be filmed. Alternatively, towed observation platforms or drop cameras can be utilised. Drop camera is not recommended for visual mapping of corals or discretely distributed habitats that are to be re-filmed in follow up studies. Drop cameras might be suitable for classifying sponge occurrences or seapen aggregations over larger areas. A general comparison of ROV vs. drop camera and AUV as visual platform is given in Table 4-2.

Use of HD camera is recommended. Visual equipment must as a minimum be able to render objects smaller than 0,5 cm on screen.

Laser points should be utilised for size estimates.

Table 4-1 Summary of acoustic methods used for obtaining site survey data.

Method	**Summary**
Multibeam echo sounder (MBES)	A sonar sends out sound waves as a swath of multiple beams. The ping sent out generates data for obtaining **depth readings** along the seabed. The data can be compiled into a digital terrain model. The width of the swath and resolution of the data depends on distance from the seabed and platform used (hull mounted on vessel, on ROV or AUV).
Side Scan Sonar (SSS)	Sound waves (100-500 kHz) are sent out in a swath. Data obtained/ backscatter is used to analyse **structure and reflectivity** of the seabed. The technology provides information on the **height of objects**, based on the shadow it casts. The width of the swath and resolution of the data depends on distance from the seabed and platform used (towed from vessel, on ROV or AUV).
Synthetic aperture sonar (SAS)	SAS combine a number of acoustic pings to form an image with much higher along-track resolution than conventional sonars. The principle of synthetic aperture sonar is to move the sonar while illuminating the same spot on the sea floor with several pings. Resolution is down to 4 cm. Imagery and bathymetry is obtained.

Table 4-2 General comparison of ROV vs. drop camera and AUV as visual platform.

Visual platform	Pros	Cons
ROV	- Stable video footage - Accurate control over survey pattern - Generally large field of view - Sonar making it possible to actively search for targets horizontally - Possible to perform detailed studies of sizes	- More expensive - Need for specialised crew - Tether/fibre can be more sensitive for breakage - Vessel must have DP system
Drop camera	- Generally cheaper - Less need for specialised crew - Downward looking camera making coverage calculations easier - Can be utilised on vessel without DP system	- Little control over movements and actual survey pattern - Risk of missing seabed features, or unintentionally crashing into structures. - Difficult to stop at certain points of interest - Sensitive towards wave action resulting in erratic vertical movements and variable visual scale of assessment area - Usually not possible to scan horizontally for possible targets
AUV	- Covers large areas fast - Downward looking camera is good for making mosaics	- Expensive in operation - Little room for detailed studies of e.g. coral reefs or particular targets that show up. - Low manoeuvrability at target areas - Black and white images, generally not colour. - No video obtained

4.2 Mapping strategies

Requirements and recommendations for visual mapping in relation to oil and gas activities is given in M300 (M408) (Miljødirektoratet, 2015 – revised 2023).

Requirements for visual mapping might vary depending on geographical area and expected SHEC. The recommended mapping strategy will also vary accordingly. After having established the need for visual mapping and expected SHEC in the area, if any, (see Figure 2-1 and Figure 2-2) there might be a need for visual mapping. If no targets are identified in SSS or MBES data or identified targets are outside any expected influence area of activities, there might be no need for visual mapping. In many instances, however, there is a need for performing detailed visual mapping. Visual survey pattern to be used will vary depending on type of expected fauna or planned operations.

When mapping offshore development projects in relation to environmental issues there is generally a need for covering larger areas relatively quick, and data gathered is generally used for descriptive purposes (e.g. describing where there are many, few or no sponges, and for classifying coral reefs as input for impact assessments and mitigation planning. A map summarising relevant SHEC in the area is referred to as a resource map.

For drilling activities in new areas or areas where SHEC potentially can occur, the general recommendation is to perform visual surveys of the area surrounding the PWL out to at least 250 meter in four directions, also in instances where no coral structures have been identified.

In coral reef areas, target surveys based on initial interpretations of side scan sonar and multibeam data is recommended. Coral reefs and coral gardens needs to be assessed specifically, and recommended strategies are presented in section 4.4.

In the Barents Sea where sponge beds are expected, it is generally recommended to perform a two-step survey, with extended and denser survey pattern in case initial mapping reveals sponge occurrences. See section 4.5.

As a rule of thumb visual survey speed should not exceed 1 knot, and height above seabed should be between 1-3 meter, this will help secure stable image quality. All underwater positions and preferably heading, depth and altitude should be recorded together with time. A temporal resolution of 1 second is sufficient.

It is recommended to take a still image at least every 30 meters. Much more frequent on specific targets.

Further details regarding data formats and storage are presented in section 4.7.

4.3 Classification of visual data

Classified interpretations of visual data, following standardised naming conventions ensures comparable units for scoring of SHEC resources in risk assessments and for reporting to the government.

When mapping the seabed habitats, the interpretations should be performed by experienced personnel with relevant training. identification of organisms should be carried out by personnel with documented education or experience within relevant areas of marine taxonomy (NS-EN 16260).

Naming of sediment and fauna categories should as a minimum follow naming conventions as giving in Table 4-3 and Table 4-4. The fauna categories will be described in detail in the following chapters (4.4 Corals, 4.5 Sponge communities and 4.6 other fauna types). As high detail level as possible is desirable when performing logging and classifications of fauna. For logging specific species abundances use of SACFOR scale is recommended (NS-EN 16260).

NOTE. Data obtained must also adhere to the Norwegian Environmental agency's requirements for visual data, and data to be exported to the data base must follow specified data model (https://visuell.miljodirektoratet.no/). Requirements for mapping seabed according to Nature types in Norway classification system (NiN) might be expected as NiN 3.0 will be presented during 2023 (see https://artsdatabanken.no/Files/55164/Marin_feltveileder_NiN_3.0.pdf for marine seabed systems near shore). It is recommended to map of the seabed according to this system when details regarding offshore marine nature types are in place.

For the purpose of mapping seabed fauna for impact assessments for the offshore industry, a visual assessment area of 25 m^2 is convenient. This is also a unit sometimes utilised by OSPAR for describing habitat types and for guidelines for inshore mapping. It is recommended that a new assessment or count of individuals is continuously made, based on what is found in the surrounding area of the observation platform as it moved along the survey line (Figure 4-1). The unit should be the base for classifying habitat types "Coral garden", "Sea pen communities" and other fauna counted over an area of 25m^2. Counting all single individual of e.g. gorgonian corals on single reefs can be performed, but is not recommended practice, instead semi-quantitative classes is recommended. Sponge communities and substrate types should in most cases be running categories along the survey line. Single *Desmophyllum* colonies should be classified according to coverage of live polyps and colony size.

Events/ classifications should be logged when underwater position of ROV/camera is directly above centre of the event (i.e. a coral unit), or a navigation offset will have to be implemented to compensate for the distance between camera and navigation transponder.

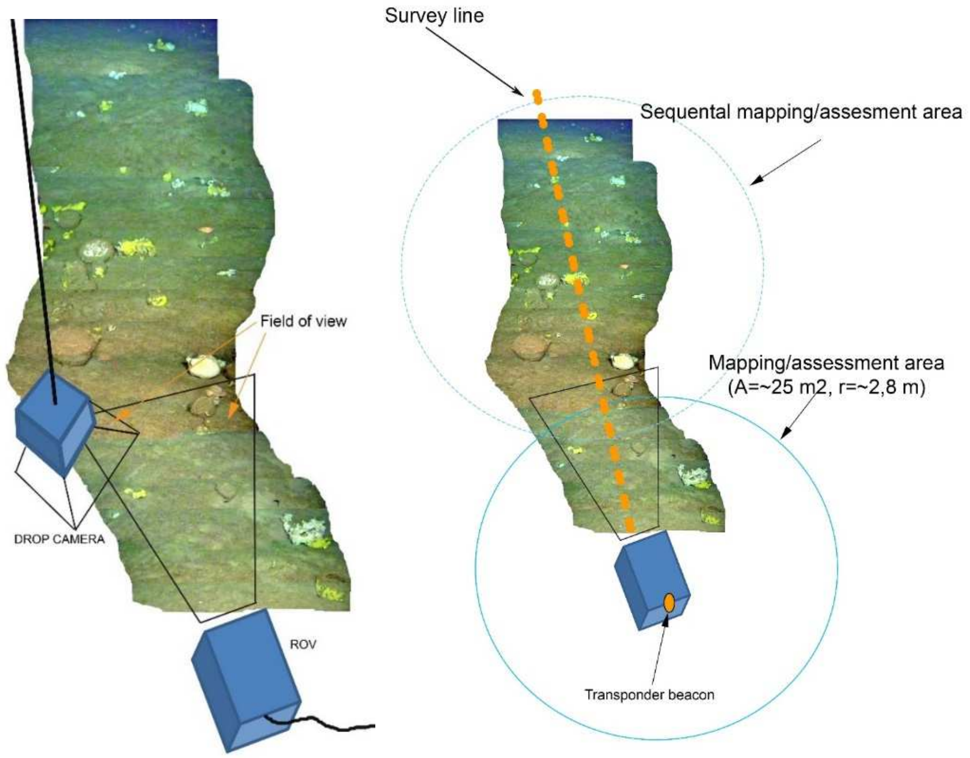


Figure 4-1 Figure showing field of view and recommended assessment area (25m^2) for categorizing the habitat types coral garden, sea pen communities etc. Sponge categories and substrate categories should be logged continuously along the survey line. Single *Desmophyllum* coral structures should be classified according to a set of rules based on size and coverage of living polyps (see next section).

Table 4-3 Substrate classification categories recommended for visual surveys on the NCS.

Name	Code	Category type	Category extent	Definition/comment
Mud and sand	S1	Substrate	Continuous	<2 mm
Sand	S2	Substrate	Continuous	0.063 – 2 mm
Mud and sand with gravel, cobbles and boulders	S3	Substrate	Continuous	<2 - >256 mm
Gravel, cobbles and boulders	S4	Substrate	Continuous	2 -> 256 mm
Bedrock or consolidated sediments	S5	Substrate	Continuous	
Coral gravel	S6	Substrate	Continuous	2 - 64 mm
Coral framework	S7	Substrate	Continuous	Dead or living intact reef
Shell hash	S8	Substrate	Continuous	2-64 mm
Drill cuttings	S9	Substrate	Continuous	
Drill cuttings partial cover	S9-1	Substrate	Continuous	
Drill cuttings complete cover	S9-2	Substrate	Continuous	
Boulder	SF1	Seabed feature	Single point	> 256 mm
Cobbles	SF2	Seabed feature	Single point	64-256 mm
MDACs	SF3	Seabed feature	Single point	Methane derived autogenic
Pock Mark	SF4	Seabed feature	Single point	
Gas seep	SF5	Seabed feature	Single point	
Bacterial mats	SF6	Seabed feature	Single point	
Iceberg Scour Mark	SF7	Seabed feature	Single point	Glacial
Hydrothermal vent	SF8	Seabed feature	Single point	
Trawl track	A1	Anthropogenic	Single point	
Garbage	A2	Anthropogenic	Single point	Type as comment

Table 4-4 Fauna classification categories recommended for visual surveys on the NCS

Name	Code	Category type	Categori extent	Definition/comment
Soft bottom sponges single	F1	Fauna	Single point	Single sponge or <1% coverage
Soft bottom sponges scattered	F2	Fauna	Continuous	1-5% coverage
Soft bottom sponges common	F3	Fauna	Continuous	6-10% coverage
Soft bottom sponges high	F4	Fauna	Continuous	>10% coverage
Hard bottom sponges single	F5	Fauna	Single point	Single sponge or <1% coverage
Hard bottom sponges scattered	F6	Fauna	Continuous	1-5% coverage
Hard bottom sponges common	F7	Fauna	Continuous	6-10% coverage
Hard bottom sponges high	F8	Fauna	Continuous	>10% coverage
Desmophyllum Dead	F9	Fauna	Single point	See section 5.2.3
Desmophyllum Poor	F10	Fauna	Single point	See section 5.2.3
Desmophyllum Fair	F11	Fauna	Single point	See section 5.2.3
Desmophyllum Good	F12	Fauna	Single point	See section 5.2.3
Desmophyllum Excellent	F13	Fauna	Single point	See section 5.2.3
Coral Garden Poor	F14	Fauna	Single point	1-5 hard bottom coral garden individuals per 25 m^2
Coral Garden Fair	F15	Fauna	Single point	6-10 hard bottom coral garden individuals per 25 m^2
Coral Garden Good	F16	Fauna	Single point	11-15 hard bottom coral garden coral individuals per 25 m^2
Coral Garden Excellent	F17	Fauna	Single point	>15 hard bottom coral individuals per 25 m^2
Paragorgia, single on boulder	F18	Fauna	Single point	1 Paragorgia on top of larger boulder
Sea Pen Communities Poor	F19	Fauna	Single point/Continuous	1-5 individuals per 25 m^2
Sea Pen Communities Fair	F20	Fauna	Single point/Continuous	6-10 individuals per 25 m^2
Sea Pen Communities Good	F21	Fauna	Single point/Continuous	11-15 individuals per 25 m^2
Sea Pen Communities Excellent	F22	Fauna	Single point/Continuous	>15 individuals per 25 m^2
Umbellula	F23	Fauna	Single point	Single specimen
Gersemia/Capnella/Drifa Rare	F24	Fauna	Single point/Continuous	1-5 individuals per 25 m^2
Gersemia/Capnella/Drifa Scattered	F25	Fauna	Single point/Continuous	6-10 individuals per 25 m^2
Gersemia/Capnella/Drifa Common	F26	Fauna	Single point/Continuous	11-15 individuals per 25 m^2
Gersemia/Capnella/Drifa High	F27	Fauna	Single point/Continuous	>15 individuals per 25 m^2
Soft bottom coral garden Poor	F28	Fauna	Single point/Continuous	1-5 individuals per 25 m^2
Soft bottom coral garden Fair	F29	Fauna	Single point/Continuous	6-10 individuals per 25 m^2
Soft bottom coral garden Good	F30	Fauna	Single point/Continuous	11-15 individuals per 25 m^2
Soft bottom coral garden Excellent	F31	Fauna	Single point/Continuous	>15 individuals per 25 m^2

4.4 Mapping cold water coral reefs

4.4.1 Growth forms of importance in relation to mapping

The following section describes main growth forms of coral structures that will be important to be aware of when planning to map corals on the NCS.

The stony coral *Desmophyllum pertusum* (*previously Lophelia pertusa*) is a hermatypic species, meaning it builds reef structures that can reach substantial size. The growth pattern of a *Desmophyllum* reef can be classified into mounds and single coral structures/colonies (composed of a single branching individual). A mound can consist of several dead and alive *Desmophyllum* colonies ("mini reefs") together with coral rubble and fragmented reef remains and can reach heights up to more than 30 meters. On old mounds there can be several terraces upon each other with living colonies. In some ridge areas the coral mounds have grown together creating reef complexes reaching several hundred meters in length. In specific areas, such as sills *Desmophyllum* colonies can form a more or less continuous blanket reaching more than 50 meters in length.

Every single *Desmophyllum colony* is characterised by a living front end with living coral polyps facing towards the prevailing current direction. The living front is frequently followed by dead reef framework and a tail of coral rubble (Figure 4-2). The size of the dead part of the reef can be substantial on old systems. Soft corals grow on living and dead reef structures as well as on boulders between reefs. Dead coral reefs also have value in terms of hard substrate and added niches/hiding places.

The living front side of the *Desmophyllum* reef is important to map, but is often overlooked in visual surveys, or ROV pilots are not aware of the coral's growth form.

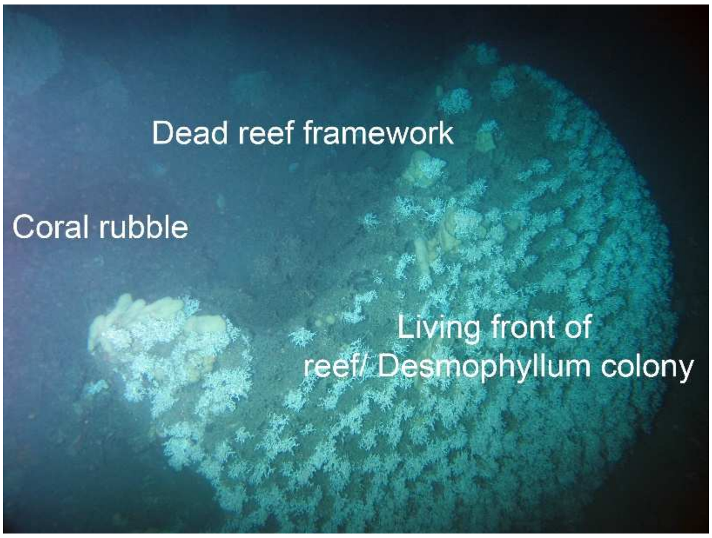
Desmophyllum reefs are rich in biodiversity and parts of the reef are often overgrown by the soft corals *Paragorgia arborea*, *Primnoa resedaeformis* or *Paramuricea placomus* and various types of sponges (E.g. *Phakellia*, *Mycale, Geodia*) are found on or between reefs. Entirely dead reefs with respect to *Desmophyllum can* still have dense populations of soft corals. Aggregations of soft corals are not uniformly distributed over any reef formation, - rather they are perched on top of living or dead reef framework or boulders; most of the time facing into the prevailing current direction. The soft corals are frequently clustered together in certain areas and these aggregations can be actively searched for with an ROV. In general, not all soft corals on a reef structure can be counted, as this would be too time consuming, but smaller areas along the survey route should be assessed. Solitary *Paragorgia* specimens on top of boulders are very common in certain areas and is proposed logged as a separate class unit.

4.4.2 Survey strategy for coral reefs

For visual mapping of coral reef habitats in relation to offshore activities, two main habitat types are recommended:

- ***Desmophyllum* structures/colonies**
- **(Hard bottom) Coral gardens, -** consisting of several gorgonian coral species when they occur grouped together

Mapping of these habitats are described in detail in the following sections, categories are given in Table 4-3. An example of the recommended mapping practice is shown in Figure 4-2. The basis for decision on where to visually map comes from site survey data, i.e. side scan sonar and multibeam data, where potential coral areas are identified. It is important to note that there can be large areas of seafloor where no corals occur, before suddenly a coral mound appears, therefore a systematic acoustic mapping and inventory of potential targets is needed. The operator should decide in the planning phase if multibeam and SSS data should be collected from Vessel, from ROV or from AUV. The vessel data will cover a larger area while ROV data can yield higher resolution data, sometimes required. AUV's can cover large areas with high resolution data relatively fast but can be expensive. Note: If no potential areas are identified within expected influence area of activities there might not be a need to perform visual mapping.



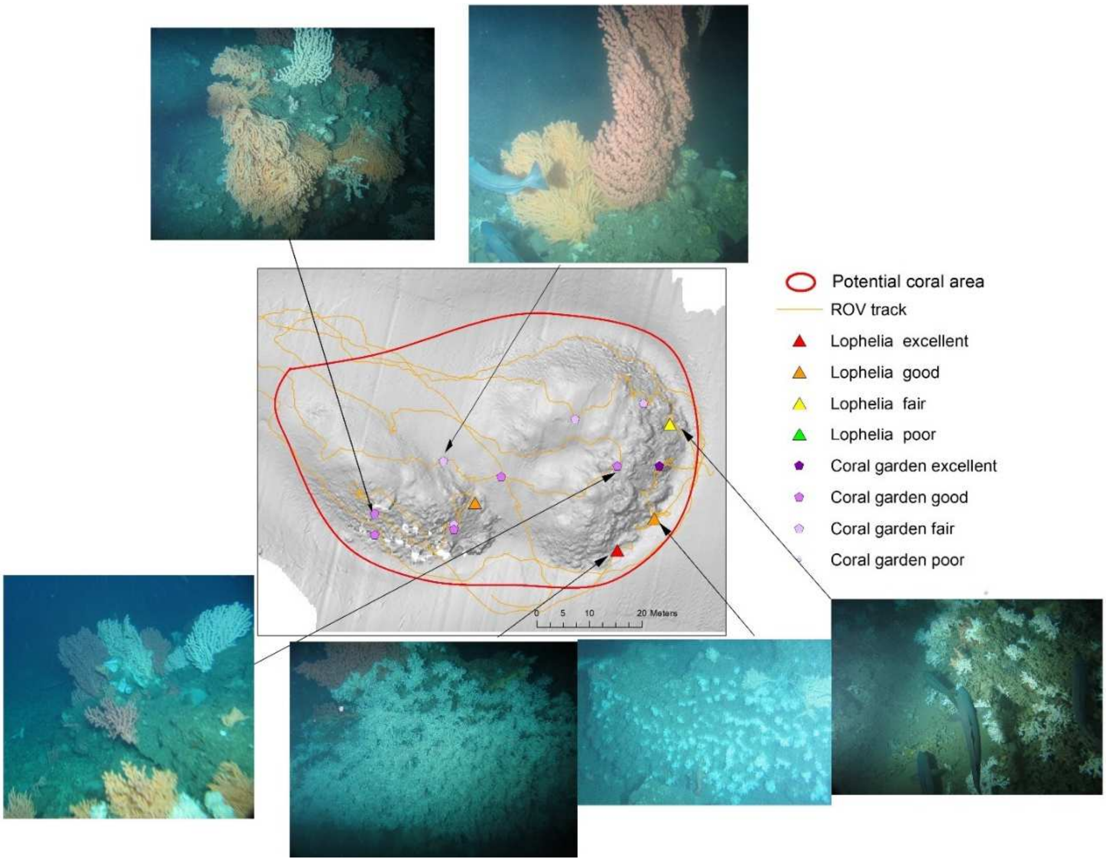


Figure 4-2 Example showing *Desmophyllum* reef Top: single *Desmophyllum* colony with a living front end. Bottom: Mound consisting of several living *Desmophyllum* colonies and Gorgonian coral gardens and how the results from visual mapping can be presented in maps. Note that symbology can vary from project to project. It is important that symbols are distinguishable from each other in maps. In this example Excellent *Desmophyllum* are marked red, a colour commonly used by the industry for obstacles/ objects to avoid.

4.4.3 Interpretations of side scan mosaic and multibeam data

The first stage when mapping corals is to delineate potential coral areas within the expected influence area of operations. If none are found there might be no need for visual mapping. Side scan sonar and multi-beam echo sounder are commonly used during site surveys to collect data of the seabed features in an efficient way. The area covered using these methods may vary, but a typically size is at least 4x4 km around a planned well position is recommended. The area should cover any possible moved spud locations and anchor patterns. 50 – 100 meters to the side of planned pipeline route should be considered mapped, depending on density potential coral areas. Careful considerations of size of mapped area should be performed in early phases to minimise the need for additional mapping in later stages.

The resolution of the data collected may also vary depending on different factors, such as distance between the sampling lines, height of the sonar above sea floor, frequency on the sensor used and towing speed. Experience has proven that resolution of at least 0.5x0.5 meter is required for determining occurrences of coral reefs with acceptable precision.

The data provided from the side scan sonar in a mosaic image and multibeam echosounder data, creates the basis for interpretation of potential coral structures within the surveyed area. Backscatter data indicates the reflectivity of the seabed and provides essential information on where the reefs are located, with *Desmophyllum* reefs being harder than the surrounding sediments. Areas should be interpreted by personnel experienced with locating coral reef areas. The multi beam echo sounder primarily collects depth data and will reveal seabed features such as ice scouring plough marks but can also have sufficient resolution to reveal potential coral features. In most cases ground truthing interpretations of potential coral areas will result in more reliable maps of potential coral areas. Several methods for automating classification of polygons exist and can give good classifications of polygons in many cases (e.g. see Jarna, 2019). Frequently, potential coral areas that are drawn are inaccurate, and creates extra work later on. It is recommended to draw the polygons as accurate as possible to begin with, covering the whole potential coral area including a buffer to compensate for inaccuracies in positioning.

A 'suitable' software package should be utilized for the interpretation of the side scan sonar mosaics. All potential coral structures down to the limitation of the resolution of the mosaic should be:

- Circled as accurately as possible around the outermost edges of the potential structure/area
- Geo-referenced in the middle of the structure (for tabulated purposes)
- Area for each structure calculated (for tabulated purposes and possibly impact assessments)
- Labelled with a unique number (for tabulated purposes)
- A buffer around each structure should be made to reflect the limits of accuracy of the positioning of the mosaic.

An example of how potential coral areas should be georeferenced as polygons in maps is shown in Figure 4-3.

When the coral reefs are stretched over long ridges, classifying smaller potential coral areas are recommended over drawing a large polygon over the ridge. Polygons correctly drawn over coral areas but not including empty seabed will be more flexible when performing risk assessments and finding mitigation alternatives e.g. for pipeline routes.

Based on what is found in each potential coral area during visual survey, the polygons can be scored with an overall value for impact assessments.

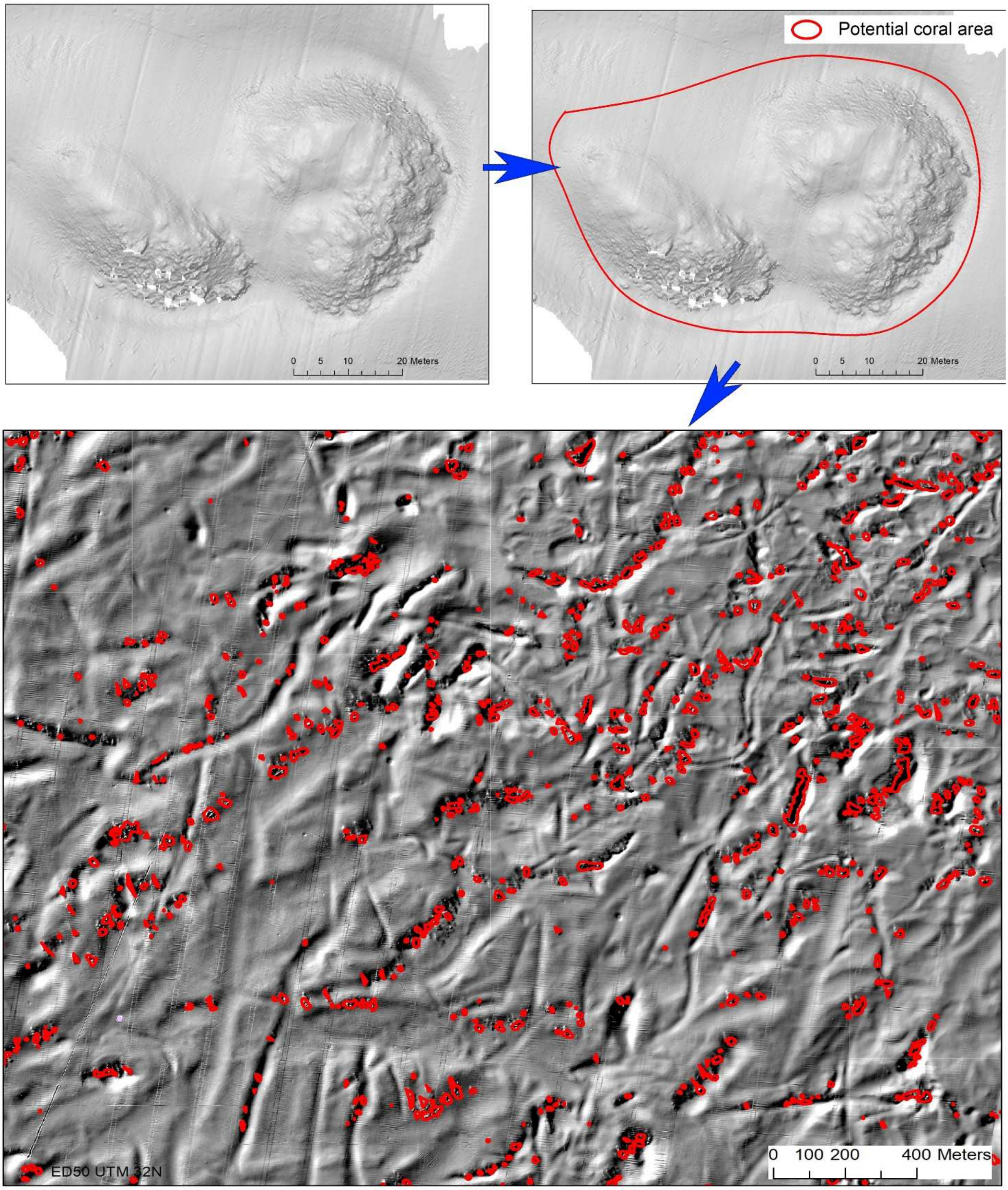


Figure 4-3 Figure showing interpretations of (SSS and MBES) at a drilling location and representation of potential coral areas as polygons.

4.4.4 Mapping *Desmophyllum (=Lophelia)* structures

Use the interpreted potential coral area for each of the identified mounds as a basis for targets to be mapped. In some instances, when potential coral structures are found outside any expected influence area of activities, there might be no need to perform further visual mapping. The unmapped areas should then be treated as high value habitats ("Excellent") and avoided.

The basic entity for mapping *Desmophyllum* reefs should be single *Desmophyllum* colonies. The size can range from < 0.5 m in height for young colonies up to >8-meter-high solid globular shaped reef structures consisting of one colony (see Figure 4-4).

When filming the potential coral areas make sure the whole reef is covered visually and **always film the front of each *Desmophyllum* colony** where living polyps are most likely to occur. Each colony should be assessed according to coverage of living polyps on the living part of the colony and area of living *Desmophyllum*. See Table 4-5 for recommended classification scheme. Real time assessment of area extent should be made by the aid of laser reference points and requires experienced personnel. Close up filming and still photo should be obtained for future monitoring.

Desmphyllum colonies should be logged as point data. Sizes should be registered. Substrate types such as "coral reef" and "coral rubble" as it changes over the reef should be logged as running categories.

When mapping irregularly shaped colonies or structures grouped over multiple terraces on top of each other, make an assessment based on the center of the cluster of polyps (Figure 4-5).

Table 4-5 Single *Desmophyllum* (*Lophelia)* colony classification

DESMOPHYLLUM		**Density of living polyps on colony front**					
		0 %	**0 - 5 %**	**5 - 20 %**	**20 - 40 %**	**40 - 60 %**	**60 - 100 %**
Total area of living *Desmophyllum* polyps on colony front	**< 0.25 m^2** Length and height: < 0.5 m or radius < 0.3 m	Dead	Poor	Poor	Poor	Poor	Poor
	0.25 - 2.5 m^2 Length and height: < 0.5 - 1.6 m or radius <0.3- 0.9 m	Dead	Poor	Poor	Poor	Fair	Good
	2.5 - 10 m^2 Length and height: 1.6 - 3.2 m or radius 0.9-1.8 m	Dead	Poor	Poor	Fair	Good	Excellent
	10 - 25 m^2 Length and height: 3.2 - 5 m or radius 1.8 - 2.8 m	Dead	Poor	Fair	Good	Good	Excellent
	> 25 m^2 Length and height: > 5 m or radius >2.8 m	Dead	Fair	Fair	Good	Excellent	Excellent

Figure 4-4 Example images of *Desmophyllum* colonies of various sizes and densities of living polyps.

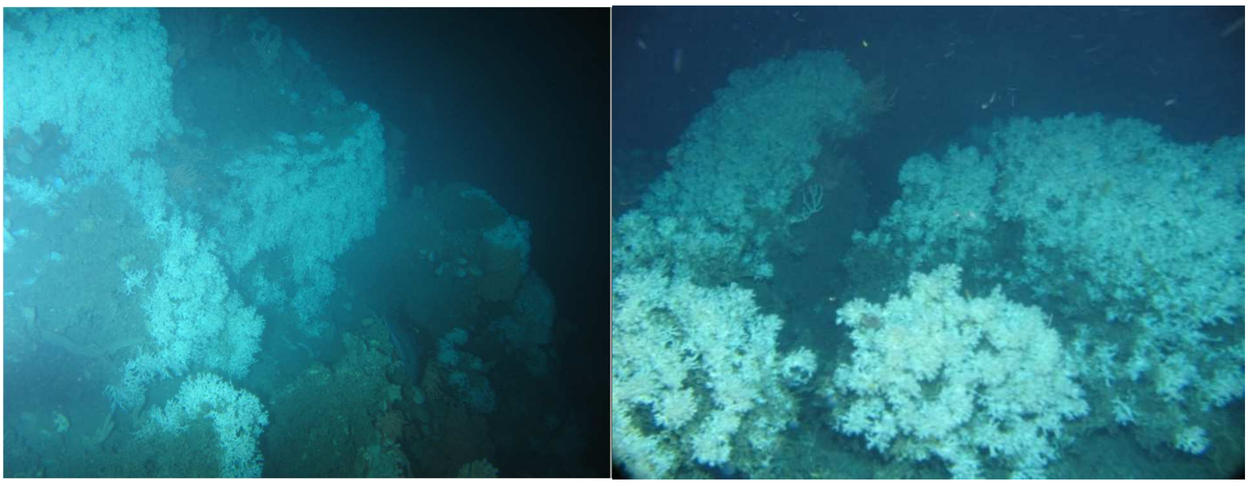


Figure 4-5 When mapping irregularly shaped colonies or colonies over several terraces, make an assessment based on the centre of the cluster of polyps within the assessment area.

4.4.5 Mapping of (hard bottom) Coral gardens

With the object of mapping reef systems for impact assessments in relation to offshore activities it is recommended to map hard bottom coral gardens (Gorgonian corals) as one mappable unit in addition to *Desmophyllum* classifications. Some reefs might have dense Gorgonian coverage, but few or none living *Desmophyllum* colonies.

The habitat should be mapped based on an assessment area of 25 m^2 as the observation platform moves around and over the potential coral areas. Criteria for classifications are shown in Table 4-6, example images given in Figure 4-6. Each event should be mapped as a point registration. For the sake of simplicity hard bottom coral gardens / Gorgonian Coral gardens is referred to as "Coral garden" in the remainder of this document. For presentations in maps the category should be described with reference to this document or as a footnote.

Table 4-6 Criteria for gorgonian coral garden (="Coral garden") classification

CORAL GARDEN	Specimens per 25m^2
Paragorgia, single on boulder	1
Poor	1-5
Fair	6-10
Good	11-15
Excellent	>15

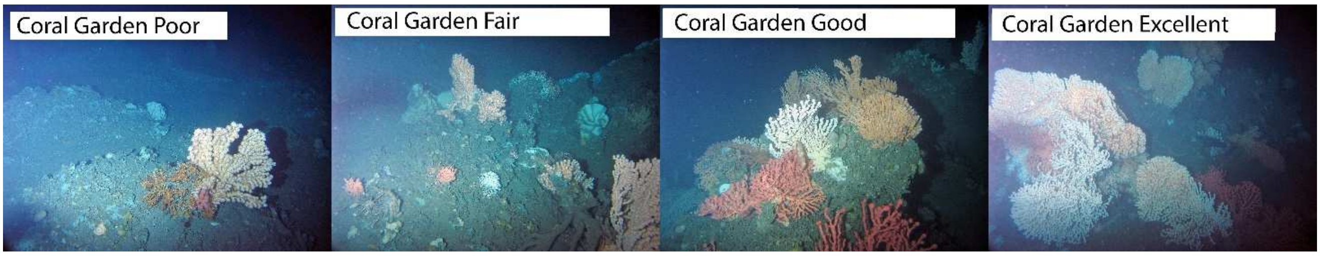


Figure 4-6 Coral garden classification examples. Assessments are made over an area of 25m^2, i.e. the immediate area surrounding the ROV.

4.4.6 Combining point classifications to coral area value

After mapping all potential coral areas, the stand-alone findings of both *Desmophyllum* and coral gardens can be combined to give a value for each whole coral area. Giving value to the different coral areas can be important input for risk/impact assessments, and for planning of mitigation. Setting a value to the areas can vary from case to case and depending on geographical area and occurrences of other fauna such as sponges. As a rule of thumb, for small to moderate sized polygons a "worst rules" principle should be administered, that is, the highest value of either *Desmophyllum* colonies or Coral Garden should count for the whole area. The size of the polygon can also be of importance when deciding how to value the areas, depending on the spatial resolution needed it might be necessary to subdivide polygons. Dead reef framework also holds value and should be taken into consideration.

According to the precautionary principle, unmapped potential areas should be treated as high value habitats (excellent) in any impact assessments.

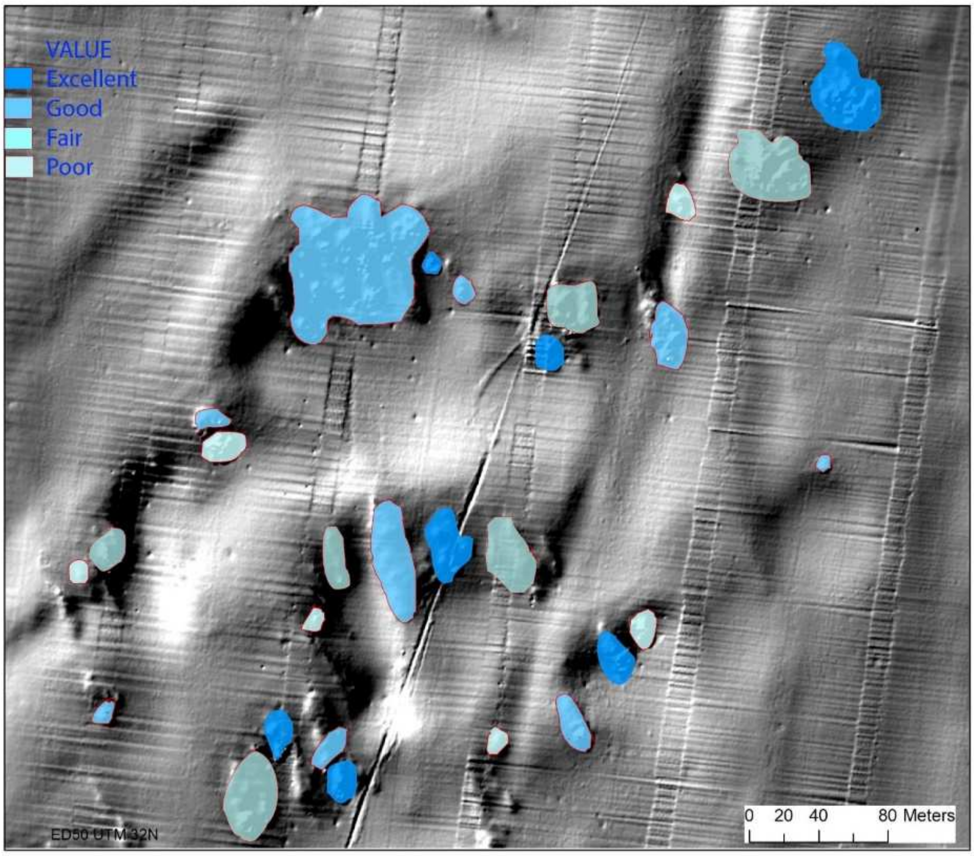


Figure 4-7 Map showing example of coral areas (polygons) given an overall value based on combined findings of *Desmophyllum* and Hard bottom coral gardens. Note: in this example is high value polygon given the colour dark blue. In offshore projects red colour is commonly used and generally indicates obstacles or areas to be avoided. Colour coding and symbology can vary from case to case.

4.5 Mapping of Sponge communities

4.5.1 Survey strategy sponge grounds

Sponges can occur at high densities in certain areas or be scattered on the seabed. Often there are gradients in densities over single oil and gas sites. Survey pattern to be followed differs from coral mapping because there are generally not any particular areas of interest identified to begin with. Soft bottom sponge occurrences do generally not show up in SSS data. Main objective when planning survey route for sponge mapping should be to cover the range of environmental variables (e.g. depth, current exposure sediment type) that exists, and give an assessment of sponge occurrences in the planned impact area.

Survey pattern will depend on the purpose of the survey, and if a drilling location is established or not. Mapping for sponge occurrences in the area of drilling activities is routinely made, while mapping pipeline routes are sometimes made as documentation. Inspecting impact area of anchor lines is sometimes required. Filming of the anchor lines would serve as a documentation of environmental impact, but would not aid in mitigating effect, unless the whole area of possible anchor spread is filmed with dense survey lines (area up to 3*3 km).

It is recommended to perform a two-stage mapping when surveying sites with potential sponge occurrences. If there are made noteworthy findings after an initial survey (Stage 1), covering the whole area, a more detailed study should be performed (Stage 2). Examples of survey patterns is shown in Figure 4-8. A standard “bow tie” survey pattern over the drilling location can also be performed as a stage 1 survey. It is recommended that center location is crossed at least two times as a minimum. In general, for assessing if there are sponges in an area it is recommended to film at least 2 km lines per 1 km^2 of seabed. For detailed studies (Stage 2), distance between lines can be between 25-50 meter in order to obtain hi-resolution data for interpolating sponge occurences between lines. Distance between lines should preferably not exceed 50 meter in order to obtain acceptable interpolation results.

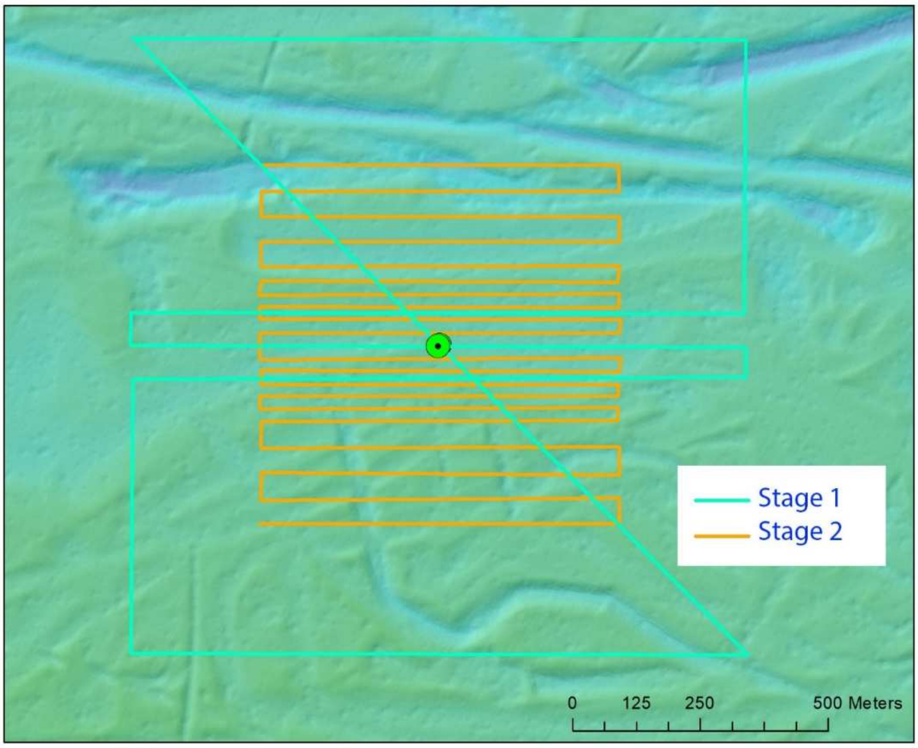


Figure 4-8 Figure showing example of planned visual survey routes for two-stage mapping of sponges. Stage 2 to be performed if significant findings are made in Stage 1.

4.5.2 Classification of sponge occurrences

Mapping of sponge bed habitats is described in M408/M300 (Miljødirektoratet, 2015 – revised 2023). Sponge habitats should as a minimum be classified in the following main categories:

- **«Soft bottom sponges»**: Species growing directly on the seabed, generally voluminous. And sometime long lived. Several species, especially *Geodia* spp. ("Kålrabisvamp") but also *Aplysilla sulphurea*, *Stryphnus ponderosus* and *Steletta* sp.). Typical species mentioned in OSPAR habitat "Deep sea sponge aggregation" (OSPAR, 2010b).
- **«Hard bottom sponges»:** Species most frequently found growing on rocks and hard substrates, particularly *Phakellia sp., Axinella infundubiliformis, Mycale, Antho dichotoma*. The species are commonly found on hard substrates and at higher densities the habitats can be regarded as ecologically important.
- «**Glass sponges»**: Hexactinellidae. Particularly deep waters, sometimes forming dense aggregations.

Example of Hard bottom sponges or soft bottom sponges are shown in Figure 4-9. Sponge coverage at the seabed should be assessed by trained personnel, logging sponge coverage as running categories along the survey route. The sponge coverage categories should be according to Table 4-7. Example images of densities are shown in Figure 4-10.

It is important that a large enough field of view is assessed (Figure 4-10), for density calculations. Still images taken with drop camera with a small field of view is not suited for classifying sponge coverage according to Table 4-7 (a single sponge filling much of the screen will result in severe over estimations of sponge coverage), instead an assessment over an small area should be made by analysing several (>10 images).

Figure 4-9 Example images showing Hard bottom sponges (L) and soft bottom sponges (R). Recommended minimum categories for mapping in relation to offshore activities.

Table 4-7 Criteria for sponge classifications, along the seabed.

SPONGES (hard-/softbottom)	Seabed coverage	Comment
Single individual	<1%	As single point
Rare	<1%	Running category
Scattered	1-5%	Running category
Common	6-10%	Running category
High	>10%	Running category

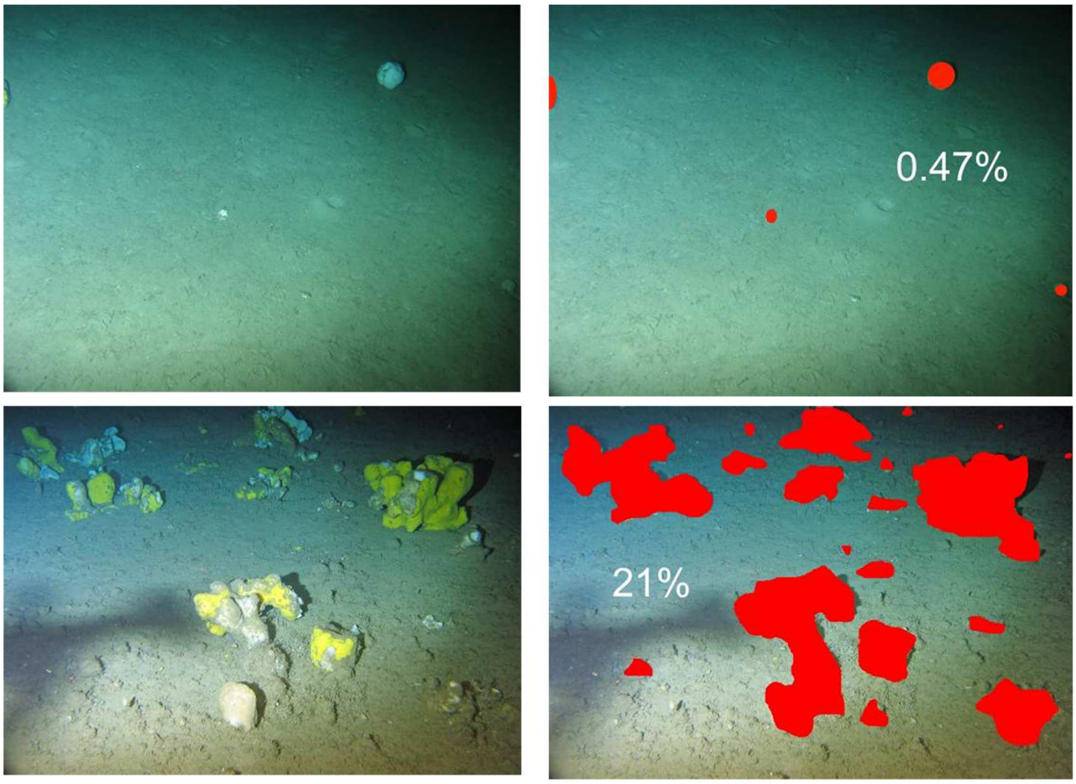
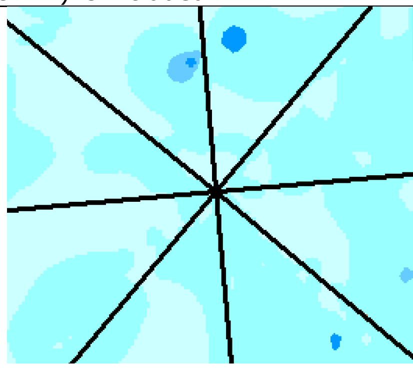


Figure 4-10 Image showing examples of sponge coverage and recommended minimum field of view when assessing seabed sponge coverage.

For risk assessments interpolated or modelled (predictive modelling) sponge occurrences can be used for delaminating specific areas with sponges that should be avoided during operations. Proposed values relating to size of the interpolated values are summarised in Table 4-8.

Table 4-8 Recommended value categories for interpolated sponge areas (polygons) in relation to size of the area, only sponge classification "High" and "Common" (Ref Table 4-7) is included.

	Seabed sponge classification	
Interpolated Sponge area value	**High**	**Common**
Poor	<100 m^2	<500 m^2
Fair	100-500 m^2	500-1000 m^2
Good	500-1000 m^2	1000-5000 m^2
Excellent	>1000 m^2	> 5000 m^2



4.6 Mapping of other habitat types

Other fauna types that should be mapped specifically when encountered during visual inspections are:

- **Sea pen communities "Sjøfjærbunn"** (occurrences of the sea pens *Kophobelemnon stelliferum, Virgularia mirabilis, Funiculina quadrangularis* or *Pennatula phosforea*).
- **Soft bottom coral gardens** (*Isidella lofotensis* or *Radicipes gracilis*)
- **"Blomkålskoralleng"/carnation corals** (occurrences of either *Drifa, Capnella* or *Gersemia* species).
- ***Umbellula encrinus***
- **Other coral species**, such as *Anthelia fallax*, *Anthomathus grandiflorus*, *Anthothela grandiflora*, *Swiftia pallida.*

The categories should be classified according to Table 4-9.

Table 4-9 Recommended **c**ategories for classifying seapen communities, soft bottom coral gardens carnation corals and other fauna types

SEA PEN COMMUNIIES	**Specimens per 25m²**	**Comment**
Sea Pen Communities Poor	1-5	Single point/Continuous
Sea Pen Communities Fair	6-10	Single point/Continuous
Sea Pen Communities Good	11-15	Single point/Continuous
Sea Pen Communities Excellent	>15	Single point/Continuous
Soft bottom coral gardens	**Specimens per 25m²**	**Comment**
Soft bottom coral garden Poor	1-5	Single point/Continuous
Soft bottom coral garden Fair	6-10	Single point/Continuous
Soft bottom coral garden Good	11-15	Single point/Continuous
Soft bottom coral garden Excellent	>15	Single point/Continuous
Drifa/Capnella/Gersemia		
Gersemia/Capnella/Drifa Rare	1-5	Single point/Continuous
Gersemia/Capnella/Drifa Scattered	6-10	Single point/Continuous
Gersemia/Capnella/Drifa Common	11-15	Single point/Continuous
Gersemia/Capnella/Drifa High	>15	Single point/Continuous
Umbellula encrinus	-	Single point
Other coral species	-	Single point

Mapping of sand eel habitats are sometimes required. Options for mapping the sand eel habitats are sledge/ trawl sampling, sediment grabbing or echo sounder surveys. Visual mapping is not recommended because sand eels tend to move away from disturbances or bury in the sediments. For more info see e.g. Holland et al. (2005), Johnsen and Harbitz (2013) or Green (2017).

4.7 Data structure and reporting

According to requirements as addressed in M300/M408 (Miljødirektoratet, 2015 - revised 2023), data from visual surveys shall be imported to Miljødirektoratets (Norwegian Enviornmantal Agency) portal for visual data: https://visuell.miljodirektoratet.no/. The data shall be imported following specified data structure as described in M300/M408.

The national system for nature type mapping NiN 3.0 (Natur i Norge) will be established also for the marine environment in 2023 (see https://artsdatabanken.no/Files/55164/Marin_feltveileder_NiN_3.0.pdf for near shore seabed nature types). Requirements for mapping and reporting offshore seabed nature types according to this classification system might be expected when offshore nature types are in place.

Where applicable, species occurrence datasets (sampling event datasets) should be reported according to GBIF and Darwin Core protocols.

Video is recommended overlaid with the following information: Date, Time, Easting, Northing, Heading, Depth, Altitude, SurveyID and LocationID. If data strings are available; Pitch, Roll and Speed over ground (m/s) should be overlaid as well.

Video files should be stored with accompanying survey track data in tabulated form (e.g., ASCII comma separated files)

Video and survey track data should be synchronized with respect to date/time, SurveyID and LocationID

Image quality should be stored as metadata. Low quality images should be kept since they might still hold valuable information. Each still image must/should also be delivered as a GIS point class feature. Where relevant (e.g., during coral surveys), the point features should include the same attributes as associated polygon features.

All data should be stored with a traceable time code referring to time stamps in video and still image material. Geographical datum must be clearly presented, and preferably denoted in column names (e.g. in excel files such as ED50UTM32North). All interpretations should be reported in a convenient format such as a shape file and in a tabulated form and handed over to operator for storage and possible governmental use. Point data can be aggregated into classified line data to reduce storage, but no resolution of the data set should be lost when doing this. See FUGRO (2017) for further specifications on recommended storage formats.

5 RISK ASSESSMENT

5.1 Objective and method

It is recommended to perform a risk assessment for identified environmental resources in relation to

- Smothering and particle exposure from discharges (drilling or cementing)
- Physical impact from anchoring
- Physical impact from pipelaying / placement of infrastructure
- Other potential impacts such as noise and vibration

The assessment is intended to be used as decision support with regards to drilling- and discharge locations, discharge volumes of cuttings and mud, location of anchors, anchor chains, pennant wires, pipelaying, rock placement etc., and for planning mitigative actions.

By systematically evaluating the risk inflicted upon SHEC/seabed habitats, operators can plan activities with the lowest possible risk for the SHEC. Also, by working out an overall risk picture for SHEC, it is easier to tailor a monitoring program, focusing on specific areas or reefs that might be at risk. It should also be noted that following a standardized approach for assessing risk will ease communication with stakeholders, legislative bodies, and NGOs.

The environmental resource map should reflect different values for the species and habitats within the area as described and exemplified in chapter 4.

A common approach is suggested to be applied combining anticipated influence areas (modelled or generic values) and environmental resource map in an overlap analysis terminating in an expression for consequence (Table 5-1). Depending on availability on data for estimates for probability, risk assessment can be performed (Example of risk matrix shown in Table 5-2.

Table 5-1 Generic Consequence matrix based on condition of SHEC and expected impact.

		Identified SHEC value (chpt. 4)			
		Poor	**Fair**	**Good**	**Excellent***
Degree of impact	**Negligible**	Minor	Minor	Minor	Minor
	Low	Minor	Moderate	Moderate	Serious
	Significant	Minor	Moderate	Serious	Severe
	Considerable	Minor	Serious	Severe	Severe

** Unmapped / not visually assessed coral areas should be treated as "Excellent" in impact/ risk assessments*

Table 5-2 Example of risk matrix

			Consequence			
			Minor	**Moderate**	**Serious**	**Severe**
Probability	<10%	**Unlikely**				
	10-25%	**Rare**				
	25-50%	**Likely**				
	>50%	**Expected**				

5.2 Threshold values and consequence matrixes, overview

Relevant threshold values derived for risk assessment of offshore activities on NCS, and corresponding consequence matrixes for SHEC is summarised below. The threshold levels adheres to SHEC on the seafloor and not eggs, larvae and organisms in the water column.

Further details regarding each activity and basis for deriving threshold levels is given in following sections and in Appendix A and B. Recommendations for assessing impact /risk on SHEC from the various activities is given in each section.

A summary of relevant threshold values for degree of impact in relation to **discharges from drilling operations** is given in Table 5-3:

- for **deposited particles**
- generic values for **deposition in relation to distance from top-hole discharges**

and in Table 5-4:

- **Proposed threshold levels for exposure to suspended solids** exceeding a threshold value of 10 mg/L (long term), 20 mg/L (short term) or 100 mg/L (storm/ bursts over very short periods). See appendix B for examples illustrating risk assessments in relation to exposure time.

A summary of relevant threshold values for degree of impact in relation to **pipelaying operations and installation of infrastructure** is given in **Table 5-5**:

- distance from **trenching**
- distance from **rock dumping**

Table 5-3 Consequence matrix drilling operations, degree of impact from deposition of discharges in relation to identified SHEC (*Desmophyllum*, coral gardens and sponges).

	Drilling operations, deposition			**Identified SHEC value**			
	Deposition (mm)	**Distance from well location - generic impact area, deposition from top hole discharges (m)***		**Poor**	**Fair**	**Good**	**Excellent**
Degree of impact	0,1-1	> 500	**Negligible**	Minor	Minor	Minor	Minor
	1-3	250 – 500	**Low**	Minor	Minor	Moderate	Serious
	3 -10	100 - 250	**Significant**	Minor	Moderate	Serious	Severe
	>10	< 100	**Considerable**	Minor	Moderate	Severe	Severe

* Generic distances for drilling one single top hole (9 7/8”, 36” and 26”). Modelling of sedimentation is recommended for multiple discharge scenarios and production drilling.

Table 5-4 Suggested threshold levels for suspended solids in relation to identified SHEC (*Desmophyllum*, coral gardens and sponges), for different exposure time regimes. Note that in risk assessments, degree of impact can be assessed in relation to exposure times within the exposure duration, e.g. for short time exposure expressed as number of hours with concentrations exceeding threshold level of 20 mg/L.

Drilling operations, suspended solids

Exposure duration	Suggested exposure thresholds, suspended solids concentration*
Long term (>60 hours)	10 mg/L
Short term (<60 hours)	20 mg/L
Storm / burst (< 1 hour)	100 mg/L

* Depending on total exposure time as well as actual particle concentration exceeding threshold level

Table 5-5 Consequence matrix pipelaying and installation of infrastructure in relation to identified SHEC

	Pipelaying and installation of infrastructure			Identified SHEC value			
	Distance from trenching (m)	**Distance from rock dumping (m)**		**Poor**	**Fair**	**Good**	**Excellent**
Degree of impact	>15	>25	**Negligible**	Minor	Minor	Minor	Minor
	10-15	15-25	**Low**	Minor	Minor	Moderate	Serious
	5-10	10-15	**Significant**	Minor	Moderate	Serious	Severe
	0-5	0-10	**Considerable**	Minor	Moderate	Severe	Severe

5.3 Drilling discharges

5.3.1 Model tools in risk assessments; deposition of discharges and suspended solids

Models are important tools for analysing the probable environmental impact and thereby risk to SHEC resources as accurately as possible. Of relevance for this handbook are models for distribution of discharges and particles from drilling activities (dispersion modelling). Several models are in use and can provide data on the deposited layer thickness or the distribution of suspended particles in the water column for the different phases of the drilling operations.

Important input parameters are discharge types, volumes, and times of discharges as well as current data/ hydrography.

The fate of drilling discharges and defining the influence area may depend on a range of variables and can be grouped into 1) site- and 2) discharge specific elements. Typically, the site-specific elements include the temporal and spatial currents patterns and bathymetry at the location, while the discharge specific elements include:

- volumes and rates of cuttings, mud and chemicals
- characteristics of discharge such as grain size distribution and settling velocities.
- discharge location(s) and depths (CTS, surface, sea floor)
- time and duration of the discharge

The following parameters have shown to be of high importance and are therefore influencing the accuracy in modelling:

- Input parameters and drilling data
- Model set up and grid cells
- Particle size distribution
- Post processing of results

In order to obtain figures for calculating risk, based on modelled scenarios a stochastic approach is required (e.g., running several scenarios with various input data for currents). To apply such an approach a certain amount of confidence in the input parameters is needed. E.g. the current patterns must have temporal resolution covering tidal variations and the period the discharge, high resolution bathymetry and e.g. the drilling plan must be in place. Current can either be measured or be generated from met Ocean models (e.g. SINMOD or NorKyst800). High resolution bathymetry is usually collected during site survey.

Results relating to risk to SHEC should be presented as probability overlap maps. Results from modelling simulations should link each SHEC with corresponding probabilities in maps, and it is important that corresponding risk matrixes for the risk assessments harmonise with probability intervals in the probability overlay maps. Degree of exposure / impact to SHEC is recommended presented by means of box/ whisker plots, presenting comparable summary of variability.

5.3.2 Threshold for deposited particles

Based on studies and references presented in Appendix A and B a consequence scale for sedimentation has been proposed for both corals and sponges expected on the NCS. The consequences are described as "Low" for the 1-3 mm category, "Significant" for the 3-10 mm category and "Considerable" for deposition above 10 mm. See Table 5-6 for summary of expected consequences for different sedimentation coverage.

Table 5-6 Threshold values for consequences for deposition of discharges

Deposition thickness	**Degree of impact**	**Consequences**
0.1-1 mm	Negligible	No detectable influence
1-3 mm	Low	Minor smothering Good ability to shed sediments, but might start to aggregate
3-10 mm	Significant	Moderate smothering Reduced ability to shed sediments. Some polyp mortality or sponge necrosis can occur.
>10 mm	Considerable	Considerable smothering Potential suffocation. Polyp mortality or sponge necrosis excpected. Potential for depletion of energy reserves.

From empirical studies and modelling of discharges from previous drilling campaigns of **one single top hole** (9 7/8", 36" and 26"), **a generic influence area with intervals of deposition of discharges** can be applied in the risk assessment (

Table **5-7**). Note that generic influence areas and distances has not been developed for production drilling with discharges from multiple top holes.

Table 5-7 Threshold values for consequences for deposition of top hole discharges in relation to distance from well location. Generic distances, for one single top hole (9 7/8", 36" and 26").

Thickness	**Distance**	**Impact**	**Consequences**
0.1-1 mm	> 500m	Negligible	No detectable influence
1-3 mm	250 -500 m	Low	Minor smothering Good ability to shed sediments, but might start to aggregate
3-10 mm	100 -250 m	Significant	Moderate smothering Reduced ability to shed sediments. Some polyp mortality or sponge necrosis can occur.
>10 mm	< 100m	Considerable	Considerable smothering Potential suffocation. Polyp mortality or sponge necrosis expected. Potential for depletion of energy reserves.

5.3.3 Threshold for suspended solids

Thresholds for short-term realistic exposure of suspended solids of barite, bentonite and drill cuttings on *Desmophyllum pertusum* and sponges are under development. Impact will depend on actual concentrations bursts of particles in the water masses as well as exposure times. Relevant threshold levels can be 20 mg/L for short exposure times (<60 hours), 10 mg/L for longer exposure periods (>60 hours) and a "storm threshold" for peaks/ bursts in suspended solids of 100 mg/L (limited to very short durations).

Based on studies described in Appendix B an effect threshold for corals and sponges for short-term realistic pulse exposure (<60 h) to suspended solids is proposed to 20 mg/L and consequence categories are based on exposure period exceeding this threshold level. Example of risk assessment methodology based on this approach is shown in Appendix B.

Note that threshold levels for effect from suspended solids for organisms and life stages associated with the water column has not been established in this handbook. Fish and invertebrate larvae stages might exhibit sub-lethal effects and eggs might have reduced ability to float at levels of suspended solids even lower than 10 mg/L. See examples in Appendix A.

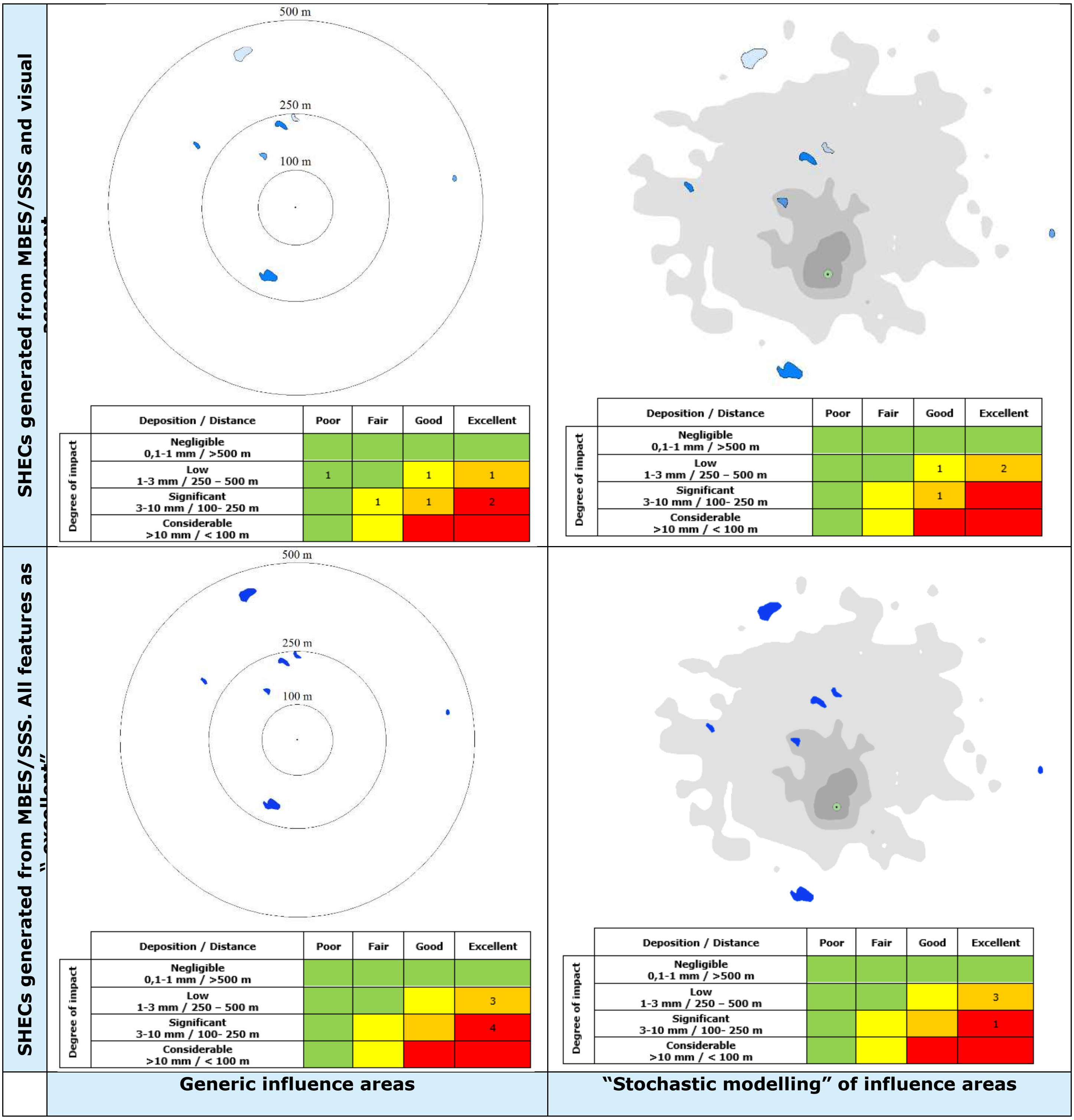
5.3.4 Assessment of impact (exposure) from drilling discharges

For assessing impact from deposition of single top hole discharges a generic distance from the well location as presented in

Table **5-7** can be implemented. This approach will however generally overestimate the actual impact area.

Single scenario modelling could be used for documentation purposes during or after the discharges has commenced. However, risk assessment using single scenario modelling (deterministic) not reflecting the variance in e.g. the current regime is not recommended to be applied in the planning phase of multiple top holes. Hence, it is recommended to apply stochastic dispersion modelling if there are identified SHECs in the area. By running multiple scenarios, numbers relating to probability for a consequence (exposure + value) can be obtained. The generated sedimentation footprint, or exposure to suspended solids should be expressed with a confidence interval or similar expressing the probability.

As an example of how impact from deposited particles can be assessed, overlap analysis between **generic influence areas** vs. **"stochastic modelled influence area"** and environmental resource map for SHECs generated from **only MBES/SSS** vs. **MBES/SSS and visual assessment** is exemplified in Figure 5-1. In the same figure the various scenarios are assessed with regards to impact. The example demonstrates that with increased efforts in visual mapping and modelling of influence areas, the impact / risk can be reduced (Figure 5-2).



Generic influence areas – SHECs generated from MBES/SSS and visual assessment:

Degree of impact: Deposition / Distance	Poor	Fair	Good	Excellent
Negligible 0,1-1 mm / >500 m				
Low 1-3 mm / 250 – 500 m	1		1	1
Significant 3-10 mm / 100- 250 m		1	1	2
Considerable >10 mm / < 100 m				

"Stochastic modelling" of influence areas – SHECs generated from MBES/SSS and visual assessment:

Degree of impact: Deposition / Distance	Poor	Fair	Good	Excellent
Negligible 0,1-1 mm / >500 m				
Low 1-3 mm / 250 – 500 m			1	2
Significant 3-10 mm / 100- 250 m			1	
Considerable >10 mm / < 100 m				

Generic influence areas – SHECs generated from MBES/SSS, all features as "excellent":

Degree of impact: Deposition / Distance	Poor	Fair	Good	Excellent
Negligible 0,1-1 mm / >500 m				
Low 1-3 mm / 250 – 500 m				3
Significant 3-10 mm / 100- 250 m				4
Considerable >10 mm / < 100 m				

"Stochastic modelling" of influence areas – SHECs generated from MBES/SSS, all features as "excellent":

Degree of impact: Deposition / Distance	Poor	Fair	Good	Excellent
Negligible 0,1-1 mm / >500 m				
Low 1-3 mm / 250 – 500 m				3
Significant 3-10 mm / 100- 250 m				1
Considerable >10 mm / < 100 m				

Figure 5-1 Examples of overlap analysis SHEC resources and impact assessment between generic influence areas vs. "stochastic modelled influence area" and environmental resource map for SHECs generated from only MBES/SSS vs. MBES/SSS and visual assessment.

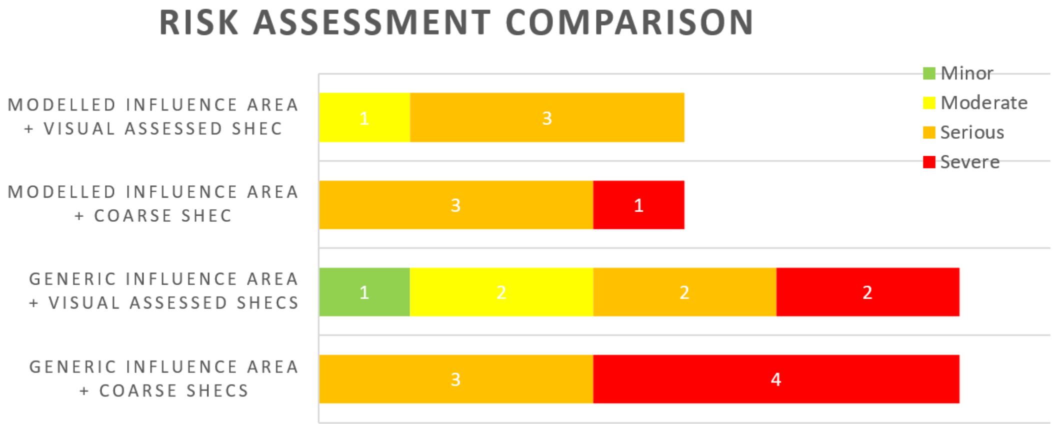


Figure 5-2 Comparison of different approaches for assessing impact to SHEC. Increased efforts in visual mapping and modelling of influence areas reduces the risk on SHECs based on examples in Figure 5-1.

5.4 Pipelaying operations and installation of infrastructure

Impact from placement of pipeline, placement of rocks and jetting/trenching should be assessed when planning the pipe route. Impact from rock placement in larger infill areas must be assessed specifically from case to case. Impact from installation of other infrastructure must be assessed specifically depending on technical solutions, heigh of rock pile and seabed footprint. Footprint used in risk assessments should be increased with uncertainty, i.e. +/-5 m laying accuracy and 10m buckling, when needed.

General expected risk to any SHEC can be as shown in Table 5-8, the impact will depend on pipelaying technology, dimensions of pipeline and type of pipeline. An example of risk distances is shown in Figure 5-3. Risk from smothering from jetting operations and rock placement decreases with increased distance from the pipe route.

Smaller operations such as placing out umbilical or similar sized pipelines is expected to have smaller impact than shown in the table. Placing of pipeline directly on the seabed without trenching and rock placement should take into consideration lay accuracy, generally not exceeding 1 meter but can deviate up to 5 meter in some instances.

Planning of routes and mitigation of risk (implementing installation restrictions) should be performed according to recommendation given in section 7.4.

Table 5-8 Potential influence areas from pipelaying operations, generic distances for early-stage planning.

Trenching / jetting		
Distance from centerline (m)	**Degree of impact**	**Consequences**
> 25	No impact	No expected impact
15 - 25	Negligible	Minor sediment load
10 - 15	Low	Temporary sediment load
5 – 10	Significant	Partial coverage, some burial/smothering
0 - 5	Considerable	Complete fauna loss or potential crushing from trencher/ belts
Rock placement		
Distance from centerline (m)	**Degree of impact**	**Consequences**
> 50	No impact	No expected impact
25-50	Negligible	Minor sediment load
15 - 25	Low	Temporary sediment load to fauna
10 – 15	Significant	Partial crushing, fauna loss/ change, altered seafloor characteristics
0 – 10	Considerable	Crushing, total loss of fauna, new habitat niche

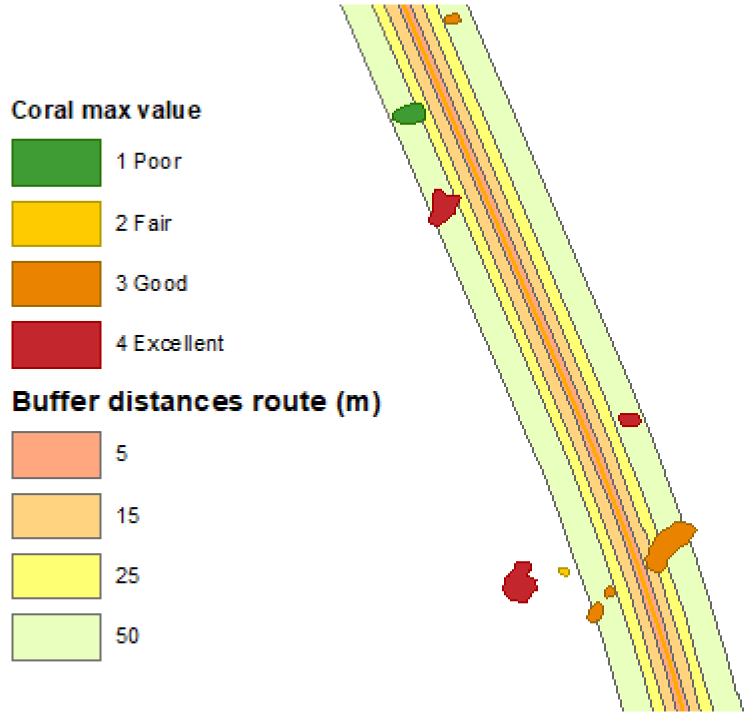


Figure 5-3 Example showing a planned pipeline and buffer distances from coral areas.

5.5 Anchor operations

It is important to define the influence area from anchor operations in relation to the SHEC as part of the risk assessment (Table 5-9, Figure 5-4). The risk analysis must take into consideration the vertical and horizontal impact of the anchor chains and need to account for altered skid positions. Maximum skid positions should be implemented. The potential impact zone is larger towards the rig and smaller towards the anchor positions. In instances where there exist multiple habitats of environmental concern at the seabed (e.g. potential coral areas), performing a best fit analysis to identify environmental risk and finding the anchor corridor with least impact is recommended (see example Figure 5-5).

Table 5-9 Example showing influence area from anchor chains at various distances from rig.

Influencing Element	**Comment**	**Exemplified meters**	**Sum**
Pre-laying of chains	Accuracy of the positioning system used on the vessel during the operation. Particularly influencing perpendicularly on the corridor	+-5m	
Tensioning of anchors	May cause increased influence area at the end of the corridors	+-50-100m	
Rig movement	Defining the skid positions so the side way movement of the chains can be calculated. See example in figure XX	+-13m	
Sum Operations at anchor position			**+-18m**
Sum Operations at influence area closest to rig position			**+- 60 m**
Positioning of the SHEC	Accuracy in the positioning system used on the vessel and towed equipment during data collection.	+-10m	
Sum Influence at anchor position			**+-28m**
Sum influence closest to rig position			**+- 70m**

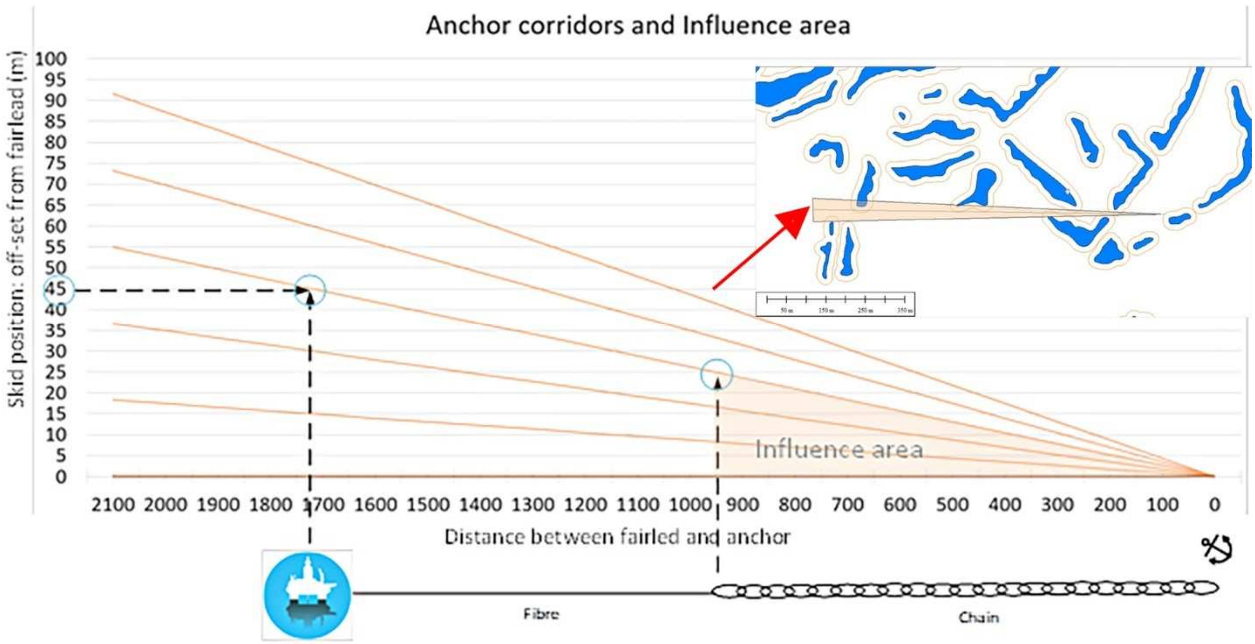


Figure 5-4 Influence area from anchor chain and direction, in relation to distance from rig and skid position. Blue polygons demarcate coral areas.

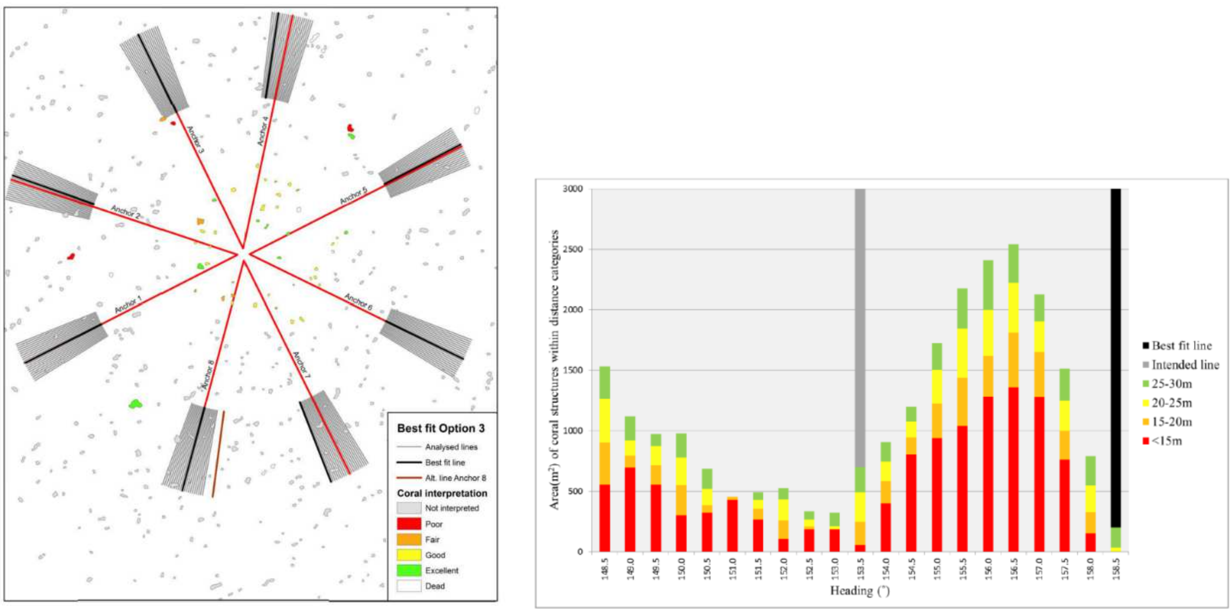


Figure 5-5 Illustration showing example of how a best fit anchor spread analysis can be performed. Multiple anchor corridor alternatives are placed (L) and the various alternatives impact on e.g. corals from each anchor corridor assessed seperately (R), best fit line symbolised as a black bold line, original planned line for the specific anchor corridor symbolised with grey bar in histogram. **NOTE: The analysis should take into consideration larger influence area closer to the rig** (ref. Figure 5-4).

6 ENVIRONMENTAL MONITORING

Applicable methods for monitoring of drilling operations described in this guideline, are indirect methods which could demarcate the influential area, and/or give results which could be interpreted according to threshold values identified in laboratory experiments or empirical results from already exposed known coral or sponge communities. The purpose of the monitoring is to document any impact on SHEC (conventional monitoring of sediments is described in M300/M408, Miljødirektoratet, 2015 – revised 2023).

Depending on several factors, technical solutions vary from operation to operation and occurrences species and habitats of environmental concern (SHEC) vary from site to site. Hence, a tailor-made monitoring program must be made for each case. The different monitoring methods listed in Table 6-1 and Table 6-2, are thought to be used as a "tool box", and the use of the methods are suggested depending on influence source (Figure 6-1). An evaluation of the methods has been graded according to importance to "high", "medium" and "low" for the sampling periods before-, during- and after drilling operations.

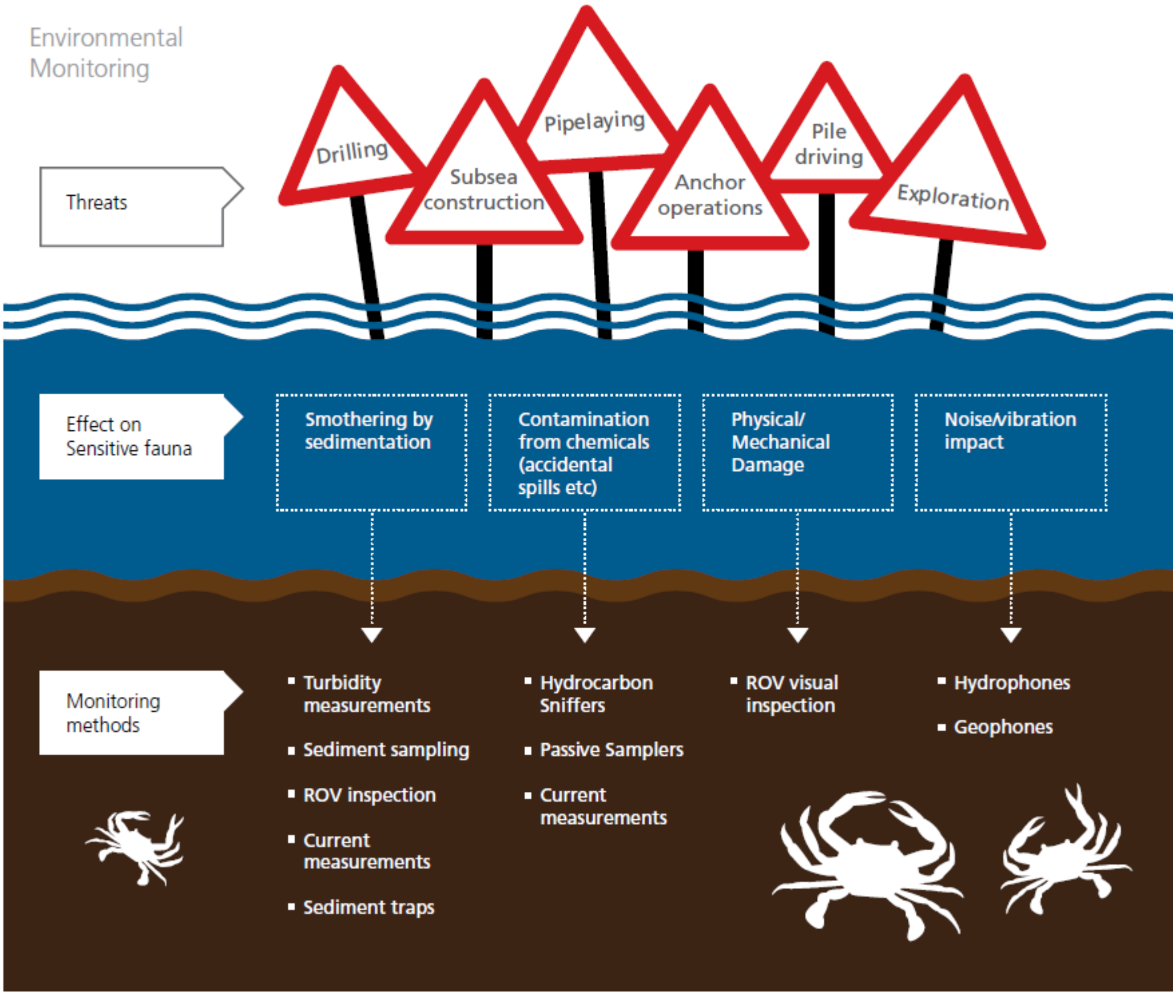


Figure 6-1 Suggested applicable monitoring methods for sources with potential of influencing seabed habitats.

Table 6-1 Overview and general description of various particle and pollutant dispersion monitoring methods.

Sample/analyses	**Description**	**Purpose**
Sediment traps	Vertical cylinders "trapping" sinking particles in the water column.	Collect particles to be analysed for grain size distribution, barium and other metals. Increased levels will indicate spreading of drill cuttings.
Sediment samples	Core samples which can be cut in various depth intervals, e.g. surface sediments and deeper sediments.	Samples to be analysed for drill cuttings constituents, thus mapping the spread of drill cuttings.
Visual inspection	Use camera on ROV etc.	Visual evaluation of the particle dispersion in water and at the seabed. Observe excessive sedimentation Used in sediment sampling and deployment of equipment.
UHI camera – Hyperspectral imaging	Attached to ROV or AUV, scanning the seabed	Able to detect much more of the light waves, can potentially be used for classification of seabed/pollution based on visual cues.
Image analysis of polyp activity (PAMS)	Lander system/ camera technology taking still images of coral polyps. Images are transformed to silhouettes and polyp activity can be analysed.	Monitoring of coral individuals without physical contact. Polyp activity analysed with respect to response to suspended solids.
Turbidity	Sensors that measure the transparency of the water, thus indicating particle concentrations. The data are stored in the sensor.	Indicate particle concentrations in the water to reveal spreading of drill cuttings.
Water currents	Sensors measuring water currents (velocity and direction). Can be of profiling type (measuring in the whole water column) or single depth measurements.	Gives the main current direction and velocity at certain depths for a period of time. Main parameter regarding expected direction of dispersion, and when deciding where to place the measuring equipment/ sampling stations.
Hydrophones Geophones	Sensors placed on the seabed or on landers	Records noise and vibrations from underwater operations
DGT Diffuse gradients in thin films technique	Passive sampler that can be placed out on landers or instrument rigs. Analysed in lab.	Passive sampler. Measures dissolved metals
POM Polyoxymethylen	Passive sampler that can be placed out on landers or instrument rigs. Analysed in lab	A passive sampler for hydrophobic chemicals
Hydrocarbon sniffers	Instruments sensoring dissolved hydrocarbons often via membrane technology.	Able to detect hydrocarbons and PAH's in the water masses. Suitable for screening of leaks.

Table 6-2 Summary of monitoring methods and their relevance in different phases of drilling activities. For each methodology, relevance has been graded to "high", "medium" and "low" for the sampling periods before-, during- and after drilling operations, and at a reference station.

Method	**Before**	**During**	**After**	**Reference**	**Comments**
Current measurements	High	High	Low	Low	Experiences have proven changes in the current regime during drilling periods, and one can question the importance of having measurements prior to drilling. When discharges are at the sea surface it could be valuable with a profiling current meter.
	Generally important regarding risk assessment, dispersion modelling and placement of monitoring equipment.	Important in regards of interpretation of other data. Important input data for re-running the sediment dispersion model	Generally not important. Nevertheless, for secondary dispersion through re-suspension, it could be an important element	One measuring location should be sufficient when the depth and bottom topography are relatively homogenous.	
Turbidity measurements	Low	High	Low	Medium	Measurements are subject to bias from biological activities such as fish whirling up sediment. A threshold value has not been established and NTU/FTU is a relative value.
	Data collection reflecting natural variances in NTU/FTU, and exposure of natural particle loads on corals.	Important for identifying plumes during the discharges.	Data collection reflecting natural variances in NTU/FTU, and exposure of natural particle loads on corals.	Temporal and spatial changes could disguise NTU/FTU values. Hence, a reference station could be important	
Sediment traps	Low	High	Low	High	Could be challenging getting enough material for analysis, using small traps. Larger sediment traps (aperture 0.5 m^2) with several sampling containers, which can be preset to sample at a certain interval, can be of great value. Barium, TOC and dry weight are regarded as relevant parameters
	Seasonal variations; can not immediately be compared with suspended matter during the drilling campaign. Reflecting natural variance, and exposure of natural particle loads on corals.	Reflecting exposure of particle loads on corals.	Could be important regarding re suspension of discharges.	Temporal and spatial changes could disguise sedimented matter from drilling discharges. Hence, a reference station is important	

Sediment samples	High A few samples prior to drilling seems to be sufficient for baseline values of barium	Low Will not give added value during a short drilling campaign.	High A number of samples within the surveyed area should be retrieved in different directions and distances from the discharge location in order to identify the influential area.	Medium As long as background samples has been collected within reasonable time prior to drilling, one can anticipate that changes observed over the drilling period is due to the drilling activities.	Barium has proven to be a valuable parameter for measuring the dispersion of drill cuttings. One corer sample gives enough material for analysis of metals.
Visual mapping/ monitoring	High Very important for mapping purposes. The results are basis for planning of anchor corridors, what and where to monitor, as well as planning the discharge location.	Medium Has proven valuable for identifying dispersion of suspended solids during discharges.	Medium Could discriminate between excessive sediment on corals. Important for visual assessment of drill cutting deposits and any impact from anchor operations	Low	In general, there is difficult to find an appropriate parameter for monitoring directly of corals, which will reflect any influences from drilling activities. High resolution still photos have from experience not been able to identify change in polyp behaviour on *Desmphyllum pertusum* when exposed to drill cutting plumes. Counts of living vs. dead polyps or exposed coensarc area might be of importance in high exposure scenarios.

7 MITIGATING THE ENVIRONMENTAL IMPACT TO SEABED HABITATS

7.1 General

To minimise the impact of offshore activities and to protect SHEC, mitigating (risk reducing) measures should be considered in the Operators drilling plans. The selection of the optimal risk reducing measure(s) should be based on the planned well operation, the actual local conditions and seabed habitat, i.e. the area of impact should be adequately surveyed, with the position and condition (where possible) of sensitive marine features such as CWC. To improve the accuracy of particle dispersion modelling, local current measurements should be acquired.

Furthermore, the Operator should expect to perform a risk assessment of the impact of drilling activities in relation to local environmentally sensitive features before any risk reducing measure is selected. The selection of the optimal risk reducing technology should be primary consideration of the risk assessment results, availability of the technology, complexity, reliability, and cost & benefit.

To understand how drilling activities can impact sensitive marine features such as CWC, it is best to consider a typical drilling operation and the actual mechanisms that can lead to impact and damage. The following activities may affect seabed habitats:

- Discharge of drilled cuttings and drilling fluids at the wellhead through top-hole drilling activities, i.e. the discharge of drilled cuttings and drilling fluids at the sea floor.
- Drilling with the marine riser in place, i.e. all drilling fluid and cuttings are returned to the drilling unit for separation, before reuse in the case of the drilling fluid or discharge of the separated cuttings at the sea surface.
- Anchor and mooring chain installation and recovery operations.
- Deployment of infrastructure, i.e. template, pipeline, umbilical etc.

The activities are described in the sections below.

7.2 Drilling

A summary of conventional drilling methods and handling of drill cuttings and fluid are given in Table 7-1.

An overview of technology and techniques that should be considered as possible strategies with which to reduce the impact of drilling activities is presented in Table 7-2. Several of the measures described are well established in the industry today and have a proven track record of reliability and success, others are less mature and under development. As an example can be mentioned use of RMR, riserless mud recovery (Macdonald, 2016).

Discharges from top-hole drilling at sea floor

Top-hole drilling generally refers to riser-less drilling of the two upper sections of the well. Normally this is the 36” and 26” sections where the drilled cuttings and fluids are discharged directly from the wellbore at the seafloor – this is the case normally in exploration and appraisal wells. In the case of production wells to avoid burial of the well head, the discharges from the well bore (both drilled cuttings and drilling fluid) are collected at the wellhead, transported a short distance away and discharged.

Wellbore drilling discharges generally consist of: cuttings - mainly coarse particles, fines from viscous bentonite pills and barite weighted fluid. All chemicals added to the drilling fluid such as bentonite and barite are PLONOR (Pose Little or No Risk to the Marine Environment).

Wellbore discharges are discontinuous, i.e. discharge will only occur when drilling, when displacing the well with weighted fluids and when cementing. A typical 36” section is normally 80 meters deep. This corresponds to a total duration of drilling and discharge of approximately 8 hours, and a normal rate of cuttings generation of 7m3/h, with peaks of ca. 20 m3/h. A typical 26” section may be ca. 700 meters long. This corresponds to a total duration of drilling and discharge of approximately 33 hours, and a normal rate of cuttings generation of at least 16 m3/h with peaks of ca. 20 m3/h. In this example, the total discharge of drilled top-hole cuttings will be approximately: 1,400 tonnes or 400 m^3.

Visible dispersion of particles at the seafloor generated from top-hole drilling activities is normally limited to 150 meters downstream of the discharge point. However, fine particles in suspension may travel much further, and can occasionally be visible up to 600 meters from the wellhead. However, in all cases, the visible distance will be a function of dilution of the discharge along with local current variations.

Discharges from the drilling unit at sea surface, i.e. drilling after the marine riser has been connected

Once top-hole drilling has been completed and the riser has been installed, all drilling fluid returns including drilled cuttings are returned drilling unit for separation. In the case of cuttings generated in a water-based mud system (WBM), the collected drilled cuttings are normally discharged from the drilling unit to the sea surface. Separated WBM is also normally reused and discharged to sea at the end of drilling operations - but only under the conditions and specifications of an earlier permit approval. In the case where cuttings are generated in an oil-based drilling mud system (OBM), the cuttings are normally separated and collected on the drilling unit for onshore disposal. The separated OBM system will be continuously used until the end of drilling operations, before being returned to shore for future reuse. In this scenario, neither OBM fluid nor drilled cuttings are ever discharged offshore.

The normal discharge of WBM drilled cuttings from the drilling unit to sea will result in a dispersion of both the large and fine cuttings particles over a large area. The dispersion pattern will be a function of water depth and prevailing current patterns.

Table 7-1 Standard practice for the management of drilling fluid and cuttings returns

Technique	Description	Pros	Cons
Conventional (standard) riser less top-hole drilling operations			
Conventional (standard) riser less top hole drilling.	Drilling with sea water, pumping viscous pills of bentonite for the purpose of lifting/transporting the drill cuttings out of the well and displacing with barite weighted fluid. Discharge at or near the well head.	• Standard industry practice • Simple technology and techniques • No need for additional equipment • No additional cost	• Discharge of cuttings and fines • Risk of sedimentation or particle exposure of close SHEC
Conventional (standard) drilling after the riser is in place			
Conventional (standard) drilling with the riser in place.	Drilling with weighted drilling fluid to maintain borehole stability and to clean waste cuttings from the wellbore. Either water based (WBM) or oil based (OBM). When drilled with WBM fluid, cuttings are normally separated on the drilling unit and discharged directly onto the sea surface. The separated WBM is reused in the wellbore. When drilled with OBM fluid, the drilled cuttings are separated and collected for disposal onshore. When OBM is used in the wellbore, neither the drilling fluid nor the separated drilled cuttings are discharged to sea at any point. All waste products are returned to shore for disposal.	• Standard industry practice • Simple technology and techniques • No need for additional equipment • No additional cost	• Discharge of cuttings and fines from the drilling unit to the sea surface results in dilution of the particles in the full column of seawater and dispersion over a greater area.

Table 7-2 Risk reducing technology for drilling in areas with seabed habitats of environmental concern

Technique	Description	Pros	Cons
Technology to reduce generation of solids			
Piling of conductor, 36”-section	Conductor/36”-section will be forced/piled normally approx. 80 meter down in the formation/seafloor. Drilling through 36”–section with 26” bit is needed. CAN (Conductor Anchor Node) is a piling and wellhead foundation technology newly developed and available in the market today.	• Reduced generation and discharge of drill cuttings • Reduced risk for sedimentation of close SHEC	• Marginal gain (26” in 36”-section) • Limited to specific soil or formation characteristics • High risk for failure with piling of conductor
Slim hole well design	Top-hole cross section diameter and corresponding volume of generated cuttings will be reduced. Slim hole design is often used in exploration wells.	• Reduced discharge of fines • Reduced generation and discharge of drill cuttings • Reduced particle distribution • Reduced risk for sedimentation of close SHEC •	• Possible limitation in equipment availability • Limitations in flexibility to mitigate against drilling problems in the well. • Restriction in maximum possible completion size.
Reduced number of sections. No 26”-section	Replacing the 26”-section with a longer 17 ½”- section (or even a 12 ½”-section). Installation of riser prior to drilling of the 17 ½”-section will eliminate discharge of drill cuttings and fines from drilling fluids from drilling of a 26”-section.	• Reduced discharge of fines • Reduced generation and discharge of drill cuttings • Reduced particle distribution • Reduced risk for sedimentation of close SHEC • Increased flexibility in location of well or template	• Limited to specific formation characteristics • Increased use and discharge of drilling fluids with special specifications (17 ½” or 12 ½”) • Use and discharge of yellow chemicals, but only if discharges are permitted. • Limitations in flexibility to mitigate against drilling problems in the well.

Drilling without barite/bentonite using heavy brine and cellulose	Cellulose is used in viscous pills to replace bentonite and heavy brine is used as drilling fluid to avoid use of barite.	• Reduced discharge of fines • Reduced risk for exposure of SHEC of suspended matter • Eliminated risk for exposure of SHEC of barite • Improved working environment on the drilling unit	• Slightly increased cost • Limited to 1,3 sg for low cost brines ($CaCl_2$)
Utilising Conductor Anchor Node (CAN) conductor support technology	System that is installed prior to rig arrival.	• No cementing • Less cuttings	• Advanced installation • Requires piling or jetting
Utilise particle free drilling fluids	Drilling fluids with salts instead of Barite or Bentonite	• Limited amount of particles will be dispersed • Can aid in flocculation of cuttings particles	• Effects from possible increased salinity at seabed should be considered.
Technology to transport cuttings and drilling fluids to a specific deposit site (CTS) away from the well head			
Subsea cuttings transport systems (CTS)	Subsea cuttings transport systems known as 'CTS', collect the drilling fluid and cuttings from the wellhead and transport them to a specified discharge point away from the well. The system utilizes a wellhead interface module, a suction hose, a suction module (driven by either a surface or subsea pump), a discharge hose and a discharge module. The system has several years of history and success in production drilling from templates and recently where CWC populations in the vicinity of the well location have been of concern to remove the discharges to a area with minimal environmental impact.	• Increased flexibility in the selection of the surface position for the well head and correspondingly in the location of an environmentally acceptable discharge point. • When CWC structures are deemed to be at risk of impact from drilling activities, use of a CTS system generally reduces the impact to an acceptable level. • Mature and proven technology. • Standard oilfield practice on production wells from a template. • Current industry standard in areas with CWC structures requiring mitigating measures • Lots of regional experience with discharge distances in the range of ca. 500m. • Theoretical discharge range of more than 3,000m could be possible.	• Risk of leak/ accidental discharges along CTS hose relatively high • Discharge footprint generally larger than during conventional discharges • Open system that requires good communication with the driller and awareness and experience by the operator • Open system that will imply discharge at well head if failure in operation or equipment • Experience of discharge transfer over 1000m is limited. • High installation costs. Subsea installation vessel required for mobilization and recovery. • Installation and recovery operation is weather dependent. • For extended reach (250 m +), access to an ROV either on a supply vessel or stand-by vessel is recommended for system monitoring during multi-well campaigns. This can add significant costs to the operation if an ROV spread does not pre-exist.

Technology for the return of cuttings and drilling fluids to the rig for alternative disposal or use (Mud Recovery System)			
Return of cuttings and drilling fluids to the drilling unit by seabed pump	Riserless Mud Recover systems (RMR or MRR) is a technology that has been developed principally to optimally manage the use of engineered drilling fluid systems, where significant volumes of drilling fluid would otherwise be required should returns not be taken back to the drilling unit. The mud recovery system allows the drilling fluids and cuttings to be separated on the drilling unit, such that the fluids can be reused in the well bore, and the cuttings to be discharged (normally) to the sea surface. In the case of a well location where CWC are present, use of a mud recovery system almost fully eliminates any discharge of drilled cuttings or fluid from the wellhead during top hole drilling.	• Significantly reduced risk of cuttings sedimentation or particle exposure at the sea floor near the wellbore. • Proven technology (limitations regarding 36”-section) • Recovery of drill fluids for efficient reuse. • Potential benefit of earlier detection of shallow gas or shallow water flows. • Enables drilling of top-hole with weighted mud	• Open system that requires good communication with the driller and awareness and experience by the operator • Open system that will imply discharge at well head if failure in operation or equipment • Increased operational risk, both for halt in operation and for personnel • Risk for reduced progress in drilling operation • Need weighted and viscous system to lift cuttings • Added challenge of how to handle and dispose of the drill cuttings on the drilling unit. • Increased cost when compared with a CTS system. • Installation and recovery vessels are required, with the operation more susceptible to weather conditions.
Technology for disposal of cuttings and drilling fluids after return to the rig			
Discharge untreated from rig	Discharge of collected water based drill cuttings from the rig after passing shaker (separation).	• Significant dilution of fines and reduced risk for exposure of environmental SHEC at the sea floor • Standard configuration and method for discharge of drilled WBM generated cuttings on all drilling units. • Low cost solution • Reliable. • Can be interfaced with the RMR system with minimal modifications.	• Less controllable disposal of cuttings compared with CTS • Impact of surface discharge to sea may actually prove to be a higher environmental risk for the CWC habitat than from discharge to a specific location as achieved through use of a CTS system alone.
Coarse slurrification and discharge from rig	Coarse slurrification of drill cuttings requires a slurry unit. The drill cuttings are processed through grinding to finer particles, before mixing with water and discharge to sea.	• Significantly reduced risk of cuttings sedimentation or particle exposure at the sea floor near the wellbore. • Less risk to personnel by being less lifting dependent	• Increased operational risk, both for halt in operation and for personnel • Constrained progress in drilling operation (ROP) • Need for additional equipment, space and man hours on the rig • Increased cost • Bottle neck in the waste management system that could result in reduced performance.

Slurrification and reuse as spud mud	Slurrification of drill cuttings requires a slurry unit. The cuttings are ground to finer particles, mixed with water and chemicals (yellow) to obtain drilling fluid specifications. The slurrified fluid may then be reused in the next section of the well. The slurry process is a bottle neck in the handling process and will imply reduced drilling progress. To obtain drilling fluid specifications a significant volume of water needs to be added. The reduction in discharge of cuttings and drilling fluid is limited to the volume equal to one section. If effort is made it may in some cases be possible to reuse at a different rig. There is no existing system for transport, treatment and reuse of slurrified cuttings and recovered drilling fluids from top-hole drilling.	• Significantly reduced risk of cuttings sedimentation or particle exposure at the sea floor near the wellbore. • Reduced generation of cuttings and use of drilling fluid equal to the volume of one section	• Increased operational risk, both for halt in operation and for personnel • Constrained progress in drilling operation (ROP) • Need for additional equipment, space and man hours at the rig • Reduced generation of cuttings and use of drilling fluid limited to one section if reused at the same rig • No system for reuse within industry established • Limited applicability • Increased cost • Increased use of yellow chemicals
"Skip and ship" of separated drill cuttings for disposal onshore	"Skip and ship" is the collection of separated drill cuttings and transportation to shore for disposal. This method of waste management requires mobilization of a significant number of specialized transportation containers (cuttings skips), and the ability to support an increased frequency of lifting operations (almost continuous during drilling) at the drilling unit, and the likely additional provision of a dedicated supply vessel. Normally Skip & Ship operations are adopted by the operator when OBM drilling fluids are being used to prevent any oil discharges to sea. Drill cuttings and drill fluids is transferred to containers and shipped to shore for treatment and disposal. The handling of large volumes of cuttings and fluids in containers imply a significant number of lifting operations by rig crane. Essential personnel and space at the rig will be occupied during lifting operation.	• Standard configuration and method for collection and disposal of drilled OBM generated cuttings on all drilling units. • Mature technology - proven system (when OBM is used), technically reliable, with extensive and historic use in the E&P industry. • Waste WBM can be discharged at the rig site, but only under permit approval.	• Increased risk of operational delays due to limitations in system capacity. • Lower than expected performance – restrictions of ROP may be necessary to maintain optimal system performance. • The impact of poor weather can be significant. Increased risk for suspension in drilling operations as a result of restricted crane operations. • Need for dedicated space on the drilling unit for storage of containers. • Significant increase in the frequency of lifting operations by the rig crane. • Increased risk exposure to personnel involved in the lifting operations both on and offshore. • Dedicated personnel required to support the operation. • Dedicated supply vessel required to support continuous drilling operations. • Logistics costs will be high. • Increased generation of emissions due to additional logistics requirements. • System has not been extensively used for the

			collection and transportation of WBM generated cuttings. It is expected that an increased risk of operational problems would be likely if this were to be adopted for larger hole sections unless additional engineering – system upgrades were possible.
Bulk handling of cuttings to a supply vessel whilst drilling, for transport and disposal onshore	Collection and bulk handling of drilled cuttings for disposal onshore requires the installation of additional equipment on the drilling unit. Bulk cuttings storage tanks along with transfer lines (temporary flexible hoses) are necessary in the process. This technology is normally associated with OBM generated cuttings. This technology is comparable to skip and ship, in that all cuttings are collected and transported to shore for treatment and disposal.	• The impact of poor weather on this technology is much less when compared with skip and ship. • A significant number of crane lifting operations are eliminated with this process. • Bulk storage tanks allow continuous, unrestricted drilling performance, i.e. ROP is not controlled for cuttings waste management.	• Weather impact – drilling operations will likely be suspended if transfer hose cannot be connected for a prolonged period. • Constrained progress in drilling operation (ROP) • Limited to inhibited (glycol) fluids • Limited bulk tank volume available due to space restrictions on rig. • Dedicated supply vessel is required • Need for dedicated personnel to operate system. • On its own, not suitable for recovery of top-hole cuttings without additional equipment. • Limited successful experience.
"Blowing" cuttings to vessel while drilling, for transport and disposal onshore	Drill cuttings are transferred directly to a vessel from the shakers, by temporary lining and pressurized air. Collection and bulk handling of drilled cuttings for disposal onshore requires the installation of additional equipment on the drilling unit. Bulk cuttings storage tanks along with transfer lines (temporary flexible hoses) are necessary in the process. This technology is normally associated with OBM generated cuttings. This technology is comparable to skip and ship, in that all cuttings are collected and transported to shore for treatment and disposal.	• A significant number of crane lifting operations are eliminated with this process over skip and ship. • No restrictions on ROP if bulk transfer hose can be connected.	• Weather impact – drilling operations will likely be suspended if transfer hose cannot be connected. • Installation and rig space availability issues • Dedicated supply vessel is required • Specialist equipment required – blowing system and transfer hose system. • Need for dedicated personnel to operate system. • On its own, not suitable for recovery of top-hole cuttings without additional equipment.

Coarse slurrification of separated cuttings for disposal at sea floor	Coarse slurrification and disposal at the sea floor is a combination of the CTS and the mud recovery techniques. A coarse slurrifying at the rig enables transport of cuttings and drilling fluids, with reduced risk for obstructions, to a deposit site further away from the well to a more optimal location.	• A significant number of crane lifting operations are eliminated with this process over skip and ship. • Suitable for all sections of the drilling operation, not just top-hole. • Perceived lower overall environmental impact than skip and ship.	• Very limited experience - unproven technology. • Increased operational risk due to uncertainty with success. Skip and ship may be required as contingency. • Likely reduction in progress if system is used during Top-hole drilling. • Need for additional specialist equipment and deck space. • High complexity over alternative solutions. • Likely high cost over other solutions.

Based on evaluation of reliability, complexity, environment and cost-benefit, CTS (Cuttings Transport System) is often preferred technology in areas with SHEC. The risk of leaks and accidental discharges from the CTS hose will increase according to length of the planned CTS system, and discharge area is in most cases larger than with conventional discharges at spud location. This should be taken into consideration when deciding to use CTS or not. With thorough and early seabed mapping and planning of the drilling operation, it is in most cases possible to locate a suitable deposition area within range of a CTS and with no or minor risk of effects to seabed habitats.

7.3 Anchor and mooring chain handling

Anchor and mooring chain handling may cause mechanical damage to corals or other SHEC at the sea floor. Damage may occur when deploying and recovering the anchors and anchor chains or lines. Damage may also occur during normal drilling operations through the horizontal movement of the anchor chains on the sea floor when moving the rig and by touch-down (vertical movement) of anchor chains caused by tension.

Normal drilling operations implies movement of the drilling unit 50 meters in any direction. In an emergency situation the drilling unit may be moved 100 meters in any direction to obtain "survival position". When moving the drilling unit, the sector of horizontal movement of the anchor chains at the sea floor is close to zero near the anchors and increase with decreasing distance to the drilling rig. This should be considered when planning a mooring pattern and deciding mitigating measures to minimise harm to corals and SHEC.

Depending on local soil conditions, along with the sea current and wind, the tension on each anchor and chains will vary during a normal drilling operation. An anchor chain with low tension may have touch-down as close as 250-300 meters from the rig. Increased impact area closer to the rig should be included in anchor impact analyses.

A mooring analysis must always be performed prior to arrival and positioning of a mobile offshore drilling unit at location. The objective of a mooring analysis is to obtain stable and safe positioning of the mobile drilling unit and to avoid conflict with seabed infrastructure such as - pipelines, umbilicals and general equipment at the sea floor. At locations where CWC or other sensitive populations are present, all seabed fauna of environmental concern prioritised for protection should be considered as an obstacle in the mooring analysis such that consideration is given in the design of the anchor-spread and mooring analysis. Early identification of CWC prioritised for protection is critical. The resulting anchor-spread should avoid interfering with corals as far as possible. Where interference may occur, additional measures should be considered. Performing a anchor best fit analysis (section 6) is recommended. Available mitigating techniques are listed in Table 7-3.

Table 7-3 Mitigating techniques for anchor and mooring handling.

Technique	Description	Pros	Cons
DP-rig	DP (Dynamic Positioning)-rig will be positioned by continuously working thrusters controlled by GPS and other reference systems. No mooring needed.	• No risk for mechanical damage or harm on corals and environmentally SHEC	• Restriction on min depth • Significant increase in fuel consumption and CO2 emissions • Significant increased well cost due to high rig rate • Shallow water depth limitations
Pre-laid anchors and chains	To obtain accuracy in positioning of anchors and chains in alignment with the mooring analysis and to avoid corals and environmentally SHEC closer to the rig than expected touchdown, anchors and chains may be pre-laid before the rig arrives at location.	• Reduced risk for mechanical damage or harm on corals and environmentally SHEC • Monitoring of pre-laying operation through an anchor handling vessel (AHV) complete with ROV ensures optimal placement within corridor.	• Separate marine operation • Pre-laying on occasion can result in increased well costs, however this is dependent on availability of AHV's and spot market costs. • Vessel with ROV required
Techniques for pick-up of pre-laid anchors	To avoid "grappling" for pick-up of anchor chains ROV assisted pick-up and pick-up buoys may be used	• Reduced risk for mechanical damage or harm on corals and environmentally SHEC	• Vessel with ROV required • Increased cost
Use of fiber wire and sub-surface buoyancy	The anchor chains may be partly replaced by fiber (nylon) wire and given buoyancy by attaching buoys to the fiber wire that may interfere with a coral structure when touchdown	• Reduced risk for mechanical damage or harm on corals and environmentally SHEC • Reduced footprint as possible touch down is moved further away from the rig • Reduced footprint of anchor chain as impact of horizontal (sideways) movement is less further away from the rig	• Increased complicity • Increased operation time and weather window necessary. • Increased cost
Use of larger anchor and/or larger chain dimension	Use of larger anchor or larger dimension of anchor chain gives heavier weight, and the chain length may be reduced and/or the anchor may be moved closer to the rig. The objective is to reduce the footprint and/or adding flexibility in anchor position	• Reduced risk for mechanical damage or harm on corals and environmentally SHEC • Reduced footprint will increase flexibility in placing anchor and chain in areas with high density of CWC, increased number of possible anchor chain corridors	• Increased cost
Implementing maximum skidding positions	Implementing max skidding position as meters (e.g. 50 m) in certain degrees	• Reduced footprint • Reduced risk of mechanical damage to SHEC	• Less flexibility

7.4 Pipelaying and deployment of infrastructure

Preparation for deployment of infrastructure may imply rock placement to even the sea floor terrain of for example a pipeline route. Deployment of infrastructure, rock placement and sediment jetting imply a risk for mechanical damage and particle exposure to seabed habitats such as corals. The risk for harm to habitats by particle exposure from such operation is relatively limited. The duration of exposure is considered short and the particle load on a specific habitat area is limited.

The planned pipeline route should be surveyed at least 50 meters to each side, if high density of coral structures is expected the survey should be extended to 100 meters to each side of the planned route.

To avoid harm to present corals of value, consideration should be made to adjust the pipeline route or implementing installation restrictions for the operations. Such restrictions can be to minimise jetting, rock placement or to place out barriers for pipeline movements (Table 7-4 and Figure 7-1). Utilising Residual curvature method (RCM see e.g. Endal et al., 2014), or similar for controlling where buckling should take place, should be considered. In case of multiple targets along the pipe route the conservation value of the areas can be scored depending on findings, so that the route with least impact to the most valuable areas can be chosen, this is typically verified and documented in a risk assessment.

The pipeline deployment vessel may be dependent on anchoring. The use of anchored vessels being pulled along by the chains can have high potential for damaging seabed communities. On locations where high density of corals are identified one should consider use of DP vessel.

Table 7-4 Example showing installation restrictions for pipelaying in areas with spatially defined SHEC (e.g. coral area polygons). Installation restriction zones adapted from Wintershall (2015), adjusted according to known impact.

Distance from area of environmental concern (meter)	Area	Restrictions
0-5	Lay accuracy buffer	Pipe must be laid outside this boundary; pipe shall not buckle inside this boundary
5-15	Jetting/trenching buffer	No jetting or trenching within this boundary
5-25	Rock placement buffer	No rock placement within this boundary
25-50	Minimise rock placement	Accurate rock placement allowed
>50	Background	All activities OK

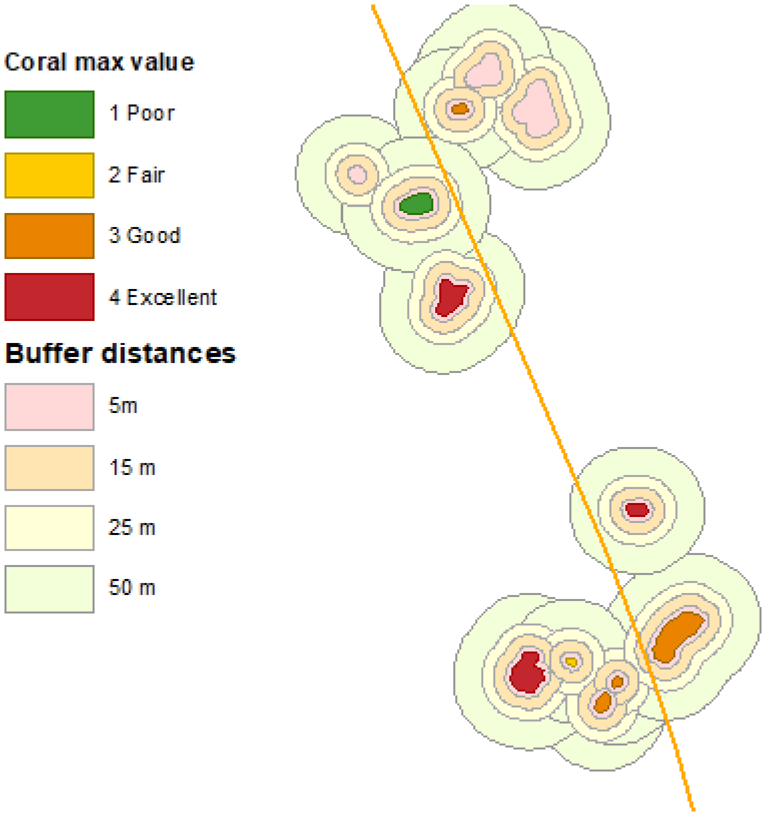


Figure 7-1 Example showing mapped pipe route corridor and identified SHEC (corals) with 5-, 15-, 25- and 50-meter buffer zones demarcated. The buffer zones represent areas where various activities such as jetting or rock placement or should be limited, depending on proximity to SHEC.

7.5 Conclusions

After mapping potential habitats and planning with consideration of the available risk reducing technologies for mitigating the impact of drilling, anchor operations or pipelaying the operator's primary strategy should be to adapt operations to alternatives with the least impact on the seabed habitats, within feasible cost / benefit frames.

Operators should consider positioning the well head location on the sea floor at a location with the lowest impact on the local sensitive seabed fauna of concern, whilst maintaining well objectives and recognition of shallow geological hazards such as shallow gas, boulders and faulting. Drilling strategy and discharges locations can be adopted to minimise impacts.

When routing pipelines the route with least impact on seabed fauna should be considered. Installation restrictions (e.g. localised halt in rock placement or jetting/trenching or deployment of barriers for movement of pipeline) should be adapted so that impact on conflicting fauna in the planned route is minimised.

If a moored drilling unit is planned, the operator must also consider the impact of anchors and mooring chain activity, and if necessary, mitigating measures should be taken.

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9 ABBREVATIONS

AUV Autonomous Underwater Vehicle

CAN Conductor Anchor Node

CTS Cuttings transportation system

CWC Cold water corals

DGT Diffuse gradients in thin films technique – Measures dissolved metals

DPS Dynamic positioning system

FTU Formazine Turbidity Units

GIS Geographical Information Systems

HD High Definition (camera)

IUCN International Union for Conservation of Nature

IMR Institute of Marine Research

NEA Norwegian Environment Agency

RCM Residual curvature method

ROV Remotely Operated Vehicle

SSS Side Scan Sonar

MBES Multi beam echo sounder

NOCS Norwegian Continental Shelf

NML Naturmangfoldloven, Nature diversity act

NiN Naturtyper i Norge

OBM Oil based mud

OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic (previously Oslo-Paris Convention, thus the name OSPAR)

PLONOR Pose Little Or No Risk to the Marine Environment

POM Polyoxymethylen – A passive sampler for hydrophobic chemicals

RMR Riserless Mud Recovery

SHEC Species and Habitats of Environmental Concern

TCC Thermomechanical Cuttings Cleaner

WBM Water Based mud

APPENDIX A
Literature review, effects on corals and sponges relevant to NCS

A general review of known studies on effects relevant for corals and sponges relevant for the NCS is given below. The studies provide the basis for proposed threshold levels presented in this report. References of particular interest are summarised in Table A1 and A2 and A3.

Effects on *Desmophyllum pertusum* (*Lophelia pertusa*)

Deep water coral reefs are situated in areas with relatively high current velocities, with periodical disturbances in form of naturally occurring sedimentation or increased particle loads (Mortensen, et al. 2001; White et al., 2005; Thiem et al., 2006; Kiriakoulakis et al., 2007; Davies et al., 2008). In general sedimentation and covering of the live coral polyps is regarded as one of the threats to living coral reefs from drilling, imposing a sedimentation regime on the corals higher than what can be normally expected.

The scientific programme “Coral Risk Assessment, Monitoring and Modelling” (CORAMM) has indicated that sedimentation in the order of 6.3 mm may cause adverse effect on *Desmophyllum pertusum* (Larsson and Purser, 2011). This level could further be supported by the threshold level (PNEC, Predicted No effect Concentration) for sediment burial of benthic fauna used by the oil companies on the Norwegian Continental Shelf in the risk assessment of drilling discharges based on Smit et al. (2008) which is set to 6.5 mm. This burial level reflects a hazardous level for 5 % (HL5) of benthic species (Smit et al., 2008). However, the benthic species in Smit et al. (2008) did not include corals.

The Larsson and Purser (2011) study suggest that the threshold for burial used by the offshore industry may result in damage to *D. pertusum* (the proportion of coral fragments that lost coenosarc (outer tissue) was significantly affected by sediment load, polyp mortality increased with sediment load (0.5% and 3.7%) at exposure levels of 6.5 and 19 mm respectively over a period of 21 days). A later study; Allers et al., (2013) found that sedimentation from drill cuttings would not cause coral death within <12 days, even at concentrations 3x and 7x that required to achieve the 6.3 mm risk assessment guideline maximum depositional depth. Long term effects or reduced fitness was not studied. Allers et al. (2013) did however find that complete burial of coral branches for >24 h in reef sediment resulted in suffocation.

D. pertusum’s ciliary movement and removal of sediment embedded in mucus has been investigated in some studies (e.g. Provan et al., 2016; Zetsche et al., 2016), and can explain why *D. pertusum* is able to recover from sedimentation, as is shown in a number of lab experiments (e.g. Larsson et al. 2013; Allers et al., 2013; Baussant 2018). Results on long term effects from various concentrations of particles and drill cuttings vary. Larsson et. al (2013) found that skeletal growth was significantly lower under exposure concentrations of ~25 mg/L than ~5 mg/L and there was a trend of lower growth rates when exposed to water-based drill cuttings than to natural benthic sediment. The study concluded however, that the effects on the adult form of *D. pertusum* from exposure to particles during drilling of an exploration well at the above specified threshold level (6,3 mm deposition or 10 mg/L) is likely marginal. Baussant et al., (2018) stated that a drill cuttings concentration of 10 mg/L seems to represent a threshold above which changes in coral conditions were observed however with no apparent physiological consequences for the coral within the experimental time scale. Baussant (2022) revealed effects after 2 weeks on bentonite exposed nubbins of *D. pertusum* at 23 and 48 mg/L bentonite concentration and that polyp mortality increased significantly at the two highest drill cuttings doses (19 and 49 mg/L) 2 and 6 weeks postexposure. Findings indicated overall a risk for long-term effects at a threshold of ~20 mg/L.

The corals spawning period, could be taken into account if drilling will commence during this period. Studies point out that *Desmophyllum pertusum* larvae are sensitive towards suspended particles due to ciliary clogging and as a result larvae mortality. *D. pertusum* larvae are particularly vulnerable to elevated particle concentrations, with moderate to high particle concentrations (>~25-40 mg/L over a few days) causing significant larvae mortality (Larsson et al., 2013; Järngren et al., 2017). Järngren et al. (2020) assessed larval sensitivity with regards to behavioural effects or lethal effects at various particle Järngren et al. (2017) reported increased sediment load for a duration of 24 h caused significant larval mortality. Larsson (2013) suggested that early life stages, coral larvae, may be particularly vulnerable to high particle concentrations and that more research is needed in this area. concentrations from bentonite, barite and drill cuttings. The study concluded that larvae showed greatest sensitivity to bentonite, followed by barite and drill cuttings, and also showed age-related responses that differed among the test materials. Post exposure recovery was variable, with larvae exposed to bentonite having the lowest recovery rates.

Spawning period has generally been considered to occur in February-March in the NE Atlantic (Waller and Tyler, 2005; Gillespie and Clague, 2009, Larsson et., al, 2014). Brooke and Järnegren (2012) indicate that spawning period might be different in fjord systems.

Effects on sponges

Tjensvoll et al. (2013) documented a 86% reduction in oxygen consumption when exposed to natural sediments in concentrations of 100 mg/ L (suspended solids), with thresholds of responses occurring between 10 to 50 mg/L.

Edge et al. (2016) reported sub lethal effects of WBM on *G. baretti* and concluded that exposure to suspended barite decreases cellular viability in *G. barretti*. Cellular toxicity may have been caused by an increase in exposure to the clearly bioavailable metal contaminants as well as the physiological stress associated with the barite particle. The study documented that lysosomal membrane stability was reduced at 30 mg TSS/L for both continuous and intermittent exposures over 14 days.

Kutti et al. (2015) reported that *G. barretti* appears to have well developed mechanisms to resist sediment stress, however, the study demonstrated that operations releasing large amounts of suspended crushed rock such as exploration drilling and submarine tailings disposal near sponge beds should be carefully planned to avoid long-term losses of benthic ecosystem functions, such as organic matter re-mineralization. The study reported rapid recovery after short induction of 50 mg/L solution of particles, but there was a 60 % drop in oxygen consumption with long term exposure (50 mg/ L) 12 hours a day for 29 days.

Effects on fish, larvae and eggs

Most animals can cope with moderate amounts of physical disturbance in the form of suspended particle load. Short term particle exposure caused by industrial activities has been evaluated by US EPA who have concluded on a multisector general permit for stormwater discharges of 100 mg TSS/L. The nature of particles matter; size, shape and chemical composition. With regards to shape, particles with sharp edges are generally found to be more toxic as they can damage gills and the digestive system. A report by Aquateam COWI (2014), focussing specifically on thermal treated OBM drill cuttings (TTC), concluded based on microscopic evaluation of several TTC samples that these particles have rounded shapes. Acute toxicity to Calanus finmarchicus was documented at the g/L level for TTC in studies with 96 h exposure

(Aquateam COWI, 2014). This suggests that TTC particles are relatively inert. While most studies on particles document significant effects at levels above 10 mg/L, a single study referenced in Aquateam COWI (2014) show detectable effects of water-based mud particles on cod larvae gills at particle loads of 0.5 mg/L after three weeks of exposure. In the study, fish survival was affected at much higher concentrations (40 mg/L), which is more in line with other studies. In general, fish will avoid the most densely affected areas, so a short exposure time is probably more relevant for a risk assessment targeting fish population. For water-based drilling mud, Smit et al. (2008) estimated PNEC values of 7.6 and 17.9 mg/l for suspended bentonite and barite, respectively, based on SSD tests on 12-15 marine species. A study by Ogonowski et al. (2018) compares the effect of mineral particles, documenting how they are generally less toxic than microplastic particles. He notes that even for mineral particles, some studies show significant effects at levels below the stormwater limit of 100 mg/L, but those are in general reflecting longer exposure times. To conclude, available data do not indicate that TCC particles are particularly toxic compared to other types of particles (Aquateam COWI, 2014). For intermittent release (short duration), the stormwater limit of 100 mg TSS/L appears to be a relevant threshold value and aligns well with the EIFAC (1965) observed reductions in fish survival. For longer durations of particle exposure, which might be relevant to a drilling operation, a limit of 10 mg TSS/L is probably more robust as a PNEC estimate. This aligns well with the suggested "5 % affected species level" for suspended bentonite and barite as discussed by Smit et al. (2008).

The findings and recommendations above are in line with a literature study described in DNV GL (2014). Based on the studies cited in the report, the following effect levels of lethal and sublethal effects (including behavioural effects) were identified in adult/juvenile fish, and fish eggs/larvae:

- Lethal effects adults/juveniles: 400 mg/L (Newcombe, 2003)
- Lethal effects eggs/juveniles: 100 mg/L (Van Dalfsen, 1999)
- Sublethal effects adults/juveniles: 7 mg/L (Newcombe, 2003)

Westerberg et al. (1996) carried out a number of studies of effects on increased concentration of lime/clay particles on, among other things, adult cod. The study shows that adult cod are generally little affected by increased particles in the water bodies. Some impact could be documented related to orientation due to lower visibility as a result of increased turbidity. The study concluded by finding partial avoidance behaviour at 3 mg/l and total avoidance behavior at 6-8 mg/l. Westerberg et al. (1996) also found that cod larvae with egg sacs had higher mortality than cod eggs when exposed to sediment, which was thought to be due to clogging of the larval gills. Furthermore, the study showed that concentrations above 10 mg/l lime resulted in faster utilization of nutrients in the yolk sac, lower activity level, higher predation and generally increased mortality, sensitivity was higher for lime particles than clay particles. An important conclusion from the study was also that an increased concentration of suspended particles led to an increased density of pelagic cod eggs. An increased sink rate proportional to sediment concentration and exposure time was recorded. At the lowest concentrations (5 mg/l), an exposure time of 11 hours was necessary to create an increased sink rate corresponding to an increased sink rate at a reduced salinity in the water of 1 PSU (‰). Poorer buoyancy as a result of increased turbidity and sedimentation is also indicated in recent studies (e.g. Wenger et al. (2017). FeBEC (2013) carried out experiments with cod eggs and showed that small particles stick to the eggs and cause them to sink to the bottom, with measurable effects already at a particle concentration of 4 mg/l. Eggs exposed to concentrations of 10 mg/L resulted in sedimentation lasting a change in salinity from 19 to 24 PSU in less than 20 hours. At 5 mg/L exposure, it was calculated that it took 59 hours to sink from 19-24 PSU It was pointed out that the hatching time for cod eggs was 314 hours in this study.

Canadian water quality criteria of 25 mg/L for total particulate concentration in salmon rivers (Canadian Council of Ministers of the Environment, 2002) are set to guarantee protection of early life stages in salmonids. Increased direct mortality in fish larvae has been reported at concentrations above 100 mg/L (Van Dalfsen, 1999; Kiørboe et al., 1981). While 3.5 mg/l is expected to cause sublethal effects on eggs and larvae (Van Dalfsen, 1999). Reinardy et al. (2019) examined emissions from mining operations in Svalbard and found an 8% increased mortality of cod larvae when exposed to 3.2 mg/L particles over 21 days.

Johnston & Wildish (1982) showed that herring larvae fed in water with 20 mg/L suspended sediments ate less Artemia than larvae from the control group, which was also reflected in a lower growth rate in exposed larvae. The study also showed that the smallest larvae were more sensitive than larger larvae. Messieh et al. (1981), however, reported reduced food intake in herring larvae already at 3 mg/L.

Table A1 Summary of relevant peer-review literature studies related to deposition of particles and impact on *Desmophyllum pertusum* (previously *Lophelia pertusa*). References given in Section 8.

Species	Exposure	Amount	Duration	Measure	Relevant findings	Reference
Lophelia pertusa (2 morphs)	Natural sediments	sediments >1 cm	1, 2, 4, and 7 d.	Polyp survival	Almost complete survival of both morphotypes after 24 h, which dropped to an average of 89.5% (SE: 9.53) after 2 d for the heavily calcified growth form and 73.3% (SE: 15.27) for the fragile morphotype. After 4 d, almost all the polyps had died, and mortality was complete after 7 d	Brooke et. Al (2009)
Lophelia pertusa	Natural sediments and WBM with glycol and Barite	33 mg cm^2	Every second day for 45 days, cleaning between	Sediment-free area	There were no signs of exhaustion of the sediment rejection ability from coenosarc covered coral surfaces with long-term exposure.	Larsson and Purser (2011)
	Burial study: Drill cuttings	6.5 mm 1.36 g /cm^2, or an avg. deposition rate of 65 mg cm^2/ day	21 days	Coenosarc damage, polyp mortality and coral skeletal growth	Tissue was smothered and polyp mortality occurred where polyps became wholly covered by material. Burial of coral by drill cuttings to the current threshold level used in environmental risk assessment models by the offshore industry (6.3 mm) may result in damage to *L. pertusa* colonies	
	Burial study: Drill cuttings	19 mm, 4.08 g / cm^2 or 195 mg cm^2 /day	21 days	Coenosarc damage, polyp mortality and coral skeletal growth	The sediment-free coral area decreased by up to 26% as a result of the repeated exposure. significant effect of sediment load on the proportion of coral fragments that lost coenosarc during the experiment. 3.7% of polyps died in the 19 mm treatment and 0.5% died in the 6.5 mm treatment whereas all polyps survived in the control aquaria.	
Lophelia pertusa	Reef sediments, drill cuttings and mix	66 mg cm^2 (=6,3 mm), 198 mg cm^2 and 462 mg cm^2	introduction then settle for 12 h-> measured for 11 d	steady-state O2, pH and H2S	A very high sediment load is needed to achieve persistent sediment coverage of living *L. pertusa* branches.	Allers et al. (2013)
	sediment amended with lyophilized algal cells	Total polyp coverage (in sufficient concentration to ensure total polyp coverage and burial)	24 h, 48 h and 72 h of incubation in anoxic sediment	Polyp survival	complete burial of coral branches for >24 h in reef sediment resulted in suffocation	

Table A2 Overview of relevant peer-review literature studies on impacts of suspended particles on cold-water corals.

Cold-water coral species	Particle type	Exposure/ recovery	Effect endpoint measured	Relevant findings	Literature source
Desmophyllum pertusum (scleractinian coral). Adult (coral nubbins).	Natural benthic sediment (NS) and drill cuttings (DC) with residual WBM (glycol and barite). Particle grain size: <63 µm.	Long-term 12-weeks continuous exposure to suspended NS and DC particles: Exposure concentrations (nominal): NS low: ~5 mg/L and NS high: ~25 mg/L. DC low: ~5 mg/L and DC high ~25 mg/L plus control. Actual concentrations (see footnote)[19]. Three replicates per treatment.	Polyp activity, skeletal growth, skeletal surface particle accumulation, respiration, structural and storage fatty acid content in coral tissue, polyp mortality.	Polyp activity (% extended polyps) was significantly lower at the high DC and NS treatments (25 mg/L) than at the low DC treatment (5 mg/L). Polyp activity in control treatment did not differ significantly from any DC or NS treatments. Skeletal growth was significantly lower (~50%) at 25 mg/L compared with 5 mg /L NS and DC treatments but was not significantly different from control. There was a trend of lower growth rates when exposed to DC than to natural sediment (at 25 mg/L). Accumulation of particles (smothering) on skeletal surface tissue was higher at 25 mg/L than 5 mg/L after 8- of 12-weeks continuous exposure to NS and DC, mainly on surface lacking coenosarc. Loss of coenosarc due to smothering from accumulated. particles not measured in this study. Respiration rate: A general increase in coral respiration rate in all treatments (incl. control) over the 12-weeks experimental period (up to 71%), but no significant effect in NS and DC treatments detected compared with control. Fatty acid (FA) content: High variability in the storage FA among nubbins. No significant difference among treatments of structural and storage FA. Polyp mortality: In general, mortality was very low in all treatments; 0.3% and 2.2% in the high NS and DC exposure (~25 mg/L), respectively, likely due to particle accumulation and resultant particle smothering.	Larsson et al. 2013 (CORAMM)

Cold-water coral species	Particle type	Exposure/ recovery	Effect endpoint measured	Relevant findings	Literature source
Desmophyllum pertusum (scleractinian coral). Adult (coral nubbins).	Barite (BA) particle size: <63 µm (90%).	Short-term 12-hours continuous exposure to suspended BA ~25 mg/L plus control (smaller scale experiment).	Coral mucus production.	No significant difference detected in mucus production between the control and the BA treatment.	
Desmophyllum pertusum (scleractinian coral). Larvae (23-days after spawning - fully developed).	Drill cuttings (DC) with residual WBM (glycol and barite). Particle grain size: fine fractions (washed drill cuttings).	Short-term 5-day continuous exposure to suspended DC nominal concentrations of ~5 mg/L and ~25 mg/L plus control (smaller scale experiment).	Survival.	Significant mortality (67%) in larvae after 5-days exposure to 25 mg/L fine fraction of DC particles, whereas the mortality in the 5 mg/L treatment was identical to control.	
Desmophyllum pertusum (scleractinian coral). Larvae.	Drill cuttings (DC)[4] Particle grain size: <100 µm.	Short-term 24-hours static exposure suspended DC. Experiment 1: >15-20-day old larvae. Exposure to decreasing concentrations of DC (nominal): control, 0.5, 1, 2, 4, 10, 40, 80, 160 and 640 mg/L. Experiment 2: 19-20-day old larvae. Continuous exposure concentrations (nominal): control, 10, 40, 80, 160, 320, 640 mg/L. Experiment 3: ~5-day old larvae. Continuous exposure concentrations (nominal): control, 40, 80, 160, 320, 640 mg/L.	Observation of live, live clogged and dead larvae[5].	Overall, 5-day old larvae were significantly more affected to lower DC concentrations (<174 mg/L) than older larvae (15-20 days), while the older larvae were significantly more affected at higher DC concentrations (>344 mg/L). Experiment 1 (>15-20-day old larvae): Close to 100% survival in most treatments with exposure up to 160 mg/L. Exposure to the highest treatment (650 mg/L): ~12% live clogged and ~23% dead larvae. 50% effect not reached. Experiment 2 (19-20-day old larvae): Higher mortality observed in 19-20-day old larvae compared with 15-20-day larvae at similar treatment. - Less than 10% larvae affected (dead or live-clogged) up to 160 mg/L. - At 320 mg/L treatment: ~5% live-clogged and ~68 % dead. - At 640 mg/L treatment: ~5% live-clogged and ~92% dead. Estimated EC50 = 280 mg/L for >15 days old larvae. Experiment 3 (5-day old larvae): Showed higher mortality at lower DC concentrations than for older larvae. Statistical modelling showed that 5-day	Järnegren et al. 2017

Cold-water coral species	Particle type	Exposure/ recovery	Effect endpoint measured	Relevant findings	Literature source
				old larvae was affected at DC concentrations as low as 40 mg/L. Survival declined with increasing particle concentration: ~91% live at 40 mg/L, ~84% at 80 mg/L, ~48% at 320 mg/L and ~18% at 640 mg/L. Estimated EC50 = 330 mg/L for 5-day old larvae.	
Desmophyllum pertusum (scleractinian coral). Larvae.	Drill cuttings (DC), bentonite (BE) and barite (BA). Particle grain size: <63 µm.	Short-term 24-hours continuous exposure to suspended DC, BA and BE followed by 24-hours recovery in clean seawater. Experiment 1: 8-day old larvae. Exp. concentrations (nominal): control, 10, 30, 50, 100 and 200 mg/L[7,8,9]. Actual concentrations: DC: control, 6, 12, 18, 32 and 62 mg/L. BE: control, 7, 18, 26, 54 and 75 mg/L. BA: control, 6, 16, 27, 55 and 88 mg/L. Three replicates per treatment.	Observation of normal larvae (N), normal with particles attached (NP), abnormal (AN), live-clogged encased in mucus (LC) and dead larvae (D) after end of particle exposure and after recovery in clean seawater[6].	Overall, impacts on 8-day old larvae vary with particle type. Larvae showed highest sensitivity to BE, followed by BA and DC. Lowest recovery observed in larvae when exposed to BE (highest treatment - 75 mg/L), incapsulated in mucus prevented from swimming. After recovery from DC exposure ≥87% both larvae stages recovered and seemed unaffected, swimming at normal speed, and no dead or live clogged larvae observed after 24-hours recovery. Also, recovery from BA exposure showed high recovery potential with all swimming at normal speed and no live clogged or dead larvae. **Response to DC exposure (actual concentration):** Abnormal effects incl. mortality: A small percentage (~3-7%) of normal larvae with particles attached (NP) at 6 and 12 mg/L treatments, however swimming normally. At DC concentrations > 18 mg/L, the number of larvae classified as NP increased, with ~70% at the highest DC treatment (62 mg/L) and reduced swimming speed. The percentage of live clogged was low (~4% at 62 mg/L) and no dead larvae observed. **Recovery:** After recovery from DC exposure, ≥87% recovered at all treatments and seemed unaffected, swimming at normal speed, and no dead or live clogged larvae observed	Järnegren et al. 2020

Cold-water coral species	Particle type	Exposure/ recovery	Effect endpoint measured	Relevant findings	Literature source
				after 24-hour recovery. Derivation of LC(EC)20/50 values[11, 12] after end of exposure (nominal concentration): EC50=38 mg/L (EC20=16 mg/L). LC50=112 mg/L (LC20=90 mg/L)[10]. **Response to BE exposure (actual concentration):** <u>Abnormal effects incl. mortality</u>: >76% of the had particles attached (NP) in the 7 and 18 mg/L treatments, but larvae were swimming normally at the lowest exposure while at lower speed in the 18 mg/L treatment. Swimming speed decreased with increasing treatment concentration. In the highest treatment (75 mg/L) 35% of the larvae were alive but clogged (LC) with bentonite and mucous, which formed a capsule around the larvae preventing larvae swimming (particles attached to cilia). 3.5% of the larvae were dead at 75 mg/L. **Recovery:** After recovery, at the lowest treatment (7 mg/L) ~6% were abnormal and ~5% normal with particles attached. At the highest DC treatment (75 mg/L), 19% were normal but still had particles attached, 24% were abnormal and 34% were live clogged. All larvae except live clogged were swimming at normal speed. Derivation of LC(EC)20/50 values[11, 12] after end of exposure (nominal concentration): EC50=10 mg/L (EC20<10 mg/L). LC50=80 mg/L[10] (LC20=63 mg/L). **Response BA exposure (actual concentration):** <u>Abnormal effects incl. mortality</u>:	

Cold-water coral species	Particle type	Exposure/ recovery	Effect endpoint measured	Relevant findings	Literature source
				Larvae showed normal behavior until treatment concentration reached 55 mg/L despite having particles attached. At the highest treatments 88 mg/L 92% of larvae were categorized as NP, but with reduced swimming capacity and had mucus strings attached. Only 6% of larvae were live clogged with particles but none were dead. BA particles appeared to attach more to the larval body rather than the cilia and they did not form mucus capsules, as they did with bentonite. **Recovery:** After recovery from BA exposure, ≥82% of larvae were normal across all treatments except 27 mg/L (4% abnormal and 47% were normal with particles attached). However, no dead or live clogged observed and all were swimming at normal speed. Derivation of LC(EC)20/50 values[11, 12] after end of exposure (nominal concentration): EC50=20 mg/L (EC20=14 mg/L). LC50=133 mg/L (LC20=110 mg/L)[10].	
Desmophyllum pertusum (scleractinian coral). Larvae.	Drill cuttings (DC) and bentonite (BE). Particle grain size: <63 µm.	<u>Short-term</u> 24-hours continuous exposure to suspended DC and BE followed by 24-hours recovery in clean seawater. <u>Experiment 2:</u> 21-day old larvae. Exp. concentrations (nominal): control, 30, 50 and 100 mg/L[8, 9]. <u>Actual concentrations:</u> DC: control, 23.1, 31.7 and 70 mg/L. BE: control, 20.5, 28.8 and 51.8 mg/L.	Observation of normal larvae (N), normal with particles attached (NP), abnormal (AN), live clogged encased in mucus (LC) and dead larvae (D) after end of DC and BE exposure and after recovery in clean seawater[6].	Similar to 8-day larvae (experiment above), 21-day larva were more severe affected to BE than to DC exposure. Higher mortality and lower recovery potential was observed in <u>21-day larvae</u> when exposed to BE than with DC. After recovery from DC treatments, ≥93% of the larvae recovered (normal) in all treatments, while in the highest BE concentration, the recoveries were not as successful. It appears that if larva is clogged by BE particles it cannot recover as it is incapsulated in mucus. **Response to DC exposure (actual concentration):** <u>Abnormal behavior incl.</u>	Järnegren et al. 2020

Cold-water coral species	Particle type	Exposure/ recovery	Effect endpoint measured	Relevant findings	Literature source
		Three replicates per treatment.		mortality: In the 23 mg/L treatment 22% had particles attached (NP) and 2% were dead. At the highest DC treatment (70 mg/L), 79% had particles attached and 2% dead. No live clogged observed in this experiment. **Recovery:** After recovery from DC treatments, ≥93% of the larvae were normal in all treatments. However, 2% of larvae in the highest treatment (70 mg/L) had particles attached. No live clogged or dead larvae observed. Derivation of LC(EC)20/50 values[11, 12] after end of exposure: EC50=40 mg/L (EC20=17 mg/L). LC50=380 mg/L (LC20=248 mg/L)[10]. **BE exposure (actual concentration):** Abnormal behavior incl. mortality: In the two lowest treatments (21 mg/L and 29 mg/L), 100% of the larva had particles attached (NP), and occasionally with mucus string ragging behind. In the 52 mg/L treatment 18% were classified as live clogged and were trapped in a bentonite-mucus capsule, while 26% were dead. **Recovery:** After recovery from BE treatments, ≥94% of the larvae were normal in treatments up to 29 mg/L. At 52 mg/L treatment 12% of the larvae had particles attached swimming at normal speed while 13% were live clogged and encapsuled in particles prevented from swimming. Derivation of LC(EC)20/50 values[11, 12] after end of exposure: EC50=10 mg/L (EC20<6 mg/L). LC50=53 mg/L (LC20=45 mg/L).	
Desmophyllum	Drill	"Short-term"	Impacts measured after	Exposure: High variability at	Baussant

Cold-water coral species	Particle type	Exposure/ recovery	Effect endpoint measured	Relevant findings	Literature source
pertusum (scleractinian coral). Adult (coral nubbins). Collected at Tautra reef in Trondheims-fjorden. Acclimatized 4-weeks in laboratory.	cuttings[1] (DC) containing 5% barite. Particle size distribution: 97% < 63 µm, 40% < 10 µm.	experiment (6.5-weeks): 2.5-weeks continuous exposure to suspended DC followed by 4-weeks recovery. Exposure concentrations (respiration rate, skeletal growth rate) actual mean: 4, 13, 27 and 42 mg/L plus control. Exposure concentrations (polyp activity, capture rate and coenosarc tissue damage) actual mean: 4, 10, and 23 mg/L plus control. Measurements: turbidity sensors.	4-weeks recovery from DC exposure on respiration rate, skeletal growth rate, prey capture rate, polyp activity and coenosarc tissue disturbance.	high exposure loads. Mortality: No mortality of polyps recorded during the experiment in any treatments. Respiration rate: not affected by DC treatments, no significant difference between treatments and control, but experimental duration exerted a significant effect. Skeleton growth rate: Significant increase in growth rate compared to control at the lowest treatment (4 mg/L) after recovery. Prey capture rate: no significant difference between DC treatments and control. Polyp activity: An immediate increase in polyp activity (extended polyps) observed during exposure in all coral nubbins at 10 and 23 mg/L that maintained throughout the exposure period. At the onset of recovery, polyp activity returned to pre-exposure conditions in both treatments. Coenosarc tissue disturbance: Coenosarc tissue in all control coral nubbins affected during the experimental period with 70% of observations displaying no or <25% reduction in coenosarc area coverage. All DC treatments exhibited a higher frequency of coenosarc disturbance; with ~40%, 70% and 50% of observations displaying more than 50% reduction in coenosarc area coverage at 4, 10 and 23 mg/L, respectively. Significant difference compared with control observed for 10 mg/L treatment only. DC accumulation/smothering was consistently higher on bare coral skeleton (where the skeleton was not covered by coenosarc tissue), observed at exposure to 10 and 23 mg/L.	et al. 2018

Cold-water coral species	Particle type	Exposure/ recovery	Effect endpoint measured	Relevant findings	Literature source
				DC accumulation/smothering also on areas initially covered by coenosarc even after 4 weeks of recovery.	
	Drill cuttings, containing 2.5% organic content. Particle size: <63 µm.	Long term experiment: 12-weeks with 3-hours repeated exposure to suspended DC followed by 14-weeks recovery. Exposure concentration (actual mean): 1, 6 and 25 mg/L. Peak exposure: 2, 12 and 52 mg/L.	Impacts measured after 14-weeks recovery from DC exposure on respiration rate, skeletal growth rate, mucus production (POC and DOC[2]), and tissue fatty acid.	Mortality: No mortality of polyps recorded during the experiment in any treatments. Respiration rate not affected in any of the DC treatments. Skeleton growth: No significant difference in effect on skeletal growth rate between DC treatments and control. Mucus production: Significant increase in mucus POC at the highest treatment (25 mg/L) at end of exposure (12-weeks) compared to the start and to the other treatments (incl. control). Pre-exposure POC levels retrieved after 14-weeks recovery. No significant difference in DOC production between treatments. Fatty acid content did not change significantly after 12-weeks exposure.	Baussant et al. 2018
Desmophyllum pertusum (scleractinian coral). Adult (coral nubbins; white morphotype). Collected near the Tautra reef in Trondheims-fjorden. Acclimated for three weeks in laboratory.	Drill cuttings (DC), barite (BA) and bentonite (BE). Particle size distributions: DC: 50% <10 µm 30%>100 µm BA: 50% <10 µm 50% 10-100 µm BE: >95% < 10 µm.	Short-term 5-days, 4-hours repeated exposure to suspended particles followed by 2- and 6-weeks recovery. Exposure concentration range (mean actual)[13]: DC: 4, 14, 49 and 49 mg/L. BA: 12, 26 and 63 mg/L. BE: 11, 23 and 48 mg/L. Flow-through system.	Impacts measured after 2- and 6-weeks recovery from particle exposure on polyp mortality and physiological responses: respiration rate, growth rate[14], mucus related particulate production of organic carbon (OC) and particulate organic nitrogen (ON), and OC:ON ratio in mucus.	Polyp mortality: Polyp mortality in control: ~20%. Mortality increased significantly at DC exposure 19 mg/L and 49 mg/L after 2- and 6-weeks recovery (median mortality ~ 25 -70 %). Polyp mortality increased between 2- and 6-weeks of recovery in the BA and BE treatment but was not significantly different to control (high variability between corals). No significant difference in respiration and growth rates in any of the DC, BA or BE treatments compared with control. Particulate OC/ON production: OC production in coral mucus was not significant different from control across the different DC, BA and BE	Baussant et al. 2022

Cold-water coral species	Particle type	Exposure/ recovery	Effect endpoint measured	Relevant findings	Literature source
				treatments. OC:ON ratio: A significant increase in the OC:ON ratio in mucus produced in BE exposure to 23 and 48 mg/L observed after 2-weeks recovery. Indicated effect threshold: ~20 mg/L.	
Desmophyllum pertusum (scleractinian coral). Adult (coral nubbins; white morphotype). Acclimated for 80 days in laboratory.	Barite (BA).	Long-term 35-days repeated exposure to suspended BA: 7-days continuous exposure to suspended BA in two cycles interrupted with periods of 7-days recovery between exposure periods. Control, BA: 50 mg/L (nominal); 53.5 mg/L (actual average of two exposure cycles) BA: 100 mg/L (nominal); 140 mg/L (actual average of two exposure cycles)[19]. 7-days acclimatization period in the exposure aquaria before BA exposure. Recirculating system. Three replicates per treatment.	Polyp activity (time-lapse camera and direct observations), polyp survival and mucus production observation. All corals transferred to clean seawater at the end of the experiment and monitored for mortality over 47 days.	Exposure measurement: The mean BA concentrations (3 replicates) for the two cycles were 7% above the nominal concentration of the 50 mg/L treatment and 40% above the 100 mg/L treatment, with coefficients variation of 52 and 55%, respectively. High variation in replicates. Polyp survival: 100% in control group, ~94% in 50 and 100 mg/L treatment after 35 days – no significant difference between control and treatments. No mortality recorded after additional 47 days in clean seawater. Mucus production: Greater mucus production in 100 mg/L treatment compared with 50 mg/L and control. Polyp activity: Replicates of the control showed constant activity throughout the experiment. No mortality observed after recovery in clean seawater in 47 days (after exposure).	Rocha et al. 2021
Desmophyllum pertusum (scleractinian coral). Adult (2 morpho-types: fragile gracilis and heavily calcified brachycephaly,	Natural benthic sediment (NS): clay. Particle grain size: primarily 93% < 20 µm (core sediment samples	Long-term 14-days continuous exposure to suspended NS followed by 4-days recovery. Exp. concentration nominal (actual): 50 (54), 150 (103), 250 (245), and 350 (362) mg/L plus	Polyp mortality and sediment removal measured after 4-days of recovery from NS exposure.	Survival decreased with increasing NS concentrations. 100 % mortality observed at the highest NS concentration (362 mg/l) in the gracilis morphotype (and ~10% mortality at 54 mg/L). ~ 93 % at highest treatment (362 mg/L) in the brachycephala morphotype. Sediment deposited on coral surface (calyx) was removed	Brooke et al. 2009

Cold-water coral species	Particle type	Exposure/ recovery	Effect endpoint measured	Relevant findings	Literature source
Gulf of Mexico).	from the Green Canyon coral site).	control.		after 9-hours recovery.	
Primnoa resaeformis (octocoral). Adult soft coral Nubbins. 2 months acclimation in laboratory.	Crushed granite (CG) rock (i.e. simulated inert mine tailings). Particle grain size: <63 µm.	Long-term 40-days repeated exposure (12-hours per 24-hour) to suspended CG: 10 mg/L (nominal). Actual mean: 11.3 mg/L. Flow through system.	Respiration rate, nutrient flux: nitrogen release rate (ammonium/ammonia), O:N ratio: oxygen uptake vs. nitrogen release ratio, (metabolic index), silicate uptake, and membrane stability (LMS). Measurement after 26-, 33- and 40-days exposure.	No effect on the release of ammonia after 26- and 33-days exposure, while after 40 days an increase was recorded (not significant). Respiration was not affected after 26- and 33-days exposure, while it increased after 40-days exposure (not significant). A significant reduction in the O:N ratio after 40-days exposure, while 26- and 33-days exposure did not influence on the O:N ratio. No effect on LMS at any time points.	Scanes et al. 2018
Primnoa resaeformis (octocoral). Adult soft coral nubbins (red tree coral). 2 months acclimation in laboratory.	Mine tailings (MT)[3], sharp-edged. Particle grain size: 60% between 1 and 20 µm. Glass beads[3] (GB) spherical smooth-edged. Particle grain size: 15.6% between 1 and 20 µm. Both sediment types: Particle grain size: <63 µm.	Long-term 3-months repeated exposure (6-hours cycle) to suspended particles of MT and GB. Actual mean control (background): 10.6 mg/L. (additional 8 mg/L anthropogenic contribution to the background concentration). Actual mean MT concentration: 18.8 mg/L. Actual mean GB concentration: 17.7 mg/L. Three replicates per treatment.	Mortality, food uptake, polyp activity/behavior (expanded vs. contracted), feeding behavior, particle polyp accumulation, loss of polyps.	Mortality: After three months under sediment exposure in the laboratory, no total mortality observed, exposed to suspended particles (MT and GB) concentration of ~18 mg/L were 8 mg/L from anthropogenic sources. No change in polyp behavior observed under any treatment. Control: (~10 mg/L) Polyp loss (tissue abrasion) observed in control individuals (19.4%). **MT particle treatment:** Food uptake increased significantly compared with control. Exhibited significant polyp loss (average 33.8%) compared with control. Polyp loss first observed in the tip of branches. No mucus production observed. MT particles accumulation in certain areas seen enveloped in mucus and embedded in the tissue. **GB particle treatment:** Food uptake increased	Liefmann et al. 2018

Cold-water coral species	Particle type	Exposure/ recovery	Effect endpoint measured	Relevant findings	Literature source
				compared with control but was not significant. Exhibited significant polyp loss (average 37.9%) compared with control. No mucus production observed. No particles accumulated in the tissue (histological samples). There was no significant difference in polyp loss between those exposed to GB and those exposed to MT.	
Duva florida (octocoral). Adult soft coral nubbins (cauliflower coral).			Food uptake, polyp activity/behavior (expanded vs. contracted), feeding behavior, sediment polyp accumulation, loss of polyps.	Mortality: After three months particle exposure, no mortality observed when exposed to MT and GB concentration of ~18 mg/L (8 mg/L in addition to the background at ~10 mg/L). **MT particle treatment:** Food uptake decreased significantly. Polyps contracted during exposure and expanded during the 6-hours cycle when exposure ceased. MT accumulation observed on top of the contracted individuals and embedded in the tissue (<10 µm). No polyp loss observed. **GB particle treatment:** Food uptake decreased compared with control but was not significant. No significant change in polyp activity (fully expanded). No polyp loss observed. No particles accumulated on surface or embedded in the tissue (histological samples).	Liefmann et al. 2018
Dentomuricea aff. meteor (octocoral). Adult.	Quartz particles (silicon dioxide-inert)	Long-term 27-days repeated exposure (4-hours cycle) to suspended quartz particles 25 mg/L	Mortality, tissue damage, respiration, polyp behavior, inorganic nutrients excretion rates	Bleaching of tissues through time of exposure suspended quartz. No mortality and undamaged	Carreiro-Silva et al. 2022

Cold-water coral species	Particle type	Exposure/ recovery	Effect endpoint measured	Relevant findings	Literature source
	shape: round and did not contain metals. Particle grain size: 0.5-10 µm (80%) 50-70 µm (20%).	(nominal). Control, Actual average quartz concentration: 15-18 mg/L after 4 hours (24 mg/L after particle addition).	(ammonia, ammonium), cellular stress biomarkers[15] and gene expression[16] (involved in cellular stress, immune response, and antioxidant reaction system).	tissues/polyps in control and quartz treatments since accumulated quartz particles on surface were easily rejected by corals. Polyp extension behavior observed to be fully extended both in the control and in quartz treatment. Respiration: No significant difference found in respiration rates between control and quartz particle treatment at the end of the experiment. Ammonium excretion rates significantly lower in treatments than in control at end of experiment (day 27). Cellular stress biomarkers: There were not significantly difference among quartz treatments and control in cellular stress biomarkers. However, an increase, was seen in GST and CAT activity from day 13 to the end of the experiment (day 27), accompanied by lipid peroxidation, indicated by slightly higher MDA concentrations. Gene expression: Several genes involved in cellular stress (HSP70, ferritin), immune response (RHD, ferritin), antioxidant defense (SOD) and in cell cycle control (RP Tyr-PH) by the end of the exposure (day 27) were upregulated in relation to levels prior to the experiment (T0). RHD, ferritin, RP Tyr-PH was also upregulated in control.	
Scleractinian corals: *Dendrophyllia cornigera* (colonial cup coral), *Desmophyllum dianthus* (solitary, cup coral), *Desmophyllum*	Natural benthic sediment (NS). Particle grain size: 83,5: silt and 16% clay.	Long-term 9-months repeated exposure (6-hours cycle) to low and high suspended natural sediment (NS)[17]. Control, Low NS: initial maximum average	Polyp mortality, growth, respiration, and excretion rates[18]. Observation of coenosarc deterioration and sediment ingestion.	Mortality: No mortality observed in *D. dianthus* and *M. lepida.* *D. cornigera* showed a low increase in mortality (not significant) in both treatments compared to control. *D. pertusum* showed significant increase in polyp mortality (average of 16%) in the treatments (initial max average	Bilan et al. 2023

Cold-water coral species	Particle type	Exposure/ recovery	Effect endpoint measured	Relevant findings	Literature source
pertusum (colonial) *Madrepora oculata* (colonial). ***Black coral:*** *Leiopathes glaberrima*. **Octocoral:** *Muriceides lepida*. Collected in Mediterranean Sea, submarine canyons.		conc.: 6.7 mg/L. High NS: initial maximum 38.1 mg/L, both treatments followed by a gradual decrease towards background conc. (0.5 mg/L) reached within 6-hours. Exposure designed to simulate bottom trawling-induced turbidity.		conc. 6.7 and 38.1 mg/L) when compared to the control treatment, but no differences between the two NS treatments. A significant increase in mortality (64%) observed in *M. oculate* (most sensitive) in both NS treatments compared with control (but not between NS treatments). *L. glaberrima (black coral)* showed high mortality as tissue loss in all treatments, with no statistical differences among treatments (included control). Growth: None of the NS treatments showed statistically significant impact on growth rates on the coral species studied. Respiration: *D. cornigera* and *D. dianthus* did not show any significant differences in respiration after 4 and 9 months compared with control, and no difference among treatments. *D. pertusum* showed a significant decrease at high NS treatment on respiration, and with time (from 4 to 9 months). *M. oculata* showed a significant decrease in respiration from 4 to 9 month in all the treatments, included the control. A significant effect was recorded in the low NS treatment. *L. glaberrima* showed no significant differences in respiration with time and treatment. *M. lepida* showed a statically significant decrease of respiration with time in all the treatments but not among treatments. Excretion: *D. cornigera* did not show any significant differences in excretion after 4- and 9-months and no differences between the treatments. *D. dianthus* showed a significant increase in excretion	

Cold-water coral species	Particle type	Exposure/ recovery	Effect endpoint measured	Relevant findings	Literature source
				in high NS treatment after 4-months, but not after 9-months. *D. pertusum* showed statistically significant difference in the low NS treatment as well as with time (separately and in combination). Highest excretion values observed in low NS treatment after 4-months, after which there was a significant decrease in excretion. Excretion did not change significantly in *M. oculate* and *L. glaberrima.*	
Caryophyllia (Caryophyllia) huinayensis) (scleractinian coral; solitary). Juveniles Collected from habitats sheltered from sedimentation stress.	Natural benthic sediment (NS). Particle grain size: <200 µm.	Long-term 12-weeks ex-situ experiment with exposure to three suspended natural sediment (NS) concentrations: Treatments (nominal) concentrations: Control/background concentration (BC): ~ 1.6 mg/L. 100 times BC: ~160 mg/L. 1000 times BC: ~1600 mg/L. Exposure designed to mimic sediment levels expected from gravel road and coastal erosion.	Coral mortality, changes in tissue cover, polyp behavior, tissue retraction, respiration, growth.	No mortality of the juveniles observed in any of the treatments throughout the experiment. Exposure to 100-fold (~160 mg/L) and 1000-fold (~1600 mg/L) magnitude levels compared with natural ambient NS levels (~1.6 mg/L) resulted in a decrease in tissue cover of 32% and 80%, respectively, along with a decrease in respiration rate of 34% and 66%, respectively. At the highest exposure concentration (1000-fold BC) partly or no polyp expansion was seen over the experimental period while corals in control and 100-fold treatment most of the corals showed fully polyp expansion. A significant reduction (~95%) in growth at the highest exposure load compared to corals exposed to background NS condition.	Fähse et al. 2023

[1]Drill cuttings from the upper well (17 ½") section of a production well (Haltenbanken, Norwegian Sea containing 5% barite (weighing agent).
[2]POC: particular organic carbon, DOC: Dissolved organic carbon.
[3]Actual mine tailings: Contained mainly quartz, muscovite, chlorite and magnetite. Glass beads were mimicking natural, smooth sediment.
[4]Drill cuttings from exploration well "Trolla" from 36" section, drilled with pre-hydrated bentonite.
[5]Affected larvae: Live clogged plus dead larvae.
[6]Responses on larvae measured at the end of the exposure period (24-hours), representing at an average about 50% of the initial target concentration (actual concentrations), categorized into five categories: Normal larvae (N) were those swimming normally "normal speed" and had no particles attached. Normal with particles (NP) were swimming normally but often with reduced speed compared to N, and had particles attached to the larvae or as mucus trails. Abnormal (AN) defect behavior (swimming in circles, misshapen body). Live-clogged (LC) were encased in mucus and/or could not swim but were still moving. Dead larvae (D) showed no cilia movement.
[7]Bentonite concentrations dropped to an average final concentration of 47.7% and 54.3% of target concentration after 24 hours in 8-day (7, 18, 26, 54 and 75 mg/L) and 21-day (20.5, 28.8 and 51.8 mg/L) larvae, respectively. The paddle system was designed to maintain particle concentrations in suspension.
[8]Barite concentrations dropped to an average final concentration of 54% of target concentration after 24 hours in 8-day larvae (6, 16, 27, 55 and 88

mg/L). The paddle system was designed to maintain particle concentrations in suspension.
[9]Drill cuttings concentrations dropped to an average final concentration of 31.5% and 52.3% of target concentration after 24 hours in 8-day (6, 12, 18, 32 and 62 mg/L) and 21-d larvae (23.1, 31.7 and 70 mg/L), respectively. The paddle system was designed to maintain particle concentrations in suspension.
[10] The LC values exceeded the highest treatment concentration and was derive from model projections.
[11]Derivation of LC(EC)20/50 values calculated from logistic regression modelling using target concentrations (not measured).
[12]The concentration at which 20 and 50% of the larvae were affected (any classification other than normal (N)) including mortality is referred to as the Effect Concentration (EC20, EC50). The concentration at which 20 and 50% of the larvae were dead or live clogged (LC), is referred to as the Lethal Concentration (LC20, LC50).
[13]Suspended particle concentration monitored by turbidity measurements (assuming 1 FTU= 1 mg/L), however, were quantified by weight measurements from water filtration. On average, 50% decrease in the actual suspended particle concentration compared with target concentrations.
[14]Growth rate measured as change in skeleton dry weight based on buoyancy weight measurements.
[15]Cellular stress biomarkers: antioxidant enzymes: Glutathione S-transferase (GST), Superoxide dismutase (SOD), Catalase (CAT) and lipid peroxidation by determination of malondialdehyde (MDA).
[16]Cellular stress: Heat shock protein (HSP70), ferritin; antioxidant defense: superoxide dismutase (SOD), ferritin, cell structure/integrity [α-carbonic anhydrase; cell cycle control: receptor-type protein tyrosine phosphatase (RP Tyr-PH); immune responses: toll-like receptor (TLR), lysozyme, rel. homology domain (RHD), ferritin.
[17]Conversion from turbidity to suspended sediment concentration (SSC) in mg/L by formula: SSC = 0.74 * FTU - 0.11. Linear relationship in range with previous studies for the Western Mediterranean (Arjona-Camas et al., 2021).
[18]Coral respiration and excretion rates measured after 4- and 8-9-months SSC exposure.
[19]Measured concentrations of suspended particles: Natural sediment (NS): low: 3.3 to 6.2 mg/L and high: 19-22 mg/L; drill cuttings (DC): low: 3.6-5.7 mg/L and high: 17-26 mg/L.

Table A3 Overview of relevant peer-review literature studies on impacts of suspended particles on cold-water sponges. References given in section 8.

Cold-water sponge species	Particle type	Exposure/recovery	Effect endpoint measured	Relevant findings	Literature source
Phakellia ventilabrum Deep-water demosponge. Adult. Sponges collected at two different seasons[1].	Natural sediment (NS) and drill cuttings (DC). Particle grain size: DC: <250 µm NS: 75% sand <295 µm.	Long-term 14-day continuous exposure to suspended NS and DC. NS treatment: 30 and 100 mg/L (nominal), DC treatment: 30 mg/L (nominal) plus control. Two experiments with sponges collected at two different seasons[1]. Flow-through system. 12 replicates.	Respiration rate, particle uptake, molecular stress responses: heat shock protein (hsp70), enzyme nitric oxide synthase (NOS). Visual observation of mucus.	**NS and DC treatments:** In both experiments[1], representing two seasons, no significant effect on respiration rate between seasons nor between control and any of the NS and DC treatments were observed. Particle uptake did not differ between control and treatments in experiment 1 (sponges collected in May). However, an increase in particle uptake compared to control and DC treatments was observed at the highest NS treatment (100 mg/L) in experiment with sponges adapted to low sedimentation condition (collected in September), that triggered increased oxygen consumption in a few specimens. Target genes hsp70 and NOS[2] were up regulated in all DC and NS treatments compared to the control (significant different from control on a few days during the	Schuster, 2013

Cold-water sponge species	**Particle type**	**Exposure/recovery**	**Effect endpoint measured**	**Relevant findings**	**Literature source**
				14-days exposure period). No mucus production observed.	
Sycon ciliatum Shallow water calcareous sponge[1]. Adults and juveniles.	Natural sediment (NS) and drill cuttings (DC). Particle grain size: DC: <250 µm NS: 75% sand <295 µm.	Short-term 6-days continuous exposure to suspended NS and DC in adults (experiment 1) and 3-days exposure to suspended NS in juveniles (experiment 2). NS treatment: 30 and 100 mg/L (nominal), DC: 30 mg/L (nominal) plus control. Flow-through system.	Experiment 1 (adults): Respiration rate and gene expression (molecular biomarker responses): stress heat shock protein (hsp70), enzyme nitric oxide synthase (NOS) and tubelin. Visual observation of mucus. Experiment 2 (juveniles): Respiration rate.	**NS and DC treatments:** No significant change in respiration rate during NS and DC particle exposure compared to the control in adults and juveniles. However, there are clear differences in respiration rates between juveniles and adults. Gene expression/molecular biomarker responses (adults): hsp70 down-regulated in all treatments (30 and 100 mg/L NS treatment and 30 mg/L DC tratment), tubelin down-regulated in the 100 mg/L NS treatment and 30 mg/L DC treatment, up-regulation of NOS at high NS treatment (100 mg/L) compared to controls. No mucus production observed.	
Geodia barretti Deep-water demosponge. *Adults.* 2-months adaption to laboratory conditions prior to exposure experiments.	Natural sediment (NS). Particle grain size: median: 71 µm, mean: 139 µm.	Short-term 4-hours continuous single exposure to suspended NS followed by three consecutive 4-hours recovery periods. NS treatments: 10, 50, 100 and 500 mg/L (nominal) plus control. 3 replicates per treatment. Flow-through system.	Respiration rate and sediment coverage. (measured before, during and after exposure period). Visual observation of pumping activity before and after exposure.	Particle concentration was reduced by an average of 35% during the 4-hours exposure period. A significant decrease in the respiration rate at 50, 100 and 500 mg/L suspended NS (range 52-86%). This coincidence with an arrest or reduction in pumping activity during particle exposure. At 10 mg/L NS treatment, no effect on respiration was observed. Rapid recovery to initial respiration levels directly after cessation of exposure and in pumping activity 1 hour after end of exposure. Threshold of respiration responses occurring between 10 and 50 mg/L. Sponges were covered with sediment in all treatments except for control after exposure.	Tjensvoll et al. 2013

Cold-water sponge species	Particle type	Exposure/recovery	Effect endpoint measured	Relevant findings	Literature source
Geodia barretti Deep-water demosponge. Adults. 2-months acclimation in laboratory prior to exposure experiments.	Crushed rock (CR) particles (mimick drill cuttings). Particle grain size: <250 µm^3, median: 56 µm, mean: 72 µm.	Short-term 4-hours continuous single exposure to suspended CR followed by three consecutive 4-hours recovery periods[4]. CR treatments: 10, 50, 100 and 500 mg/L (nominal) plus control. Three replicates per treatment. Flow through system.	Respiration rate.	The oxygen consumption was significantly reduced (50%) in the 500 mg/L treatment compared with pre-exposure level. All sponges recovered quickly to pre-exposure oxygen consumption once CR concentrations returned to background levels.	Kutti et al. 2015
Geodia barretti Deep-water demosponge. Adult explants. 8-months cultivation in the open sea and 2-months acclimation in laboratory prior to exposure experiments.	Crushed rock (CR) particles (mimick drill cuttings). Particle grain size: <250 µm, median: 56 µm, mean: 72 µm^3. Natural benthic sediments (NS). Particle grain size: <250 µm^3, median: 71 µm, mean: 139 µm.	Long-term 50-days intermittent exposure (12-hours exposure per day) to suspended NS and CR particle concentrations: ~10 and ~50 mg/L (nominal) plus control. Two replicates per treatment. Flow-through system.	Respiration rate[5] and tissue energy content parameters[6]: ash content and elementary inorganic particles (C, H, N and S) in sponge tissue expressed as higher heating value (HHV) and ash content.	Respiration rates in sponges is highly dependent on particle type. Sponges are more sensitive to suspended CR than to NS treatments. **CR treatment**: After 29-days cyclic exposure oxygen consumption was significantly reduced (60%) exposed to high CR treatment (50 mg/L) compared to controls (and to NS treatments). **NS treatment:** Oxygen content and energy content exposed to NS treatments (10 and 50 mg/L) were not significantly affected. No statistically differences in tissue energy content and inorganic matter between the particle treatments (after 50-days). This indicates that sponges do not appear to incorporate mineral particles into their tissues when exposed to suspended sediment particles. However, protruded spicules on sponge surface were observed after 29-days exposure to NS and CR treatments (but not on control sponges and before exposure).	

Cold-water sponge species	Particle type	Exposure/recovery	Effect endpoint measured	Relevant findings	Literature source
Geodia barretti Deep-water demosponge Adults.	Natural benthic sediment (NS), barite (BA) and bentonite (BE). Particle grain size: <125 µm. Mean particle grain size: BA: ~22 µm, BE: ~24 µm, NS: ~20 µm.	Short-term 12-hours continuous exposure (12 hours per day) to suspended NS, BA and BE to concentrations: 10, 50 and 100 mg/L (nominal) Actual conc.: ~13, ~64 and ~102 mg/L. Three replicates per treatment. Flow-through system.	Biomarker responses: lysosomal membrane stability (LMS), lipid peroxidation (LPO) and glutathione (GST).	**LMS:** BA treatment: Sponges exposed 12-hours to BA at 50 and 100 mg/L had significantly lower levels of LMS than those exposed to 10 mg/L. BE and NS treatment: Exposure to BE and NS up to concentration of 100 mg/L resulted in no significant change in LMS compared with control. **LPO:** No significant effect in any of the treatments. **GSH:** A significant decrease in GSH exposed 100 mg/L NS compared with control. Conversely, GSH conc. increased upon exposure to suspended BA of 100 mg/L (significant different to the 10 mg/L BA treatment). No clear pattern in GSH concentrations exposed to BE.	Edge et al. 2016
Geodia barretti Deep-water demosponge Adults.	Natural sediment (NS) and barite (BA). Particle grain size: <125 µm. Mean particle grain size: BA: ~22 µm, NS: ~20 µm.	Long-term 14-days continuous and intermittently exposure to suspended NS and BA to 10 and 30 mg/L (nominal) plus control. Actual concentrations: ~11 and ~36 mg/L. Flow-through system. Three replicates per treatment.	Biomarker responses: lysosomal membrane stability, (LMS), lipid peroxidation (LPO) and glutathione (GST), organic energy content: ash content and elementary inorganic particles (C, H, N and S) in sponge tissue expressed as higher heating value (HHV) and metal accumulation[7].	**Continuous exposure:** **LMS:** BA treatment: 14-days exposure to 30 mg/L BA resulted in a significant decrease in LMS (~44%) compared control, 10 mg/L BA (~25%) and 30 mg/l NS treatments (~16%). NS treatment: 6-days exposure to 30 mg/L treatment resulted in a significant decrease in LMS compared with control, however, not significant different after 14-days exposure. **LPO:** BA and NS treatment: No significant difference in LPO concentrations exposed to any of the BA and NS treatments. **GSH:** BA treatment*:* GSH were significantly higher exposed to 30 mg/L BA at day 6 (not significant at	

Cold-water sponge species	Particle type	Exposure/recovery	Effect endpoint measured	Relevant findings	Literature source
				day 14) compared with 10 mg/L BA and 10 mg/L NS treatment. NS treatment: No significant difference in the GSH level in sponges between control and any of the NS treatments. **Total organic energy content:** BA and NS treatment*:* No significant difference between any of the NS and BA treatments after 14 days exposure. However, a significant difference observed between suspended NS at 10 and 30 mg/L and the control at day 6 (but not significant different at day 14). **Metal accumulation:** Metal accumulation in sponge tissues was low. However, total concentration of Pb was significantly higher in sponge tissues exposed 14-days to BA at 30 mg/L compared with control tissues. **Intermittent exposure:** **LMS:** Sponges exposed to BA at 30 mg/L had significantly lower LMS that those exposed to BA 10 mg/L (6 and 14 days), NS treatment and control. **LPO:** Significant differences in LPO levels among BA and NS treatments were measured but responses were inconsistent. Sponges exposed to 30 mg/L BA had significantly lower LPO concentrations than those exposed to 10 mg/L BA and 30 mg/L NS at day 6 but not at day 14. **GSH:** No clear or inconsistent pattern in GSH concentrations. **Total organic energy content:** No significant difference between	

Cold-water sponge species	Particle type	Exposure/recovery	Effect endpoint measured	Relevant findings	Literature source
				any treatments over 14 days exposure.	
Geodia barretti Deep-water (arctic-boreal) demosponge Explants cultivated in open sea cages in eight months. Acclimated to laboratory conditions prior to exposure experiments.	Natural sediment (NS), bentonite (BE) and barite (BA). Particle grain size: <63 µm.	Long-term 33-days intermittent (12-hours per day) exposure to suspended NS, BE and BA to the concentration range: ~ 4 to 15 mg/L Actual average ~ 10 mg/L plus control. Followed by 33-days recovery. 3 replicates per treatment. Flow-through system.	Mortality, net fluxes of oxygen, ammonium, nitrate and nitrite, tissue oxygen content measured after 33-days exposure and on recovery day 33.	Top surfaces of sponges were largely covered by deposited particles during the exposure period, but no sponge mortality observed in any of the treatments. Spicules protruding from the sponge surface observed, however not sufficiently for removal of particle deposits (smothering) from the surface. NS, BE and BA treatments resulted in significant reductions in net fluxes of oxygen, ammonium, nitrate and nitrite after 33-days exposure compared to control. Net fluxes of oxygen decreased significantly by 26-33% on average both for NS, BE and BA after 33-days exposure, that was linearly correlated with reduced nitrite/nitrate release by sponges. Effects reversed after 33-days recovery period for BE and NS treatment, while effects were not reversible for BA treatment. Overall effect on net fluxes in BA treatment remained significant after 33-days recovery period with oxygen flux significantly remained reduced at 28%. The changes in net fluxes were accompanied by decrease in tissue oxygen content all particle treatments, however significantly reduced in BE treatment only, compared to control. This indicates that the fine particle exposure reduces aerobic respiration and microbial nitrification. No significant differences in the oxygen contents among treatments compared with control after 33-days recovery.	Fang et al. 2018
Stryphnus fortis and its epibiont				Top surfaces of sponges were largely covered by deposited	

Cold-water sponge species	Particle type	Exposure/recovery	Effect endpoint measured	Relevant findings	Literature source
Hexadella dedritifera Deep-water (arctic-boreal) demosponge. Explants cultivated in open sea cages in eight months. Acclimated to laboratory conditions prior to exposure experiments.				particles during the exposure period, but no sponge mortality observed in any of the treatments. A significant effect of barite on the net fluxes of oxygen, ammonium, nitrate and nitrite after 33-days exposure compared to control and BE treatment was measured, with a decrease (52-58%) in the net release of nitrate and nitrite. A strong delayed responses in net ammonium flux (79-96% reduction) on recovery day 33 pre-exposed to BA, BE and NS compared to control. These changes drove a significant overall difference in the net fluxes that remained different from control after 33-day recovery for pre-exposure to BA as well as BE and NS. Tissue oxygen content was significantly reduced in all particle treatments (BA, BE and NS) that was significantly reduced by up to 54% compared to control. This indicates that the fine particle exposure reduces aerobic respiration and microbial nitrification. No significant differences in the oxygen contents among particle treatments compared with control after 33-days recovery period.	
Geoida atlantica Deep water demo sponge. Explants. 8-months healing time of explants in the field and 2 months acclimation in laboratory	Crushed rock (CR) (i.e. simulated inert mine tailings, drill cuttings). Particle grain size: <63 µm.	Long-term 40-days intermittent exposure (12-hours per day) to suspended CR to 10 mg/L (nominal). Actual mean: ~11.3 mg/L Flow-through system (mesocosm)	Respiration rate, nutrient flux: silicate uptake and nitrogen release rate (ammonium, nitrate and nitrite) and lysosomal cell stability (LMS). Measurement after 26-, 33- and 40-days of	Respiration rate: Exposure to CR treatment (~10 mg/L) reduced oxygen uptake/consumption to 50% compared with control sponges after 40-days (not after 26 and 33-days). Silicate uptake was significantly reduced by suspended CR treatment after 33-days of exposure. No significant effect on nitrogen release in the CR treatment compared to control.	Scanes et al. 2018

Cold-water sponge species	Particle type	Exposure/recovery	Effect endpoint measured	Relevant findings	Literature source
prior to exposure experiments			exposure. 5 replicates.	The oxygen uptake to nitrogen release ratio (O:N) was significantly reduced by the CR exposure (10 mg/L) after 26-, 33- and 40-days compared to control. A significant increase in mean LMS compared to control after 26-days exposure, while this effect was not observed after 33- or 40-days of exposure.	
Vazella pourtalesii Hexactinellid deep-water glass sponge. 7 months acclimation in laboratory prior to exposure experiments.	Natural benthic sediment (NS). Particle grain size: <63 µm; 70% particles <6 µm.	Long-term 21-days cyclic 12-hours per 24-hour) exposure to nominal 50 mg/L (actual mean: 44.9 mg/L) of suspended NS plus control (actual mean: 1.9 mg/L). Exposure measurement (LISST) at days 0, 7, 14 and 21. 5 replicates in treatment and control.	Survival, oxygen consumption rate (respiration) and bacterial clearance. Sponges transferred to particle free seawater for recovery in 38 days for observation of particle accumulation	No mortality observed over the 21-day exposure and no necrosis or other signs of decreased health status. Initially sediments accumulated on the spicules but with repeated exposure the atrial surface became covered and turned brown in color. Respiration rates increased slightly in NS treatment during exposure (not significant). After 14 days of exposure to suspended NS clearance rates differed significantly from the control group and continued until end of exposure (21 days). NS exposed sponges showed large particles expelled from the osculum. Atrial surfaces of most NS exposed sponges returned to their pre-exposure state (cleared their pinacoderm of particles) 14 days after end of exposure. A few sponges had structural necrosis and died over the course of 38-day recovery phase.	Wurz et al. 2021
Crella incrustans Shallow temperate coastal demosponge (New Zealand)	Natural sediment (NS). Particle grain size: 3-125 µm, mean: 54 µm.	4-weeks exposure to a gradient in suspended NS the range 7- 832 mg/L plus control. 2 weeks recovery in ambient seawater[6]	Survival, respiration and morphology recorded after 8, 23 and 30-days exposure and after 2-weeks recovery,	Survival was high in NS treatments. Oxygen consumption varied between sponges and respiration rates was not significantly affected by exposure to suspended NS (a slight negative relationship on day 23 and end of recovery). Sponges developed apical fistules	Cummings et al. 2020

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Cold-water sponge species	Particle type	Exposure/recovery	Effect endpoint measured	Relevant findings	Literature source
Explants.		Flow through system.	particle accumulation (visual observation).	(morphological changes) in all treatments except control after exposure day 8. A positive relationship between suspended NS and appearance of apical fistules. Suspended sediment accumulated internally within sponges but about 30% of the sponges cleared these sediments after 2 weeks recovery.	

[1] Experiments conducted with sponges collected in May (experiment 1) and September (experiment 2); to identify potential variations in respiration of sedimentation levels at two different seasons. The fist experiment in May reflecting conditions with high sedimentation (algae blooms peak and high levels of particulate organic particles (POC) and experiment 2 in September coincides with low sedimentation (low algae and POC). In experiment 2, negative oxygen consumption values were measured and must be carefully interpreted (methodical issues).
Sycon ciliatum is shallow water calcareous sponge with wide distribution in the North Atlantic and is representative in Norwegian fjords in coastal kelp forests. It has a short life cycle (one year).

[2] The expression of hsp70 and NOS was elevated in all treatments including the control from day 6 and indicates that the laboratory conditions may also affect the organisms at least form day 6 onwards (potentially due to temperature difference between the natural sponge habitat and the laboratory).

[3] Particle size distribution of 1) natural sediment: <3.9 µm (7%), 4-62.9 µm (42%), 63-124.9 µm (23%), 125-250 µm (28%) 2) crushed rock: <4.9 µm (12%), 5-62.9 µm (42%), 63-124.9 µm (24%), 125-250 µm (22%). The crushed granite rock particles did not contain heavy metals (mimicking drill cuttings or mineral particles submarine mine tailings disposals.

[4] Five consecutive 4-hour intervals consisting of one pre-exposure period, one exposure interval and 3 post-exposure intervals each separated by a 30-60 min long flushing cycle.

[5] Respirated measured (during the non-exposure period) on the same 3 sponge explants from each tank on days: 1,2,5,9,14, 20 and 29 and on 2 sponges at day 50.

[6] Tissue samples were collected 5,14, 29 and 50 days of exposure and analyzed for energy content parameters: relative percentage of elementary particles (carbon, hydrogen, oxygen, nitrogen and sulfur) and ash content and was expressed as higher heating value (HHV).

[7] Biomarker and energetic responses measured at day 6 and day 14 of continuous and intermittent exposure and metal accumulation exposed continuously to 30 mg/L for barite and in seawater (control) were measured after 14 days.

APPENDIX B
Deriving threshold criteria for impact on corals and sponges

Deriving threshold values for deposited particles

Smit et al. (2008) derived a deposition thickness of 6.3 mm, below which 95% of the species should not be affected by burial (the study did not include corals or sponges). The threshold levels are in part supported by the studies mentioned in Appendix A for corals and sponges. A threshold level for the total concentration of suspended particles used in risk assessment models is 10 mg /L (Rye et al., 2011). For suspended barite particles, Smit et al. (2008) derived a threshold level of 0.2 mg / L. Pineda et al (2017) supports using 10 mg/L as a lower threshold for "no-effect" on sponges (natural sediment). Baussant (2018) notes that 10 mg/L (drill cuttings) seems to represent a threshold above which changes in coral conditions can be observed. 10 mg/L exposure over a typical drilling period (~6 weeks) can be expected to be equal to 6.3 mm total deposition (e.g. Larsson et al., 2013), but the impact on sessile fauna will vary depending on current regime and the specimen's ability to remove excessive particles. Further studies focusing on realistic effects from drill cuttings release are needed before reliable threshold values for evaluating overall ecological impacts can be established (e.g. Larsson et al. 2013; Tjensvoll et al., 2013; Zetsche et al., 2016. Järnegren et al., 2017; Baussant et al., 2018). Many of the existing studies have focused on long time exposure with continuous sediments loads, while during drilling operations the discharge dynamics and plume is more fluctuating and complex. Several monitoring projects e.g. DNV, 2014; DNV GL 2015b have shown that exposure to suspended solids is heterogenous over time.

For drill cuttings impact assessments in relation to plume modelling it is recommended to rely on total deposited material during the drilling campaign in order to assess impact on seabed fauna. Amount of suspended solids will vary substantially over time and can be hard to assess.

Based on the mentioned studies, and particularly the references given in Appendix A, experience and anticipated long term effects, a consequence scale for excessive sedimentation has been proposed for both corals and sponges expected on the NCS. The consequences are described as "Minor" for the 1-3 mm category, "Moderate" for the 3-10 mm category and "Considerable" for deposition above 10 mm. See Table A1 for summary of expected consequences for different sedimentation coverage.

Table A3 Threshold values for consequences for deposition of discharges

Deposition thickness	**Degree of impact**	**Consequences**
0.1-1 mm	Negligible	No detectable influence
1-3 mm	Low	Minor smothering Good ability to shed sediments, but might start to aggregate
3-10 mm	Significant	Moderate smothering Reduced ability to shed sediments. Some polyp mortality or sponge necrosis can occur.
>10 mm	Considerable	Considerable smothering Potential suffocation. Polyp mortality or sponge necrosis excpected. Potential for depletion of energy reserves.

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Deriving threshold values for suspended solids

Thresholds for short-term realistic exposure of suspended solids of barite, bentonite and drill cuttings on *Desmophyllum pertusum* and sponges are under development. Impact will depend on actual concentrations of particles in the water masses as well as exposure times. Relevant threshold levels can be 20 mg/L for short exposure times (<60 hours), 10 mg/L for longer durations and a "storm threshold" for peaks/ bursts in suspended solids of 100 mg/L.

Several research projects have been performed in the period 2012 to 2019 under the Research Council of Norway's PROOFNY program in addition to Equinor initiated projects. The objective has been to close the knowledge gap related to physical impact of suspended drilling discharges on cold-water corals, represented by the deep-water coral species *D. pertusum.* In the following results from a study by Baussant, *et al*. (2022) is presented in order to show example on how risk from suspended solids can be assessed, based on exposure period of water masses containing suspended solids above a threshold level of 20 mg/L). As a preliminary effect threshold for short-term realistic pulse exposure to suspended solids (applied to sum of barite, bentonite and drill cuttings) is set to 20 mg/L (actual concentration), reflecting the actual discharge and exposure scenario in terms of releases from upper sections at seabed when drilling one exploration well. This effect threshold is based on 120 hours experimental period with discontinuous pulse supply of particles to the experimental system (added in pulses of 4 hours followed by 4 hours with no particle addition). In total particles are supplied to the exposure system 50% of the experimental period, that resulted in 60 hrs exposure of corals. The effect threshold for suspended solids is determined from measurement of sub-lethal responses (respiration rate, growth rate, mucus production) and polyp mortality, measured 2 - and 6-weeks post-exposure (in clean seawater), for assessment of long-term effects of short-term realistic exposure. The highest ranked category "considerable" is based on exposure > 60 hrs exceeding the threshold value of 20 mg/L for the sum of particles in laboratory experiments. Further, ranking categories are simply set as 50% of the exposure period of the higher ranked category (see Table A4).

Table A4 Example of risk assessment for suspended solids in relations to exposure time. Degree of impact as function of total exposure period (hrs.) exceeding the suggested threshold for suspended particles (20 mg/L) reflecting environmentally relevant discharge and exposure conditions.

Impact category	**Exposure period exceeding threshold (20 mg/L)**
Negligible	<10 hrs.
Low	10-30 hrs.
Significant	30-60 hrs.
Considerable	>60 hrs.

APPENDIX C
Experiences from top hole drilling on the NCS

Several monitoring projects in areas with cold-water corals and sponges have been executed the last years on the NCS (>30). These projects have given valuable experiences with regards to effects on seabed habitats due to drilling operations, as well as experience on monitoring techniques.

Some general conclusions can be made. The used monitoring methods are in general in line with each other and give a reasonably good indication of the spreading of the discharges and the potential impact on the seabed habitats in the area.

Summary of findings from monitoring campaigns:

Visual: The deposit area can visually be registered out to a maximum of ~150m.

Barium: Elevated Ba values in sediment are usually having a decreasing gradient out to 300-400m from discharge location, compared with baseline data, but are sometimes found 600 meters away in trap material.

Sediment traps: Elevated levels of deposition have been observed from sediment in traps at least 400 m from discharge location.

Current measurements: Current regimes may vary substantially throughout the drilling campaign.

Turbidity: There is a correlation between elevated turbidity values and different drilled sections. When discharges are made from the seabed the particle plume generally is confined to the seabed, following seabed topography. Several monitoring projects the last years support that there are fluctuating and sometimes high particle concentrations, but that any effects on the corals have not been identified.

In general, modelled results support the conclusions above. Nevertheless, there are also discrepancies between DREAM simulations and actual measurements where the modelled results are overestimated both for turbidity and barite in sediments with a factor of 15 (Rye et al. 2012). However, in some cases where seabed bathymetry is not accounted for in the model or CTS (or several discharge locations) is used, opposite findings are made where actual deposition is higher than what was modelled, e.g. by a factor of 30 (Frost et al., 2014). Such discrepancies are rare, and in general the models are in line with what is seen during monitoring, or the models are slightly overestimating the extent of the dispersion on the seabed.

When combining experiences from monitoring and a number of DREAM model simulations, the following potential dispersion areas of sediment thicknesses (radius) from drilling **one** top hole section (such as exploration drilling) is proposed:

Deposition >10 mm: 0 - 100m

Deposition 3 - 10 mm: 100 - 250m

Deposition 1 - 3 mm: 250 - 500 m

Discharges from multiple top-holes during production drilling must be separately assessed. The use of CTS must also be evaluated specifically.

The dispersion area radius is based on modelled cases data from discharge location and does not separate between sea surface and sea floor deposits. It is generally recommended performing case specific dispersion modelling, considering planned releases, current regime and seabed topography. In some cases the dispersion distances will be shorter than shown above, or will only reach these distances in the prevailing current direction.

In terms of sea surface deposits, it is expected that particles will be distributed over a larger area resulting in less sediment thickness within the same range as sea floor deposit. There are however relatively few drilling campaigns which exclusively has had discharges at the sea surface.

Jones et al. (2006 and 2012) showed that disturbance by physical smothering and burial of organisms and mortality of sessile organisms was severe within 100 m of drilling activity. DNV GL (2015a and 2018) investigated drill sites 7 and 10 years after drilling had occurred in sponge rich areas. The studies showed evident mortality on sponge communities at least out to 40-80 meters out from drilling location, supporting the fact that deposition thicknesses above 10 mm will have adverse effects on sponges.

Recent studies performed in the BARCUT project (http://site.uit.no/ewma/barcut/) have shown that visual extent of drill cuttings as far out as 178 meters from drill centre (Cochrane et. al. 2019).

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