



Assessment of the disturbance of drill cuttings during decommissioning

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ABBREVIATIONS

| | |
|-------------------------|--|
| Al | Aluminium |
| APE | Alkyl phenols and alkyl phenol ethoxylates |
| As | Arsenic |
| BAC | Background Assessment Concentrations |
| BaSO₄ | Barite |
| BC | Background Concentrations |
| BEIS | Department for Business Energy and Industrial Strategy |
| CA | Comparative Assessment |
| cAL1 | Chemical Action Level 1 |
| cAL2 | Chemical Action Level 2 |
| Cd | Cadmium |
| CEMP | Coordinated Environmental Management Programme |
| CNS | Central North Sea |
| CSM | Conceptual Site Model |
| Cu | Copper |
| DTI | Department of Trade and Industry |
| EAC | Environmental Assessment Criteria |
| ERL | Effects Range - Low |
| EU | European Union |
| Fe | Iron |
| FRS | Fisheries Research Services |
| GBC | Gravity Based Concrete |
| Hg | Mercury |
| ICES | International Council for the Explorations of the Sea |
| IMO | International Maritime Organisation |
| JAMP | Joint Assessment and Monitoring Programme |
| K_{oc} | Organic carbon-water partition coefficient |
| K_{oil} | Oil-water partition coefficient |
| K_{ow} | Octanol-water partition coefficient |
| LC | Low Concentrations |

| | |
|----------------|---|
| Li | Lithium |
| LTMO | Low Toxicity Mineral Oil |
| LTOBM | Low Toxicity Oil Based Mud |
| MCZ | Marine Conservation Zone |
| M/D/TBT | Mono, di and tri-butyltin |
| MFO | Cytochrome P450 mixed function oxygenase |
| Mn | Manganese |
| NADF | Non Aqueous Drilling Fluid |
| NAPL | Non Aqueous Phase Liquid |
| NCMPA | Nature Conservation Marine Protected Area |
| NEA | Norwegian Environment Agency |
| Ni | Nickel |
| NNS | Northern North Sea |
| OBM | Oil Based Mud |
| OGA | Oil and Gas Authority |
| OGUK | Oil & Gas UK |
| OIC | Offshore Industry Committee |
| OPF | Oil Phase Fluid |
| OSPAR | Oslo Paris commission |
| PAH | Polycyclic Aromatic Hydrocarbon |
| Pb | Lead |
| PCB | Polychlorinated biphenyl |
| PEC | Predicted environmental concentration |
| PNEC | Predicted no effect concentration |
| PVA | Particularly Valuable Area (Norway) |
| ROV | Remotely Operated Vehicle |
| SAC | Special Area Conservation |
| SAL | Surface Active Layer |
| SBM | Synthetic Based Mud |
| Sn | Tin |
| SNS | Southern North Sea |

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| | |
|---------------|---|
| SOAFD | Scottish Office Agriculture and Fisheries Division |
| Sr | Strontium |
| TCC | Thermo-mechanical Cuttings Cleaner |
| Te | Tonnes |
| THC | Total Hydrocarbons |
| TLP | Tension Leg Platform |
| TOC | Total Organic Carbon |
| UCM | Unresolved Complex Mixture (also referred to Unresolved chromatographic material) |
| UK | United Kingdom |
| UKOG | UK Oil and Gas |
| UKOOA | United Kingdom Offshore Operators Association |
| UNCLOS | United Nations Convention on the Law of the Sea |
| US EPA | United States Environment Protection Agency |
| V | Vanadium |
| WOS | West of Shetland |
| Zn | Zinc |

1.0 EXECUTIVE SUMMARY

Studies into drill cuttings pile management in recent years have concluded that leaving the piles *in situ* to degrade naturally is generally the best option. However, disturbance during decommissioning may be unavoidable and there is therefore a need to better understand the options available to manage drill cuttings during decommissioning and how they could impact the environment.

Estimate of volume of cuttings piles likely to be disturbed during decommissioning

The total volume of cuttings in UK waters is estimated at 1,150,086 m³, giving an average volume of a single cuttings pile in UK waters (ERT, 2009) of around 6,610 m³. Some of these cuttings piles are located around installations that are likely to be derogation cases, and therefore any disturbance is likely to be minimal. There are, however, around 129 installations in UK waters likely to require removal with the potential for disturbance of associated cuttings piles. There are a further 72 installations on the Norwegian Continental Shelf likely to require removal, amounting to potentially 201 installations in the OSPAR region to be removed from the seabed in the next 20 to 30 years, with the potential for disturbance of associated drill cuttings piles.

Impacts of cuttings piles on the seabed

The time needed for the seabed to recover following the deposition of cuttings is influenced by the rate of biodegradation of hydrocarbons and other contaminants, the resuspension and redistribution of matter on the seabed due to currents and wave action and the time for recolonisation of the biota.

During the natural degradation of cuttings piles, aerobic biodegradation of hydrocarbons typically occurs only in the upper few centimetres of the pile. Anaerobic degradation may take place down to at least 20 - 50 cm but will occur very slowly, with oil and other contaminants in the deeper parts of the pile remaining essentially unchanged. If the cuttings piles remain undisturbed then the release of hydrocarbons and other contaminants is likely to be limited.

Environmental impacts resulting from deposition or re-deposition of cuttings include smothering, grain size changes, deoxygenation and toxicity, which in turn can result in localised changes to the plankton, the benthos and other organisms. Benthic fauna, including crustaceans and molluscs, appear to be at most risk from persistent oil in the sediments as they can accumulate chemical contaminants in their tissues.

Based on the case studies reviewed, the majority of impacts from cuttings piles are noted within 100 m of the centre of the pile; and, generally, beyond 500 m there is little discernible impact. When cuttings piles are disturbed, the pile is aerated allowing some additional degradation to take place. However, this disturbance results in additional, albeit generally short-term and localised impacts on the water column, and in some (not all) cases could cause contamination of the seabed outwith the areas impacted by the original cuttings discharge.

Fishing may be able to resume over cuttings piles previously contained in a 500 m safety zone where fishing activities would have been excluded. Where cuttings are left *in situ* or relocated on the seabed there is the potential for trawling activities to disturb the cuttings pile resulting in the release of contaminants contained within the cutting pile into the water column, as well as the potential for the nets and catch to be contaminated.

Options for disturbance of historical cuttings piles during decommissioning

The disturbance of drill cuttings piles during decommissioning may be unavoidable if infrastructure is to be removed. Therefore, there may be some localised disturbance of cuttings piles prior to the preferred option of leaving piles *in situ* to allow natural degradation to take place. This report focusses particularly on the potential impacts of dispersing cuttings offshore in the vicinity of the existing pile.

To date the most commonly used methods for relocating cuttings on the seabed have been suction dredging and water jetting. The choice of technology used for relocating cuttings can help reduce potential impacts. For example, suction dredging will usually result in a more localised impact on the water column and seabed sediments than jetting, and impacts will be even more localised if other methods such as physical ploughing are used. However, in many cases physical constraints (i.e. the configuration of the cuttings pile and installation infrastructure) may dictate the selected method and physical ploughing is unlikely to be suitable at congested locations. Relocation of cuttings inevitably causes short term impacts but can also increase degradation rates and recovery, and a key consideration is whether cuttings should be deliberately dispersed widely to speed recovery, or whether cuttings should be relocated to distinct new ‘piles’ to limit the spatial coverage of the contaminated sediments. The optimum solution is likely to depend on the local balance of risks to fishing and ecology, but there is little field data at present on actual uptake by biota of contaminants.

Mitigation and monitoring

Where historical contamination is disturbed and there is a high impact risk profile (e.g. larger scale disturbance, a more sensitive environment, designated species nearby, or the potential for susceptible seabed fisheries) it is recommended that pre and post disturbance monitoring is undertaken. Monitoring should include sampling of the water column, seabed sediments, and the benthos, in order to assess potential impacts on the environment. Where relevant, uptake in food species should also be considered. In addition, any monitoring should not be limited to the hydrocarbon content of the cuttings pile and should consider other potential contaminants such as heavy metals.

RECAPITULATIF

Les études sur la gestion des tas de déblais de forage, réalisées au cours des quelques dernières années, ont conclu que la meilleure option consiste dans l'ensemble à laisser les tas se dégrader naturellement sur place. Il risque cependant que des perturbations au cours d'un démantèlement soient inévitables et il y a donc lieu de mieux comprendre les options disponibles permettant de gérer les déblais de forage au cours d'un démantèlement et leur impact sur l'environnement.

Estimation du volume des tas de déblais risquant d'être perturbés au cours d'un démantèlement

On estime que le volume total de déblais de forage dans les eaux du Royaume Uni s'élève à 1.150.086 m³, ce qui correspond à un volume moyen par tas dans les eaux du Royaume Uni (ERT, 2009) d'environ 6.610 m³. Certains tas de déblais de forage sont proches d'installations qui risquent de faire l'objet de dérogation et toute perturbation risque donc d'être minime. Environ 129 installations se trouvant dans les eaux du Royaume Uni risquent cependant de devoir être retirées entraînant potentiellement une perturbation des déblais de forage correspondants. Le plateau continental norvégien comporte 72 autres installations qui risquent de devoir être retirées. Potentiellement 201 installations risquent donc d'être retirées du sol marin dans la Zone OSPAR au cours des 20 à 30 prochaines années, entraînant une perturbation potentielle des tas de déblais de forage correspondants.

Impacts des tas de déblais de forage sur le sol marin

La période de rétablissement du sol marin à la suite du dépôt de déblais dépend du taux de biodégradation des hydrocarbures et autres contaminants, de la remise en suspension et de la redistribution de matière sur le sol marin par les courants et les vagues et du temps de recolonisation du milieu vivant.

Au cours de la dégradation naturelle des déblais de forages, une biodégradation aérobie des hydrocarbures ne se produit habituellement que dans quelques centimètres supérieurs du tas. Une dégradation anaérobique peut se produire jusqu'à une profondeur de 20 à 50 cm au moins mais très lentement, les hydrocarbures et autres contaminants des parties plus profondes du tas demeurant essentiellement inchangés. La libération d'hydrocarbures et d'autres contaminants est probablement limitée si les tas de déblais de forage ne sont pas perturbés.

Les impacts environnementaux du dépôt et du re-dépôt des déblais sont notamment l'étouffement, la modification de la granulométrie, la désoxygénation et la toxicité, qui entraînent à leur tour des modifications localisées du plancton, du benthos et d'autres organismes. La faune benthique, notamment les crustacés et les mollusques, semble être la plus menacée par les hydrocarbures persistants dans les sédiments car elle peut accumuler des contaminants chimiques dans ses tissus.

En se fondant sur la revue des études de cas, la majorité des impacts des tas de déblais de forage sont relevés dans un rayon de 100 m du centre du tas et, dans l'ensemble, au-delà de 500 m on ne relève qu'un impact minime. Lorsque des tas de déblais de forage sont perturbés, ils sont aérés permettant une dégradation supplémentaire. Cette perturbation a cependant des impacts supplémentaires, quoique généralement à court terme, et localisés sur la colonne d'eau et dans certains cas (mais pas tous) pourrait entraîner une contamination du sol marin à l'extérieur des zones subissant les impacts initiaux de déblais.

La pêche peut reprendre au-dessus de tas de déblais de forage situés antérieurement dans une zone de sécurité de 500 m dans laquelle les activités de pêche ont été exclues. Lorsque les déblais sont laissés sur place ou déplacés sur le sol marin, les activités de chalutage risquent de les perturber, dégageant ainsi dans la colonne d'eau les contaminants que contiennent les tas de déblais et les filets et captures risquent potentiellement d'être contaminés.

Options concernant la perturbation des tas de déblais de forage historiques au cours d'un démantèlement

La perturbation des tas de déblais de forage au cours d'un démantèlement risque d'être inévitable si l'infrastructure doit être retirée. Une perturbation localisée des tas de déblais de forage risque donc de se produire avant de choisir l'option préférée de laisser les tas en place, permettant une dégradation naturelle. Le présent rapport se focalise en particulier sur les impacts potentiels de la dispersion des déblais offshore à proximité de tas existants.

Jusqu'à présent les méthodes le plus couramment utilisées pour le déplacement des déblais sur le sol marin ont été le dragage par aspiration et le jet d'eau. La technologie sélectionnée pour le déplacement des déblais peut permettre de réduire les impacts potentiels. Le dragage par aspiration par exemple cause habituellement un impact plus localisé sur la colonne d'eau et les sédiments du sol marin que le jet d'eau et les impacts seront encore plus localisés si l'on utilise d'autres méthodes telles que le labourage physique. Cependant, dans nombre de cas des contraintes physiques (c'est-à-dire la configuration des tas de déblais de forage et l'infrastructure de l'installation) risquent d'imposer la méthode sélectionnée et il est peu probable que le labourage physique convienne aux sites congestionnés. Le déplacement des déblais a des impacts à court terme inévitables mais peut également augmenter les taux de dégradation et le rétablissement. Il importe donc d'envisager si les déblais devront être délibérément dispersés largement pour accélérer le rétablissement ou déplacés dans de nouveaux tas distincts afin de limiter la couverture spatiale des sédiments contaminés. Il est fort probable que la solution optimale dépende de l'équilibre local des risques pour la pêche et l'écologie mais l'on dispose actuellement de très peu de données de terrain sur l'absorption de contaminants par le milieu vivant.

Atténuation et surveillance

On recommande une surveillance avant et après toute perturbation lorsque la contamination historique est perturbée et que le risque d'impact est élevé (par exemple perturbation à grande échelle, environnement plus sensible, espèces désignées à proximité ou pêche potentielle affectant le sol marin sensible). Cette surveillance devrait inclure l'échantillonnage de la colonne d'eau, des sédiments du sol marin et du benthos afin d'évaluer les impacts potentiels sur l'environnement. On se penchera également sur l'absorption par les espèces comestibles, le cas échéant. De plus, toute surveillance ne devra pas se limiter aux teneurs en hydrocarbures des tas de déblais de forage et devrait envisager d'autres contaminants potentiels tels que les métaux lourds.

2.0 INTRODUCTION

2.1 Background

For most of the 1970s, 1980s and 1990s, cuttings and all associated drilling fluids were discharged during drilling operations, resulting in the formation of large cuttings piles at many offshore oil and gas locations, most notably at multi-well drill sites in the central and northern North Sea. Historically, some of the drilling fluids used were oil based, resulting in hydrocarbon contamination of the cuttings, as well as heavy metals and other contaminants. The chemical and physical composition of drill cuttings piles varies widely depending on the drilling history of the location, the source rock, the type and volume of drilling fluid used and local hydrographic conditions.

There have been a range of studies of drill cuttings piles over the years, including the UK Offshore Operators Association (UKOOA) Joint Industry Project (JIP) carried out in three phases between 1998 and 2004. The goal of that initiative was to identify the best environmental practice for dealing with historical drill cuttings accumulations in accordance with the principles set out by the OSPAR Convention.

Recent studies on drill cuttings pile management have generally concluded that leaving the piles *in situ* to degrade naturally is the best option. However, in order to decommission installations, the cuttings piles present under installations may need to be disturbed, for example in order to recover drilling templates, conductor guide frames and/or to access jacket legs for cutting prior to removal. The disturbance may take place as a one-off event or there may be repeated disturbance over a period of time. Generally, this disturbance will take place before the cuttings piles have had a chance to fully degrade naturally.

Disturbance of cuttings piles results in oxygenation of the pile and enhanced degradation of the hydrocarbons present. It can also result in the spreading of contaminants over a much wider area within a short timescale, potentially resulting in impacts on living organisms in the water column and on the seabed. As more installations are being decommissioned or planned for decommissioning, there has been increasing focus on the issue of how to manage historical cuttings piles, notably where leaving the piles *in situ* is not a feasible option. Work is therefore required to improve the understanding of the likely impacts of disturbing cuttings piles during decommissioning and to review the options available for moving cuttings. Disturbance in this context has been taken to mean deliberate disturbance of cuttings piles to allow decommissioning work to take place rather than accidental disturbance, although the impacts of the latter would be expected to be similar.

2.2 Objectives and Scope

The Joint Assessment and Monitoring Programme (JAMP) 2014 – 2021 requires an assessment of the impacts of the offshore oil and gas industry on the marine environment, including possible releases of oil and chemicals from any disturbance of cuttings piles containing non-aqueous drilling fluids (NADFs, see Section 2.3). As part of the implementation of the JAMP, the United Kingdom was made responsible for compiling information on the disturbance of cuttings piles during decommissioning (OIC, 2017) and other Contracting Parties were asked to contribute information to the UK by 29th September 2017. Responses were received from The Netherlands (email from Licensing Department, Rijkswaterstaat Sea and Delta, September 2017) to confirm that they have no cuttings piles below their installations, and from Norway who provided the DNV summary report on drill cuttings piles in the Norwegian sector (DNV, 2008). In addition, the Norwegian Oil and Gas Association (NOROG) commissioned DNV to undertake a separate study to look at current best practice for management of cuttings piles and likely environmental impacts resulting from dredging of cuttings piles (DNV, 2017a). The findings of the DNV/NOROG study have been reviewed and where applicable these have been incorporated into this report. The references reviewed by NOROG were largely the same as

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those reviewed for this report and therefore the material covered and the conclusions of the two reports are similar.

The objectives of the current study are to:

- Assess the scale of the issue within the context of the OSPAR region;
- Review the evidence base relating to potential or actual biological effects on the seabed and in the water column from cuttings pile disturbance;
- Review the methods used for disturbing drill cuttings, focusing on any technical issues and the resulting environmental impacts;
- Review previous examples of areas where drill cuttings piles have been disturbed, and in particular, sites where monitoring results are available post-disturbance; and
- Highlight key areas for discussion, notably lessons learnt from cuttings pile disturbance operations undertaken to date, areas of uncertainty and potential for future work.

2.3 Classification of Drilling Fluids and Historical Context

Any cuttings pile is effectively made up of:

- A solid fraction, which in turn is made up of
 - A rock fraction (the cuttings as such);
 - Barite; and
 - Bentonite;
- and
- A liquid fraction (the liquid components of the drilling fluids).

Chemicals can be contained within either the liquid or solid fractions. The chemical composition of the pile reflects the muds/fluids used during drilling. Drilling fluids can be divided into water-based fluids, most commonly referred to as Water Based Muds (WBM) and non-aqueous drilling fluids (NADFs), often called Oil Based Muds (OBM) and Organic Phase drilling Fluids (OPF). NADFs contain a non-aqueous fluid (NAF) component, usually a type of oil known as the base oil.

WBMs are generally used to drill the upper sections of a well and where possible for drilling shallow vertical wells, but they are not suitable for drilling all formations. The main additive to WBM is barite (BaSO_4) which is used as a weighting agent, although other gel strength agents, such as lignosulphates and synthetic polymers are also used.

NADFs, often offer better technical performance and improved drilling rates compared to using WBMs e.g. in shale strata that are reactive to water and they can offer better productivity interfaces in the reservoir section of the well.

Over the years the type of NAF used has evolved, in part due to occupational health and environmental concerns. NAFs can be split into three groups as summarised in Table 2-1. Table 2-1 also shows the key periods during which different types of drilling fluids have been used. Understanding the drilling history at a particular site is crucial to understanding the type of contamination likely to be present in the cuttings pile.

Table 2-1 Classification of NAFs (OPFs)

| NAF category | Components | Aromatic content | Timescales of use |
|---|--|--|--|
| Group I: High aromatic content fluids | Crude oil, diesel oil and conventional mineral oil (referred to as Oil Based Muds OBMs) | 5-35% | 1960s and 1970s Phased out during the early 1980s Offshore use banned in 1984 |
| Group II: Medium aromatic content fluids | Low toxicity mineral oil (LTMO) (referred to as Low Toxicity Oil -Based Muds or LTOBMs) | 0.5-5% | 1980s to date Untreated discharge effectively banned under OSPAR 2000/3 (OSPAR, 2000b) ¹ |
| Group III: Low / negligible aromatic content fluids | Synthetic based muds (SBM) such as esters, poly alpha olefins, ethers (sometimes described as first generation SBMs), linear alpha olefins, linear paraffins and highly processed mineral oil (sometimes referred to as second generation SBMs). | <0.5% and polycyclic aromatic hydrocarbons (PAH) lower than 0.001% | 1990s Discharge effectively banned under OSPAR 2000/3 (OSPAR, 2000b) ¹ |

Sources: OGP/IPIECA, 2009 and OSPAR, 2000b.

Note. Under OSPAR 2000/3:

- The use of diesel oil-based drilling fluids is prohibited.
- The discharge of cuttings contaminated with organic-phase drilling fluids (effectively LTMO) is prohibited at a concentration greater than 1% weight on dry cuttings.
- The discharge of cuttings contaminated with SBM can only be authorised under exceptional circumstances based on BAT/BEP.

The use of OBM (i.e. containing relatively unrefined oils with high PAH content) was banned in 1984. The controls introduced in 2000 meant that cuttings contaminated with either LTOBMs or SBMs could no longer be discharged as achieving 1% weight of oil on cuttings was not technically achievable at that time. Since then, the development of reliable thermomechanical cuttings cleaning (TCC) technology means that cuttings drilled with OBM, and associated mud, can be discharged, as concentrations of oil below 1% (often below 0.1%) can be achieved. In a study organised by Norwegian Oil and Gas examining a TCC operation in Norway, the impacts of TCC-treated cuttings with <0.1% oil have been assessed as similar to those of water-based mud cuttings (Vik *et al.*, 2014).

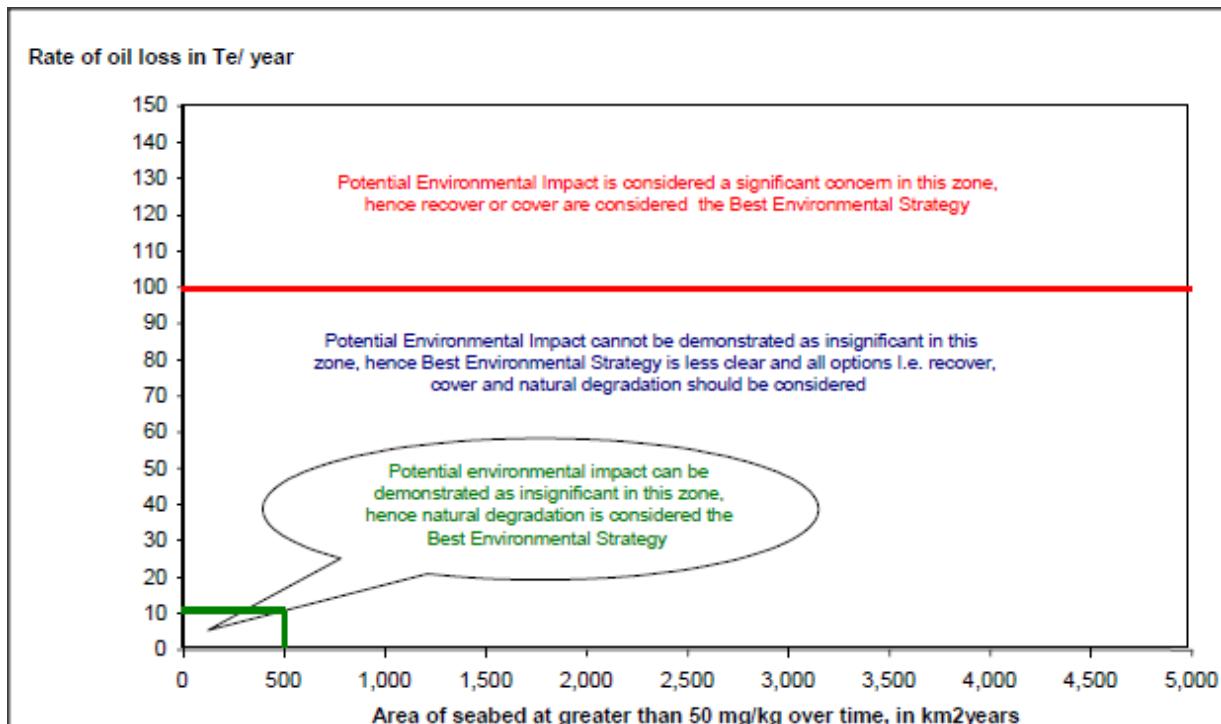
2.4 Current Management Regime for Cuttings Piles

In 2006, OSPAR agreed Recommendation 2006/5 (OSPAR, 2006) on a Management Regime for Offshore Cuttings Piles. Stage 1 required the assessment of drill cuttings piles against two criteria:

- The rate of oil loss from the cuttings pile to the water column should be less than 10 Te/year; and
- The persistence of the area of contaminated seabed should be less than 500 km².year. This is based on the area of the seabed where contamination of oil in surface sediments is above 50 mg/kg and the rate at which this area reduces.

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Where both the rate and persistence are **below** the set thresholds and no other discharges have contaminated the cuttings pile, no further action is considered necessary and the cuttings pile may be left *in situ* to degrade naturally (Figure 2-1). If the agreed criteria are exceeded then Stage 2 is required, to determine the Best Available Technique (BAT) and Best Environmental Practice (BEP) to be adopted in dealing with the cuttings pile. Following the publication of OSPAR 2006/5 (OSPAR, 2006), Contracting Parties with offshore installations were required to report by 30 November 2008 on the implementation of OSPAR Recommendation 2006/5. Responses were received from the UK, Norway and The Netherlands (OSPAR, 2009a).



Source: UKOOA, 2005

Figure 2-1 OSPAR identified management strategies relating to historic drill cuttings piles

The Netherlands reported that none of the former OBM discharge sites on the Dutch continental shelf exceeded the threshold for Stage 1 (OSPAR, 2009a). Norway reported that the cuttings piles in the Norwegian sector were likely to be well below the OSPAR thresholds, but also noted the technical problems associated with sampling and the uncertainties in the calculation of oil loss (OSPAR, 2009a). ERT carried out the screening assessment on behalf of the UK and concluded that the rate of oil loss and persistence values for all 174 UK installations where potentially significant piles may be present were below the relevant thresholds (ERT, 2009).

The conclusions of all three Contracting Parties were that there was no evidence of substantial oil loss and that there was a substantial improvement in the levels of contamination following the implementation of OSPAR decision 2000/3 on the Use of Organic Phase Drilling Fluids. The assessment concluded that no immediate action was required to reduce the environmental impact of cutting piles and that the management of piles could be addressed as part of decommissioning.

OSPAR Recommendation 2006/5 only looked at the hydrocarbon content of the pile, but other contaminants such as heavy metals are also important in assessing environmental risk. Work has been undertaken in recent years to ensure that characterisation of drill cuttings piles is not limited to hydrocarbon content but also includes an assessment of the full range of potential contaminants (OSPAR, 2017a and NOROG, 2016).

In terms of disturbance of cuttings piles, Recommendation 2006/5 does not strictly apply. The oil release rate and footprint metrics are representative of levels of concern derived from expert judgement. It is possible that large scale cuttings disturbance will release volumes of oil in excess of ten tonnes, and much more quickly than the annual leaching rate detailed in the Recommendation. In terms of footprint, modelling and monitoring studies suggest that footprints above the 50 mg/kg oil in sediments level will be created in some scenarios but only temporarily and not to an extent that would alter a long term conclusion on whether the 500 km².years threshold would be exceeded.

3.0 DISTRIBUTION, SCALE AND COMPOSITION OF EXISTING PILES

Some of the installations that will require decommissioning in the coming years have large cuttings piles present under the installation. These piles have resulted from extensive drilling programmes, often spanning several decades and they therefore generally contain cuttings drilled with NADFs of different types which are likely to be disturbed to allow installation removal.

3.1 Distribution and Scale

As part of an industry wide review of cuttings pile management ERT (ERT, 2009) estimated that of the 286 fields/installations in UK waters operational at the time, 112 were either single well installations (i.e. unlikely to have formed a cuttings pile) or were in areas where no OPFs had been used, leaving 174 locations where cuttings piles containing NAFs were likely to be present (i.e. two or more wells drilled with NADFs). ERT estimated the size of the piles based primarily on the number of wells drilled at each location. Although the relationship between pile size and the number of wells drilled is not straightforward, as factors such as well length, cuttings discharge point (surface, mid-point or seabed), hydrological conditions, properties of the discharged material, drilling chronology, degree of subsequent disturbance and the time elapsed following cessation of cuttings discharge will all influence the size of a particular cuttings pile, it does provide a reasonable estimate of likely cuttings volumes. ERT estimated the total volume of cuttings in UK waters to be 1,150,086 m³ giving an average cuttings pile volume in UK waters of around 6,610 m³.

Table 3-1 and Figures 3-1 to 3-3 show the number and location of installations likely to have cuttings piles in the Northern North Sea (NNS) and West of Shetland (WOS), in the Central North Sea (CNS) and in the Irish Sea respectively (ERT, 2009), as well as identifying those installations for which a derogation is likely, i.e. installations which under OSPAR 98/3 could be left in place. Potential derogation applies to Gravity Based Concrete (GBC) installations and large steel jackets (weight > 10,000 Te). Available data for Norway is discussed at the end of this section.

Table 3-1 indicates there are at least 129 installations, at which cuttings piles are likely to be present and likely to be disturbed during decommissioning (assuming that where derogation is granted and installations are left in place no disturbance of drill cuttings takes place). Of these, most (115) are likely to be relatively small piles (i.e. 20 or fewer wells were drilled) or there may be no pile present. Seabed surveys undertaken since the collection of the ERT data, for example at the Beatrice field have shown that there is only a cuttings pile at Beatrice Alpha and not under the neighbouring Beatrice installations. Similarly, the installations in Morecambe Bay have been shown not to have any underlying cuttings piles.

No Southern North Sea (SNS) installations are included as available data suggests that the relatively high energy seabed conditions in the SNS and the use of mobile drilling rigs which discharge most of the cuttings at or near the sea surface, will have resulted in discharged cuttings being dispersed rapidly and no physical piles will have formed (UKOOA, 2002).

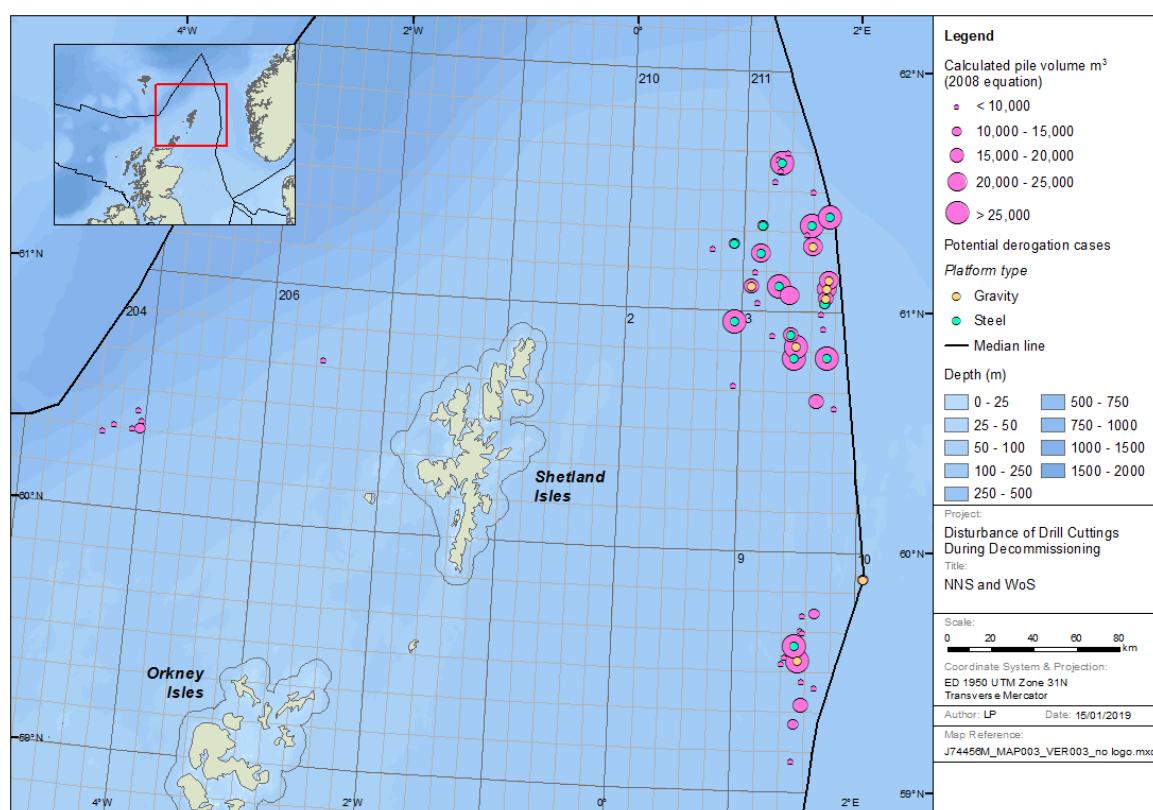
Table 3-1 Distribution of drill cuttings piles by installation type (UK)

| Size of cuttings pile ¹ (Tonnes) | Number of installations ¹ | Number of potential derogation cases ² | Number of cuttings piles likely to be disturbed during decommissioning |
|--|--------------------------------------|---|--|
| <10,000 | 115 | 4 (0 GBC, 4 steel) | 111 |
| 10,000 to 15,000 | 19 | 9 (1 GBC, 8 steel) | 10 |
| 15,000 to 20,000 | 10 | 5 (2 GBC, 2 steel) | 5 |
| 20,000 to 25,000 | 7 | 6 (4GBC, 2 steel) | 1 |
| >25,000 | 14 | 12 (2GBC, 10 steel) | 2 |
| Total | 165 | 36 (9 GBC + 26 large steel) | 129 |

Sources:

1. ERT, 2009. There are slight discrepancies between installation names in the ERT report and in current UK Oil and Gas (UKOG) data, www.ukoilandgasdata.com. ERT identified 174 installations with likely cuttings piles but nine of these could not be identified in the UKOG data. Size of pile based on ERT equation relating to number of wells drilled at each location.

2. Department for Business Energy and Industrial Strategy, BEIS, 2017.

**Figure 3-1 UK installations with potential cuttings piles: NNS and WOS**

Assessment of the disturbance of drill cuttings during decommissioning

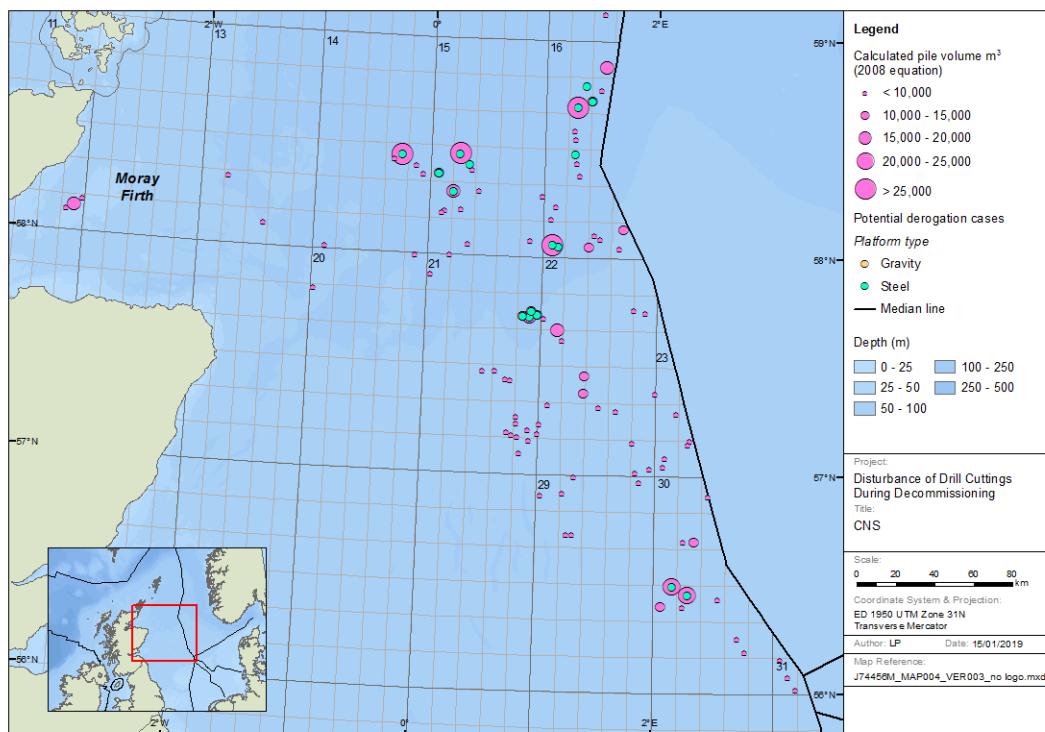


Figure 3-2 UK installations with potential cuttings piles: CNS

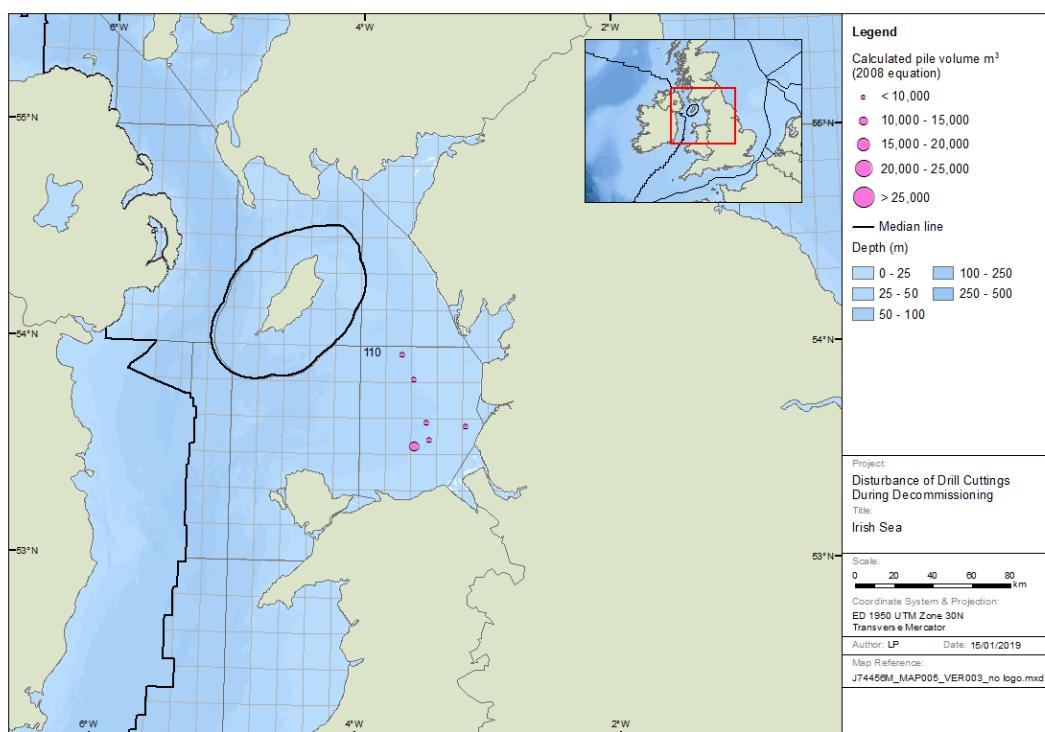


Figure 3-3 UK installations with potential cuttings piles: Irish Sea

There is no direct equivalent data set for Norway. The OSPAR offshore database (OSPAR, 2001) shows the number, types and weights of installations for all OSPAR Contracting Parties. For Norway this shows a total of 167 installations, of which 17 are potential derogation cases (11 GBC, 6 large fixed steel > 10,000 Te). DNV have estimated the volume of drill cuttings likely to be present below Norwegian installations (DNV, 2008). This shows 123 installations with potential drill cuttings piles, although only 89 of these could be identified within the Norwegian Petroleum Directorate GIS. Therefore, there are of the order of 70 installations where the cuttings piles are likely to be disturbed during decommissioning. The 2017 NOROG/DNV study pulled together current knowledge of cuttings piles on the NCS (see Appendix A of DNV, 2017a), showing installations with known cuttings piles and information on contamination, dredging and surveying of those piles. However, it does not provide data on the size of the cuttings piles and therefore the data presented in Table 3-2 and Figure 3-4 is based on the 2008 DNV data.

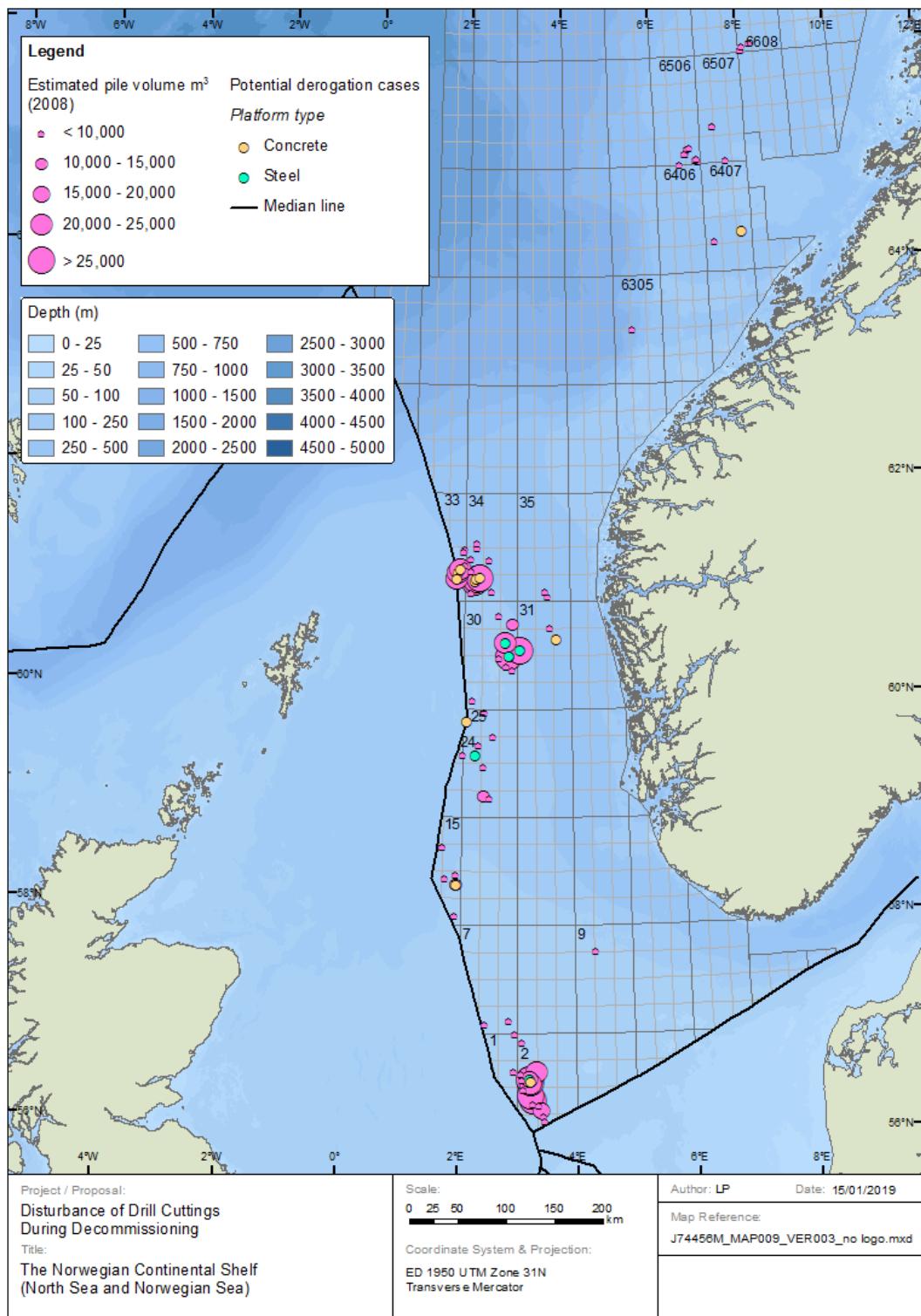
Table 3-2 Distribution of drill cuttings piles by installation type NCS

| Size of cuttings pile ¹ (Tonnes) | Number of installations ¹ | Number of potential derogation cases ² | Number of cuttings piles likely to be disturbed during decommissioning |
|---|--------------------------------------|---|--|
| <10,000 | 69 ³ | 6 | 63 |
| 10,000 to 15,000 | 3 | 1 | 2 |
| 15,000 to 20,000 | 2 | 1 | 1 |
| 20,000 to 25,000 | 6 | 4 | 2 |
| >25,000 | 9 | 5 | 4 |
| Total | 89 | 17 | 72³ |

Sources:

1. DNV, 2008
2. OSPAR, 2001
3. In the NOROG/DNV study Ekofisk 2/4W, Edda 2/7C, Grane, Snorre and Osberg C are noted as not having a cuttings pile but they have been included in this total as the DNV, 2008 study showed an estimated volume.

Assessment of the disturbance of drill cuttings during decommissioning



Note: Snøhvit CDU-1 not shown in the Barents Sea, over 800 km to the north east from the top of the map

Figure 3-4 NCS installations with potential cuttings piles

Information provided by The Netherlands (Rijkswaterstaat Sea and Delta, September 2017) indicates that no cuttings piles containing NAFs are likely to be present in the Dutch sector, where conditions will be similar to those in the UK SNS.

3.2 Pile Composition: Common Contaminants

Contamination within drill cuttings piles is generally very heterogeneous and can be difficult to characterise. Further details of contaminants typically found in cuttings piles are provided in the following sections.

3.2.1 Hydrocarbons

Hydrocarbons in the cuttings piles are derived mainly from OBM, LTOBM or SBM base fluid and may include:

- Diesel – mixture of saturated and aromatic hydrocarbons in the range C₉ to C₂₅ (OBMs);
- More refined mineral oil distillates, predominantly C₁₀ to C₂₁ alkanes (LTOBMs);
- First generation synthetic base fluids such as esters, ethers, poly alpha olefins and acetyl (SBMs); and
- Second generation synthetic base fluids such as linear alpha olefins and internal olefins (SBMs).

Before regulations were introduced in relation to the discharge of OBMs, LTOBMs and SBMs, hydrocarbon contamination at some fields could be detected out to 5 - 10 km distance (Bakke *et al.*, 2013).

The quantity and integrity of hydrocarbons still remaining in the piles is a result of the piles' depleted dissolved oxygen content, the type of drilling fluids used, the low temperatures, and the resulting reduction in the numbers and composition of benthic communities present due to cuttings deposition (smothering). The balance between oxygen transport processes and the chemical reactions occurring within the cuttings piles effectively determines the rate of degradation and the ultimate fate of hydrocarbons in the piles. Typically, aerobic biodegradation of hydrocarbons occurs only in the upper few millimetres of the pile. Anaerobic degradation may take place down to at least 20 - 50 cm but very slowly, with oil in the deeper parts of the pile remaining essentially unchanged (Breuer *et al.*, 1999).

In marine sediments the dominant sediment transport mechanism is due to bioturbation by benthic fauna, and redistribution of sediment particles and fluids will occur during feeding (but this is minimal in cuttings piles), burrowing, tube construction, and irrigation (Aller, 1998 – as referenced in Breuer *et al.*, 1999). In cuttings piles bioturbation is minimal and oxygen transport is limited to diffusion or tidal advection and pumping so that oxygen is quickly consumed by the breakdown of organic matter, resulting in much slower biodegradation.

The key hydrocarbon components potentially present in cuttings piles are:

- Total Hydrocarbon Concentration (THCs) which is the basic parameter used to estimate the total amount and distribution of oil present; and
- PAHs of which the 4 to 6 ring compounds are of particular importance due to their toxic nature even at very low concentrations.

Other hydrocarbons that may also be present in cuttings piles include:

- Alkyl phenols and alkyl phenol ethoxylates (APEs) which are suspected endocrine disruptors. Alkyl phenols are natural constituents of petroleum and can be found in produced water discharges. APEs were previously used as surfactant additives in drilling fluids;
- Polychlorinated biphenyls (PCBs), synthetic mixtures of chlorinated hydrocarbons, which are known endocrine disrupters and were used on North Sea installations prior to the mid-1980s; and

Assessment of the disturbance of drill cuttings during decommissioning

- Mono, di and tri-butyltins (M/D/TBT) which are highly toxic, very persistent in the environment and known endocrine disruptors. TBT was used in antifouling paint until the mid-1980s.

There is also a concern that biodegradation and other diagenetic processes in the piles over the years may have produced other potentially toxic compounds such as complex esters and organic acids which until recently could not be identified analytically (Bakke *et al.*, 2013).

The range of concentrations of hydrocarbons measured in cuttings piles in the North Sea is shown in Table 3-3. An explanation of assessment and background levels is given in Annex 1.

As oils degrade, their composition changes from well-defined aliphatic and aromatic molecules to new compounds with a wide range of molecular structures that become indistinguishable in mass spectrometer analysis, and which are therefore referred to as unresolved complex mixture (or unresolved chromatographic material) (UCM). The general properties of UCM are uncertain. By definition, it is a somewhat unidentified material, and across the scientific literature it has received much less attention than the hydrocarbons released, for example in an oil spill or in the form of a discharge of a refined material. These factors mean there is a large uncertainty in drawing conclusions from the literature that is available.

UCM composition in oil-contaminated sediments is discussed in a number of papers and a typical summary of characteristics is given in Brownawell *et al.* (2007), which references other studies, and is also reviewed in Neff (2002). The components of the UCM include alkanes, branched alkanes, cycloalkanes, mono-aromatics, multi-ring aromatics, hetero-atomic aromatics, steranes and cyclic triterpenoids. Studies performed have shown that the mono-aromatic components of the UCM (Rowland *et al.*, 2001) amongst other components produce a toxic response in the common mussel *Mytilus edulis* at concentrations found in polluted environments. The UCM is lipophilic and therefore can accumulate in the fatty tissues of benthic organisms like *Mytilus edulis* which are continuously exposed to it in the environment.

Since it has already undergone some form of biological degradation, and probably chemical and physical weathering, oil that is transformed to UCM is potentially more persistent than the original material. There are suggestions that UCM may also be a component of certain refined products.

As cuttings piles age, overall oil content will decrease, but UCM will become an increasing large fraction of what remains. There are examples of cuttings piles deposited mainly in the 1980s with LTOBM, in which UCM content was measured at over 80% of the total petroleum hydrocarbons (TPHs) measured.

3.2.2 Metals

The metals of greatest concern in the cuttings piles because of their potential toxicity and/or abundance in drilling muds are arsenic (As), barium (Ba), chromium (Cr), cadmium (Cd), copper (Cu), iron (Fe), lead (Pb), mercury (Hg), nickel (Ni) and zinc (Zn), (Breuer *et al.*, 2004). The mineral barite (BaSO_4) is one of the main constituents used in drilling mud resulting in high levels of Ba in cuttings piles.

Detailed sampling of the Beryl A cuttings pile showed elevated solid phase metal concentrations in the cuttings pile compared to the surrounding environment indicating that the pile is a contaminated site. However, calculated dissolved metal fluxes were similar in magnitude to fluxes calculated for other marine environments, with the exception of Ba, suggesting that the pile in its undisturbed state is not a significant source of metals to the surrounding environment (Breuer *et al.*, 2008).

Breuer *et al.*, (2008) concluded that trace metals released into the porewaters of the cuttings pile migrate either upward to the overlying water (Ba, Mn, and Fe), possibly adsorbing onto Mn and Fe oxyhydroxides at the sediment water interface, or diffuse downward (Cr, Cu and Pb) where they become incorporated into Fe monosulfides. The exposure of these Fe monosulfides to oxygen as a result of transport of oxygen into the cuttings via bioturbation or advection and/or pile resuspension

may then lead to the release of the associated metals into the water column (Saulnier and Mucci, 2000; Huerta-Diaz *et al.*, 1998).

Monitoring studies on the Norwegian Continental Shelf (NCS) have only found elevated levels of trace metals in sediments collected close to the installations, which have been attributed primarily to historical discharges of drill cuttings, but there is no indication that the levels of trace metals in fish and shellfish collected close to offshore installations are significantly above natural background concentrations (Bakke *et al.*, 2013).

The range of concentrations of metals measured in cuttings piles in the North Sea is shown in Table 3-3. An explanation of assessment and background levels is given in Annex 1.

OSPAR guidance on sampling of cuttings piles (OSPAR, 2017a) recognises the importance of fully characterising cuttings piles. The aim of the guidelines is to ensure that samples collected are representative of the pile and relevant to the decommissioning process. They include recommendations for sampling and analysis of a complete suite of determinants including: metals, THCs, PAHs, PCBs, APEs and M/D/TBTs.

Table 3-3 Comparison of selected hydrocarbon and metal concentrations at different cuttings piles

| Component | Units | Cuttings Pile | | | | | | | | | | Background | | | |
|--------------------|----------------------|---|--|--|--|--|---|------------------------------|-------------------------|--------------------------|---|-----------------------|-----------------------------------|------------------------|--|
| | | Murchison Cuttings Pile, July 2011 (push cores) | Murchison Surface Sediments, July 2011 | North Cormorant Cuttings Pile, July 2011 | Beryl A Cuttings Pile (Station B1) (Breuer et al., 2008) | Cuttings Review ¹ (Cordah/Rogal and Research, 1999) | Cuttings Review ² (Cordah, 2000) | NW Hutton (BMT Corrib, 2004) | Miller (Anuatera, 2007) | Ekofisk 2/4A (DNV, 2009) | East Shetland Basin Background ³ | Background Conc. (BC) | Background Assessment Conc. (BAC) | Effect Range Low (ERL) | |
| THC | % | 0.16 to 1.0 | 0.0001 to 0.045 | 0.3 to 13.3 | - | 0 to 14.3 | 0 to 37.9 | 4.9 | 1.8 to 7.7 | 4.7 ^b | 0.0005 to 0.0015 | - | - | - | |
| Total PAH | $\mu\text{g g}^{-1}$ | 14.1 to 65.8 | 0.028 to 2.41 | 11 to 302 | 134 to 472 | 0 to 1,282 | - | 773 ^b | - | - | - | 0.19 | 0.36 | 3.34 | |
| PCB | ng g^{-1} | 0.44 to 0.99 | <0.10 to 0.56 | - | - | - | - | - | - | - | - | 0.20 | 0.46 | 11.50 | |
| APE | $\mu\text{g g}^{-1}$ | 574 to 1,690 | 4.1 to 784 | - | - | - | - | - | - | - | - | - | - | - | |
| TBT | ng g^{-1} | 1.7 to 5.0 | <0.4 to 2.5 | - | - | - | - | - | - | - | - | - | - | - | |
| Total Barium (TBa) | $\mu\text{g g}^{-1}$ | 173,000 to 231,000 | <500 to 54,000 | 7,500 to 216,000 | 228,557 | 202 to 231,000 | - | 101,000 | - | - | 500 to 1,000 | - | - | - | |
| Chromium (Cr) | $\mu\text{g g}^{-1}$ | 36 to 41.7 | 5.50 to 05.3 | 42 to 59 ^a | 426 | - | 12 to 101 | 87 | 27 to 56 | - | 5 to 10 | 60 | 81 | 81 | |
| Lead (Pb) | $\mu\text{g g}^{-1}$ | 279 to 3,043 | 3.05 to 447 | 82 to 296 ^a | 689 | 7 to 361 | - | 170 | 12 to 172 | 75 ^c | 5 to 15 | 25 | 38 | 47 | |
| Arsenic (As) | $\mu\text{g g}^{-1}$ | 10.1 to 24.6 | 1.42 to 22.5 | 14 to 29 ^a | - | 2.9 to 2.8 | - | - | 7 to 15 | - | - | 15 | 25 | - | |
| Cadmium (Cd) | $\mu\text{g g}^{-1}$ | 0.99 to 5.74 | <0.03 to 1.58 | 1.7 to 8.8 ^a | - | 0.1 to 8.0 | <1 to 25 | 1.5 | 0.2 to 1.5 | 0.5 ^c | 0.05 to 0.1 | 0.20 | 0.31 | 1.20 | |
| Mercury (Hg) | $\mu\text{g g}^{-1}$ | 1.73 to 3.89 | <0.03 to 2.33 | 0.61 to 1.57 ^a | - | 0.1 to 32.6 | 0.01 to 1.52 | - | 0.03 to 2.25 | 0.16 ^c | 0.01 to 0.05 | 0.05 | 0.07 | 0.15 | |
| Aluminium (Al) | $\mu\text{g g}^{-1}$ | 12,030 to 18,890 | 1,450 to 10,700 | 23,200 to 31,200 ^a | - | - | - | - | - | - | - | - | - | - | |
| Copper (Cu) | $\mu\text{g g}^{-1}$ | 59.8 to 237 | 1.85 to 140 | 58.2 to 81.7 ^a | 281 | - | - | - | - | - | - | 20.0 | 27.0 | 34.0 | |
| Iron (Fe) | $\mu\text{g g}^{-1}$ | 26,580 to 41,440 | 3,830 to 25,100 | 24,800 to 37,000 ^a | - | - | - | - | - | - | - | - | - | - | |
| Lithium (Li) | $\mu\text{g g}^{-1}$ | - | - | 29.3 to 80.1 ^a | - | - | - | - | - | - | - | - | - | - | |
| Manganese (Mn) | $\mu\text{g g}^{-1}$ | 397 to 860 | 39.0 to 278 | 466 to 1,370 ^a | - | - | - | - | - | - | - | - | - | - | |
| Nickel (Ni) | $\mu\text{g g}^{-1}$ | 24.6 to 50.4 | 2.85 to 25.2 | 33.4 to 42.1 ^a | - | - | - | - | - | - | - | 30 | 36 | - | |
| Strontium (Sr) | $\mu\text{g g}^{-1}$ | 221 to 2,018 | 72.1 to 820 | - | - | - | - | - | - | - | - | - | - | - | |
| Vanadium (V) | $\mu\text{g g}^{-1}$ | 33.6 to 44.4 | 4.00 to 61.2 | 64.8 to 105 ^a | 523 | - | - | - | - | - | - | - | - | - | |
| Tin (Sn) | $\mu\text{g g}^{-1}$ | - | - | 1.73 to 3.33 ^a | - | - | - | - | - | - | - | - | - | - | |
| Zinc (Zn) | $\mu\text{g g}^{-1}$ | 523 to 753 | 5.77 to 628 | 658 to 3,410 ^a | - | - | - | - | - | - | - | 90 | 122 | 150 | |

^arange of data obtained from a review of 10 different cuttings piles. ^brange of data obtained from a review of 15 different cuttings piles. ^cestimated from various surveys in East Shetland Basin, data obtained from UKOOG benthic database (UKOOG, 2000). *data from the uppermost core sections ^atotal NPD average concentration.

Source: Genesis, 2016

4.0 LITERATURE REVIEW OF POTENTIAL ENVIRONMENTAL IMPACTS OF DISTURBANCE OF CUTTINGS PILES

The impacts of drill cuttings discharge on the environment have been widely studied, including joint industry projects by UKOOA and a parallel project managed by SINTEF in the late 1990s and early 2000s. These studies form much of the basis for predicting potential impacts resulting from the subsequent disturbance of an existing cuttings pile, as the impacts are likely to be largely similar to the impacts of the initial discharge and there is a limited data set relating solely to the impacts of disturbance. The disturbance of historical cuttings piles is likely to result in the resuspension of cuttings material into the water column, and its subsequent dispersion and resettlement. In its undisturbed state there is limited potential for new impacts from a historical cuttings pile, but when disturbed there is renewed potential for impact on biota in various compartments of the marine environment.

A proportion of a disturbed cuttings pile is likely to resettle on seabed sediment that has not been previously impacted by cuttings. The potential impact this has on benthic communities results from a combination of physical smothering, changes in sediment texture/grain size, oxygen depletion, organic enrichment and direct toxicity from drilling fluids and cuttings (e.g. from hydrocarbons, heavy metals and sulphides in the drilling fluids). This can result in a decrease in both the abundance and diversity of benthic fauna.

The extent of impact from direct toxicity will depend on the relative biodegradability, bioaccumulation and toxicity of different drilling fluids as well as other contaminants in the cuttings piles. This is primarily determined by the physical and chemical properties of the chemicals contained in the drilling fluids. Generally, impacts from disturbed cuttings drilled with WBM are expected to be minor as they will resemble the impacts from currently consented discharges, and any concern is more likely to focus on cuttings drilled with NADF. It is rare for significant cuttings accumulations to relate solely to drilling with WBM, so where there is a significant accumulation and disturbance, there will normally be NADF present which will dominate the potential impacts. This report therefore focusses on risks relating to disturbance of cuttings drilled with NADF.

Smaller, simpler organic compounds generally degrade faster than more complex compounds, and more soluble compounds will be more easily taken up by marine organisms. Metal sulphides found in barite are largely insoluble, as are Group III drilling fluids (SBMs, see Table 2-1) and typically do not bioaccumulate in the lipids of marine organisms (IOGP, 2016). The PAH components of Group I and Group II drilling fluids on the other hand, have been shown to bioaccumulate in the tissues of marine organisms. As noted in Section 3.2.1, as cuttings piles age, the overall oil content will decrease, but UCM will become an increasing fraction of what remains. The toxicity of the remaining UCM is less well defined than that of the original hydrocarbons, resulting in greater uncertainty around the potential impacts of disturbing historical drill cuttings piles, compared to impacts resulting from the initial discharges.

4.1 Benthos

Prior to regulations being introduced in relation to the discharge of NADFs, changes in benthic macrofauna could be traced out to 2-5 km or more from installations on the NCS (Bakke *et al.*, 2013). Since the termination of discharges of NADF cuttings to the NCS, the recovery of local sediment fauna has been substantial (Bakke *et al.*, 2011; Bakke and Nilssen, 2004; Carroll *et al.*, 2000; Renaud *et al.*, 2008; Schaanning and Bakke, 1997 as quoted in Bakke *et al.*, 2013). Recent surveys have shown effects on benthic macrofauna, notably a decrease in diversity and abundance, are most often confined to within a 250 m radius of the cuttings pile, and seldom detected beyond 500 m, even around the largest piles, (Breuer *et al.*, 1999 and Breuer *et al.*, 2004). Contaminants within cuttings piles generally have low solubility and are mainly bound to particulate matter (OSPAR, 2016). Therefore, most of the contaminants follow the solids to the seabed where they settle.

Benthic amphipods are known to be susceptible to oil pollution and are often used as biomarkers for oil pollution (e.g. Word, 2014) and used as a fundamental test species in oil and gas permitting. Tests, including toxicity studies using the benthic amphipod *Corophium volutator* (UKOOA, 1999a and 1999b), led to the adoption of the 50 mg/kg THC level in sediments within OSPAR countries (OSPAR, 2006 and 2009a). The studies undertaken by ERT (UKOO, 1999b) indicated that the critical tissue residue (the highest tissue concentration at which no significant mortality was observed) was approximately 900 mg/kg, in sediment containing 31 and 48 mg/kg of cuttings derived hydrocarbons. They deduced a no-effect residue concentration in the region of 50 mg/kg dry weight.

As part of the UKOOA initiative (UKOOA, 2002), aerobic and anaerobic degradation processes for the organic fraction of drill cuttings material were examined. UKOOA concluded that biodegradation processes are slow, that they mainly take place in the oxygenated surface active layer (SAL), and that they probably are little influenced by macrofaunal presence and bioturbation activity. However, bioturbation activity may influence the effective thickness of the SAL.

Bradshaw *et al.* (2006) undertook experiments using three macrofaunal species to examine the role of bioturbation by benthic infauna in transporting sediment associated contaminants in the Baltic Sea. They found that bioturbation by macrofauna buries surface contaminants and remobilises those that are buried but the effects are small and on a similar scale to transport caused by meiofauna. They concluded that physical processes are likely to be far more important than biological processes in the redistribution of contaminants.

Recent work looking at how drilling discharges influence sediment reworking (bioturbation) of two benthic species (the brittle star *Amphiura filiformis* and the bivalve *Abra segmentum*) (Trannum, 2017) has showed that deposition of WBM cuttings has the potential to reduce sediment reworking. Both species showed reduced sediment reworking activity when a layer of 2.5 mm drill cuttings was added, compared to a similar thickness of natural sediment. There has been limited research on this topic and the reasons for reduced bioturbation are not fully understood. Trannum (2017) suggests that there might be a toxic response, limiting energy devoted to feeding and movement and reducing the capacity of the organism to mix the upper sediment. This in turn results in a large fraction of contaminants remaining at the surface and a slowing down of transport of oxygen and nutrients downwards.

Data is still emerging on the possible effects on other parts of the benthic ecosystem (Bakke *et al.*, 2013). Some studies suggest that meiofauna does not respond to cuttings discharges in a fundamentally different way than macrofauna (Montagna and Harper, 1996; Moore *et al.*, 1987; Netto *et al.*, 2010 as referenced in Bakke *et al.*, 2013), but there is relatively little knowledge on the sensitivity of microfauna, epifauna, hyperfauna and coral and sponge communities to drilling discharges.

Recovery of benthic communities from the impacts of drill cuttings will generally occur by the recruitment of new colonising organisms and the subsequent migration from adjacent undisturbed sediments. Typically, there is a succession of benthic community composition and diversity during recovery. In a literature review, Rye *et al.* (2006) concluded that re-colonizations appear in successions, where different species dominate at various time intervals during the restitution of the sediment. Estimated times for re-colonization vary and are in the order of years for new wells, and a generalised re-colonization time of five years (after degradation of toxic components) was recommended for use in risk assessment. When discharges have changed the nature of the sediment, then a permanent change of community may occur due to the change of the substrate, but the new community will be biologically productive.

Jones *et al.* (2012) looked at recovery of megabenthic assemblages from physical disturbance at the Laggan deep water hydrocarbon drilling site in the Faroe-Shetland Channel. The study suggested partial recovery between 3 and 10-years post-disturbance, except in the area remaining completely covered by drill cuttings where few megafauna were observed even after 10 years. However, megafauna may recover more slowly than the more commonly studied smaller infauna.

Bakke *et al.*, 1986 (as summarised in Bakke *et al.* 2013) found almost no macrofauna recolonization over a two-year period on sediments impacted by diesel and LTOBM cuttings. Bakke concluded that as well as chemical toxicity factors, grain size deviation and hydrogen sulphide content may retard fauna recovery.

In terms of physical effects, field studies have shown that the presence of standard grade barite is not acutely toxic to seabed fauna but does alter benthic community structure when it is persistent (Strachan, 2010).

4.2 Plankton

During disturbance of drill cuttings piles, particles are re-suspended into the water column, resulting in similar impacts as those during the initial discharge. Contamination of the water column is expected to be local and reduced soon after the disturbance stops (OSPAR, 2016).

Water column risks from discharges of cuttings during drilling activities were examined by the ERMS joint industry project and classified as chemical toxicity and pseudo-chemical toxicity from fine particulate material. The study concluded that the most sensitive groups were zooplankton, which ingest fine particles, and molluscs which are filter feeders. Barite particles in particular were observed to be more toxic than equivalent marine suspended solids (Rye *et al.*, 2006) and this may be due to the angular nature of mined barite versus the rounded surface of weathered marine sediments.

An outcome of this study was a predicted no effect concentration (PNEC) for suspended barite of 0.2 mg/l. This can be used in impact assessments where the plume of suspended material results in a combined predicted environmental concentration PEC: PNEC¹ ratio above one for the assorted components, and to compare different options. Overall, planktonic communities are robust, widespread and have rapid recovery times. Their ability to recover quickly is due to short generation times, the production of large numbers of eggs and juveniles, distribution over large areas and rapid water exchange (IPIECA/IOGP, 2015). Studies following the grounding of the tanker *Tesis* in 1977 during which 1,000 tonnes of fuel oil were released into the Baltic Sea, showed that zooplankton biomass declined substantially close to the wreck during the first few days after the spill but was re-established within five days, (IPIECA/IOGP, 2015).

4.3 Fish

Resuspension of cuttings piles into the water column as a result of disturbance during decommissioning gives rise to the potential for exposure of fish to contaminants in the cuttings. Resettlement of disturbed cuttings may also impact demersal species and/or fish eggs. As noted earlier, monitoring studies on the NCS have found elevated levels of trace metals (thought to derive from cuttings discharges) in sediments collected close to the installations but there was no indication that the levels of trace metals in fish and shellfish collected close to offshore installations were significantly above natural background concentrations (Bakke *et al.*, 2013).

Haddock and cod caught in the North Sea have shown biomarker effects (Balk *et al.*, 2011; Grøsvik *et al.*, 2010 as referenced in Bakke *et al.*, 2013) which may reflect exposure to cuttings when the fish are foraging on the piles (the study related to existing piles, but would be applicable to disturbed piles), but this may also stem from exposure to produced water discharges. Furthermore, beyond what can be inferred from the functional roles of impacted macrofauna species, there is virtually no information

¹ The Predicted No Effect Concentration (PNEC) is the concentration of a chemical below which no adverse effects of exposure in an ecosystem are measured. PNEC values are intended to be conservative and predict the concentration at which a chemical will likely have no toxic effect. The PNEC is used in conjunction with the predicted environmental concentration value (PEC) to calculate risk.

of potential long-term effects on fish population and community functions such as production, reproduction, and trophic interaction.

APEs, including nonylphenol ethoxylate as a common example, have been raised as substances of concern due to their endocrine disrupting properties. APE can appear above background levels near the centre of some cuttings piles, but do not appear to be present above background in the surrounding areas (e.g. BMT Cordah, 2013). An expert panel of scientists commissioned by SINTEF considered inclusion of APEs during development of risk assessment methodology for drilling discharges (Frost *et al.* 2006, drawing on Neff, 2002). However, on the basis of sampling results at the time it was considered that their concentrations were below toxic levels, and on this basis they were not included in their risk calculation for drilling discharges.

Ingestion of oil is a potentially important source of contamination where there is oil in the water column. However, following disturbance of a cuttings pile, any oil released into the water column would only be present for a short period of time. The water solubility of PAHs decreases with increasing molecular weight, thus high molecular weight PAHs tend to be associated with organic matter and sediment, whereas low molecular weight PAHs (2-3 rings) may have an appreciable proportion in the dissolved phase. Higher molecular weight PAHs are also more persistent.

The trophic level of a particular fish (i.e. the level it occupies in the food chain) also influences how much PAH will accumulate. A study in the Persian Gulf (Monikh *et al.*, 2014) showed that high molecular weight PAHs increase in fish of increasing trophic levels. *Netuma bilineata* (bronze catfish) for example is a carnivorous predator as well as being a benthic species and was found to have higher concentrations of heavier PAHs compared to *Liza abu* (Abu Mullet) which is a phytoplankton feeder and lives in the upper layer of the water column. Heavier PAHs are also more toxic than the lighter PAHs.

When fish and some higher invertebrates are exposed to PAHs and similar compounds, an enzyme system known as cytochrome P450 mixed function oxygenase (MFO) is triggered which initiates the breakdown of PAHs. While most fish will therefore experience elevated levels of PAH in the bloodstream and tissues when exposed, these will be largely eliminated over weeks and months.

The biological effects of an offshore oil platform on local fish populations were assessed as part of the Norwegian Water Column Monitoring programme (NIVA/IRIS, 2014). The Njord A platform was chosen as the study location, as it was not in operation and had no current discharge of produced water. Demersal fish species were targeted since they were believed to be less likely to migrate away from the platform than pelagic fish. By targeting organisms deeper in the water column and selecting a platform currently not in operation, the impact of drill cuttings and other sediment sources including leakages from the well deposits were considered to be the main sources of contamination. PAH concentrations in fish fillet were found to be low or undetected in all four fish species from both the platform and reference populations. PAH metabolites in fish bile were also low or marginally above the limit of quantification. However, despite the apparent low exposure to PAH compounds significant biomarker responses were observed e.g. damage to individual cells in the liver or gills. The biological responses indicate exposure to both neurotoxic and genotoxic chemicals in fish residing in the vicinity of the Njord A platform.

Evidence from oil spills sheds light on biological effects of PAHs, and although large oil spills have significant differences to cuttings disturbance, they are well studied and allow general conclusions to be drawn. In the Braer spill of 1993 in Shetland, roundfish such as cod and haddock were less affected than flatfish in contact with the sediments and contamination levels in all finfish reduced rapidly over a period of months (Davies and Topping, 1997). Marine salmon and trout were relatively unaffected

after the Sea Empress spill, although salmon spawning was affected after the Exxon Valdez spill (Lawrence and Hemingway, 2003).

In general, fish eggs are susceptible to oil pollution through mortality, hatching success and presence of deformities, although the exposure pathway is via dissolved oil components and effects would therefore be localised to the area and timescale of the disturbance of the cuttings pile. There may be specific requirements to minimise disturbance of the seabed in the vicinity of seabed spawning grounds (e.g. sandeel spawning, herring spawning). In the UK blocks where seabed disturbance at spawning sites may be a concern have been identified (see OGA, 2017) and seabed surveys may be required before drilling. In Norway sandeel grounds can be found at <https://kart.barentswatch.no/arealverktoy> and licensees must use development solutions that entail the least possible alteration of the seabed in these areas.

Further information on fish taint and potential food chain effects is given in Section 4.8.

4.4 Crustaceans and Molluscs

Some of the conclusions for fish in general also apply to molluscs and crustaceans. There are, however, important differences in their exposure pathways and responses to pollutants encountered in cuttings piles and by inference, from resettled cuttings material disturbed during decommissioning. Molluscs can accumulate chemical contaminants in their tissues, notably PAHs, and in the extreme these contaminants can present a risk to human health.

Filter feeders such as mussels and scallops preferentially feed during times of higher suspended solids, and tissues are damaged by ‘sharp’ suspended barite particles compared with weathered marine sediments. There has been 100% mortality observed at deposition levels of 0.5 mm per day in the laboratory through damage to gills and altered filtration rates (Strachan, 2010). Overall recovery from such damage would be expected over a few reproductive cycles. This could be of concern in longer-lived species such as the ocean quahog, *Arctica Islandica*, although areas of high exposure would be spatially very limited as indicated by modelling studies.

There is a significant difference in how oil, including PAHs, is metabolised by crustaceans and molluscs compared to fish. If active metabolism and excretion do not occur, PAHs (especially those of higher molecular weight) may accumulate in tissues (e.g. FERA, 2012). Bivalve molluscs in particular generally lack the ability to produce the enzyme MFO and can accumulate PAH in tissues, the only real means of eliminating it being passive equilibration (Neff, 2002). This characteristic means that there are legal limits for PAH in shellfish such as mussels and scallops, and food chain effects are discussed in Section 4.8.

Nephrops are also potentially susceptible for the same reason and are an important commercial food species. As context, in the Braer spill, *Nephrops* and bivalve molluscs including mussels and scallops were severely affected by oil contamination and restrictions on *Nephrops* and mussels continued from 1993 until 2000 (Lawrence and Hemingway, 2003). *Nephrops* were identified as a species worthy of further investigation in the context of uptake from cuttings piles (DNV, 2000) although little literature has been found on the impacts or otherwise on *Nephrops*.

In terms of ecological impacts, mortality of crustaceans and molluscs from drill cuttings disturbance is unlikely, and even less likely to threaten populations, but local effects are possible. It is also worth noting that scallop dredging gear has significant potential for sediment disturbance (OSPAR, 2016), therefore as well as being more sensitive to the potential impacts of contamination, scallops are also more likely to be exposed to the contaminants as a result of gear interaction. However, the vast majority of historic cuttings piles are not in scallop dredging areas.

4.5 Seabirds

The disturbance of cuttings may evolve droplets of oil that are sufficiently buoyant to rise to the surface quickly enough to produce a discernible sheen. This has been observed at two significant relocation projects at Valhall and Magnus, but not during disturbance of piles at Oseberg, Sleipner and North West Hutton (see case studies in Section 5.2). The sheen observed was patchy, transient and localised.

Sheens can affect seabirds at low doses of oil (10 - 50 mg of certain oil types in plumage can significantly harm thermoregulation in seabirds), nevertheless it is not considered that such unusual and small scale exposures would be environmentally significant.

4.6 Marine Mammals

Marine mammals will be primarily impacted by contaminants present in the water column rather than on the seabed. When originally discharged into the sea, cuttings form a plume in the water column which dilutes rapidly as it drifts away from the discharge point. Dissolved components of the plume dilute rapidly by mixing in the water column. Suspended solids in the plume undergo dispersion, dilution, dissolution, clumping, flocculation and settling (IOGP, 2016) with the large particles sinking more rapidly and settling nearer the discharge point. Finer grained particles disperse and sink more slowly and end up spread over a wider area of the sea floor. Similar processes take place during cuttings pile disturbance although monitoring has indicated that water column impacts tend to be restricted to a few metres above the seabed (see Section 5.4.6 Albuskjell case study) rather than the full depth of the water column.

Monitoring of cuttings discharges, which are physically similar to disturbance operations, indicates that discharges are diluted rapidly to very low concentrations, usually within 1 - 2 km down current and within 2 to 3 hours after discharge (Neff, 1987), and the area and duration of impact would be expected to be significantly less for disturbance operations. This means that marine mammals are unlikely to be exposed to high concentrations of chemicals for any significant time period and they are not normally considered to be at risk.

4.7 Protected Habitats

There are a range of protected habitats (international and national designations) within the OSPAR area. Those most relevant to the potential impact of cuttings disturbance are cold water corals and pockmarks. Reefing species such as *Sabellaria* are less likely to be impacted as they are normally present in areas of high currents where discharges are more easily dispersed and cuttings piles are less likely to be present.

Protected habitats in UK waters are shown in Figure 4-1 and the NCS in Figure 4-2 (insufficient cuttings data was available for the Netherlands to produce similar maps). Whilst many of the installations are well away from these protected habitats there are some areas where existing cuttings piles are within or in close proximity to protected habitats.

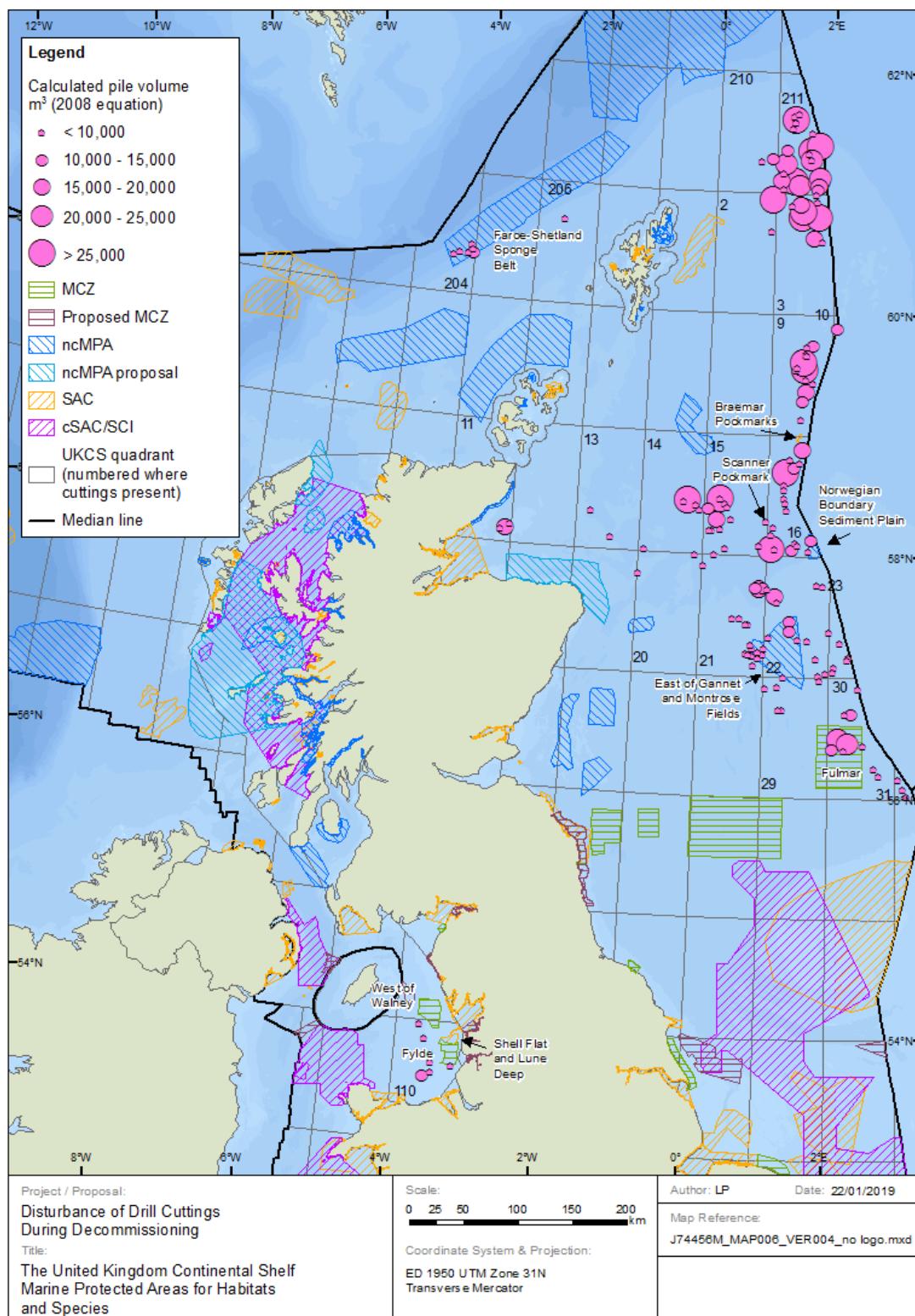


Figure 4-1 Location of protected habitats relative to cuttings piles, UK waters

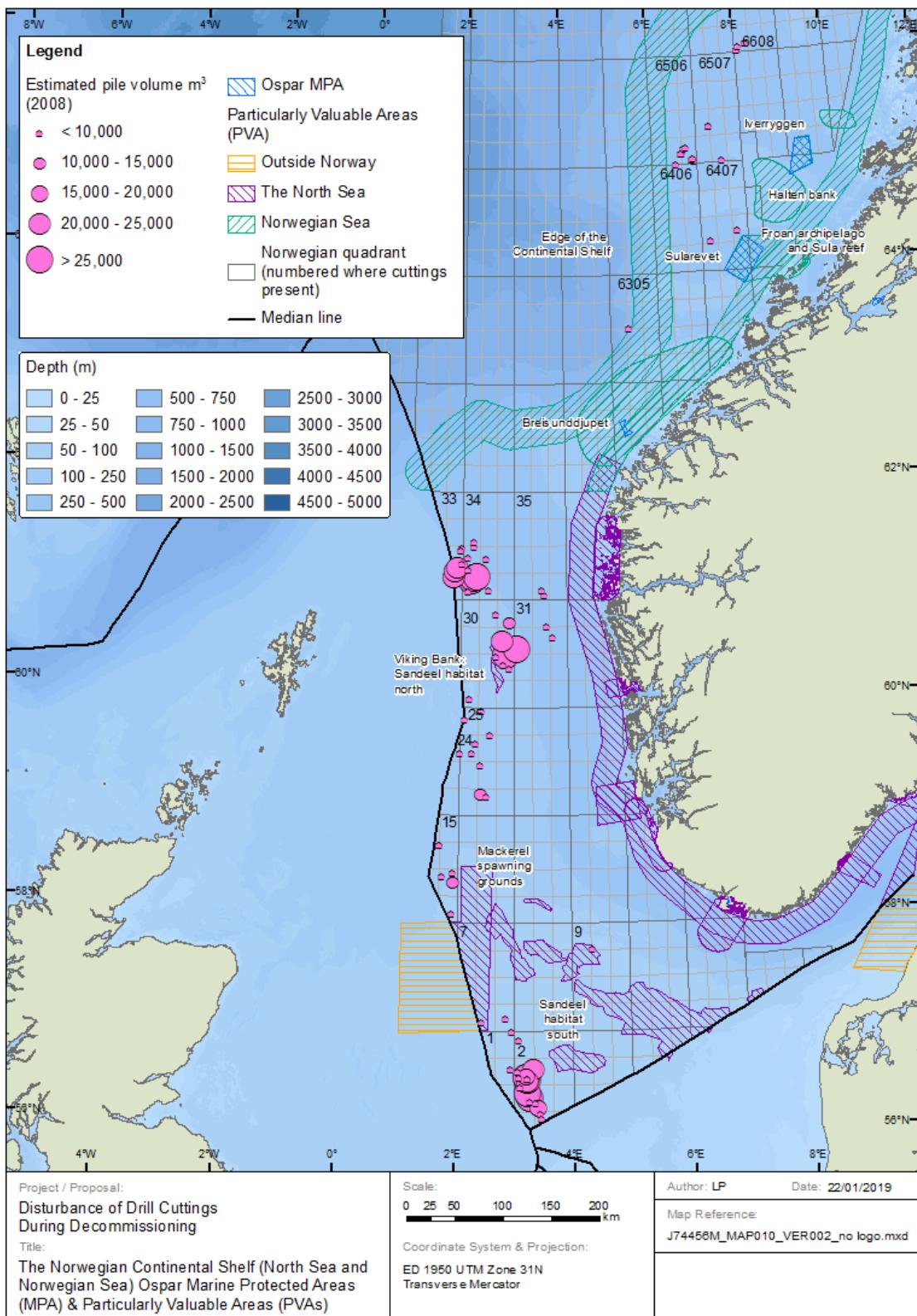


Figure 4-2 Location of protected habitats relative to cuttings piles, NCS

Further details are given in Tables 4-1 and 4-2.

Table 4-1 Protected areas in UK waters containing or in close proximity to cuttings piles

| Name of protected area | Status | Features |
|------------------------------------|--------|--|
| Faroe-Shetland Sponge Belt | NCMPA | Deep sea sponge aggregations Offshore subtidal sands and gravels Ocean quahog (<i>Arctica islandica</i>) aggregations Continental slope, with channels, iceberg plough marks, prograding wedges and slide deposits Sand wave fields and sediment wave fields |
| East of Gannet and Montrose Fields | NCMPA | Offshore deep sea mud Ocean quahog (<i>Arctica islandica</i>) aggregations |
| Norwegian Boundary Sediment Plain | NCMPA | Ocean quahog (<i>Arctica islandica</i>) aggregations |
| Braemar Pockmarks | SAC | Submarine structures made by leaking gases (Annex I habitat) |
| Scanner Pockmark | SAC | Submarine structures made by leaking gases (Annex I habitat) |
| Fulmar | MCZ | Subtidal sand Subtidal mud Subtidal mixed sediments Ocean quahog (<i>Arctica islandica</i>) aggregations |
| West of Walney | MCZ | Subtidal sand Subtidal mud Sea-pen and burrowing megafauna communities |
| Fylde | MCZ | Subtidal sand Subtidal mud |
| Shell Flat and Lune Deep | SAC | Sandbanks which are slightly covered by sea water all the time Reefs |

Source: <http://jncc.defra.gov.uk/marineprotectedareas>

Note:

NCMPA Nature Conservation Marine Protected Area

SAC Special Area Conservation

MCZ Marine Conservation Zone

Table 4-2 Protected/valuable areas on NCS containing or in close proximity to cuttings piles

| Name of protected/valuable area | Status | Features |
|------------------------------------|--------|---|
| Iveryggen | MPA | Important nursery, juvenile, or spawning areas <i>Lophelia pertusa</i> reefs |
| Sularevet | MPA | <i>Lophelia pertusa</i> reefs |
| Breisunddjupet | MPA | Important nursery, juvenile, or spawning areas <i>Lophelia pertusa</i> reefs |
| Viking Bank: Sandeel habitat north | PVA | Habitat and spawning grounds for sandeels. Coarse sandy seabed. Important feeding areas for whales that feed on sandeels |
| Sandeel habitat south | PVA | |
| Mackerel spawning grounds | PVA | Areas where mackerel spawn and eggs and larvae drift. Spawn and feed near to surface and vulnerable to surface pollution. |
| Edge of the continental shelf | PVA | Area supports high biological production and diversity, large concentrations of fish and seabird species, and many coral reefs. |
| Froan archipelago and Sula reef | PVA | Key feeding area for seabirds and whelping area of grey seals. The Sula reef is a major <i>Lophelia</i> reef. |
| Halten bank | PVA | Important spawning ground for herring. |

Source: Norwegian Environment Agency (NEA), 2009 and NEA, 2012.

Note:

MPA Marine Protected Area

PVA Particularly Valuable Area (Norway)

The cold-water coral *Lophelia pertusa* is a relatively widely distributed reef-framework forming coral species found in the deep waters of the north-east Atlantic. The species provides habitat for a diverse and abundant assemblage of invertebrates and fish, including commercially valuable species. *L. pertusa* reefs are included on the OSPAR list of threatened and/or declining species and habitats (OSPAR, 2014).

High sediment loads in the water column (which could be produced during cuttings disturbance) are known to negatively affect adult corals, but impacts on the early life history stages are unknown. Järnegren *et al.* (2016) investigated the effects of a range of drill cutting concentrations (0.5–640 ppm) on larvae of *L. pertusa* at ages five days and 15 to 20 days. Increased sediment load for a duration of 24 hours caused significant larval mortality. The sensitivity of the larvae varied with age, with younger larvae significantly more susceptible to lower concentrations of drill cuttings than older larvae, while the older larvae were significantly more affected at higher concentrations. Five day old larvae were affected at a treatment concentration of 40 ppm. The larval cilia (which are used for locomotion) became clogged, preventing the larvae from swimming actively and ultimately causing mortality. Larvae of many species use cilia for swimming and feeding, so negative impacts of increased sediment concentrations may not be limited to corals.

Ocean quahog (*Arctica islandica*) is a widespread and very long-lived species, but is declining probably through disturbance from bottom trawling (OSPAR, 2010). Adult mortality could also take a long time to recover. As a mollusc it is relatively susceptible to oil pollution and as a filter feeder it is susceptible to the toxic effects of fine drilling solids.

4.8 Food Chain Impacts

The potential for the disturbance of cuttings piles to influence food chain contamination is primarily related to the increased exposure of lower trophic level species to contaminants (primarily bioaccumulative contaminants) that have been previously buried in the cuttings piles. During disturbance of a cuttings pile, there will be a brief period of re-oxygenation but the re-deposited pile is expected to behave in a similar way to existing cuttings piles and therefore potential impacts from disturbing cuttings piles during decommissioning are expected to be similar.

Hartley *et al.* (2003) made a comprehensive assessment of the potential for bioaccumulation and food chain transfer of organic and inorganic contaminants in cuttings piles based on data from the North Sea and the Gulf of Mexico. Studies summarised in Hartley *et al.*, 2003, showed that the metals associated with cuttings piles on the sea floor are mostly in solid, poorly soluble forms. Small amounts of some metals go into solution in sediment pore waters in the subsurface layers of the cuttings pile as a result of diagenetic reactions in the sediments. In the oxygenated sediment layers at the surface of the cuttings pile, most metals are complexed with iron and manganese oxides. In the reducing subsurface layers, they precipitate with the sulphide produced by sulphate reducing bacteria. In a stable cuttings pile with little physical disturbance or bioturbation, it is probable that the fraction of the total cuttings pile metals that is in the dissolved, bioavailable fraction remains low. Because the redox potential discontinuity is at a shallow depth in the cuttings pile, it is probable that some dissolved metals diffuse into the overlying water column and escape from the pile. This efflux is not sufficient to raise the concentration of metals above natural background levels to an ecologically significant extent.

Many of the metals associated with cuttings are present as solid sulphide inclusions in drilling mud barite. These metals are not readily solubilised from the cuttings under either oxidising or reducing conditions and have a low bioavailability. Marine animals that are exposed in the laboratory or field to cuttings in sediments do not bioaccumulate significant quantities of metals (Hartley *et al.*, 2003). There is some evidence of a limited bioavailability of a few metals, such as Pb and Zn, from cuttings piles, but it is doubtful that metal bioaccumulation from cuttings piles is sufficient to cause harmful effects in marine animals living on or near cuttings piles. Modelling of cuttings pile relocation (disturbance and re-deposition) has also confirmed that potential impacts of metals are minimal.

Most of the hydrocarbons in OBM cuttings are aliphatic or saturated hydrocarbons, such as paraffins and cyclic alkanes (naphthenes), which generally have very low aqueous solubilities and are not considered very bioaccumulative and toxic, (Hartley *et al.*, 2003). There is very little information available about the bioavailability of aliphatic hydrocarbons or other organic chemicals associated with drill cuttings piles. The slow microbial biodegradation of hydrocarbons observed in OBM and SBM cuttings piles is indicative that the hydrocarbons in the cuttings are not readily accessible.

PAHs rarely represent more than about 5% of the OBM hydrocarbons, even in a diesel OBM. However, they tend to be persistent in the marine environment and are toxic to marine organisms (Neff *et al.* 2000a and b, as referenced in Hartley *et al.*, 2003) and are therefore the hydrocarbons of greatest concern in cuttings. Measured and estimated acute toxicity increases with increasing molecular weight. PAHs in solution in ambient water or pore water of sediments are much more bioavailable and toxic than those adsorbed to particles or associated with a nonaqueous phase liquid (NAPL), such as the emulsified oil phase in an OBM. The PAHs in sediments or a cuttings pile are distributed between the dissolved (pore water) and the particulate or NAPL phases of the sediment according to their relative affinities for the phases. This distribution can be expressed as an organic carbon/water partition coefficient (K_{oc}) or an oil/water partition coefficient (K_{ow}). Both partition coefficients are similar to the octanol/water partition coefficient (K_{ow}) that is used frequently to model bioconcentration of nonpolar organic compounds from water by aquatic animals. The K_{oc} and K_{ow} of PAHs increases and the solubility decreases with increasing molecular weight, indicating that the affinity of PAHs for the sorbed phase increases with molecular weight. Thus, the fraction of PAHs that

is in the dissolved, more bioavailable fraction of the sediment or cuttings pile decreases as PAH molecular weight increases.

In an undisturbed pile, high molecular weight PAHs therefore tend to be bound to sediment organic phases and have a relatively low bioavailability. Physical, energetic, disturbance of the pile would, however, be expected to dissociate PAH and disperse it into the water column attached to sediment microparticles that are available to filter feeders in particular.

As degradation of oil proceeds, UCM content increases in cuttings piles (and is therefore likely to be present in higher concentrations in piles disturbed during decommissioning) when compared with original discharge concentrations. However, there is a lack of data regarding its chemical character, toxicity, biodegradation (which may be slower than reference hydrocarbons) and biological pathways.

Overall, Hartley *et al* (2003), concluded that old cuttings piles were unlikely to have a significant food chain effect and did not pose a risk to human health. However, they also emphasized that very little direct information existed on physical and chemical pile structure and on contaminant uptake and accumulation in pile surface organisms, and the study did not refer to the disturbance of historic piles.

Food chain effects from undisturbed piles are predicted to be negligible. Pile disturbance could potentially cause a local impact resulting from the release of toxic materials such as sulphide and ammonia. However, such chemical effects would not be translated up the food chain.

Some fish species can acquire an abnormal taste (a “taint”) when exposed to petroleum hydrocarbons. Tainting has been shown to occur as a result of the disposal of large quantities of diesel based drilling muds (Stansby, 1981 as referenced in Cordah/Rogaland, 1998) and as a result of gross contamination. A series of studies in the Danish sector of the North Sea showed that LTOBMs caused taint in plaice and that the proportion of fish with taint increased as the amount of mud discharged increased. No correlation was found between taint and the hydrocarbon concentrations in the tissues (Rogaland, 1990 as referenced in Cordah/Rogaland, 1998).

A number of other studies were reviewed in the Cordah/Rogaland report, with most concluding that although hydrocarbons were sometimes recorded in the flesh of the fish, taint was generally not detected. In addition, accumulation of oil occurred in bottom feeding fish (e.g. cod) but not in pelagic fish caught in the same areas of contamination (various studies quoted in Cordah/Rogaland 1998). This was also noted by Monikh *et al.*, (2014, see Section 4.5).

Dabs (*Limanda limanda*) caught within 860 m of the Beatrice installation were found to contain elevated concentrations of hydrocarbons. Taint was described by several members of the test panel but not by a majority and the fish were not classed as tainted (McGill *et al.*, 1987). However, comparison with fish that had been caught at distances between 1,000 m and 1,900 m from the installation indicated that the fish caught close to the installation had a “tendency towards taint”, and it is reasonable to assume that fish closer to the pile than 860 m would be affected to a greater degree. Monikh *et al.* (2014) identified that the levels measured in fish from near the Beatrice installation were clearly the highest amongst a group of eight samples of fish muscle collected from contaminated sediments worldwide.

Since the direct evidence base is small, context is drawn from research on other oil releases, although these are considerably more severe in terms of the level of exposure and impact. In the Exxon Valdez spill, crustaceans and molluscs were significantly contaminated and were unsafe to eat following exposure to crude oil, whereas finfish were found safe to eat (Lawrence and Hemingway, 2003). In the Braer spill, *Nephrops* and bivalve molluscs including mussels and scallops were severely affected and restrictions on *Nephrops* and mussels continued from 1993 until 2000. After the *Sea Empress* spill,

fishing for crabs, lobsters and whelks was restricted for six months while fishing for other shellfish was restricted for over 18 months.

In order to protect human health, European Union (EU) Member States are required to adopt appropriate surveillance measures to verify concentrations of contaminants in foodstuffs. In Scotland, the Competent Authority is the Food Standards Agency (Scotland) (FSA(S)). Marine Scotland Science (MSS) carries out monitoring on behalf of FSA(S) to ensure that concentrations of contaminants, including PAHs and trace metals, do not exceed the permitted levels as defined in Commission Regulation 208/2005. Table 4-3 shows maximum allowable levels of PAHs, Pb and Hg in selected food products.

Table 4-3 Maximum PAH, Pb and Hg levels in selected food products (Scotland)

| Product | Maximum PAH level ($\mu\text{g}/\text{kg}$ wet weight) | Maximum Pb level (mg/kg wet weight) | Maximum Hg level (mg/kg wet weight) |
|---|---|--|--|
| Muscle meat of fish, other than smoked fish | 2.0 | 0.05 | 0.5 |
| Crustaceans, cephalopods, other than smoked | 5.0 | 0.5 (crustaceans) 1.0 (cephalopods) | Not listed separately |
| Bivalve molluscs (includes scallops, mussels, oysters etc.) | 10.0 | 1.5 | 0.5 |

Sources: Commission Regulation no 208/2005 amending Regulation 466/2001, Commission Regulation no 221/2002 and Commission Regulation no 466/2001.

There are also EU regulations regarding the quality of shellfish waters (Directive 2006/113/EC). However, as shown in Table 4-4, these do not give absolute limits on all contaminant concentrations. It is therefore not possible to relate predicted hydrocarbon or metal concentrations in the water column, for example, with an allowable concentration under the regulations.

Available information from environmental surveys do not provide sufficient information to conclude that there is no risk of these levels being exceeded locally following disturbance of a historic cuttings pile, although this seems extremely unlikely. Monitoring would therefore be prudent at sites where susceptible molluscs or crustaceans are harvested. In practice, the oil and gas operations causing cuttings pile disturbance may exclude local fishing and allow a period of natural recovery.

Table 4-4 Shellfish water quality: selected parameters

| Parameter | Value / Description |
|---------------------------------|---|
| Suspended solids (mg/l) | A discharge affecting shellfish waters must not cause the suspended solid content of the waters to exceed by more than 30 % the content of waters not so affected. |
| Dissolved oxygen (saturation %) | $\geq 80\%$ |
| Metals | The concentration of each substance in the shellfish water or in the shellfish flesh must not exceed a level which gives rise to harmful effects on the shellfish and their larvae. |
| Petroleum hydrocarbons | Hydrocarbons must not be present in the shellfish water in such quantities as to: — produce a visible film on the surface of the water and/or a deposit on the shellfish, — have harmful effects on the shellfish. Analysed by visual examination. |

Source: Directive 2006/11/EC on the quality required of shellfish waters

4.9 Potential Impacts on Fishing

Future decommissioning of installations could result in the fishing industry gaining access to areas of seabed that were previously within 500 m safety (exclusion) zones. As a result, cuttings piles may be exposed to over-trawling by fishing gear.

Trawling is a key mechanism of seabed sediment disturbance, resulting in suspension of material in a cloud of particles in the wake of the fishing gear. This can lead to the release of nutrients, pore water, hydrocarbons and metals from the sediment into the water column. However, a number of independent studies have found that fishing gear typically re-suspend the equivalent of 1 mm depth of seabed sediment. The contaminant content of the top (approximately 100 mm) layer of a cuttings pile is often relatively low, having leached into the water column over time and biodegraded. This suggests that the release of contaminants into the water column by over-trawling of cuttings pile is unlikely to be significant (OSPAR 2009/337 and update to OIC 2014 (Genesis, 2014)).

The amount of sediment disturbed depends primarily on the fishing gear and rigging type, the hydrodynamic conditions and the sediment type. Results suggest that scallop dredging gear has the greatest potential for sediment disturbance, but the majority of historic cuttings piles are not in scallop dredging areas.

The Fisheries Research Services (FRS, now Marine Scotland Science) conducted a study in the outer Moray Firth at an abandoned single well location drilled with a unique synthetic oil based mud that had a simple and readily identifiable gas chromatograph. The site was trawled over at varying degrees of intensity with a heavy monkfish trawl. Impacts were measured through a combination of water column sampling and tracking of artificial “surrogate” cuttings particles (OSPAR 2009/337). Modelling was also undertaken and modelled results correlated well with measured concentrations. The highest counts of tracer concentrations were found within 2 km of the well.

The results indicated that the dispersal of contaminated cuttings as a result of over trawling will not be of measurable environmental significance. Contamination will spread but not in amounts or at rates that are likely to pose serious wider contamination or toxicological threats to the marine environment. The act of spreading will, however, encourage aeration of material and enhance degradation.

5.0 METHODS USED FOR MANAGEMENT OF DRILL CUTTINGS DURING DECOMMISSIONING

Over the years, a number of general studies have been carried out (Centre for Environmental Risk, 1999; UKOOA, 2001 and UKOOA, 2002) to look at solutions for managing existing cuttings piles in the North Sea, as well as detailed studies to compare options for specific decommissioning programmes (examples discussed in Sections 5.1 and 5.4). A number of Environmental Statements for decommissioning carried out over recent years have concluded that the natural degradation or the “leave *in situ*” option, combined with long term monitoring of the seabed, represents BAT. However, in many instances, there is a need to disturb the cuttings pile in order to remove infrastructure during decommissioning, and it may therefore not be possible to leave a pile *in situ* without some localised disturbance of the pile. The main options for management of cuttings piles are summarised in Table 5-1.

Table 5-1 Methods for managing drill cuttings piles

| Method | Implications for decommissioning |
|--|--|
| Leave <i>in situ</i> for natural degradation. | In terms of general management of cuttings piles this is often considered to be the best option. Removal of infrastructure could result in some localised disturbance of the cuttings prior to leaving <i>in situ</i> . |
| Leave <i>in situ</i> plus capping. | Capping would have to be undertaken after the removal of infrastructure. Removal of infrastructure could result in some localised disturbance of the cuttings prior to leaving <i>in situ</i> . There are currently no proven methods of capping beneath existing installations and there are uncertainties regarding the stability of capped piles. Method has not been considered further by offshore operators. |
| Leave <i>in situ</i> plus bioremediation. | Removal of infrastructure could result in some localised disturbance of the cuttings prior to leaving <i>in situ</i> . Bioremediation solutions were investigated as part of the UKOOA drill cuttings initiative (UKOOA, 2002) but deemed unattractive in terms of timescales, feasibility and uncertainties relating to clean up concentrations achieved. Method has not been considered further by offshore operators. |
| Dispersal/redistribution offshore in the area immediately adjacent to the existing pile. | Relocation of the cuttings to neighbouring area resulting in localised disturbance of the seabed. |
| Removal from the seabed, followed by re-injection. | Disturbance during uplift of the cuttings, but less than during relocation of the cuttings. No further impacts at the seabed, therefore not considered further in this study. |
| Removal from the seabed, for treatment and disposal offshore. | Disturbance during uplift of the cuttings but less than during relocation of the cuttings. However, subsequent discharge of treated cuttings to the seabed would need to be carefully considered. |
| Removal from the seabed, for | Disturbance during uplift of the cuttings, but less than during relocation of the cuttings. No further impacts at the seabed, |

| Method | Implications for decommissioning |
|---------------------------------|---|
| treatment and disposal onshore. | therefore not considered further in this study. |

Re-injection and treatment and disposal onshore are outwith the scope of this report, and the options of capping or bioremediation *in situ* are not considered in any detail in this report as they are not considered to be feasible management options.

5.1 Natural Degradation (*Leave in Situ*)

5.1.1 Background Information

Natural degradation (*leave in situ*) effectively represents the simplest management option for cuttings piles, albeit one that may not be feasible if some or all of the cuttings need to be relocated to allow access to infrastructure during decommissioning.

The Implementation Report (OSPAR, 2009a) on OSPAR Recommendation 2006/5 identified that all cuttings piles assessed in the North Sea by Contracting Parties were below the thresholds established for determining where cutting piles may pose a significant environmental impact (see Section 2.4). The Implementation Report noted that there was no evidence of significant oil loss and the sites of discharge had recovered substantially since the cessation of discharges of OBMs, LTMOs and SBMs. As such OSPAR concluded that there was no need for further action (OSPAR, 2009b). Given that the environmental impact of existing piles was deemed to be insignificant, the general long-term approach to cuttings piles management is to leave them *in situ* to degrade naturally.

The UKOOA drill cuttings initiative studies (UKOOA, 2002) looked at a range of management options. No single management option was considered to be the best environmental strategy under all circumstances, but natural degradation and recovery was cited by most stakeholders as the preferred option. UKOOA (UKOOA, 2002) recommended that if natural degradation is chosen as the management option, a minimum of two monitoring surveys at three yearly intervals should be undertaken, with further surveys required depending on the outcome of the initial surveys.

There are two key issues associated with leaving a pile in place:

- How long will the contaminated cuttings pile remain on the seabed?
- How much contamination will leach out of the pile over time and how will this impact the benthic fauna?

As part of the UKOOA drill cuttings initiative, SINTEF undertook laboratory studies to determine the response of cuttings piles to wave and current action (SINTEF Fisheries and Aquaculture, 2001) in order to establish the likely behaviour of leaving a cuttings pile *in situ* to degrade naturally. Experimental facilities were set up using samples of cuttings piles from Ekofisk and Beryl which were subjected to a range of currents to determine threshold levels of shear stress for incipient motion and estimate the proportion of cuttings mobilised as suspended material and as bedload. Although only a limited number of experiments were conducted some broad trends were identified:

- The required current to initiate significant erosion of a cuttings pile is in the range 0.35 to 0.40 mm/s;
- Most eroded material is transported as bedload (there were virtually no suspended solids from the Ekofisk samples and approximately 10% suspended solids from the Beryl samples as the eroded particles were generally smaller at Beryl than Ekofisk);
- Indications were that the crust found on some samples at Ekofisk did not seem to inhibit erosion as no change in the behaviour of the cuttings was observed when the crust was removed; and

-
- It was not possible to establish experimentally whether there was a stage at which no further erosion would occur.

As can be seen from the SINTEF experiments relatively strong seabed currents are required to move the cuttings, conditions that are infrequent in most parts of the CNS and NNS. This suggests that left undisturbed, cuttings piles are likely to remain on the seabed for a considerable length of time.

Although all cuttings piles in the North Sea have been shown to be below the OSPAR thresholds for leaching of oil and persistence of oil on the seabed, there is still some loss of contaminants from the pile. Typically, aerobic biodegradation of hydrocarbons occurs only in the upper few centimetres of the pile. Anaerobic degradation may take place down to at least 20-50 cm, but only very slowly, with oil in the deeper parts of the pile remaining essentially unchanged (Breuer *et al.*, 1999). A number of large cuttings piles have now been surveyed in detail and further information on the Murchison cuttings pile is given in Section 5.1.2.

5.1.2 Case Study: Murchison

The cuttings pile at the Murchison installation was a result of over 20 years of drilling. Between 1980 and 2000 OBM's were used and discharged in line with permitted operations at the time. The cuttings pile is approximately 15.3 m in height, covering 6,840 m² and with an estimated volume of 22,545 m³ (BMT Cordah, 2013). The Murchison installation is a large steel installation (jacket weight 44,300 Te, topside weight 24,000 Te) and was therefore a potential case for derogation.

Concentrations of THCs in the surface of the pile ranged from 1,310 mg/kg to 10,100 mg/kg compared to background concentrations in the sediments which ranged from 1 to 450 mg/kg. These levels of hydrocarbons were not expected to result in either a rate of oil loss or persistence above the 2006/5 OSPAR thresholds. Metal concentrations were found to decrease with distance from the centre of the pile and are elevated in the inner area. PCB and APE concentrations were found to be above background concentrations and TBTs were above the OSPAR Environmental Assessment Criteria (EAC) threshold.

Faunal analysis indicated that there were fewer species within the cuttings pile than in the surrounding sediment. The species that were present in the largest numbers were the pollutant tolerant polychaete *Capitella capitata* and other tolerant species such as *Cirratulus cirratus*, *Chaetozone setosa* and *Ophryotrocha sp.*

The greatest benthic perturbation was recorded during surveys in 1987, 1990 and 1993. In 2011, a highly modified community was recorded at 250 m from the installation and only subtle differences in species composition were noted between 200 m and 500 m (Fugro ERT, 2011a).

Although the pile was predicted to be below the OSPAR thresholds indicating that natural degradation *in situ* would be the best environmental strategy during decommissioning, Canadian Natural Resources International UK Ltd (CNRI) did not know at the time of writing the Decommissioning Programme whether the jacket would require removal or whether the case for derogation would be accepted. If the jacket was required to be removed, it was considered that the entire cuttings pile would need to be moved to allow access to the installation footings. If the jacket footings remained in place, it was also noted that eventual collapse of the footings could disturb the pile in the future.

CNRI undertook a Comparative Assessment (CA) in line with OSPAR recommendations to examine the options for the management of the drill cuttings pile. Five options were considered:

- Recovery to installation or vessel, treatment of liquids offshore, disposal of solids onshore;

- Recovery to installation or vessel, onshore treatment and disposal;
- Recovery to installation for reinjection;
- Dispersion/redistribution offshore adjacent to jacket; and
- Leave *in situ*.

Modelling was undertaken for the dispersion option and the leave *in situ* option, taking into account subsequent disturbance by collapse of the footings. The CA concluded that leaving the pile *in situ* to degrade naturally was the best overall management option.

5.2 Leave *in Situ* plus Capping

Initial work undertaken by UKOOA indicated that *in situ* covering of drill cuttings was practical and that materials such as sand, gravel and rock armour could all be used. During Phase II of the drill cuttings initiative further work was undertaken by Dredging Research Ltd (UKOOA, 2002) and a number of limitations were identified.

There are currently no proven methods of construction beneath existing installations. There are also uncertainties surrounding the *in situ* geotechnical properties of drill cuttings and many piles may be only marginally stable. If capping was feasible, the armour layer would provide adequate short term protection against the impacts of severe storms, trawling and collapse of parts of partially-removed structures but it was not practical to provide guaranteed long-term protection against the cumulative effects of trawling, emergency anchoring by large vessels and repeated structure collapse events, particularly in the case of part-removed concrete structures, (UKOOA, 2002).

To date, there are no examples of the capping of cuttings piles in the North Sea.

5.3 Leave *in Situ* plus Bioremediation

Bioremediation solutions were investigated as part of the UKOOA drill cuttings initiative (UKOOA, 2002). AEAT investigated the potential and cost of treating contaminated drill cuttings on the seabed using a sub-surface reactor. Although the initial concept was to move the subsea bioreactor from place to place it was concluded (UKOOA, 2002) that this would be impractical and only possible after the installation jacket had been removed. An alternative process was developed where a remotely operated vehicle (ROV) and dredging pump are used to transport the cuttings from the pile to the reactor. The cuttings are treated in the bioreactor on the seabed. The rate of biodegradation is encouraged by the circulation of warm water, bacteria and oxygen from the topside facilities into the reactor. The cleaned cuttings are then discharged onto a specified location on the seabed. Bioremediation primarily targets hydrocarbon contamination.

UKOOA concluded that this was not an attractive option with reservations around timescales (5 to 20 years depending on cuttings pile size), endpoint hydrocarbon concentrations and practicalities. To date, there are no examples of the bioremediation of cuttings piles in the North Sea.

5.4 Dispersal/Redistribution on the Seabed

5.4.1 Background Information

There have been concerns about the potential for oil and other contaminants to be released into the marine environment, most notably as a result of the disturbance of cuttings piles during decommissioning activities, but also as a result of trawling (once the installation has been removed and the pile is within an area accessible to fishing). A number of cuttings relocation operations have now taken place in the UK and Norway, accompanied by extensive monitoring, which provide evidence of the potential impacts on the environment.

A range of methods (see Figure 5-1) are available to allow relocation of cuttings on the seabed, including:

- Suction dredging;
- Air lift with discharge into the water column;
- Water jetting;
- Use of a grab bucket;
- Use of a mass flow excavator; and
- Trawling.

During suction dredging the drill cuttings are removed from the site by suction through a pipe or a hose and then discharged at the seabed at a pre-determined site(s). A range of pumps and dredgers are commercially available. A large volume of water is entrained with the cuttings and care is required to avoid blocking of the discharge hoses. Suction dredging of cuttings is the most commonly used technique for removal/relocation of cuttings, and has been undertaken at both NW Hutton and Valhall, as discussed in the case studies included in this report.

Air-lift is a method where compressed air is injected into the lower end of a pipe. The air bubbles cause water to move through the pipe sucking material from the bottom of the pipe and depositing it from the upper end of the pipe. Although it is a known technique, a number of disadvantages have been highlighted: low manoeuvrability, vulnerable to obstacles and hard substrate, possible high particle dispersion since the outlet is high in the water column and the solids may follow the air bubbles/water flow further upwards and to the surface (DNV, 2017b). No reported uses of air-lift to move cuttings have been found.

Water jetting involves pressurized water being applied to the drill cuttings to suspend them into the water and thus moving them from their original position. The method is highly efficient at mobilising the cuttings and generally has good manoeuvrability but there is less control over the sediment settling area and particle dispersion (DNV, 2017b). An example of jetting, at the Hutton installation, is given in the case studies included in this report.

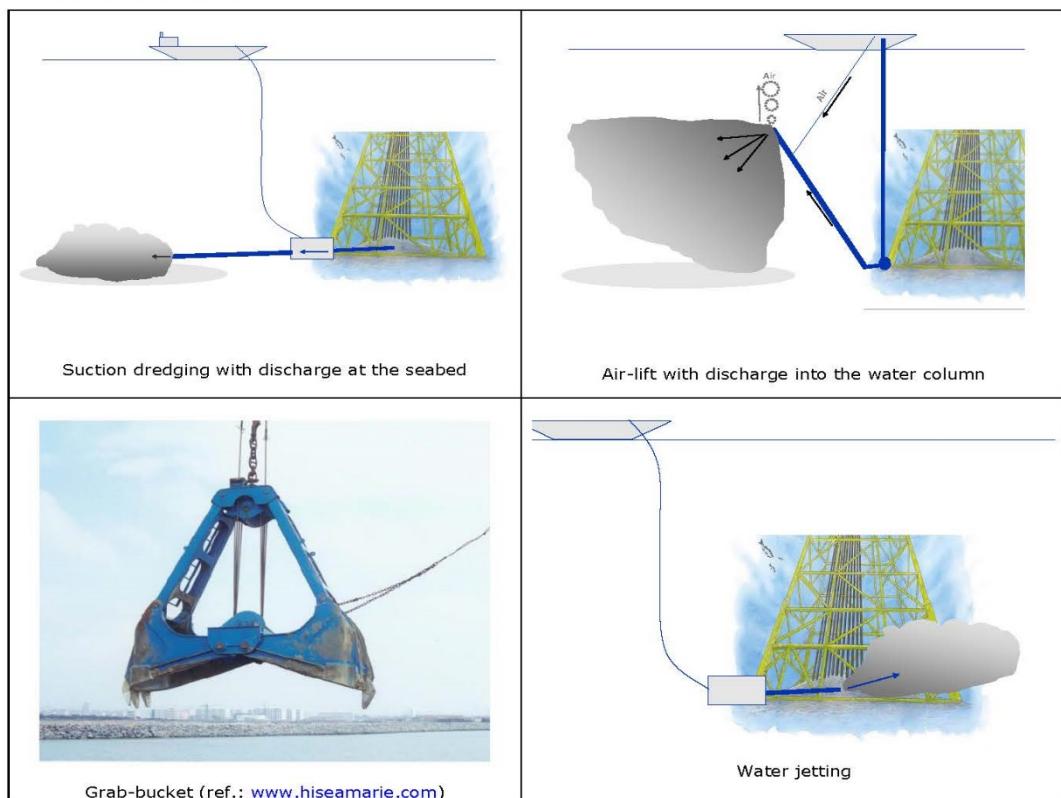
Drill cuttings can be removed mechanically using a grab-bucket. This method is less vulnerable to obstacles and provides good control of the disposal area and less mixing between water and drill cuttings (DNV, 2017b). However, it has low capacity, low manoeuvrability (it cannot be used inside a jacket structure for example) and only short transport distances are feasible. No reported uses of a grab bucket to move cuttings have been found.

Mass flow excavators are more commonly used for seabed debris clearance from pipelines, cables, jack-up leg etc. and for freespan correction. They can however, also be used for drill cuttings removal. They work by creating a vortex that lifts the seabed material and ejects the material out to the side. No reported uses of mass flow excavators to move cuttings have been found.

Given that all the methods described under “dispersal/redistribution” are effectively resulting in the movement of waste at sea, it is not clear whether this redistribution constitutes “dumping”. To date, such operations have been permitted by some state authorities, however, it would be useful to get a fuller understanding of the legal position taken by different Contracting Parties.

A range of case studies are given in the following sections to illustrate the potential impacts of dredging or jetting. No studies to date appear to have used the air-lift, the grab-bucket or the mass

flow excavator methods of relocation. One example of trawling (see Section 5.4.7) to disperse cuttings was found but this dated back to 1991.



Source: DNV, 2017b

Figure 5-1 Schematic view of different relocation methods

5.4.2 Case Study: North West Hutton

The UKOOA drill cuttings JIP specifically looked at drill cuttings recovery options (UKOOA, 2002) and as part of that project, a range of drill cuttings removal trials were carried out on the North West (NW) Hutton cuttings pile. Much of this work focused on looking at the ability of different systems to dredge and lift cuttings.

A total of 53 wells were drilled at the NW Hutton installation. All drill cuttings between 1983 and 1992 were disposed of on the seabed, accumulating under the installation to form a pile, approximately 5.5 m high, covering an area of 200 x 150 m and with an estimated volume of 31,000 m³.

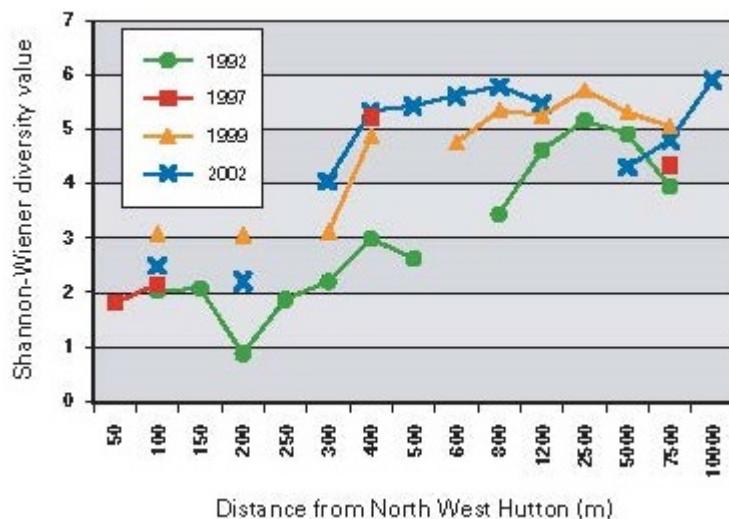
Surveys were undertaken at NW Hutton in 1992, 2002 and 2013 and the THC concentration were found to reduce over time. In the 2013 survey (Gardline, 2013), THC concentrations ranged from 13 mg/kg at 5,000 m from the installation to 5,379 mg/kg 100 m north of the installation. There was a high proportion of UCM in surface sediments suggesting that the majority of the hydrocarbons are well weathered. PAH contamination was found at stations up to 600 m of the installation.

Barium concentrations ranged from 812 mg/kg to 39,300 mg/kg, decreasing with increasing distance from the installation. Other metals (As, Cd, Cr, Cu, Hg, Ni, Pb and Zn) were above background concentrations, with contamination extending to approximately 200 m from the installation.

A change in fauna over time was also noted in the surveys, with a reduction of the pollutant tolerant *Capitella capitata* and a corresponding increase in *Owenia fusiformis* (more pollutant intolerant, and generally observed in undisturbed locations).

Overall the surveys identified that disturbance decreases away from installation, with the most disturbed zone extending to about 300 m in 1992 and to 150 m in 2013. Disturbance zones have

reduced both in extent and magnitude, confirming that the environmental footprint of the drill cuttings pile will reduce if cuttings are left undisturbed (Gardline, 2013). Figure 5-2 shows the faunal diversity increasing with distance from the NW Hutton installation as well as over time.



Source: BP, 2005

Figure 5-2 Change in macrofaunal species diversity over time

An offshore trial of a drill cuttings recovery system was carried out on the NW Hutton installation as part of the UKOOA JIP Drill Cuttings Initiative (UKOOA, 2002) and detailed monitoring was undertaken around the installation to quantify any disturbance of the pile and any release of contaminants to the local environment.

Results indicated that plume generation and drifting of re-suspended material was low during dredging operations. Levels of oil contamination on the disturbed cuttings were found to be similar to those that would have been expected from generic undisturbed oiled cuttings. It was concluded that during dredging operations the majority of the oil remains bound on cuttings and that the low level of oil in the water associated with the dredged material was possibly due to the large volume of water recovered with the solids. Little secondary pollution was discernible at a distance of 100 m from the dredging operations and no effects were seen at the surface.

During the offshore trials (UKOOA, 2000) a number of technical issues associated with dredging were identified, including:

- Obstruction of hoses;
- Retrieval of dredging tool and removal of debris is time consuming; and
- Hard sections of material in the piles are difficult to move with the dredger.

Major decommissioning activities took place between 2008 and 2010 (Gardline, 2013), however the installation footings have been left in place and therefore the drill cuttings pile has effectively been left *in situ*.

5.4.3 Case Study: Hutton Field

A total of 47 wells were drilled at the Hutton field generating an estimated pile volume of 24,252 m³ (ERT, 2009) or 18,000 m³ (Cordah, 2000). The Hutton Tension Leg Platform (TLP) was decommissioned in 2002/2003 (Kerr McGee, 2001). In order to provide access for removal it was necessary to move the cuttings pile; this was undertaken using a high pressure water jet. The cuttings pile was known to contain a combination of water based, diesel based, LTOBM and synthetic muds. The use of a high pressure water jet resulted in the suspension of significant amounts of oil contaminated cuttings in the water column and their subsequent re-deposition on the seabed (OSPAR, 2009b/337).

A post decommissioning sampling survey was carried out in 2003 and the results were compared to the 2001 survey results. The 2003 survey (ERT, 2004) indicated significant quantities of cuttings derived material within 300 m of the TLP. Beyond 1,000 m there was little or no evidence of cuttings derived components. In the 2003 survey, macrobenthic communities were shown to be highly modified up to 500 m from the centre of the Hutton site. This was similar to historical surveys which also show modified macrobenthic communities within about 500 m of the centre off the Hutton site.

The conclusions from the study were that disturbance of the cuttings pile due to decommissioning activities had no major effect on the spatial distribution of cuttings contamination or on the biological communities (OSPAR, 2009b/337).

5.4.4 Case Study: Ekofisk

The cuttings pile at Ekofisk 2/4A was approximately 4 m in height, covering an area of 3,722 m² and with an estimated volume of 3,951 m³ (DNV, 2017b). In order to cut the steel jacket, most of the drill cuttings would need to be relocated as well as 5,000 m³ of original seabed material. The plan was to use suction dredging and to discharge the cuttings near the installation. Cuttings relocation was estimated to take 70 days (DNV, 2017b). The seabed material would be dredged at a later date and no further details were provided in the Environmental Impact Study (DNV, 2017b).

The cuttings pile on Ekofisk 2/4A was known to contain significant oil contamination. Drilling took place between 1974 and 1995, and it is estimated that about 90% of drilling fluids used were water based, 7% were olefin based and 3% were ester-based compounds. Highly variable contamination levels have been measured in the pile. In the 2012 cuttings pile survey the highest concentration of THC was 73,100 mg/kg and mean concentration of 18,700 mg/kg (DNV, 2017b).

Seabed surveys have been undertaken as part of regional seabed monitoring around the installation in 1999, 2002, 2005, 2012 and 2014. The contaminated area around the pile (i.e. the area where THC is greater than 50 mg/kg) is decreasing: from 0.58 km² in 1999, to 0.25 km² in 2002 and to 0.1 km² in 2005. A slightly greater area was observed in the 2014 survey (0.19 km²) but this was noted to be due to changes in the method of calculation (DNV, 2017b).

In 2005 seabed fauna was found to be dominated by polychaetes (73%), echinoderms (10.9%) and molluscs (6.2%). In general, the bristle worm *Myriochele oculata* dominated the fauna, often followed by the bristle worm *Paraphinome jeffreysii* and the brittle star *Amphiura filiformis*. All of these species are indicators of sediment disturbance or pollution. Faunal disturbance was observed at 100 m from Ekofisk 2/4 A in the north east, south east and south west direction. The number of species varied from 65 per 0.5 m² at a station 100 m to the north west to 103 species 250 m to the south east. The number of individuals varied from 851 per 0.5 m² 100 m to the north west to 3,658 per 0.5m² 100 m to the north east. Indications in 2014 are that former discharges still influence the local fauna composition (DNV, 2017b).

Laboratory analysis of sedimentation, oil content, grain size distribution and leaching were carried out on a deep sediment core sample from the cuttings pile at Ekofisk 2/4A in 2005 (OSPAR, 2009b). Potential hydrocarbon losses resulting from theoretical dredging of 2,700 m³ of material were estimated based on hydrocarbons concentrations and leaching behaviour. Sedimentation tests showed that a large amount of material would sink one metre within a short time span. The heaviest fractions

would sink first and the lighter fractions (clay and silt) would sink last. Given that the THC will be more associated to the clay and silt this has implications with regards to the spreading of contamination during dredging.

The report concludes that leaching from dredging (water phase hydrocarbons) and leaching from a pile left undisturbed are small compared to the particle bound hydrocarbons. However, the conclusions were based on sedimentation and leaching tests undertaken on a single sample and it is possible that the rate of oil loss was underestimated (OSPAR, 2009b).

Drill cuttings relocation at Ekofisk 2/4A took place in May/June 2018 under a permit and 3,000 m³ of cuttings pile material was relocated locally utilizing suction dredging. Water column monitoring was undertaken during relocation operations and a seabed survey will be undertaken at a later stage.

The water column monitoring was undertaken at several stations around the installation at different distances in the prevailing current direction, suspended approx. 3 m above the seabed. Reference stations in undisturbed areas were also included. Instrumentation included membranes for inorganic and organic pollutants, sediment traps, turbidity meters, current meters and CTD (Conductivity, Temperature and Density) for monitoring of stratification.

The overall conclusions from the monitoring are (DNV, 2018):

- The impacted area from the dredging is generally limited to within 50 m of the dredging location; and
- There was less dispersion beyond 50 m distance but particles were recorded at a distance of between 100 m and 260 m.

The concentration of contaminants that settled in the monitored area and the settlement of resuspended particles will likely have local effects on the benthic fauna. Based on previous surveys the dispersed THC in the sediment surface will be subject to significant degradation. The concentration of water soluble contaminants was low and not likely to elicit any significant negative biological effects. The contaminants are likely to be attached to the particles and generally settle to the seabed rather than being dissolved in the water.

5.4.5 Case Study: Valhall

The cuttings pile at Valhall is approximately 12 m high, 70 m in diameter and with an estimated volume of about 21,000 m³. The cuttings were discharged between 1982 and 1991 and included OBM. THC levels are between 2 and 15%. Surveys show that significant contamination extends to less than 250 m from the centre of the pile although THCs are still above background levels at 500 m from the centre.

In 2014, approximately 3,500 m³ contaminated cuttings and seabed sediments were relocated (DNV, 2017b) to three approved disposal areas using a dredger. The dredging rate varied between 7 and 32 m³/hour.

A site specific local environmental monitoring survey was undertaken during dredging and further regional seabed monitoring was undertaken in May 2014. The seabed monitoring found dispersion of particles and contaminants at 200 m to 400 m in the water column and concluded that there could be impacts on organisms within the water column but that these would be temporary. There is anecdotal evidence that some oil sheens, generally between 1 and 10 m² in size, were observed during the dredging and relocation activities. Seabed conditions were poor both before and after the dredging and there was no major change. Low levels of contaminants were traced some distance from the operations but not in concentrations that could result in negative impacts on fauna.

5.4.6 Case Study: Albuskjell

The cuttings pile at Albuskjell 2/4F has an estimated volume of 3,600 m³ (DNV, 2008) although field measurements indicate a volume of 4,700 m³ (prior to relocation). The average THC concentration in the cuttings pile was 1,100 mg/kg.

Relocation of cuttings was undertaken in 2010. The majority of solids settled close to the exhaust from the dredger but small particles spread over a greater distance. The water column monitoring undertaken during the cuttings relocation demonstrated that the stations at 150 m and 250 m from the centre of the pile were more influenced than the reference station located at 800 m. Water 2 m above seabed had more particles than 10 m above seabed (DNV, 2017b). However, the level of contaminants in the water was not particularly high and was comparable to results from produced water discharge monitoring (DNV, 2017b).

Seabed monitoring was undertaken in 2011 and 2014. This showed that most of the sedimentation took place within 100 m of the site and elevated concentrations of metals were found at 100 m and 250 m but not at 500 m distance from the centre of the pile, although increased barite levels were detected 2 km away (DNV, 2017b). For THCs an increase in levels was identified following relocation, with concentrations reaching 100 mg/kg at 100 m distance compared to around 10 mg/kg prior to relocation. Beyond 100 m the THC concentration also showed some increase to about 10 mg/kg (DNV, 2017b).

The seabed monitoring undertaken in 2014 (DNV, 2017b) indicated a reduction in THC, barium and other measured parameters compared to the 2011 monitoring. The changes were most obvious in the near stations (100 m and 250 m).

Benthic fauna was also monitored in 2011 and 2014. but were found not to have been significantly influenced by the dredging of drill cuttings. Samples had a comparable number of species and individuals (DNV, 2017b).

5.4.7 Other examples

In 1987 water jetting was used to remove about 3,500 m³ of drill cuttings at the BP Magnus installation to allow subsea work to be undertaken (Centre for Environmental Risk, 1999). Oil was seen to float up to the surface and form a sheen on the sea. No further information is available and it is not thought that an environmental survey was carried out (Centre for Environmental Risk, 1999).

The Crawford (former gas installation decommissioned in 1990) cuttings piles were trawled in 1991. The piles were reported to be 10 to 15 m in diameter and about 0.5 m high. Concern was expressed about leaching of oil from these piles. Initial proposals were to leave the cuttings *in situ* to degrade over time but the Scottish Office Agriculture and Fisheries Division (SOAFD) recommended dispersion to encourage rapid biodegradation and alleviate concerns relating to fishing of the area once the installation had been decommissioned, (Centre for Environmental Risk, 1999). Trawling was carried out along a 500 m wide corridor using heavy chains. The area was trawled repeatedly until no more drag was felt. Two post trawling surveys were undertaken, one in 1991 and one in 1994. The surveys indicated that in the most heavily contaminated area around the wellhead THCs dropped from 1,100 mg/kg to 250 mg/kg between 1991 and 1994 (Centre for Environmental Risk, 1999). Indications from faunal analysis were that sediments across the area were recovering (secondary opportunist species numerically dominant in 1994).

At the Oseberg field, 350 - 500 m³ contaminated cuttings were relocated in 2005 (DNV, 2017b). The overall volume of cuttings in the Oseberg field is estimated to be in excess of 65,000 m³ (DNV, 2008). Significant changes in contamination levels were identified at 200 m but not at 250 to 350 m.

At Sleipner A, 2,500 m³ of cuttings, out of an estimated volume of 11,721 m³ (DNV, 2008) were relocated in 2011; no significant effects were noted at 250 m (the nearest monitoring station). Neither the Oseberg or Sleipner relocation campaigns reported an oil sheen during the dredging operations, (DNV, 2017b).

5.5 Offshore Treatment

Systems exist to treat cuttings offshore in order to reduce the oil on cuttings to a level at which they can be discharged. These systems are mostly based on thermal desorption.

During thermal desorption cuttings are heated to the distillation temperature of the base oil and this temperature is maintained until all the oil is vaporised. Most thermal desorption systems use a thermo-mechanical cuttings cleaner (TCC), also known as a hammermill system, which uses a series of hammer arms mounted on a central drive shaft rotating at high speed in a process chamber. Friction from the hammers and cuttings generates enough heat (240°C to 260°C) to evaporate the water and then the oil from the cuttings. The water and oil can then be condensed and separated for recovery. The processed powder typically contains less than 0.1% hydrocarbons by weight (Kirkness and Garrick, 2008). This is well within the regulatory limit of 1% set by OSPAR 2000/3 (OSPAR, 2000b).

Recovered cuttings powder is mixed with recovered water and seawater and pumped to sea via an overboard chute. It is necessary to mix the cuttings powder with the recovered water to form a slurry to avoid formation of surface flocs of powder due to trapped air. Recovered powder and water are monitored to ensure they meet relevant discharge limits.

The commercially available systems are efficient for the purpose of treating fresh cuttings generated during drilling operations, but have not been designed to deal with the large volumes of water and cuttings that would be generated by the recovery of cuttings from the seabed. Even if the water levels were to be reduced, it is unknown whether the systems would be suitable for the treatment of recovered cuttings material (OGUK, 2014) and additional treatment of the separated water might also be required.

5.6 Comparison of Environmental Impacts of Cuttings Management Options

Table 5-2 summarises the potential environmental impacts of the different cuttings management options, based on the literature review and case studies.

Table 5-2 Potential environmental impacts associated with cuttings management options during decommissioning

| Method | Natural degradation | Capping | Bioremediation | Dispersal | | Offshore treatment |
|------------------------------|---|---|---|--|--|---|
| | | | | Dredging | Jetting | |
| Energy/atmospheric emissions | None | Sand/gravel/stone cap placed using vessel with fall pipe. Only power required is for vessel(s). Comparatively low energy requirement. | Power needed for ROV, pumps and heater to circulate warm water around the bioreactor to raise its temperature. Comparatively high energy requirement. | Power needed for dredging/jetting operations. Energy requirement relatively high though not as great as for bioremediation or offshore treatment. | | Power needed for lifting cuttings, for thermal treatment and for treatment of associated water. Energy requirement high. |
| Seabed | Limited impacts given slow release of contamination from top layer of pile only. | No further impact on the seabed providing capping material remains in place. | Treated cuttings need to be discharged to chosen location on seabed. Short term impacts of smothering. | Cuttings displaced onto clean (or less contaminated) seabed with potential impacts on benthic fauna. Recovery likely within a few years. | Cuttings displaced onto clean (or less contaminated) seabed. Dispersal likely to be greater than using a dredger. Potential impacts on benthic fauna recovery likely within a few years. | Discharge of cuttings powder should be widely dispersed and have insignificant impact. |
| Water column | Limited impacts on water column given slow release of contaminants from top layer of pile only. | Capping prevents contamination of the water column providing capping material remains in place. | Resuspension of sediment during dredging to move cuttings to reactor likely to result in a localised plume. | Resuspension during dredging, localised plume, little 2ndry pollution discernible at 100m. In most cases no oil sheen detected at the surface. Backflushing to clear hose blockages can result in more resuspension. | More extensive resuspension of sediment during jetting. Oil sheens have been detected at the surface. | Resuspension of sediment during dredging to lift cuttings to surface, likely to result in a localised plume similar to dredging option. Discharge of treated water should have insignificant impacts. |

| Method | Natural degradation | Capping | Bioremediation | Dispersal | | Offshore treatment |
|--------------------------|---|--|---|---|---------|--------------------------|
| | | | | Dredging | Jetting | |
| Onshore impacts | None. | Quarrying and transport of capping material. | None. | None. | None. | None. |
| Fishing gear interaction | Residual contamination of seabed for many years. Potential for disturbance from fishing gear resulting in release of contamination and/or snagging of fishing nets. | Capping layer can be designed to withstand extreme storm events and short /medium term trawling events but impractical to design for indefinite protection against repeated trawling and anchor impacts. | Cleaned cuttings discharged to chosen location on the seabed. Potential for snagging of fishing nets. | Although some degradation will take place during relocation of the pile, contaminated core is likely to remain in situ for many years. Potential for disturbance from fishing gear resulting in release of contamination and/or snagging of fishing nets. | | Clean seabed no impacts. |

5.7 Summary of Experience to Date

Table 5-3 summarises the information collected on specific cuttings piles in terms of levels of contamination, degree of disturbance and the results of any post disturbance monitoring.

Table 5-3 Summary of cuttings pile relocation activities

| Installation | Size of pile | Type of cuttings Degree of contamination | Pile disturbance undertaken | Results of post decommissioning monitoring |
|--------------|---|--|---|---|
| Murchison | Height 15.3 m, Area 6,840 m ² , Volume 22,545 m ³ | THC 1,310 mg/kg to 10,100 mg/kg Metals mostly similar to background except innermost samples PCBs above background concentrations but lower than ERL APEs above background concentrations. No recognised assessment criteria. TBT above OSPAR EAC NB deepest samples only 0.5 m | CA concluded natural degradation <i>in situ</i> was the best environmental option. Derogation obtained to leave jacket footings in place. No extensive cuttings disturbance undertaken. | No disturbance monitoring undertaken. |
| NW Hutton | Height 5.5 m Area 200 x 150 m Volume 31,000 m ³ | THC 13 mg/kg at 5,000 m from the installation to 5,379 mg/kg 100 m Mostly UCM Elevated PAHs and metals. Barium 812 mg/kg to 39,300 mg/kg | Cuttings dredging trials undertaken as part of UKOOA study. On decommissioning, installation footings were left in place therefore cuttings pile left <i>in situ</i> for the long term. | Monitoring during cuttings disturbance trials showed drifting of re-suspended material was low during dredging operations. The majority of oil remains bound on cuttings and low level of oil in the water associated with the dredged material was possibly due to the large volumes of water recovered with the solids. Little secondary pollution was discernible at a distance of 100 m from the dredging operations and no effects were seen at the surface. |

| Installation | Size of pile | Type of cuttings Degree of contamination | Pile disturbance undertaken | Results of post decommissioning monitoring |
|--------------|--|---|--|--|
| Hutton | Height 4.5 m (Average thickness 2 m) Volume 24,252 m ³ | 32 wells drilled with a mix of WBM, OBM and SBM. Pile known to contain diesel based mud, LTOBM and synthetic muds. | Cuttings were removed in 2003 using jetting to allow access for installation removal. Volume unclear, but modelling was undertaken for a volume 3,900 m ³ . | 2003 survey indicated macrobenthic fauna to be highly modified to approximately 500 m but this is not significantly different to historical impact of operations and undisturbed pile. |
| Magnus | 27,864 m ³ | No details provided. | 3,500 m ³ moved in 1987 using water jetting. | Oil sheens observed at the surface. |
| Ekofisk 2/4A | Height 4 m Area 3,722 m ² Volume 3,951 m ³ | WBM and synthetic Contaminated area around the pile (where THC is greater than 50 mg/kg) is decreasing: 0.58 km ² in 1999, 0.25 km ² in 2002 and 0.1 km ² in 2005. Maximum THC 55,000 mg/kg. Fauna dominated by hydrocarbon tolerant species. | 3,000 m ³ cuttings to be moved using dredging. | Decommissioning/monitoring not yet undertaken. Cuttings may also have been moved using jetting prior to 1999 but no details are available. |
| Valhall | Height 12 m Area: 70 m in diameter Volume 21,000 m ³ | OBM. Elevated THCs. | 3,500 m ³ relocated by dredging in 2014. | Monitoring during and after dredging. Seabed conditions poor throughout. Particles and contaminants detected up to 400 m away. Anecdotal evidence of small surface sheens during dredging. |
| Albuskjell | Volume 3,600 m ³ | WBM. | Undertaken in 2010. Volume relocated and relocation method not known. | Monitoring in 2011. Elevated metals at 250 m but not at 500 m. Elevated THCs at 100 m. Water column impacted up to 250 m away. |
| Oseberg | Volume 65,000 m ³ | OBM, WBM and synthetic. | 350 to 500 m ³ in 2005. Relocation method not known. | Monitoring post relocation, date not known. Changes in contaminant levels |

| Installation | Size of pile | Type of cuttings Degree of contamination | Pile disturbance undertaken | Results of post decommissioning monitoring |
|---------------------|------------------------------|---|--|--|
| | | | | detected at 200 m but not at 250 m. No surface oil sheens during relocation. |
| Sleipner A | Volume 11,721 m ³ | OBM and synthetic. | 2,500 m ³ in 2011. Relocation method not known. | Monitoring post relocation, date not known. No changes in contaminant levels detected at 250 m (nearest station). No surface oil sheens during relocation. |

6.0 DISCUSSION

6.1 Overall Scale of the Disturbance

The total volume of cuttings in UK waters is estimated to be approximately 1,150,000 m³ for 174 installations (equivalent to 2.4 million Te), giving an average volume of a single cuttings pile in UK waters (ERT, 2009) of around 6,610 m³. Based on subsequent seabed surveys it is considered that this is an overestimate, with many of the installations where only a few wells were drilled having no cuttings piles. It should also be noted that where cuttings need to be disturbed, in many cases it will not be necessary to disturb the whole pile. In addition, some of the installations with significant cuttings piles are likely to be derogation cases, and it is therefore estimated that around 129 installations in the UKCS and a further 79 in the Norwegian CS are likely to be removed from the seabed with the potential for disturbance of all or part of the associated drill cuttings piles in the next 20 to 30 years.

Disturbance of cuttings drilled with WBM is not expected to result in any significant impact. The majority of piles, however, include cuttings drilled with NADF whose properties dominate the risks.

6.2 Releases of Oil Compared with other Anthropogenic Sources

The quantity of hydrocarbons present in cuttings piles was estimated to represent up to 4% of the total mass of the piles, and in UK the six largest oil-based mud piles were estimated to account for 24% of the total mass of oil in piles. The rate of release of oil from all North Sea piles is thought to be of the order of 330 Te/ year, which equates to less than 0.5% of the total annual input of hydrocarbon from all other sources (UKOOA, 2002). By comparison, the contribution of oil from produced water was estimated at around 4,900 Te in 2009, declining to around 4,000 Te in 2017(OSPAR, 2017b), approximately one order of magnitude greater than the estimate of oil to be released from cuttings piles. The quantity of oil spilled in recent years from oil and gas operations ranges from around 60 Te (2011) to approximately 650 Te (2014) (OSPAR, 2017b).

6.3 International Environmental Protection Standards

There is a range of environmental protection standards used across the OSPAR region in different contexts and industries.

OSPAR have developed a number of benchmark concentrations for heavy metals, PAHs and PCBs (see Annex 1). There is no OSPAR benchmark for THCs.

As described in Section 2.4, the only two OSPAR standards specifically developed in relation to drill cuttings are for:

- The rate of oil loss from the cuttings pile to the water column which should be less than 10 Te/year; and
- The persistence of the area of contaminated seabed which should be less than 500 km².year. This is based on the area of the seabed where contamination of oil in surface sediments is above 50 mg/kg and the rate at which this area reduces.

6.4 Expected Environmental Impacts

Environmental impacts resulting from deposition or re-deposition of cuttings include smothering, grain size changes, deoxygenation and toxicity, which in turn can result in changes to the plankton, the benthos and other organisms.

The time needed for sediment to recover following deposition of mud and cuttings is influenced by a number of processes (Rye *et al.*, 2001):

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- The depth of deposition;
 - Particle size;
 - The rates of biodegradation of organic chemicals in the sediment;
 - The resuspension and redistribution of matter on the sea floor due to currents and wave action; and
 - The time for recolonization of the biota after disturbance on the sea floor.

Based on the case studies reviewed the majority of impacts from cuttings piles are noted within 100 m of the centre of the pile and generally beyond 500 m there is little discernible impact. A similar range of impacts have been noted following pile redistribution.

The evidence indicates that short term uptake of contaminants in zoobenthos is to be expected, including crustaceans and molluscs. Demersal fish that feed on the zoobenthos may take up contaminants in the short term, but they are likely to be able to metabolise oils quickly and are unlikely to be significantly affected in the medium or long term.

Crustaceans and molluscs appear to be at most risk from burial and from persistent oil in the sediments. This indicates that at sites where susceptible molluscs or crustaceans are present, techniques that minimise resuspension of cuttings would be favourable and represent BAT/BEP. While the evidence suggests that any effects would be localised, monitoring would be prudent if biota in the vicinity would be expected to be harvested in the following years. In practice, the oil and gas operations causing cuttings pile disturbance may themselves exclude local fishing and allow a period of natural recovery, such that there is little realistic prospect of significant contamination at the majority of sites.

6.5 Expected Socio-economic Impacts (Fishing Gear Interaction)

After decommissioning, the 500 m safety zone (exclusion zone) around an installation may cease to exist and therefore fishing could resume in the area.

Where cuttings are left *in situ* or relocated on the seabed there is the potential for trawling activities to impact and potentially disturb the cuttings at a later date resulting in snagging of nets (and in some cases contamination of nets), and release of contamination within the pile into the water column. There is also potential for some of the catch to be physically contaminated and fish and shellfish found in the area could also accumulate chemical contaminants in their tissues. Notably, PAHs are known to persist in shellfish, as filter feeding species appear unable to effect bio-transformation of these contaminants (FERA, 2012).

In the UK, the location of decommissioned structures will be indicated on offshore charts and in FishSAFE (FishSAFE charts offshore surface and subsea oil & gas structures on the UK Continental Shelf, www.fishafe.eu). Other measures are also possible, for example there is a 200 m fishing advisory safety zone around the decommissioned NW Hutton footings, and this will include the cuttings pile. In addition, a fishing exclusion zone could be created by the Food Standards Agency under Part 1 of the Food and Environmental Protection Act 1985 if there was concern about the quality of the fish caught when trawling through an area impacted by drill cuttings on the seabed.

6.6 Mitigation Measures

It is unlikely that significant ecosystem effects could result from disturbance of cuttings piles. However, local effects are possible, and mitigation may therefore be relevant.

The principal mitigation measure to minimise impacts would be to leave the material *in situ* to degrade naturally. However, this may not be an available option if access is required to remove facilities during decommissioning.

The aim should therefore be to minimise disturbance through the choice of decommissioning technology. For example, the use of internal cutting methods to release jacket legs from their foundations would result in much smaller volumes of cuttings being disturbed than the use of external cutting methods.

The choice of technology used for relocating cuttings can also help reduce impacts. Suction dredging for example produces impacts that are more localised in the water column and surrounding seabed than jetting, and impacts from physical ploughing produces even more localised water column impacts. However, in many cases physical constraints (i.e. the configuration of the cuttings pile and installation infrastructure) may dictate the selected method and physical ploughing is unlikely to be suitable in congested areas.

Where cuttings disturbance is unavoidable, there should be a case by case assessment of the proposals to take into account any environmental and socio-economic sensitivities.

6.7 Monitoring

Options for monitoring the impact of disturbance of a cuttings pile should be considered on a case by case basis. In some cases, there may be little justification for marine monitoring, either because the components of ecological value are unlikely to be significantly affected by the changes, and/or because the disturbance activity is very small in scale, such as would be required to expose specific structural components for removal.

There may be situations, however, where the risk profile is greater, through a combination of a larger scale disturbance such as moving the majority of a large historic pile, a more sensitive environment or adjacent protected habitat (e.g. cold water corals), or a potential impact on seabed fisheries in the following months or years for specific species. In these cases, monitoring is likely to be of value.

Demersal fish over 500 m from an active cuttings discharge have been shown to have elevated levels of PAH. Taint in such fish appears to be weakly correlated with PAH content. Several references conclude that risks to fish are mainly via PAH uptake and that they are able to metabolise PAH efficiently; therefore, long-term monitoring is unlikely to be relevant, and short-term uptake over weeks or months is often mitigated by the exclusion of fisheries from sites of cuttings pile disturbance.

Where pre and post monitoring is recommended, measurements of turbidity, sampling of the water column, seabed sediments and the benthos may be appropriate in order to assess potential impacts on the environment. Where relevant, uptake in food species should also be considered.

Existing guidelines for monitoring the impact of oil and gas activities (OSPAR, 2017c and NEA, 2016) should be used as well as more specific guidance relating to drill cuttings such as OSPAR (2017a) and NOROG (2016). In areas where cold water corals have been identified specific guidance (DNV, 2013) should also be taken into consideration.

6.8 Data gaps

Key gaps in data that may affect conclusions are as follows:

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- A lack of specific studies on uptake of contaminants by food species present at cuttings pile sites;
 - A lack of data on the properties of UCM in cuttings piles which increases in proportion as biodegradation advances - its chemical character, toxicity, biodegradation (which may be slower than reference hydrocarbons) and biological pathways;
 - A lack of data on the evolution of oil from a cuttings pile into the water column and to the sea surface from pile disturbance. The few studies undertaken to date have focused on seabed concentrations of oil; and
 - Difficulty in relating seabed concentrations of oil, or degrees of exposure in the water column, to levels that would be considered safe in the context of fishing, particularly for crustaceans e.g. *Nephrops*, and molluscs. This difficulty can be managed through monitoring where risks are considered plausible.

Pre and post monitoring will help to build a body of evidence that will greatly improve the understanding of impacts from cuttings disturbance and help inform subsequent decommissioning activity. However, information available to date suggests that any impacts will be localised and insignificant, and that the disturbance could enhance the remediation of the contaminated cuttings.

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ANNEX 1 CHEMICAL ASSESSMENT CRITERIA

OSPAR has defined Environmental Assessment Criteria (EAC) as part of their Coordinated Environmental Management Programme (CEMP). EACs represent the contaminant concentration in the environment below which no chronic effects are expected to occur in marine species, including the most sensitive species. Therefore, concentrations below the EACs are considered to present no significant risk to the environment. EACs for a range of contaminants were proposed in 2004 and updated EACs for polychlorinated biphenyls (PCBs) were proposed in 2008. Further EACs continue to be developed for use in data assessments (OSPAR, 2000a, 2009e and 2009d). Where EACs are not available Effects Range Low (ERL) values developed by the US Environmental Protection Agency (US EPA) may be used instead. ERLs are defined as the lower tenth percentile of the data set of concentrations in sediment which were associated with biological effects. Adverse effects on organisms are rarely observed when concentrations fall below the ERL value. EACs and ERLs are not directly equivalent but ERLs can be used for the sediment assessment of contaminants as an interim solution where recommended EACs are not available (OSPAR 2009f).

Under CEMP, OSPAR has also defined Background Concentrations (BC) and Background Assessment Concentrations (BAC). BCs represent concentrations of substances at remote or pristine sites, free of anthropogenic inputs, which describe the environmental conditions that would be expected if certain industrial developments had not occurred. BCs for man-made substances are zero. BCs are based on historical and contemporary data and are applied across the OSPAR maritime area. There will however be substantial variability in the natural background concentrations of contaminants across the maritime area because of differing geological or oceanographic characteristics. Local conditions of the study area should therefore be taken into account when assessing the significance of any exceedance of a BC.

Where there have been difficulties in assembling a dataset from remote or pristine areas from which to derive BCs, low concentrations (LC) are used (OSPAR, 2009f). These are concentrations from areas considered to be remote but which could not be guaranteed to be free from the influence of long range atmospheric transport of contaminants.

BACs are statistical tools defined in relation to the BCs which enable statistical testing of whether observed concentrations can be considered to be near background concentrations. BACs are calculated according to the method set out in Section 4 of the CEMP Assessment Manual (OSPAR, 2008). The outcome of this method is that, on the basis of what is known about variability in observations, there is a 90% probability that the observed mean concentration will be below the BAC when the true mean concentration is at the BC. Where this is the case, the true concentrations can be regarded as "near background" (for naturally occurring substances) or "close to zero" (for man-made substances).

Tables A-1 to A-3 summarise OSPAR benchmark concentrations for metals, PAHs and PCBs.

Table A-1 OSPAR heavy metal benchmark concentrations

| Heavy metal | BC ¹ mg/kg dw | BAC ² mg/kg dw | EAC mg/kg dw | ERL mg/kg dw |
|-------------|--------------------------|---------------------------|--------------|--------------|
| Arsenic | 15 | 25 | - | - |
| Cadmium | 0.2 | 0.31 | 0.06 | 1.2 |
| Chromium | 60 | 81 | - | 81 |
| Copper | 20 | 27 | - | 34 |
| Lead | 25 | 38 | 2.2 | 47 |
| Mercury | 0.05 | 0.07 | 0.220 | 0.15 |
| Nickel | 30 | 36 | - | - |
| Zinc | 90 | 122 | - | 150 |

Sources: 1 OSPAR, 2009e and 2 OSPAR, 2009d

Notes: dw dry weight

BC and BAC both normalised to 5% Aluminium. EAC normalised to 1% TOC.

Table A-2 OSPAR PAH benchmark concentrations

| PAHs | BC µg/kg dw | BAC µg/kg dw | EAC µg/kg dw | ERL µg/kg dw |
|--------------------------|-------------|--------------|--------------|--------------|
| Naphthalene | 5 | 8 | 43 | 160 |
| Phenanthrene | 17 | 32 | 1250 | 240 |
| Anthracene | 3 | 5 | 78 | 85 |
| Fluoranthene | 20 | 39 | 250 | 600 |
| Pyrene | 13 | 24 | 350 | 665 |
| Benzo (a) anthracene | 9 | 16 | 1.5 | 261 |
| Chrysene | 11 | 20 | - | 384 |
| Benzo (a) pyrene | 15 | 30 | 625 | 430 |
| Benzo (ghi) perylene | 45 | 80 | 2.1 | 85 |
| Indeno (1,2,3-cd) pyrene | 50 | 103 | 1.5 | 2404 |
| DBT | 0.6 | - | - | 190 |

Sources: OSPAR, 2009e, 2009d and 2009f

BC, BAC and EAC normalised to 2.5% TOC

Table A-3 OSPAR PCB benchmark concentrations

| PCBs | BC/LC µg/kg dw | BAC µg/kg dw | EAC µg/kg dw |
|-------|----------------|--------------|--------------|
| CB28 | 0.0/0.05 | 0.22 | 1.7 |
| CB52 | 0.0/0.05 | 0.12 | 2.7 |
| CB101 | 0.0/0.05 | 0.14 | 3.0 |
| CB118 | 0.0/0.05 | 0.17 | 0.6 |
| CB138 | 0.0/0.05 | 0.15 | 7.9 |
| CB153 | 0.0/0.05 | 0.19 | 40 |
| CB180 | 0.0/0.05 | 0.10 | 12 |

Sources: OSPAR, 2009e, 2009d and 2009f

Notes: BC and BAC normalised to 2.5% TOC, seven PCB congeners shown are referred to as the International Council for the Exploration of the Sea (ICES)/Dutch/EC7



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