Oil & Gas UK
the voice of the offshore industry

THE MANAGEMENT OF MARINE GROWTH DURING DECOMMISSIONING

Contents

Key Findings	4
Introduction	6
Management of Marine Growth During Decommissioning, *BMTCordah 2011*	7
Causes and Consequences of Odours from Marine Growth Organisms, Institute of Estuarine and Coastal Studies, *University of Hull 2012*	78
Review of the Management of Marine Growth During Decommissioning, Comparative Assessment, *BMTCordah 2013*	112

Key Findings

The following Key Findings are from three separate reports commissioned by Oil & Gas UK between 2011 and 2013. These reports are included in full in this document and are titled:

1. *The Management of Marine Growth Report*, carried out by BMTCordah in 2011
2. *The Causes and Consequences of Odours from Marine Organisms*, by the Institute of Estuarine and Coastal Studies at the University of Hull in 2012
3. *The Review of the Management of Marine Growth During Decommissioning Comparative Assessment*, by BMTCordah in 2013

What is Marine Growth?

- After submersion in the North Sea, oil and gas structures are colonised by opportunistic marine organisms that adhere to the structure. These colonies are termed 'marine growth' and may form habitats containing a range of individuals and species on a single structure.
- In the North Sea, marine growth comprises a variety of soft- and hard-bodied organisms that occur naturally on hard substrata. These organisms include seaweeds such as kelp, anemones, hydroids, mussels, barnacles, tube worms, and soft and hard corals, for example, the cold water coral *Lophelia pertusa*.
- The composition of marine growth on a particular structure will depend on a variety of factors such as water temperature, water depth, wave action and the season in which the structure was installed.

Management of Marine Growth During Decommissioning

- During decommissioning, these colonised subsea structures are removed and transported to shore. Transportation can take several days during which time some marine growth organisms will dislodge or die off or mummify. Those organisms which are adapted to survive for periods out of the water for example, mussels, may survive several days especially in humid cooler conditions. This marine growth must be managed when it is brought onshore as part of the decommissioning project.
- There is no evidence found to date to suggest that non-native species occur on oil and gas structures in the North Sea and, therefore, the risk of transferring non-native species as marine growth during decommissioning is considered low.
- Onshore the management of marine growth is handled at licensed disposal yards. A survey of disposal yards in Norway and the UK in 2011[1] concluded that each yard has adopted marine growth management practices that are appropriate to local circumstances. These are relatively low-tech and effective and are accepted by regulators and local communities.
- Current practices for the disposal of marine growth at onshore yards include removal at the yard followed by landfilling or composting, or land-spreading. In some cases, the marine growth may be allowed to dry onshore and is then sent (still attached) to a recycling facility for steel smelting.
- The main constraint on the management of marine growth is the disposal routes available. The principal disposal route for the yards surveyed was landfilling. Identifying landfill or composting sites close by that are willing to accept marine growth remains a challenge for disposal yards.
- The disposal yards surveyed in 2011 indicated that the amount of marine growth they process for each structure was actually much less than the estimated weights supplied by operators. This was due to losses in the cutting and lifting process and natural drying of the marine growth during transportation.

---

[1] *Management of Marine Growth During Decommissioning*, BMT Cordah 2011, see page 7

Sources of Odour from Marine Growth

- A study was carried out in 2012[2] to identify the possible causes of odour from marine growth during disposal of offshore oil and gas structures. It concluded that the disturbance of low-oxygen layers and removal of putrefying organisms are the main sources of smell.
- Odour emitted from removing marine growth is more intense only under certain circumstances which may pose a nuisance. The marine growth removed from biologically productive areas of the North Sea or removed in highly biologically productive times of the year will tend to emit stronger smells as the natural fat and dimethlysulphide content of organisms will be higher.
- Environmental conditions also influence the odour; wet and slightly warm conditions will prolong decomposition and during this period the prevailing winds will determine the direction and extent of the area affected by the smell.

Comparative Assessment of Marine Growth Management Options

- A comparative assessment was carried out in 2013[3] to evaluate and compare the performance of offshore and onshore options for removing marine growth on decommissioned oil and gas structures. The following approaches were considered: removal at the onshore disposal yard, removal offshore at the field location and removal at an intermediate location such as a fjord, inlet or inshore waters.
- The removal of marine growth onshore at a decommissioning yard attained the top-ranked overall score in the Comparative Assessment study.
- The removal of marine growth onshore was strongest in four out of the five assessment criteria: technical feasibility, energy usage, safety and cost. This option did score the lowest for environmental and societal impact due to concern about the odour caused by decaying marine growth.
- It was emphasised during consultation with the disposal yards that odour management is proactive and largely successful. Mitigation measures include the rapid removal of marine growth and spraying of odour suppressants. Preventative measures which may be considered include the removal of the upper productive layers of marine growth offshore, particularly if there is a clear dominance of mussels.

---

[2] *Causes and Consequences of Odours from Marine Growth Organisms,* Institute of Estuarine and Coastal Studies 2012, see page 78

[3] *Review of Management of Marine Growth During Decommissioning, Comparative Assessment,* BMTCordah 2013, see page 112

Introduction

After submersion in the North Sea, oil and gas structures are colonised by opportunistic marine organisms that adhere to the structure. These colonies are termed 'marine growth' and may form habitats containing a range of individuals and species on a single structure. At decommissioning, these colonised subsea structures are removed and transported to shore and marine growth must be managed as part of the decommissioning project.

Oil & Gas UK facilitated a series of studies between 2011 and 2013 to collate knowledge and experience in decommissioning. This document contains three separate studies on the management of marine growth during decommissioning:

1. *The Management of Marine Growth Report*, carried out by BMTCordah in 2011, characterises marine growth and describes the common organisms found. It also draws on the experience of four disposal yards in Norway and the UK and outlines management practices currently used.
2. *The Causes and Consequences of Odours from Marine Organisms*, by the Institute of Estuarine and Coastal Studies at the University of Hull in 2012. This study evaluates and assesses the possible sources of odour from marine growth during decommissioning.
3. *The Review of the Management of Marine Growth During Decommissioning Comparative Assessment*, by BMTCordah in 2013, is a high level comparative assessment of three different options for the removal of marine growth: onshore, offshore and at a near-shore location.

Oil & Gas UK would like to acknowledge the valuable contribution made by the following groups and organisations in the preparation of this document: The Decommissioning Baseline Study Joint Industry Project Sponsors[4], the members of Oil & Gas UK's Decommissioning Task Group 2, BMTCordah and the Institute of Estuarine and Coastal Studies.

[4] The Decommissioning Baseline Study Joint Industry Project Sponsors are: Apache North Sea, BP Exploration Operating Company Limited, CNR International (UK) Limited, ConocoPhillips UK Limited, DONG E&P AS, Fairfield Energy Limited, Marathon Oil Decommissioning Services Limited, Mobil North Sea LLC, Shell UK Limited, Statoil AS, Talisman Energy UK Limited, Total E&P UK Limited, Venture North Sea Gas Limited.

A part of BMT in Energy and Environment

BMT Cordah

Management of Marine Growth during Decommissioning

Client: Oil & Gas UK Ltd
Report Ref.: A.CON.093
Date: 04 October 2011
Commissioned by Oil & Gas UK

Report Title	Management of Marine Growth during Decommissioning
Client	Oil & Gas UK Ltd
BMT Cordah Report Ref.:	A.CON.093
Version:	04 FINAL
Date of Release:	04 October 2011

BMT Cordah Limited,
Scotstown Road,
Bridge of Don, Aberdeen,
UK, AB23 8HG.

Tel: +44(0)1224 414200
Fax: +44(0)1224 414250
Email: enquiries@bmtcordah.com
Website: www.bmtcordah.com

CONTENTS

1 EXECUTIVE SUMMARY 12
1.1 Characteristics of marine growth 12
1.2 Overview of management practices 14
1.3 Limiting factors 15
1.4 Opportunities for improvement and further investigation 16
2 INTRODUCTION 17
2.1 Definition of Marine Growth 17
2.2 Study Background 17
2.3 Scope of Work 19
2.4 Overview of Methods 19
3 REVIEW OF MARINE GROWTH 21
3.1 Characteristics of Marine Growth on Offshore Structures 21
3.2 Illustrations and descriptions of marine growth species typically found on offshore platforms 22
3.3 Depth Zonation and Geographical Distribution 26
3.4 Weights of Marine Growth Waste 30
3.5 Fate of Marine Growth During Decommissioning 31
3.6 Non-Native and Protected Species 32
3.7 Key Findings 34
4 LEGISLATIVE FRAMEWORK 36
4.1 UK and Norwegian Environmental Legislation 37
4.2 Overview of relevant legislation 42
4.3 Key Findings 44
5 MANAGEMENT OF MARINE GROWTH........ 45
5.1 Information Sources 45
5.2 Current practices to manage marine growth 45
5.3 Yard 1 46
5.4 Yard 2 49
5.5 Yard 3 51
5.6 Yard 4 53
5.7 Previous Marine Growth Removal Strategies 55
5.8 Key Findings 56
6 ADVANCES, CHALLENGES AND OPPORTUNITIES........ 58
6.1 Potential Changes in Management Practices and Technologies 58

6.2 Supply Chain Factors 60
6.3 Regulatory Factors 61
6.4 Technology Improvements and Gaps 61
6.5 Potential Constraints 62
6.6 Key Findings 62
7 CONCLUSIONS 64
8 RECOMMENDATIONS 65
APPENDIX A: BMT CORDAH SCOPE OF WORK 70
APPENDIX B: QUESTIONNAIRE FOR DECOMMISSIONING CONTRACTORS 76

1 EXECUTIVE SUMMARY

This review of the management of marine growth during the decommissioning of offshore oil and gas installations was carried out by BMT Cordah Ltd for Oil & Gas UK Ltd under their Joint Industry Project (JIP) for the Decommissioning Baseline Study. It was prepared by drawing mainly on the experience of four decommissioning contractors who operate the facilities at which most UK and Norwegian decommissioning projects have taken place.

1.1 Characteristics of marine growth

The organisms that form the marine growth are opportunistic colonists of the artificial habitats provided by the man-made structures offshore. Marine growth comprises a variety of soft- and hard-bodied organisms that occur naturally on hard substrata. These organisms do not naturally inhabit the seabed at offshore areas where oil and gas fields are located in the North Sea, and where the substrata are predominantly sand, silt, mud and clay in varying proportions.

The predominant soft-bodied organisms are kelps and other seaweeds, plumose anemones, soft corals and hydroids. The predominant hard-bodied organisms are blue mussels, barnacles, solitary tubeworms and the cold-water coral, *Lophelia pertusa* (hereafter referred to as *Lophelia* in accordance with common usage).

During the initial period after installation, the composition of the marine growth will change as a succession of macroscopic organisms colonises the structure: firstly seaweeds and hydroids; then mussels; then anemones and soft corals; and then the hard coral *Lophelia* (on deeper parts of northern North Sea jackets). After the succession stages, 'mature' assemblages (combinations of particular 'dominant' types of marine growth) typically establish. With the exception of *Lophelia*, these are characteristic of all North Sea jackets:

- Mussel, seaweed and hydroid assemblage forming within 3 to 5 years after placement on parts of the structure at depths down to *circa* 15m – 40m but can extend to greater depths. Mussels typically cover from 10% to 100% of surfaces, and thickness vary from around 25mm to 350mm for multi-layered mussel beds. Seaweed typically cover from 25% to 100% of surfaces, and lengths vary from 15mm to 5m for large kelps.

- Anemones, soft coral and hydroid assemblage forming within 5 to 15 years after placement at depths below the mussel/seaweed and continuing through most of the remainder of the depth range. Anemones can occur as scattered individuals but typically form a blanket cover on up to 100% of surfaces; lengths vary from *circa* 50 mm to 450mm. Soft corals can occur as scattered individuals but typically cover less 50% of surfaces; lengths vary from *circa* 50mm to 300mm. Hydroids typically form a blanket cover in spaces between the other organisms; lengths vary from circa 10mm to 300mm.

- *Lophelia* has to-date been reported on northern North Sea jackets where it forms dome-shaped colonies covering up to 80% of surfaces at depths from *circa* 60m to 140m, with thicknesses up to 770mm. *Lophelia* was first reported on the body of the Brent Spar oil storage buoy (Bell & Bradshaw, 1999) and are relatively late colonists of offshore structures. The colonies observed have reached the size observed by the second or third decade after placement, and occur along with anemones, soft coral and hydroids. Hydroids tend to predominate on the surfaces of the deepest parts of structures.

The review (Section 3) deals with other characteristics of marine growth which can be summarised as follows:

- ***Lophelia* requires caution**: Special measures will be required before decommissioning if *Lophelia* is observed or suspected to be present on the jacket because Lophelia reefs are listed under the European Habitats Directive. These include a survey as part of the EIA for the decommissioning project and a CITES certificate if the installation bearing Lophelia is to be transferred between states.

- **Low risk of transfer of non-native species**: The risk of the transfer of non-native species of marine growth during decommissioning is considered to be low because no evidence has been found to-date that non-native species occur on platforms in the North Sea.

- **Weights of marine growth**: The weights of marine growth reported in pre-decommissioning documents usually represent the wet weight of the growth in air. Reported estimates of wet weight of marine growth in relation to jacket/support structural weight were: 10% for Miller (BP, 2009), 9% for Heather (Hustoft & Gamblin, 1995) and 6% for North West Hutton (BP, 2006; BMT Cordah, 2009). Decommissioning yards actually process much lower weights than these estimates due to losses during the cutting and lifting process and natural drying of the growth. Two of the decommissioning contractors surveyed reported 80% and 82% to 95% differences between the estimated wet weight and the actual weigh of marine growth that that the yard received. The corresponding tonnages received were 200 tonnes for a large steel jacket and 7 tonnes for a small steel jacket from the southern North Sea.

1.2 Overview of management practices

Figure 1 provides an overview of all of the management practices for marine growth during decommissioning used by the four yards interviewed. Section 6 provides diagrams showing the processes at each yard.

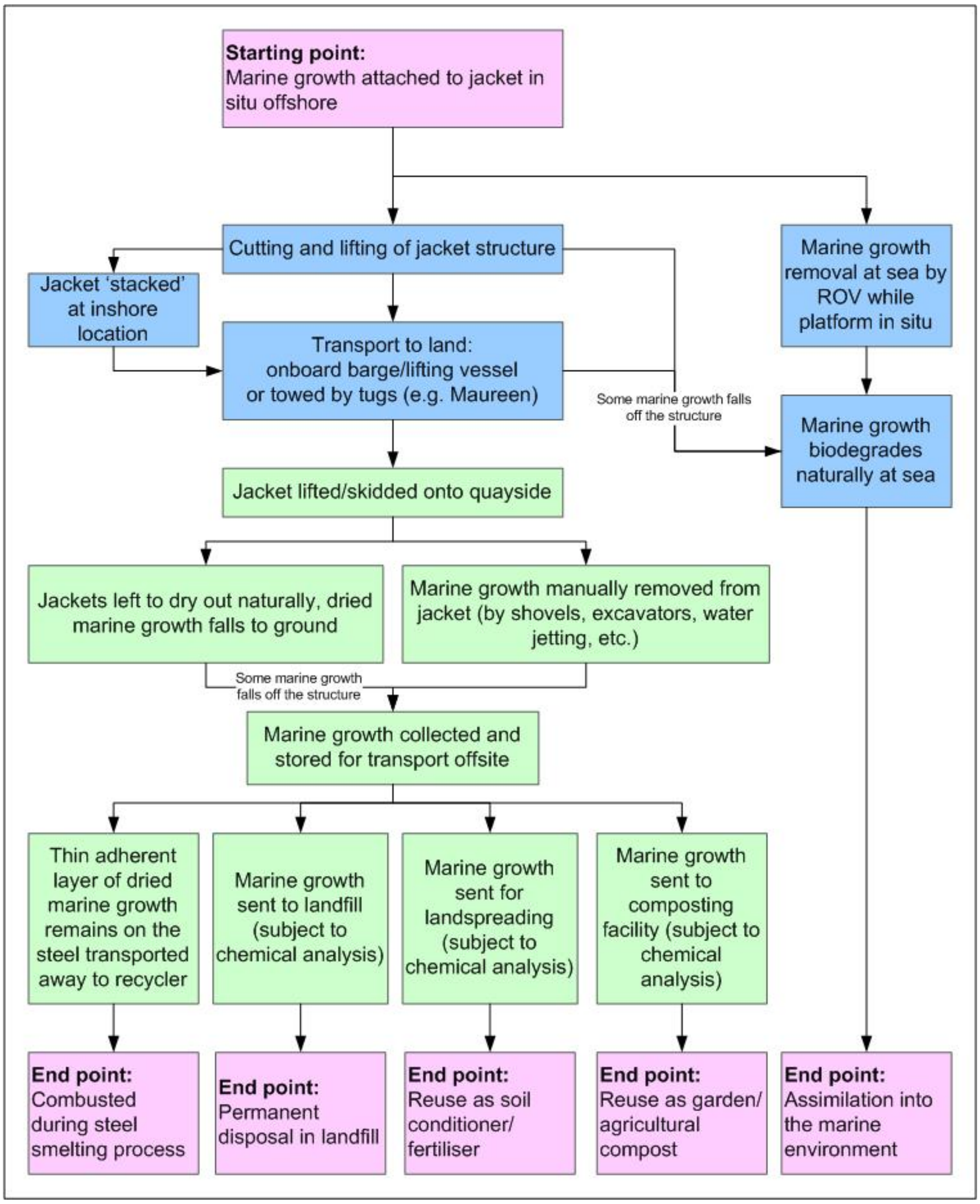


Figure 1: Overview of the processes for managing marine growth offshore (blue) and onshore (green). Also shown are the start points and end points of the management processes (pink).

Each yard has adopted marine growth management practices that are appropriate to local circumstances. These are relatively low-tech, effective and are accepted by the regulators and local communities. Section 6 describes the management practices of the individual yards and Section 7 reviews potential constraints and opportunities for improvement.

In Norway one of the yards receives structures where bulk removal of marine growth has been carried out *in situ* offshore, as opposed to simply removing growth to allow cutting and lifting operations. This work is carried out by the offshore contractors with whom the yard maintains close communication. In the UK, neither of the yards spoken to request that marine growth is removed offshore, however relatively small quantities are removed by the cutting and lifting contractors. If more widely practiced, offshore removal would reduce the weight of landed marine growth that the yards have to deal with, and ultimately reduce pressure on onshore disposal routes such as landfill and composting. However there may be significant technological, financial and regulatory restrictions on this practice. These factors are discussed in Section 7.

The current onshore disposal approaches (described fully in Sections 6 and 7) can be summarised as;

- removal at the yard followed by landfilling;
- removal at the yard followed by composting at a large, local municipal composting facility;
- removal at the yard followed by land-spreading; and
- natural drying of marine growth at the yard then sending the steel to the recycling facility with some growth still attached.

The last process, natural drying, involves the least effort by the decommissioning contractor in terms of physical intervention on the marine growth and with respect to pressure on final disposal routes, and therefore may merit further investigation as to whether this represents a Best Available Technique (BAT). However, as only one of the yards spoken to currently use this practice, further research is required into the suitability of this method for other yards and under other regulatory regimes.

1.3 Limiting factors

The main constraints on the management of marine growth are the disposal routes currently used. Landfill is currently the principal disposal route for marine growth from decommissioned structures in the UK and is also used in Norway (Section 6). Finding landfill facilities that are sufficiently close to the site and willing to accept marine growth is a challenge for the decommissioning contractors. A further problem is finding suitable alternative landfill sites to provide contingency back-up. These challenges may intensify as government policy on waste management is likely to drive further restrictions on the quantities of non-hazardous waste that can be disposed of to landfill (see Section 4.2).

The availability of suitable local composting facilities and sites for landspreading willing to accept marine growth is also a challenge, particularly in the UK. On the evidence of the interviews, none of the UK contractors have been able to compost their marine growth. One of the Norwegian yards uses composting as their main disposal route but only one local composting facility exists (Section 6).

Objections from stakeholders have the potential to cause issues for decommissioning yards, especially considering the potential odour and pest nuisances associated with marine growth. However to-date the decommissioning yards have engaged well with stakeholders and there have been no notable objections causing delays or otherwise (Section 7.5).

1.4 Opportunities for improvement and further investigation

The main recommendations as outlined in Sections 8 and 9 of this report concern the potential for further investigation into the management processes and final disposal routes which were considered to have the least environmental impact and the least financial/health and safety impact. It is recommended that:

1. The decommissioning contractors should be made aware of the findings of this study because these may benefit their industry.

2. Further analysis and investigation is necessary to establish the cost/benefit, applicability, environmental impacts, health and safety risks/benefits and legislative requirements relating to the bulk removal of marine growth at the offshore site.

3. Further analysis and investigation is necessary of the cost/benefit, feasibility, environmental impacts health and safety risks/benefits and legislative requirements relating to planned natural drying of marine growth at onshore decommissioning facilities.

4. Oil & Gas UK should facilitate a workshop with the decommissioning contractors to discuss the following issues which are likely to impact the effectiveness of the decommissioning supply chain:
    a. the physical capacity and availability of, and legislative constraints on landfill (in the EC Landfill directive), landspreading and composting facilities;
    b. new technology requirements of their industry; and
    c. knowledge sharing on the BAT options for the management of marine growth.

2 INTRODUCTION

This report provides an overview of the characteristics of marine growth on offshore structures in the North Sea, surveys current practices for managing marine growth during decommissioning and highlights where opportunities may exist for new approaches and technologies. It was prepared by drawing mainly on the experience of four decommissioning contractors who operate the facilities at which most UK and Norwegian decommissioning projects have taken place.

2.1 Definition of Marine Growth

'Marine growth' (or 'marine fouling') is the covering of marine plants, animals and other organisms found on those parts of man-made structures that are fully submerged in the sea or intermittently immersed during the tidal cycle.

Marine growth develops by exploiting hard substrata that are created artificially by the presence of offshore structures. These organisms do not normally inhabit the silts, muds, clays, sands and other sedimentary seabeds that lie far offshore around North Sea oil and gas fields.

During the decommissioning of offshore structures, marine growth constitutes a waste that has to be managed within the environmental legislative framework and the capabilities and capacity of the decommissioning supply chain.

2.2 Study Background

In relation to marine growth as a decommissioning waste, the Norwegian Climate and Pollution Agency's report on the Decommissioning of Offshore Installations (Klif, 2011) flags key issues that are important in the context of this review. It states that:

> *'Various marine organisms start to grow on platform legs and other subsea structures after they have been in the sea for only a few months, and the quantity of fouling is much larger after 30–40 years in the sea. Mussels, barnacles, benthic algae and sea cucumbers* [probably means 'anemones' because sea cucumbers are not major fouling organisms of offshore structures] [anemones] *quickly colonise installations, followed by soft corals and, after some years, colony-forming stony corals. The species that colonise a particular installation will depend on a number of factors such as recruitment potential, currents, water depth, distance from land and latitude.*
>
> *In some cases, the quantity of fouling organisms on underwater structures has been somewhat overestimated when calculating the weight to be lifted. However, it is clear that large quantities of organic material are involved. Much of the material has a very*

high water content (for example sea cucumbers and soft corals) and dries out/decomposes quickly, but calcareous shells and skeletons of organisms such as mussels and stony corals may be deposited in the recipient at the decommissioning facility, on land or in a landfill... Disposal of the material on land and composting is a possibility, but often results in odour problems.'

Decommissioning statistics collated for the purposes of this review show that the UK and Norway have more decommissioning experience than the other North Sea states. During the 35-year period from 1976 to mid-2011: 25 redundant steel structures (jackets, flare support structures, gravity bases and spars) were removed from the UKCS, and one redundant concrete structure was decommissioned in line with the derogation requirements of OSPAR. The corresponding figures for the Norwegian sector are: 20 steel structures removed and derogations for 3 concrete support structures. In contrast, during the same period, thirteen small gas jackets were removed from the Dutch sector and one was removed from the German sector. According to the Offshore Centre Danmark, no Danish installations were decommissioned (from the report of January 2010).

Over 60% of these decommissioning projects have been carried out at four sites: Able UK's facility at Teesside in the UK (6 structures); Veolia's (and formerly Swan Hunter's) facility at Tyneside in the UK (10 structures); AF Decom's facility at Vats in Norway (15 structures); and Aker Stord's facility at Stord in Norway (9 structures). As part of the dismantling operations, the same companies have also dealt with most of the landed wastes arising from the marine growth on decommissioned structures.

During the period from 2001 to 2010, a total of 17 platform jackets were decommissioned on the UKCS. It is predicted that decommissioning activity will increase substantially over the next decade, and will continue beyond 2050. Oil & Gas UK (2011) has estimated that around 100 jackets may be subject to onshore disposal, re-use, recycling or derogation during the years from 2011 to 2020, with an estimated peak number of 23 jacket removals taking place in 2019. This six-fold step change in decommissioning activity could potentially create significantly greater quantities of marine growth waste for the decommissioning contractors to manage. The imminent step change also provides a driver for an examination of current management processes and opportunities for new approaches and technologies.

2.3 Scope of Work

The scope of work for the study is as follows:

- to provide an overview of the current legislation relevant to marine growth issues;
- to summarise the marine growth typically encountered on the North Sea installations and how this varies with geographic location and water depth. Oil & Gas UK requested that Danish and Dutch infrastructure as well as facilities in the Irish Sea be included within the review's scope; however we were unable to source information on these installations;
- from contact with experienced 'dismantling practitioners' (i.e. organisations with a track record in receiving marine structures onshore as part of a decommissioning programme), to identify facilities and equipment required in the management of marine growth during decommissioning; and
- to identify decommissioning options for marine growth and, where appropriate, identify current practice and opportunities for improvement and further investigation.

2.4 Overview of Methods

This desk-based review was carried out on the basis of:

- a review of the public-domain literature provided in internet and library sources;
- reports on inspections of marine growth on offshore structures held by BMT Cordah;
- BMT Cordah's experience in the assessment of marine growth on offshore structures and environmental management for decommissioning projects; and

It should be noted that the findings and recommendations of this review reflect the information obtained from the four decommissioning yards on marine growth management.

2.5 Acknowledgements

BMT Cordah wishes to express its sincere thanks to the representatives of the decommissioning companies that provided help during this review.

3 REVIEW OF MARINE GROWTH

The descriptions of marine growth that this section provides are based on a variety of sources. These include published studies, reviews and guidance documents (Edyvean, Terry & Picken 1985; Forteath, Picken, Ralph & Williams, 1982; Picken, Ralph & Williams, 1984; Picken, 1984 & 1985; Sell & Picken, 1986; MTD, 1992; Sell, 1992); later publications relating to the discovery of the hard coral *Lophelia pertusa* on Brent Spar, North West Hutton and other installations in the northern North Sea (Bell & Smith, 1999; BP undated; BP, 2006; Gass & Roberts 2006; Roberts, 1999); and BMT Cordah's experience of marine growth assessment.

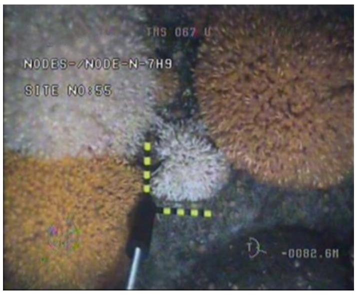
3.1 Characteristics of Marine Growth on Offshore Structures

The marine growth that is attached to offshore structures in the North Sea can be subdivided into hard-bodied and soft-bodied organisms. Hard-bodied marine organisms have rigid external skeletons formed by calcareous shells, tubes or calcareous body walls that have a higher density than seawater. This group includes mussels, barnacles, solitary tubeworms, aggregate tubeworms, hard corals, saddle oysters and bryozoans. On offshore platforms in the North Sea, the predominant organisms in this group are the blue mussel *Mytilus edulis*, the barnacles *Balanus crenatus* and *B. hameri*, the solitary tubeworms *Pomatoceros triqueter, Hydroides norvegica* and *Serpula vermicularis,* and the hard coral *Lophelia pertusa*.

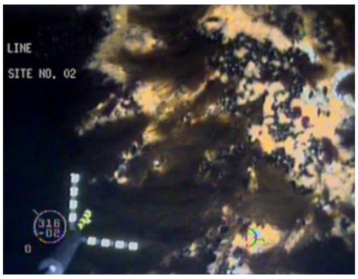
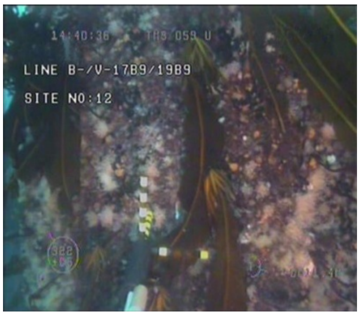
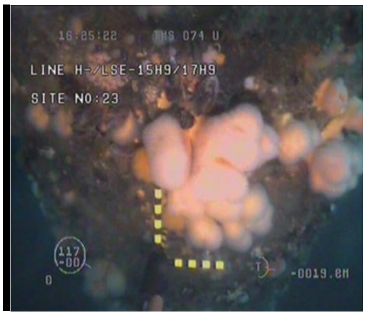
Soft-bodied marine growths are flexible and compliant, with a density approximately equivalent to that of seawater. This group includes kelp and other seaweeds, anemones, soft corals, hydroids, tunicates, and sponges. The predominant organisms in this group are the kelps *Laminaria digitata, L. hyporborea, L saccharina* and *Alaria esculenta*, a variety of other seaweed species, the plumose anemone *Metridium senile,* the soft coral *Alcyonium digitatum* and a variety of hydroid species.

In addition, there are conspicuous 'slime' films formed by bacteria, protozoa, diatoms and their exudates which entrap sand, silt, mud, rust and detritus. Section 3.2 provides concise descriptions of each type of marine growth.

3.2 Illustrations and descriptions of marine growth species typically found on offshore platforms

Marine species typically found on offshore platforms (common and scientific name)	Representative images	Description
Barnacles, *Balanus hameri*	 (AUMS, 1980) (possibly *Balanus hameri*)	Barnacles are exclusively marine life and are sessile. Hard, white and sharp-edged growths tapering from the base and firmly attached to the surface. The top of the barnacle is protected by a pair of plates (AUMS, 1980).
Bryozoans	 (AUMS, 1980) (possibly *Membranipora sp.*)	Also called moss animal. Colonial organisms that occur as thin, flat encrusting forms or as erect leaf-like colonies, or as calcareous coral-like structures. Rough to touch and usually dull greyish or sandy coloured (AUMS, 1980).
Diatoms	No clear images available	Variety of microscopic, single-celled marine algae.
Exudate	No clear images available	Gelatinous material that is produced by bacteria, diatoms and protozoa.
Hard Coral, *Lophelia pertusa*	 (BMT Cordah 2008) (Scale divisions are 2cm long)	Single or branching calcareous growth, hard and stony, firmly attached to the surface. Hard corals may occur in two types: (i) Single, columnar, types about 2-3 cm in diameter that look like a sea-anemone; (ii) A larger, branching form (AUMS, 1980).

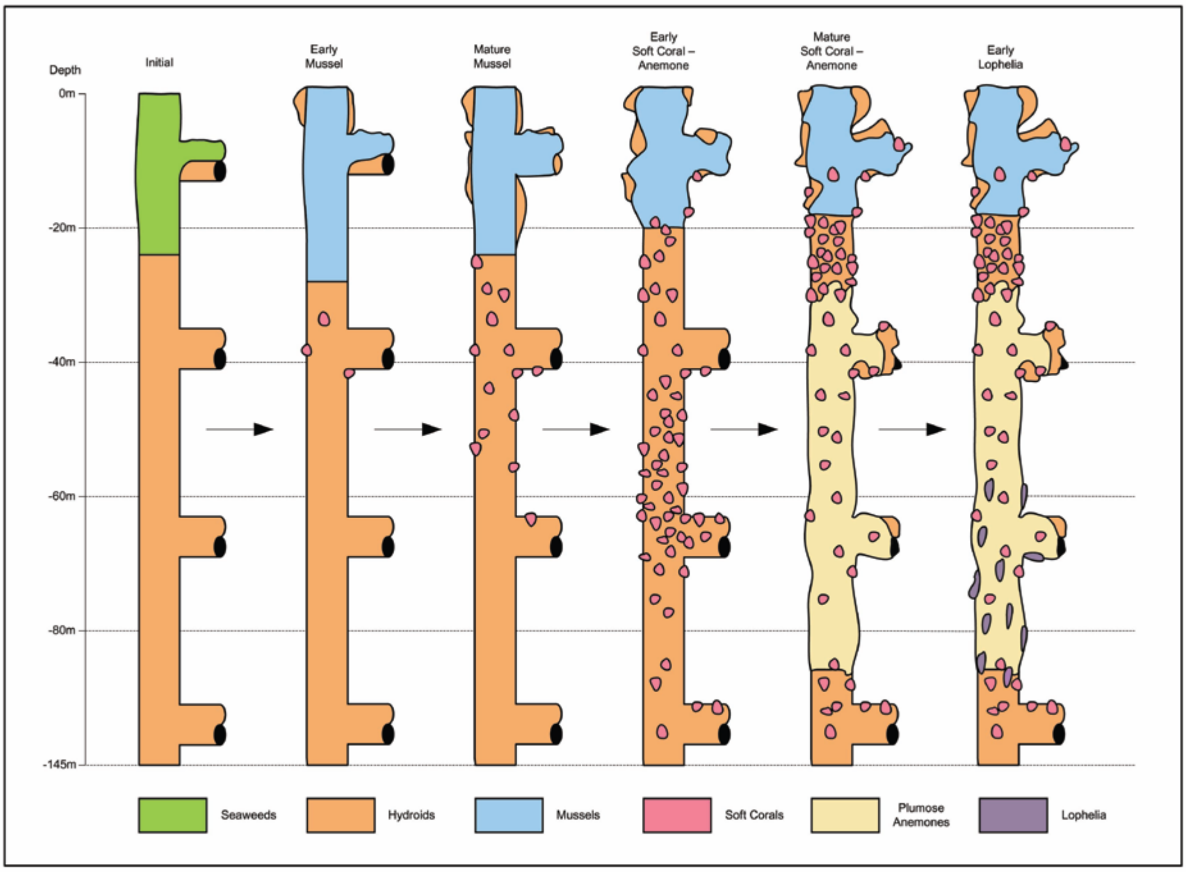
Marine species typically found on offshore platforms (common and scientific name)	Representative images	Description
Hydroids, *Obelia* sp., *Tubularia* sp. and *Eudendrium* sp.	 (AUMS, 1980)	Small plant-like colonial animals, forming feathery or flower-like growths, usually no more than 50 mm high, but occasionally up to 300 mm high. Any algal-type growth seen below 30 m will almost certainly be a hydroid (AUMS, 1980).
Mussels, *Mytilus edulis*	 (AUMS, 1980)	Bivalves attached to surface by flexible threads. They may occur individually, in clumps, or in dense encrustations. (AUMS, 1980).
Plumose Anemone, *Metridium senile*.	 (BMT Cordah, 2008) Sponges are pictured in-between anemones. (Scale divisions are 2cm long)	Soft columnar growths each with a circle of tentacles which withdraw when touched. Adhere to surface by a basal disc which secretes mucus (AUMS, 1980).
Protozoa	No clear images available	Microscopic, single-celled animals.
Saddle Oysters, *Anomia ephippium*	 (AUMS, 1980) (possibly *Anomia ephippium*)	Brittle, white, almost circular shell tightly pressed down to the surface. There are actually two shells, but the lower one is firmly attached, or even cemented onto the surface, and hidden beneath the upper shell. Up to 5 cm in diameter (AUMS, 1980).

Marine species typically found on offshore platforms (common and scientific name)	Representative images	Description
Seaweeds/Kelp (Algae), *Laminaria spp*, *Himanthalia elongata*, *Porphyra umbilicalis,* *Palmaria palmata,* *Ceramium sp.* *Alaria esculenta.*	 (BMT Cordah, 2008)  (BMT Cordah, 2008) (Scale divisions are 2cm long)	Brown: Tough leathery, brown seaweeds of various shapes, usually in bunches. Most have obvious bladders on the fronds – 300-600 mm. Green: Soft green plants, very variable in form, up to 300 mm in length. Either flat membranes – branched or unbranched, thin and delicate, or branched or unbranched threads, of long chains of long thin filaments. Red: Red plants, very variable in form, up to 300 mm in length. Either soft, filamentous or leaf-like growths, or stiff, branched growths often very dark and glossy (AUMS, 1980).
Soft Coral, *Alcyonium digitatum*.	 (BMT Cordah, 2008) (Scale divisions are 2cm long)	A fleshy lobed growth up to 200 mm long. When undisturbed the surface of the colony is densely covered with outgrowths (AUMS, 1980)

Marine species typically found on offshore platforms (common and scientific name)	Representative images	Description
Sponges	 (AUMS, 1980) (possibly *Halichondria panicea*)	Patches of soft coloured tissue spreading over and adhering to the surface. Very variable in colour and size, irregular in shape and penetrated by many small holes. Growth either both flat and encrusting (similar in appearance to sea squirts or corrosion product), or globular (similar in appearance to soft coral) (AUMS, 1980).
Tubeworms *Pomatoceros triqueter*, Serpula vermicularis *Hydroides norvegica*	 (BMT Cordah 2008) (Scale divisions are 2cm long)	Worms living in hard, white, calcareous tubes. Solitary forms have a tube 30-50 mm long, usually attached firmly to the surface for most of its length. Colonial types have long fine tubes which form domed colonies 100-300 mm in diameter. When undisturbed the worms extend a fine crown of tentacles from each tube. (AUMS, 1980).
Tunicates, *Ascidiella aspersa*	 (AUMS, 1980) (possibly *Ascidiella aspersa*)	Also known as sea squirts, they may be solitary or colonial in an encrustation resembling sponges. Individuals are white or cream, each with two openings and no tentacles (AUMS, 1980).

3.3 Depth Zonation and Geographical Distribution

Figure 3 provides a schematic outline of the development of marine growth on a hypothetical steel structure in the northern or central North Sea. During the initial period after installation, the composition of the marine growth will change as a succession of organisms colonises the structure. In succession, the principal colonists are: seaweeds and hydroids; then mussels; then anemones and corals; and the hard coral *Lophelia* (to date reported only on deeper parts of northern North Sea jackets). After the 'initial' stages, 'mature' assemblages of characteristic species of marine growth should become established. Although their composition could fluctuate, these assemblages are likely to represent a long-term pattern of predominant species on the jacket.



Source: Sell, 1992

Figure 2: Schematic overview of stages in the development of marine growth on a hypothetical offshore jacket in the northern or central North Sea (data held by BMT Cordah).

In general, the length of time that it takes for the mature stage to become established becomes greater the farther north the jacket lies. Many factors could influence this process, for example sea temperature, type or water mass and currents, temperature and depth tolerances of species, distance from shore or from other fouled structures, exposure to wave action, food availability, predation and competition between species, genetic differences, tolerance to scour and sediment deposition.

Typically, the 'Mature Mussel' stage could become established within 3 to 5 years of placement, the 'Mature Anemone/Soft Coral' within 5 to 15 years, and the emergence of the 'Early *Lophelia*' stage on northern North Sea jackets has not so far been reported until the second or third decade after placement.

Although patterns of marine growth can vary considerably even between adjacent offshore structures (Forteath et al., 1982), characteristic combinations of particular types of marine growth tend to occur within defined depth zones. Descriptions are given below of 'mature' assemblages within four depth zones:

Shallow-water assemblage: This zone is characterised typically by mussels, barnacles and solitary tubeworms, and kelp and other seaweeds. Mussels are bivalve (two shelled) molluscs that attach to substrata and each other by a network of strong threads (called a 'byssus'). They colonise in large numbers to form encrusting continuous or discontinuous single layers, multiple layers or clumps, and are often covered in seaweeds, hydroids and tubeworms. Kelps (large brown seaweeds) and other seaweeds also attach directly to the steel and concrete surfaces. Tightly packed mussels can sometimes occlude Jarlan holes on concrete jackets, and bridge gaps between the struts in conductor guide frames, and the anodes and members of steel jackets. Mussels may be scarce on some structures.

Multi-layered mussel beds can attain thicknesses in excess of 350mm. Barnacles and solitary tubeworms attach as scattered individuals or settle *en mass* to form encrusting layers or patches. Layers of tubeworms and barnacles rarely attain thicknesses above 15mm but multi-layered concretions can exceed 120mm. Seaweeds have a variety of forms, from fine filamentous types (15mm to 300mm long), through more robust types with flapping fronds (100mm to 1m long), to large kelps with a robust stalk and blade (leaf) (300mm to 3m long).

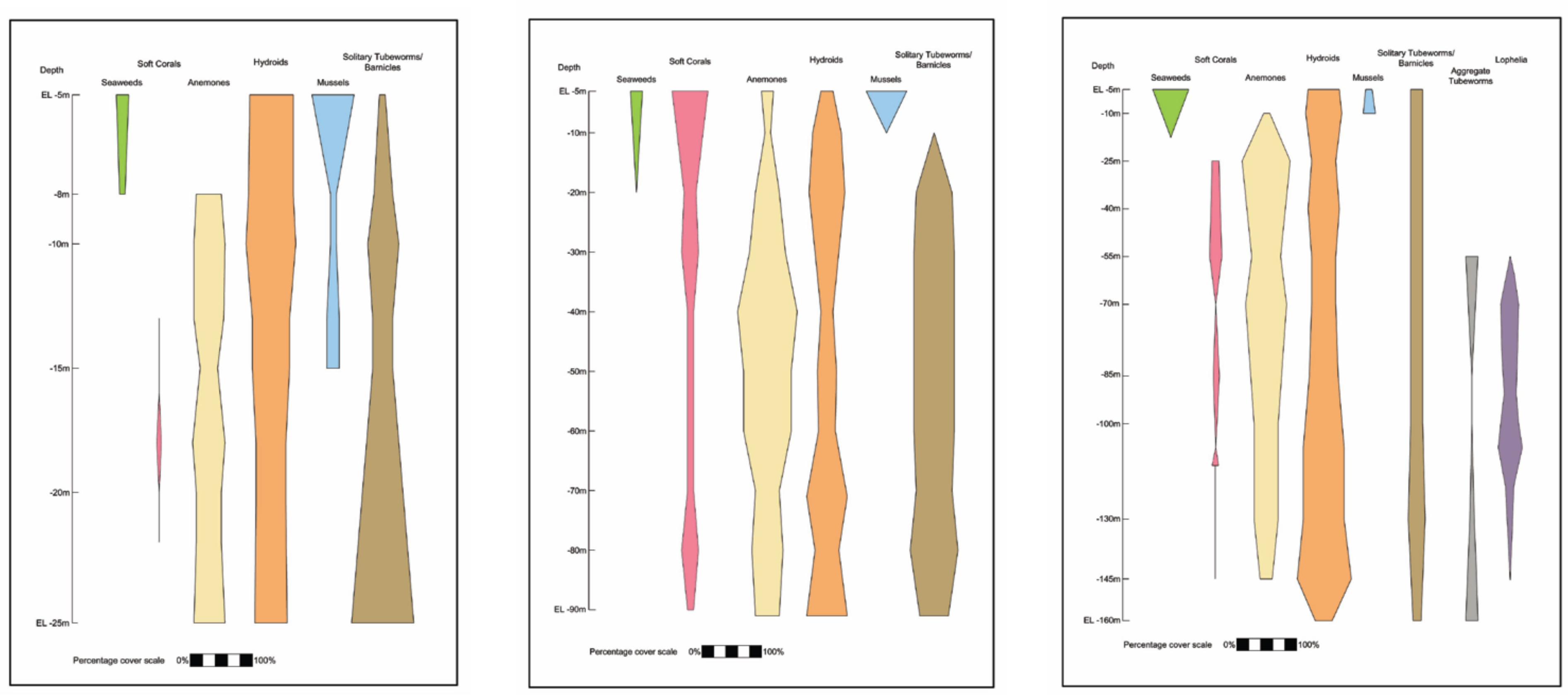
Upper mid-water assemblage: This zone is characterised typically by anemones, soft corals and hydroids. On some jackets, hydroids, solitary tubeworms and barnacles predominate. It is more usual, however, for plumose anemones, soft corals and hydroids to form a mosaic pattern. Plumose anemones are relatively large, long-lived cylindrical organisms (50mm to 450mm height) which can form a continuous blanket cover. Soft corals are also relatively large fleshy, lobed organisms (30mm to 300mm height) but tend to be less abundant than plumose anemones. Hydroids are colonial animals which form a blanketing turf-like cover on submerged surfaces (3mm to 150mm height).

Lower mid-water assemblage: This zone is characterised typically by anemones, soft corals, hydroids and the hard coral *Lophelia.* The distribution of anemones, soft corals and hydroids would be similar to that of the upper mid-water assemblage, but *Lophelia* would also be present. *Lophelia* is a columnar or branching, calcareous growth that is hard, stony and firmly attached to the substratum. It is a long-lived, large colonial organism that has the capacity to encrust significant proportions of the subsea structures in the depth range in which it occurs (> *circa* 50m). A recent subsea survey showed that colonies can attain thicknesses of 770mm (data held by BMT Cordah).

Deep-water assemblage: This zone is characterised typically by coarse hydroids, and scattered anemones, soft corals, tubeworms and barnacles. There is usually a gradual transition from the anemone dominated mid-water zone into this more sparsely covered deep-water zone. Upward facing surfaces of structural members often bear a covering of silt. The deep-water zone can be narrow or absent on anemone-dominated jackets in the southern North Sea.

Depth zonation: Figure 4 compares the depth distributions of the predominant types of organism in mature assemblages of marine growth on steel jackets from the southern, central and northern North Sea. This information was obtained from surveys of marine growth during structural inspection programmes. The figure indicates that:

- Mussel and seaweed dominated shallow assemblages typically occupied parts of structures at depths down to circa 15m. Occasionally mussel beds can form on deeper parts of the structure.
- *Lophelia,* the indicative species of the lower mid-water assemblage, was present between depths of circa 60m to 140m on the northern jacket only. Aggregate tubeworms were also present within this zone. These colonial organisms form dome-shaped concretions which are brittle and fragile.
- The anemone, soft coral and hydroid dominated mid-water assemblage was present throughout most of the remainder of the depth range.
- The hydroid dominated deep-water assemblage was particularly pronounced only on northern jackets (below the depths of 145m).



Source: Sell, 1992 and unpublished data held by BMT Cordah

Figure 3: Percentage cover by the main groups of fouling organism in relation to depth from subsea inspection data for steel jackets in the southern sector (left diagram), central sector (middle diagram) and northern sector (right diagram) of the North Sea.

3.4 Weights of Marine Growth Waste

The weight of marine growth material attached to a platform is a matter of importance for many decommissioning stakeholders. For those involved in the lifting and cutting of jackets this weight must be accounted for along with the weight of the object to be removed. Similarly this affects transportation of removed structures, putting constraints on the capabilities of barges, tugs, etc.

Decommissioning yards require estimates on the weight of material that they are to receive, firstly to ensure that their facilities are capable of handling such weights and volumes, and secondly so that they can find appropriate disposal or recycling routes with large enough capacity to handle removed material. This is especially important in the case of marine growth, as disposal routes local to decommissioning sites, for example landfill sites or composting facilities, may have limited physical or permitted capacity for this kind of material. Furthermore, decommissioning yards themselves may be restricted through regulation in the quantities of certain waste materials that they can store onsite.

To set the issue of the weight of marine growth in context, a paper on decommissioning planning for Heather Alpha in the northern North Sea estimated that the weight of accumulated marine growth of 2,000 tonnes (assumed to be a fresh wet weight) represented around 9% of the overall weight in air of this large steel jacket plus piles and conductors (Hustoft & Gamblin, 1995). The weight of marine growth on the NW Hutton platform was estimated at 915.9 tonnes (BMT Cordah, 2009), which equated to 6% of the weight of the jacket plus piles. The estimated wet weight of marine growth attached to the Miller jacket was 1,657 tonnes (BP, 2010), which equated to 10% of the weight of the jacket.

The experience of many decommissioning contractors so far has been that the amounts (masses and volumes) of marine growth that they expect to have to handle have been overestimated. For example, during the decommissioning of the 7 southern North Sea gas platform jackets, the UK yard estimated that they would receive 40 to 50 tonnes of marine growth per platform. In reality this figure was much lower, with an estimated 7 tonnes being received per jacket dismantled (, *pers com*). In Norway, a yard reported that the estimated weight of marine growth present on a large steel jacket would be in the region of 1,000 tonnes, however they ultimately disposed of around 200 tonnes of material (*pers com*).

The method of calculating the weight of marine growth (MTD, 1992), and losses as a result of removal and dislodgement during cutting, lifting and transportation of the jacket could be contributors to the overestimation. However, the principal driver for the difference between the initial weight estimates and the actual weights of marine growth to be dealt with at decommissioning yards is the weight of the water naturally retained by the marine growth.

The water content of marine growth is typically between 70-90% of its total weight (Tvedten, 2001), and the water content begins to decrease as soon as the structure has been removed from the sea and the natural drying process begins.

Depending on local weather conditions, the natural drying process can proceed quickly. It was estimated that, during the week it took to transport the Maureen Alpha platform from its site to the decommissioning yard, 20-60 % of the original wet weight of the marine growth was lost (Tvedten, 2001). If undisturbed and in dry conditions, the drying process will continue to reduce the weight and volume of marine growth until the material reaches its dry weight (which depends on the relative humidity of the air).

The figure which must be taken into account by decommissioning yards, at the time of disposal of marine growth, is the reduced weight resulting from the natural drying process.

3.5 Fate of Marine Growth During Decommissioning

The information provided in this section is based on information provided during the interviews with the decommissioning contractors and BMT Cordah's observations. On removal from seawater during decommissioning, the soft internal parts of the dead mussels will decay when moist or will dry out (desiccate) to a stable mummified state in dry conditions. Shells will remain attached to the structure by the byssus threads but may also drop off as the material dries out or by being dislodged readily during the handling, movement or cleaning of the structure. The hard plates of barnacles and tubes of tubeworms and the branched structures or columns formed by *Lophelia* can remain firmly attached to decommissioned structures. Soft internal tissue will desiccate or decay. Air-dried hard marine growth would typically comprise the attached dried-out shells of mussels, which could readily be scraped off, and the more firmly attached remains of the encrusting hard-bodied organisms (barnacles, tubeworms and *Lophelia).*

Seaweed and hydroids will fall off, decay when moist, or desiccate to a stable mummified state in dry conditions. Soft corals have a narrow point of attachment and are likely to drop off or be dislodged during the handling, movement or cleaning of the structure. Anemones have seawater-filled body cavities and decay when moist, but readily desiccate to a stable mummified state in dry conditions. Air-dried soft marine growth would typically form a thin dark brown layer which remains attached to the underlying steel or concrete.

If removal is carried out at sea, the detached marine growth will fall to the seabed or be dispersed by currents. The soft tissue of dead organisms will degrade naturally in the marine environment or be consumed by marine organisms. Shells and other calcareous material will remain on the seabed. A bulk release of marine growth to the sea could potentially cause the water quality in the vicinity of the release to deteriorate (initiated by the breakdown products of the dead marine growth). If this were to happen, however, the effect is likely to be localised and transient given the dispersive environment that exists offshore.

3.6 Non-Native and Protected Species

Non-native species: The transportation of decommissioned structures through North Sea waters presents a risk to the marine environment through the potential introduction of non-native species (i.e. species from outside their natural range that have established North Sea waters). The introduction of non-native species often has a negative impact on native communities. For example; the Acorn barnacle *Elminius modestus* was first recorded in UK waters in 1946 (Avant, 2007), by which time it had already spread along the southern coast of England (Crisp, 1958). Later surveys in the 1970s confirmed the spread of this species had reached as far as Shetland (Hiscock et al., 1978). This species has not only colonized areas not previously inhabited, but outcompeted endemic barnacle species such as *Semibalanus balanoides* (Bassingdale, 1964).

During the transportation of a decommissioned structure, the risk to North Sea marine environment can be categorised based on the following parameters:

- the presence of non-native species on the structure;
- the period of exposure of the marine growth to air during transport, and resultant mortality of marine fouling species;
- the capacity of non-native species to survive, colonise and out-compete native species on hard sub-strata along the transport route and at the final destination.

From 1979 to 1986, AUMS Limited (a predecessor of BMT Cordah) carried out analysis of the marine fouling found on steel and concrete jackets in the UKCS for a number of operators. Fouling was analysed using photographs taken by divers and ROVs and, importantly, samples obtained by divers. Individual fouling organisms were studied in the laboratory and identified to species level wherever possible. Several hundreds of samples were analysed from structures that had been in place for up to 15 years.

No species that was not native to the UKCS was found. All the species found on offshore structures were already known to be present on the European Continental Shelf, and were widely distributed in intertidal and sub-tidal habitats around the UK and in various parts of the North Sea.

Evidence from these surveys and samples therefore suggests that the transportation of structures from their present offshore sites to ports or receiving sites on the NE coast of Europe presents no risk of transferring non-native species. There is no evidence to indicate that there are non-native species on any offshore platform, and if the structure is only moved around the North Sea it will remain within the North Sea ecoregion (Spalding et al., 2007).

Additionally, mortality of marine growth exposed to air would occur during transport of jackets on barges. Tolerance to desiccation during transport varies widely between organisms. The blue mussel *M. edulis* has high tolerance levels to prolonged periods of exposure to air (Dare, 1974). The two sub-tidal species found lower on the structure, *A. digitatum* and *M. senile*, both exhibit limited tolerance to desiccation (Hiscock & Wilson, 2007; Budd, 2008). It is likely that sub-tidal organisms would suffer high mortality rates because these fully marine organisms would not be well adapted to prolonged exposure in air.

Protected species: The cold-water coral, *Lophelia pertusa* was observed on the Brent Spar oil storage prior to the reuse during decommissioning of its body sections as quay foundations at Mekjarvik in Norway (Bell & Smith, 1999). This reef-building organism had previously only been recorded on natural substrata in deep-water locations (mainly at depths from: 200m to 600m) such as the Norwegian Trench and Atlantic margin, or at shallower depths in fjords (shallowest depth: 39m). *Lophelia*'s presence has also been reported on a further 13 offshore structures in the northern North Sea (at depths from 59m to 132m) (Gass, 1996; Gass & Roberts, 2006).

Recognition that *Lophelia* reefs are listed as a Habitat of Community Interest (priority habitat for protection) under Annex 1 of the European Habitats Directive evoked a concern about habitat loss caused by the decommissioning of offshore installations. Consultation with stakeholders during the decommissioning of Brent Spar (1998) and North West Hutton (2008–2009; on which *Lophelia* was also found) ruled out the option of leaving *in situ* those parts of the structure that bore the *Lophelia* colonies. The removal option was justified on the basis that *Lophelia* was present in relatively low abundance as an opportunistic colonist of an artificial structure that was not representative of the surrounding natural, seabed habitat. Additionally, *Lophelia* reefs are not known to not occur naturally on the seabed habitats in these offshore areas.

The polychaete worm (*Sabellaria spinulosa)* (hereafter referred to as *Sabellaria* in accordance with common usage) is another reef building organism that is listed under Annex 1 of the Habitats Directive, and occurs in the southern North Sea. These reefs only occur with a high abundance of the tube-building worm which uses suspended sand grains to form its tubes. The reefs are relatively fragile and are unlikely to form on jackets of offshore structures.

DECC's Guidance Notes on the Decommissioning of Offshore Oil and Gas Installations and Pipelines under the Petroleum Act 1998 (DECC, 2011) provide direction that relates to both *Lophelia* and *Sabellaria*. They state that:

> *'The cold-water coral, Lophelia pertusa and reef forming worm Sabellaria are known to exist on or around offshore installations. The coral and Sabellaria are species of conservation interest and surveys may be necessary to establish their presence. As with all marine species, if there is a significant growth of coral or an established Sabellaria reef the potential impact of the operations on these species should be assessed in the EIA. An Appropriate Assessment [assessment of the impact on the qualifying features of designated conservation areas] may also be conducted. If the coral is present and the installation upon which it is located is to be returned to the shore it will be necessary to discuss with DEFRA the requirements of the Convention on International Trade in Endangered Species.*
>
> *If the coral, Lophelia pertusa, is present on an installation located outside of territorial waters that is being transported to the UK or elsewhere, a CITES certificate will be required from DEFRA. Corresponding arrangements exist in other states.'*

Lophelia is listed under CITES (Convention on International Trade in Endangered Species of Wild Flora and Fauna) which sets controls on the international trade and movement of animal and plant species that have been, or may be, threatened as a result of excessive commercial exploitation. The CITES certificate is necessary for transportation between states.

3.7 Key Findings

Similarities in marine growth: The types of marine growth that will be encountered during decommissioning will be very similar from project to project. These include: kelps, other seaweeds, plumose anemones, soft corals, hydroids, blue mussels, barnacles, solitary tubeworms and the cold-water coral, *Lophelia pertusa*.

***Lophelia* requires caution:** Special measures will be required before decommissioning if *Lophelia* is observed or suspected to be present on the jacket because *Lophelia* reefs are listed under the European Habitats Directive. These include a survey as part of the EIA for the decommissioning project and a CITES certificate if the installation bearing *Lophelia* is to be transferred between states.

Low risk of transfer of non-native species: The risk of the transfer of non-native species of marine growth during decommissioning is considered to be low because no evidence has been found to-date that non-native species occur on platforms in the North Sea.

Weights of marine growth: The weights of marine growth reported in pre-decommissioning documents usually represent the wet weight of the growth in air. Decommissioning yards actually process much lower weights than these estimates (values reported by two decommissioning contractors: 14% to 18%, and 20% of the original estimated weights) due to losses during the cutting and lifting process and natural drying of the growth.

4 LEGISLATIVE FRAMEWORK

The management of marine growth during decommissioning falls under a variety of regulatory instruments that stem from international, European and national legislation. Of relevance is legislation on: the decommissioning of offshore structures, the management of Controlled Wastes, pollution prevention and the control of polluting processes, the protection of the marine environment, the protection of habitats that are threatened or important for biodiversity, and the importation of endangered species.

The EU Waste Framework Directive (WFD) (2006/12/EC) defined ‘directive waste’ as “any substance or object in the categories set out in Annex 1 of the Directive which the holder discards or intends or is required to discard”. Annex 1 provides a list of definitions and includes a general category – “Any materials, substances or products which are not contained in the above categories”. As such, marine growth falls under this category.

In the UK, the Environmental Protection Act 1990 defines marine growth as a ‘Controlled Waste’, which is household, industrial and commercial waste. Marine growth becomes a Controlled Waste as soon as it arrives onshore. Controlled Waste can be further subdivided into waste that does or does not qualify as a ‘Hazardous Waste’ (or ‘Special Waste’ in Scotland) which is waste that has hazardous properties that may render it harmful to human health or the environment (SEPA, 2011). Chemical testing is required in order to identify which subdivision marine growth falls under but, on the basis of chemical analyses on consignments of marine growth received by decommissioning yards (see Sections 6.3.4 and 6.4.4), it has been found to be non-hazardous.

For legislative purposes, the Environment Agency refers to marine growth as a ‘Biowaste’ which includes the biodegradable parts of municipal wastes, livestock manures and slurry, treated sewage sludge, organic industrial waste (such as paper and textiles) and compost.

4.1 UK and Norwegian Environmental Legislation

Tables 1 and 2 provide an overview of the applicable legislation for the UK and Norway respectively.

Table 1: Summary of UK environmental legislation relevant to the management of marine growth during decommissioning

Aspect	Legislation	Regulator	Description
Decommis-sioning	Petroleum Act 1998 Energy Act 2008	DECC	These acts provide the basic legislative framework for the oil and gas decommissioning process on the UKCS including the requirement for the approval of a Decommissioning Program which sets out (in high level) the measures to be taken to quantify the waste inventory and manage the waste streams during decommissioning projects. An EIA is prepared to support the DP and waste management is included in the scope of this document.
Environmental Protection	Convention on International Trade in Endangered Species (CITES) 1973	DEFRA	If CITES protected species such as *Lophelia pertusa* are present on an installation located outside of territorial waters that is being transported to the UK or elsewhere, a CITES certificate will be required.
Environmental Protection	Convention on Environmental Impact Assessment in a Transboundary Context (Espoo, 1991)	MMO	The Convention sets out the obligations of States to carry out an environmental impact assessment of certain activities at an early stage of planning. It also lays down the general obligation of States to notify and consult each other on all major projects under consideration that are likely to have a significant environmental impact across boundaries.
Environmental Protection	The Offshore Petroleum Activities (Conservation of Habitats) Regulations, SI 2001 No 1754	DECC	Implements the European Directives for the protection of habitats, wild flora and wild fauna, in relation to oil and gas activities. Current consensus is that this does not apply to artificial habitats on man-made structures.
Pollution Prevention	Environment Act 1995	EA/SEPA	Requires SEPA to prepare a national waste strategy for Scotland. Enables regulations to be made that impose responsibility for waste onto the producer of the waste.

Aspect	Legislation	Regulator	Description
Pollution Prevention	Environment Protection Act 1990	EA/SEPA	Introduced a 'Duty of Care' process for Controlled Wastes, requiring waste producers to identify and store waste appropriately and ensure waste is only transferred to authorised persons. This applies especially to onshore decommissioning facilities.
Pollution Prevention	The Marine & Coastal Access Act 2009 & The Marine (Scotland) Act 2010	DECC	Many activities which were previously subject to a FEPA licence are now subject to MCAA licensing. These regulations are still at an early stage and many licensable activities are yet to be defined, however, removal of marine growth at sea and subsequent disturbance of the seabed may be subject to licensing (see Section 4.2).
Pollution Prevention	Pollution Prevention and Control Act 1999, under which come PPC (England and Wales) Regulations (SI 2000 No 1973) and the PPC (Scotland) Regulations (SSI2000/323) as amended	EA/SEPA	Implements European Union Council Directive 96/61/EC concerning integrated pollution prevention and control (IPPC) into UK Legislation. Defines the PPC permit requirements of onshore decommissioning facilities and other waste management facilities. Permits are reviewed to ensure the application of Best Available Technique (BAT).
Pollution Prevention	International Convention for the Prevention of Pollution from Ships (MARPOL)	IMO	Designed to minimize pollution of the seas, specifically from ships, including dumping, oil and exhaust pollution. Its stated object is: to preserve the marine environment through the complete elimination of pollution by oil and other harmful substances and the minimization of accidental discharge of such substances. Affects deliberate discharge of marine growth overboard during transit.
Waste Management	Environment Protection (Duty of Care) Regulations, SI 1991 No 2839	EA/SEPA	Under these Regulations any person who imports, produces, carries, keeps, treats or disposes of Controlled Waste has a duty to take all reasonable steps to ensure that their waste is handled lawfully and safely. Special/Hazardous Waste is a sub-category of Controlled Waste

Aspect	Legislation	Regulator	Description
Waste Management	The Environmental Permitting (England and Wales) Regulations, SI 2007 No 3538	EA	Legislation created to standardise environmental permitting and compliance in England and Wales to protect human health and the environment. Environmental permits are designed to reduce and simplify the administration of industrial facilities and waste management operations. The regulations apply in England and Wales only. This includes compliance with an odour management plan.
Waste Management	Waste Management Licensing Regulations 1994 SI 1056 under which comes the Waste Management Licensing Amendment (Scotland) Regulations, SSI 2003 No 171	SEPA	Covers applications for waste management licences in Scotland, which authorise the deposit, disposal and treatment of Controlled Waste. Includes conditions on the use of certain mobile plant. This includes compliance with an odour management plan.
Waste Management	Landfill Directive (1999/31/EEC)	EA/ SEPA	Imposes a ban on co-disposal of hazardous, non hazardous and inert waste. Certain types of waste are banned including liquid wastes (which may pose issues for marine growth disposal). All waste must undergo pre treatment prior to disposal. Sets targets to reduce the amount of Biodegradable Municipal Waste sent to landfill based on the amount of this material landfilled in 1995 to 75% by 2010, 50% by 2013 and 35% by 2020.
Waste Management	Landfill Tax Regulations, SI 1996 No 1527	Customs and Excise	A tax on the disposal of waste to landfill. Encourages efforts to minimise the amount of waste produced and encourages the use of non-landfill waste management options, which might include recycling, composting and recovery.
Waste Management	Hazardous Waste Directive (91/689/EEC) under which come The Hazardous Waste (England & Wales) Regulations (SI2005 No 894) and the Special Waste Amendment (Scotland) Regulations (SSI 2004 No 112)	EA/ SEPA	The Regulations require special wastes to be correctly documented, recorded and disposed of at an appropriately licensed site. Waste consignments must be compliant as soon as the waste is offloaded at an onshore facility.

Aspect	Legislation	Regulator	Description
Waste Management	European Union Council Regulation (EC) No 1013/2006 on shipments of waste	EA/SEPA	Regulation aimed at strengthening, simplifying and specifying the procedures for controlling waste shipments to improve environmental protection. It thus reduces the risk of waste shipments not being controlled.
Waste Management	Transfrontier Shipment of Waste Regulations, SI 2007 No 1711	EA/SEPA	Implements the above in the UK. The regulations prevent the import and export of waste, to and from the UK that could damage human health or the environment. Written permission is required to ship certain types of waste. In the event of an offshore structure being transferred across international boundaries in the course of decommissioning, both the structure and the marine growth would be defined as waste and would be subject to these regulations.

Table 2: Summary of Norwegian environmental legislation relevant to the management of marine growth during decommissioning

Category	Applicable Legislation	Regulator	Description
Decommis-sioning	The Petroleum Activities Act	Ministry of Petroleum and Energy	Covers the submission of a full decommissioning plan for operations in Norwegian territories.
Pollution Prevention	Pollution Control Act	Klif (Climate and Pollution Agency) and County Governor's Offices	Onshore decommissioning yards are classed as waste treatment plants, and are subject to permitting as such. Permits are reviewed to ensure the application of Best Available Technique (BAT). Operations at sea may also require permitting. Permits may include requirements on waste storage to minimise odour (ConocoPhillips Norway, pers comm). This act also covers the import and export of waste.
Pollution Prevention	The Planning and Building Act	Municipal Authorities	Act responsible for the appropriate zoning of industrial areas incl. decommissioning yards. Activities which may impact society or the environment (e.g. Decommissioning Yards) are subject to a full EIA process.
Pollution Prevention	Municipal Health Services Act	Municipal Authorities	Act which gives municipalities responsibility for environmental health matters in their locality. Applies alongside other legislation.

4.2 Overview of relevant legislation

There are four main issues with regard to legislative requirements:

Permit requirements for the removal of marine growth offshore: Currently, permits are not required for the removal of marine growth from the jackets of operational installations, for loading relief or structural inspection. The outcome of this well established process is that marine growth degrades naturally in the marine environment, thereby removing the need for collection, containment, transport to shore and onshore disposal (see Section 3.5).

However, if removing marine growth from the jacket or other subsea structures is likely to disturb the seabed then a Marine Licence may be required under the Marine and Coastal Access Act (MCAA), which came into force on 6th April 2011. Equally, the activity may be exempt or not fall within the licensing provisions. As this system recently came into force, the licensing requirements remain to be clarified.

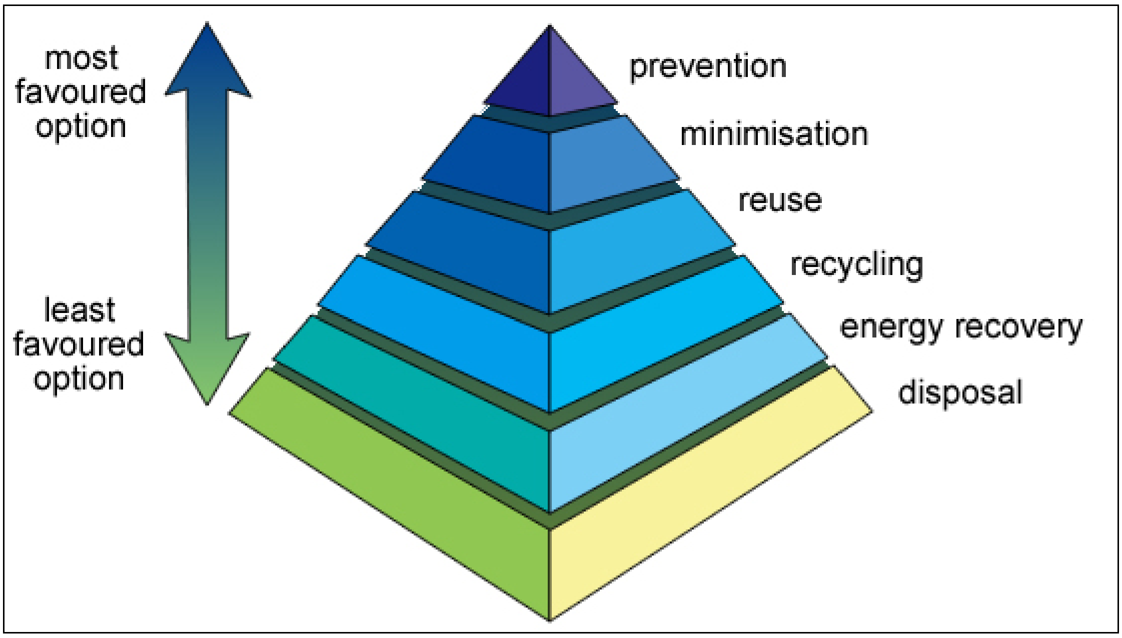
Disposal of marine growth wastes: Whether a material or substance is 'waste' is determined by EU law. Marine growth is defined as 'directive waste' under the EU Waste Framework Directive (WFD) (2006/12/EC). It is also a 'controlled waste' under UK legislation. Consequently, the action of removal, transfer to shore and disposal of marine growth during decommissioning falls within the legal definition of waste.

It is the responsibility of the producer or holder (operator) to decide whether a substance or object is waste. Although waste legislation applies once onshore, from a logistical and practical perspective, determination and management of the materials as 'waste' must begin offshore. Once identified, the waste must be treated, stored, handled, transported and disposed of in an appropriate manner in relation to the type of waste. In addition the Waste Producer has a legal 'Duty of Care' under the provisions of Section 34 of the Environmental Protection Act 1990 and the associated Environmental Protection (Duty of Care) Regulations 1991. The legal 'Duty of Care' requires that all waste is:

- accurately identified, labelled and contained during storage and transport to prevent its escape into the environment;
- transferred to an authorised person, such as a registered carrier, broker or licensed waste manager, this includes transfer for treatment such as recycling of scrap metals; and
- documented for handover using Controlled Waste transfer notes, with the transfer notes being retained by the waste producer for a period of two years.

Policy for reduction in the volumes of wastes sent to landfill: In response to the diminishing capacity available for waste disposal to landfill, and stakeholder pressure, there is an increasing focus on reducing the volume of waste that is sent to landfill. Waste reduction is driven by regulatory controls such as the 'Waste Hierarchy' and the Landfill Directive.

The Waste Hierarchy (Figure 4) depicts the progression of preference for waste management methods. The higher up the action is taken, the greater the potential to save resources, money, minimise any impact on the environment and, crucially, reduce the volume of waste disposed of in landfills, which is seen as a last resort. The DECC (2011) Guidance Notes for the Decommissioning of Offshore Oil and Gas Installations and Pipelines under the Petroleum Act 1998 require that the decommissioning programme include a statement indicating how the principles of the Waste Hierarchy will be met.



Source: http://www.eventsustainability.co.uk/pages/uploadedimages/www/waste_hierarchy.jpeg

Figure 4: The Waste Hierarchy

The European Union (EU) Landfill Directive (1999/31/EC) includes an obligation to reduce the amount of biodegradable municipal waste, which includes commercial and industrial wastes such as marine growth, sent to landfill. Targets for the UK, based on the amount of biodegradable municipal waste sent to landfill in 1995, are for a reduction to 75% by 2010, to 50% by 2013 and to 35% by 2020. Furthermore, the European Commission has recently announced (Spring 2011) that it intends to include a proposed "phase-out of biodegradable waste going to landfill in 2020-2025" in a revision of the 1999 EU Landfill Directive.

The oil and gas operators, the decommissioning sector and waste management companies are coming under increasing pressure from the regulators to reduce the quantities of waste sent to landfill, and to adopt more sustainable alternatives. It is significant that landfill availability and a scarcity of suitable composting facilities are issues that affect all of the decommissioning contractors interviewed.

EEMS reporting of marine growth wastes: A review of the 2009 data from the annual returns that UK operating companies made under the Environmental Emissions Monitoring Scheme (EEMS) indicates that none of the 3200 returns submitted were made for 'Marine Growth' which is one of the EEMS categories for Decommissioning Waste. DECC operates this publicly available database, and regard this key element of their environmental regulatory program as an aid to the formulation of future policy and legislation. The finding could highlight a lack of awareness by the operators of the EEMS reporting requirements, or a lack of understanding on the part of the decommissioning contractors as to the reporting of volumes disposed of to their clients. It also means that EEMS returns cannot be used as a means of determining volumes of marine growth disposed of.

4.3 Key Findings

Essentially, the UK and Norway have similar basic requirements, namely:

- The operator must deliver the relevant technologies, management processes, controls and commitments described in the Decommissioning Programme and EIA that accompanied the permit application for the decommissioning consent;
- The operator and contractors must ensure that all necessary licenses, consents, authorisations, records, and methods for the management and disposal of Controlled Waste are legally compliant, effective and follow good practice, particularly relating to the waste hierarchy of avoidance, reduction, reuse, recycling and disposal; and
- The decommissioning contractors must abide by the permits that govern the potentially polluting processes at their facilities. Of relevance are processes for the management of wastes, odour and discharges arising from marine growth and the use of odour suppressant chemicals. Both the UK and Norway apply a 'multi-media' permit system where all of the potentially polluting processes at industrial sites are encompassed within a single permit. Permits are reviewed on a rolling basis, during which the contractor is required to demonstrate to the regulator that their techniques for the control of polluting processes are the Best Available Technique (BAT). BATs are required by the Environment Agency and SEPA in the UK and Klif (the Norwegian Climate and Pollution Agency) in Norway to be considered in order to avoid or reduce emissions resulting from certain installations and to reduce the impact on the environment as a whole (EA , 2011). The same 'multi-media' permit system is in place for operators of waste management facilities such as landfill and composting.

5 MANAGEMENT OF MARINE GROWTH

The section describes the previous and current processes that the four decommissioning contractors undertake to manage marine growth during decommissioning. Although the processes differ from project to project, and between the individual decommissioning contractors, the processes occur at five common intervention points;

1) at the offshore location;

2) during transit at sea;

3) at an intermediate location at sea;

4) at the decommissioning yard; and

5) during final treatment or disposal.

For consistency, the descriptions of the processes use common headings, e.g. Processes at the offshore location, Processes during transit at sea, etc.

5.1 Information Sources

The primary sources of information for the following descriptions of marine growth disposal operations are the interviews that were conducted with four of the main decommissioning yards in the UK and Norway. Each process has not been linked to a specific yard so as to protect potentially commercially sensitive information; however the country that the yard is located in has been identified so as to distinguish between the different legislative regimes that each process must follow.

5.2 Current practices to manage marine growth

The following sections (Sections 5.3 – 5.6) present the information provided by four of the main decommissioning yards in the UK and Norway. Initially the yards were provided with a standard list of questions around which the interviews were structured. One yard chose to answer these questions in writing; the rest responded by telephone interview. The list of questions sent to each decommissioning yard is included in Appendix B.

5.3 Yard 1

Figure 5 outlines the current practices for the management of marine growth on offshore structures that are decommissioned at Yard 1. This diagram uses different colours to denote: Starting and End Points (pink), Marine Operations (blue) and Onshore Operations (green). This convention also applies to the diagrams for the other yards.

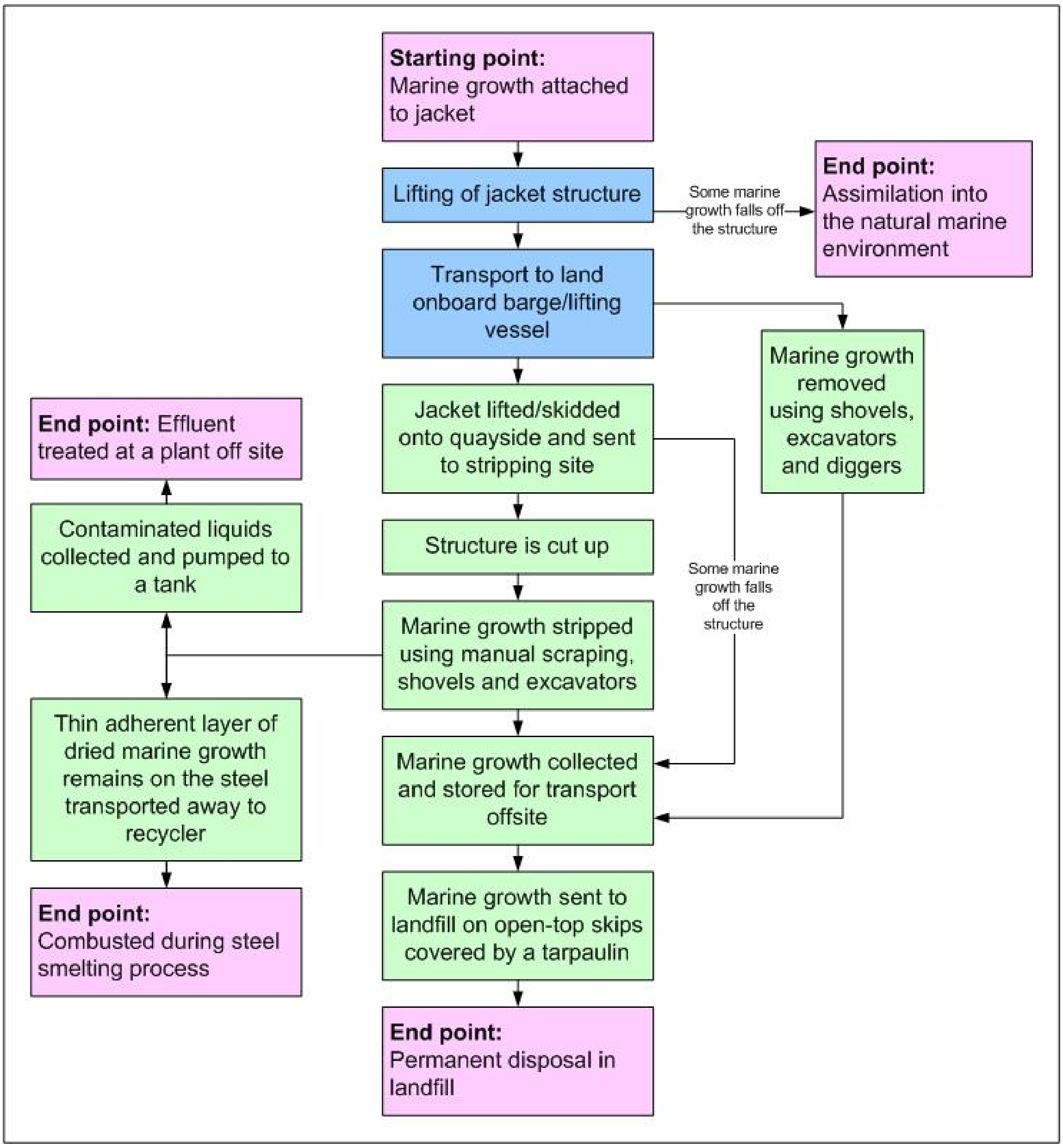


Figure 5: Process diagram of decommissioning operations at Yard 1

5.3.1 Process at the offshore location

Yard 1 did not specify any intentional removal of marine growth at sea when the structure is *in situ*. There will still be some removal of marine growth during the cutting and lifting / refloating of the structure. This growth will fall to the seabed where it will naturally degrade.

5.3.2 Process during transit at sea

Yard 1 did not specify any intentional removal of marine growth at sea while the structure is in transit to the yard. However, in their experience, a substantial amount of marine growth falls from the structure to the transport barge during the transit time; this is due to both the natural drying processes and to the movement of the lifting and transport processes that dislodge loose and attached growth. This marine growth is collected from the barge on arrival at the decommissioning site, as detailed below.

5.3.3 Process at the decommissioning yard

Upon arrival at the decommissioning yard the first activity which takes place is the removal of marine growth which has fallen to the deck of the barge during transit. The mixture of mud and marine growth is collected by manual sweeping and shovelling, and by using mini-excavators which can operate on the barge deck. This debris may also include ropes and cables which have become completely covered in marine growth and mud.

The structure is then lifted from the barge onto the quayside; during this process more marine growth naturally falls from the structure, and is collected from the quayside in the same manner as collection from the barge.

The structure is then moved to a dedicated stripping site for dismantlement; this site is as far from sensitive receptors (i.e. local housing and industrial premises) as possible and is also fully bunded (enclosed within an impermeable containment structure) to contain liquid effluent. Once the metal of the decommissioned structure has been cut into smaller pieces, any substantial marine growth remaining is removed by manual scraping, or by scraping using a mechanical excavator. Water jetting is not used at this site to avoid generating further liquid effluent.

Because it is not practical to remove 100% of the marine growth attached to the structure, some will remain attached to the materials sent to recyclers. As attached marine growth can cause problems for recyclers, however, this amount is kept as low as feasible.

5.3.4 Process during final treatment or disposal

Marine growth collected at all stages of the decommissioning project, whether it has fallen naturally from the structure or been actively removed, is first analysed for contamination with hydrocarbons, other organics and metals to determine if it contains any hazardous materials and then loaded into open top containers on-site and covered with a tarpaulin. As per guidance from the Environment Agency, these containers are removed from the site within 3 days of completion of the dismantling of the structure. Initially this guidance specified 3 days from removal of the marine growth; however as the volumes recieved have been lower than expected, dispensation has been granted to allow removal after dismantlement completion.

This waste is then transported to a landfill site where it is immediately covered to suppress odours. The landfill site used is not the closest site to the decommissioning yard due to constraints on the amount of material the nearer site can handle. Instead, the waste must be transported by road to a site farther away. Composting is not a viable option as there are no suitable composting facilities in the area.

Any liquid effluent collected from the bunded decommissioning area is collected in tanks and removed by specialist liquid waste contractors for treatment.

The small amount of marine growth that remains on the structure is accepted by the recyclers. This steel is typically transported by barge to the recycling site, where it is smelted down. This process incinerates any residual marine growth.

5.4 Yard 2

Figure 6 outlines the current practices for the management of marine growth on offshore structures that are decommissioned at Yard 2.

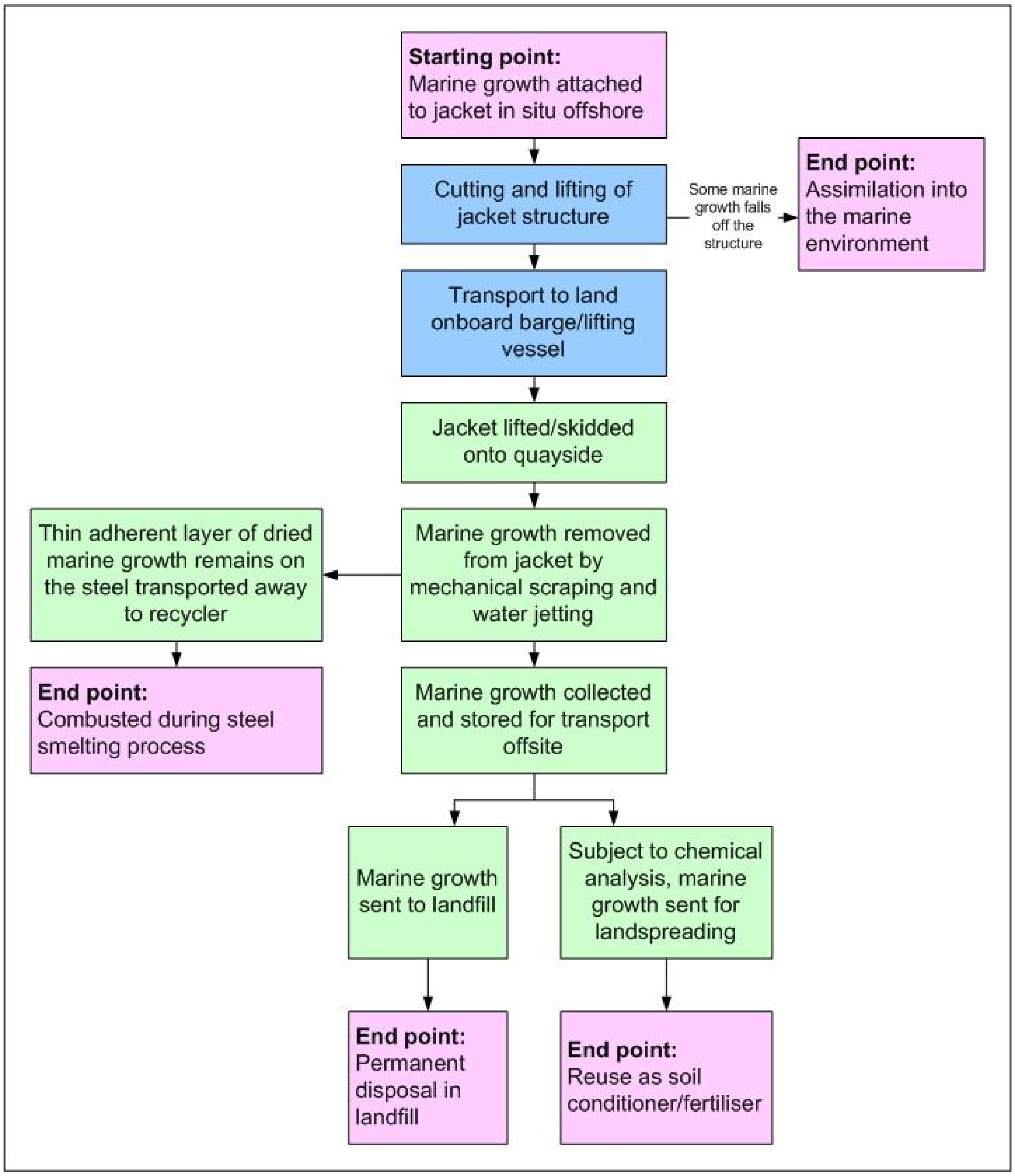


Figure 6: Process diagram of decommissioning operations at Yard 2

5.4.1 Process at the offshore location

There is some removal of marine growth during the cutting and lifting/refloating of the structure. This growth will fall to the seabed where it will naturally degrade.

5.4.2 Process during transit at sea

Yard 2 did not specify any intentional removal of marine growth at sea while the structure is in transit to the yard. However the natural drying process will continue (see Section 3.4) during the transportation process, depending on weather conditions.

5.4.3 Process at the decommissioning yard

At the dismantling yard, marine growth is removed from the structure by mechanical scraping and water jetting. Subsequently, the waste is collected and then segregated in demountable lorry trailers or skips for transport offsite.

5.4.4 Process during final treatment or disposal

Chemical analysis for contamination with hydrocarbons, other organics and metals is carried out on the collected marine growth to determine its suitability for landspreading. If deemed suitable, the untreated biodegradable waste is spread on farmland owned by the decommissioning company. By this process the marine growth ultimately acts as a soil conditioner/fertiliser on the agricultural land.

Alternatively, if chemical quality standards are not met, the marine growth is disposed of in a licensed landfill.

5.5 Yard 3

Figure 7 outlines the current practices for the management of marine growth on offshore structures that are decommissioned at Yard3.

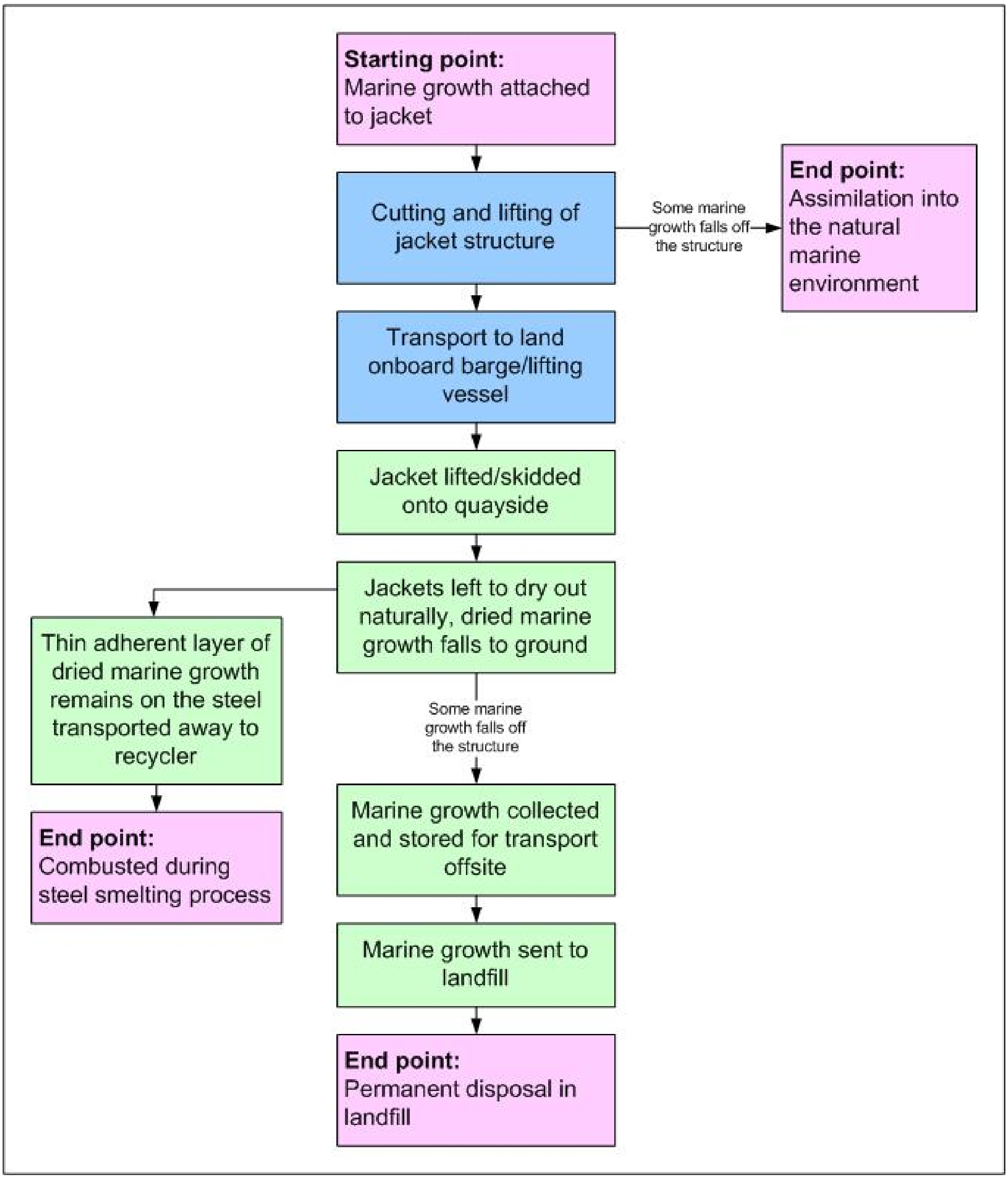


Figure 7: Process diagram of decommissioning operations at Yard 3

5.5.1 Process at the offshore location

Yard 3 did not specify any intentional removal of marine growth at sea when the structure is *in situ*. There will still be some removal of marine growth during the cutting and lifting/refloating of the structure. This growth will fall to the seabed where it will naturally degrade. Previously, ROVs have been used to remove some marine growth while the structure is still *in situ*. Removal *in situ* did not produce any notable advantage for the decommissioning yard when compared to the natural drying process that they currently follow (see below).

5.5.2 Process during transit at sea

Yard 3 did not specify any intentional removal of marine growth at sea while the structure is in transit to the yard. However the natural drying process will continue during the transportation process depending on weather conditions.

5.5.3 Process at the decommissioning yard

Upon arrival at the yard, the structure is lifted or skidded from the barge to the quayside and is left to dry out before dismantling takes place. This drying process will have already begun during jacket lifring and transport on barges and after a period of 3 to 5 days the majority of the water content of the marine growth will have been lost (see Section 6.3). Accordingly, the weight and volume of the growth will be reduced.

Any marine growth that falls from the structure during the drying process or during subsequent dismantling operations is collected for disposal, but there is no active intervention at the yard to remove marine growth.

5.5.4 Process during final treatment or disposal

Any marine growth which has fallen off during the drying stage or during the dismantling operations at the yard is collected and sent to a licensed landfill site close to the yard. Mussel shells which cannot be composted are used as dry cover on a local landfill.

The marine growth which adheres to the structure after it has been dismantled will now have fully dried out, and reduced significantly in weight and volume. As a result the steel of the structure can be sent for recycling without any further intervention to remove the growth. This has so far posed no problems to the recyclers. Any liquid effluent that is produced while the structure is drying out is captured by bunds and drains and treated at an onsite water treatment plant.

The process of ‘natural drying’ is standard practice for this facility.

5.6 Yard 4

Figure 8 outlines the current practices for the management of marine growth on offshore structures that are decommissioned at Yard 4.

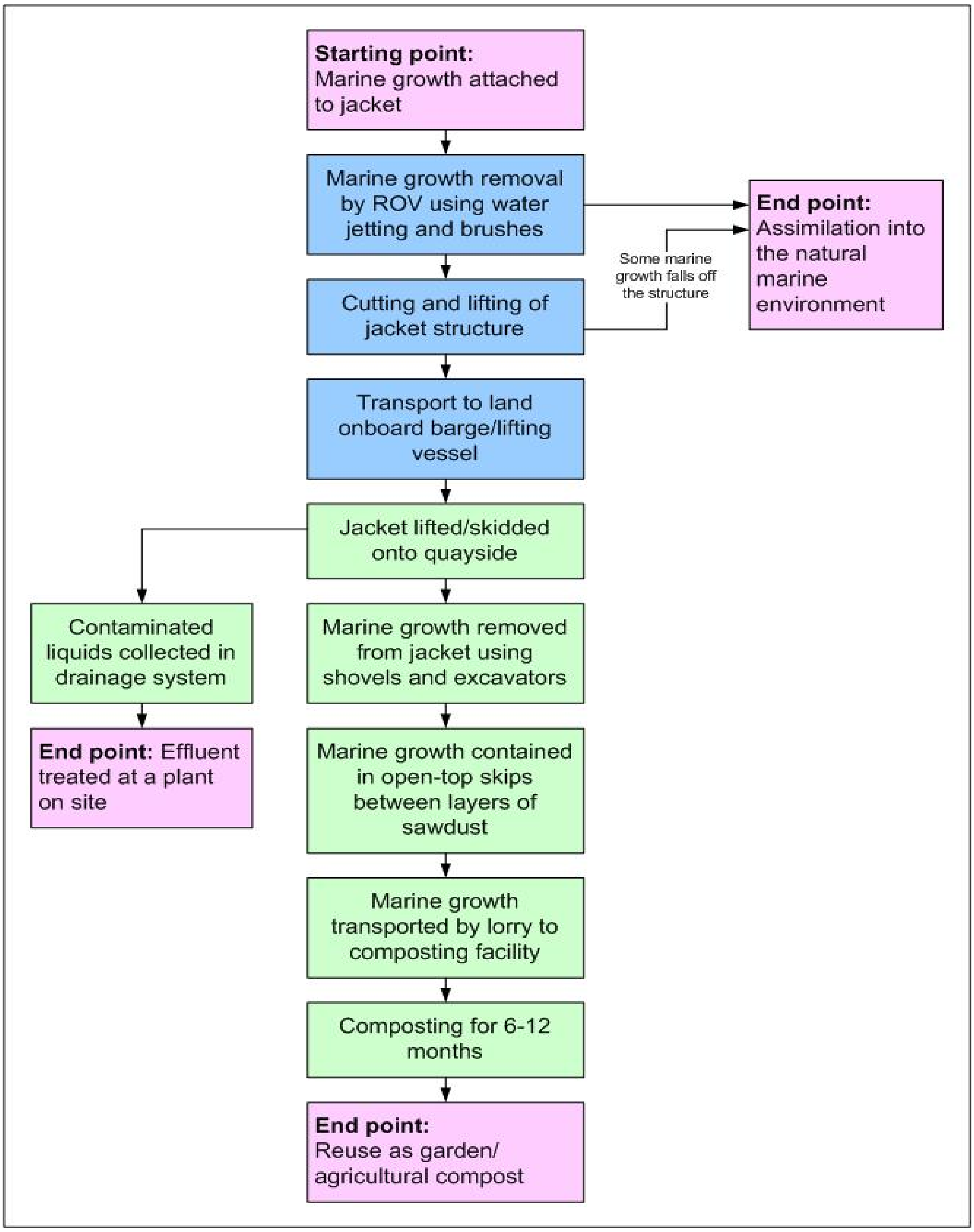


Figure 8: Process diagram of decommissioning operations at Yard 4

5.6.1 Process at the offshore location

During the projects that this yard has been involved in, up to 50% of the marine growth present on the structure has been removed by ROVs while the structure is *in situ* at the offshore field location. The interviewee understood that this was accomplished using ROVs fitted with rotating brushes and water jets during ROV downtime.

5.6.2 Process during transit at sea

Yard 4 did not specify any intentional removal of marine growth at sea while the structure is in transit to the yard. However the natural drying process will continue (see Section 3.4) during the transportation process, depending on weather conditions.

5.6.3 Process at the decommissioning yard

Upon arrival at the decommissioning yard the structure is lifted or skidded onto the quayside. The marine growth that is within reach from the ground is removed from the structure prior to dismantlement. This is accomplished using water jetting, manual scraping and mechanical excavators. The growth which cannot be reached is removed or falls off as the structure is dismantled.

The removed marine growth is enclosed between layers of sawdust when placed in skips in order to absorb excess moisture and suppress odours; the sawdust also acts as a bulking agent for the composting process.

5.6.4 Process during final treatment or disposal

Once collected, the marine growth is sent to a municipal composting centre for treatment. The growth, including solids such as shells, is mixed with sawdust and domestic waste and left to compost. The composting process takes between 6 months and a year to complete, after which the product is sold as a soil conditioner/fertiliser to domestic and agricultural customers.

Any liquid effluent that is produced while the structure is drying out is captured by bunds and drains to be treated at an onsite water treatment plant.

5.7 Previous Marine Growth Removal Strategies

Along with the current processes for managing and disposing of marine growth at decommissioning yards, the interviews conducted covered strategies for former projects from as much as ten years ago. Only Yard 3 provided information on a previous management strategy that differs significantly from current practice. The following descriptions highlight these differences:

Removal and disposal in suitable dispersive environments inshore: During a previous project at Yard 3, a structure was refloated and towed from its offshore site rather than lifted onto a barge for transport. This structure was 'stacked' at a relatively deep-water inshore location. Approximately 50% of the marine growth on the structure was removed while it was still in the water at the inshore location, where it degraded naturally in the water. This approach is no longer practiced at this yard.

The contractor was required to monitor water quality around the discharge site and conduct surveys on the local benthos. Monitoring was also carried out to ensure that removed marine growth sank to the seabed where it would degrade naturally, rather than float on the surface where it could pose a visual or odour nuisance.

Removal and disposal of marine growth at inshore locations has not been typical of recent experience in Norway, where current practice is for marine growth to be dealt with at the offshore location and decommissioning yard. The Norwegian Climate and Pollution Agency (Klif) decommissioning review (Klif, 2011) states:

> *'Marine fouling should be removed from the installation while it is still offshore if this is technically possible. The open sea usually functions as a satisfactory recipient where the material decomposes naturally. Studies have also shown that disposing of fouling material in open fjords does not cause problems. In more enclosed, shallow waters, however, this may result in an excessive load of organic material and oxygen depletion on the seabed. Disposal of the material on land and composting is a possibility, but often results in odour problems.'*

Marine disposal at a suitable marine location could avoid or lessen some of the disposal constraints that occur with onshore disposal. However, other considerations, such as equipment availability, structural accessibility, cost and safety, need to be evaluated. Marine disposal does not seem to be an option that is often used in the UK.

Removal at the yard has been superseded by 'natural drying': Former practice at Yard 3 was the physical removal of marine growth from steel structures upon their arrival onshore at the yard. This was accomplished using manual scraping and high pressure water jetting equipment. Current practice differs radically in that the yard uses ‘natural drying’ which requires limited intervention (see Section 7.1).

5.8 Key Findings

The interviews with the decommissioning yards produced some important conclusions, and also raised four main issues for further research and discussion.

1) Overall, the weight of marine growth that the yards have had to dispose of during projects completed to-date has been relatively low. It has also been less than originally anticipated by the yard and the operator responsible for the structure being decommissioned. As previously discussed, this is probably due to the reduction in the weight of marine growth through the natural drying process. Despite making an allowance for weight reduction through natural drying, all of the yards interviewed said that they were still dealing with lower than expected quantities of marine growth.

2) The current onshore disposal approaches can be summarised as;

   - removal at the yard followed by landfilling;
   - removal at the yard followed by composting at a large, local municipal composting facility;
   - removal at the yard followed by landspreading; and
   - natural drying of marine growth at the yard then sending the steel to the recycling facility with some growth attached.

   The last process involves the least effort by the decommissioning contractor in terms of physical intervention on the marine growth and with respect to pressure on final disposal routes, and therefore may merit further investigation as to whether this represents a BAT.

3) Bulk removal of marine growth while the structure is *in situ* offshore, as opposed to simply removing growth to allow cutting and lifting operations, appears to be a solution that is practiced by one of the yards in cooperation with the offshore contractors. In the UK, neither of the yards spoken to request that marine growth is removed offshore, however relatively small quantities are removed by the cutting and lifting contractors.

   Interestingly, none of the yards interviewed specify a limit on the quantity of marine growth that they can accept for decommissioning; therefore, in relation to the yards’ capability and capacity to deal with marine growth, there is no requirement for offshore removal. This would indicate that marine growth is not currently a capacity or management issue for yards; speaking to the yards has confirmed this.

If more widely practiced, offshore removal would however reduce the weight of landed marine growth that the yards have to deal with, and ultimately reduce pressure on onshore disposal routes such as landfill and composting. However there may be significant technological, financial and regulatory restrictions on this practice, especially in the UK. These factors are discussed in Section 7.

4) Importantly, each yard has adopted marine growth management solutions that are appropriate to local circumstances. These are relatively low-tech, effective and are accepted by the regulators and local communities. However, there are still constraints to the disposal processes and potential improvements that could potentially be made which are discussed in Section 7.

6 ADVANCES, CHALLENGES AND OPPORTUNITIES

The following assessment of the potential improvements that can be made, and the challenges and opportunities presented by the disposal of marine growth, is primarily based on the information gained from the interviews with the decommissioning yards, and information gained from wider reading of the legislation and guidelines related to the practice. It is not an exhaustive review and may be affected by future changes in legislation.

6.1 Potential Changes in Management Practices and Technologies

Removal Onshore: Current yard operations are mainly based on removal of marine growth once the structure has been landed on the quayside. This is understandable as it is the first time that the decommissioning yard has full control over the structure, as opposed to relying on other contractors for assistance and cooperation. It is also a lot easier to access all parts of the structure once it has been landed. However onshore removal is not completely without difficulties, as a degree of working at height may be involved along with other complications encountered in the dismantling of such a structure. Decommissioning yards are more accustomed to these problems due to the nature of their work. The primary benefit of onshore removal is that it poses far fewer logistical and health and safety issues than working at sea, and therefore may be cheaper, easier and safer. Nevertheless it could be argued that the environmental benefits of at sea disposal outweigh the initial benefits of onshore removal.

When marine growth is removed on land the conventional disposal method is to send the material to landfill. As with many industries which require disposal of organic wastes, composting and landspreading is now seen as an effective alternative. The yards interviewed that do not currently compost marine growth are still actively researching it as an option. Composting and landspreading alternatives work but there are constraints which are discussed in Section 7.2.

Removal at Sea: There is some disposal of marine growth to sea while the structure is *in situ*; however it does not appear to be a prevalent current practice. Although all of the decommissioning contractors were asked, only one yard stated that marine growth removal at sea took place prior to the delivery of structures to their yard. Norwegian government recommendations specify disposal at sea (offshore/inshore waters) as an alternative to land-based disposal (Klif, 2011). Structural cleaning carried out in fjords with suitably dispersive environments is a specified inshore disposal method. This method has been used in the past but does not appear to be a current practice. The UK Decommissioning Guidance document (DECC, 2011) does not mention these offshore or inshore marine growth disposal options.

Removal of marine growth at sea, whether in inshore or offshore waters, does pose particular challenges, for the most part these are similar to the challenges faced by any offshore operation, namely the logistical and health and safety issues caused by the environment, and the financial costs involved in overcoming these. The primary benefit of removal at sea is that the marine growth is allowed to degrade naturally in the marine environment, and therefore does not increase pressure on land for landspreading, landfill or composting facilities. At-sea removal also has the added benefit of reducing potential odour and pest problems associated with allowing the marine growth to decay onshore. It should be noted that, due to the recent introduction of the MCAA licensing scheme, the UK legislation on the disposal of large quantities of marine growth at sea is currently unclear. One of the yards interviewed stated that NGOs have previously expressed concerns about this type of disposal.

Natural Drying: A further management option that has been identified but which does not appear to be widely used at present is the natural drying approach. As previously mentioned, all marine growth begins to dry out naturally as soon as it is removed from the sea. This process continues after the structure has arrived at the decommissioning yard, reducing the weight and volume of the marine growth, potentially to a level where it does not need to be removed from the structure before its components are sent for recycling. This approach also has the benefit of minimising the amount of physical intervention required to remove and process marine growth, reducing the need to allocate manpower and equipment to the task.

Under dry conditions, mussel shells will remain attached or become dislodged; barnacles, tubeworms and *Lophelia* will remain firmly attached; soft corals will fall off; seaweed, hydroids and anemones will desiccate to a stable mummified state and remain attached to the underlying steel or concrete. In this state, odour is much less of an issue than when moist, when the marine growth will decay.

Natural drying will lessen, but may not completely remove, the need for an onward onshore disposal route such as landfilling, landspreading or composting, because debris will continue to fall from the structure as it dries, and recyclers may not accept quantities of ‘hard’ waste such as mussel shells and hard corals. The only yard of the study which currently carries out natural drying has experienced no additional impacts in terms of odour or pests from this process than occur with other management processes. Due to differing local environments and regulatory schemes these issues would require careful monitoring if this practice were to be used at other locations.

6.2 Supply Chain Factors

Capacity and Availability of Disposal Facilities: The main factors affecting the supply chain for marine growth disposal is the capacity of the disposal method i.e. landfilling, landspreading, composting or recycling which has been defined as an 'end point' in the marine growth management process flow diagrams. Landspreading, landfilling and composting facilities are subject to strict regulation which determines how much and what types of waste that they can accept. If a disposal facility cannot accept any more waste of a specific type, in this case organic waste, then the decommissioning yard will have to find somewhere else to dispose of the waste.

From the interviews with the yards it is clear that availability of disposal sites is an ongoing issue. Although all of the yards currently had acceptable disposal routes in place, it was stated that the landfill site closest to the yard was not always capable of handling the types and quantities of waste being generated, forcing the yard to send the waste by road to a facility further away. None of the yards mentioned that they had readily available back-up disposal facilities. This issue can be exacerbated by the remote location of many large decommissioning facilities, especially in the Norwegian Fjords or the Northern Isles of Scotland.

Another constraint on the final disposal of the marine growth, especially in the UK, is the current low capacity and lack of availability of large scale composting facilities. The UK yards expressed a desire to find an acceptable composting facility but had been unsuccessful thus far.

Waste Quality Constraints: Landfill and compost facilities may not be able to accept waste consignments on quality grounds. A common theme of the conversations with the decommissioning yards was that both landfills and composters will not accept the waste if the liquid content is too high or if the waste has too obnoxious an odour. Composting facilities may not accept large quantities of shells and other 'hard' waste because they do not readily decompose. Solutions to these some of these issues include mixing marine growth with sawdust to absorb some of the remaining liquid, and treating containers of marine growth waste with odour suppressant chemicals prior to delivery to the waste disposal facility.

In the case of material being sent to recyclers with dried marine growth still attached, the recycling facility, particularly metal smelters, may reject any material which still has a large enough covering of growth such that it would negatively affect the quality of their product. The recycler may impose financial penalties on the yard for having to process contaminated material.

6.3 Regulatory Factors

All of the yards interviewed expressed satisfaction in general with the regulatory regime that applies to them. All of the companies involved are experienced in environmental and waste management and, from the beginnings of their operations, have worked closely with local and national authorities to ensure that all applicable legislation is adhered to.

In both the UK and Norway the primary permits issued for waste management are multi-media integrated permits which cover the wide range of waste generation and disposal activities undertaken by the yards. From the survey of the yards it would be reasonable to suggest that regulators in the UK and Norway are satisfied with all of the techniques that the yards are using, including the less common techniques such as landspreading and leaving marine growth to dry naturally. The yards have a good track record of consulting the applicable regulators before embarking on a large project.

The Environment Agency has published a position statement on the 'Sustainable management of biowastes' in order to explore the possibilities for alternative treatment technologies. They encourage the treatment and recovery of biowastes to maximise their benefit as a resource, as a source of quality material and energy, whilst minimising their impact on the environment. Currently, the main end points for biowastes are re-use as a fertiliser after composting, incineration and disposal at a landfill.

There is no prescriptive procedure for biowaste management at the moment; there are some restraints in place but there is also a freedom to explore new management opportunities.

6.4 Technology Improvements and Gaps

The technology used in the marine growth removal process at decommissioning yards is currently relatively 'low-tech' but effective. Usually, for the actual removal of growth, this involves manual scraping or scraping with the bucket of an excavator. High pressure water jetting, though effective, is rarely used as it increases the water content and therefore the weight of the marine growth, and can also exacerbate problems with liquid effluents. Yards identified potential improvements in these technologies, including the development of tools to speed up the scraping process especially from tubular metal structures, and equipment to make it possible to remove marine growth from tall structures (e.g. some structures that have been decommissioned have had sections that rise 50m above the quay surface).

Although none of the yards interviewed had experienced any serious problems with odour to-date, interest was expressed in the development of more effective odour suppressant chemicals, and equipment to assist in the application of these treatments directly to structures prior to dismantling (particularly for tall structures).

The removal of marine growth while the structure is *in situ* offshore could potentially benefit from introducing improvements on equipment that can be used underwater by ROVs or by divers. Options may include improvements on the existing technologies of high pressure water jetting systems and rotating brushes or a new, novel solution which can be easily mounted on multipurpose ROVs and which would quickly remove a significant amount of the marine growth. High speed removal of marine growth using ROVs is crucial so that the bulk removal of marine growth can take place alongside other decommissioning activities, without requiring the dedication of additional equipment or manpower. It should be noted that the potential for offshore technology improvements was not further investigated within the scope of the study.

6.5 Potential Constraints

Stakeholder responses, particularly public and NGO objections to marine growth removal activity on grounds of nuisance caused by visual impact, odour and pests, are potentially constraints which must be taken into account before any decommissioning project begins. The yards that were contacted in the course of this study should all be commended for their proactive approach towards stakeholder engagement; ensuring that communities local to the yards and other interested parties are kept informed of the work being carried out at the yard, and giving an opportunity for concerns to be aired before they become serious problems. To-date none of the yards reported any serious problems from stakeholder concerns. As the pace of decommissioning work quickens in the North Sea and the yards become busier, operators and waste handlers must continue to undertake appropriate levels of engagement with stakeholders.

Given that the European Commission intends to include a proposed “phase-out of biodegradable waste going to landfill from 2020-2025”, further constraints will be imposed on the already tightly controlled use of landfills, and this may lead to a reduction in the number of landfills accepting marine growth waste. This means that finding alternative disposal methods to landfill for marine growth components will become even more important.

6.6 Key Findings

Three principal findings should be taken into account:

1) The treatment and use of biowastes are regulated by a range of measures. Suitable treatments depend on the type of material being treated. It is the responsibility of those planning and delivering the waste management infrastructure to find the BAT for their particular situation, considering potential impacts to the environment and other issues.

2) The decommissioning yards interviewed do not follow exactly the same processes for the disposal of marine growth. Each yard has found an effective solution that is applicable to the projects that they have worked on and the environments in which they operate. It may be possible to recommend a potential BAT; however this should be caveated by saying that each decommissioning project should be treated as an individual project, and that what works well in one location on one project may not necessarily work elsewhere.

3) To address the need to reduce pressure on onshore disposal facilities such as landfills, areas for landspreading and composting units, there are two approaches which create the least amount of onshore waste and may therefore be considered the BAT. These apoproaches are bulk removal offshore and natural drying onshore. Natural drying onshore will lead to some waste to be disposed of which recyclers will not accept (e.g. mussel shells and skeletons of hard corals) and debris which falls to the ground as it dies; alternative disposal routes must be found for both of these wastes. Removal offshore may also pose some challenges in terms of the costs and timescales involved. Additionally, in the UK, the regulatory system regarding the disturbance of the seabed and MCAA licensing is currently unclear (see Section 4.2) and therefore may potentially be an issue to be addressed for offshore removal.

7 CONCLUSIONS

This report concludes by briefly summing up the main findings of the legislative review and the interviews conducted with the decommissioning yards. These conclusions are followed by a brief set of recommendations for future research and work.

- The decommissioning yards interviewed are all well managed and highly experienced; and have generated suitable solutions to the disposal of marine growth adapted to local legislation and environments. To-date all of these solutions have proved effective.

- All of the currently practiced methods of removing and disposing of marine growth have pros and cons. Some methods may be subject to further constraints in the future, such as new legislation and reduction in the capacity of waste disposal end points.

- The technology required to remove marine growth on and offshore is relatively low-tech, however there is an opportunity for new technologies, which will save time or money or be safer to use.

- Landfill of marine growth is still a common disposal end point, but there are constraints on the volume and quality of waste disposed of in this way, and these constraints may become tighter with the introduction of future legislation. As decommissioning activity increases, the availability of suitable landfill facilities also has the potential to be an issue if the current landfills become unavailable and alternative disposal sites or methods cannot be found.

- Composting and landspreading currently exist as alternatives to landfill, but their capacity is still limited, especially in the UK. Furthermore these alternatives are subject to strict quality controls, which may lead to a continued need for landfills.

- The bulk removal of marine growth at sea could help reduce quantities disposed of to land, but is likely to have larger cost and health and safety impacts, and may possibly be subject to objections from some stakeholders.

- In terms of the smallest overall environmental impact, and a potentially reduced cost impact, allowing the marine growth to dry as far as possible, and only actively removing as much as is required by recyclers, could be considered a potential Best Available Technique. However, as only one of the yards spoken to currently use this natural drying practice, further research is required into the suitability of this method for other yards and under other regulatory regimes.

8 RECOMMENDATIONS

Based on the information gathered from the compilation of this report four primary recommendations have emerged. Readers with other technical backgrounds may be able to draw further recommendations from their reading of the report.

1. The decommissioning contractors should be made aware of the findings of this study because these may benefit their industry.

2. Further analysis and investigation is necessary to establish the cost/benefit, applicability, environmental impacts, health and safety risks/benefits and legislative requirements relating to the bulk removal of marine growth at the offshore site.

3. Further analysis and investigation is necessary of the cost/benefit, feasibility, environmental impacts health and safety risks/benefits and legislative requirements relating to planned natural drying of marine growth at onshore decommissioning facilities.

4. Oil & Gas UK should facilitate a workshop with the decommissioning contractors to discuss the following issues which are likely to impact the effectiveness of the decommissioning supply chain:

    a. the physical capacity and availability of, and legislative constraints on landfill (in the EC Landfill directive), land-spreading and composting facilities;

    b. new technology requirements of their industry; and,

    c. knowledge sharing on the BAT options for the management of marine growth.

References

Avant, P., 2007. *Elminius modestus*. An acorn barnacle. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 20/07/2011]. Available from: <http://www.marlin.ac.uk/speciesinformation.php?speciesID=3252>

Bassindale, R., 1964. British Barnacles. London: The Linnean Society of London. Synopses of the British Fauna, no.14.

Bell, N. & Smith, J., 1999. "Coral growing on North Sea oil rigs". Nature 402 (6762): 601

BMT Cordah, 2009. Assessment of the weight of marine growth on the North West Hutton platform. BMT Cordah Ltd.

BP, 2002. An evaluation of the distribution of the cold-water coral *Lophelia pertusa* on NW Hutton. BP Aberdeen.

BP, 2006. North-West Hutton Decommissioning Programme. BP Aberdeen.

BP, 2010. Miller Decommissioning Program Consultation. MLR-A-D0-PM-PRO-00217.

Budd, G., 2008. *Alcyonium digitatum*. Dead man's fingers. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 20/07/2011]. Available from: <http://www.marlin.ac.uk/speciesinformation.php?speciesID=2442>

Crisp, D.J., 1958. The spread of *Elminius modestus* Darwin in north-west Europe. Journal of the Marine Biological Association of the United Kingdom, 37, 483-520.

Dare, P.J., 2007. Damage caused to mussels (*Mytilus edulis* L.) by dredging and mechanized sorting. J. Cons. int. Explor. Mer (1974) 35(3): 296-299

DECC, 2011. List of Approved Decommissioning Programmes, https://www.og.decc.gov.uk/upstream/decommissioning/programmes/approved.htm, accessed on 21/0711

Gass, S. & Roberts, J.M., 2006. "The occurrence of the cold-water coral *Lophelia pertusa* (Scleractinia) on oil and gas platforms in the North Sea : Colony growth, recruitment and environmental controls on distribution". Marine pollution bulletin 52 (5): 549–559

Edyvean, R. G. J., Terry, L. A. T. & Picken, G. B., 1985. Marine fouling and its effects on offshore structures in the North Sea – a review. International Biodeterioration Bulletin 21, 277-84.

EA, 2011. Environment Agency Website, Best Available Technique (BAT) and Best Practicable Environmental Option (BPEO), http://www.environment-agency.gov.uk/research/policy/32949.aspx, accessed on 04/08/11

Forteach, G. N. R., Picken, G. B., Ralph, R. & Williams, J., 1982. Marine growth studies on the North Sea oil platform Montrose Alpha. Marine Ecology Progress Series 8, 61-8

Heerema, 2011. Heerema Marine Contractors list of Decommissioning and Removal Experience, http://hmc.heerema.com/Default.aspx?tabid=419, accessed on 21/07/11

Hiscock, K., & Wilson, E., 2007. *Metridium senile*. Plumose anemone. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 20/07/2011]. Available from: <http://www.marlin.ac.uk/speciesinformation.php?speciesID=3806>

Hustoft, R. & Gamblin, R, 1995. Offshore Europe Paper No 30372-MS. SPE.

Klif, 2011. Decommissioning of offshore installations, Document number TA-2761, Published February 2011.

MTD Ltd., 1992. 'Appraisal of Marine Growth on Offshore Installations.' Marine Technology Directorate Limited, Publication 92/102, London.

Niall Bell *pers com*, Provision of information about previous decommissioning projects in the UKCS, July 2011

Oil & Gas UK, 2011. Decommissioning Baseline Study, Database of North Sea infrastructure and North Sea decommissioning cases to-date, Genesis job number: J-71891/A Document no. / File name: J71891-A-A-TN-001-B1.docm

Offshore Center Danmark, 2010. Decommissioning and rig repair, Decom is under way, ON/OFF News Magazine (20), January 2010

Picken, G. B., Ralph, R. & Williams, J., 1984. Patterns of macrofouling on steel platforms in the central and northern North Sea. In Corrosion and marine growth on offshore structures, pp. 10-22, eds. Lewis, J. R. & Mercer, A. D. Chichester: Ellis Horwood.

Picken, G. B., 1984. The operational assessment of marine growth on offshore structures. In Proceedings of 5th Offshore Inspection, Repair and Maintenance Conference. Offshore Conference & Exhibitions Ltd. And Spearhead Exhibitions Ltd.

Picken, G. B., 1985. Review of marine fouling organisms in the North Sea on offshore structures. In Offshore engineering with elastomers, paper 5. London: Plastics and Rubber Institute.

Roberts, J.M., 1999. www.sams.ac.uk/dml/projects/benthic/lophns.htm.

Sell, D. & Picken, G. B., 1986. ROV-based marine growth inspections. In Proceedings of 6th offshore Inspection, Repair and Maintenance Conference. Offshore Conferences & Exhibitions Ltd and Spearhead Exhibitions Ltd.

Sell, D., 1992. Marine fouling. Proceedings of the Royal Society of Edinburgh, 100B, 169-184.

SEPA, 2011. SEPA website on Special waste, http://www.sepa.org.uk/waste/waste_regulation/special_waste.aspx, accessed on 04/08/11

Spalding, M.D., Fox, H.E., Allen, G.R., Davidson, N., Ferdaña, Z.A., Finlayson, M., Halpern, B.S., Jorge, M.A., Lombana, A., Lourie, S.A., Martin, K.D., McManus, E., Molnar, J., Recchia, C.A. & Robertson, J., 2007. Marine ecoregions of the world: a bioregionalization of coastal and shelf areas. BioScience, 57, 573–583.

Tvedten, 2001. EIA of disposal of marine growth from Maureen at Aker Stord. Øyvind F. Tvedten, RF – Rogaland Research. 2001.

Veolia *pers com*, Telephone interview with Peter Daniels of Veolia Environmental Services UK Wallsend Decommissioning Yard, 13th July 2011.

Whomersley, P. & Picken, G. B., 2003. Long-term dynamics of fouling communities found on offshore installations in the North Sea. In Journal of Marine Biological Association of the United Kingdom, 83, 4288/1-5.

APPENDIX A

APPENDIX A: BMT Cordah Scope of Work

Task	Title	Client's Scope	Method	Output	Assumptions & Considerations
1	Legislative framework	High level review of environmental legislation relevant to the removal, transportation, cleaning and disposal of marine growth on decommissioned structures (including that relevant to the transport and removal of protected species)	Production of a desk-based review from internet sources of UK and Norwegian environmental legislation.	High level review of current and impending legislation both offshore and onshore relevant to the removal, transportation, cleaning, protected species, treatment and ultimate disposal processes, fates and liabilities. The output will be a matrix which will cover the most common scenarios for the management of marine growth, specifically removal of marine growth at the offshore location of the structure to be decommissioned, removal in transit, removal nearshore/inshore and removal onshore.	Includes UK and Norwegian legislation, because decommissioning of UK structures takes place in Norway. Given the scope and the budget, it will not be possible to provide a detailed comprehensive review of legislation and the implications in detail. The aim is to flag relevant legislation.
2	Summary of marine growth in the North Sea	A description of the types of marine growth encountered throughout the North Sea on offshore installations including how these relate to depth, temperature and other physical parameters.	Literature review on marine growth typically encountered in the North Sea using in-house sources (marine growth inspection reports and reviews and published literature / internet sources)	List of organisms by water depth and region (using GIS format as appropriate), summary of characteristics, comment on likelihood of transfer of viable species at receiving yards. The review of marine growth will be concise and will be aimed at non-specialist readers. The review will also	Most of the collated information on marine growth is for the northern, central and southern sectors of the UKCS. Information on marine growth in the Norwegian, Danish and Dutch sectors, and the Irish Sea are likely to be limited.

Task	Title	Client's Scope	Method	Output	Assumptions & Considerations
				summarise any potential implications regarding the transfer of non-native species, the viability of species on exposure to air, the degradation of marine organisms as a result of removal, and the implications of for transport of species designated under CITES.	
3	Review of the management of marine growth in decommissioned facilities	Production of matrix of the following information on structures decommissioned to-date: a) structure, development name and operator, date of installation and removal, (c) description of recovered structures, (d) location of installation offshore, (e) location of initial onshore receiving facility (and name of facility owner) and ultimate post-decommissioning status of structure or its components.	Sourcing and collation of data using a combination of consultation with JIP participants, decommissioning yards and web searching. Please note that we believe that the study is critically dependent upon the availability of this information and anticipate that it could be difficult without assistance from the JIP. We will use the data provided on decommissioning projects to-date by O&G UK as a starting point. In so far as practicable, we will collate the data that is publicly available to prepare a matrix. We will supplement this with information gathered from JIP	Table of collated information, as per the client's brief.	As there is no publicly accessible source of the required information, it is assumed that the JIP participants will be able to provide information and effect introductions to the relevant contacts in their companies, the engineering contractors responsible for individual decommissioning projects and/or the decommissioning yards. The review will focus on offshore structures (i.e. jackets) rather than subsea infrastructure (wellheads, manifolds, pipelines, etc).

Task	Title	Client's Scope	Method	Output	Assumptions & Considerations
			participants and the major decommissioning yards. From this and any additional information that we gather, we will select a limited number of case studies from each yard and determine how marine growth was managed. Given our understanding of the situation, we cannot guarantee to provide a comprehensive inventory of the ultimate post-decommissioning status for the structures or its components. Note that tasks 3 and 4 are linked.		
4	Facilities equipment and other technology	Production of a summary of the facilities, equipment and any other technologies currently being used to manage marine growth recovered with marine structures both offshore and onshore. Also the identification of other facilities with the capabilities necessary to perform	Sourcing of information predominantly through consultation with the two main decommissioning yards (Stord/Vats in Norway, Able in Teesside and Veolia in Tyneside), consultation with engineering contractors with experience of decommissioning and internet search. The aim of this task is to understand	Text, process flow diagrams of marine growth management options during decommissioning operations, and illustrations of facilities, equipment and technologies. The section will cover the three main strategies for the management and ultimate disposal of marine growth during decommissioning as well as any other strategies that become apparent	The JIP partners can provide introductions as above. We understand that introductions are going to provided for Vats in Norway (by Niall Bell), Able in Teesside (by BP for NW Hutton) and Veolia in Tyneside (by Shell for Indefatigable).

Task	Title	Client's Scope	Method	Output	Assumptions & Considerations
		decommissioning projects, including marine growth management, and the identification or technology gaps and challenges.	the practices and procedure that have been used previously and are being used currently to manage marine growth. We will break the process down into stages, and identify the inputs, outputs and ultimate end-points associated with each stage and the overall process. We will identify the any issues and lessons learned and implications regarding handling, storage, treatment and disposal, including issues such as odour and effluent management. Prior to contacting the yards, we will prepare a list of information requirements. Information gathering will be done by telephone. Technologies used offshore will be covered by a literature review and by contacting operators, as appropriate and if time allows).	during the study. The three strategies are: 1. Onshore landfilling 2. Onshore land-spreading 3. Offshore removal	

Task	Title	Client's Scope	Method	Output	Assumptions & Considerations
5	Compilation, quality assurance and issue of the draft report	N/A	N/A	Microsoft Word file of the draft report for review comments by the JIP	Most of the internal QA checking will be done during Tasks 1 to 5. Final formatting and review of the whole report will be carried out once all of Tasks 1 to 5 have been completed.
6	Review comments and issue of the draft report	Addressing two iterations of reviewers' comments and issue of the final report.	Meetings to discuss the comments and revision of the draft report (including text and figures) and justification of our response, as required.	Microsoft Word file of the final report.	The response will be based on a check sheet of comments provided by the client.
7	Project management, progress reporting and communications with client	Weekly e-mailed report and other communications.	Project management, compilation of weekly e-mail report on progress against each of the tasks, any factors that affect performance, progress against budget, and planned activities, and assistance required from the JIP (if necessary). This will be supported telephone and e-mailed communications with the client.	Interim meeting and weekly e-mailed reports.	N/A
8	Presentation of findings at meeting on 24th August 2001 at AECC	Preparation of materials for half hour presentation and presentation of findings at meeting.	Preparation of Microsoft PowerPoint presentation, and presentation and attendance at meeting at AECC.	See under Method.	N/A

APPENDIX B

APPENDIX B: Questionnaire for Decommissioning Contractors

Aim

1. To survey the main decommissioning contractors: Able Teeside; Veolia Tyneside and Shetland; Aker Stord; and AF Vats
2. To focus on structures which will have marine growth attached, such as submerged parts of steel and concrete jackets and not topsides, subsea infrastructure and smaller components

Questions for Decommissioning Companies

A. ***Track record in decommissioning – we will pre-populate this section with the information that we have gathered from other sources before asking the questions. The focus here is on the end-points***:

1. Which decommissioning projects have taken place the decommissioning companies (name of project)?
2. For which operator?
3. In which year(s) was the decommissioning work carried out?
4. At which facility (facilities) or yard(s) was the structure initially received onshore?
5. For individual projects, what structures were decommissioned (e.g. topsides, jacket, wellheads)? Note that we are only really interested in jackets.
6. What were the post-decommissioning end points/waste streams of the decommissioning process for each project, i.e. metals, concrete, plastics, hydrocarbons and marine growth? We do not need a detailed breakdown of every waste stream. We do need to understand what has happened to the waste streams which had marine growth on them.
7. Where did each of these waste streams go, e.g. metals and plastics for recycling, concrete for reuse or landfill, marine growth for landfill, land-spreading, composting or processing in the effluent treatment system?
8. What is the weight (or volume) of the wastes arising from marine growth on each project (if possible) or on a 'typical' project?

B. ***Management of marine growth:***

1. How do you address the management of marine growth?
   a. Project-by-project basis?
   b. General practice/operating procedures that apply to all projects?
2. Where is marine growth removed:
   a. Offshore at the field location?
   b. In transit on the barge while offshore or nearshore (e.g. in the fjord or near the port)?
   c. On the quayside?
   d. In the dismantling yard?
3. How is the marine growth removed at each of the relevant locations (both equipment and practices):

a. Equipment, e.g. water jetting, manual removal, other?
b. Onshore Practices e.g. do nothing (no specific practice); segregation and containment (skips, trailers or other) and subsequent treatment onsite or offsite; (dewatering, desalting, composting, landfilling, or others), discharge to the site's drainage and effluent treatment system or other?
c. Offshore practices e.g. do nothing (no specific practice), removal and disposal in the field; removal and disposal from the barge in transit; removal, containment on the barge and subsequent disposal onshore? [This question is likely to be more applicable to the operators].

During the interviews it became logical to alter the structure of questions 2 and 3 into "marine growth management procedures in previous decommissioning projects" and "current management practices".

C. Advances and challenges

1. Have the practices and facilities for the removal and management of marine growth improved over time (e.g. as a result of technological or regulatory change, or market driven investment by companies, or as a result of awareness of the issue). Are there lessons learned that would drive improvement?
2. Are there any regulatory drivers or constraints at present or impending? For example, requirement for pre-treatment prior to landfill or land-spreading, and exclusion of biodegradable wastes from landfill in future.
3. Are there any supply chain standards that affect the management options (e.g. relating to composting or recycling scrap metal; Would it be sufficient just to remove the attached mussels before sending the scrap metal for recycling)?
4. Are you aware of any technology gaps (needs for better equipment and practices) or are you considering the use of new equipment and practices at present? Are you aware of any new technologies under development?
5. Are there any constraints (bottlenecks) to limit the management options or throughput capacity (e.g. financial limitations, site location limitations, technology limitations, capacity limitations, transport infrastructure, available landfill, composting processes, land-spreading sites, and regulatory limitations)?
6. How do you deal with challenges relating to any of the following issues that many be relevant to your operations or decommissioning projects:
    a. Handling, storage and transport issues (e.g. containment and transport of a non-homogeneous biodegradable waste)
    b. Human health issues (from contact with the material)
    c. Odour or other types of nuisance (e.g. vermin)

Marine pollution, pollution of water courses (e.g. BOD, eutrophication) the INSTITUTE of ESTUARINE and COASTAL STUDIES

UNIVERSITY OF Hull
Institute of Estuarine and Coastal Studies

Causes and Consequences of Odours from Marine Growth Organisms

Report

Report to Oil and Gas UK

Institute of Estuarine and Coastal Studies

University of Hull

17 December 2012

Author(s): Dr. María C. Alvarez, Ellen Bell and Professor Michael Elliott

Report: ZBB801-F-2012

Institute of Estuarine & Coastal Studies (IECS)
The University of Hull
Cottingham Road Hull
HU6 7RX
UK

Tel: +44 (0)1482 464120
Fax: +44 (0)1482 464130

E-mail: iecs@hull.ac.uk

Web site: http://www.hull.ac.uk/iecs

Report to Oil and Gas UK

Causes and Consequences of Odours from Marine Growth Organisms

Report

17 December 2012

Reference No: ZBB801-F-2012

For and on behalf of the Institute of Estuarine and Coastal Studies

Approved by: Nick Cutts

Signed:

Position: Deputy Director, IECS

Date: 17 December 2012

This report has been prepared by the Institute of Estuarine and Coastal Studies, with all reasonable care, skill and attention to detail as set within the terms of the Contract with the client.

We disclaim any responsibility to the client and others in respect of any matters outside the scope of the above.

This is a confidential report to the client and we accept no responsibility of whatsoever nature to third parties to whom this report, or any part thereof, is made known. Any such parties rely on the report at their own risk.

Printed on 100% recycled paper

EXECUTIVE SUMMARY

After years of immersion, the subsurface section of offshore oil and gas platforms will have variable amounts of marine growth of uneven thickness attached to them. The final composition of the marine growth community will depend of several biotic and abiotic factors, such as temperature, species competition, wave action and the season of immersion.

When platforms reach the end of their productive life they need to be recovered and decommissioned onshore. The transportation of the platforms on to shore can take several days during which, the more susceptible organisms will dislodge or die off and rot or mummify. However, the organisms which are better adapted to survive prolonged periods of time out of the water, eg. those adapted to intertidal environments, will take longer to die-off and decompose. Organisms such as mussels and some macroalgae may survive out of the water for several days, especially under humid and cooler conditions and their death and decomposition may be delayed releasing strong odours during the cleaning process. This will occur until the flesh mummifies or the waste is taken to landfill.

During decommissioning, metal jackets are cleaned of marine growth, cut into pieces and recycled. During this process, the marine growth can emit substantial odours to lead to public concern. Oil and Gas UK commissioned the Institute of Estuarine and Coastal Studies (IECS) to evaluate the circumstances in which the different types of marine growth can be observed on offshore platforms and assesses the possible sources of odour during decommissioning. The report concludes that, of the possible sources of odour during the removal of marine growth, disturbance of anoxic layers and removal of putrefying organisms are the major sources of smell.

The report also identifies the circumstances where odours emitted during the cleaning process are likely to be more intense. For example, platforms originating from productive areas or removed in highly productive areas/times of the year will tend to emit stronger smells as organism fat content and DMS (odorous substance) emissions will be higher. Moreover, environmental conditions will also play a role in defining the extent and magnitude of the problem. On wet and slightly warm days, decomposition can be prolonged. During this period prevailing winds will determine the direction and extent of area affected by the smell.

Mitigating the problem during decommissioning will call for rapid removal of marine growth and spraying of odour suppressants when odour levels are high. However, the best approach will be the use of preventive measures such as clamp-on devices on jackets prior removal for the physical cleaning of the top *ca.*20m of marine growth prior decommissioning to land, particularly when a clear dominance of mussels in this layer is present.

TABLE OF CONTENTS

EXECUTIVE SUMMARY 82

1. BACKGROUND 85
   1.1. General trends in current management observations 86

2. INTRODUCTION 91
   2.1. Platform structure and decommissioning 91
   2.2. Biogrowth (marine growth) definition and process 91
   2.3. Odour sources 91

3. BIOGROWTH SEQUENCE OR SUCCESSION 93
   3.1. Types of organisms and communities 93
   3.2. Development of layers 97
   3.3. Environmental factors affecting communities 99

4. ODOURS FROM MARINE GROWTH 101
   4.1. Putrefaction 101
   4.2. Anoxia 102
   4.3. Living organisms 103

5. BIOGROWTH AND ODOURS DURING DECOMMISSION 104

6. CONCLUSIONS 108

7. REFERENCES 109

This page is intentionally blank.

1. BACKGROUND

With many North Sea oil and gas platforms reaching the end of their economically viable life, full decommissioning and removal of these installations after cessation of production is required (OSPAR, 1998). After decades at sea the amount of marine growth associated to the metal jackets of these structures can be significant. The decommissioning process includes the recycling of steel from the jacket at inshore yards; although removal of marine growth is required before this can be done.

Marine growth is defined here as the accumulation of marine organisms, the remains of marine organisms, their exudates and the accompanying marine sediments trapped by the growth. It may also be termed marine fouling and marine biofouling. Jusoh and Wolfram (1996) classified marine fouling into three types: hard growth, soft growth and long and flapping weed.

The 2011 Decommissioning Baseline Study (BMT, 2011) reviewed the management of marine growth during the recovery and decommissioning of offshore platforms onshore. Building on this, there is currently an assessment required by the client (Oil & Gas UK) to study the causes and consequences of odours from decaying marine growth on jacket surfaces, which in some cases have caused concern for local communities adjacent to platform deconstruction sites.

Experience from the client indicates that the magnitude of the odour problems during decommissioning of platform jackets will vary from one platform to another. There is therefore a need to investigate the causes and consequences of odours, together with some proposed solutions.

1.1. General trends in current management observations

The current study includes a literature review of the causes and consequences of odours from marine growth and of the odours emanating from marine organisms both alive and dead. In addition, the study approaches representatives from three onshore dismantling companies, two in Norway and one in the UK a trade association and Operators. Questions were posed regarding odours and marine growth attached to offshore platform jackets. Their responses have been combined in Table 1 together with some additional information from interviews conducted by BMT (2011).

Table 1. Summary of responses of decommissioning industries in Norway and the UK in relation to odour problems during marine fouling removal.

	Marine fouling	**Decommissioning**	**Odours**		
	Marine fouling and its removal.	**Jacket collection and treatment**	**Odour description**	**Odour reduction plans.**	**Conditions which increase odour.**
Onshore Dismantling Yard	Some marine fouling falls off very quickly while some can stay attached for a long time. Marine fouling is allowed to drop off unaided and then collected and disposed of.	Platforms are collected during spring and summer. Usually two days are allowed for transportation. Platforms are usually dismantled in the winter.	Odours smell like the sea. Strong odours have been experienced but are rare and usually dissipate after seven days.	In the case of strong odours, teams are sent up the jackets to scrape off mussels, which are then collected and disposed of.	Wet and windy weather make odour issues worse.
Operator and Onshore Dismantling Yard	The bulk of marine fouling observable at the arrival of the platform to the yard is due to blue mussels. Some marine fouling is removed offshore, with heavy lifting machinery. Once on dock, hydroblasting is done while the jacket is still erect. Marine fouling is sent for composting at a nearby landfill site, after composting the organic matter is used as a top layer for full	Removal occurs during spring and summer. In the past jackets have been left for several weeks before being dismantled and marine fouling removed. The current tendency is to remove marine fouling as soon as is reasonably practical.	Odours similar to composting seaweed or “rotten cabbage” arise from the jackets standing on the yard waiting to be cleaned.	Removal of marine fouling as soon as it arrives on dock to minimise the cleaning time.	Wet weather avoids flesh mummification which worsens and prolongs odour problems. Windy conditions will determine the extent and location of the affected area.

	landfill sites, this allows flora to colonise.				
Onshore Dismantling Yard	Jackets collected in spring have less marine fouling than jackets collected in late summer or autumn.	The jacket which waited two weeks for the cleaning process to start caused more problems. Weather during removal was very hot for the area, changing to colder, humid and windy during cleaning and dismantling.	Very bad smell that can last up to a month.	Removal of marine fouling as soon as it arrives in the dock to minimise the cleaning time. Suggest earlier removal of platforms from site to minimise marine fouling.	Odour problems seem mostly related to weather conditions: warm during removal followed by sudden wet and windy periods. Jackets gathered in spring do not give out as much odour as those collected in summer or autumn.
Onshore Dismantling Yard	Generally the marine fouling found on North Sea platform jackets is seaweed and mussels. By the time the platform arrives in the dock the marine fouling is dried out and dead and much of the marine fouling falls off in transit. The jacket is then collapsed within a week of it being brought into the dock and the dead marine fouling is scraped off. Although the need for composting was expected insufficient organic matter was produced so waste was incinerated and the energy produced	Platforms are collected during spring and summer. Usually four days are allowed for transportation. Platforms are usually left for no more than seven days before being dismantled.	Odours smell like the sea. Odours are only detectable close to the structure.	The contingency plan although never used is to spray odour suppressant onto the structure.	

	via incineration was recycled.				
Trade association	Platforms placed in the southern North Sea tend to come from shallower waters, are lighter and smaller and tend to have a smaller amount of marine fouling. The opposite applies to platforms from the northern North Sea, where platforms are larger; they come from deeper waters and the amount of marine fouling tends to be greater.				
BMT report Onshore Dismantling Yard 1 (2011)	Some marine fouling falls off while the jacket is being lifted from the sea. The rest is removed during transit by shovels and excavators or at the yard when it is scraped off the collapsed structure. It is then transported to a landfill site.				
BMT report Onshore Dismantling Yard 2 (2011)	Although some marine biota falls off while the jacket is being transported most is removed on shore by mechanical scraping or jet washing. It is then either sent to landfill or used in agriculture as a fertiliser.				

BMT report Onshore Dismantling Yard 3 (2011)	Again some marine fouling falls off in transport although on shore jackets are allowed to dry out and marine fouling falls off naturally. It is then sent to landfill. Any marine fouling remaining is combusted with the steel in the smelting process.				
BMT report Onshore Dismantling Yard 4 (2011)	Marine fouling is intentionally removed offshore using an ROV, water jets and brushes. This marine fouling will naturally be assimilated into the marine environment. Marine fouling is further removed onshore using shovels and excavators. Marine fouling is then composted.				

2. INTRODUCTION

2.1. Platform structure and decommissioning

There are many coastal developments which require the construction of different structures in the sea. One such is the installation of oil and gas platforms offshore for the exploration, extraction and processing of oil and natural gas.

Over the last five decades the North Sea has become one of the most productive energy suppliers. This has resulted in the installation of many oil and gas platforms that, as technology has become available, have been placed in increasingly deeper waters. However, when a field stops being profitable at the end of its economic life, the wells are plugged and abandoned and the platform is decommissioned. The OSPAR Convention and UK Petroleum Act 1998 requires that a full decommissioning and removal to shore of all offshore installations is undertaken (OSPAR, 1998).

There are several stages for this process but after the removal of the superstructure (accommodation and drilling apparatus), the jacket (the framework and legs surrounding the drilling structure) needs to be removed and transported onshore for recycling. This process ranges in duration between a few days to months during which marine growth needs to be removed and transported to composting or landfill sites.

2.2. Biofouling (marine fouling) definition and process

Biofouling (or marine fouling) is the attachment and subsequent growth of organisms, their remains and exudates as well as settled or entrapped material such as sediments on the structures immersed in water (totally or partially). The economic cost of biofouling has fuelled an active research field, specifically in methods for its prevention and control with emphasis on the development of antifouling compounds. However, the length of time platforms are immersed makes them a suitable settlement place for marine flora and fauna and consequently large quantities of marine fouling can attach.

The types and extent of the marine fouling is dependent on the nature and depth of the receiving surface, the speed and direction of the prevailing currents in relation to the source populations (and hence the time of the dispersing stages in the water-column), the date/season of installation in the year and the length of time (number of years) since installation.

During the decommissioning process of such offshore and underwater structures, marine fouling needs to be dealt with creating in some instances significant odour problems.

2.3. Odour sources

Decommissioning of platforms covered with marine fouling can result in an odour problem that can potentially reach a sufficiently significant level to induce complaints from the nearby public. There are three sources of such odours: putrefaction, anoxia and biologically-emitted smells (from living organisms).

Marine organisms will die off and decompose when platform jackets are removed and taken out of the water. This is the most significant source of odour although there are other possible sources. Several years of biofouling can extend to a considerable thickness (Jusoh & Wolfram, 1996) and produce a highly organic layer. The densely packed layers can become anoxic and colonised by anaerobic and methanogenic bacteria. As by-products of their metabolism, these microorganisms produce compounds such as hydrogen sulphide, which has the characteristic smell of 'rotten eggs'. Finally, some organisms are capable of producing volatile compounds as a defence mechanism; for example, some macroalgae species produce strongly smelling chemicals to deter herbivores.

3. BIOFOULING SEQUENCE OR SUCCESSION

Manmade offshore structures represent a suitable environment for marine sessile organisms to establish and grow. The area of virgin hard substratum provided by a platform will vary depending on the depth at which the platform is located. It has been estimated that in the Gulf of Mexico a 20m depth platform will provide over 8000 m^2 of hard substrate (Gallaway and Lewbel, 1982).

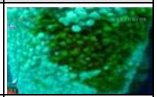
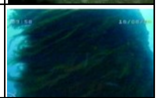
Biofouling succession is the sequence of species, their replacement and change in community structure through time following the colonisation of a new available hard substratum (Jenkins and Martins, 2010). This succession is in part predictable with early opportunistic species settling first and being gradually replaced by more long-lived taxa. However, abiotic conditions (temperature, season, currents, and wave action) will determine the final composition of the fouling assemblage.

3.1. Types of organisms and communities

Any material immersed in water will soon start being colonised by bacteria and other organisms such as yeasts and other fungi which together with mucopolysaccharides (mucus) create a biofilm. Biofilms are important in the biofouling process because they produce cues that induce some organisms to settle, this has been referred to as 'weathering' the surface thus mimicking natural hard marine substrata.

Table 1 details the general groups found on artificial structures in the North Sea. The first macrosessile colonisers are opportunistic species. Areas of high disturbance, like the splash zone will always be colonised by this kind of species. Species such as mussels, hydroids and macroalgae will therefore dominate the first 15-20m and be abundant throughout in the early stages of immersion and in areas of high disturbance. After a period of approximately 6-7 years better competitors but slower growers like anemones, soft corals and cold water corals will take over and tend to become dominant. This is the case for *Metridium senile*, a sea anemone that with time will takeover in many cases and dominate the platform community (Whomersley and Picken, 2003). Each type of colonising organisms has a particular set of environmental preferences. The presence of the first settlers depends on the time of year at which the structure was deployed. For example, barnacles have a restricted spawning period as their reproductive behaviour requires that they settle adjacent to each other. They also prefer high velocity currents and so would prefer bare surfaces. Other species, such as mussels, prefer more turbulent conditions and so may be a secondary settler.

Table 1; Maximum depth (m) of different groups of fouling organisms found on platforms of the different sectors of the North Sea. Hyphens indicate that the organisms were not recorded at the corresponding site (data from BMT, 2005; Forteath *et al.,* 1982; Guerin 2009, and BMT, 2011)

Sector	North	North	North	North	North	North	North	Mid	Mid	Mid	South	South	Images
Source	MacPherson, 2011	BMT, 2005	Guerrin, 2009	Guerrin, 2009	Guerrin, 2009	Guerrin, 2009	Guerrin, 2009	BMT , 2011	Forteath, 1982	Guerrin, 2009	MacPherson, 2011	Guerrin, 2009	
Depth	-160	-144	-120	-140	-140	-120	-120	-91	-91	-80	-25	-30	
Instalation year	-	1981	1992	1993	1978	1985	1986	-	1975	1996	-	2001	
Platform name	???	North West Hutton	Bruce	Dunbar	Heather alpha	North alwyn A	North alwyn B	???	Montrose alpha	Andrew	???	Hoton	
Sea anemonies (*M. senile*)	-145	-144	-120	-140	-140	-120	-120	-90	-91	-80	-25	-30	
Soft corals	-145	-144	-100	-60	-60	-40	-40	-90	-91	-80	-22	-	
Lophelia pertusa (coldwater coral)	-145	-144	-	-	-140	-120	-120	-	-	-	-	-	
Hydroids (white weed)	-160	-144	-	-	-140	-	-	-90	-31	-	-25	-	
Macroalgae	-20	-34	-20	-20	-15	-20	-20	-20	-13	-15	-8	-5	
Mussels	-10	-34	-	-	-	-	-	-10	-13	-	-15	-	
Bryozoans (sea mat)	-	-	-	-	-	-	-	-	-71	-	-	-	
Polychaetes (e.g. coral worm and keel worm)	-	-	-	-	-	-	-	-	-91	-	-	-	
Agregated tube worms	-160	-144	-	-	-	-	-	-	-	-	-	-	
Barnacle / solitary tube worms	-160	-	-	-	-	-	-	-90	-91	-	-25	-	
Sponges	-	-	-	-	-	-	-	-	-51	-	-	-	
Sea slugs	-	-	-	-	-	-	-	-	-31	-	-	-	
Star fish	-	-	-	-	-	-	-	-	-91	-	-	-	

Sessile fauna is dominated in many instances by hydroids (often called ‘white-weed’ by marine engineers, including *Tubularia sp.*), mussels and other bivalves such as saddle-oysters and macroalgae. The amount of mussel growth can vary largely between platforms (Forteath *et al.*, 1982; Guerin, 2009). Mussels are mostly present in the wave zone (0-20m) where they are generally overgrown by algae (Forteath *et al.*, 1982; Whomersley and Picken, 2003) hence large mussel beds are not commonly recorded but are more frequently observed as scattered individuals inbetween the seaweed. However, mussels can be the dominant organism in the fouling community for many years when the conditions are right and in areas of high disturbance.

Of the macroalage species the most commonly encountered are *Polysiphonia spp* and *Alaria esculenta* with especially large beds on the sunlit top areas of platforms. In the shaded areas macroalage are usually replaced by hydroids. The plumose anemone, *Metridium senile*, is also very abundant. It recruits later to platforms and grows slower but is a strong competitor that can regulate populations of fouling communities by smothering and killing competitor settlers (Nelson and Craig, 2011). This anemone has a broad distribution and can be found at all depths and on all beams (Table 1) becoming dominant in many cases from 30m to 80m depth (Whomersley and Picken, 2003).

An important fouling species in terms of their conservation status are cold-water corals, *Lophelia pertusa* as it is a protected species and special measures are needed when decommissioning. *L. pertusa* is reported to be present on several platforms of the North Sea (Gass and Roberts, 2006, Guerrin, 2009) creating in some places colonies sufficient for it to be the dominant species. In addition, as with any hard marine substrata, once certain taxa have settled then this dictates the following sequence of subsequent colonisers. For example, colonisation by limpets would control and perhaps prevent the development of algal populations.

Guerin (2009) extensively reviewed marine fouling on several platforms in the North Sea. The platforms studied were from three different areas (north, mid and south North Sea) and in platforms located at variety of depths and of different ages (Figure 1& 2 and Table 1). This study found that there was a difference in marine fouling assemblages of areas and between the inside and the outside faces of the jackets possibly as a result of a combination between the exposure to light and wave action. It also found that all platforms studied had occurrences of the main fouling organisms and that there was not a consistent pattern of fouling. Therefore, platforms share the same core fouling species but not the same pattern of fouling, with variations of species abundance and depth of occurrence not relating to the platform depth or location. However, the study observed that the year in which the platform was installed had an effect on fouling communities observed which was independent of the time elapsed since installation. It was concluded that season and inter-annual differences in larval availability might have an effect on composition of marine fouling organisms which may be detectable many years down the line. However, location is also expected to have an influence as different areas have particular currents and tidal conditions which can affect the supply of settling organisms. A good example of this is the occurrence of *Lophelia pertusa* as its presence or absence is expected to depend on water temperature and current patterns. These factors result in an absence of this cold water coral from platforms in the southern fields of the North Sea (Gas and Roberts, 2006).

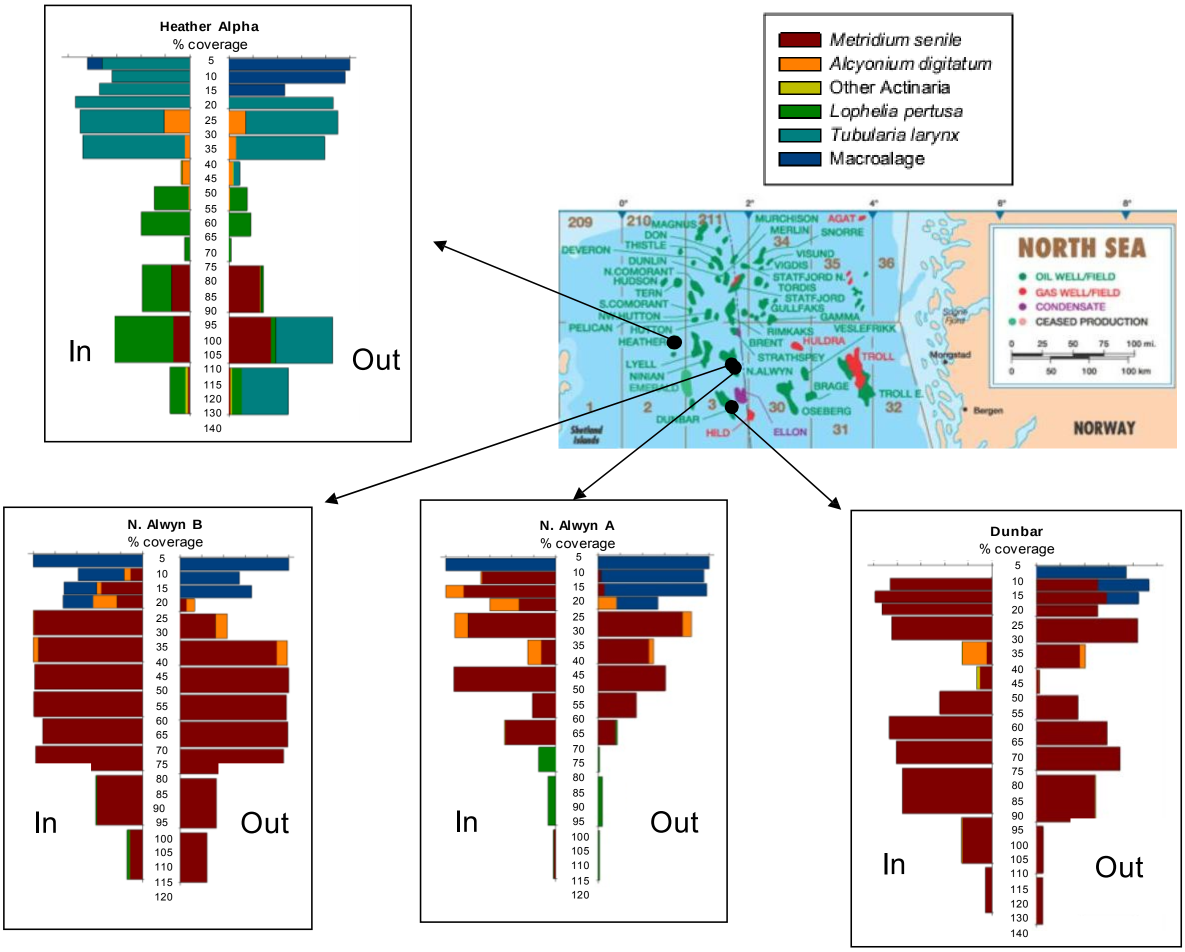


Figure 1. Heather alpha, North Alwyn A, North Alwyn B, and Dunbar platforms studied by Guerin (2009) in the oil fields in the northern North Sea. Graphs indicate the distribution with depth of major marine fouling groups. (Map from World Oil Inc., data from Guerin, 2009)

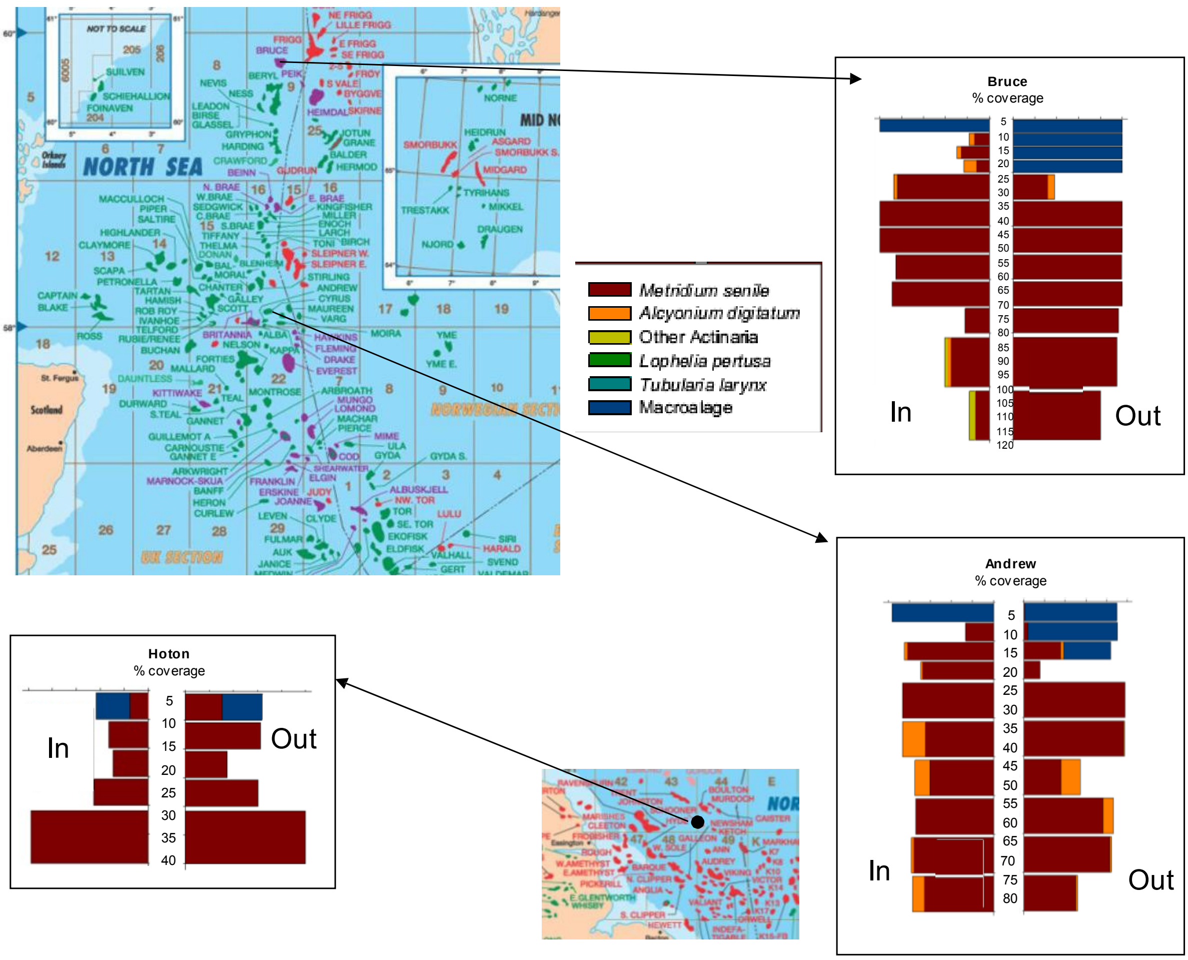


Figure 2. Platforms studied by Guerin (2009) in the Northern and Central gas fields of the North Sea (Bruce and Andrew respectively) and from the oil fields in the southern North Sea (Holton). Graphs indicate the distribution with depth of major marine fouling groups. (Map from World Oil Inc., data from Guerin, 2009)

3.2. Development of layers

The succession process is partly predictable, with opportunistic species that reproduce and grow quickly arriving first and being gradually replaced by longer lived, slower growing and better competitor species.

In general terms the process is as follows. As an artificial structure is immersed in seawater, organic dissolved compounds adsorb to the wetted substratum almost immediately creating what is known as a conditioning film. Microorganisms can then attach to the surface forming a biofilm. In order to anchor and protect themselves, bacteria and other microorganisms secrete polymeric substances that in certain circumstances promote the settlement of other organisms (Chambers *et al.,* 2006). It is then that settlement of the larvae and propagules of sessile organisms occurs (Figure 3).

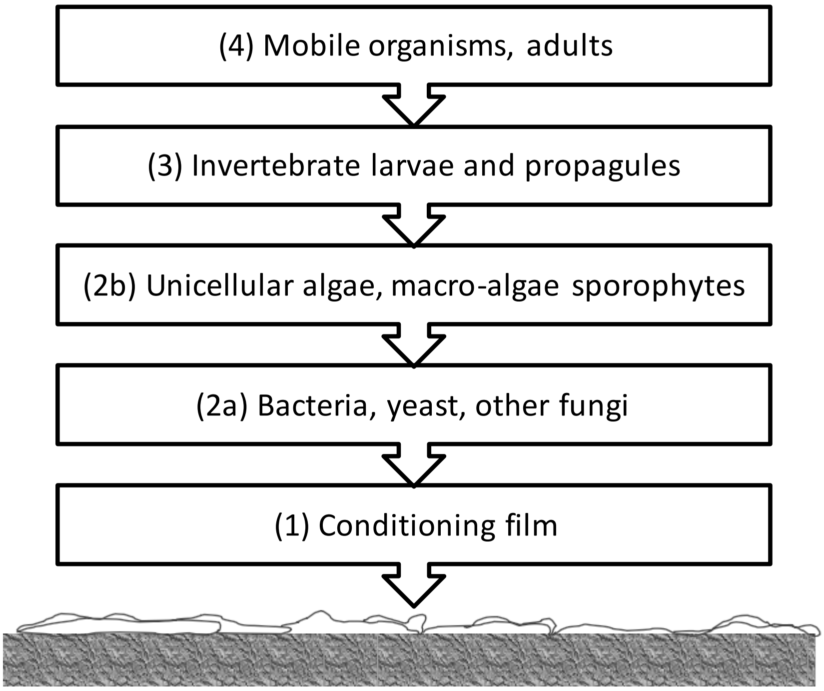


Figure 3: Theoretical biofouling succession processes (expanded from Terlizzi and Faimali, 2010).

However, this simplified model does not take into account the different factors that regulate the process. For example, the substratum features such as type of material and roughness of the surface will have an influence on these early stages. Colonisation of the substratum will depend on the probability of biofouling organisms encountering the structure once the conditioning film is formed. Further colonisation will again depend on the probability of an organism encountering the substratum, as all marine growth stages are continuously occurring being regulated by biological interactions (competition and predation) together with water-substrate and water-biofouling organisms interactions (Figure 4). Hence the local hydrodynamic regime, incorporating the direction and strength of currents, tidal influences, the wind and wave climate, will dictate the delivery of settling stages and their ability to become established. For example, although marine mussels may settle as spat, high energy conditions may mean that they are removed once a critical size is reached.

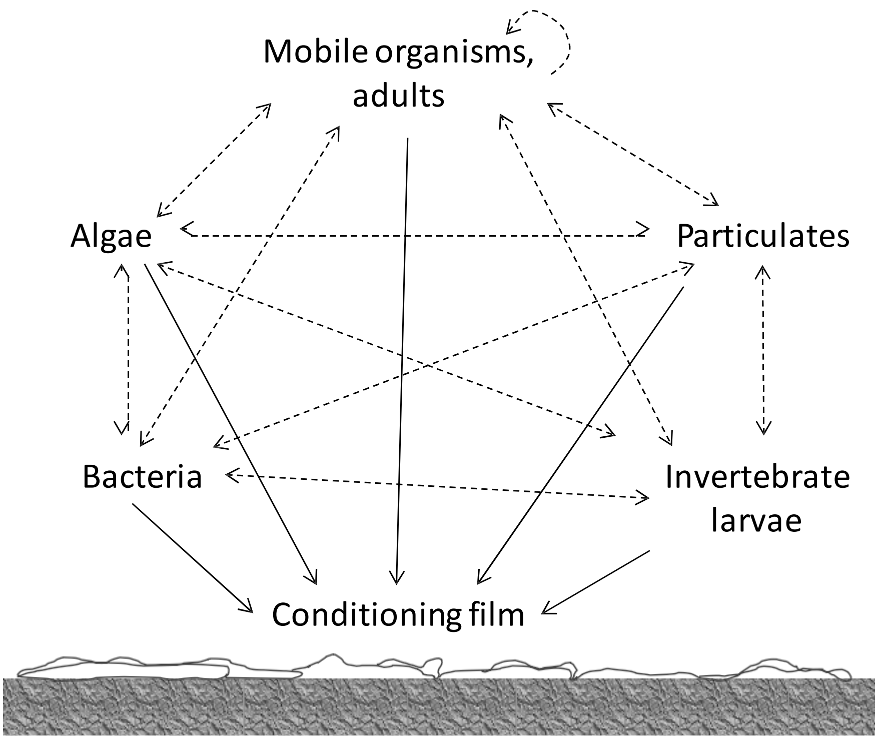


Figure 4 The development of layers is a continuous and dynamic process with all stages occurring continuously and regulated by species interactions and abiotic factors (modified from Terlizzi and Faimali, 2010).

3.3. Environmental factors affecting communities

Environmental factors play an important role in determining the species composition and amount of marine growth present by affecting biofouling organisms either directly or indirectly. Light availability will determine the proportion and type of micro- and macro-algae within the sessile community. Temperature will determine the type of marine growth assemblage as it regulates spawning period, settlement, and growth, reproduction and development of settled marine organisms. Salinity, although relatively constant in open marine waters, will have an important effect on determining the marine gorwth species in coastal waters where salinity regimes can fluctuate considerably. Therefore, environmental variables by modifying biofilm/substrata interactions can limit larval perception of the substratum leading to a slower rate of larval settlement (Figure 5).

The season of first submersion and length of submersion affect the colonisation of the jackets because of the natural fluctuation in the availability of larvae and/or propagules and the biological interactions between settled and settling individuals. The effect of the season of installation can be observed in the structure of the community for many years. This is especially true for species with peaks of larval availability. For example, barnacles have peaks where planktonic larvae are dispersing. If immersion occurs within this peak, the colony will receive large numbers of cyprid larvae (the settlement stage) and become dominated by these for many years as shown by long term studies (10yrs) conducted in the Baltic Sea (Qvarfordt *et al.,* 2006). However, there are also other species with a more constant supply of settling larvae that show no effect of season of immersion in their distribution. This is the case of mussels that will colonise throughout the year and hence show no difference in relation to the season of first immersion. It is of note that marine mussels often settle initially on algal or hydroid filaments, having primary and secondary settlement periods in which the dominant spring (i.e. early) settlers may eventually relocate to other sites.

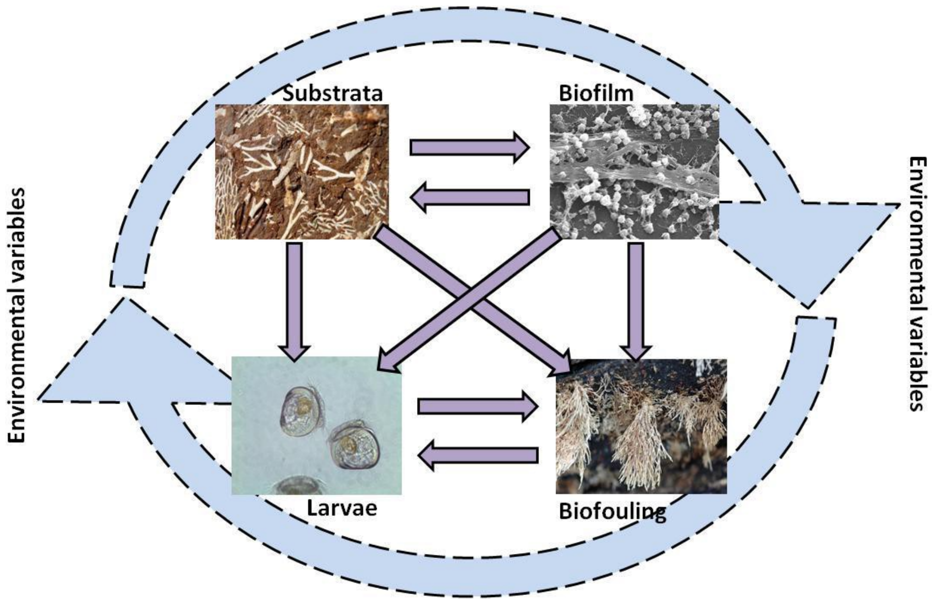


Figure 5; Conceptual model of the interactions between substratum, biofilm and larvae during larval settlement and the role of environmental variables. (Adapted from Terlizzi and Faimali 2010; larvae picture by Eric Sanford, UC Davis Bodega Marine Lab)

On a global scale, latitude is shown to have an effect on the diversity in terms of species richness of the marine fouling. It is well documented that structures located at lower latitudes will experience a larger diversity of marine growth (Canning-Clode and Wahl, 2010).

4. ODOURS FROM MARINE FOULING

Sources of smell from marine fouling attached to platforms can be classified in three major groups.

- ☐ Smell from organisms decaying or putrefying as they are exposed to air;
- ☐ Smell from the formation of anoxic environments,
- ☐ Smells produced by living organisms.

4.1. Putrefaction

When platform jackets are removed from the water, marine life attached to them starts to die off and decompose. This is the most significant source of odour as the decomposition processes take place. However, there are a number of odours associated with decomposing marine life and not all organisms emit the same types of odours. These odours can be associated with individual or groups of chemical compounds. Some of these odorous compounds are used as indicators of spoilage in fish, shellfish and crustaceans and, as a result, they are well documented in the literature. These include trimethylamine (TMA), indole, hydrogen sulphide, dimethyl disulfide, methyl mercaptan, ammonia, skatole, putrescine and cadaverine (Sarnoski *et al.,* 2010). Details of these odours associated with each of these chemicals can be found in Table 2. It is important to note that some of these chemicals can be detected at much smaller concentrations by the human nose

Table 2; Description of odours associated with specific chemical compounds regularly found at sites of decomposition in seafood (Table adapted from Olafsdottir and Fleurence 1998). OT_{50} =Odour Threshold at 50%, or the concentration at which at least half of the population exposed will experience an odour (US EPA, various)

Compound	Description of aroma.	Approximate OT_{50} (ppm)
Trimethylamine	Fishy, ammoniacal	$3.2\ 10^{-5}$
Indole	Moth ball, faecal-like	1.89
Hydrogen sulphide	Sulphury, rotten egg	$4.7\ 10^{-3}$
Dimethyl disulphide	Putrid, onion-like	$2\ 10^{-2}$
Methyl mercaptan	Rotten, cabbage-like	$4.1\ 10^{-2}$
Ammonia	Ammoniacal	50

Skatole	Moth ball, faecal-like	$7\ 10^{-4}$
Putrescine	Putrid, rotten	$8\ 10^{-5}$
Cadaverine	Putrid, rotten	---

Unfortunately, there is little information in the literature about the decomposition process of non-consumable marine life. Some reports have indicated that decomposing sponges and seaweeds also emit the odorous gas hydrogen sulphide (Weber *et al.,* 2012; Salovius and Bonsdorff, 2004).

It is important, when considering the odours emitted by the decomposition of marine growth during the decommissioning of jackets, to realise that organisms will die off and decompose at different rates. Bio-fouling organisms may be further separated into sessile and sedentary organisms: the former may be regarded as being firmly fixed to the substratum (such as hydroids, bryozoans and barnacles) whereas sedentary organisms occur in a place but may be moved more easily without damage to the organisms. Mussels, which can detach their byssus threats, anemones and limpets are sedentary and may have a limited ability to relocate elsewhere if they have the opportunity to detach from the substratum.

While soft bodied anemones will tend to dislodge easily and dry quickly, some other organisms are adapted to be exposed to air for a period of time. Their natural intertidal environment has selected species resistant to desiccation and some can take several days or weeks to die and decompose. For example, Babarro and Zwaan (2008) demonstrated that 50% of the population of intertidal bivalves species exposed to air such as the blue mussel, *Mytilus edulis*, and *Macoma baltica* can survive approximately 14 and 25 days respectively, while 10% of mussels were able to live exposed to air by up to nearly 20 days. Also, some macroalgae are resistant to periods of desiccation and can survive periods of exposure to air of several days (Little *et al.,* 2009). These algae will therefore take longer to die off and decompose. Moreover, this resistance to desiccation will be in some instances prolonged by humid environments (Little *et al.,* 2009). Similarly, any marine organisms adapted to living in the intertidal zone between high water neap and high water spring tide zones will have an ability to survive limited periods out of water.

4.2. Anoxia

Several years of biofouling can extend to a considerable thickness. Mussel beds can form and develop a thickness of up to 350mm while some of the larger seaweeds can add to this thickness, reaching lengths of up to 5m (BMT, 2011). These densely packed layers can become anoxic and colonised by anaerobic and methanogenic bacteria. This is most likely to occur in areas with a high abundance of mussels or macroalgae and may be exacerbated as marine mussels and other bivalves produce pseudofaeces (filtered and deposited sediment) which may accumulate in the interstices between the organisms again reducing oxygen diffusion and enhancing anoxia. When the number of mussels exceeds a specific threshold for a set area, oxygen levels are depleted and anaerobic bacteria start to form colonies and breakdown dead organic matter (Norling and Kautsky, 2008). Some seaweed species are also capable of creating anoxic areas. *Ulva compressa,* because of its large sheet like structure, sometimes prevents the access of oxygen to an area. As a result the oxygen deprived area under the seaweed becomes anoxic and once more anaerobic bacteria start colonisation (Bäck *et al.,* 2000). These anaerobic and methanogenic bacteria decompose organic matter and produce odorous compounds like hydrogen sulphide and methyl mercaptan (Dunnette *et al.,* 1984; Mazik 2004; Gray & Elliott, 2009). In the case of hydrogen sulphide, human detection of the smell (Table 2) is at <0.005 ppm and the occupational exposure maximum is 5 ppm, therefore monitoring the emission of hydrogen sulphide will allow actions to be taken before reaching critical levels.

4.3. Living organisms.

Some marine organisms are capable of producing volatile compounds (as a defence mechanism) that have a characteristic smell. Amongst the organisms potentially colonising platform jackets in the North Sea there are a number which may produce odours whilst alive. These organisms include the seaweeds *Ulva lactuca, Ulva intestinalis* and other macro-algae (Forteath *et al.,* 1982). *U. lactuca* and *U. intestinalis* produce and contain dimethylsulphoniopropionate (DMSP) (Smit *et al.,* 2007 and Summers *et al.,* 1998). DMSP in itself is odourless but is the precursor to dimethylsulphide (DMS) which has been described as having an "off", "petroleum like" or "seaweed or kelp like" smell (Smit *et al.,* 2007). DMS has an odour threshold of 0.003ppm (Nagata, 1993). DMSP is produced by many types of macro-algae, it functions as an osmoregulator and a cryoprotectant although there is also evidence to suggest that it functions as a herbivore deterrent. Mechanical damage to macro-algae leads to the release of DMSP ligase which cleaves breaks up DMSP into DMS and acrylic acid; this reduces herbivory for the plant as well as producing the odours described above (Alstyne and Houser, 2003). The amount of DMSP released is also variable between species. Some species of the algae *Polysiphonia* or *Ulva* can produce considerably high levels of DMS (Karsten *et al.,* 1994). Moreover, trimethylamine may also be released from seaweeds to prevent herbivory; this has a fishy, ammoniacal odour (Yun *et al.,* 2012, Olafsdottir and Fleurence 1998) having that has a very low odour detection threshold i.e. perceivable by human sense of smell at relatively low levels (Table 2).

5. BIOFOULING AND ODOURS DURING DECOMMISSIONING

All literature reviewed indicates that platforms in the North Sea are not identically fouled and that differences between marine growth assemblages could arise by a combination of factors. Guerin (2009) compared marine growth between several platforms from different areas of the North Sea and of different ages (see Table 1). He found that age/season of installation had a greater influence on the differences observed between platforms while location had a lesser influence. Platforms located adjacent to each other (e.g. North Alwyn A and B) showed significant differences that might be partly explained by the one year difference in installation. This suggests that there is an annual variation in microfouling organisms. Settling larvae due to environmental conditions/seasons might account for those differences observed through effects on the colonisation and early succession stages/rates. Rasmussen (1973) detailed the spawning period, time in the plankton and settlement time of many different marine organisms in relation to ambient seawater temperature in NW Europe. This indicates that many organisms have temperature thresholds for spawning and hence times of settlement may vary with the climatic conditions each year.

The information evaluated and the interviews held with individuals from different industries, suggest that putrefaction is the main source of odours during the decommissioning process. The other possible source of odour is the disturbance of anoxic layers created by the layering of biofouling organisms. Odours from both processes will be enhanced during the warm and humid summer months and while the platform jackets are dismantled.

During the decommissioning process some (sedentary) marine growth will fall off, by dislodging themselves soon after the platform is removed from its site and thus will not cause odour problems (e.g. anemones). Other (sessile) organisms will not be able to do this and will eventually die and start to decompose .

Decomposition will end when the organisms have either fully decomposed or the flesh dehydrates and mummifies as decomposing organisms require certain amount of water.

This process is temperature and humidity dependent, as decomposition will run faster in hot and humid conditions. Under certain weather conditions (hot, windy and dry weather) this process will be relatively short as flesh will mummify quickly. However, when the weather is warm and humid, the process can take longer, with odours being produced for longer periods of time.

Moreover, some marine intertidal organisms are adapted to survive out of the water for a period of time. A good example is mussels, which can survive up to 20 days while being exposed to the air (Babarro and Zwaan, 2008). Under stress or emersion, mussels will shut their shells (valves) creating a microenvironment and adjusting their metabolism to be able to remain alive for a length of time. The amount of time mussels can survive like this will be temperature and humidity dependant. Some seaweed species are also adapted to intertidal conditions and are able to survive for some time out of the water without drying out completely.

Anoxic layers created during years of marine fouling deposition are not expected to give out strong odours until they are disturbed. Therefore, once a platform is taken out of the water, there is an expected timeline of odours produced by different groups of organisms at different times (Figure 6)

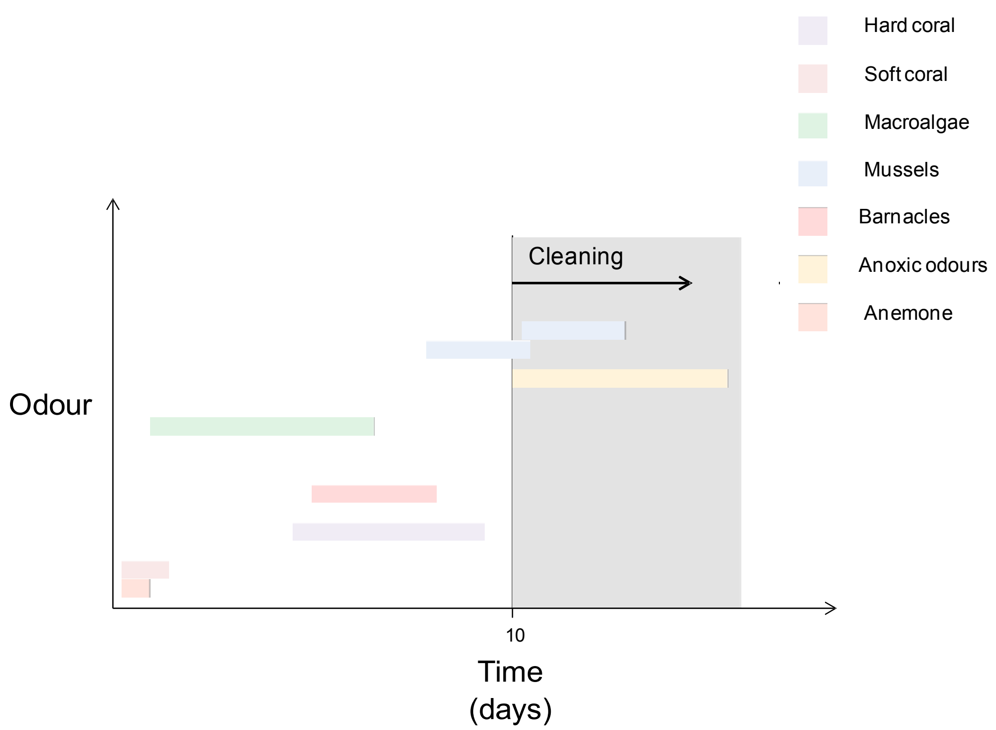


Figure 6. Model of odour production during decomposition by the different fouling organisms, taking into account; the survival rates of different organisms out of water, the capacity or easiness for some organisms to dislodge themselves when under stress and the importance of odours emitted by the disturbance to the anoxic layer.

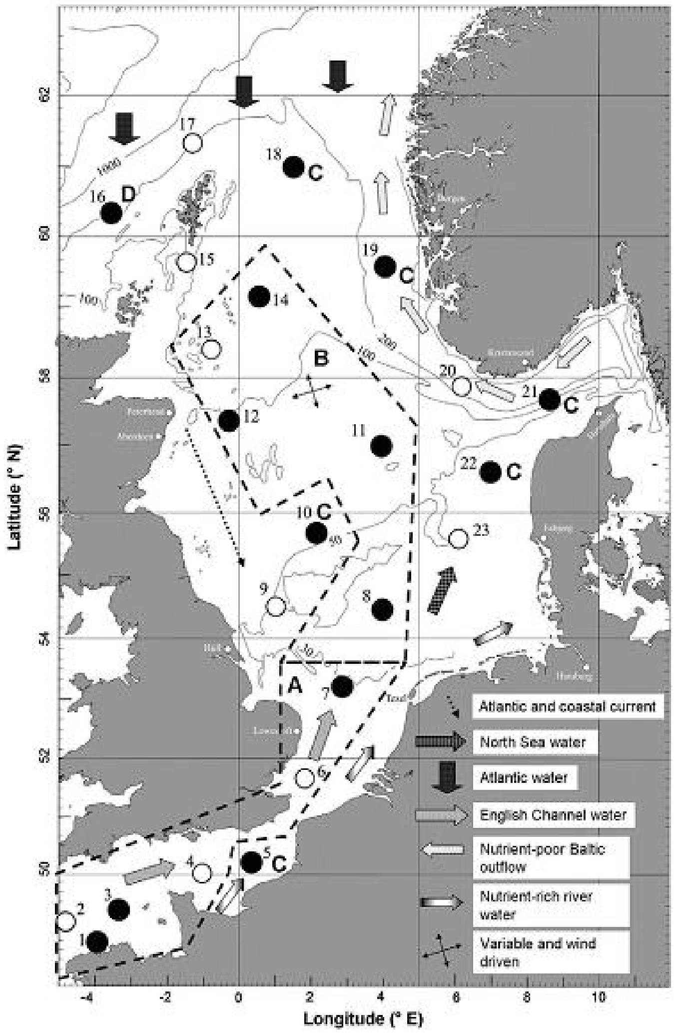
Furthermore, the literature suggests that organisms that are well fed in rich and highly productive environments will be more likely to emit stronger odours during decomposition. This is due mainly to higher levels of amines and DMS emissions (Smit *et al.,* 2007 and Summers *et al.,* 1998). Therefore, platforms removed during a period of higher productivity in surrounding waters will be more liable to emit stronger odours during decommissioning.

There are a number of environmental factors that may enhance odour production from decaying marine life. These include temperature, humidity, precipitation and wind strength. Decommissioning companies have indicated that warm, wet and windy weather enhances odour problems. It is expected that in humid and warm (not hot) conditions, the flesh of organisms and anoxic layers will be kept wet allowing bacterial decomposition to go on for a lengthy period of time. This will result in odour emission from the platform for a longer time. Winds will then determine the direction and extent of the area affected by the odour problems.

Not surprisingly, odour problems are also affected by the quantity of marine fouling. This is influenced by the season of platform removal as fouling community production will be larger in late summer and early autumn. Therefore jackets removed during this time of the year will be expected to emit stronger smells than jackets collected in the spring. Related to this will be the location of the platform decommissioned.

It has also been pointed out in one of our interviews that there is a tendency for jackets from more northern areas of the North Sea to come from deeper waters and have more marine growth than jackets taken from southern areas of the North Sea. This may mean that jackets from northern areas are more likely to develop odour issues. These observations can be partly explained by description of the types of organisms under different conditions and the sequence of growth described above. This is also supported by the observations made by Masquelier *et al.,* (2011, Figure 7), different areas of the North Sea (between English Channel, North Sea and Atlantic waters) were clustered in four different groups according to their phytoplankton composition. Differences between sites were mainly explained by the variations in temperature, nutrients and total chlorophyll-a. The phytoplankton studied was of one single type responsible for most of the flux of organic matter to higher trophic levels. This also indicated significant differences between areas of the North Sea in terms of their biological composition and productivity.

A)



B)

	Stations	Stratification	Temperature (°C)	Salinity (p.s.u.)	Phosphates (µM)	Nitrates (µM)	Ammonium (µM)	Silicates (µM)	Water masses
A	1-3-7	-	14.6-15.1	34.2-35.3	0.07-0.15	0.1-1.5	0.1-0.7	0.4-1.8	English Channel
B	8-11-12-14	+	7.6-15.4	34.5-35.2	0.01-0.8	0.04-11.1	0.05-2.9	0.03-3.74	North Sea
C	5-10-18-19-21-22	±	7.4-16.1	30.2-35.4	0.01-0.8	0.03-12.3	0.05-1.68	0.06-5.74	Freshwater
D	16	-	10-12.3	35.3-35.4	0.2-0.8	3.2-11.8	0.05-1.2	1.14-4.31	Atlantic

Figure 7. Distribution of North Sea sampling stations where a variety of physico-chemical parameters and abundance of microphytoplankton were measured in the summer of 2007. The map shows the stations numbers and the clusters of sites (stations with the same letter belong to the same cluster) based on Bray-Curtis distances calculated from microphytoplankton abundances (A). Specific characteristics of each cluster are identified bellow (B) indicating the level of stratification (- for well mixed and + for stratified), range of values of salinity, nutrients, and water origin.

6. CONCLUSIONS

- Biofouling (or marine growth) is the attachment and subsequent growth of organisms, their remains and exudates and settled material such in between. This occurs in steps that are in some degree predictable.
- The biofouling sequence or succession starts with the adsorption of compounds by the inert surface. This induces colonisation of microorganisms which then enhances the settlement of 'seeds' of larger organisms. The final composition of the fouling assemblage will depend on many biotic (species interactions) and abiotic factors (temperature, current speed, light, etc).
- Odours from marine growth can be either emitted by dead or living organisms. The types of odours can be a result of putrefaction, anoxia or emitted as a defence mechanism. During onshore decommissioning, anoxia and putrefaction will be the main sources of odour.
- Intertidal organisms are more resistant to desiccation and will take longer to die, therefore causing odour problems for an extended period of time, especially in wet conditions.
- Of the many organisms that can colonise offshore platforms, mussels are expected to create the worst odour problems due to their ability to close their shells and survive out of water for several days.
- Location of platforms can have an effect on odour production as it has been reported that jackets from northern and deeper areas tend to have more marine growth on them and produce stronger odours when cleaned.
- Within a location, removal of platforms after highly productive season (e.g. end of summer) will be liable to greater odour problems mainly because marine growth biomass will be higher.
- Reports of dominance of mussels in the upper-most sections of decommissioned platforms from a North Sea field producing strong odour problems supports the conclusions above.
- Environmental conditions will influence the strength of odour problems. Warm and humid weather is expected to worsen and prolong odour problems, while windy conditions will just increase the affected area.
- Of the many chemicals that can give odour problems, their intensity in terms of odour threshold at which 50% of the population exposed will detect the odour (OT_{50}) varies. In general their order of detectability (beginning with the most detectable) is: trimethylamine, putrescine, skatole, DMS, hydrogen sulphide, dimethyl disulphide, methyl mercaptan, indole, and ammonia (note: no values was found for cadaverine)
- There are various solutions or mitigations to odour problems during decommissioning. It is always important to act quickly in the removal of marine growth, especially when decommissioning yards are located in humid areas. Continuous monitoring on strategic sites, where odours can reach populated areas, is important. When odours are detected, spraying with odour suppressants might be an option, however, working conditions might make spraying difficult in some cases. When weather conditions favour the quick drying of marine growth, decommissioning without removal has been possible.
- Preventive measures that will result in the removal/prevention of marine fouling seem to be the best approach. One of such preventive measures is the removal of marine fouling on site using 'clamp-on' devices eg. Wave Marine Growth Preventers, which physically clean structures using wave/tidal power.

7. REFERENCES

Babarro, J.M.F., Zwaan, A.D. 2008. Anaerobic survival potential of four bivalves from different habitats. A comparative survey. Comparative Biochemistry and Physiology, Part A 151: 108-113.

Bäck, S., Lehvo, A., Blomster, J. 2000. Mass occurrence of unattached Enteromorpha intestinalis on the Fnnish Baltic Sea coast. Annales Botanici Fennici 37: 155-161.

BMT Cordah Ltd., 2005. Assessment of the weight of marine growth on the North West Hutton platform. Report BPX54/NWH/06.

BMT Cordah Ltd., 2011. Management of marine growth during decommissioning. Report A.CON.093.

Canning-Clode, J. and M. Wahl. 2010. Patterns f fouling on a global scale. *In:* Biofouling (ed Dürr, s. and Thomason, J.C.) Wiley_Blackwell, Oxford, UK

Chambers, L.D., K.R. Stokes, F.C. Walsh, R.J.K. Wood. Modern approaches to marine antifouling coatings. Surface and Coatings Technology 201: 3642–3652

Dunnette, D.A., Chynoweth, D.P., Mancy, K.H.1985. The source of hydrogen sulphide in anoxic sediment. Water research 19: 875-884.

Forteath, G.N.R., Picken, G.B., Ralph, R., Williams, J., 1982. Marine growth studies on the North Sea oil platform Montrose Alpha. Marine ecology- Progress Series 8:61-68.

Gallaway, B. J. and Lewbel, G. S. 1982. The ecology of petroleum platforms in the northwestern Gulf of Mexico: A community profile. U.S. Fish and Wildlife Service, Office of Biological Sciences,Washington DX. FWS/OBS-82/27. Bureau of Land Management, Gulf of Mexico OCS Regional Office Open-file Report 82-03. 92 pp

Gass S.E. and J.M. Roberts. 2006.The occurrence of the cold-water coral Lophelia pertusa (Scleractinia) on oil and gas platforms in the North Sea: colony growth, recruitment and environmental controls on distribution. Marine Pollution Bulletin 52: 549-559

Grey, J.S. and M. Elliott. 2009. Ecology of marine sediments. OxfordUniversity Press, London

Guerin, A.J. 2009. Marine communities of North Sea offshore platforms, and the use of stable isotopes to explore artificial reef food webs. PhD Dissertation. University of Southhampton, UK.

Jenkins, S.R. and Martins, G.M. 2010. Succession on hard substrata. *In:* Biofouling (ed Dürr, S. and Thomason, J.C.) Wiley_Blackwell, Oxford, UK pp: 60-72

Jørgensen, D. 2012. OSPAR's exclusion of rigs-to-reefs in the North Sea. Ocean & Coastal Management 58: 57–61

Jørgensen, T. S. Løkkeborg, and A.V. Soldal. 2002. Residence of fish in the vicinity of a decommissioned oil platform in the North Sea. ICES Journal of Marine Science, 59: S288–S293.

Jusoh, I. and J Wolfram. 1996. Effects of marine growth and hydrodynamic loading on offshore structures. Jurnal Mekanikal, Jilid 1:77-98

Karsten, U., K. Kück, C. Daniel, C. Wiencke, and G. O. Kirst 1994. A method for complete determination of dimethylsulphoniopropionate (DMSP) in marine macroalgae from different geographical regions. Phycologia, 33 171-176.

Little C., G.A. William, and C.D. Trowbridge. 2009. The biology of rocky shores (2nd Ed.) Oxford University Press, New York.

Masquelier, S., E. Foulon, F. Jouenne, M. Ferréol, C.P.D. Brussaard, and D. Vaulot. 2011. Distribution of eukaryotic plankton in the English Channel and the North Sea in summer. Journal of Sea Research 66: 111–122

Mazik, K. 2004. The influence of petrochemical discharge on the bioturbation and erosion potential of an intertidal estuarine mudflat (Humber estuary UK). The University of Hull, UK.

Nagata Y. 1993. Measurement of odor threshold by triangle odor bag method. In: Odor measurement review. Tokyo: Office of Odor, Noise and Vibration Environmental Management Bureau, Ministry of Environment. p 118–127 (available at http://www.env.go.jp/en/air/odor/measure/02_3_2.pdf)

Nelson, M.L. and S.F. Craig. 2011. Role of the sea anemone *Metridium senile* in structuring a developing subtidal fouling community. Marine Ecology Progress Series 421: 139–149

Norling, P., Kautsky, N. 2008. Patches of the mussel Mytilus sp. Are islands of high biodiversity in subtidal sediment habitats in the Baltic Sea. Aquatic Biology 4: 75-87.

Øen, S., P.E. Iversen, R. Stokke, F. Nielsen, T. Henriksen, H. Natvig, Ø. Dretvik, F. Martinsen, G. Bakke, 2010. Decommissioning of offshore installations. Climate and Pollution Agency, Norway.

Olafsdottir, G., Fleurence, J. 1998. Evaluation of fish freshness using volatile compounds – classification of volatile compounds in fish. In Methods to Determine the Freshness of Fish in Research and Industry, Proceedings of the Final meeting of the Concerted Action “Evaluation of Fish Freshness” AIR3 CT94 2283. Nates Nov 12-14, 1997. International Institute of Refrigeration, 55,69.

OSPAR, 1998. OSPAR Decision 98/3 on the Disposal of Disused Offshore Installations. OSPAR 98/14/1-E, Annex 33. p. 8

Rasmussen, E., 1973. Systematics and ecology of the Isefjord marine fauna (Denmark). Ophelia, 11: 1-507

Salovius, S., Bonsdorff, E. 2004. Effects of depth, sediment and grazers on the degradation of drifting filamentous algae (Cladophora glomerata and Pilayella littoralis). Journal of Experimental Marine Biology and Ecology 298: 93-109.

Sarnoski, P.J., O’Keefe, S.F., Jahncke, M.L., Mallikarjunan, P., Flick, G.J. 2010. Analysis of crab meat volatiles as possible spoilage indicators for blue crab (Callinectes sapidus) meat by gas chromatography-mass spectrometry. Food chemistry 122:930-935.

Smit, A.J., Robertson-Andersson, D.V., Peall, S., Bolton, J.J. 2007. Dimethylsulfoniopropion-ate (DMSP) accumulation in abalone Haliotis midae (Mollusca: Prosobranchia) after consumption of various diets, and consequences for aquaculture. Aquaculture 269: 377-389.

Terlizzi, A. and M. Faimali, 2010. Fouling on artificial substrata. *In:* Biofouling (ed Dürr, s. and Thomason, J.C.) Wiley_Blackwell, Oxford, UK

Weber, M., de Beer, D., Lott, C., Polerecky, L., Kohls, K., Abed, R.M.M., Ferdelman, T.G., Fabricius, K.E. 2012. Mechanisms of damage to corals exposed to sedimentation. Proceedings of the National Academy of Sciences E1558-E1567.

Whomersley, P. and G.B. Picken. 2003. Long-term dynamics of fouling communities found on offshore installations in the North Sea. Journal of the Marine Biological Association of the UK, 83: 897-901

A part of BMT in Energy and Environment

Decommissioning Baseline Study: Review of the Management of Marine Growth during Decommissioning, Comparative Assessment

Reference: A.O&G.003
Client: Oil & Gas UK Limited
Date: May 2013

Commissioned by Oil & Gas UK

Intentionally blank page

Document Control

Document Title	Decommissioning Baseline Study: Review of the Management of Marine Growth during Decommissioning: Phase 1A Comparative Assessment
Client Project Title	As above
Client	Oil & Gas UK Limited
BMT Cordah Document Ref.	A.O&G.003
Client Document Ref.	Not Applicable
Rev.	V2.0 Final Report

BMT Cordah Limited

Broadfold House,
Broadfold Road, Bridge of Don
Aberdeen
AB23 8EE

Tel: +44(0)1224 414200

Fax: +44(0)1224 414250

Email: enquiries@bmtcordah.com

Website: www.bmtcordah.com

Intentionally blank page

Contents

Non-Technical Summary 117

Introduction 121

1. Scope of Study 121

2. CA Approach 121

3. Marine Growth on the Generic Offshore Structure 124

4. Marine Growth Removal at Decommissioning Yard 126

5. Marine Growth Removal *In Situ* at Offshore Location 132

6. Marine Growth Removal at Intermediate Offshore Location 140

7. Comparison of Overall Performance 149

8. Emerging Technology 153

9. Conclusions 154

10. References 156

NON-TECHNICAL SUMMARY

Oil & Gas UK Ltd (O&G UK) commissioned BMT Cordah Ltd (BMT) to conduct a high-level comparative assessment (CA) of operations for the removal of marine growth from the steel jackets of redundant oil and gas platforms at offshore and onshore locations in northern European waters. This work follows on from an initial study to establish the management options for marine growth during decommissioning (BMT, 2011). Both studies form part of O&G UK's Joint-Industry Programme on Decommissioning.

The CA's purpose was:

- to evaluate and compare the performance of the offshore and onshore removal options against the following performance criteria:
    - technical feasibility;
    - environmental and societal impact;
    - energy usage and CO_2 emissions;
    - safety in terms of Potential Loss of Life (PLL); and
    - cost.
- to identify specific advantages and disadvantages that may affect the selection or development of options for marine growth removal during decommissioning.

The study compared the following options for removing marine growth:

- onshore at a decommissioning yard where marine growth would be removed by mechanical scraping with buckets and other tools on excavators and wheel loaders of varying sizes, manual removal using shovels and water jetting;
- offshore where the jacket would be *in situ* at the field location where marine growth would be removed by ROVs (Remotely Operated Vehicles) equipped with devices to scrape off the growth; and
- an intermediate location, such as a fjord, sea loch, inlet or inshore waters where the entire jacket or sections of the jacket would be moved to on a barge, where marine growth would be removed by water jetting or scraping.

The study's starting point was to establish a common jacket structure from which marine growth would be removed. A large steel jacket of a hypothetical northern North Sea installation was used in the comparison of the three removal options.

The CA's methodology followed DECC's 'Guidance Notes: Decommissioning of Offshore Installations under the Petroleum Act 1998' (DECC, 2011). However, the assessment was conducted at a higher level than typically used for specific decommissioning projects, mainly because of commercial confidentiality and technical and operational uncertainties about particular methods for removing marine growth. Information on the methods for removing marine growth was gathered through consultation with experienced practitioners from industry (see Acknowledgements).

Table 1 summarises the results of the comparative assessment. Section 8 gives the scoring and ranking method. The remainder of this summary outlines the results and conclusions of the CA.

Table 1: Summary of the comparative assessment of the three options for the removal of marine growth during decommissioning (Scoring: 0 – most favourable to 5 – least favourable)

Assessment Criterion	Removal at decommissioning yard		Removal *in situ* offshore		Removal at intermediate location		Differentiator
	Assessment	Score	Assessment	Score	Assessment	Score	
Technical Feasibility	• Feasible and proven. • Used for most decommissioning projects to date. • Well established technique; no development required.	0	• Feasible based on pilot trial on offshore conductors. • Development required for full scale application.	5	• Feasible; not trialled as standalone operation, but previously used during jacket dismantling in fjords. • Development required for full-scale application.	2.5	• Removal onshore is positively differentiated by being a well-established, proven and fairly standard technique. • Development would be required for the other options.
Environmental and Societal Impact	• History of intermittent complaints about odour from decaying marine growth for adjacent communities. • Yards' odour management measures well established and mainly successful.	5	• Temporary localised impacts caused by deposition of marine growth on the seabed and dispersal in the water column would not be significant.	0	• Norwegian studies have shown that disposal of marine growth in open fjords with good water exchange would not cause water quality problems. Site selection is therefore critical. • Odour of decaying marine growth on the jacket could potentially be an issue for sheltered sites close to shore.	2.5	• Removal *in situ* is positively differentiated because it lessens the risk of odour nuisance and removes a weight burden from the jacket prior to lifting. • Odour nuisance negatively differentiates the onshore removal option because, although odour management is routine, complaints have actually occurred.
Energy Usage (GJ) and Emissions (tonne CO_2)	• 1,992 GJ (148 tonne)	0	• 64,219 GJ (4,768 tonne)	5	• 12,219 GJ (907 tonne)	1	• Removal onshore is positively differentiated by having the lowest energy usage and emissions resulting from combustion of fuel used by vehicles and equipment and gaseous emissions from marine growth disposed of to landfill. • Emissions from fuel consumption during vessel operations negatively differentiate the remaining options.
Safety as Potential Loss of Life (PLL)	• 5.1×10^{-5} • No safety constraints were identified.	0	• 3.9×10^{-3} • No safety constraints were identified.	5	• 1.7×10^{-3} • Safety concerns would rule out removal operations on a moving barge.	2	• Removal in an onshore work environment is positively differentiated by having a statistically lower inherent safety risk than the options involving vessel operations. Worker exposure hours for the onshore option are also lower.
Cost as a 'ball park' range and an incremental cost on top of an average of £25 million for decommissioning a barge launched jacket	• Range: £0.07 to £0.1 million • Embedded Cost: 0.3% to 0.4% as costs contained within the overall £25 million (i.e. not an incremental cost).	0	• Range: £10 to £15 million • Increment: 40% to 60%	5	• Range: £2 to £3 million • Increment: 8% to 12%	1	• Cost is the strongest differentiator between the options. • Relatively low-cost, low- tech removal operations onshore have cost advantages over marine operations which are driven by vessel day rates.
Total Score		**5**		**20**		**9**	• The onshore removal option has the overall best performance. The principal differentiators are proven technical feasibility and lowest cost. Odour nuisance is a relatively weak driver because existing controls are mainly successful. • The option for the intermediate location was assessed as a standalone operation for removing marine growth. Its overall score would improve in cases where jacket dismantling could only be carried out in open fjords or similar water bodies (i.e. not possible onshore). In this instance marine growth removal would be a subsidiary activity and the cost burden would mainly be borne by the dismantling work. • *In situ* offshore removal has the highest cost.

Results and Conclusions

Removal Onshore

Removal of marine growth at a decommissioning yard attained the top-ranked overall score in the CA, being the strongest performer in four out of the five assessment criteria (technical feasibility, energy usage, safety and cost), but weakest in one criterion (environmental and societal impact).

Historically, onshore removal has been the prevalent method of managing marine growth during decommissioning and has a successful track record. Operators use this as a primary removal and disposal option because the commercial and technical risks and costs are relatively low.

Concern about instances of odour nuisance to local communities caused by decaying marine growth could be a disincentive to the onshore removal option. However, it was emphasised during consultation that odour management by the decommissioning yards is proactive and largely successful.

Availability and capacity of suitable onshore disposal facilities (landfill, composting and land spreading sites) could potentially become a constraint but do not currently appear to be limiting.

Removal at an Intermediate Location

The option of removing and disposing of marine growth at an intermediate location such as a fjord or similar type of water body, ranked second in the CA, with scores for all five assessment criteria lying in second position.

Technical uncertainty, high cost of technical development, costs of vessel operations, and the competitive advantage of onshore yards create a strong disincentive for marine growth removal at an intermediate location to be undertaken as standalone operation.

Historically, marine growth removal and disposal to sea has been subsidiary to the dismantling operations on infrequent, one-off decommissioning projects in fjords, where onshore decommissioning has been impracticable. The option of removal at an intermediate location could be viable under these circumstances.

The majority of costs would be borne by the dismantling work and removal would be relatively straightforward, i.e. from parts of the dismantled structure placed on the deck of a barge or vessel prior to transport to shore.

Concern about pollution caused or exacerbated by nutrients released to sensitive water bodies after the disposal to sea of marine growth could potentially be a disincentive for the intermediate removal option. However this is a relatively weak differentiator. Typically this issue would be addressed by modelling or other studies within the EIA processes.

If site selection is stringent and in line with permitting requirements, then sites will be located in open water bodies where water exchange is sufficient to mitigate pollution risks. Marine growth is a naturally occurring material that will break down in the marine environment until all that is left are the calcareous shells and skeletons of organisms.

Removal In Situ Offshore

Removal *in situ* offshore had the lowest-ranked overall score, having the lowest scores (poorest performance) in four out of the five criteria, but the highest in one criterion (environmental and societal impact).

Offshore disposal of marine growth offers the advantages of lessening the risk of odour nuisance onshore and removing a weight burden from the jacket prior to lifting. However these advantages would be unlikely to counterbalance the cost disadvantage caused by prolonged vessel operations offshore.

Due to the comparatively long duration offshore work programme, marine growth removal from the jacket *in situ* at the field location would be considered expensive.

Prospects

To summarise, the overlying deciding factors in the selection of options come down to costs and risks. The prevalent practice of onshore removal is unlikely to change because the method is well established, reliable and is cost-effective.

To establish an efficient and cost-effective technology or array of technologies needed to remove marine growth *in situ* would require a substantial investment of both time and money from parties central to the decommissioning process (developers/contractors/operators). The variation in steel jacket types needs to be considered carefully as the removal scenarios would change from one offshore structure to another.

INTRODUCTION

Oil & Gas UK Ltd (O&G UK) commissioned BMT Cordah Ltd (BMT) to conduct a high-level comparative assessment (CA) of operations for the removal of marine growth from the steel jackets of redundant oil and gas platforms at offshore and onshore locations in northern European waters. This work follows on from an initial study to establish the management options for marine growth during decommissioning (BMT, 2011). Both studies form part of O&G UK's Joint-Industry Programme on Decommissioning.

The CA's purpose was to assess the performance of the current offshore and onshore removal options against a suite of key performance criteria; and identify specific advantages and disadvantages which could affect the selection or development of options for marine growth removal during decommissioning.

1.0 SCOPE OF STUDY

The scope of work for the CA study is as follows:

- To provide a CA methodology for comparing generic options for the removal of marine growth from redundant steel jackets of offshore structures:
  a) onshore at a decommissioning yard;
  b) offshore where the jacket would be still *in situ* at the field location; and
  c) at an intermediate location, such as a fjord, sea loch, or inshore waters where the entire jacket or sections of the jacket would on a barge;
- To conduct the CA in order to evaluate and provide a representative comparison of the performance of the offshore and onshore removal options in relation to technical feasibility, environmental and societal risk, energy usage and emissions, safety risk and cost, and identify where particular benefits and constraints could affect the suitability of options.

2.0 CA APPROACH

In addressing the scope, the study attempted to provide a balanced comparison of the three generic options for marine growth removal for decommissioning projects in the UK and Norwegian offshore oil and gas sectors base their comparisons on these criteria (DECC, 2011; Klif, 2011a).

By necessity, the CA in this study provides a higher level (less detailed) assessment than would be possible when evaluating the options for particular decommissioning projects. The broad approach taken recognises sensitivities relating to:

- commercial confidentiality;
- uncertainties about variations in current practice;
- hypothetical methods which have not been applied;
- extrapolation from pilot trials to full scale application; and
- the need for the CA to encompass a wide range of project types, locations and environmental and societal characteristics.

Consequently, the study provides a representative, rather than absolute, comparison between the three marine growth removal options.

Sections 3.1 to 3.9 describe the CA approach.

2.1 Generic Offshore Structure

In order to provide a common basis for comparison, the scenario was created for a generic steel jacket from which marine growth removal would take place. This 'worst case' scenario represents a large steel jacket in the northern North Sea. Section 4 describes the scenario.

2.2 Consultation

Information for the CA was largely obtained through consultation with representatives of industry. Between them, the consultees possess extensive knowledge and practical experience of decommissioning both onshore and offshore, management of marine growth onshore, offshore inspection and marine growth removal, structural cleaning using water jets and other methods, and emerging technologies.

Their contribution is gratefully acknowledged at the beginning of this report. In order to respect commercial confidentiality, information reported from the consultations is non-attributable (with one exception which was made with the consultee's permission).

2.3 Marine Growth Removal Methods

From information provided during consultation, descriptions were prepared of the hypothetical approach for the removal of marine growth in each option. These descriptions were amalgamated from the information provided by several consultees.

This information was also used to construct hypothetical work programmes, estimate labour, vessel and equipment requirements, and describe or predict outcomes of the removal process.

Note that the CA only assessed the specific parts of work programmes that were required for marine growth removal. The CA did not therefore consider lifting and transport of the jacket to the onshore decommissioning yard or an intermediate marine location where marine growth removal would take place, because these activities would have to be carried out in preparation for dismantling.

2.4 Technical Feasibility

The assessment of technical feasibility and the benefits and constraints associated with the option was based on the opinions of the consultees. The CA outputs are qualitative assessments of technical feasibility, constraints and benefits of the options.

2.5 Environmental and Societal Impact

The assessment of environmental and societal impacts and risks considered the potential causes, consequences and likelihood of impact within the environmental and social settings relevant to each option.

This high-level assessment attempted to distinguish between:

- **Non-differentiators -** impacts and risks that routinely occur in similar types of project, which lie within levels that are generally tolerable and acceptable to society, and would not serve to differentiate between the options; and
- **Differentiators -** impacts and risks that could potentially form the basis for differentiation.

The CA outputs are brief outlines of the non-differentiators and a more detailed consideration of differentiators. Included are the stated assumptions, the advantages, disadvantages and implications associated with the option.

2.6 Energy Usage and Emissions

Energy usage and CO_2 (carbon dioxide) emissions were calculated from estimates of diesel fuel consumption by vessels, vehicles and equipment during hypothetical work programmes of individual options. The methodology, the energy and CO_2 emissions values of diesel, and diesel consumption for different types of vessel were mainly obtained from the Guidelines for Calculation of Energy Use and Gaseous Emissions in Decommissioning (Energy Institute, 2000). Other information sources were used and are cited.

The CA outputs are quantitative energy and emissions tables and stated assumptions.

2.7 Safety

Safety risk for the individual options was determined from Potential Loss of Life (PLL) calculations. In order to achieve this:

- Individual PLLs for each activity during the work programme for the particular option were calculated by multiplying worker exposure hours by the corresponding Fatal Accident Rate (FAR); and
- PLLs for all of the activities were summed to provide the total PLL for that option.

The report on the Joint Industry Project on the Risk Analysis of Decommissioning Activities (Safetec 1995) describes the PLL calculation methodology and FAR values.

The CA outputs are quantitative PLL tables, stated assumptions and descriptions of safety benefits and constraints for each option.

2.8 Cost

Cost estimates for the three generic options were provided by the study’s consultees in the form of ‘ball park’ ranges. The consultees were also asked about uncertainties and assumptions, and whether or not the costs could be scaled for different sizes of steel jacket. Vessel costs had not been incorporated into the costs given for one option. In order to fill the gap, BMT Group provided vessel day rates. The CA outputs comprise cost estimates plus the stated assumptions for each option.

2.9 Overall Comparison

Section 9 provides an overall comparison of the options which are ranked using a normalised scoring system. An explanation of the scoring and ranking method is given in that section.

3.0 MARINE GROWTH ON THE GENERIC OFFSHORE STRUCTURE

The CA considered three options for the removal of marine growth from the same jacket. This hypothetical large steel jacket represents a challenging but realistic scenario. The structure would typically be located in a water depth around 120 m to 140 m in the northern North Sea, and have been installed during the 1970s or early 1980s.

Characteristically, it would have eight legs, six horizontal framings, with around 40 conductors in conductor guide frames, and 400 to 800 horizontal, vertical, and vertical diagonal members, bearing numerous anodes, clamps, bracings, grout pipes, cables, ring stiffeners, etc.

BMT Cordah's 2011 study reviewed the distribution, composition and thickness of marine growth based on marine growth assessments of offshore structures in the North Sea spanning over 30 years. Based on this, Figure 1 provides a stylised representation of marine growth on the hypothetical jacket in the northern North Sea. This would usually comprise:

- **Shallow water assemblage:** Layers of mussels, kelp, other seaweeds, hydroids, anemones and soft coral on submerged surfaces down to circa 30 m depth. Mussels (two shelled, hard bodied organisms) typically cover from 10% to 100% of surfaces, with thickness varying from around 25 mm to 350 mm for multi-layered mussel beds. Seaweeds (soft bodied organism) typically cover from 25% to 100% of surfaces, with lengths varying from 15 mm to 5 m for large kelps. Hydroids, anemones and soft corals are described below;
- **Mid-water assemblage:** Anemones, soft coral and hydroids (all soft bodied organisms) from circa 30 m to 60 m depth. Anemones can occur as scattered individuals but can form a blanket cover on up to 100% of surfaces; lengths vary from circa 50 mm to 450 mm. Soft corals can occur as scattered individuals but typically cover less 50% of surfaces; lengths vary from circa 50 mm to 300 mm. Hydroids often form a blanket cover in spaces between the other organisms; lengths vary from circa 10 mm to 300 mm; and
- **Deep-water assemblage:** Anemones, soft coral, hydroid and the cold water coral, *Lophelia pertusa* (hard bodied encrusting organism) from circa 60 m depth to the seabed. *Lophelia* forms large brittle dome-shaped colonies with thicknesses up to 770 mm, covering up to 80% of surfaces. It has been reported on northern North Sea jackets (Gass and Roberts, 2005) but not on jackets in the central and southern sectors.

The wet weight of fresh marine growth in air on a large structure could possibly be in the range 1000 to 2000 tonnes, although lower weights have usually been recorded (BMT 2011). By the time the material had been removed at the decommissioning yards the weight of the marine growth recorded as waste would typically be less than 10% of the original estimate.

The difference in weight can be mainly accounted for by inherent conservatism in methods for estimating the weight of marine growth on jackets *in situ,* desiccation (water loss as organisms dry out) and losses of material (marine growth falling off) during lifting operations, transit to the decommissioning yard and onshore handling prior to weighing.

If it is assumed that the generic jacket was originally a barge-launched type weighing around 15,000 tonne (O&G UK, 2012), then the wet weight of marine growth could potentially represent around 7% to 14% of the jacket's weight in air. The corresponding figures for the marine growth removed by the yard would be around 0.7% to 1.4% of the jacket's weight (BMT, 2011).

Under OSPAR 98/3, this size of jacket would be eligible for submission of a derogation request from the requirement for complete removal during decommissioning (DECC, 2011). Although derogation could result in the lower 30-40 metres remaining *in situ*, the CA does not make this assumption.

The common objective for all of the options would be for the bulk removal of marine growth. The end-point of the process is to remove sufficient growth to ensure that the quality of the steel is adequate for recycling.

Sections 5 to 7 respectively provide the assessments for the three removal options.

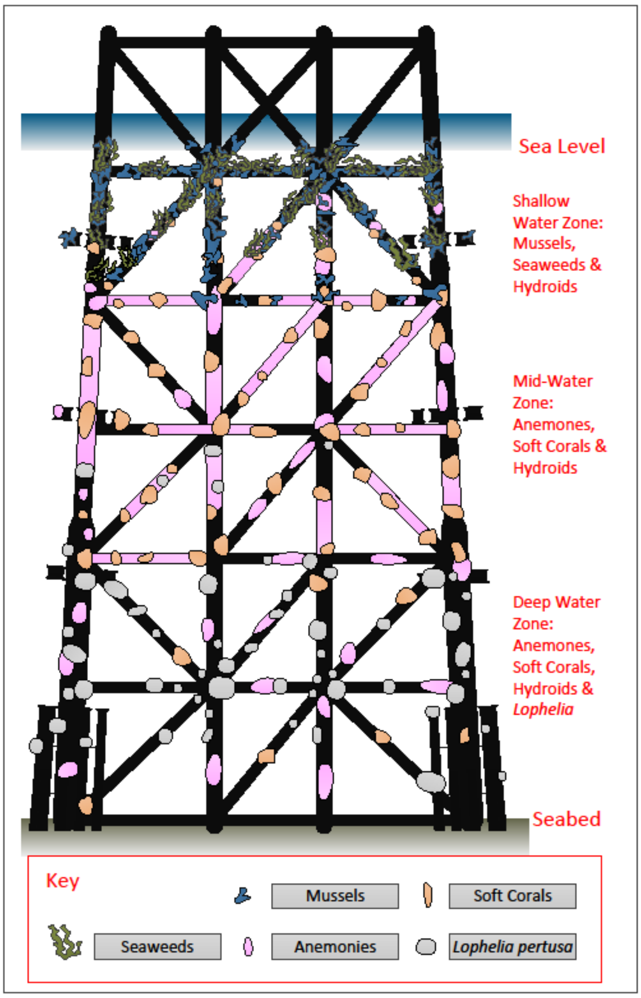


Figure 1: Stylised representation of the distribution of marine growth on a large steel jacket in the northern North Sea

4.0 MARINE GROWTH REMOVAL AT A DECOMMISSIONG YARD

Previous experience in the UK for removal of steel oil and gas jackets has resulted in the majority being removed, either partially or completely and taken on-shore (Oil & Gas UK, 2012). Historically, steel jackets in UK waters have been lifted either in one piece for smaller structures or in multiple sections for larger jackets. Transportation to shore of these jackets has mainly used barges or heavy lift vessels (HLV).

In Norway, removal of marine growth at onshore decommissioning yards has also been the prevalent practice, although large jackets which could not be landed at, or handled by, decommissioning yards have been dismantled in deep water in Norwegian fjords (e.g. Frigg DP 2; Oil & Gas UK, 2012).

Once lifted or skidded from the barge to the quayside at the yard, the jacket is then methodically cut into smaller and smaller sections using a variety of equipment, such as demolisher excavators with shear attachments. The process ends when the steel pieces are at the appropriate size for transport to the recycling facility.

The current practice of onshore decommissioning yards is to remove the marine growth from parts of the structure as it is progressively dismantled. Their methods have included mechanical scraping with buckets and other tools on excavators and wheel loaders of varying sizes, manual removal using shovels, and water jetting. The marine growth can be removed at reachable height or when parts are on the ground. Material also falls off during lifting and mechanical handling operations.

Marine growth is collected using mechanical sweepers, excavator or wheel loader buckets and manual methods, and is stored in skips or containers on site. Disposal may be to landfill, composting facilities and/or by land-spreading (ploughing the material into fields designated for this purpose).

4.1 Technical Feasibility

Removal of marine growth removal at the onshore yard has been used for the majority of decommissioning projects for North Sea steel jackets (BMT, 2011). It is therefore, entirely feasible, well established and reliable.

4.2 Environmental and Societal Impacts

The decommissioning facilities on the UK mainland, Shetland and Norway occur in a variety of environmental and societal settings. These include:

- relatively sparsely populated locations with quay frontages on Vatsfjord in Norway or Dales Voe in Shetland;
- locations adjacent to industry and settlements with quay frontages on Bressay Sound in Shetland and Stord in Norway; and
- urban sites within long-established industrial areas on Tyneside and Teeside.

Removal of marine growth at these locations would occur as the structure is dismantled. A relatively small team would undertake marine growth removal, collection and storage on site. They would do this along with dismantling and other tasks. Machinery for scraping off and collecting marine growth (excavators and wheel loaders) would be used for other decommissioning tasks. Waste transport and disposal to landfill, composting or land spreading would be carried out by contractors.

Environmental and societal impacts could arise from:

- noise and exhaust emissions during the operation of machines and vehicles;
- the odour of decaying marine growth;
- liquid effluent draining from fresh or decaying marine growth;
- the presence on the road network of skip loaders or lorries during the transportation of marine growth for final disposal; and
- the uses of resources for landfilling, composting or land spreading.

Impacts relating to onsite operations could potentially affect people living or working in the vicinity of the site. Off-site impacts mainly relate to resource capacity and residual impacts in landfills, composting and land spreading facilities.

The sections that follow provide background information on integrated pollution prevention and control that applies to environmental aspects of decommissioning facilities in the UK and Norway (Section 5.2.1), and distinguish between the causes of impacts that are differentiators (Section5.2.2) and non-differentiators (Section 5.2.3) for the onshore removal option.

4.2.1 Environmental Permitting for Onshore Decommissioning.

As with all decommissioning projects under the Petroleum Act 1998, the management of decommissioning wastes (including the removal method for marine growth) would be described within the Decommissioning Plan and accompanying Environmental Statement for the decommissioning project (DECC, 2011). These would be subject to consultation, review and the approval by DECC. Comparable provisions exist for decommissioning projects under the Norwegian Petroleum Act 1996.

Decommissioning yards in both the UK and Norway work within similar frameworks of integrated pollution prevention and control (IPPC) which are laid down in national environmental legislation. The legislation requires industrial sites to operate within single permits that regulate:

- how the site operates and the technology used;
- reduction and management of emissions into air, water and land (including atmospheric emissions, aqueous discharges, noise, dust, odour and vibration);
- conservation of energy and natural resources;
- reduction, management and disposal of waste;
- prevention of environmental accidents; and
- remediation of site condition (contaminated land).

Regulations made under the UK Pollution Prevention and Control Act 1999 implement the European IPPC Directive (Directive 96/61/EC) by creating the requirement for integrated permits which encompass sites (called ‘installations) with polluting processes. Guidance to the regulations defines the Pollution Prevention and Control (PPC) permit requirements of onshore decommissioning facilities and other waste management facilities. Permits are reviewed to ensure the site operator can demonstrate the application of Best Available Technique (BAT) which balances benefits to the environmental against costs to the operator (DEFRA, 2012). Disposal facilities are governed by the same permitting regime.

The Pollution Control Act 1981 lays down the integrated permitting system for Norway. The Climate and Pollution Agency, Klif or the county environmental agency is the administrative authority for all enterprises involved in the decommissioning and recycling of offshore installations in Norway. Like the UK, permits are periodically reviewed and operators are required to demonstrate 'satisfactory environmental quality based on a balance of interests, which includes costs associated with any measures and other economic considerations' (Klif, 2004).

The process of removal and disposal of marine growth during decommissioning will be covered under permits for the decommissioning yard and disposal facility.

4.2.2 Non-differentiators

The following would not provide the basis for differentiating between options:

Environmental noise: During routine decommissioning operations, the site would have a continual level of background noise. Sounds from the variety of onsite dismantling activities and marine growth removal operations together would form part of that background. Any impact of environmental noise would depend on the extent of neighbouring community tolerance to noise as nuisance.

The potential for nuisance from environmental noise would be managed within the conditions of the site permit, and would typically include onsite and offsite noise monitoring and community consultation. Industry representatives in both the current and previous (BMT, 2011) studies mentioned that consultation with the local community and the regulators formed part of their management approach.

Emissions from vehicles and machinery: Emissions of CO_x, NO_x, SO_x and VOCs (oxides of carbon, nitrogen and sulphur and volatile organic compounds) and particulates from fuel combustion by engines and fugitive sources such as valves, seals and refuelling points would occur during the routing operation of vehicles and machinery.

Management would be largely through good maintenance. The emissions would cause a localised deterioration in air quality immediately around exhaust or fugitive source, and be a small input of greenhouse gases and other contributors to atmospheric processes.

Liquid effluent draining from fresh or decaying marine growth: Decommissioning yards have systems for the collection of liquid effluents from marine growth which could potentially be a pollutant and cause to odour issues. These systems include concrete surfaces with impermeable membranes leading to on site drainage and effluent treatment plants, and designated bunded areas which contain the effluents for subsequent uplift, treatment and disposal by specialist waste management contractors.

Transportation of marine growth for final disposal: Road haulage of waste marine growth by skip loader or lorry to the final disposal site could potentially cause or contribute to road congestion and nuisance to pedestrians and road users. In order to gauge the impact, it can be assumed that disposal of 100 to 200 tonnes of marine growth waste from the hypothetical jacket (worst case; Section 4) would result in 6 to 12 road journeys by an 18 tonne capacity skip loader during a six week dismantling programme. It is unlikely that road haulage impacts would be significant.

4.2.3 Differentiators

The following could provide the basis for differentiating between options:

Odour from decaying marine growth: Noxious odour from decomposing marine growth is recognised as an issue (e.g. Brock *et al*, 2008; BP, 2006 Klif, 2011a & b; O&G UK, 2012; BP, 2006; Total 2007). The previous study (BMT, 2011) noted that the odour from decaying marine growth was addressed by the four yards that were contacted. They observed that odour was prevalent when the marine growth was wet but abated as the material dried. They also said that odour from desiccated marine growth could only be detected at close distance. Complaints from neighbouring communities were not prevalent but there had been instances when these had arisen. They believed that the issue was being well managed and was not a problem, a view that was reinforced by the consultees for the present study.

Various measures are used to manage odour from marine growth. These include removing the material as quickly as practicable, allowing the material to dry, storage in covered skips, mixing or covering the marine growth with sawdust to absorb liquids and suppress odour, applying odour suppressant or masking chemicals, screening the storage area and collection and treatment of liquid effluents (Section 6.2.2). Odour management plans, monitoring (by site staff walking around the periphery of the site) and regular community consultation are also used.

It can be concluded from this assessment that the potential for odour nuisance from marine growth is a differentiator for onshore decommissioning yards. It would not, however, be a strong disincentive to the option because, although complaints from neighbouring communities have occasionally arisen, mitigation has mainly been successful (BMT, 2011).

Availability of disposal sites and disposal impacts: Marine growth falls into the category of non-hazardous animal and vegetal waste in the UK and ordinary waste in Norway (OJ, 2004; AF Environment, 2011).

In the previous study (BMT 2011, a representative of one of the decommissioning yards commented that the availability of suitable, local landfill sites could potentially limit their operations. However this view was not predominant, as has also been the case in the present study. Availability of facilities for disposal by landfilling, composting and land spreading appears not to be limiting.

No concerns were raised in either study about impacts or issues associated with composting or land spreading. One of the consultees pointed out that, for commercial reasons, composting sites are not particularly keen on receiving infrequent loads containing relatively small quantities of marine growth. The future capacity of landfills to receive biodegradable waste may affected by reduction targets imposed under the Landfill Directive (1999/31/EEC), which may create a greater drive for composting.

The conclusion from this assessment is that disposal processes appear to be functioning satisfactorily and capacity does not appear to be limiting. Odour from decaying marine growth is addressed proactively by the decommissioning contractors but infrequent complaints have actually occurred. For that reason, the direct impact of odour nuisance on local communities would negatively differentiate this option.

4.3 Energy usage and Emissions

Table 2 provides the estimates of energy usage and CO_2 emissions which were based on:

- estimates of the vehicle usage from the proportion of a dismantling team's working time spent on the removal, collection and onsite storage of marine growth during a six week dismantling programme for the entire jacket;
- an estimate of the operational time required for an 18 tonne capacity skip loader (mid-range skip loader) to make 12 round trips between the decommissioning yard and the disposal site (Section 5.2.2);
- estimates of fuel consumption rates for a five tonne wheel loader and an 18 tonne capacity skip loader (Motive Traction, 2012; Alibaba, 2012) calculated from engine power output and standard fuel consumption rating;
- emissions factors of 43.1 GJ (Giga Joules) and 3.2 tonne CO_2 per tonne fuel used (Energy Institute,2000); and
- CO_2 equivalent emissions factor per tonne of landfilled mixed food and garden waste (approximates to marine growth) given in AEA, 2011. This factor was applied to 200 tonne of waste marine growth (Section 5).

Table 2: Energy usage and fuel consumption estimates for onshore removal

Operation	Duration (days)	Fuel consumption rate (tonne/day)	Fuel consumed (tonne)	Energy Usage (GJ)	CO_2 Emissions (tonne)
2 wheel loaders/excavators removing marine growth	50	0.9	45	1,940	144
Transport by skip loader	1.5	0.9	1.4	52	4
Degradation of marine growth in landfill	-	-	-	-	51
Overall Energy Usage and Emissions				1,992	148

4.4 Safety Risk

Table 3 provides an estimate of the PLL for the work programme for marine growth removal onshore. It was based on:

- an estimate of exposure hours during the working time that 2 to 5 personnel would spend on marine growth removal, collection and onsite storage spread over a six week dismantling programme;
- an estimate of exposure hours for the transport of marine growth to a landfill or composting facility. This assumes that a 36 hour working time would be needed for the driver of an 18 tonne capacity skip loader to make 12 round trips of around 100 km to collect, transport and dispose of 200 tonne of marine growth; and

- Fatal Accident Rate (fatalities per 100 million exposed hours) for deconstruction operations onshore (Safetec, 1995). This value has also been applied to waste collection, transport and disposal.

No safety constraints to this option were identified during discussions with consultees.

Table 3: PLL estimates for onshore removal

Activity involving worker exposure	Number of Personnel	Exposure hours	FAR*	PLL
Mechanically (using wheel loaders/excavators) and physically (using shovels) scraping off, collecting and storing marine growth	2 - 5	1,200	4.1	4.9×10^{-05}
Transport of waste marine growth by skip loader to landfill or composting facility	1	36	4.1	1.5×10^{-06}
Overall PLL				5.1×10^{-05}

4.5 Cost

The ‘ball park’ cost estimate provided during consultation ranged from £70,000 to £100,000 for the removal of marine growth from a large jacket (around 15,000 tonne) at an onshore decommissioning yard, and for transportation and disposal of marine growth at a landfill or composting facility. Costs could be broadly scaled in proportion to the size and complexity of the jacket.

4.6 Alternative Approaches

No alternative methods for the onshore removal and disposal of marine growth were identified in the present study.

4.7 Summary for Onshore Removal

Table 4 highlights the key the findings for the assessment for the onshore removal option.

Table 4: Summary for the onshore removal option

CA Criterion	Assessment Outcome
Technical Feasibility	Removal of marine growth at onshore yards has been used for the majority of decommissioning projects for North Sea steel jackets. The method is therefore entirely feasible, well established and reliable.
Environmental and Societal Impact	Odour from decomposing marine growth is an issue for onshore removal. It would not, however, be a strong disincentive because, although complaints from neighbouring communities have occasionally arisen, the decommissioning contractors apply a suite of controls which have largely been successful. Availability or capacity of landfill sites (predominant disposal method for marine growth) does not currently appear to be limiting. Composting and land spreading are also used.
Energy Usage and Emissions	Energy: 1,992 GJ CO_2: 148 tonne
Safety	PLL: 5.1×10^{-5}
Cost	£70,000 to £100,000 This represents 0.3% to 0.4% of an average decommissioning cost of £25 million for a barge launched jacket (derived from O&G UK, 2012). Note that the costs of marine growth removal are embedded within the overall decommissioning costs for the jacket.

5.0 MARINE GROWTH REMOVAL *IN SITU* AT AN OFFSHORE LOCATION

Removal of marine growth *in situ* would primarily provide the benefit of reducing the overall weight of the jacket prior to the lifting operations. *In situ* removal would also eliminate or significantly reduce the onshore removal, handling, transport and disposal that are carried out be decommissioning contractors onshore. It could also avoid or diminish the issue of nuisance caused by odour from decaying marine growth.

From discussions with decommissioning, structural inspection and structural cleaning contractors it is apparent that *in situ* bulk removal of marine growth is not a current practice. However, bulk removal has been used over many years for the relief of structural loading on areas of the jackets of operational installations which have become heavily fouled with mussels. This has occurred mainly in the southern North Sea where divers have typically carried out the work.

Recently, Integrated Subsea Services Limited (ISS) has used Remotely Operated Vehicles (ROVs) for the bulk removal of marine growth from conductors on the Ninian Northern Platform (NNP). Their experience on that jacket has been scaled up to create a scenario where ROVs would be used to remove marine growth from submerged area of the entire jacket of a hypothetical northern North Sea installation. Section 6.1 describes the approach.

5.1 Technical Feasibility

During consultation, ISS considered that it would potentially be feasible to use work class ROVs for the large-scale bulk removal of marine growth. On NNP, the ROV dislodged marine growth by running a braided wire down vertical conductors. This scraping device was strung between two pieces of angle iron mounted on a skid. ISS pointed out the device could be mounted on a rotating boss to provide the ROV with more flexibility for dealing with marine growth on horizontal and vertical diagonal members.

Their technique worked effectively for the bulk removal of mussels (which are attached by thread-like structures and can be dislodged in clumps) and soft growth. ISS found that it was less successful on the large dome-like structures of *Lophelia* colonies which are attached to the underlying member and formed from closely packed, interlinked, calcareous branches bearing the coral polyps. They commented that if a metal bar was fitted to the ROV, the impact from this should be sufficient to break and dislodge the brittle colonies of *Lophelia*.

The ROV spread could be deployed from an ROV Support Vessel (ROVSV) or from topsides of the platform. The latter could be effective on larger platforms with laydown areas on opposite sides of the platform. Two ROVs would typically work simultaneously but up to four ROVs could potentially be used, depending on the capabilities of the ROVSV. Two ROVSVs could potentially be used.

When working on steel jackets, ROV operations are constrained by the need to relocate and to reposition umbilicals; by access limitations in congested areas e.g. conductor guide frames; by instability in wave affected shallow depths; by difficulties in maintaining position on undersides of members; when turbid conditions restrict visibility; and during downtime in rough weather.

ISS and other industry representatives consulted discounted the use of conventional water jets for marine growth removal *in situ*. Maintaining an appropriate stand-off distance and angle with relatively narrow jets for prolonged periods would be critical for effective removal. For ROVs, fine positioning of the nozzle would be affected by sea current movements, impediments to access to members and ROV movement during water jet operation. Additionally, the ROV pilot’s visibility could be obscured by marine growth dispersed by the water jet.

Use of water jets for grit blasting for marine growth was also discounted because of the frequent blockage of hose lines and need to replace abraded, worn out hose lines and nozzles.

ISS and others consulted pointed out that, while this option was considered feasible, the time needed to carry out the work programme would be protracted and could be a disincentive. An estimate of around 100 days was provided for single ROVSV working on large jacket. Clearly, this is a ‘ball park’ estimate based on practical experience. The schedule for any given structure would depend, however, on the location and characteristics of the jacket, the resources available and the design of the work programme.

It can be concluded, therefore, that the *in situ* removal option offshore has not been applied offshore but is considered feasible. It has defined limitations, requires development to improve and demonstrate effectiveness, and could potentially involve protracted work programmes offshore.

Additionally, if the period between bulk clearance and the removal of the jacket was protracted, then marine growth could re-establish. In particular, mussels could potentially blanket shallower parts of the structure to form multi-layered beds on previously cleaned areas if, for example, decommissioning did not occur within one to three years of structural cleaning (BMT, 2011).

5.2 Environmental and Societal Impacts

Marine growth removal would take place with the jacket *in situ* at the offshore location. For the generic structure used in the study, this location typically could be:

- lying within a water depth of 120 m to 140 m
- remote from land (60 km to 120 km from the coast) but relatively near to other offshore oil and gas installations;
- surrounded by extensive areas of sedimentary seabed providing habitat for benthic fauna (animals living on or in seabed sediments);
- within a widespread area of open sea with good water exchange, that provides habitats for plankton, fish, seabirds, marine mammals (whales, dolphins and seals; protected species)
- within a widespread sea area that contains commercial fish and shellfish stocks, and spawning and nursery areas for stocks; and
- in proximity to commercial shipping and fishing vessels (although the jacket would be within a 500m radius, safety zone from which unauthorised shipping would be excluded).

The *in situ* removal option would involve an ROVSV, Dive Support Vessel (DSV) with suitable moon pool or Multi-Purpose Vessel (MPV). Marine growth removal operations would occur on a 24-hour basis until complete.

The ROV would physically scrape of, or dislodge, marine growth as clumps growth, individual organisms and fragments) which would then:

- sink and settle on the seabed (particularly in the case of mussels, *Lophelia* and other hard-bodied marine growth); or
- be transported within sea water currents (particularly seaweeds, hydroids, and other soft-bodied organisms). This material may remain in suspension or sink to the seabed.

Environmental and societal impacts could arise from:

- operational emissions, discharges, wastes from vessels working on the marine growth removal project;

- impedance to fishing activity and commercial vessel traffic;
- overboard spills;
- dispersed marine growth within the water column; and
- deposited marine growth on the seabed.

The sections that follow provide background information on the environmental legislation relating to the disposal of marine growth at sea (6.2.1) and the causes of impacts that are non-differentiators (Section6.2.2) and differentiators (Section 6.2.3) for the onshore removal option.

5.2.1 Disposal of Marine Growth at Sea

This section does not attempt to provide and exhaustive account of the environmental legislation affecting marine growth removal offshore but highlights some of the key provisions. As with all decommissioning projects in the UK, the removal method for marine growth would be described within the Decommissioning Plan and accompanying Environmental Statement for the decommissioning project (DECC, 2011) and subject to DECC approval.

An MCAA Licence (Maritime and Coastal Access Act 2009) for deposition of the marine growth originating from an offshore structure on the seabed may be required (DEFRA, 2012). Alternatively, grounds for exemption could be that it is disposal of non-hazardous waste at the place of production (which is cited as a case for exemption). Additionally, marine growth could be considered to lie within the category of “organic material of natural origin” which would be exempt from the prohibition on dumping of wastes to sea under Annex 1 of the London Protocol, 1996.

For decommissioning projects in Norway, the Petroleum Activities Act (1996) states that disposal decisions are to be made on a broad-based evaluation in each individual case, with an emphasis on the technical, safety, environmental and economic aspects as well considerations for other users of the sea. Klif administer the permitting process. They have also advocated marine disposal on the grounds that it avoids the waste disposal and odour issues associated with the onshore removal of marine growth (Klif, 2011a&b).

Marine disposal would therefore be subject to regulatory approval to be obtained by the operator.

With regard to the operation of ROVSVs and other vessels, the annexes of the Convention for the Prevention of Pollution from Ships (MARPOL 73/78) lay down international standards to be met by vessels in relation to pollution prevention from oily discharges, noxious liquids, sewage, garbage (waste) and air pollution (atmospheric emissions), which are enacted in both UK and Norwegian legislation.

5.2.2 Non-differentiators

Mobilisation of ROVSVs, DSVs and MPVs in port, voyages to the field location, work programmes at field locations, return voyages to port and demobilisation occur frequently and routinely in offshore projects and operations. The environmental and societal issues relating to vessel operations for the majority of offshore projects would therefore be similar and include:

Onshore traffic: Impacts during road haulage, loading and offloading during the mobilisation and demobilisation of vessels in port would be similar to those given in Section 5.2.2;

Emissions: Atmospheric emissions from power generation and fugitive losses during vessel operations would be similar to emissions impacts in Section 5.2.2;

Operational wastes: These include the generation and management of hazardous and non-hazardous solid and liquid wastes. Wastes would be segregated, contained and stored on-board, then transported, stored, recycled, treated or disposed of onshore in line with the authorisations, licences or permits held by the contractors and/or facilities;

Resource use: Use and consumption of fuel, chemicals and raw materials. Chemical usage would be subject to permits for use and discharge which are administered by the regulatory authorities in the UK and Norway. The consumption of raw materials in vessel operations to support ROV work would be low;

Operational discharges: Permitted marine discharges of treated bilge water, macerated food waste, sewage and ‘grey’ water (from sinks, showers, etc) would cause a local deterioration in water quality around the discharge point;

Non-native species: There is the risk of spread of non-native species carried in ballast water of vessels moving into northern European waters from other parts of the world. Ballast management practices to mitigate this risk are laid down by the International Maritime Organisation;

Underwater noise: The effects of underwater noise from vessel engines, thrusters and sub-sea machinery on marine mammals and other marine organisms, is non-impulsive and has not been linked with physical injury. It is possible that marine mammals within the vicinity of the vessels may exhibit avoidance behaviour (Southall *et al*, 2007).

Other sea users: Minimising risk of impedance of access to fishing vessels and other sea users would be managed through communication during project planning (Notices to Mariners, Shipping Alerts, and consultation during project planning) and on-going operations at sea, and through navigation systems, good seamanship and vigilance.

Spills: Accidental spillage could occur during fuel transfers at the worksite or vessel collisions. Although the spill consequences could be potentially serious, the plans, equipment, procedures and operational practices to minimise spill risks would be specific for the project but relatively standard for the industry.

In the context of this CA, the impacts and risks from the vessel operations are at levels that are generally tolerated or accepted by society. Detailed comparison of these would not serve to differentiate the decommissioning options.

5.2.3 Differentiators

Bulk removal of marine growth from the jacket *in situ* would disperse fragments or whole organisms (e.g. seaweeds and hydroids) within the water column and deposit clumps, individual organisms, shells or broken pieces (e.g. mussels and *Lophelia*) on the seabed within or around the jacket footprint. The following consequences of bulk removal provide the basis for differentiation between the options:

Marine disposal: The ROVs would act as point sources from which marine growth would be intermittently discharged during a work programme of up to three months.

Dispersed marine growth would be likely to cause localised transient turbidity, nutrient enhancement and increase in biochemical oxygen demand (BOD) within the plume of dispersed material. Deposited material would initially lie on the seabed, but organic material would be released during the breakdown of body tissues of dead organisms. Deposited material could cause localised nutrient enrichment, BOD increase and proliferation of the many types of organism involved in the breakdown of organic material on the seabed.

Natural processes will aid the breakdown of both the dispersed material and the marine growth that falls to the seabed. These include: consumption by marine organisms, cell breakdown, microbial biodegradation, dispersion by currents and incorporation into marine sediments. Once these natural processes cease, only the shells, tubes and other calcareous skeletal materials from dead organisms would persist. Dislodged live *Lophelia* may possibly survive on the seabed.

Operational and other consequences: The material could also lie on top of or be incorporated into the drill cuttings pile. Accumulations of marine growth on the cuttings pile and around the legs or members near the seabed could possibly impair inspection and access.

As stated earlier, *in situ* removal of marine growth would also:

- reduce the overall weight of the jacket prior to the lifting;
- reduce or eliminate of the need for marine growth removal and disposal by the decommissioning yards; and
- reduce the likelihood of odour issues onshore associated with decaying marine growth.

The main conclusion to be drawn from the section is that societal consequences relating to elimination of odour or possibly jacket weight are likely to be the strongest differentiators for the *in situ* removal option. The environmental consequences of the disposal to the open sea of this naturally occurring material would be insignificant and, although a negative differentiator, would be unlikely to be a disincentive for the option.

5.3 Energy Usage and Emissions

Table 5 provides the estimates of energy usage and CO_2 emissions which were based on:

- the assumption that an ROVSV would be used for a 100 day work programme offshore with 2 days mobilization and 4 days in transit;
- fuel consumption rates which the mid-range values for a DSV (nearest equivalent to ROVSV given in Energy Institute, 2000); and
- emission factors of 43.1 GJ and 3.2 tonne CO_2 per tonne fuel used (Energy Institute, 2000).

Table 5: Energy usage and fuel consumption estimates for *in situ* option

Operation	Duration (days)	Fuel consumption rate (tonne/day)	Fuel consumed (tonne)	Energy Usage (GJ)	CO_2 Emissions (tonne)*
Mobilisation and demobilisation in port	2	3	6	259	19
In transit	4	21	84	3,620	269
Working at location	100	14	1,400	60,340	4,480
Overall Energy Usage and Emissions				**64,219**	**4,768**

5.4 Safety Risk

Table 6 provides an estimate of the PLL for the work programme for marine growth removal *in situ*. It was based on:

- the assumption that 40 people on board for a mid-sized ROVSV with ROV operations involving limited deck crew would undertake the work programme for a total period of 106 days (including mobilisation/demobilisation, transit and working at the offshore location);
- twelve hour shift patterns;
- Fatal Accident Rates (fatalities per 100 million exposed hours) for marine operations on a DSV with diving excluded (nearest equivalent to an ROVSV) and off-duty time offshore (Safetec, 1995).

No safety constraints to this option were identified during the discussion with consultees.

Table 6: PLL estimates for the *in situ* option.

Activity involving worker exposure	Number of Personnel	Exposure hours	FAR	PLL
Working	40	50,880	7.5	3.8×10^{-03}
Resting	40	50,880	0.2	1.0×10^{-04}
Overall PLL				3.9×10^{-03}

5.5 Cost

From consultation, 'ball park' costs for *in situ* removal of marine growth on a large jacket was estimated to be in the range £10 million to £15 million. Costs are largely determined by the length of offshore work schedule and the scale of the ROV spread. Day rates for ROVSVs range from around £100,000-£250,000.

Platform deployment of ROV spread could possibly reduce costs to around a third by eliminating the need for the ROVSV. Similarly, confining the removal to members in shallower depths, where mussel fouling is greatest, could reduce costs while retaining significant benefit (in terms of jacket weight relief and reduced onshore handling).

5.6 Alternative Approaches

Air and saturation dive teams or a combination of ROVs and divers could potentially carry out the work programme. Dive teams would be deployed from an ROVSV or Dive

Support Vessel (DSV). Platform deployment is unlikely because the fast rescue craft required to support diving operations are not normally carried on platforms. Costs may be similar to those stated above but safety risks associated with diving operations would be significantly higher, which would be seen as the dominant factor.

5.7 Summary of Results

Table 7 highlights the key the findings for the assessment for the *in situ* removal option.

Table 7: Summary for the *in situ* removal option

CA Criterion	Assessment Outcome
Technical Feasibility	Technically feasible, with defined limitations; requires development to improve the removal method and demonstrate effectiveness; and could involve protracted work programmes offshore.
Environmental and Societal Impact	Removal of marine growth *in situ* would be unlikely to cause detrimental environmental impacts and would not be a disincentive for the option. Benefits would be weight reduction for jacket lifting operations, avoidance or lessening of the odour issue associated with decaying marine growth onshore and avoidance of the need for onshore disposal. These are differentiators for the option.
Energy Usage and Emissions	Energy: 64,219 GJ CO_2: 4,768 tonne
Safety	PLL: 3.9 x 10^{-03}
Cost	£10 million to £15 million This could add 40% to 60% to an average decommissioning cost of £25 million for a barge launched jacket (derived from O&G UK, 2012).

6.0 MARINE GROWTH REMOVAL AT INTERMEDIATE MARINE LOCATION

The industry representatives consulted during the study were not aware of any experience of bulk removal of marine growth from an entire jacket at an intermediate location between the offshore field and the decommissioning yard

However, in order to provide a comparison with the removal *in situ* option, the following scenario for an intermediate location was examined. Alternatives were also considered as outlined in Section 8.2.6. The scenario comprises:

- The northern North Sea jacket would be cut sections which would be transported on individual barges to the removal site. The scenario has three sections, each on an individual barge.
- Marine growth would be removed before the jacket was transported to the onshore decommissioning site.
- Transit from the field location and to the onshore location has not been included because it would be part of the overall decommissioning project;
- The barge would be stationary because operations on a moving barge would be ruled out on safety grounds. Those consulted were unanimous on this point;
- Marine growth removal would be by water jetting or physical methods, with on-site disposal of the detached growth to the surrounding marine environment.
- The jacket sections would remain on the transport barge and the operation would be supported by other vessels. No consideration has been given in this CA to shore support or logistics which would nevertheless be critical to the success of the option.
- Marine growth removal would be carried out as a standalone operation and not as part of an overall dismantling project at the intermediate location.

6.1 Technical Feasibility

From the consultation, it was agreed that the removal scenario would be feasible. However, because the jacket sections could be structurally complex and potentially 30 m to 40 m tall, access could be an issue. The structure would need to be ‘cocooned in scaffolding’ (term that was mentioned), riggers would be used to gain access, or another method would need to be devised to ensure that fouled members could be cleaned.

It was suggested that scaffolding and cleaning teams could work in tandem to access and clean the jacket section. Operational and safety concerns were raised about space constraints for the equipment that needed to be on the barge. This led, however, to a convergence of opinion that conventional high pressure water jets, scrapers, scaffolding and rigging may not be necessary.

As an alternative, powerful, high volume water jets similar to fire monitors on tugs and fire fighting vessels were proposed. Large monitors can, for example, deliver around 3,600m^3 of water per hour with a 150m push height (Alco, 2012). The jetting system can be aimed at target areas and would be tailored to the work.

Monitors could potentially be deployed on the transport barge (outside or within the footprint of the jacket section), or on a workboat or fire fighting tug (which would be already have fire monitors) which could manoeuvre around the barge. They could be manually or remotely operated (as on fire fighting vessels). Cranes or boom lifts may be needed for access.

The spread for the operation could comprise: the transport barge, work boat (s), fast rescue craft, compressor(s), jetting and other equipment. Work boat(s) would house the jetting equipment and also transport personnel, provide office, food, shelter, and storage facilities. The tug used during transit could carry out barge mooring. A standby boat may be required for safety purposes.

Engineering development would be needed for anything other than jetting from a workboat or other vessel. Effective logistics for both offshore and onshore support would be crucial. From an operational viewpoint, relatively sheltered locations that are near to shore would suit this option. Availability of these locations may be a limiting factor because of depth limitations, environmental sensitivity, lack of shelter and access to the location.

It can be concluded therefore that bulk removal of marine growth from a jacket on a barge at an intermediate location is technically feasible but would require further development. Site availability could be a limiting factor.

6.2 Environmental and Societal Impacts

Marine growth removal would take place with the jacket on a barge at an intermediate location. This location typically could be:

- Located in waters of sufficient depth, shelter and proximity to onshore logistical support to enable the operation to take place. These would typically occur in inshore waters such as: Norwegian fjords, Scottish sea lochs and firths, inlets, channels and the open sea in coastal waters;
- In areas where water exchange and quality would be variable, but should be sufficient to mitigate water quality being compromised as a consequence of marine growth disposal at the location;
- Within an area that provides habitats for plankton, fish, seabirds, marine and terrestrial mammals and other wildlife;
- Typically within proximity of sensitive coastal habitats such as bird colonies, mud flats, salt marshes and estuaries;
- In a sea area that contains commercial fish and shellfish stocks, spawning and nursery areas for stocks, and farmed fish and shellfish; and
- Relatively close to land and to commercial shipping, fishing, aquaculture, leisure and recreational activities, coastal settlements, ports and harbours and industry.

Removal of marine growth at an intermediate location would involve vessel operations, the mooring and physical presence of a succession of barges on site, the transport of personnel and equipment, the operation of water jets, compressors and other equipment and the disposal of marine growth at the location.

Environmental and societal impacts could arise from:

- noise and exhaust emissions during the operation of vessels, compressors and other equipment;
- operational emissions, discharges, wastes from vessels working on the marine growth removal project;
- impedance to fishing activity and commercial vessel traffic;
- overboard spills;
- the odour of decaying marine growth;
- liquid effluent draining from fresh or decaying marine growth;
- dispersed marine growth within the water column; and
- deposited marine growth on the seabed.

The sections that follow provide background information on the frameworks for environmental legislative frameworks for integrated pollution prevention and control that apply to decommissioning facilities in the UK and Norway (Section 5.2.1), and then distinguish between the causes of impacts that are differentiators (Section 5.2.2) and non-differentiators (Section 5.2.3) for the onshore removal option.

6.2.1 Disposal of Marine Growth in Inshore Waters

The environmental legislative requirements for offshore disposal (Section 6.2.1) also apply to the disposal of marine growth in inshore waters. Operational discharges of sewage and treated oily bilge water from vessels would, however, be prohibited within Special Areas as defined under MARPOL (73/78).

Regarding the disposal of marine growth, licences would be required under the UK Marine and Coastal Access Act, 2009 and Marine Scotland Act 2010 (see below). For Norway, inshore disposal would be subject to a permit under the Petroleum Act 1996.

There are precedents in Norway for disposal in inshore waters, where marine growth has been removed from offshore structures that have dismantled in fjords (Klif, 2011a). Indeed, the Norwegian Climate and Pollutions Agency, Klif, has advocated marine disposal by stating (Klif, 2011a) that: '*Marine fouling should be removed from the installation while it is still offshore if this is technically possible. The open sea usually functions as a satisfactory recipient where the material decomposes naturally. Studies have also shown that disposing of fouling material in open fjords does not cause problems. In more enclosed, shallow waters, however, this may result in an excessive load of organic material and oxygen depletion on the seabed. Disposal of the material on land and composting is a possibility, but often results in odour problems*'.

Because BMT was not aware of any license awards for disposal of marine growth in UK inshore waters, they consulted Marine Scotland (permitting authority) about licensing requirements in Scottish waters (where most of the decommissioning activity in UK inshore waters would be likely to take place). They responded that, in principle, cleaning and disposal of marine growth could be a licensed activity in Scottish inshore waters (i.e. 0-12 nautical miles) under the Marine (Scotland) Act 2010 or in Scottish offshore waters (i.e. 12-200 nautical miles) under the Marine & Coastal Access Act, 2009. Any application for such an activity would have to be accompanied by a Best Practicable Environmental Option report (similar to a comparative assessment) and determined by Marine Scotland.

In summary, both the UK and Norwegian environmental licensing/permitting regimes allow for disposal of marine growth in inshore waters.

6.2.2 Non-differentiators

The environmental and societal issues that would not differentiate the option are similar to those given in Section 6.2.2.

6.2.3 Differentiators

The following consequences of marine growth removal and disposal to sea are considered to be differentiators of intermediate option:

Inshore disposal: Once moored onsite, the barge would act as a point source from which marine growth would be intermittently discharged during a work programme. As with the *in situ* option (Section 5.2.3), dispersed marine growth would be likely to cause turbidity, nutrient enhancement and increase in biochemical oxygen demand (BOD) within the plume of dispersed material. Deposits of marine growth could cause localised nutrient enrichment, BOD increase and proliferation of the many types of organism involved in the breakdown of organic material on the seabed. Breakdown mechanisms would be as stated in 5.2.3.

There is a concern however that the nutrients released from the discharged marine growth could potentially contribute to wider effects of nutrient enrichment (also called eutrophication) within sensitive water bodies, such as certain fjords, sea lochs and inlets where water exchange is limited. Modest inputs of nutrients may have a beneficial effect on biodiversity as well as the total production of the ecosystem. Excessive nutrient loading (surpluses) can initiate increased productivity and biomass (phytoplankton blooms), oxygen depletion and restricted light penetration leading to instability and changes in biodiversity in ecosystems. Inputs from agriculture, aquaculture, municipal waste-water and industry are the main anthropogenic contributors (NIVA, 2003; Klif, 2012; Gilibrand *et al*, 2006).

The selection of locations with good water exchange and oxygen levels appears to be critical to the suitability of an intermediate location for the removal and disposal to sea of marine growth. As stated in the preceding section, Klif, 2011a make reference to studies which have shown that marine growth disposal to open fjords would not cause problems. They further state that disposal of the material to more enclosed, shallow waters may cause excessive nutrient loading and oxygen depletion on the seabed. Careful site selection is the only mitigation and consultation, site selection studies, water quality assessment, modelling, monitoring should be considered in preparation for the permit application.

Odour nuisance: Decaying marine growth on the jacket could potentially create an odour nuisance to the public onshore, if the barge was moored in proximity to coastal dwellings and settlements. The extent to which this could become an issue would depend on the nature of the project, organisation and scheduling of the work, quantity and condition of the marine growth, proximity to shore, weather conditions, population distribution, and the attitudes of individuals exposed to the odour. Mitigation would be similar to odour management onshore (Section 5.2.1). Odour suppressants would be subject to regulatory permit.

Noise nuisance: Emission of sound by engines, machinery, jetting, vessel and barge operations would be inevitable for this type of project. Risks to workers from occupational noise would be assessed and managed using industry-standard safeguards. The extent to which environmental noise could become a nuisance to the public onshore would be similar to the odour issue (see above). Noise during night working could be an exacerbating factor. Public consultation before and during the project would be a key part of the management of this issue. As for onshore projects, noise level limits may apply.

Moorings: Impacts to the seabed and benthic organisms (organisms living on the seabed or within seabed sediments) created by the mooring system (anchor blocks or anchors, chains and mooring lines) for the barge. The seabed impacts would be localised within the footprint of the anchoring system and would depend on the seabed conditions and the type of anchoring system. The anchoring system would be removed at the end of operations (or possibly left in place for future operations).

Obstruction to other sea users: Physical presence of the barge, vessel spread and moorings could potentially create obstructs to inshore fishing, fish and shellfish farming, commercial shipping and recreational activities. As with offshore removal, the intermediate removal operation would be subject to Notices to Mariners, Shipping Alerts, and consultation during project planning. Management of vessel operations, communication, navigation systems, good seamanship and vigilance are the principal controls. Consultation with the local authorities, onshore communities, coastguards, harbour authorities, representative of local fishing, shell fishing and aquaculture interests, leisure and tourist bodies and conservation bodies would be an essential part of the mitigation.

Accidental spills: Spillage of diesel fuel could possibly occur during operations for fuel transfers at the worksite or vessel collisions. Although the spill consequences within a semi-enclosed water body could be potentially serious, the plans, equipment, procedures and operational practices to minimise spill risks would be specific for the project but also relatively standard for the industry.

Introduction of *Lophelia* to an inshore water body: *Lophelia pertusa* has been found mainly at depths from 200m to 1,000m in the north-east Atlantic region, occurring on the Rockall Bank, northern Rockall Trough, Porcupine Seabight and the Norwegian continental shelf and margin. It also exists in Norwegian fjords at much shallower depth (39 m shallowest depth) and at the Mingulay reef complex (120m shallowest depth) to the south west of the Hebrides (Glass and Roberts, 2006; Roberts *et al*, 1999). *Lophelia* has not been recorded in UK sea lochs, voes, bays, firths, inlets or coastal waters (distribution map in Davies *et al*, 2009)

Overboard disposal of live *Lophelia* could potentially form a nucleus on the seabed enabling this reef building organism to colonise a new environment. Although the possibility of the unintended introduction of *Lophelia* into a suitable habitat cannot be ruled out, the prospect of *Lophelia* remaining alive following removal from its marine environment, exposure to air and desiccation during transit on a barge is likely to be limited.

In summary, the main conclusion to be drawn from this section is that careful site selection is critical to ensure that the disposal of marine growth would not cause or exacerbate water quality problems within sensitive water bodies. Klif (2011a) have drawn attention to this distinctive facet of the intermediate option. Although BMT could find no reference to its occurrence, the odour of decaying marine growth on the jacket could potentially be an issue for sheltered sites close to shore. The remaining adverse consequences and risks have low probability of occurrence and/or are subject to fairly standard controls. They are therefore weak differentiators of the intermediate option.

6.3 Energy Usage and Emissions

Table 8 provides the estimates of energy usage and CO_2 emissions which were based on:

- the assumptions that manoeuvring and mooring of the barge would be carried out during 6 half-day operations and the duration of the marine growth removal programme assumed to be 84 days (3 x 28 day operations; one per jacket section);
- fuel consumption rate corresponds to a mid-range value for a working cargo barge tug given in Energy Institute, 2000. Estimates are also given for a work boat which is assumed to be mainly on standby and for two 350kW diesel generator sets to provide power for water jetting, lighting and other facilities (AEH Power, 2012)
- a work programme of four weeks per section (estimates given ranged from 2 weeks to 6 weeks); and
- energy and emissions factors of 43.1 GJ and 3.2 tonne CO_2 per tonne fuel (Energy Institute, 2000).

Table 8: Energy usage and fuel consumption estimates for the removal of marine growth from jacket sections on barges at an intermediate marine location.

Operation	Duration (days)	Fuel consumption rate (tonne/day)	Fuel consumed (tonne)	Energy Usage (GJ)	CO_2 Emissions (tonne)
Barge mooring by tug	1.5	21	32	1,358	101
Workboat operations	84	1	84	3,620	269
Generator to power water jetting and other equipment/facilities	84	2	168	7,241	538
Overall Energy Usage and Emissions				12,219	907

6.4 Safety Risk

Table 9 provides an estimate of the PLL for the work programme for marine growth removal at an intermediate location. It was based on:

- estimated numbers of personnel provided during consultation;
- exposure hours for a tug working that is relatively close to port working on 6 x 12 hour long mooring and manoeuvring operations;
- exposure hours for marine operations with 2 x 12 hour shifts per day covering an overall work programme of 84 days for the marine growth removal from the three sections. The table shows the numbers of personnel on board or present at any given time during the operation; and
- Fatal Accident Rates (fatalities per 100 million exposed hours) taken from Safetec, 1995 for marine operations (tugs) and marine operations (cranes, barges and vessels).

Table 9: PLL estimates for the removal of marine growth at an intermediate marine location.

Activity involving worker exposure	Number of Personnel	Exposure hours	FAR	PLL
Tug operations	6	216	13.2	5.7×10^{-05}
Workboat operations	3	6,048	5.5	3.3×10^{-04}
Water jetting team	6	12,096	5.5	6.7×10^{-03}
Operations and safety crew	6	12,096	5.5	6.7×10^{-03}
Overall PLL				1.7×10^{-03}

During consultation, the importance of work planning and adequate safety supervision (i.e. with 3 safety advisors per shift) was emphasised. The consultees' concerns about the safety of working on a moving barge in transit (e.g., stability, bad weather and capacity to evacuate the towed barge in event of emergencies) effectively ruled out this version of the intermediate option.

6.5 Cost

£2 million to £3 million was the estimated 'ball park' cost for a standalone operation for the removal of marine growth at an intermediate location. The cost of the jetting equipment, operational personnel was estimated to range from around £1.2 million to £1.8 million. The remaining costs were for barges and vessels.

These estimates assume that that the removal of marine growth from jacket sections on three barges would be carried out as a standalone operation (i.e. not part of a jacket dismantling operation at the intermediate location). Cost would be scalable in proportion to jacket size, complexity and number of barge loads.

6.6 Alternative Options

The consultees proposed several alternatives:

Removal of marine growth during jacket dismantling - As stated above, a standalone operation for removing marine growth was assessed. There are cases (e.g. Frigg DP2), however, where jacket dismantling could only be carried out in open fjords or similar water bodies because of depth restrictions preventing quayside access at the onshore decommissioning yard or for other technical or operational reasons.

In such instances marine growth removal would take place as the jacket was being dismantled. Marine growth would be removed when fouled members became available for cleaning and were accessible (e.g. when dismantled parts of the jacket were on the deck of the barge) and disposed of to sea. This technique has been carried out.

Removal during wet storage - It was suggested that marine growth could be removed from jackets which had been put in storage on the seabed at an inshore site (typically a Norwegian fjord) to await dismantling at the location or onshore. Again, it was suggested that fire monitors on tugs could be used for the bulk of marine growth from exposed parts of the jacket (e.g. mussels). As far as the consultees were aware, removal during wet storage had not occurred. Vessel costs at around £35,000 per day for a seagoing tug could be a disincentive.

Removal after the offshore lift - It was also suggested that marine growth could be removed using fire monitors on tugs when the jacket was suspended from the hook of a heavy lift vessel (HLV) or barge or on its deck. Concerns were raised about vessel/barge stability, safety and cost. With HLV day rates at around £450,000, the costs of delaying the HLV to enable marine growth to be cleaned off would be a substantial disincentive.

6.7 Summary of Results

Table 9 overleaf highlights the key the findings for the assessment for the intermediate removal option.

Table 9: Summary for the intermediate removal option

CA Criterion	Assessment Outcome
Technical Feasibility	This concept could be technically feasible as a standalone marine growth removal operation (i.e. not linked to dismantling at the intermediate location) but requires development to establish a proven removal technique for whole jackets or large sections of jackets. Marine growth removal and disposal to sea at an intermediate location has occurred during jacket dismantling in Norwegian fjords and this version of the concept has been proven.
Environmental and Societal Impact	There is a concern that disposal of marine growth to sea could potentially cause or contribute to nutrient enrichment in sensitive inshore water bodies where water exchange is limited. Provided that the site has been carefully selected to ensure that water exchange is good then this issue should not arise. Studies for decommissioning projects in Norway (Klif, 2012) have shown that marine growth disposal to open fjords would not cause problems. Odour from decomposing marine growth could be an issue for sheltered inshore locations that are relatively close to coastal communities. Controls would be similar to those used onshore.
Energy Usage and Emissions	Energy: 12,219 GJ CO_2: 148 tonne
Safety	PLL: 1.7×10^{-3}
Cost	£2 to £3 million. This adds 8% to 12% to the average decommissioning cost of £25 million for a barge launched jacket (derived from O&G UK, 2012).

7.0 COMPARISON OF OVERALL PERFORMANCE

Table 10 provides the results of the comparative assessment of the three options for the removal of marine growth from decommissioned structures. The table uses a normalised scoring system of 0 (highest performance) to 5 (lowest performance) to rank the performance of the options for each of the five criteria used in the assessment.

Scores for the two qualitative criteria of technical feasibility and environmental and societal impact were assigned evenly, with 0 for the highest performance, 2.5 for the intermediate performance and 5 for the lowest performance.

Scores for the three quantitative criteria of energy usage and emissions, safety and cost were assigned in proportion to the assessed numerical values. For each criterion, the intermediate performance score was assigned proportionately (to the nearest whole number) between 0 for the highest performance and 5 for the lowest performance.

An overall performance ranking was then established by totalling the scores for all of the performance criteria for each option.

7.1 Overall Performance

Table 10 shows that the outcome of the CA was that:

- onshore removal at a decommissioning yard had the top-ranked overall score, being the strongest performer in four out of the five criteria, but weakest in one criterion (environmental and societal impact);
- removal at an intermediate location ranked second, with scores for all five criteria lying in second position; and
- removal *in situ* offshore had the bottom-ranked overall score, being weakest in four out of the five criteria, but strongest in one criterion (environmental and societal impact).

The discussion in remainder of Section 8 provides the justification of the scores assigned to each of the options.

Table 10: Summary of the comparative assessment of the three options for the removal of marine growth during decommissioning (Scoring: 0 – most favourable to 5 – least favourable)

Assessment Criterion	**Removal at decommissioning yard**		**Removal *in situ* offshore**		**Removal at intermediate location**		**Differentiator**
	Assessment	**Score**	**Assessment**	**Score**	**Assessment**	**Score**	
Technical Feasibility	Feasible and proven. Used for most decommissioning projects to date. Well established technique; no development required.	0	Feasible based on pilot trial on offshore conductors. Development required for full scale application.	5	Feasible; not trialled as standalone operation, but previous use during jacket dismantling in fjords. Development required for full-scale application.	2.5	All of the techniques were assessed to be feasible. Removal onshore is positively differentiated by being a well-established, proven and fairly standard technique. Development would be required for the other options.
Environmental and Societal Impact	History of intermittent complaints about odour from decaying marine growth for adjacent communities. Yards' odour management measures well established and mainly successful.	5	Temporary localised impacts caused by deposition on of marine growth seabed and dispersal in water column would not be significant.	0	Norwegian studies have shown that disposal of marine growth in open fjords with good water exchange would not cause water quality problems. Site selection is therefore critical. Odour of decaying marine growth on the jacket could potentially be an issue for sheltered sites close to shore.	2.5	Removal *in situ* is positively differentiated because it lessens the risk of odour nuisance and removes a weight burden from the jacket prior to lifting. Odour nuisance negatively differentiates the onshore removal option because, although odour management is routine, complaints have actually occurred.
Energy Usage (GJ) and Emissions (tonne CO_2)	1,992 GJ 148 tonne	0	64,219 GJ 4,768 tonne	5	12,219 GJ 907 tonne	1	Removal onshore is positively differentiated by having the lowest energy usage and emissions resulting from combustion of fuel used by vehicles and equipment and gaseous emissions from marine growth disposed of to landfill. Emissions from fuel consumption during vessel operations negatively differentiate the remaining options.
Safety as Potential Loss of Life (PLL)	5.1×10^{-5} No safety constraints were identified.	0	3.9×10^{-3} No safety constraints were identified.	5	1.7×10^{-3} Safety concerns would rule out removal operations on a moving barge.	2	Removal in an onshore work environment is positively differentiated by having a statistically lower inherent safety risk than the options involving vessel operations. Worker exposure hours for the onshore option are also lower.
Cost as a 'ball park' range and an incremental cost on top of an average of £25 million for decommissioning a barge launched jacket	Range: £0.07 to £0.1 million Embedded Cost: 0.3% to 0.4% as costs contained within the overall £25 million (i.e. not an incremental cost).	0	Range: £10 to £15 million Increment: 40% to 60%	5	Range: £2 to £3 million Increment: 8% to 12%	1	Cost is the strongest differentiator between the options. Relatively low-cost, low- tech removal operations onshore have cost advantages over marine operations which are driven by vessel day rates.
Total Score		5		20		9	The onshore removal option has the overall highest performance. The principal differentiators are proven technical feasibility and lowest cost. Odour nuisance is a relatively weak driver because existing controls are mainly successful. The option for the intermediate location was assessed as a standalone operation for removing marine growth. Its overall score would improve in cases where jacket dismantling could only be carried out in open fjords or similar water bodies (i.e. not possible onshore). In this instance marine growth removal would be a subsidiary activity and the cost burden would mainly be borne by the dismantling work. *In situ* offshore removal has the highest cost.

7.2 Technical Feasibility

Feasibility was a strong differentiator between the options. Although all of the options were considered feasible, the onshore removal option, with a well-established track record of successful use on the majority of UK and Norwegian decommissioning projects and a relatively low-tech approach, would present the lowest technical risk to operators. In contrast, removal at an intermediate location has had a history of infrequent use on one-off dismantling projects in fjords, and removal *in situ* by ROV has undergone a small scale trial on the conductors of a large jacket but has not yet been used for a full scale application offshore.

7.3 Environmental and Societal Impact

The environmental and societal differentiators between the options are weaker than those for technical feasibility and cost (see below) because the technical and operational controls enacted during the decommissioning projects are designed to minimise environmental and societal risk.

Removal *in situ* offshore had the highest score for the environmental and societal impact criterion. Dispersive conditions in the open sea offshore would facilitate the breakdown of marine growth, which is a naturally occurring material. Bulk removal would be similar to processes that occur naturally when marine organisms growing on submerged sea cliffs, rocky shores, sea defences, harbour walls, offshore installations and other man-made structures die or are dislodged in bulk during storms.

Removal at an intermediate location was in second position. Concern about pollution caused or exacerbated by nutrients released to sensitive water bodies after the disposal to sea of marine growth was the reason for the assessment. However this is a relatively weak differentiator. If site selection is stringent and in line with permitting requirements, then sites will be located in open water bodies where water exchange is sufficient to mitigate pollution risks.

Because of an intermittent history of odour issues, onshore removal had the lowest score. During consultation, however, it was stressed that odour management by the decommissioning yards is proactive and largely successful and complaints about odour nuisance are infrequent. Indeed, odour nuisance may equally be an issue during removal at sheltered inshore locations where distances between the odour source and members of the public likely to be affected could be similar to those at an onshore yard.

7.4 Safety

The PLL results in Table 10 reveal differences in the inherent safety risk between the options. The ratio of 1:33:114 between PLL values for the onshore, intermediate and offshore *in situ* options highlights this observation.

PLL is derived from statistically based FARs for the type of activity (Safetec, 2005), estimates of number of personnel at risk and the durations of their work programmes. On this basis, onshore working on marine growth removal for relatively short periods is inherently safer than more prolonged working on barges and vessels at intermediate locations and ROVSVs at the field locations.

During consultation, no safety constraints for the three options were identified, other than concerns about the safety of working on a moving barge which ruled out this version of the intermediate option. For each option, enactment of technical and operational controls and safe systems of work would minimise safety risk.

7.5 Energy Usage and Emissions

The energy usage and emissions results in Table 10 largely reflect differences in the estimated fuel consumption between the options. These differences are reflected in the ratio of 1:6:32 which applies for both the energy usage and emission values for the onshore, intermediate and offshore *in situ* options.

In turn, fuel consumption by vehicles used during onshore would be lower than by vessels and compressors at the intermediate location which would be less than by the ROVSV during prolonged working at the field location.

7.6 Cost

Cost was a strong differentiator between the options. A comparison of costs reveals that the cost ratio between the onshore, intermediate and offshore *in situ* options is 1:30:150 (based on the higher figures given in the estimates in Table 10). Essentially, the onshore option has the lowest costs because it uses wheel loaders, excavators and lorries rather than sophisticated seagoing vessels with much higher day rates. To put this in perspective, the day rate for an ROVSV (mid-range rate around £150,000) would be greater than the entire estimated cost of marine growth removal onshore.

Table 10 also compares the cost estimates for the options with a cost benchmark of £25 million, representing an average decommissioning cost of a barge-launched steel jacket (figure derived from O&G UK, 2012). Because onshore removal has been used for the majority of decommissioning projects, the costs of this mainstream practice would be embedded within the £25 million benchmark. In contrast, while the onshore option would in effect be cost neutral, the intermediate and offshore *in situ* options respectively represent additional costs of 8% to 12% and 40% to 60%.

The incremental costs for the intermediate (inshore) option could make this option unviable. It is important to recognise, however, that the CA was based on the standalone cleaning operation. This approach tested the strength as a differentiator of the intermediate option’s advantage of lessening the risk of odour nuisance from decaying marine growth onshore and the requirement for onshore disposal.

During consultation, opinion was that removal would only be beneficial and cost-effective if it could be carried out on structures that needed to be dismantled at sea like Frigg DP2. They found difficulty in seeing the advantages of a standalone operation. Their question was: Why interrupt the transport of the jacket to shore to carry out a costly cleaning operation when this could be done more cost effectively onshore?

While there are strong disincentives for a standalone cleaning operation, the intermediate option would be viable where removal of marine growth was undertaken during a dismantling programme that could only take place at an inshore location. In this case the alignment of strong technical and operational drivers for dismantling at an intermediate location (e.g. prevention of quayside access to an onshore decommissioning yard because of insufficient water depth) would rule out onshore decommissioning.

The majority of the costs (tugs, barges, workboat, equipment, logistics, etc.) would then be borne by the dismantling work. Marine growth removal would be a subsidiary activity and would be relatively straightforward, with growth being removed when parts of the dismantled structure were placed on the deck of a barge or vessel prior to transport to shore. Marine growth removal costs could possibly approximate to those for onshore removal.

On the basis of the incremental cost arising from a prolonged work programme, offshore removal from the jacket *in situ* at the field location would be considered expensive. Advantages of lessening the risk of odour nuisance onshore and removing a weight burden from the jacket prior to lifting would be unlikely to counterbalance this cost disadvantage.

8.0 EMERGING TECHNOLOGIES

8.1 Cavitation Jets

Cavitation jetting has been used in the Gulf of Mexico and the West Coast of Africa for marine growth removal on offshore installations, and trialled on jackets in the southern North Sea. Cavitation jets can be fitted to ROVs but have mainly been used by divers for structural inspection. They have been used successfully for the rapid removal of bulk marine growth on ship hulls and anchor chains.

The nozzle of the jet is designed to create a plume of cavitation bubbles which collapse at or near to the solid boundaries therefore guiding high speed flow. Pressure changes caused by the collapse of bubbles produce mechanical removal of the marine growth (Parker *et al*. 1979). The devices cannot be used in air.

The suppliers of the cavitation jet have expressed confidence in the technology and the feasibility of its use for bulk marine growth removal by both ROVs and divers offshore.

8.2 Remotely Operated Cleaning Devices

A remotely operated water jet tool has been developed for the removal of marine growth on monopiles in the offshore wind industry. It wraps around the circumference of the structure and moves vertically when in operation removing marine growth via internal water jets (Proserv, 2012). The tool has been used on jacket legs but requires further engineering before it could have a wider application on steel jackets.

9.0 CONCLUSIONS

The following are the conclusions from the CA:

1. Removal of marine growth at a decommissioning yard attained the top-ranked overall score in the CA.
2. Historically, onshore removal has been the prevalent method of managing marine growth during decommissioning and has a successful track record. Operators use this as a primary option for the removal and disposal of marine growth because the commercial and technical risks and costs are relatively low.
3. Concern about instances of odour nuisance to local communities caused by decaying marine growth could be a disincentive to the onshore removal option. However, it was emphasised during consultation that odour management by the decommissioning yards is proactive and largely successful.
4. Availability and capacity of suitable onshore disposal facilities (landfill, composting and land spreading sites) could potentially become a constraint but do not currently appear to be limiting.
5. The option of removing and disposing of marine growth at an intermediate location such as a fjord or similar type of water body, ranked second in the CA.
6. Technical uncertainty, high cost of technical development, costs of vessel operations, and the competitive advantage of onshore yards create a strong disincentive for marine growth removal at an intermediate location to be undertaken as standalone operation.
7. Historically, marine growth removal and disposal to sea has been subsidiary to the dismantling operations on infrequent, one-off decommissioning projects in fjords, where onshore decommissioning has been impracticable. The option of removal at an intermediate location could be viable under these circumstances. Scheduling advantages where yards at capacity with, for example, decommissioning of topsides modules could also provide an incentive.
8. Under these circumstances, the majority of costs would be borne by the dismantling work and removal would be relatively straightforward, i.e. from parts of the dismantled structure placed on the deck of a barge or vessel prior to transport to shore.
9. Concern about pollution caused or exacerbated by nutrients released to sensitive water bodies after the disposal to sea of marine growth could potentially be a disincentive for the intermediate removal option. However this is a relatively weak differentiator.
10. If site selection is stringent and in line with permitting requirements, then sites should be located in open water bodies where water exchange is sufficient to mitigate pollution risks. Marine growth is a naturally occurring material that will break down in the marine environment until all that is left are the calcareous shells and skeletons of organisms.
11. Removal *in situ* offshore had the lowest-ranked overall score in the CA.

12. Offshore disposal of marine growth offers the advantages of lessening the risk of odour nuisance onshore and removing a weight burden from the jacket prior to lifting. However these advantages would be unlikely to counterbalance the substantial cost disadvantage of prolonged ROVSV operations offshore.

To summarise the overlying deciding factors in the selection of options come down to costs and risks. The prevalent practice of onshore removal is unlikely to change because the method is well established, reliable and is the most cost-effective.

To establish an efficient and cost-effective technology or array of technologies needed to remove marine growth *in situ* would require a substantial investment of both time and money from parties central to the decommissioning process (developers/contractors/operators). The variation in steel jacket types needs to be considered carefully as the removal scenarios would change from one offshore structure to another.

10.0 REFERENCES

AEA, 2011 Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting. Produced by AEA for the Department of Energy and Climate Change (DECC) and the Department for Environment, Food and Rural Affairs (Defra), Ricardo-AEA, London.

AEH Power, 2012. Website of AEH Power, www.aehpower.nl accessed 12 December 2012.

AF Environment, 2011. Website containing AFD0-50-T-001 Waste Management Plan, www.klif.no/nyheter/dokumenter/horing2011-613_avfallsplan.pdf Accessed 12 December 2012.

Alco,2012. Website of Alco, www.alco-frankfurt.de accessed 12 December 2012

Alibaba, 2012. Website of Alibaba Inc, www.alibaba.com accessed 12 December 2012

BMT 2011. *Decommissioning Baseline Study Review of the Management of Marine Growth during Decommissioning*. Report for Oil & Gas UK Ltd. BMT Cordah, Aberdeen.

BP, 2006. *Northwest Hutton Decommissioning Programme*. BP, London, UK

Brock B., Bernstein, B.B., Bressler, A., Cantle, P., Henrion, M., DeWitt J., Kruse, S., Pondella, D., Scholz, A., Setnicka, T. and Swamy, S. 2008. *Evaluating Alternatives for Decommissioning California's Offshore Oil and Gas Platforms: A Technical Analysis to Inform State Policy.* California Ocean Science Trust, Oakland, California, USA.

Davies, A.J., Green, S.L., Long, D. and Roberts, J.M. (2009). *Developing the necessary data layers to inform the development of a site boundary for the East Mingulay dSAC – Phase II*. Scottish Natural Heritage Commissioned Report No. 306 (ROAME No. 1390).

DECC, 2011. *Guidance Notes: Decommissioning of Offshore Oil and Gas Installations and Pipelines Under the Petroleum Act 1998*. Offshore Decommissioning Unit, Department of Energy and Climate Change, Aberdeen. UK

DEFRA, 2012. *Environmental Permitting Guidance. The IPPC Directive Part A(1) Installations and Part A(1) Mobile Plant For the Environmental Permitting (England and Wales) Regulations 2010.* Department for Environment, Food and Rural Affairs, London, Updated March 2010, Version 3.0.

Energy Institute, 2000. Energy Institute, *Guidelines for the Calculations of Estimates of Energy Use and Gaseous Emissions in the Decommissioning of Offshore Structures*, ISBN 0 85293 255 3, 2000.

Gass, S. E. and Roberts. J.M, 2005. *The occurrence of the cold-water coral Lophelia pertusa (Scleractinia) on oil and gas platforms in the North Sea: Colony growth, recruitment and environmental controls on distribution.* Marine Pollution Bulletin, Volume 52, Issue 5, May 2006, Pages 549–559

Gillibrand P., Cromey C.,. Black K.,Inall M., Gontarek S. 2006. *Identifying the Risk of Deoxygenation in Scottish Sea Lochs with Isolated Deep Water*. Scottish Association for Marine Science, Dunstaffnage Marine Laboratory, Oban.

Klif, 2004.Website of the Norwegian Climate and Pollution Agency http://www.klif.no/artikkel_33746.aspx accessed 19 December 2012.

Klif 2011a. *Environemtal Impacts Associated with the Decommissioning of Offshore Installations*. Report TA-2761. Climate and Pollution Agency, Oslo, Norway.

Klif 2011b. Environmental challenges from offshore decommissioning. Presentation by Reidunn Stokke, Senior Advisor, Klif at the North Sea Decommissioning Conference, Bergen, 15 February 2011. Climate and Pollution Agency, Oslo, Norway.

Klif, 2012. Website on State of the Environment Norway: Eutrophication. www.environment.no/Topics/Marine-areas/Eutrophication/ accessed 3 January 2013.

Motive Traction, 2012. Website of Motive Traction www.motive-traction.com accessed 17 December 2012

Niva, 2003. *Common Porcedure for Identificaton of the Eutrophication Status of Maritime Area of the Oslo and Paris Conventions*. NIVA report no. 4653-2003 (SFT TA-1928/2003)

Oil & Gas UK. 2012. *The Decommissioning of Steel Piled Jackets in the North Sea Region.* Oil & Gas UK Ltd, Aberdeen.

OJ, 2014. *Commission Regulation (EC) No 574/2004 of 23 February 2004 amending Annexes I and III to Regulation (EC) No 2150/2002 of the European Parliament and of the Council on waste statistics (Text with EEA relevance).* Official Journal of the European Union. OJ L 90, 27.3.2004

Parker, J. Bohli, W. Thiruvengadam, A. 1979. *A cavitating water jet cleaning system for removing marine growth and fouling from offshore platforms*. Research and Development Programme for OCS Oil and Gas Operations. U.S. Geological Survey.

Porserv, 2012. Website of Proserv Ltd, www.proserve.com accessed 17 December 2012.

Roberts, J.M., Davies, A.J., Henry L.A, Dodds L.A., Duineveld G.C.A., M. S. S. Lavaleye M.S.S, Maier C., van Soest R.W.M., Bergman M.J.N., Hühnerbach V., Huvenne V.A.I., Sinclair D.J., Watmough T., Long D., Green S.L., van Haren H, 1999. *Mingulay reef complex: an interdisciplinary study of cold-water coral habitat, hydrography and biodiversity*. Marine Ecology Progress Series Volume 397, pages 139–151.

Safetec, 1995. *Risk Analysis of Decommissioning Activities*. Joint Industry Project No. P20447. Doc No. ST-20447-RA-1-Rev03. Safetec UK Ltd, Aberdeen.

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

Total, 2007. *MCP01 Decommissioning Programme.* Total E&P UK Ltd, Aberdeen.

Oil & Gas UK (Aberdeen)
2nd Floor
The Exchange 2
62 Market Street
Aberdeen
AB11 5PJ

Tel: 01224 577 250

Oil & Gas UK (London)
6th Floor East
Portland House
Bressenden Place
London
SW1E 5BH

Tel: 020 7802 2400

info@oilandgasuk.co.uk

www.oilandgasuk.co.uk

ISBN 1 903 004 15 2
© 2013 The UK Oil and Gas Industry Association Limited, trading as Oil & Gas UK.