OIL SPILL RESPONSE IN GREENLAND: NET ENVIRONMENTAL BENEFIT ANALYSIS, NEBA, AND ENVIRONMENTAL MONITORING

Scientific Report from DCE – Danish Centre for Environment and Energy No. 221 2017

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Data sheet

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Abstract:	This review describes the state-of-the-art techniques for combating marine oil spills: mechanical recovery, chemical dispersants and *in situ* burning, and their applicability in the Arctic (Part I). The derived environmental effects from the techniques are described in Part II. Monitoring programme of the fate and effect of the oil spill/response methods is suggested in Part III. This includes monitoring at spill location, monitoring in the trajectory and the spreading/dispersion of the oil slick and analysis of the oil itself to identify changes in the physical and chemical properties due to weathering (e.g. evaporation, degradation) of the oil. Shoreline clean-up methods and strategy is treated in Part IV. Furthermore, wildlife response methods and strategies are described in Part V. This includes prevention of animals from exposure to oil, and when wildlife has been exposed, collection, euthanasia and/or rehabilitation of oiled wildlife.

Keywords:	Oil spill response, mechanical recovery, dispersion, in situ burning, net environmental benefit analysis, NEBA, wildlife response.
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Preface

This report includes environmental assessment and recommendation of offshore oil spill response strategies in Greenland in relation to oil / gas and mineral activities, including review of response techniques, development of guidelines and manual for approval procedure for use of specific response techniques, as well as strategies for sampling / monitoring, shoreline clean-up and wildlife response to support contingency planning.

For developing the contingency plan for oil exploration activities, the national strategies for response techniques must be established and included. For Greenland, DCE has recommended that dispersants and *in situ* burning operations can be allowed if based on a robust net environmental benefit analysis (NEBA).

It should be noted that this report only includes recommendations regarding oil spill response related to oil / gas and mineral activities.

The report consists of five parts and an appendix:

Part I: Review of techniques for combating oil spill at sea; mechanical recovery, chemical dispersion, *in situ* burning (ISB)
Janne Fritt-Rasmussen

Part II: Proposal for a NEBA based approval procedure for use of dispersants or *in situ* burning in oil spill response in Greenland
Susse Wegeberg
Based on:
- A generalised strategic NEBA for Greenland
- Procedure for performing a NEBA and which information needed by hand.

Part III: Environmental monitoring and sampling strategy in connection with an acute oil spill
Susse Wegeberg

Part IV: Strategy for shoreline clean-up for Greenland, including review of shoreline clean-up techniques, existing strategies and experience
Susse Wegeberg & Janne Fritt-Rasmussen

Part V: Wildlife response strategy in Greenland
David Boertmann

Summary

This review describes the state-of-the-art techniques for combating marine oil spills:

- mechanical recovery,
- chemical dispersants and
- *in situ* burning,

and their applicability in the Arctic (Part I). The derived environmental effects from the techniques are described in Part II.

Mechanical containment and recovery are the primary method and first choice in all the Arctic countries and use of pre-approved chemical dispersants is the secondary method. For the US, Iceland and Greenland, however, the use of chemical dispersant requires specific approval and authorization prior to use. *In situ* burning is only considered used in the US, Canada, Russia and Greenland upon approval.

The fate of an oil spill at sea depends on e.g. the physical / chemical properties of the oil, the ambient conditions and the release conditions. At sea, a number of weathering processes will change the properties and thereby the fate of the oil that will also change the window of-opportunity for the different oil spill response techniques. Of these weathering processes particular evaporation and emulsification are in focus.

Oil spill response in the Arctic differs from oil spill response in other regions, particularly due to the ice-affected conditions. Other challenges that should be dealt with are limited infrastructure due to remote locations and hence the need for a wider action time-window, harsh weather conditions, winter darkness, and low temperatures. Thus, the oil spill response methods should be adapted to these conditions to achieve the most efficient and robust response to an oil spill with an overall environmental benefit.

The selection of chemical dispersion and / or *in situ* burning as part of an acute oil spill response strategy must hence add to the overall benefit for the environment, where potential adverse environmental effects of the response techniques are less than the environmental benefit from the operation. This includes a balance between presence and sensitivity of organisms in the oil slick trajectory, in the water column and on the sea surface as well as the expected richness and sensitivity of the shoreline to beaching oil.

To support this choice of the optimal response technique, a Net Environmental Benefit Analysis, NEBA, shall be performed. The NEBA includes the environmental benefits and drawbacks / consequences of burning the oil on the sea surface and / or chemically dispersing the oil slick into the water column as supplements / substitutes to mechanical recovery if the operational or logistical conditions are suboptimal or inhibiting for this response technology.

When the response strategy has been decided and approved by the authorities, the fate and effect of the oil spill / response methods should be followed (Part III). This includes monitoring at spill location, monitoring in the trajectory and the spreading / dispersion of the oil slick and analysis of the oil itself to identify changes in the physical and chemical properties due to weathering (e.g. evaporation, degradation) of the oil.

Oil spill and countermeasures may have effect in air, water, ice, sediments and on coastlines. A sampling programme therefore has to include all these environmental compartments as well as associated biota. The monitoring should also include analyses for toxic effects as well as accumulation of oil components in biota and an integrated approach is recommended. Integrated monitoring hence involves a combination of chemical and biological measurements in water, sediment and biota and includes: the spread and fate of the oil; the efficiency of the oil spill countermeasures; the environmental impacts of the oil spill; potential side effects of countermeasures; and long-term environmental impacts.

Marine oil spills will often result in the stranding of dead and alive seabirds and marine mammals. Under severe conditions very high numbers – tens of thousands of individuals, mainly seabirds – may be affected if close to an oil spill. The term 'wildlife response' is used to describe the actions taken to prevent animals from exposure to oil, and when wildlife has been exposed also to collect, kill and / or rehabilitate oiled wildlife (Part IV). The target groups are usually seabirds, marine mammals and in tropical and subtropical areas also turtles, crocodiles and other reptilia, however, in a Greenland context, only seabirds and marine mammals are relevant.

In a Greenland context, the most realistic wildlife response will be euthanasia supplemented with collecting, registration and biological examination of killed wildlife for the purpose of getting information on mortality and affected populations.

Sammenfatning

Marine oliespild kan bekæmpes på tre måder:

- mekanisk opsamling,
- kemisk dispergering, hvor olien fordeles ned i vandsøjlen,
- afbrænding af olie på havoverfladen (*in situ* burning, ISB).

Dette review omhandler disse metoder og deres anvendelighed i Arktis (Part I). Mulige miljøkonsekvenser ved anvendelsen af metoderne er beskrevet i Part II.

Mekanisk indespærring og opsamling af olien er den primære bekæmpelsesmetode i de arktiske lande. Dernæst følger dispergering med forhåndsgodkendte dispergeringsmidler. I USA, Island og Grønland kræver anvendelse af kemiske dispergeringsmidler dog en særlig tilladelse. ISB må anvendes i USA, Canada, Rusland og Grønland, men kun efter særlig ansøgning.

Oliens skæbne i forbindelse med et spild i havet afhænger af oliens fysisk / kemiske egenskaber, af omgivelserne (havets temperatur, bølger mm) og af hvordan olien er spildt. Så snart olien er ude på havoverfladen foregår der forvitringsprocesser, der ændrer oliens egenskaber og som også ændrer mulighederne og tidsvinduet for at bekæmpe olien med de forskellige teknikker. De vigtigste forvitringsprocesser er fordampning og emulgering af olien med vand.

Der stilles andre krav til oliespildsbekæmpelse i Arktis end i andre dele af verden hovedsageligt pga. af forekomsten af is. Men andre forhold spiller også ind, herunder begrænset infrastruktur, hårde vejrforhold, vintermørke og lave temperaturer. Der er derfor behov for at tilpasse oliespildsbekæmpelsesmetoderne til disse forhold, for at opnå det mest effektive beredskab under hensyntagen til en overordnet størst mulig miljøgevinst.

Muligheden for at kunne dispergere og / eller afbrænde et oliespild skal sikre, at en bekæmpelse overordnet set er til fordel for miljøet. Men både dispergering og afbrænding medfører utilsigtede effekter på miljøet, og disse skulle gerne være mindre end gevinsten ved at oliemængden reduceres og / eller fjernes fra havoverfladen. Det er derfor vigtigt at have indgående kendskab til de organismer, der kan trues af et oliespild og af bekæmpelsesmetoderne: I vandsøjlen, på havoverfladen, på og langs de nærliggende kyster. Hvor mange og hvornår forekommer de i de af olien truede områder, hvordan påvirkes de af olie og af de forskellige metoder, osv.

For at sikre at de teknikker der vælges er overordnet miljømæssigt optimale udføres en *Net Environmental Benefit Analysis*, NEBA. Denne analyse inkluderer de miljømæssige fordele og ulemper ved kemisk dispergering af olien ned i vandsøjlen og / eller ved afbrænding af olien på havoverfladen (ISB) i den konkrete situation, som supplement til eller erstatning for mekanisk oprensning i det tilfælde, at det ikke er muligt at opsamle olien.

Oliens skæbne og effekt i miljøet bør overvåges (Part III). Dette inkluderer overvågning af selve spildet - hvor driver det hen, hvordan opfører olien sig på havoverfladen - og af kemiske / fysiske ændringer af olien for at kunne sætte bekæmpelsen ind på de rigtige steder og tidspunkter.

Både selve oliespildet, men også bekæmpelsesteknikkerne påvirker miljøet. I tilfælde af oliespild anbefales derfor et integreret overvågningsprogram, som inkluderer indsamling af prøver fra alle påvirkede elementer i miljøet (herunder organismer) og inkludere analyser af toksiske effekter og bioakkumulering af oliekomponenter i dyr og planter. Et integreret overvågningsprogram omfatter således en kombination af kemiske og biologiske målinger i vand, sediment og biota, og det skal belyse oliens skæbne og effekt, effektiviteten af bekæmpelsen, kort- og langsigtet indvirkning af oliespildet på miljøet og eventuelle bivirkninger af bekæmpelsesteknikkerne.

Marine oliespild vil ofte resultere i at olieramte havfugle og havpattedyr driver i land. I svære tilfælde kan et højt antal – titusinder af individer, hovedsageligt havfugle – blive berørt. Hvad der kan gøres med sådanne olieramte dyr bliver omtalt i Part IV.

I tilfælde af at der skulle drive høje antal af olieindsmurte dyr og fugle ind på en grønlandsk kyst, vurderes det, at det mest realistiske tiltag vil være at aflive så mange som muligt af de oliepåvirkede organismer. Døde og aflivede organismer bør desuden indsamles, registreres og undersøges for at få viden om bestandsforhold og dødelighed.

Eqikkaaneq

Imaani uuliaarluerneq pingasoqiusamik akiorneqarsinnaavoq:

- Katersorlugu
- Akuutissanik arrortorlugu, tassa immap ikeranut siammartillugu
- Immap qaaniittoq ikuallallugu.

Naliliineq manna periaatsinut taakkununnga taakkulu Issittumi atorneqarsinnaassusiinut tunngavoq (Imm. I). Periaatsit taakku atorneqarnerisa avatangiisinut sunniutigisinnaasaat Immikkoortoq II-mi nassuiarneqarput.

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Uuliaarluernermik arrortitsineq aamma / imaluunniit ikuallaaneq avatangiisinut iluaqutaaniartussaavoq. Kisiannili arrortitsineq ikuallaanerlu avatangiisinut sunniuteqartarput siunertarineqanngikkaluanik, taakkulu uuliap immap qaniittup annikillineqarnerata aamma / imaluunniit peerneqarnerata iluaqutissartaanit annikinneruniartussaapput. Taamaammat uumassusillit uuliaarluernermiit uuliaarluernermillu akiuiniarnermiit navianartorsiortinneqarsinnaasut ilisimalluarneqarnissaat pingaaruteqarpoq: Tassa immap ikerani, immap qaani, aammalu sinerissami sissamilu. Uumassusillit taakku piffinni navianartorsiortitaasuni qanoq amerlassuseqartarpat, qanoq uuliamit periaatsinillu assigiinngitsuni sunnerneqartarpat il.il.

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Uuliap qanoq pinera aammalu avatangiisinut sunniutai malinnaavigineqart-ariaqarput (Immikkoortoq III). Malinnaavigineqarneranut ilaapput uuliaar-luerfiup nammineq malinnaavigineqarnera - sumut tissukarneranik malitta-rinninneq, uuliap immap qaani pissuseqarneranik malinnaaneq - aammalu uuliap akuisa pissusiatalu allanngorneri, taama malinnaanikkut piffinni pif-fissanilu eqqortuni akiuiniarsinnaanissaq siunertarineqarpoq.

Uuliaarluerneq immini, aammali akiuiniarnermi periaatsit avatangiisinut sunniuteqartarput. Taamaammat uuliaarluertoqarneranut atasumik malin-naaviginninnermi suleriaasiliortoqarsimanissaa kaammattuutigineqarpoq, tassungalu ilaassapput avatangiisit sukutsitaani tamani mingutsinneqarsi-masuni misiligutissanik tigooraasarnerit (aamma uumassusilinnik) kiisalu nalilersuinerit uuliap akuisa uumasunut naasunullu toqunartoqalersitsinik-kut sunniutigisartagaat uumassusilinnilu eqiteruttarnerat ilanngullugit mi-sissorneqartassapput. Tassalu malinnaaviginninnermut ilaassapput im-mami, marrarmi uumasunilu akuutissanik timaanniillu misissuinerit, tama-tumuunakkullu uuliap qanoq pinera qanorlu sunniuteqarnera, akiuiniarne-rup qanoq pitsaatiginera, uuliaarluernerup avataangisinut qaninnerusumi ungasinnerusumilu sunniutai kiisalu akiuiniarnermi periaaserineqartut sani-atigut sunniutigisinnaasaat paasiniaavigineqassapput.

Timmissat miluumasullu imarmiut uuliaarluersimasut nunamut tipisarne-rat imaani uuliaarluernerup kingunerikkajuttarpaa. Ajorluinnaraangat tim-misarpassuit - 10 tusindtilikkaat, annermik timmissat imarmiut - eqqu-gaasarput. Uumasut tamakku uuliaarluersimasut qanoq iliorfigineqarsin-naanerat Immikkoortoq IV-imi eqqartorneqassaaq.

Uumasut timmissallu uuliaarluersimasut amerlaqisut Kalaallit Nunaata si-neriaanut tipioralissagaluarpata iliuuserineqarsinnaasoq piviusorsiorner-paaq tassaavoq uumassusillit uuliaarluersimasut sapinngisamik amerlaner-paat toqorarneqarnissaat. Aamma uumasut toqusimasut toqutallu kater-sorneqartariaqarput, nalunaarsorneqarlutik misissorneqarlutillu tamatumu-unakkut uumasoqatigiiaat qanoq issusii qanorlu toqorartoqartigisimanerat paasiumallugu.

Part I: Review of techniques for combating oil spill at sea; mechanical recovery, chemical dispersion, *in situ* burning (ISB)

Janne Fritt-Rasmussen

This review describes the state-of-the-art techniques for combating oil spills: mechanical recovery, chemical dispersants and *in situ* burning with respect to their applicability in the Arctic. The derived environmental effects are described in Part II. An overview from AMAP (2010) of the different methods indicates that in all of the Arctic countries mechanical containment and recovery are the primary method and first choice. Use of pre-approved chemical dispersants is the secondary method in the Arctic countries. For the US, Iceland and Greenland, however, the use of chemical dispersant requires specific approval and authorization prior to use. *In situ* burning is only considered used in the US, Canada, Russia and Greenland upon approval.

The fate of an oil spill at sea depends on e.g. the physical / chemical properties of the oil, the ambient conditions and the release conditions. At sea, however, also a number of weathering processes will change the properties and thereby the fate of the oil that will also influence the window of-opportunity for the different oil spill response techniques. Of these weathering processes particular evaporation and emulsification are worth mentioning. By evaporation the most volatile oil compounds are removed resulting in oil with a higher density, viscosity, pour point and flash point. Emulsification (water-in-oil (w / o) emulsification) results in an uptake of water in the oil, thereby increasing the viscosity and the total volume of the oil that must be handled by the responders.

Oil spill response in the Arctic differs from oil spill response in other regions, particularly due to the ice-affected conditions, in many Arctic / subarctic areas. Other challenges that should be dealt with are limited infrastructure due to remote locations and hence potentially need for a wider action time window, winter darkness, and low temperatures. Thus, the oil spill response methods should be adapted to these conditions to achieve the most efficient and robust response to an oil spill. Under ice-affected conditions, an oil spill may follow different routes and have different behaviour and fate depending on the ice conditions and spill location (above, under, between the ice), as shown in *Figure 1.1*. If the oil is spilled under the ice, it is in particular challenging or even impossible to locate and respond to the oil spill with the present technology (Huntington 2007).

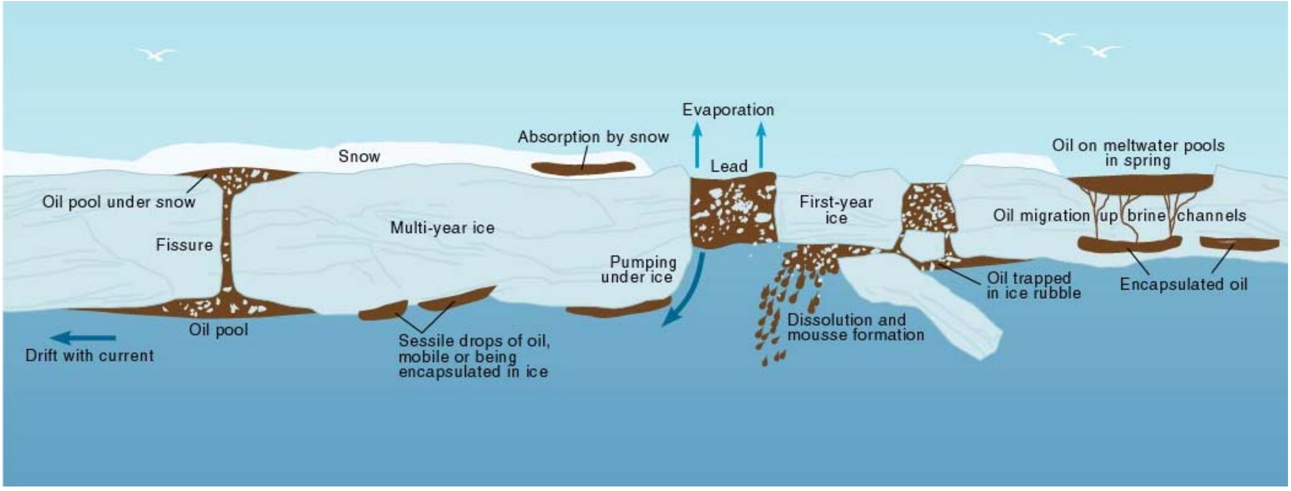


Figure 1.1. Conceptual outline of the behaviour of oil in ice-covered water (adapted from AMAP 1998).

Different seasons exist for ice-affected waters: the freezing season (new ice is forming), the more stable and cold midwinter (solid and continuous ice) and finally the thawing season (old ice is melting). The rest of the year, the open water conditions are more or less comparable with other climates / locations. The freezing and thawing periods are the most unstable and give limited access to the area, in many situations only accessible by air. Also different types of ice exist, hence the properties of ice could vary e.g. thickness and density. Ice could also be dynamic and e.g. be transported with the present current.

It has been stated by Dickins & Buist (1999) that ice coverage between 30 and 60 % are the most difficult to operate in during an oil spill response operation. In *Table 1.1* below it is indicated where the different response technologies have their operational limitations as a function of ice coverage.

Other factors such as wind and wave height also influence the operational use of the different methods. This will be treated in more detail in the next sections, however, an overview can be seen in *Table 1.2* (adapted from Nuka & Pearson 2010) that summarizes the generally accepted response limits to mechanical recovery (with and without ice management) and *in situ* burning to a range of ice coverage, wind, wave height and visibility conditions. Dispersants were not included originally in the table because their use is still not considered a mature technology in ice and have not been pre-authorized for use in the US Arctic Ocean (Nuka & Pearson 2010). Dispersants, however, have been included in the table by the authors. It is important to bear in mind that the different ranges for the limiting factors are approximate ranges / numbers, which are not fitted directly to the dispersant situation, but is the ranges / numbers put in the table originally by Nuka & Pearson (2010). Therefore, the table should be seen as indicative and guiding rather than finite.

Localization and sensing of an oil spill for oil spill response may be a challenge in areas with ice and snowfall or if the oil is located under ice. In general the oil follows the ice movements and may be possible to find from air, by use of remote sensing techniques with the potential for detecting oil in ice, such as a fluorescence detector, ground penetration radar and ethane detectors etc. (Brandvik & Buvik 2009) or by analysing cores of the ice and snow. During field experiments on Svalbard in 2008, even dogs were used to detect oil in the ice with success, however, a huge amount of research and development still needs to be done to verify the operational usefulness (Brandvik & Buvik 2009).

Table 1.1. Indication of expected operational limits of different response methods as a function of ice coverage (adapted from Evers et al. 2006).

Response method	Open water	Ice coverage									
		10 %	20 %	30 %	40 %	50 %	60 %	70 %	80 %	90 %	100 %
Mechanical recovery:											
Traditional configuration (boom and skimmer)											
Use of skimmer from icebreaker											
Newly developed concepts (Vibrating unit, MORICE*)											
***In situ* burning:**											
Use of fireproof booms											
In situ burning in dense ice											
Dispersants:											
Fixed-wing aircraft											
Helicopter											
Boat spraying arms											
Boat "spraying guns"											

* Mechanical Oil Recovery in Ice Infested Waters (MORICE) was a multi-phase Joint Industry Project (JIP) to develop technologies for more effective recovery of oil spills in ice-infested waters.

Table 1.2. Matrix of *approximate* physical oil spill response limits adapted from Nuka & Pearson (2010) and a row added for the physical response limits for chemical dispersion. The response limits should be seen as indications that might vary under specific conditions. For more details the sections below should be consulted. Green blocks indicate conditions generally considered to be favourable for the response technique and indicate only that the technique may be feasible; the effectiveness of that technique may still be limited. Yellow blocks indicate that conditions are suboptimal and that response operations *may* be impeded. Red blocks indicate that response would not be possible under these conditions.

Limiting factor	Ice coverage					Wind			Wave height			Visibility[1]		
Conditions	**< 10 %**	**11 % to 30 %**	**31 % to 70 %**	**> 70 %**	**Solid ice**	**0-9 m/s**	**9-15 m/s**	**> 15 m/s**	**< 0.9 m**	**0.9-1.8 m**	**> 1.8 m**	**High**	**Moder-ate**	**Low**
Mechanical recovery with no ice management														
Mechanical recovery with ice management					n/a									
In situ burning														
Chemical dispersion[2]			3)											

[1] Moderate visibility = light fog or > 1 mile visibility, low visibility = heavy fog, < 1/4 mile visibility, or darkness.

[2] This row was added to the original table by the authors.

[3] Depending on the application method and possibility of adding mechanical energy to the system.

In the following three sections, reviews are given of mechanical recovery, chemical dispersants and *in situ* burning in general terms, with respect to their Arctic applicability.

1.1 Mechanical recovery (containment and recovery)

In overall terms conventional containment and recovery are methods where the oil slick is kept together by containment booms followed by recovery with skimmers or similar to recover the oil from the sea surface. Oil spill in open water will quickly spread to form a thin layer, thus containment is required to thicken it for efficient recovery of the oil (Potter et al. 2012). Examples of a containment boom and a skimmer device in use with ice are shown in *Figure 1.2*.

Open water situations or minimal ice coverage are found in most places in the Arctic during summer seasons. In such cases conventional containment and recovery for open water situations can be deployed (up to 10 % ice and with some efficiency up to 20-30 % especially with active ice management (Potter et al. 2012)). However, for the rest of the year, the challenge with ice will impact the choice of techniques and equipment. After recovery the oil must be temporarily stored and the water must be separated before the oil is recycled or treated / disposed of (Fingas 2000). Pumps are necessary links in the recovery process, for recovery from the sea surface and for transferring in connection with the storage. The pumps must be able to handle viscous oil, emulsions, etc. (Potter & Morrison 2013). The storage availability of the recovered oil can be a limiting factor for an efficient containment and recovery operation as the water-oil emulsion has much larger volumes than the oil alone (Potter et al. 2012).

Mechanical recovery is the method of first choice in all the countries covering the Arctic as this method removes the oil from the environment. Mechanical recovery is, however, quite labour-intensive and requires optimal operational conditions for being efficient. Therefore, containment and recovery is especially well suited for removing oil spills in harbours or other protected waters (Potter et al. 2012).

1.1.1 Containment booms

A containment boom is a floating barrier that should prevent the oil from further spreading to e.g. protected, sensitive areas or for keeping the oil slick together for recovery or *in situ* burning (see later). Generally, booms will not work in waves higher than 1 metre or if currents are faster than 1 knot (EPA 2013). Other situations might occur where the boom might fail in different ways. Booms used for containment of oil are typically towed in a U-shaped configuration behind two vessels, however, J and V shapes can also be used. The towing speed in the apex of the U-shape must not exceed 0.5 m / s or 1 knot; this is referred to as the critical velocity (Fingas 2000). If the critical velocity is exceeded, oil will be lost. Booms can also be placed from shoreline to shoreline, in a dock, around a vessel or around a point release etc. (DEC 2013). Other deployment methods exist, including single vessel deployment e.g. in combination with a paravane, which is a device that makes use of the power of the current for deploying the boom or in combination with an outrigger with a sweeping arm attached to the vessel. However, booms that will work in higher velocities have been designed and tested, and which may achieve efficient recovery in currents over 3 knots in calm waters and 2 knot current in harbour chop waves (USGC 2001 in Potter et al. 2012). A large variety of different and commercially available booms exist designed for different situations (e.g. for skimmers, fire resistant booms, high seas, etc.) and more details regarding specific designs are available from the manufactures or the world catalogue (Potter & Morrison 2013).

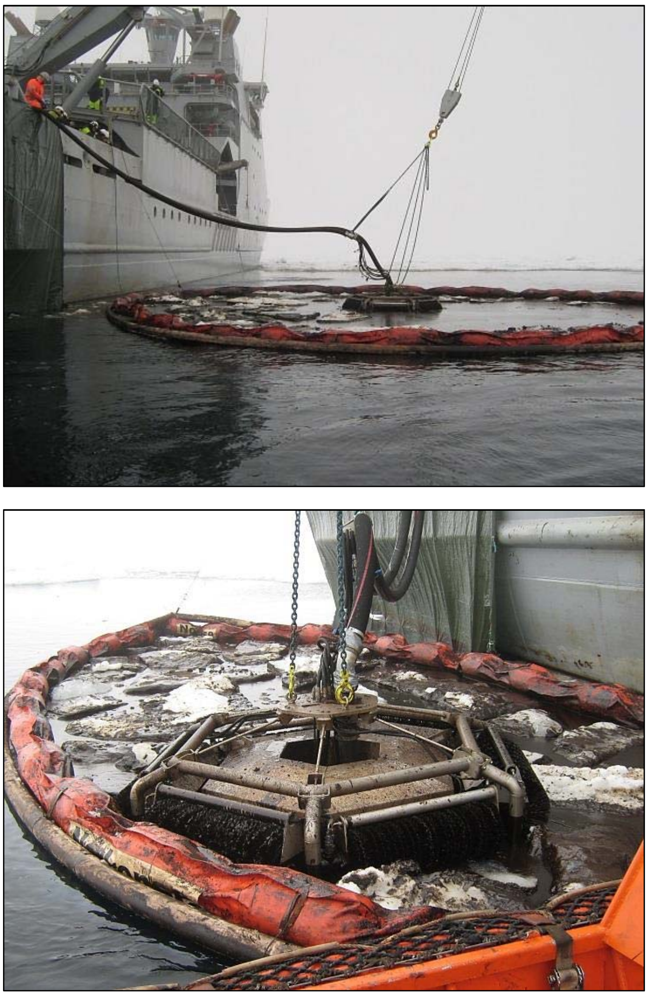


Figure 1.2. Examples of a containment boom and recovery with a skimmer devise in use with ice (from SINTEF 2013).

1.1.2 Skimmer

A skimmer is a devise that mechanically removes the oil from the water surface. The skimmer should be placed where the oil is thickest to be most efficient. Four different types of skimmers exist for recovering oil at sea: oleophilic, weir, vacuum and mechanical (Potter et al. 2012). The most used type of skimmer is the oleophilic skimmer (Broje & Keller 2006), which can be formed as e.g. a disc, drum, belt, brush or rope (Fingas 2000). The principle behind the oleophilic skimmer is that the oil adheres to a rotating surface and, when the surface with the oil is out of the water, the oil is scraped off into a collector (Broje & Keller 2006). Potter et al. (2012) describes the optimal uses of the different skimmer types: Oleophilic skimmers are generally efficient with a relatively high recovered oil-to-water ratio and most suited for light to medium viscosity oils. High viscosity oils could be handled using the brush type. Weir skimmers are systems where the oil is passing over a weir arrangement that is used to separate the oil and water phases. This method is usually less efficient than oleophilic skimmers and often recovers large amounts of water as well, thus requiring more storing capacity. Weir skimmers can handle both light and heavy products. Vacuum skimmers use vacuum or air movement to lift the oil from the sea surface, but can be inefficient by recovering more water than oil. This system can be used for most oils generally, excluding refined volatile products due to safety reasons and heavy oil. Mechanical skimmers use physical collection of oil from the surface by use of grab buckets to conveyor belts and these skimmers are more suited to very viscous oils.

The encounter rate is the amount of oil which comes into contact with a recovery devise (skimmer, sorbents) over a given period of time and the encounter rate can be negatively impacted by the spreading of the oil, resulting in reduced slick thickness and formation of windrows or patches (Potter et al. 2012).

In waves larger than 1 m or where the current exceeds 1 knot most skimmers will not work efficiently (Fingas 2000), as the rough seas can move the skimmer collection mechanisms away from the oil on the water surface (Potter & Morrison 2013). Ice or debris and very viscous oils or tar balls can have a negative impact on the recovery as such conditions make the pumping very difficult (Fingas 2000) due to the limited flow. Also low air and sea temperatures can cause problems, e.g. icing of equipment and increase of the viscosity of the oil that might result in reduced recovery in many situations (Potter & Morrison 2013). The performance of the skimmer might also change during the day as a result of the changes in temperatures (Potter & Morrison 2013).

1.1.3 Review of mechanical recovery in an Artic (Greenland) perspective

Arctic field experiments have shown that it is difficult to achieve high recovery rates (Potter et al. 2012). Problems associated with oil recovery operations in ice-infested water include: limited flow of oil to recovery devise due to low temperatures and hence increased oil viscosity, limited access to the oil, deflection of oil with ice, separation of oil from ice, contamination of ice/cleaning of ice, icing of equipment, strength considerations and detection of oil in various ice conditions (Brandvik et al. 2006). Also, extreme low temperatures present a hazard to operating heavy equipment and other hydraulic systems (Glover & Dickins 2005). As mentioned, the periods of most challenge for oil spill response are during freeze up and breakup going from predominantly open water to continuous ice cover or vice versa (Glover & Dickins 2005). During these ice unstable periods, response operations may encounter the possibility of oil trapped in or on top of the ice and moving with the ice (Glover & Dickins 2005). These different seasons have different ice regimes and thus need different mechanical recovery approaches (see *Figure 1.1*). In West Greenland the most relevant ice conditions are first year sea ice and land fast ice near the shore. The different mechanical recovery approaches for these conditions are described below, however, in general for all the methods, the goal is to prevent the oil from spreading in the environment and to recover it.

1.1.4 Oil in ice

Using containment booms to collect the oil requires working space at the sea surface, which is often limited by the ice. Thus, the main problems when using mechanical oil recovery in ice-infested waters are the ice processing (the deflection of the ice to gain access to the oil), manoeuvrability of a working platform in ice and accessibility of the oil (Brandvik et al. 2006). Further, sea ice may reduce the effectiveness of containment booms by interfering with the boom position, allowing oil to entrain or travel under the boom or causing the boom to tear or separate (Nuka & Pearson 2010). Oil also tends to mix into the ice, creating an additional step for the responders trying to separate the oil from the ice (Nuka & Pearson 2010). On the other hand, sea ice may also act as a natural containment barrier to the oil. Oil trapped in ice is contained from spreading, hopefully, until the response teams can gain access (Glover & Dickins 2005). Satellite tracking beacons can be deployed at the spill source to monitor the drift of any oiled ice away from the spill site (Glover & Dickins 2005).

In *Table 1.3* below, different measures to recover oil from different ice types/covers are listed.

Table1.3. Measures to recover oil from different ice types/covers.

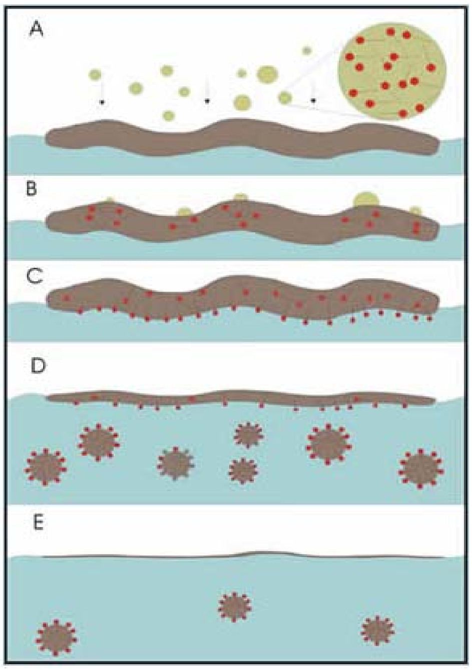
Ice cover type	Measures
30 %	Ice coverage of 30 % represents a generally accepted upper limit for deploying conventional booms and skimmers without too high risk of interruption from drifting sea ice (SL Ross 1993 in Glover & Dickins 2005; Dickins & Buist 1999), especially with active ice management. For light ice conditions it is considered feasible to use containment booms and skimmers, with shorter length of booms in a J-configuration (SL Ross et al. 1998). High-strength booms will be required for such kind of application to withstand the ice, and skimmers could be either weir-type or oleophilic rope-mop skimmers (SL Ross et al. 1998).
30-60 (70) %	Additional containment in such ice concentrations is usually required; however, the ice could destroy the booms. Therefore 30-60(70) % ice cover is expected to be the biggest challenge to mechanical recovery. However, skimmers are available for oil spilled amongst ice; these recovery systems must be able to perform effective ice processing to gain access to the oil to effectively remove it. Another general issue for the Arctic is the low temperatures that could make the skimmers to freeze; thus heating might be a necessity (Potter et al. 2012).One example of a skimmer for such ice conditions is the *Foxtail* skimmer that can be used in pockets in the ice (SL Ross et al. 2010).
70-100 %	For ice concentrations higher than 70%, the ice acts as a barrier and will prevent the oil from spreading. Such natural containment can be an advantage in a response context as the oil may remain in thick pockets, however, the recovery rate can be limited by the corresponding lowered accessibility to the oil (Dickins & Buist 1999 in Nuka & Pearson 2010). Presence of ice may dampen the wind and wave induced weathering of the oil that otherwise normally result in increase of viscosity and volume due to uptake of water as a result of emulsification and hence increase the time window for pumping the oil.
On solid land fast ice	On solid land fast ice, the ice can be used as a platform for support of equipment, e.g., heavy trucks (SL Ross et al. 1998). The ice thickness dictates the available sites access and load-bearing capacity for staging equipment and surface travel to and from the spill site (Glover & Dickins. 2005). For oil spilt on the ice, snow scraped together on the ice can be used to form booms that will last even longer if they are sprayed with water. If there is insufficient snow, other materials could be used instead, e.g., sandbags, conventional booms. Oil spilt on ice is either scraped or pumped away. Ice over-flood is a special scenario, where the surface is difficult to access due to water and any oil surfacing through the ice is potentially free to spread on the surface waters (Glover & Dickins 2005).
Under ice	For oil spilt under ice: when the oil is detected, a hole (or several, depending on the spill size) must be drilled in the ice from where the free oil is reached with a rope mop skimmer or the oil is pumped away. Such direct pumping and ice road haul operations in the mid-winter might be efficient. In order to eliminate the volume of contaminated ice, the upper layer of ice can be removed prior to exposing the oil pool. (Glover & Dickins 2005). Also snow melters can be used to melt contaminated snow and ice (Glover & Dickins 2005). By selective snow removal on fast ice, ice may grow selectively on the underside effectively “booming” the oil. Otherwise, there are limited mechanical options for recovering large volumes of oil spilled under or among new and young ice in the autumn month (Glover & Dickins 2005). Though, it is possible to use weir type skimmers under building ice conditions as long as the skimmers are equipped with mechanical systems to handle debris and ice (Glover & Dickins 2005).

1.2 Chemical dispersants

A dispersant is a chemical that, when it is sprayed onto the oil slick, enhances the natural dispersion processes that are already taking place, thus the oil concentration in the water column will increase and much of the oil is removed from the surface. The principle is presented below in *Figure 1.3*. The oil breaks up into small droplets, less than 70 µm, that will mix into the water column for further dilution and degradation (Blondina et al. 1999). To achieve an effective dispersion, the droplets must be in the range of 1-70 µm (ITOPF 2011). The resurfacing for this droplet size will be balanced by the turbulence at sea, and thus remain in suspension (ITOFP 2011).

Chemical dispersants consist of a complex mixture of surfactants, solvents and additives. A large variety of different types of commercially available chemical dispersants exist.

Figure 1.3. Conceptual outline of the principle of chemical dispersants (adapted from ITOPF 2013).



A) Dispersant droplets containing surfactants (red dots) are sprayed onto the oil.
B) The solvent (green dots) carries the surfactant into the oil.
C) The surfactant molecules migrate to the oil/water interface and reduce surface tension, allowing
D) small oil droplets to break away from the slick.
E) The droplets disperse by turbulent mixing, leaving only sheen on the water surface.

Mixing energy is needed to stimulate the dispersion process. The energy could be supplied either naturally (waves) or mechanically from e.g. thrusters from a vessel or a by the water jet from e.g. a small rescue boat (Brandvik et al. 2010) (see *Figure 1.4*). From field trials, 4-12 m/s is found to be the optimum wind speed (ITOPF 2011). Within this range a good dispersion by wave energy is secured; however, the wind is not too strong so that the dispersant will not hit the oil slick (Chapman et al. 2007).

The performance and effectiveness of the dispersants are influenced by several parameters including the properties of the oil (or oil type), type of dispersant, oil weathering degree, sea water and air temperature, sea water salinity, energy conditions, and oil availability (Brandvik et al. 2006). The weathering processes change the properties of the oil, e.g. increases the viscosity. The viscosity is an important parameter in relation to the effectiveness of different chemical dispersants. A high viscosity oil will reduce the effectiveness of the dispersant as the molecular diffusion of the dispersant into the oil becomes increasingly more difficult and requires more time with increasing viscosity (Brandvik & Faksness 2009; Brandvik et al. 2010a). Furthermore, if the penetration takes too long, the dispersant could be flushed away by wave action (Brandvik & Faksness 2009).

However, the relation between viscosity and dispersant effectiveness is not linear. The limiting viscosity value varies with test method, which probably reflects that higher viscosity oils can more easily be dispersed in rougher seas than in calm seas (Lewis & Daling 2007). If the pour point exceeds the sea water temperature with more than 10 °C, the oil might not be chemically dispersible (Potter et al. 2012). Nevertheless, chemical dispersants have been used on heavier, and hence more viscous, oils, and can be efficient if the dispersant is added fast (fresh oil and response equipment nearby) and the sea water temperature is relatively high (Chapman et al. 2007).

Figure 1.4. Example of an application system of chemical dispersants from a vessel including the use of a rescue boat to create necessary mixing energy (adapted from SINTEF 2013).

Results from studies by Brandvik et al. (1995) showed that dispersants with high efficiency for very saline waters on the contrary may result in very low efficiency for low salinity waters. With less salinity the surfactant gets increasingly soluble and therefore less available to interact with the oil (Chapman et al. 2007). Most available dispersants are formulated for use in marine waters, thus have lower effectiveness in low salinity water, however, dispersants suited for freshwater can be produced (Lewis & Daling 2007).

A vast number of methods exist for application of the chemical dispersant and for specific details the manufacturers should be consulted. The dispersants can be applied from e.g. aircraft, vessel, by hand or subsea. Conventionally, vessels are platforms for spraying dispersants due to the advantages of carrying a large quantity of dispersant on board, and staying on location day and night for a longer period. A disadvantage is, though, the relatively slow arrival at the oil spill site and spraying speed (Lewis & Daling 2007a). On the contrary, fixed-wing aircraft can rapidly go to the spill site and apply dispersant, but also spending time on transitioning between airfield and spill site for loading as well as manoeuvring (Lewis & Daling 2007a).

It is important that the spray system is able to apply the dispersant in the desired flow rate and droplet size. If these are too small, they may blow away and if they are too large, they may sink out through the oil (Potter & Morrison 2013). Also, the focus has been on spraying width and to spray as fast as possible to achieve a high “encounter rate”, i.e. the area of spilled oil sprayed per unit time (Lewis & Daling 2007a). However, this might result in under and / or over treatment. When applying dispersant, it is important to bear in mind that the thickness of the slick varies due to the spreading and drifting. For instance 90% of the oil may be relatively thick (1-2 mm), and only cover about 10 % of the spill area, while the remaining 10 % of the oil will be “sheen” (< 1 µm) and cover about 90% of the area of the spill (Brandvik 2004). Therefore, to avoid under and over treatment, due to the slick thicknesses differences, the amount of dispersant applied should not be the same all over the slick (Potter & Morrison 2013).

During the BP Deepwater Horizon incident, chemical dispersants were applied subsea to the well head, i.e. directly to the source of the leak. The results to date for this novel approach indicate that subsea use of dispersants is effective (effectively disperses the oil and reduces the amount of oil reaching the surface) and further reduces the amount of dispersants that are needed compared to surface dispersing (EPA 2015). American Petroleum Institute (API) and its industry companies have developed a research programme that will study the effectiveness of subsea injections in controlled experiments (API 2015). According to EPA (2015), the federal response team and NOAA will work closely to monitor for presence of oil and the use of surface and subsurface dispersants from the BP Deepwater Horizon incident.

1.2.1 Review of chemical dispersants in an Artic perspective

According to Lewis & Daling (2007a) the most critical parameters for operational use of dispersants under Arctic conditions are: i) contact between dispersant and oil, ii) sufficient energy for the dispersion process, iii) oil properties at low temperature, incl. weathering rate, and iv) dispersant performance and properties under relevant conditions (salinity, temperature, oil type). The potential for different application methods with different ice conditions can be found in *Table 1.1*. According to Lewis & Daling (2007a), in the highest ice concentrations (> 60 %), the slow weathering of the oil gives the potential for later treatment.

Compared to ice-free conditions, the presence of ice will influence the dispersant application in two ways: 1) the ice will alter the distribution of the spilled oil on the sea surface and 2) the presence of ice will set limits to the operation of any vessel spraying dispersants (Lewis & Daling 2007a). Dispersant spraying from aircraft onto spilled oil in ice may be feasible in low ice conditions even though the dispersant deposited onto the ice would be effectively “lost”. The areas of spilled oil between the ice floes could probably be accurately targeted up to 2-3 / 10 ice cover by fixed-wing aircraft spraying dispersant. Helicopters could conceivably operate in higher ice conditions, up to 5 / 10 ice cover and possibly higher, if flying conditions are good, by flying slower and more manoeuvrable than fixed-wing aircrafts (Lewis and Daling 2007a).

Low temperature increases the viscosity, thus reduces the dispersant effectiveness when a limiting oil viscosity is exceeded. On the other hand, the rate of weathering is inhibited by cold conditions and the sea calming effect of ice, thus the ‘window of opportunity’ may be extended in Arctic conditions (Lewis & Daling 2007). Research results with dispersant on oil with the presence of ice seem to indicate that chemical dispersion can be accomplished with presence of ice in wave conditions with small amplitude and low frequency, conditions that would be suboptimal for dispersion in ice-free conditions. These results have not been verified by field experiments (Lewis and Daling 2007). From tests at OHMSETT (Oil and Hazardous Materials Simulated Environmental Test Tank, The National Oil Spill Response Test Facility in the US), it was concluded that chemical dispersion can be effective in brash ice conditions and that increased brash ice cover increased the input of mixing energy and led to increased dispersion. Test with 8 / 10 ice cover consistently led to more effective dispersion. Test with 4 / 10 ice cover required higher wave energy input to achieve visible dispersion (Lewis & Daling 2007). During field test with up 60-70 % ice coverage, it was found that applying chemical dispersant with a manoeuvrable arm from a vessel and subsequently applying additional mechanical mixing from the vessels’ thrusters and by the water jet from a rescue boat was successful (Brandvik et al. 2010).

For the environmental benefits or consequences of applying chemical dispersants, see Part II.

1.3 *In situ* burning

In situ burning (ISB) is a technique where the oil slick is ignited on the sea surface at the spill site and thereby converted to CO_2, water and other combustion products (e.g. soot). After flame out, residues are left on the water surface for subsequent collection. The burn residue can in some situations also sink out (Fritt-Rasmussen et al. 2015). The burning efficiency, which is an expression of how much of the oil slick that has been removed from the sea surface during the burning (Fritt-Rasmussen 2010), can be relatively high and can exceed 90 % under optimal burning conditions (Guenette & Sveum 1995; Walavalkar & Kulkarni 1996). An example of an experimental *in situ* burning operation is shown in *Figure 1.5*. The first recorded burn was in 1958 on the Mackenzie River in the Northern Canada (McLeod & McLeod 1974). Since then, *in situ* burning has not been subject to intense operational use. However, during the Deepwater Horizon incident in 2010, more than 400 controlled burns were conducted removing an estimated 220,000 to 310,000 bbl. of the spilled oil in the Mexican Gulf (Mabile 2012).

To assure a successful burn, some basic conditions must be fulfilled: i) a sufficient oil slick thickness, ii) a hot igniter and iii) flame spreading.

It is possible to achieve the necessary thickness by use of e.g. either fire resistant booms or chemical herders. Chemical herders are surface-active agents that have the ability to spread rapidly over a large water surface into a one monomolecular layer, consequently small quantities (5 L / linear kilometre of slick edge or, alternatively, 50 mg / m^2 of open water surface) of these herders can rapidly clear thin oil films from large areas of water surface and hence contract (push) the oil into thicker slicks (SLRoss 2013). Herders can, however, only be used under calm conditions (wind less than 4 knots [~2 m / s] and no breaking waves) (SLRoss 2013). Examples from experiments with herders are shown in *Figure 1.6*.

Figure 1.5. Example of an experimental *in situ* burning operation in the Barents Sea, 2009 (From SINTEF 2013).

The igniter must be warm enough to heat the oil to above its fire point (the specific temperature for a specific oil for sufficient vaporization of hydrocarbons) to support continuous combustion (Buist et al. 2013). A broad variety of different igniters exists ranging from handheld (*figure 1.7*) to torches applied from a helicopter (Helitorch). For igniting water-in-oil emulsions, the water must be removed to produce a water-free oil layer before the actual burning of the oil can take place (Buist 2000). Promising results have been found with the use of emulsion-breaking chemicals added to the igniter, where the chemicals ease the removal of the water in the emulsion (Guenette & Sveum 1995a). A recent preliminary laboratory study also investigated the effect of applying the emulsion-breaking chemical directly to the water-in-oil emulsion with some promising effects (Cooper et al. 2013).

Figure 1.6. Test with herders. Field experiment in the Barents Sea. Left: prior to application of herder, max oil area. Right: area after herder application but before ignition (from SL Ross and DCE 2015).

Flame spreading must occur to make sure that the whole slick is ignited. Such flame spreading can be induced by wind. However, too much wind, more than 10-15 m/s, might result in extinguishing of the burning (Nordvik et al. 2003). Waves will also affect the burning with decreasing burning efficiency and time window when waves are higher than 30 cm and longer than 3 m

(Walavalkar & Kulkarni 1996). Another important issue is to secure safe working conditions for the responders, thus the risk of accidental secondary fires, explosions and oil splattering during the boil-over phase should be taken into consideration and burning near settlements / humans should be avoided. Thus, generally a safety distance of 3.5 times the pool diameter is recommended (Buist et al. 2013). Regarding development of soot and smoke and environmental risks see Part II.

Figure 1.7. Example of a hand-held ignition of an oil slick (from SINTEF 2013).

1.3.1 Review of *in situ* burning in an Artic perspective

The *in situ* burning technique is of experts within the field often considered a countermeasure well suited for the Arctic, due to the environmental conditions of cold temperatures and sea ice that may extend the window of opportunity for the use of the method. In warmer and ice-free seas, the weathering processes may change more rapidly the properties of the oil away from optimal burning, and in particular water-in-oil emulsification and evaporation of volatile compounds from the oil are processes that decrease the burning efficiency and shorten the window of opportunity (Fritt-Rasmussen 2010).

Tests with burning oil in Arctic conditions have primarily been burning of oil / snow mixtures, in small and mid-scale tests in basins and test pans. Mid-scale and large-scale tests have moreover taken place as part of field trials in static pack ice (Buist & Dickins 2003). Only few studies have been performed in dynamic ice, and those performed indicated that *in situ* burning is sensitive to movements (the oil drifts with the ice in dense pack ice), ice concentration / coverage, oil thickness and presence or absence of frazil ice, which can absorb the oil (Buist et al. 2003).

Burning of oil in broken ice during break-up will be easier than during freeze as a consequence of darkness and slush ice during freeze, whereas, during ice break-up, besides deterioration of floes, environmental conditions are less harsh; more light, less slush ice and warmer temperatures (Brandvik et al. 2006). During freeze the most effective strategy will likely be to utilize the ice as the natural containment and Helitorches as remote ignition source (Glover & Dickins 2005).

Oil in snow (up to 70%) can be burned with great success (Buist 2000), and also for burning in brash ice and high ice concentration efficient results have been obtained (Buist & Dickins 1987). The small pieces of brash, frazil or slush ice will accumulate with the oil against the larger ice floes and thereby control the thickness and spreading of the oil (Buist et al. 2003). Thus, it is important to know the content of slush ice between ice floes, and not only the solid ice forms, as often reported, since the slush ice concentration can significantly slow down and limit the oil spreading even in low to moderate solid ice concentrations (Buist & Dickins 2003). *In situ* burning can also be used in spill scenarios, where the oil is trapped beneath the ice (by cutting a hole in the ice where the oil can accumulate), in piled ice (ridges, hummocks and rubble fields) and in rafted ice. When rafted ice is formed, one ice sheet slides upon another and forms natural pools for the oil (Morson & Sobey 1979).

The interface between ice and oil is expected to be more efficient at transferring heat from the oil to the underlying ice than to water, which provides a greater challenge to achieve sufficient heat for the ignition due to the greater heat losses (Buist & Dickins 2003). Thus it was found that higher slick thicknesses will be needed (double) to burn oil on ice compared to burning oil on water. No difference in slick thickness is found for different ice types. Also the burning rate and burning efficiency are lower for burning oil in ice than on water (Buist & Dickins 2003). 70-90 % of ice concentrations are high enough to support natural burning with e.g. areal ignition from helicopters (Glover & Dickins 2005). Brown & Goodman (1986) performed tests with *in situ* burning of crude oil in test ice leads at Esso Research ice basin in Calgary, Canada. They found high burning efficiencies, up to 90 %, in moderate wind, if the oil was herded into long narrow leads. They also found that brash ice reduced flame spreading, lowered the burning rate and somewhat lowered the burning efficiency (Buist & Dickins 2003).

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Part II: Proposal for a NEBA based approval procedure for use of dispersants or *in situ* burning in oil spill response in Greenland

Susse Wegeberg

Dispersants and *in situ* burning are part of the oil spill response tool box for Greenland, as the techniques are considered suitable for use under the Arctic conditions with ice-infested waters, seasons of darkness, general remoteness and because mechanical recovery techniques therefore may fall short. The mentioned techniques will usually be part of an approved contingency plan for oil exploration activities, however, current practice in Greenland is that mechanical recovery of oil is first choice, and can be initiated without further approval but complying with the contingency plan, while use of chemical dispersants and *in situ* burning need case-by-case approval (Wegeberg et al. 2011a, b).

The selection of chemical dispersion and / or *in situ* burning as part of an acute oil spill response strategy must add to the overall benefit for the environment, where potential adverse environmental effects of the response techniques are less than the environmental benefit from the operation. This includes a balance between presence and sensitivity of organisms in the oil slick trajectory in the water column and on the sea surface as well as the expected richness and sensitivity of the shoreline to the potential beaching oil. To support this choice of the optimal response technique, a Net Environmental Benefit Analysis, NEBA, shall be performed. The NEBA includes the environmental benefits and drawbacks / consequences of burning the oil on the sea surface and / or chemically dispersing the oil slick into the water column as supplements / substitutes to mechanical recovery if the operational or logistical conditions are suboptimal or inhibiting for this response technology (Baker 1995).

For developing and planning oil spill contingency strategies and decision-making on inclusion of chemical dispersants and / or *in situ* burning, a general context for particular areas / regions can be assessed in a strategic NEBA (sNEBA). For details on this concept and planning tool, please consult Wegeberg et al. 2016.

2.1 Adverse environmental effects of chemical dispersion and *in situ* burning

In *Table 2.1* the benefits and consequences of mechanical recovery, *in situ* burning and chemical dispersion are presented. Description of the different techniques and operational requirements and delimitations for the different countermeasures are presented in Part I.

2.1.1 Chemical dispersion

When oil is chemically dispersed into the water column, the concentrations of oil components in the water column increase and there is a risk of increased toxic impact on plankton, fish larvae / fry and other pelagic organisms. In shallow waters, the dispersed oil plume may also reach the seabed and hence potentially impact the benthic community. The use of dispersants therefore needs to be balanced between presence of these organisms and in worst case which organisms, either on the sea surface or in the water column that shall be prioritized for protection.

Table 2.1. Benefits and adverse side effects of the response techniques: mechanical recovery, *in situ* burning and chemical dispersion. These techniques are part of the considerations in a Net Environmental Benefit Analysis (NEBA), together with knowledge on presence of sensitive organisms as well as the effect and fate of oil in the environment. Based on Fritt-Rasmussen et al. 2015, Wegeberg et al. 2016, and references herein.

	Mechanical recovery	***In situ* burning**	**Chemical dispersion**
Benefits	Oil is removed from the environment	Relatively fast and efficient removal of oil from the environment Acute toxic volatile compounds are combusted The technology can be used in open and to some degree ice-infested waters	Oil is removed from the sea surface The dispersed oil plume can be diluted to less toxic concentrations The dispersed oil droplets provide an increased surface and hence potentially faster degradation by microorganisms The technology does not require calm weather
Disadvantages/ Side effects	Requires calm weather Comprehensive requirements to on site storage and disposal capacity for the recovered oil/ oil-in-water emulsion Environmentally safe destruction of recovered oil is needed	Formation of smoke and soot Formation of environmental hazardous compounds, e.g. dioxin, PAHs Recovery and storage/destruction requirements for burning residues Unknown long-term effects of un-recovered burning residues in the environment Impact of herders and other chemicals used Risk of secondary fires	The dispersed oil may result in potentially toxic concentrations for plankton, fish larvae and fry In more shallow areas, dispersed oil may reach the sea bed fauna in toxic concentrations Impacts of chemicals are added to the effect of oil in the environment, as well as potential cocktail effects of dispersant+ oil

Comparing studies on toxicity of naturally and chemically dispersed oil shows that toxicity of chemically dispersed oil is in the magnitude of two times higher than for naturally dispersed oil (Singer et al. 1998; Otitoloju 2010) due to increased exposure of the marine organisms to dissolved and dispersed oil components (Østby et al. 2002; Fingas 2008). The concentration of dispersed oil will initially be higher when chemically dispersed compared to naturally dispersed (EMSA 2010), but concentration and exposure time, which are functions of the dilution and mixing of the dispersed oil, are key factors for the acute toxic effects of the dispersed oil. According to simulations presented by Lewis & Daling (2001), the chemically dispersed oil is dissolved into the water column faster, deeper and at higher concentrations than naturally dispersed oil.

In connection with the oil spill accident from the *Sea Empress* in 1996 off Wales, UK, the oil spill response included dispersant. The dispersed oil was monitored in the water column and the oil concentration was found to decrease from 10 ppm right after the dispersion operation to 1 ppm within two days, to 0.2 ppm after one month, and to background level concentration after three months (EMSA 2010). These finding are in accordance with the simulations presented above by Lewis & Daling (2001).

From studies of French-McCay (2002), it is concluded that no species specific oil sensitivity patterns appear to exist (some species within organism groups may be more or less sensitive than others), but that the ecological niche may be an indicator. This supports the tests performed by Wu (1981), in which species within different groups of organisms were more sensitive to a mixture of dispersant and diesel than others. Sensitivity varied between fish species up to an order of 10 times as well as between species of bivalves. The toxic levels within plankton organisms, such as copepods (*Calanus glacialis*), are 1 ppm of dispersed oil for lethal effects and 0.1 ppm for sublethal effects (Gardiner et al. 2013). For a temperate mysid shrimp and fish species (*Americamysis bahia, Menidia beryllina*) the toxic dose may be tenfold higher (Hemmer et al. 2011).

Several studies of microbial degradation of naturally and chemically dispersed oil showed that use of dispersant increased the natural degradation rate of the oil under natural conditions (e.g. Swannell & Daniel 1999; Otitoloju 2010). The *Macondo*-accident in the Gulf of Mexico in 2010 provided important knowledge on subsea chemical dispersion, i.e. from injection of dispersants into the oil flow at the seabed located in a depth of 1.5 km. Monitoring of the oil in the water column showed that a plume of oil droplets was established in a depth of 1 km (Camilli et al. 2010; Hazen et al. 2010), because they attained buoyancy equal to sea water and hence did not float towards the surface. The phenomenon may have been due to the dispersant operation but also due to release of bubbling gas with the oil flow, breaking the oil into these small droplets (Camilli et al. 2010; Kujawinski et al. 2011). However, Kujawinski et al. (2011) showed that the anionic surfactant, dioctyl sodium sulfosuccinate (DOSS), which is a component in the dispersants, Corexit 9527 and 9500A, used at the subsea operation at *Macondo*, was not a fast microbial degradable compound in deep waters (1 km). They found that nothing or just a small fraction of DOSS was degraded 2-3 months after the dispersant operation. The measured concentrations of DOSS were 1000 times less than concentrations considered to be toxic, but due to the deep water conditions, no information for assessing the environmental consequences has been available.

The above findings confirm the need for research focus on long-term effects of dispersant use as an oil spill countermeasure, as also underpinned by Fingas (2008), and more recently by Holland-Bartels & Kolak (2011) in their review of knowledge gaps regarding oil spill countermeasures for the Chukchi and Beaufort Seas, Alaska.

Conclusively, the factors of importance for environmental effects of dispersal operations consequences are:

1) Water depth and distance to land

For the dispersed oil to be dissolved and mixed at such a fast rate that toxic effects in the water column and sea bed is avoided, dilution and mixing capacity must be high. This means that a dispersant operation has to take place in a sea area with sufficient water depth and water exchange / mixing. The dispersed oil is distributed in the water column and will only reach the sea bed as a result of water movements. This generally means that in areas with relatively deep water and relatively fast water exchange rates, the sea bed communities may be unaffected by the dispersed oil spill. In contrast, in coastal and shallow waters, oil droplets and dissolved oil components have a much higher risk of reaching the sea bed and hence expose benthic organisms to relatively high concentrations of dispersed oil (EMSA 2010).

2) Special ecological concerns
Dispersion of an oil spill may be beneficial in those cases where the oil spill e.g. threatens a sea area with high concentrations of seabirds (on the sea surface), important areas for moulting and breeding of seals and / or an offshore oil spill trajectory is towards a sensitive shoreline.

On the contrary, chemical dispersal of an oil spill is considered unsuitable in shallow and / or coastal areas, e.g. fjords, bays, banks, in areas with high concentrations of planktonic organisms, including e.g. copepods, fish egg, larvae and fry, and in areas considered as being of general high ecological value.

After a chemical dispersal operation it is important to continue monitoring fate and effects of the dispersed oil to assess the environmental impact of the operation

2.1.2 *In situ* burning

In situ burning (ISB) operations possess environmental and health issues of concern. The resulting residues from the burn are considered a source of potential significant environmental impact (Fritt-Rasmussen et al. 2015) as well as the resulting smoke / soot from the burn. However, the contact with the water phase causing temporary temperature rise and potential toxic compounds in the water layer just beneath the slick are considered of minor importance due to fast water exchange and hence cooling / dilution (McKenzie & Lukin 1999; ARRT 2008; Potter & Buist 2008).

Burn residues

Few studies have investigated the effects seen from the burn residue to the environment, with mutagenicity and toxicity of the burn residues in focus. The reviewed and available information on the potential environmental impacts of ISB residues is quite inhomogeneous with regard to tests of oil type / compounds, organisms and state of ISB residues tested. This may be related to the profound complexity of oil type chemistry, ecosystems and burning efficiency. However, the literature indicates an increase in high-ring number PAHs by ISB (Wang et al. 1999; Lin et al. 2005; Garrett et al. 2000, Buist & Trudel 1995; Fritt-Rasmussen et al. 2012, Faksness et al. 2012). Again, the relative increase of these high-ring number PAHs depends on the initial oil type (Buist et al. 1999) and the efficiency of the burning (Fritt-Rasmussen et al. 2012). If ice and weather conditions in the Arctic areas potentially cause less efficient burnings in some situations, relatively higher amounts of PAHs in the residues may be a result. PAHs are pollutants of vastly concern as they are classified among the most persistent organic pollutants in Arctic areas based on moderate degradability and high bioaccumulation (AMAP 2002). There are plenty of data which clearly indicate toxicity and bioaccumulation of various PAHs in aquatic plants, molluscs, crustaceans, echinoderms, annelids and fish (Neff 1979; Varanasi 1989). Uptake of PAHs by aquatic organisms from the water column, from sediment, and from their diet varies widely among organisms and among specific PAH compounds. Bioaccumulation is generally positively correlated with physical / chemical properties of organic chemicals such as molecular weight and octanol / water partitioning coefficients (Arnot & Gobas 2006). Hence, high-ring number PAHs have a higher potential for bioaccumulation, and, in addition, high-ring number PAHs may include mutagens and carcinogens such as benzo[a]pyrene (US-EPA IRIS database).

ISB of oil spill may reduce the amount and concentration of the most volatile, water-soluble and generally more bioavailable PAHs (3 rings or less) (Li et al. 1992), and according to ARRT (2008), PAHs released and burned during the ISB operation are reduced by a factor of six compared to the initial oil contents.

Even though there is still need to clarify biological effects of two- and three-ring PAHs in the Arctic marine environment, high concern on high-ring number PAHs may be given in relation to ISB in Arctic seas. However, pyrogenic PAHs (generated during burning) are to a large extent associated with particles, sometimes even incorporated in the structure of particles, which significantly decrease the bioavailability in seawater (Hylland 2006) but may increase the PAH exposure to filtering organisms.

The potential for less effective burns resulting from the Arctic harsh weather conditions may yield higher amounts of PAHs and burning residues, which also may have an impact on the sea bed communities. Martinelli et al. (1995) found, in their review of the *M/C Haven* accident in 1991, that besides from the burning of a substantial amount of the oil, a part of the oil was heated and not combusted to an extent that changed the physical and chemical properties of the oil towards a tarry-like residual oil. Mats of this residual oil as well as the burn residues were observed on the sea floor at depths of 100-400 (> 500) m with a patchy distribution in an area of 140 km^2. The smothering of fishing gear and hence catches led to a study of the PAH concentrations in demersal fish and invertebrates which showed uptake of both pyrogenic and petrogenic PAHs in the range of 1 mg kg^{-1} (no references are given to primary information source). Martinelli et al. (1995) also discuss that the natural recovery of the deep sea floor environment covered with the residual oil may be reduced compared to oil spills at shore due to the low physical energy environment with slow biodegradation and chemical weathering processes.

In mapping knowledge gaps regarding oil spill countermeasures for the Chukchi and Beaufort Seas, Alaska, Holland-Bartels & Kolak (2011) concluded that better characterization of ISB residues is needed, especially of toxicity, physical properties and bioavailability of PAHs.

In the light of that, and as ISB by experts is considered as a future response technique in the Arctic ice-infested waters, the focus on environmental impacts of residues from ISB with different efficiencies is important.

Emissions from ISB

The other issue of environmental and health concern regarding ISB is formation of smoke and soot. It is estimated that the soot formed during a burn equals 0.1-3 % of the oil volume (ARRT 2008). Emissions of particles may be of concern regarding health of humans and animals which can be taken into account by establishing safety zones.

Furthermore, it should be considered, in case of a blowout which may lead to a major oil spill and potentially a suite of burns, that soot on snow / ice may decrease the albedo effect and result in increased melt off (H. Skov, pers. comm.), as well as emission of greenhouse gases from ISB may add to the global abundances.

Dioxin generated during burning of oil may also raise environmental concerns due to potentially increased local dioxin concentrations. For the *Macondo* accident, the dioxin emission was estimated to 1.7 ng TEQ[1] kg oil burned^{-1} (Schaum et al. 2010). In total, dioxin emission from the *in situ* burning of oil in the Macondo accident was estimated to be between 54 and 134 mg TEQ. Using the PCDD/F emission inventory for Canada and the US, Commoner et al. (2000) predicted 'dioxin' TEQ deposition of about 4-53 pg TEQ m^{-2} yr^{-1} for terrestrial surfaces near eight communities in Nunavut. In comparison the emission of dioxin from the burning of oil in the Macondo accident corresponds to the yearly deposition of dioxin in the Arctic on an area larger than 33,000 km^2.

The use of chemical herders for containment and thickening of the oil slick to assure ignitable oil slick thicknesses has been investigated in recent years (e.g. Buist et al. 2010). Latest the potential environmental impacts of herders, are part of an ongoing research programme with participation of DCE lead by J. Fritt-Rasmussen, hence an assessment of the environmental impact including use of herders awaits these results.

2.2 Inclusion and regulation of dispersants and *in situ* burning in relevant countries

In the following, a review of the regulation regarding dispersants and *in situ* burning in other relevant countries to Greenland is presented.

2.2.1 Norway

The Norwegian (incl. Svalbard) regulation on chemical dispersant of oil spills is relevant in a Greenlandic context, especially considering the Barents Sea oil exploration and exploitation activities. In Norway, dispersants can be used after a NEBA as part of an approval procedure, and the assessed potential environmental consequences need to be documented. According to the regulation (FOR 2004-06-01 nr. 931: Forskrift om begrensning av forurensning (forurensningsforskriften), Kapittel 19. Sammensetning og bruk av dispergeringsmidler og strandrensemidler for bekjempelse av oljeforurensing), the dispersants' toxic effects and efficiency should be tested using standard toxicity tests and documented beforehand. The toxicity limit for dispersants is a 50 % effect concentration, EC_{50}, < 10 mg l^{-1}. If the oil type is known, the dispersant should be optimized to oil type and physical conditions. Product optimization is following a test programme of 1) screening of relevant dispersant products, which are tested on oil samples in a weathering stage corresponding to ½-1 day of weathering in the sea; 2) for the best products from the screening, the dose relation on the specific oil type is mapped; 3) potentially at different temperatures and salinities; and finally 4) the dispersant efficiency is found for the oil type in different weathering stages.

According to the Norwegian Coastal Administration's (Kystverket) decision-form for a dispersant operation, the following criteria have to be met: water depth > 20 m and distance to land > 200 m. Special reasons may be taken into account for dispersing, if the criteria are not met, such as presence of unique populations of seabirds in the expected oil slick trajectory or particular critical wind or current directions.

Norway does not include *in situ* burning as an oil spill countermeasure. The reason, as explained by the Norwegian Environment Agency at a meeting in

[1] Toxic equivalents

January 2012, is that mechanical recovery is preferred when it is possible to contain the oil slick within booms. However, activities closer to the ice edge might lead to change in this practice [due to difficulties in mechanical recovery of oil in ice-infested waters where ISB has proven efficient see Part I]. This interpretation is in accordance with Potter et al. (2012).

2.2.2 Canada

In Canada, two regions have established guidelines, which also are stated by Potter et al. (2013).

Canada has a joint contingency plan with the US on marine pollution, including decision-making for approval of dispersant and *in situ* burning operations (CANUSDIX 2006) for the Dixon Entrance trans-boundary area on the west coast. The plan contains procedures for contacting the Canadian and US authorities when input regarding dispersant use and / or *in situ* burning decision-making is requested. The plan also contains identified factors to be considered, i.e. a list of habitats (offshore / coastal, fish, marine mammals and birds), endangered species and areas of importance for human use for Canada and the US of major, moderate and lesser concern. However, no regulations regarding water depth or distance to land are presented.

For Quebec, the Regional Environmental Emergency Team (REET) has developed evaluation procedures of request to use dispersants and *in situ* burning techniques during an oil spill (REET Quebec 2003a, b).

According to the procedure for approval of *in situ* burning for Quebec (REET 2003b), it is stated that "*The shore can be used to confine the oil slick. If this is the case, make sure that the burning is done mainly on the water and not on the shores.*" At the same time, the procedure also includes that wind direction and "*The sensitive elements that can be affected by the smoke plume released during the burning must be taken into account*", and a list of environmental issues must be developed resulting in a summary of impacts with and without ISB for the final potential recommendation for the ISB operation by REET.

2.2.3 Alaska

The operational guidelines developed for *in situ* burning by Alaska Regional Response Team (AART 2008) are relevant in the context of Greenland due to the comparable climate regimes.

ARRT (2008) follows the standards for air pollution of the US Environmental Protection Agency (US EPA) and modelling of particle concentration in the smoke in the wind direction. Initially, the safety zone was defined by the distance of which particle concentration of particles ≤ 10 µm (PM_{10}) was less than 150 µg m^{-3} air as the mean of 24 hours (ARRT 1994). The safety zone was then defined as approximately 11 km (6 nautical miles). The revised edition (ARRT 2008) follows US EPA's $PM_{2.5}$ standard for air pollution, and the regulation includes definition of safety zone, green zone (*Figure 2.1*), based on the US EPA standard:

$$\text{US EPA's } PM_{2.5} \text{ standard} = 35\ \mu g\ m^{-3}$$
$$\text{(mean / 24 hours)}$$

where $PM_{2.5}$ = particulate matter (PM) ≤ 2.5 µm

However, this is interpreted by ARRT (2008) as:

$$PM_{2.5} = 65\ \mu g\ m^{-3}\ (\text{mean / 1 hour})$$

The safety zone, i.e. the minimum distance to land or inhabited areas, which is required for an ISB operation to be approved fom the burn, results hence in app. 5-6.5 km (3-4 miles) in downwind direction. This distance corresponds with the indication of Potter & Buist (2008) of soot concentration being insignificant at sea surface in a distance of 3-6 km (2-4 nautical miles) from the ISB operation, as the smoke rises into the air due to the burning heat.

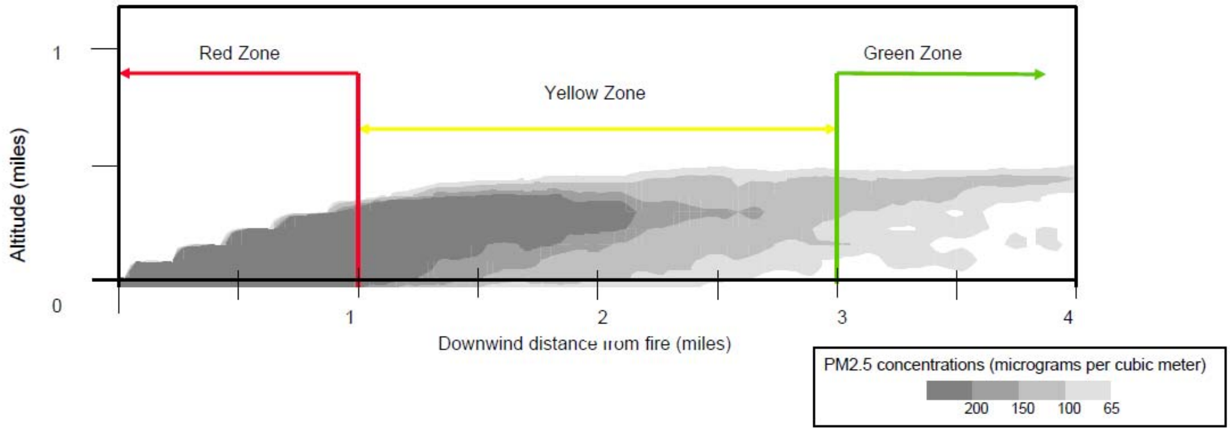

Figure 2.1. Modelled smoke development with particle concentration downwind (adapted from ARRT 2008).

Regarding chemical dispersal of oil spills, US has minimum requirements to water depth and distance to land of 10 m and 5.6 km, respectively (Chapman et al 2007).

2.2.4 Denmark, including Greenland outside the 3 nautical miles border, but excluding oil exploration activities

According to the contingency plan for the Danish state and Greenland (SOK 2004; Greenland Command 2010), the response to oil spill is based on two techniques: containment-recovery and dispersants. In Danish waters, dispersants will only be used if the oil cannot be mechanically recovered or the slicks are threatening large seabird aggregations or cooling water intakes, or if there is an acute risk of explosions or fires. Approval of chemical dispersing is restrictively regulated and can only be approved by the Minister for the Environment and Food. Use of dispersants in the Baltic Sea area follows the HELCOM REC 22/2 of 21 March 2001 regarding limited use of e.g. chemical compounds for oil pollution response in the Baltic Sea.

In Greenland, outside the 3 nautical mile limit, chemical dispersants are also considered as an oil spill response option, however, it will not be used without previous careful considerations of environmental and economic consequences (Greenland Command 2010).

Neither Denmark nor Greenland has dispersants at their disposal, and restrictions regarding e.g. water depth and distance to land have not been defined.

In situ burning is at present not included as an option of oil spill response in Denmark / Greenland, as also stated by Potter et al. (2013).

2.2.5 EU

In the EU (Chapman et al. 2007), only some countries include use of dispersants, and few have criteria for water depth and distance to land for approval of a dispersant operation; France has a 10 m's depth limit while Malta has up to 60 m, probably due to different climate and topography. However, the use of dispersants is most commonly secondary to mechanical recovery, and only the UK has dispersant use as primary option apparently due to the local weather conditions.

2.3 Recommendations regarding use of dispersants or *in situ* burning in Greenland

Recommendations regarding the use of dispersants and *in situ* burning in Greenland given in connection with the oil company Cairn Ltd.'s drilling campaigns in 2010 and 2011 (Wegeberg et al. 2011a, b) are maintained. This is based on the regulations from relevant countries, especially Norway, but also the results of the strategic NEBA (sNEBA) conducted for the Store Hellefiskebanke area (Wegeberg et al. 2016) supplied with other relevant literature.

However, despite these overall recommendations for Greenland, decision and approval of dispersion or *in situ* burning operations should always be based on a case-by-case NEBA in connection with an acute oil spill.

2.3.1 Chemical dispersion

Chemical dispersion operations for use as countermeasure in case of an acute oil spill are recommended approved in areas fulfilling the following criteria:

- Water depth > 50 m
- > 10 km distance from land.

However, in areas of particular concern such as polynias, dispersion may not be approved even though these criteria are fulfilled. On the other hand, specific conditions may justify use of dispersants (seabirds, wind / currents direction) where the criteria are not met.

The recommendations are restricted to ice-free conditions as the environmental knowledge regarding chemical dispersion in ice-infested waters is limited and still at trial stage (Sørstrøm et al. 2010).

Regarding subsea injection of dispersants, this has not been assessed for Greenland. At Store Hellefiskebanke oil spill modelling has shown that due to the small water depth, the oil droplets from a subsea spill are transported to the sea surface at once (ClimateLab 2014). However, in South Greenland licenses are located outside the shelf and hence drilling may potentially be performed at very deep water (> 2,500 m).The experiences with subsea injection of dispersants from the Macondo accident may have been a plume of oil droplets in deep water (1000 m) (Hazen et al. 2010). Modelling of oil spill from a well located in very deep waters (3,070 m) in South Greenland showed that after 30 days, 20 % of a heavy oil type in the model remained dispersed in the water column, at a mean depth of ~300 m. Over the following three months, this fraction gradually decreased to 10 %, and the mean depth to ~75 m. Only for this heavy oil, of the four tested oil types, did an appreciable fraction remain at depth (Ribergaard 2011; Frederiksen et al. 2012). In addition, the environmental consequences of a potential slower natural degradation of dispersant components in deep water (Kujawinski et al. 2011) in Greenland are still a research area to be initiated. Hence, use of subsea injection of dispersants is at present not recommended.

2.3.2 *In situ* burning

In situ burning operations for use as countermeasure in case of an acute oil spill are recommended approved in areas fulfilling the following criterion:

- > 10 km distance from land.

Specific conditions may justify use of *in situ* burning in areas not fulfilling this criterion, e.g., in case of strong offshore wind, aggregations of seabirds, sensitive shoreline in the oil slick trajectory or if land areas in the wind direction are not populated.

However, the approval shall always be based on a positive NEBA and a case-by-case assessment.

The relatively large safety margin is based on the present limited knowledge of ISB environmental impacts in Greenland, including uncertainty regarding smoke development and fate.

It is hence recommended that an ISB operation should be supported by operational modelling of smoke.

Furthermore, as the environmental impacts of burning residues, their sedimentation and spreading still are under research, it is recommended that the residues are collected as far as possible immediately after a burn operation.

Use of herders was an option introduced as a result of the JIP Oil in Ice studies (Sørstrøm et al. 2010). Considerations on using chemical herders in connection with an ISB operation and development of recommendations regarding this must await acquisition of more knowledge in this field and especially the environmental consequences of the technique.

At present several research projects and programmes are ongoing (OGP JIP, projects financed by DANCEA and the Environment Agency for Mineral Resources Activities) and will gather information and results on some of the above environmental issues. An improved knowledge base may lead to more precise regulation and hence adjustment of the above recommendations. But at present, a conservative approach is maintained as consequence of the precautionary principle.

2.4 Procedure for dispersant or *in situ* burning operation approval, including NEBA, in Greenland

Below a procedure for approval of a chemical dispersion or *in situ* burning operation, in response to an acute oil spill in Greenland, is suggested.

As presented in Part I, the window of opportunity for a dispersant or *in situ* burning operation may be quite narrow, and therefore a fast and un-hesitated decision-making process must be performed. For that, approval forms have been developed, which include information on operational conditions and NEBA, see below. The approval includes the following forms:

Form 1: Approval form with description of the oil spill, location, weather forecast and operational conditions.

Form 2: Net Environmental Benefit Analysis, of which the result is transferred to Form 1.

For filling in Form 2 regarding NEBA, the following information is crucial:

- Oil spill trajectory obtained from operational oil spill modelling
- Environmental Oil Spill Sensitivity Atlases for Greenland
- Strategic Environmental Impact Assessments for Greenland (for the specific area)
- Information on particular sensitive marine areas in Greenland (Christensen et al. 2012)

A suggested process from the warning of the oil spill through approval procedure of dispersant and / or *in situ* burning operations and response operation to monitoring sampling is presented in the step diagram below (*Figure 2.2*).

	Action	Oil spill	Documents/equipment
1.	Warning Environmental advisory team*		Roster for personnel on duty Oil spill contingency plan
2.	Description of situation		
	Environmental analysis of the area potentially impacted		Sensitivity atlases: South Greenland region 58°-62°N
3.	Identification of *safe havens*	Minor oil spill from ship	Sensitivity atlas – Physical environments and logistics
4.	Oil in drift	Large volume and/or not evaporable	Oil slick trajectory
5.	Call for environmental advisory team		Video conference
6.	Identification of prioritised areas for booming	Oil slick direction towards coast/sensitive areas	Sensitivity atlas
7.	Mechanical recovery		
8.	Application for *in situ* burning Net Environmental Benefit Analysis		Approval form, ISB, pink Modelled smoke development and drift
9.	Application for dispersing operation Net Environmental Benefit Analysis		Approval form, dispersing, blue Efficiency monitoring Vertical mixing – modelled
10.	Initiation of sampling programme for monitoring		Guidelines Sampling equipment

Figure 2.2. Step diagram for a suggested process from oil spill warning through approval procedure of dispersant and/or *in situ* burning operations to monitoring sampling in connection with oil exploration drilling operations in Greenland. The colours indicate the increasing need of response according to size of oil spill and environment at risk. * Environmental advisory team should respond within two (2) hours.

Application form for a chemical dispersion operation

Form 1

Name of applicant (e.g. company):	E-mail:
Contact person(s):	Phone:

Complete forms and, together with requested attachments, submit to Environment Agency for Mineral Resources Activities. Tel: (+299) 34 50 00, E-mail: apn@nanoq.gl.

1. Date and local time for start of spill						
2. Position of spill Longitude/latitude, indication of locality/place name:	**N**			**E**		
3. Distance to land and water depth	Distance to land (km)			Water depth (m)		
4. Description of the oil spill source (Name of vessel/ship, installation, etc.)						
5. Description of the oil spill (Oil type, surface/subsea, presence of gasses)						
6. Has the oil spill been stopped?	**No**		**Yes**		**Hrs**	
7. Estimated quantity of oil spilled (m^3) Mark or state quantity:	< 10	10-100	100-500	500-1000	1000-5000	> 5000
8. Estimated surface area of oil slick (km^2) Total area of sea surface covered by the oil slick	**km**	**×**	**km =**		**km^2**	
9. Estimated thickness of oil slick	Sheen 0.04-0.30 µm	Rainbow 0.30-5.0 µm	Metallic 5.0-50 µm	Discontinuous true oil colour 50-200 µm	Continuous true oil colour > 200 µm	

10. Weather conditions	Temp. (°C)		Wind			Wave height
	Sea	Air	Speed (m/s)	Direction	In-/decreasing	
24 hrs forecast:						
11. Forecasted location of oil slick at the time of planned dispersant application, i.e. time for arrival of dispersant equipment	**N**		**E**		**Hrs**	
	Attach latest oil slick trajectory-modelling forecast					
12. Visibility and light conditions	Cloud base (m)		Horizontal visibility (m)		Hours of daylight	
					From hrs	To hrs
13. Ice conditions Degree of coverage (%)	No ice		Open water with ice floes	Ice floes/broken ice	Consolidated/ fast ice	

14. Description of dispersant application Only dispersants product(s), preapproved for the contingency plan, can be used.	Method
	Name of dispersant (trademark)
	Amount dispersant/oil slick surface area
	Estimated total amount

15. Forecasted mixing of dispersed oil in the water column Information on dilution efficiency/vertical mixing; the depth of the expected oil concentrations in the water column and trajectory of the dispersed oil for performing the NEBA (Form 2). Attach modelled vertical mixing of dispersed oil in the water column together with modelled oil slick trajectory

16. Identification of dispersant application equipment and effectiveness monitor	Dispersant application equipment incl. dispersant spotter
	Dispersant effectiveness monitor

Net Environmental Benefit Analysis (NEBA)

Application of dispersants will in total make the spilled oil cause less harm to the environment than no response or mechanical measures? Result from NEBA, Form 2.	**Yes**
	No

Operational conditions

The operational conditions to accomplish a dispersant application operation are met? Result from evaluation of oil and operational conditions by the oil spill response team.	**Yes**
	No

Attachments

1. NEBA (Form 2)	
3. Latest forecast of oil slick trajectory modelling	
4. Modelled vertical mixing of dispersed oil	

Recommendation

	Yes	Yes, with certain limitations	No	Further information needed
Initiation of a dispersant application operation is recommended				
Comments				

Signatures

____________________ ____________________
Date and time

____________________ ____________________
Date and time

Form 2 - Net Environmental Benefit Analysis

Evaluation of the total potential environmental benefit from the application of dispersants during an oil spill assuming operational conditions are met. Information and explanations for pts 1-5 follow in Annex 1.

Net Environmental Benefit Analysis (NEBA): Application of dispersants will in total make the spilled oil cause less harm to the environment than no response or mechanical measures? Pt 1- 5.	**Yes** **No**
Operational conditions: The operational conditions to accomplish a dispersant application operation are met? Result of evaluation performed by the oil spill response team.	**Yes** **No**

Criteria for evaluation:	**Score**
Positive net environmental benefit	A
Semi-positive net environmental benefit Further evaluation/information needed	B
Negative net environmental benefit	C

Criteria to be evaluated in NEBA:		**Score**	**Comments**
1. Expected life time of oil on sea w/o use of dispersants	A: > 24 hours B: < 24 hours C: < 3 hours		
2. Oil dispersible	A: Oil is dispersible within possible time for operation B: Reduced dispersibility of oil within possible time for operation C: The application of dispersants cannot be performed within the operational window		
3. Sensitive elements in potential oil spill trajectory	A: Seabird congregation, or sensitive shorelines - **not** important pelagic spawning area or season. B: Seabird congregations and/or sensitive shorelines **and** important concentrations of pelagic eggs/larvae C: Important pelagic spawning area and season – seabird rare or absent		
4. Sea depth and distance to land	A: Depth > 50 m and distance to land > 10 km B_1: Depth > 50 m and distance to land < 10 km B_2: The criteria in A and B_1 are not met, but specific conditions justify use of dispersants (seabirds, wind/currents direction) C: The criteria in A, B_1 and B_2 are not met		
5. Possible stranding of dispersant treated oil	A: Stranding of treated oil can be prevented B_1: Stranding of treated oil can be significantly reduced B_2: Stranding of treated oil on exposed/ semi-exposed coast C: Stranding of treated oil on sheltered coast/sandy beach		

Additional comments:

Annex 1 - Information and explanations for Form 2

1. Evaluation of the lifetime of the oil slick on the sea surface
If it is expected that the oil will evaporate or naturally disperse within 3 hours, application of dispersants will not be relevant (C). If it is assessed to be within 24 hours, application of dispersants may be considered, if drift of the oil slick may be to environmentally sensitive areas (B). If type and amount of oil indicate a longer lifetime on sea surface than 24 hours, dispersant application is relevant (A).

2. Assessment of the dispersibility of oil within the operational window
The weathering degree of the oil is crucial to its ability to chemical dispersal. The type of oil and the weather conditions determine the time frame for weathering and hence the operational window for dispersant application, therefore the success of the application depends on whether the oil is dispersible within the possible time window for the operation (A), or if the dispersibility of the oil may be reduced (B), or whether the oil is not dispersible within the possible time window for operation (C).

3. Evaluation of oil harming natural resources against the benefit of dispersant application
The Environmental Oil Spill Sensitivity Atlas of Greenland will serve as background information when identifying particular environmentally sensitive areas, which may be located in the modelled trajectory of the oil slick in the relevant season. The atlas also provides information on logistics and countermeasures.

The atlas consists of five parts (pdf-files) covering the following areas:

- South Greenland region 58°-62°N
- West Greenland region 62°-68°N
- West Greenland region 68°-72°N
- West Greenland region 72°-75°N
- West Greenland region 75°-77°N

If there are seabird congregations or prioritised shorelines in the oil slick trajectory and no identified spawning area, application of dispersants will be appropriate (A). If seabirds and/or sensitive shorelines and pelagic spawning products are present at the same time in the oil spill trajectory, it has to be assessed by experts which organisms need most protection in the season in question (B). In a pelagic spawning area with no seabird congregations present, dispersants should not be used (C).

4. Evaluation of the dilution effect of the potential sea area
The benefit of chemical dispersal of the oil spill depends on the sea area's dilution capacity. In open seas the chemically dispersed oil will quickly be diluted below toxic levels. Due to gaps in knowledge on the Arctic environment, precautions have been taken for use of dispersants, which thus has been restricted to deep waters and offshore.

Therefore, dispersants can be used if the depth is > 50 m and distance to land is > 10 km (A). If depth > 50 m and distance to land < 10 km, dispersant application can be considered, and even if these criteria are not met, but specific conditions may justify the use of dispersants (sea birds, wind/currents direction), dispersant application may still be considered (B). If none of the above criteria are met, use of dispersant should not be considered (C).

5. Evaluation of the risk of oil/treated oil to strand including sedimentation in shallow waters
With reference to the marine communities along the shorelines, stranding of oil should be prevented. As toxicity of chemically treated oil is enhanced compared to the oil itself, the dilution of the dispersed oil offshore is important.

Therefore, when using dispersants it should lead to prevention of oil/treated oil to strand including sedimentation in shallow waters (A). If the oil/treated oil stranding can be significantly reduced or strands on exposed/semi-exposed coast, application of dispersants may be considered (B). However, use of dispersants is not appropriate if there is risk of stranding of oil/treated oil on a sheltered coast/sandy beach (C).

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Regional Environmental Emergency Team, Canada (2003) Evaluation procedure of a request to use dispersants during an oil spill. 22 pp.

Application form for an *in situ* burning operation

Form 1

Name of applicant (e.g. company):	E-mail:
Contact person(s):	Phone:

Complete forms and, together with requested attachments, submit to Environment Agency for Mineral Resources Activities. Imaneq 1A 801, PO Box 1614, 3900 Nuuk. Tel: (+299) 34 50 00, E-mail: apn@nanoq.gl

1. Date and local time for start of spill						
2. Position of spill Longitude/latitude, indication of locality/place name:	**N**			**E**		
3. Distance to land and water depth	Distance to land (km)			Water depth (m)		
3a. Distance to land < 10 km Assess if modelled smoke plume trajectory is necessary with regard to weather conditions	**YES** Attach modelled smoke plume trajectory			**NO**		
3. Description of the oil spill source (Name of vessel/ship, installation, etc.)						
4. Description of the oil spill (Oil type, surface/subsea, presence of gasses)						
6. Has the oil spill been stopped?	**No**		**Yes**		**Hrs**	
5. Estimated quantity of oil spilled (m^3) Mark or state quantity:	< 10	10-100	100-500	500-1000	1000-5000	> 5000
6. Estimated surface area of oil slick (km^2) Total area of sea surface covered by the oil slick.	**km**	**×**		**km =**		**km^2**
7. Estimated thickness of oil slick	Sheen 0.04-0.30 µm	Rainbow 0.30-5.0 µm	Metallic 5.0-50 µm		Discontinu-ous true oil colour 50-200 µm	Continuous true oil colour > 200 µm

10. Weather conditions	Temp. (°C)		Wind			Wave height
	Sea	Air	Speed (m/s)	Direction	In-/decreas-ing	
Presently:						
24 hrs forecast:						
9. Forecasted location of oil slick at the time of planned *in situ* burning operation, i.e. time for arrival of *in situ* burning equipment	**N**		**E**		**Hrs**	
	Attach latest oil slick trajectory-modelling forecast					
10. Visibility and light conditions	Cloud base (m)		Horizontal visibility (m)		Hours of daylight	
					From hrs	To hrs
11. Ice conditions Degree of coverage (%).	No ice		Open water with ice floes	Ice floes/broken ice	Consolidated/ Fast ice	

12. Description of *in situ* burning technique	Method
	Ignition
	Fire booms: trademark, resistance time, amount (m)
	Estimated burning time
	Attach latest smoke trajectory-modelling forecast

Net Environmental Benefit Analysis (NEBA)

An *in situ* burning operation will in total make the spilled oil cause less harm to the environment than no response or mechanical measures? Result from NEBA, Form 2.	**Yes**
	No

Operational conditions

The operational conditions to accomplish an *in situ* burning operation are met? Result from evaluation of oil and operational conditions by the oil spill response team (***Form 3***).	**Yes**
	No

Attachments

1. NEBA (Form 2)	
2. Latest forecast of oil slick trajectory modelling	
3. Latest forecast of smoke trajectory modelling	

Recommendation

	Yes	**Yes, with certain limitations**	**No**	**Further information needed**
Initiation of an *in situ* operation is recommended				
Comments				

Signatures

____________________ ____________ Date and time

____________________ ____________ Date and time

Form 2 - Net Environmental Benefit Analysis

Evaluation of the total potential environmental benefit from the *in* situ burning (ISB) operation during an oil spill presuming operational conditions are met. For explanation of pt. 1-5, please consult Annex 1.

Net Environmental Benefit Analysis (NEBA): *In situ* burning operation will in total make the spilled oil cause less harm to the environment than no response or mechanical measures? Pt 1-5.	**Yes**	**No**
Operational conditions: The operational conditions to accomplish a dispersant application operation are met? Result of evaluation performed by the oil spill response team.	**Yes**	**No**

Criteria for evaluation:	**Score**
Positive net environmental benefit	A
Semi-positive net environmental benefit Further evaluation/information needed	B
Negative net environmental benefit	C

Criteria to be evaluated in NEBA:		**Score**	**Comments**
1. Expected life time of oil on sea without ISB	A: > 24 hours B: < 24 hours C: < 3 hours		
2. Oil ignitable and burnable	A: Oil is ignitable and burnable within possible time for operation B: Reduced ignitability and combustibility of oil within possible time for operation C: The operation cannot be performed within the operational window		
3. Distance to land and wind direction	A: Distance to land > 10 km B_1: Distance to land < 10 km – but offshore wind B_2: Distance to land < 10 km – but seabirds aggregations or sensitive shoreline in oil slick trajectory and no populated land in wind direction C: The criteria in A, B_1 and B_2 are not met		

Additional information		**Description**
4. Collection of res-idues/ residual oil *Collection equipment*	The *in situ* burning operation includes collection of residues/residual oil, i.e. equipment for this part of the operation must be available. Please describe the equipment available	
5. Collection of res-idues/ residual oil *Collection plan*	Please describe the plan for collection of residuals/residual oil	
6. Storage and dis-posal of residues/residual oil	Please describe the facilities available for storage and disposal and state how these are appropriate for handling burning residues/residual oil	

Additional comments:

Annex 1 - Information and explanations for Form 2

1. Evaluation of the lifetime of the oil slick on the sea surface
If it is expected that the oil will evaporate or naturally disperse within 3 hours, application of dispersants will not be relevant (C). If it is assessed to be within 24 hours, application of dispersants may be considered if drift of the oil slick may be to environmentally sensitive areas (B). If type and amount of oil indicate a longer lifetime on sea surface than 24 hours, *in situ* burning operation is relevant (A).

2. Evaluation of ignitability and burnability of oil within the operational window
The weathering degree of the oil is crucial to its ability to ignite and burn. The type of oil and weather conditions determine the time frame for weathering and hence the operational window for the *in situ* burning operation, therefore the success of the operation depends on whether the oil is ignitable and burnable within possible time for operation (A), or if these parameters of oil may be reduced (B), or if the oil is not ignitable and burnable within possible time for operation (C).

3. Evaluation of air pollution against the benefit of an *in situ* burning operation
During an *in situ* burning operation, the emissions of particles to the air are of primary concern. The safety limit is defined as the level of fine particulate matter ($PM_{2.5}$) being below 65 µg m^{-3} on an hour mean. In Alaska the safe distance is set to 3 nautical miles (5.5 km) from the burn. This safety distance is based on computer model predictions of particulate matter in a smoke plume, and where the $PM_{2.5}$ limit value is reached at the greatest downwind distance.

The Environmental Oil Spill Sensitivity Atlas of Greenland will serve as background information when identifying particular environmentally sensitive areas, which may be located in the modelled trajectory of the oil slick in the relevant season. The atlas also provides information on populated land, logistics and countermeasures.

The atlas consists of five parts (pdf-files) covering the following areas:

- South Greenland region 58°-62°N
- West Greenland region 62°-68°N
- West Greenland region 68°-72°N
- West Greenland region 72°-75°N
- West Greenland region 75°-77°N

Due to gaps in knowledge on the Arctic environment and fast weather changes, precautions have been taken in use of *in situ* burning as a countermeasure leading to a safety zone of 10 km.

Therefore, if the operation has a distance to land > 10 km, it has a sufficient safety distance (A). *In situ* burning may also be considered if the distance to land < 10 km – but the wind is offshore (B_1); if there are seabird congregations or prioritised shorelines in the oil slick trajectory and no populated land in the wind direction (B_2). *In situ* burning cannot be considered if the distance to land is < 10 km, no specific conditions justify the use of *in situ* burning (seabirds, sensitive shoreline in oil slick trajectory) or wind direction is towards populated land (C).

4-6. Collection of oil residues/residual oil
As oil residues/residual oil may contain higher concentrations of PAHs and, in case of residual oil, be more adhesive compared to none-burned oil, collection of the residues/residual oil from the *in situ* burning operation is important. When residues cool down, they often sink, but also heated oil which has not been efficiently burned may sink. This residual oil is tar like i.e. very sticky and adhesive.

Therefore, an *in situ* burning operation must include collection as well as storage and disposal of residues/residual oil. Descriptions of available equipment and plan for collection as well as storage/disposal facilities for this part of the operation are requested.

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Part III: Environmental monitoring and sampling strategy in connection with an acute oil spill

Susse Wegeberg

The aim of developing an environmental post oil spill monitoring programme and sampling strategy for Greenland is to assess:

- The spread and fate of the oil
- The efficiency of the oil spill countermeasures
- The environmental impacts of the oil spill and potential side effects of countermeasures
- Long-term environmental impacts.

Relevant issues to consider are (ICES 2006, Studenov et al. 2009):

- Collection of pre-spill biological and chemical baseline information
- Initial chemical composition and weathering process of the oil
- Indirect effects of and interference with mitigating measures
- Monitoring sampling strategy:
  - Type and location of sampling points including reference stations
  - Sampling frequency and number of replicates
  - Duration of sampling periods
  - Selection of matrices for sampling
  - Handling of samples (short- and long-term)
  - Analyses and storage of data.

Oil spill and countermeasures may have effect in air, water, ice, sediments and on coastlines. A sampling programme has to include all these environmental compartments as well as associated biota.

When response strategy has been decided and approved by the authorities, the fate and effect of the oil spill should be followed. This includes monitoring at spill location, monitoring in the trajectory and the spreading / dispersion of the oil slick and analysis of the oil itself to identify changes in the physical and chemical properties due to weathering (e.g. evaporation, degradation) of the oil. The monitoring should also include analyses for toxic effects as well as accumulation of oil components in biota. According to the recently published report on recommendations for assessing ecotoxicological effects of oil activities in Baffin Bay (Gustavson et al. 2016), an integrated approach is recommended. Integrated monitoring involves a combination of chemical and biological measurements in water, sediment and biota and consists of *simultaneous measurements of contaminant concentration in all three matrices, and biological effect parameters, using the same species/population/individual for both biological and chemical measurements and sampling in the same area within the same timeframe.*

A detailed monitoring strategy and programme have been developed and updated for Norway (Sft 1999, KLIF 2012) and it is recommended that the following sampling manual is used for monitoring fate and effect of oil spills in Greenland:

- KLIF (2012): Miljøundersøkelser i marint miljø etter akutt oljeforurensning

This is supplemented by the recommendations of Gustavson et al. (2016), regarding biomarkers monitoring.

For monitoring and sampling of volatile compounds, the manual developed by the US Environmental Protection Agency is recommended:

- US EPA (2010a, b): a) Technical overview of ongoing air monitoring efforts in response to the Gulf oil spill; b) Quality assurance sampling plan for British Petroleum oil spill.

Regarding wildlife response, please consult Part V in this report.

3.1 Sampling strategy

As oil spill monitoring as well as efficiency / impact of response techniques may be manifested in air, ice, sediment and water as well as biota inhabiting these environmental compartments, a sampling strategy is needed for each compartment and its biota:

3.1.1 Air

Air monitoring should be performed to assess the environmental and human health impact of the volatilisation of the oil. Evaporation of volatile oil components may constitute a potential toxic source, and includes volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs).

In case of *in situ* burning of the oil spill, the programme shall include monitoring of air particles of smoke and soot.

3.1.2 Water

Samples need to be taken from the sea surface and in the water column in order 1) to determine the spread and dilution of the oil in the sea, 2) to monitor the concentration of hazardous oil components, and 3) to monitor concentrations of dispersant compounds as well as *in situ* burn residues.

3.1.3 Ice

High ice concentrations and trapping of oil beneath ice floes present major challenges to the response. The most useful remote sensors and systems applicable to oil spills under these conditions are: Side-looking Airborne Radar (SLAR), Satellite-based Synthetic Aperture Radar (SAR), aircraft and vessel-based Forward Looking Infrared radar (FLIR) or ice surface-operated ground-penetrating radar (GPR), trained dogs and search from helicopter (Sørstrøm et al. 2010).

Surface-operated GPR is the most well-known technique, and for information on this technique Bradford et al. (2008) should be consulted.

3.1.4 Sediment

Sediment samples should be collected in areas where oil pollution is indicated. The depth of oil contamination into sediment depends on type of sediment, as well as size of mixing and re-working of the sediment by bioturbation, waves, etc.

3.1.5 Coast

In the Arctic, the oil residence on shores depends on substratum, the degree of exposure to wave action and ice scouring. Samples should be collected from the coast in the tidal and subtidal zones and where oil pollution is indicated.

3.1.6 Biota

Biological monitoring should include: 1) Proxies to evaluate toxicity of the oil; 2) Assessment of the spatial extent and magnitude of the impact or damage of the marine ecosystem due to the oil and / or countermeasures; 3) Evaluation of the time horizon of recovery after the oil spill and the effectiveness of countermeasures.

The sampling programme should reflect the overall need for information as presence of oil in the environment will affect the biological resources by exhibiting physiological and ecological responses, expressed by varying effect parameters (Studenov et al. 2009): mortality, reduction in growth and loss of reproductive output and loss or alteration of habitat. Furthermore, tissue sampling for indirect measurement of organism stress (biomarker responses) should be included as recommended by Gustavson et al. (2016), see *Table 3.3*.

3.2 Monitoring programme

The sampling and monitoring activities are described below and should be initiated and performed at the stages presented in the flowchart (*Figure 3.1*). Each box in the flowchart refers to a section below (I-IV).

The three categories of oil spills, Tier 1-3, and the corresponding monitoring steps are described in *Table 3.1*.

Table 3.1. Descriptions of the three categories of oil spills and the corresponding monitoring steps. The tiered response system is based on IPIECA (2007) and Cairn Oil Spill Contingency Plan, prepared by Oil Spill Response Ltd. (Cairn 2011). The numbers I-IV refer to a section below.

Tier	Monitoring steps	Section for information
Tier 1	Localized release of oil which can be controlled with the resources available on-site.	
	In this scenario, the oil spill size is relatively small (< 11 m^3) and may evaporate and naturally disperse:	I
	Or dispersing can be promoted by the use of dispersants:	II
	Or, if slick is sufficiently thick, oil can be burned *in situ*:	III
Tier 2	Release of oil which will need resources and support from outside the geographical area to control the spill.	I-IV
	Oil spill size exceeds 11 m^3 and will need initiation of oil spill mitigating responses:	
Tier 3	Uncontrolled blow out leading to major pollution which will need mobilization of agreements and contracts (national and international) on support in oil spill mitigating responses:	I-IV

I - Fate and effect of oil

To initiate potential mitigating responses, the fate and effect of an oil spill need to be identified. This includes location and monitoring of the behaviour of the oil slick, oil spill drift on the water surface, dispersal in the water column, as well as changes in the physical and chemical properties due to weathering of the oil.

Monitoring of fate and effect of the oil spill in the sea, the sampling programme follows KLIF (2012), and for monitoring of evaporated oil compounds, the programme follows US EPA (2010a, b).

Samples for monitoring:

- Volatile compounds in the air
- Oil on the sea surface

- Oil in the water column
- Oil in the sediment
- Oil in biota.

An emergency box containing sampling equipment and sample containers is prepared and placed at the Greenland Institute of Natural Resources. Guidelines for collecting, packing and forwarding the oil samples and labels are provided in Greenland Command (2007).

Monitoring the fate and effect of oil also includes analyses of biota to assess any toxic effects of the oil.

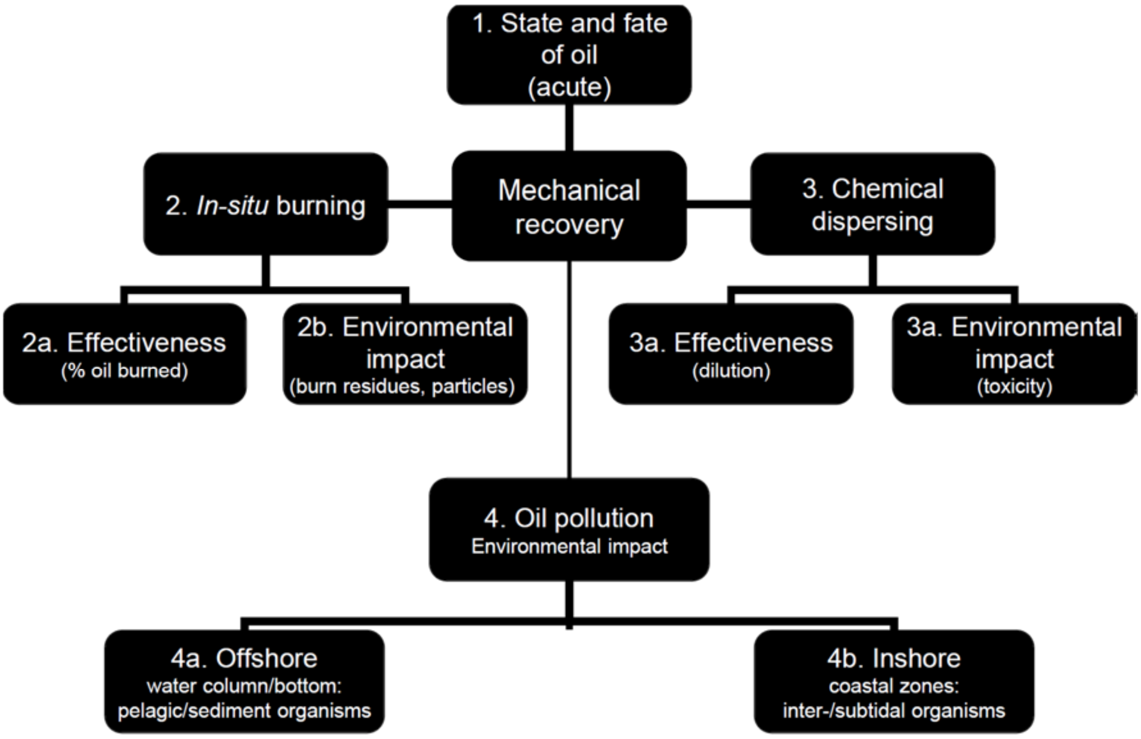

Figure 3.1. Fate of an oil spill if not combated (1, 4) or different scenarios of oil spill response (2, 3). Each box represents separate needs for monitoring and sampling, which are described in sections I-IV. Based on Wegeberg & Schiedek 2011.

A sampling programme for biota will follow KLIF (2012), but below a list of monitoring organism groups/species, relevant to Greenland, is presented (*Table 3.2*). Selection of species should, though, depend on oil drift, season and other relevant local factors. Therefore, the suggested species are intended for guidance and based on information from Mosbech et al. (2007).

A list of relevant biomarkers for monitoring is presented in *Table 3.3*, which is adopted from Gustavson et al. (2016).

Table 3.2. List of biota relevant for Greenland, from which samples should be taken according to the sampling programme presented in KLIF (2012).

Target organisms/species		
Seabirds		
Marine mammals	Seal	
	Whale	
	Walrus	*Odobenus rosmarus*
	Polar bear	*Ursus maritimus*
Fish	**Commercial/sensitive:**	
	Greenland halibut	*Reinhardtius hippoglossoides*
	Lumpsucker	*Cyclopterus lumpus*
	Atlantic cod	*Gadus morhua*
	Polar cod	*Boreogadus saida*
	Capelin	*Mallotus villosus*
	Arctic char	*Salvelinus alpinus*
Phytoplankton	Microalgae	
Zooplankton	Copepods	
	Fish larvae	
	Shrimp larvae	*Pandalus borealis*
Macrofauna	Infauna	
	Epifauna:	
	Deep sea shrimp	*Pandalus borealis*
Macroalgae	Brown algae	

Table 3.3. Recommended biomarkers for assessing exposure and effects of oil contamination in biota. Table adopted from Gustavson et al. (2016).

Method	Tissue type/matrix	Substance/group of substances	Organism	Priority analysis
PAH metabolites	Bile	PAHs	Fish	+
Alkyl phenol (AP) metabolites	Bile	APs	Fish	+
Histology	Gills	Different sources of stress	Fish	
DNA adducts	Liver	PAHs (+)	Fish	
CYP1A activity	Liver	PAHs (+)	Fish	+
Vitellogenin (VTG)	Blood plasma	Xenoestrogens	Fish	
Liver histopathology - contaminant specific	Liver	PAHs	Fish	+
Macroscopic liver neoplasms	Liver	PAHs (+)	Fish	+
PAHs (body burden)	Soft tissue	PAHs	Mussels	+
Pyrene hydroxylase	Digestive gland	PAHs	Mussels	
Micronucleus formation	Cells	Genotoxic stress	Mussels	
Lysosomal membrane stability	Haemocytes (blood cells)	Metals and organic contaminants	Mussels	
Lipofuscin	Histological sections	Different sources of stress	Mussels	
Neutral lipid	Histological sections	Different sources of stress	Mussels	
Comet assay	Haemocytes (blood cells), gill cells, digestive gland	PAHs (+)	Mussels	
Histopathology in mussels	Gonad, gills, mantle, digestive gland, kidney, foot	PAHs (+)	Mussels	+
CYP1A activity	Whole organism, pooled sample	PAHs (+)	Crustaceans (zooplankton, shrimp)	+

II - *In situ* burning (ISB)

During an ISB operation, the efficiency and any environmental impact of the burning process should be monitored to assess if the burning needs to be terminated. Monitoring at several localities using different methods should be conducted to measure, e.g. particulate matter (PM), volatile / semi-volatile organic compounds (VOCs / SVOCs), heavy metals, PAHs and dioxin which are expected to be present as a result of the oil spill and the burning process.

The environmental impacts from ISB are not that well-documented. Therefore, to minimize potential environmental impacts of the residues, it is recommended to collect floating residues on the sea surface as soon as safety allows after flame out. Some of the oil residues may float while warm and tend to sink when cooling off (Potter & Buist 2008).

IIa - Effectiveness of *in situ* burning

According to Potter & Buist (2008), efficient burns of heavier crude oils generate brittle, solid residues. Residues from efficient burns of other crude oils are described as semi-solid (like cold roofing tar).

Burn efficiency rate can be quantified by collecting the solid or semi-solid burning residues.

Inefficient burns generate mixtures of unburned oil, burned residues and soot which is sticky, taffy-like or liquid.

If, based on knowledge on the oil properties, ignition is considered barely possible and / or the burn will be too inefficient, it is recommended that no ISB operation is undertaken.

IIb. - Environmental impact of *in situ* burning

The particulate and air monitoring during an ISB operation shall follow US EPA (2010a, b):

- Measures of particulate matter (PM) and volatile organic compounds (VOCs) are obtained by continuous PM_{10} / $PM_{2.5}$ filter-based and (semi-) VOC sampler.
- The following substances have to be analysed following the Standard Operational Protocols (SOP) and relevant quality assurance (QA) measures:
  - Volatile organic compounds (VOCs)
  - Semi-volatile compounds (SVOCs)
  - Metals
  - Mercury
  - Total petroleum hydrocarbons (TPHs)
  - Polynuclear Aromatic Hydrocarbons (PAHs).

The programme of fate and effect of oil (section I) should be continued during and after the ISB process to assess if oil has dispersed into the water column and caused an oil pollution. For definition of oil pollution and continued monitoring programme, section 4 should be consulted.

III - Chemical dispersion

Chemical dispersants may provide a source of toxic compounds when applied to the environment in connection with oil spill and the environmental impact of chemicallly dispersed oil may be a result of the cumulative toxicity of the oil and dispersant or the dispersed oil itself (Part II). Therefore, it is essential to monitor the efficiency and environmental impact of the chemical dispersal in order to verify or adjust the NEBA. The monitoring information is hence essential to decide for e.g. a potential continuous application of dispersants.

IIIa - Effectiveness of chemical oil dispersing

Ultraviolet fluorometry (UVF) can be used to provide an estimate of the concentration of dispersed oil in the water column during the application of dispersants (EMSA 2010).

UVF detects the aromatic components in an oil spill. Water / oil is pumped to a UVF instrument in a boat from different depths below an oil slick treated with dispersants to measure the absolute concentrations (ppm) of dispersed oil in water.

This information should be used in combination with visual observations to decide whether a continuous application of dispersants is worthwhile as part of the NEBA.

For details of the monitoring and sampling programme, consult KLIF (2012).

IIIb - Environmental impact of chemical oil dispersing

Environmental impact of chemically dispersed oil may be the result of the cumulative toxicity of the oil and dispersant.

The programme of the fate and effect of the oil (section I) should be continued during and after the chemical dispersing process to assess if oil pollution has occurred. For definition of oil pollution and continuing monitoring programme, section 4 should be consulted.

Furthermore, in case of continuous use of dispersants, measures of dispersants in air should be included in the air monitoring programme following US EPA (2010a).

IV - Oil pollution

Untreated oil from the oil spill shall also be monitored, i.e. short- and long-term effects on the environment. The aim of the environmental monitoring is to document the extent of the impact and damage caused by the oil pollution as well as monitoring the recovery process of the environment.

An oil pollution is indicated when levels of oil components are higher than the background levels and biological effects / indicators are detected.

Depending on the oil spill location, size and duration as well as the potential success of oil spill response, the pollution may be restricted to open waters (offshore) or drift ashore (inshore), hence monitoring programmes need to be developed for both offshore and inshore oil pollution.

IVa - Offshore oil pollution environmental impact

Monitoring of the offshore environment is a follow-up on section I, excluding the air monitoring programme.

The monitoring programme will follow KLIF (2012):

- Oil components in the water column
- Phyto- and zooplankton
- Fish
- Marine mammals
- Seabirds.

For groups of organisms, target species may have to be selected (see section I).

IVb - Inshore oil pollution environmental impact

The objectives of monitoring the inshore environment are to document the extent of the impact and damage caused by the oil pollution as well as monitoring the recovery process of the environment.

Methods are developed for the three zones:

1. The supralittoral zone, defining the border to the terrestrial environment and which is never covered by water but moistened by splash and spray from waves. Marine organisms living in this zone are either highly mobile or very tolerant to desiccation and change in salinity.
2. The littoral zone, defined by being alternately covered and uncovered by water due to tides.
3. The sublittoral zone, which is always covered by water; hard and soft bottom.

Biota in zones 2-3 are less tolerant to desiccation and changes in salinity but may be highly tolerant to mechanical stress due to wave action.

The monitoring programme will follow KLIF (2012).

3.3 Sample handling for analyses

Samples should be collected using equipment and procedures appropriate to the matrix, parameters and sampling objectives, following international standard operating procedures (SOPs).

The volume of the sample collected must be sufficient to perform the laboratory analyses requested.

Samples must be stored in the proper types of containers and preserved in a manner appropriate to the analyses preformed.

The sampling and sampling handling information must be provided by the accredited, analysing laboratory.

Guidelines for the surface taking, packing and forwarding of samples and labels are provided in Greenland Command (2007).

Oil distribution profile in the water column is taken with a specially designed water sampler (still to be decided).

All necessary sampling equipment is planned to be housed at Greenland Institute of Natural Resources (GINR).

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Part IV: Strategy for shoreline clean-up for Greenland, including review of shoreline clean-up techniques, existing strategies and experience

Susse Wegeberg & Janne Fritt-Rasmussen

If an oil spill reaches the coast, the appropriate response regarding shoreline clean-up needs to be considered. Will the environment benefit from shoreline clean-up, and if so, which methods are to be used? And what are the end-points of the cleaning operation?

A shoreline may to some extent possess ability for self-cleaning, especially if the polluted coast is exposed to high wave energy and the weather conditions promote natural dispersal of the stranded oil slick. In such situations cleaning may also be impossible due to unsafe working conditions along the coast for response personnel.

However, if cleaning-up the shoreline is assessed as beneficial for the environment or for recreative purposes, several methods may be taken into account. First choice will usually be mechanical recovery by pumping and / or shovelling up the oil bulk. Cleaning with high-pressure (hot) water is also often part of the mechanical clean-up process. Shoreline washing agents can be considered if assessed beneficial for the environment and the conditions are optimal. These agents may be applied when the mechanical recovery has removed the bulk of the oil spill for removal of the remaining oil (Norwegian Environment Agency 2014).

Part IV will deal with the technique for assessing shoreline clean-up, Shoreline Clean-up Assessment Technique (SCAT), shoreline cleaning methods, experience from earlier shoreline clean-up operations and finally proposal for a shoreline clean-up strategy for Greenland.

4.1 Shoreline Clean-up Assessment Technique, SCAT

Shoreline Clean-up Assessment Technique (SCAT) is a systematic approach used for describing and documenting the oiling on shorelines and riverbanks. It was initially developed in 1989 during the *Exxon Valdez* and *Nestucca* spill response operation by Owens & Sergy (2004a). Hence the following is based on SCAT for the Arctic as described by Owens & Sergy (2004a).

SCAT is based on standard terms and definitions to describe and define shoreline oiling conditions. SCAT teams systematically survey the area affected by oil spills to provide rapid accurate geo-referenced documentation of shoreline oiling conditions. Basic principles that govern a SCAT survey are:

- A systematic assessment of all shorelines in the affected area
- A division of the coast into geographic units or ‘segments’
- A set of standard terms and definitions for documentation
- A team of interagency personnel to represent the various interests of the responsible party, land ownership, land use, land management or governmental responsibility.

In addition, SCAT surveys can also be used for e.g. provision of long-term monitoring and clean-up or treatment recommendations, standards (end-points) or criteria.

Trained SCAT team surveys provide information to build a spatial or geographic picture of the regional and local oiling conditions; an understanding of the nature and extent of the shoreline oiling which is the key to the development of an effective response. The information is provided in a standard format that can be interpreted easily and applied by planners and decision-makers. In most cases the SCAT teams complete forms and sketches for each segment in the affected area. Often SCAT teams are also asked for their recommendations regarding response techniques, to define constrains or limitations on response techniques to avoid additional damages to the shore as a result of the treatment.

The Arctic SCAT Manual was initiated by Environment Canada and the United States Coast Guard and supported by NOAA in Alaska and by private spill response and advisory services and was produced under the auspices of the Emergency, Prevention, Preparedness and Response (EPPR) Working Group of the Arctic Council. The Arctic SCAT Manual was finished in 2004 and contains four parts: procedures and forms (purpose and associated activities), applications (spill management issues), support materials and first responder guide. The second edition of the SCAT Manual is supplemented with material on Arctic shoreline types, forms of snow and ice, oil behaviour and activities of SCAT teams in such environments. The near-shore ice terminology follows that of NOAA "*Observers Guide to Sea Ice*".

The primary difference for field surveys when snow and ice are present in an Arctic or subarctic environment is the possibilities of:

- Surface oil can be covered by blowing snow
- Oil can infiltrate fresh snow
- Oil can enter ice cracks and leads
- Oil beneath or within ice cannot be detected except by drilling holes through the ice.

In general, for performing SCAT surveys in the Arctic, access may only be provided by boats, windows of opportunity may be limited during winter and expanded during summer due to hours of light. Different survey methods depending on the size of the affected area, local conditions and detail requirements, are given in *Table 4.1*.

Table 4.1. Survey methods, adapted from Owens & Sergy (2004b).

Survey method	Key objectives	
Aerial reconnaissance	Define overall scale of the problem to develop regional objectives. Mapping or documentation not required.	
Aerial videosurvey	Systematically document or map to (i) create segments, (ii) develop regional strategies and plans, and (iii) define locations and lengths of oiled shorelines, including surface oil band width and estimated distribution.	Maybe the only practical method to survey some areas with inaccessible shorelines or limited/difficult access.
Systematic ground survey	Systematically document surface and subsurface shoreline oiling conditions in all segments within the affected area.	Typically, the primary source of detailed data and information. During winter boat-based surveys may be more efficient.
Spot ground survey	Systematically document surface and subsurface shoreline oiling conditions for selected segments within the affected area.	

4.1.1 Assessment of SCAT in a Greenlandic context

The concept and guidelines of SCAT appear as very well developed for assessing the extent of the shoreline oil pollution and hence assessment of needs/possibilities for clean-up with a high level of details. However, the system also requires well-educated and highly trained personnel/teams to conduct a meaningful SCAT operation.

According to the SCAT manuals, there is a pre-spill phase in SCAT surveys which includes background knowledge about the shorelines, creating shoreline segments, collecting basic data on shoreline types and coastal character. For Greenland, much of the basic shoreline information needed is available in the Oil Spill Sensitivity Atlas to a certain level. Hence, if the SCAT concept is considered to be used in Greenland, it is advisable to link the Oil Spill Sensitivity Atlas (http://bios.au.dk/en/knowledge-exchange/for-government-agencies-and-anyone-with-a-special-interest/greenland-and-the-arctic/olie-og-miljoe/raadgivning/oil-spill-sensitivity-atlas/) to the pre-spill phase.

For a more detailed morphological mapping of shoreline segments - the first step in the SCAT operation - maps/photos and local knowledge are needed. Such information is often not available for Greenland, hence it is suggested that this type of information could be achieved as part of specific oil spill contingency plans for exploration/production activities in Greenland.

Further as stated in the manuals, locals are often the first on scene/first responders. Therefore, if SCAT is to be used in Greenland, local teams of dedicated and experienced personnel should be trained and educated to use the SCAT method in Greenland. Such trained locals should be able to quickly enter the oil spill response team as SCAT coordinators for establishing SCAT teams for the field surveys.

SCAT courses are now being offered from the Greenland Oil Spill Response A/S (http://www.gosr.gl/kursusudbud), and all reports/manuals/forms etc. are available from: http://www.shorelinescat.com/Index.html.

To make SCAT more available in Greenland and facilitate education of local teams, the SCAT manual or at least the First Responders' Guide (Owens & Sergy 2004a) could be translated to Greenlandic.

4.2 Review of shoreline clean-up techniques and strategies

If clean-up is assessed as beneficial for the environment and / or recreational purposes, several methods can be introduced.

4.2.1 Mechanical recovery

The bulk oil can be recovered by use of vacuum trucks, pumps and skimmers. For very viscous or weathered oil, pumping may not be possible and hence oil has to be recovered mechanically (manually by shovelling / by excavator or similar) (Lahrman et al. 2007). Manually shovelling may also be the case when shores are particularly sensitive or inaccessible, which are often the case in Greenland (ITOPF: http://www.itopf.com/knowledge-resources/documents-guides/response-techniques/shoreline-clean-up-and-response/).

4.2.2 Water flush

By cold or hot water pressure stream, the oil is flushed down the shore, contained by floating booms and recovered with sorbent materials (e.g. bark (Gitmark & Brkljacic 2011)) or pumped up for disposal. Depending on the type of oil and vegetation, low-pressure washing will usually remove most of the oil from rocks and vegetation. Use of high-pressure hot water washing may on the other hand do more harm than good in a marine ecosystem by forcing the oil deeper into the sediments and by killing many of the organisms on the shore by dislodging organisms, such as algae and mussels, from the rocks and sediments on which they live. However, if assessed of environmental benefit using the method, high-pressure washing has the advantage of being relatively inexpensive and simple to apply, although labour demanding (EPA 2013).

Other things being equal, the higher pressure and temperature of the water stream, the higher degree of oil removal. However, this may correlate negatively with the survival rate of the organisms exposed to the water stream. Hence, in a Greenland context, it would be of highest relevance to study the lethal and sub-lethal limits for water pressure and temperature on Arctic tidal organisms. This information is crucial for the recommendations on a shoreline clean-up operation using shoreline washing.

4.2.3 Shoreline washing agents/dispersants

Shoreline clean-up can also be aided by use of shoreline washing agents or dispersants (Walker et al. 1999; Norwegian Environment Agency 2014). Present section is based on the descriptions provided by the Norwegian Environment Agency (2014).

Dispersants modify the properties of the oil to ease flushing of the oil from the substrate / organisms. When flushed into the sea water, the dispersant promotes the creation of stable oil droplets due to a content of surface active compounds. Hence the oil's surface tension is reduced similar to the effect of dish soaps on fats, and results in stable dispersions of oil in the seawater.

For use of dispersants on the shore, water or wave action exposure is needed to release and flush the oil and dispersant mixture down the shore. When it meets the water body, it will be transported with the moving water and cannot succeedingly be collected. Therefore, a high degree of water exchange is needed to ensure sufficient dilution of the oil and dispersant mixture below toxic concentrations. Use of dispersants is hence only recommended in wind and/or current exposed areas, and is not recommended for particular environmentally sensitive areas.

Shoreline washing agents modify the properties of the oil with regard to viscosity and/or surface tension to ease the flush out of the oil of the substrate/organisms. Flush with water after application is needed. Washing agents have low concentrations of surface active agents and hence do not provide creation of stable oil droplets in the seawater as is the result of dispersant use. Therefore, the washed out oil is gathered on the seawater surface from where it can be recovered by skimmers and sorbents if contained by booms against the shoreline.

Washing agents are hence suitable for low-energy shores, e.g., wind protected shores, and can also, unlike dispersants, be used in more environmentally sensitive areas where it is important to prevent spreading of the oil and that the oil can be recovered.

Any of these types of shoreline washing chemicals can only be used in Norway after toxicity testing according to the Norwegian regulations for pollution reduction, Chapter 19 (https://lovdata.no/dokument/SF/forskrift/2004-06-01-931/KAPITTEL_7#KAPITTEL_7-1).

Guidelines for testing of toxicity and effectiveness of the washing agents/ dispersants (as well as bioremediative agents, see more details on bioremediative agents in the chapter below) have been developed by the Norwegian authorities (Norwegian Environment Agency 2014).

Efficiency of washing agents has been tested in a washing robot, of dispersants in a simulated shoreline system and of bioremediative agents in a sediment column (*Table 4.2*).

Table 4.2. Criteria for characterization of shoreline clean-up agents (redrawn and translated from Norwegian Environment Agency (2014)).

	Cleaning agent	Dispersant	Bioremediative agent
Toxicity *Skeletonema costatum* *Corophium volutator*	 EC_{50} > 100 mg/l LC_{50} > 100 mg/l	 EC_{50} > 10 mg/l LC_{50} > 100 mg/l	 EC_{50} > 10 mg/l LC_{50} > 100 mg/l
Dose (agent/oil)	1/5	1/25	1/10
Dispersability (modified WSL-test)	(1/5) > 10 %	(1/25) > 60 %	
Efficiency by water flushing (washing robot)	(1/5) > 60 %	((1/25) > 30 %	
Efficiency by wave exposure (shore system simulation)		(1/25) > 30 %	
Efficiency of biodegradation (sediment column)			(1/10) > 20 %

The required toxicity tests are standard tests on the temperate organisms *Skeletonema costatum* (diatomée, algae) (ISO 10253:2006). Dispersants with an effective concentration of EC_{50} < 10 mg l^{-1} and washing agents of EC_{50} < 100 mg l^{-1} cannot be used. It is furthermore recommended to test with the sedimental amphipod, *Corophium volutator* (ISO 16712:2006) (OSPAR 2010; Øverjordet et al. 2011; Norwegian Environment Agency 2014).

Several products have also been tested on the Arctic copepod *Calanus glacialis* and compared with results for the boreal species, *C. finmarchicus* (Øverjordet et al. 2011). In the study by Øverjordet et al. (2011), 9 products / chemicals, developed for use on oil pollution near the shore, were tested: 3 organic solvent-based dispersants and 6 washing agents, of which 3 were water based and 3 were based on an organic solvent. In the tests with the organic solvent-based products, the water accommodated fraction, WAF, was used. It was found that the dispersants were the most toxic products, while the WAF of the non-water soluble washing agents was the least toxic for both species of *Calanus*. *C. glacialis* was more sensitive than *C. finmarchicus* to most products, but in overall the results were comparable.

This is very important information. However, in a Greenland context, information on the cleaning effects on Arctic shore key organisms *(Fucus* spp / macro algae, *Mytilus edulis* / blue mussel, *Gammarus oceanicus* / crustacean, *Littorina* spp / sea snail and *Semibalanus balanoides* / barnacle*)* as well as the ecotoxicological cocktail effects of washing agents / dispersants and oil mixtures on the above tested Arctic organisms (*Calanus* spp.) is still needed, although older toxicity testing was conducted on Corexit 9580 (Walker et al. 1999, references herein). In general, field and laboratory studies have shown that the cocktail effects of chemically dispersed oil should be in focus (Østby et al. 2002; Fuller et al. 2004; Hemmer et al. 2011) due to increased exposure of the marine organisms to dissolved and dispersed oil components (Østby et al. 2002; Fingas 2008). Therefore, to provide an important input for the recommendations for shoreline clean-up under extreme temperatures, lethal cocktail dose limits on littoral organisms as well as sub-lethal effects should be identified.

A decision tree for use of shoreline washing agents has been developed by Koops et al. (2004) (*Figure 4.1*).

4.2.4 Bioremediation agents

The concept of bioremediation agents is to stimulate microbial activity and accelerate the biodegradation of oil components and hence the recovery of oil from polluted areas.

According to the Norwegian Environment Agency (2014), the bioremediation agents consist of fertilizers with or without microorganisms. Microorganisms degrade the oil components in the boundary layer between oil and water as the process is aerobic: oil is the carbon source and oxygen is supplied from the seawater. The oil components can ideally be degraded to CO_2 and water, however, several degradation products may accumulate during the process, which may be slow. Therefore, this technique will often be used as a supplement to the other cleaning techniques on shore or in the seawater and when oil is contained in soft substratum not subject to wave exposure.

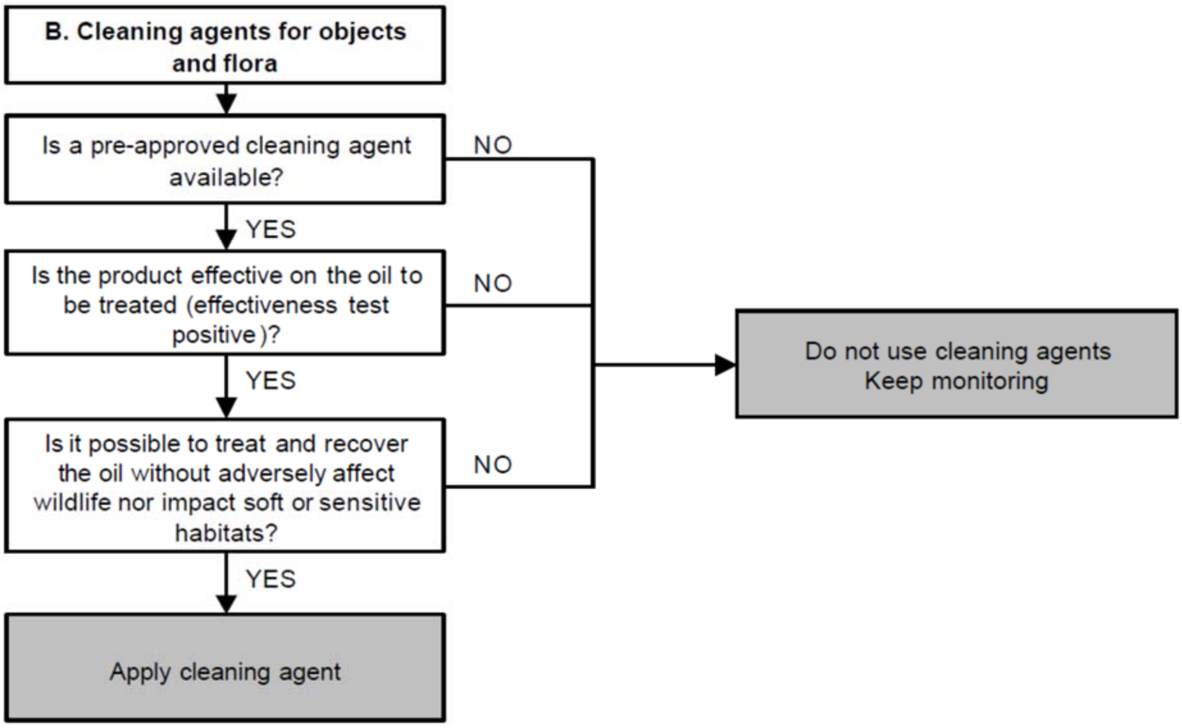

Figure 4.1. Flow chart for use of washing agents on an oiled shoreline. From Koops et al. (2004).

Although successful use of bioremediation agents (fertilizers, microorganisms) was considered to have been proven in connection with *Exxon Valdez* (Prince et al. 1999), several issues point towards a risk of less efficiency of this method in a Greenland context:

- Fertilizers will have no effect if resident bacteria flora has no ability to degrade oil components
- The microorganisms supplied need to be acclimated to Arctic conditions to survive and multiply
- The environmentally most hazardous oil components are often not readily biodegradable (Wegeberg et al. 2016).

Bioremediation agents are not allowed for use on Svalbard (Norwegian regulations for pollution reduction §19-5), but Koops et al. (2004, Fig. 5) provide a decision tree on bioremediation based on the Harmonised Offshore Chemical Notification Format (HOCNF) (OSPAR 2010).

4.2.5 Oil-mineral aggregates (OMA)

Oil-mineral aggregates (OMA) are microscopic units composed of distinct oil and mineral phases that are stable over periods of weeks in seawater. Enhanced OMA formation has been considered as a biostimulation technique for bioremediation of marine oil spills due to its potential of stimulating the growth of indigenous oil degrading bacteria (Owens & Lee 2003). The concept has been introduced by Lee & Stoffyn-Egli (2001), on which the description below is based.

Evidence from laboratory and actual oil spills indicates that significant OMA formation may occur naturally and that OMA occur primarily as droplets, but also as solid and flake aggregates. This suggests that the oil slicks have been broken up by the surf to droplets that subsequently are coated by suspended mineral particles that prevent recoalescence of the oil. Therefore, more viscous oils are likely to require more shear energy (i.e. wave energy) to form OMA. However, OMA have been observed in breaking waves in heights of less than 30 cm, thus it is expected that sufficient energy is available at most shorelines and existence of solid and flake OMA indicates that the oil does not necessarily have to be dispersed as droplets in the water to associate with mineral particles.

Oil-mineral interactions are believed to be instrumental in the natural removal of stranded oil within the coastal environment, but also in the effectiveness of surf washing as an oil spill countermeasure. Moreover, it has been shown that oil biodegradation is enhanced in OMA and that oil associated with fine mineral particles in near-shore water or marine sediments has little toxic effects.

To monitor the formation of OMA, their study rely almost solely on microscopy using bright field transmitted light, UV epi-fluorescence, scanning confocal laser and scanning electron as most OMA are below 1 mm in size.

4.2.6 Surf washing

Surf washing is also known as sediment relocation. The technique has been used widely in relation to different oil spills, e.g. Prestige, Erika, Hebei Spirit and Deepwater Horizon (Kerambrun et al. 2014).

Oil stranded above where normal wave action might influence, in the upper part of the intertidal zone, or buried in the sediments can be removed and deposited in the surf zone in piles or berms. By this method, contaminated polluted sand, shingle, pebble or cobble shorelines can be cleaned by use of natural processes, the natural energy of the surf (ITOPF 2014). Surf washing is similar to mechanical flushing but in surf washing much larger volumes of water, than can be provided by pumps in the flushing process, is naturally available (ITOPF 2014). The oil released to the water can be partly collected by fine-mesh nets (Kerambrun et al. 2014) or is naturally dispersed into the water column (ITOPF 2014). The movement of the sediment in the surf zone releases oil from the sediment even within the substrate, and the oil droplets can also be stabilized by fine particles – the oil-mineral aggregation process (see section 4.2.5). It is important to carefully locate the surf washing point to make sure that the technique will be feasible and that the released oil will not pollute sensitive locations. In such assessment, the window of opportunity for the method regarding wind conditions (strength and direction) as well as tidal conditions (often used at rising tide, but can also be used at ebb tide) should also be assessed (Kerambrun et al. 2014). Also before using surf washing, the bulk oil should be removed by other means. Surf washing can be repeated to remove the oil pollution to the desired level.

4.3 Experience from previous shoreline oil spill clean-up

To evaluate the net environmental benefit from shoreline clean-up, it is of great value to know the impacts of former cleaning-up operations. Below experience on shoreline clean-up and monitoring from more recent oil spills in Norway, Alaska and UK are presented.

4.3.1 Norway

The report on the environmental impacts of four groundings in Norway, *Rockness* (2004), *Server* (2007), *Full City* (2009) and *Godafoss* (2011) presents the experience from the incidents including evaluation of the environmental monitoring of the shoreline clean-up impacts (Boisov et al. 2012).

Only for *M/S Full City* the effect of water flush of 90 °C could be evaluated (Gitmark & Brkljacic 2011). It was concluded that a small effect of the high pressure and hot water hosing could be observed on filamentous algae and amphipods, but that the correlation was “vague”. For the other three incidents, no significant effects on fauna and macroalgae were observed after the clean-up actions. This was, however, based on careful but only semi-quantitative analyses of limited extent and / or no effective baseline. In general, it was found that the oil-polluted sites were recovered within a period of a couple of years for these oil spills (112-527 tons of heavy fuel oil (HFO)).

4.3.2 Alaska

In earlier years, e.g. the *Exxon Valdez* (1989) incident in Prince William Sound, Alaska, the clean-up techniques were more rough leading to 50-100 % mortality of organisms exposed to high-pressure hot water. The long-term intertidal monitoring programme proposed by NOAA was also designed to examine the issue of potential impacts from the more aggressive treatment methods, and in particular the use of high-pressure hot water.

The results from this monitoring programme during 25 years are presented in the report *25 Years After the Exxon Valdez Oil Spill: NOAA’s Scientific Support, Monitoring, and Research* (Shigenaka 2014):

“The decade-long duration of this program facilitated a number of insights into oil and clean-up impacts, and subsequently, the nature of recovery on the intertidal shorelines of the subarctic region. These included:

- Observations during the early stages of the spill indicated that intertidal plants and animals were generally resistant to acute toxicity of heavy oil, sometimes surviving 3-4 months of exposure
- Exposure to high-pressure hot water, however, resulted in 50 to 100% mortality of exposed organisms
- Impacts from high-pressure hot water washing were initially more severe than impacts from oiling alone. Longer-term monitoring showed that these differences diminished with time (1-2 years)
- Intertidal impacts from the spill, whether by oil or treatment, were not evident within 3-4 years
- Monitoring over the long term, however, documented a high degree of inter-annual variability in intertidal communities [considered] unrelated to the oil spill—but nevertheless very relevant to assessment of oil spills or other disturbances.”

From the *Exxon Valdez* shoreline clean-up activities it was clear that aggressive methods as high pressure hot water wash may not be environmentally beneficial. This experience has been incorporated in subsequent clean-up assessments as seen in Norway and for the later incident by *Sea Empress* in Wales, UK.

Another lesson learned from the *Exxon Valdez* oil spill was that oil was buried in coastal substrates and that heavy oiling remained in the place for decades.

The slow release of this non-weathered, and still toxic, oil leads to continuous contamination of specific sites, and hence also delays full recovery of particularly sensitive organisms (*Figure 4.2*).

4.3.3 UK

In the UK, cleaning up after the *Torrey Canyon* (1967) oil spill (9,000 tons were estimated to reach the shore) in Cornwall included the use of toxic dispersants on the shores (Southward & Southward 1978). The dispersant was shown to have LC50 (24 h) of 0.5-5 ppm on sublittoral organisms, and 5-100 ppm on littoral organisms, which are lower concentrations than are allowed in Norway today (*Table 4.2*). Most animals and some algae were killed on shores treated heavily with dispersants followed by hosing. The areas only lightly oiled and lightly treated by dispersants were considered to be recovered after 5-8 years while those heavily impacted by oil and repeatedly treated with the dispersant were considered to be almost recovered after 9-10 years, where most common species had returned. During the recolonization process, the upper limit of the kelp species raised with as much as 2 m, probably due to lack of limpet grazing and the authors concluded that: “Pollution disturbance affects the herbivores more than plants, hence the point of stability of the community is shifted towards the sheltered shore conditions of low species richness and greater biomass”.

The oil from the *Sea Empress* spill in Wales in 1996, especially in the West Angle Bay, was cleaned by mechanical removal as well as the use of high pressure water. According to Purnell (1999), intrusive clean-up methods and heavy machinery were avoided wherever possible to minimise the risk of environmental damage to the more sensitive shorelines. It was assessed that recovery was rapid, within one to two years, after a period with first massive growth of ephemeral green and red algae followed by recruitment of limpets and then colonisation of fucoids. After five years the situation was assessed as being similar to that before the oil spill (Moore 2006).

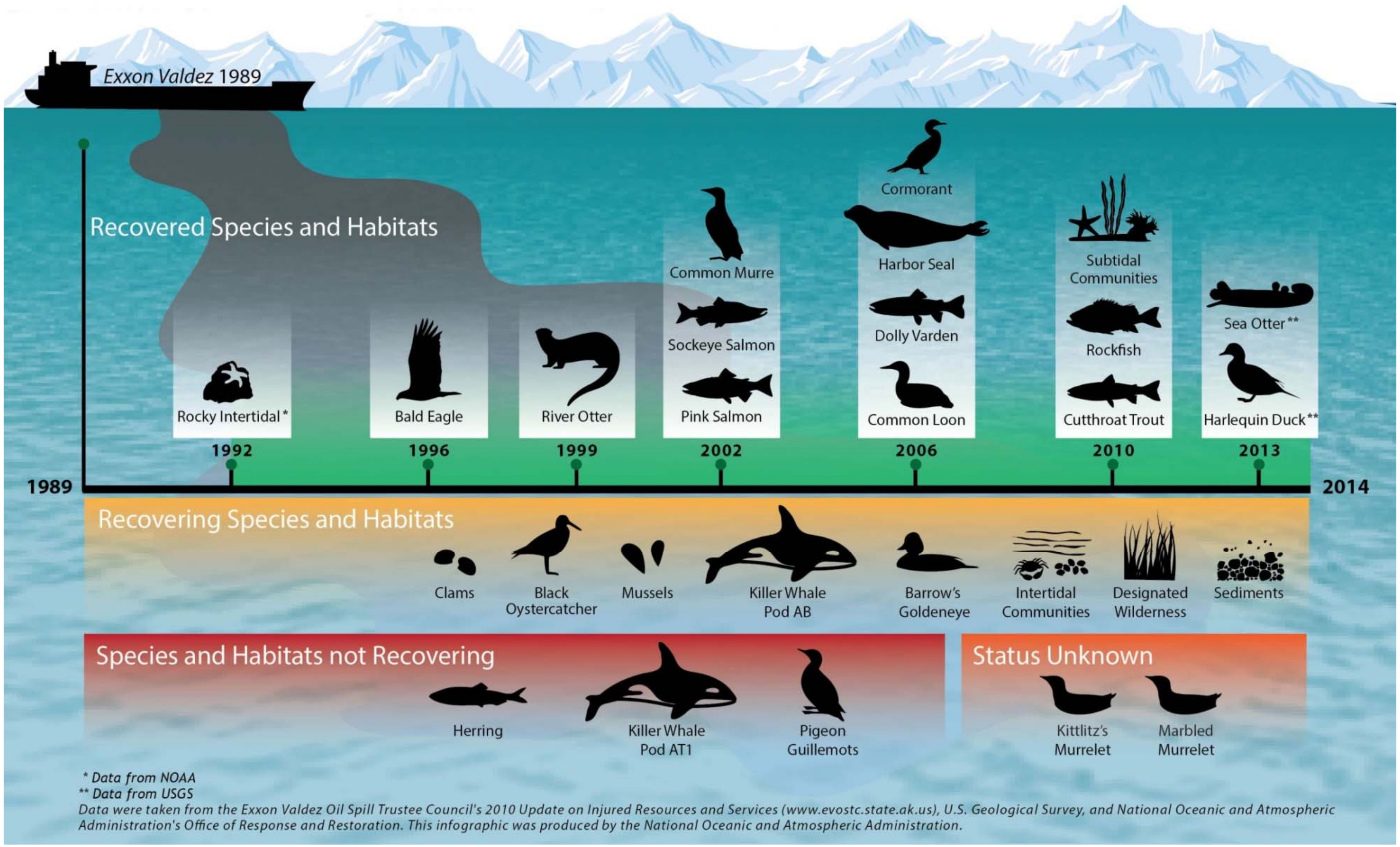

Figure 4.2. Recovery timeline for key species and habitats after *Exxon Valdez* oil spill. From http://oceanservice.noaa.gov/podcast/mar14/mw122-exxonvaldez.html.

4.4 Proposed strategy for shoreline clean-up in Greenland

When proposing a strategy for shoreline clean-up in Greenland, it is important to bear in mind the lessons learned from earlier oil spills in relevant areas, as described above.

Therefore, the proposed strategy for shoreline clean-up in Greenland is to carefully assess expected environmental impacts from shoreline clean-up techniques and the environmental benefit against specific coastal self-cleaning potential and biodegradation. The Net Environmental Benefit Analysis, the NEBA, is as important for shoreline clean-up as for oil spill combat offshore.

However, for developing a NEBA tool for shoreline clean-up in Greenland, further studies are needed. Potential environmental effects of shoreline clean-up, water wash and chemical agents, compared to the natural removal / biodegradation of stranded oil on different coastal types at different Arctic climatic regimes in Greenland:

- Fate and effect of beached oil during natural degradation, including biodegradation, physical degradation and wave wash; to estimate self-cleaning potential to support shoreline clean-up strategy
- Fate and effect of beached oil using water wash methods; to identify Arctic littoral organisms' lethal limits for water pressure and temperature
- Fate and effect of oil using cleaning agents; dispersants and washing agents according to best choice of chemicals.

Furthermore, the possibility of using *in situ* burning in near shore waters should also be investigated. As part of an integrated operational response strategy to offshore and / or coastal oil spill events in extreme oceanic conditions, e.g. ice-infested waters, and especially in remote, sparsely populated areas with difficult logistics, spilled oil could be prioritised to be boomed towards and contained in a closed water body (e.g. safe haven, a bay of sacrifice). Hence the coastline may be used to confine the oil slick for mechanical recovery and *in situ* burning, as included in the Canadian guidelines for *in situ* burning (REET 2003). To assess the potential environmental benefit for this method, several operational and environmental issues need to be considered:

- The efficiency and environmental effect of burning oil in / on the edge of the tidal zone, and its dependency of tidal waves / amplitudes
- Technologies for collection of burning residues, and shoreline cleaning using chemical agents.

Presently, it is recommended that the following manuals (in Norwegian) developed for Norway for decision-making, prioritizing and assessing shoreline clean-up strategy(ies) as well as manual for data collection is used:

- *Sft (1999a, b). Sanering av akutt forurensning på strand*
  - *Del 1: Teoretisk grunnlag for anbefalte praktiske tiltak og organisering*
  - *Del 2: Innsamling av data, prioritering av områder og valg av tiltag.*

4.4.1 When is clean clean?

The decision on when to end the clean-up processes and when a location is considered clean is important and should be related to among others the habitats, sensitivity, use and vulnerability of the spill site. A guideline for selecting these end-points is in "Guidelines for Selecting Shoreline Treatment End-points for Oil Spill Response" (Sergy & Owens 2007). But also Baker (1999) presents very useful definitions for when the environment can be considered clean from an oil spill.

Hence, according to Baker (1999) clean may be defined as petroleum hydrocarbon concentrations that:

- Do not exceed normal background levels for a particular location
- Do not exceed statutory limits (if such exist)
- Are not lethal to specified organisms
- Do not cause deleterious sub-lethal effects to specified organisms
- Do not cause tainting of food organisms
- Have no detectable impact on the function of the ecosystem
- Do not impair the use of an area
- Are not visible to the human eye
- Cannot be reduced by enhanced clean-up actions without causing an overall retardation of recovery.

The time horizon for monitoring of oil spill and shoreline clean-up impacts depends on the substratum and the impacted environmental resources and their recover time (Boitsov et al. 2012). But in accordance with Baker (1996), Boitsov et al. (2012) also consider that the environmental monitoring should be ended when no impacts can be measured, or when they are strongly reduced. However, the decline in fucoid cover after short-term recover described in Moore (2006) was also a phenomenon observed after *Exxon Valdez* after four years (Driskell et al. 2001). So even though a rapid recover of the fucoids in the littoral zone after oil pollution and shoreline clean-up activities, a decline explained by either injuries on reproduction and / or juvenile stages or slower recovery of and / or consequential effects from other organisms (e.g. limpets) in the ecosystem may occur on longer term before the stability of the ecosystem is achieved and the full recovery process accomplished. Hence continued monitoring for, as the examples of the *Exxon Valdez* and *Sea Empress* indicate, at least five years may be necessary when extensive oil pollution is the case.

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Part V: Wildlife response strategy in Greenland

David Boertmann

Marine oil spills will often result in the stranding of dead and alive seabirds and marine mammals. Under severe conditions very high numbers – tens of thousands of individuals, mainly seabirds – may hit the shores close to an oil spill.

The term 'wildlife response' is used to describe the actions taken to prevent animals from exposure to oil, and when wildlife has been exposed also to collect, kill and / or rehabilitate oiled wildlife. The target groups are usually seabirds, marine mammals and in tropical and subtropical areas also turtles, crocodiles and other reptilia, however, in a Greenland context, only seabirds and marine mammals are relevant.

During the large oil spill in 1989 in Prince William Sound, Alaska, when 41,000 m^3 crude oil was lost to the marine environment, at least 40,000 dead or injured seabirds were collected, and they constituted only a fraction of the actually killed birds (Piatt & Ford 1996). Estimates of the mortality peak at 650,000 dead seabirds. Besides the seabirds, *c.* 1,000 sea otters, 20 harbour seals, 12 sea lions and 37 whales of different species were collected (St. Aubin & Geraci 1994).

Danish waters have also been the scene for large numbers of oil contaminated seabirds on the shores. During an oil spill (amount and type unknown) in Kattegat in March 1972, 7,500 seabirds were euthanized. In the Wadden Sea in December 1972, 10,000 seabirds were euthanized following an oil spill (size and type unknown) (Joensen & Hansen 1977). The largest number of seabirds euthanatized after an oil spill was at the *Thuntank III* spill (350-500 m^3 oil) in January 1979 when 35,000 birds were killed and of these, 18,000 were collected for closer study (Clausager 1979). The so far largest oil spill in Danish waters occurred in the Baltic Sea in March 2001, when the cargo ship *Baltic Carrier* lost 2,500 m^3 heavy fuel oil. Following this spill, 1,750 seabirds were euthanized and collected for further studies (Storstrøms Amt 2007).

Especially the *Thuntank III* spill showed that even relatively small oil spills can cause a very high mortality in areas where the density of seabirds on the sea is high. In Greenland waters, high densities of seabirds are frequent in many areas (Boertmann et al. 2004; Merkel et al. 2002; Boertmann & Mosbech 2012; Boertmann et al. 2013).

The experiences from *Exxon Valdez* prove that other birds than seabirds can be hit by a marine oil spill. For example, 250 bald eagles (*Haliaeetus leucocephalus*) (a close relative to the Greenland white-tailed eagle (*Haliaeetus albicilla*)) were killed by the oil (Bowman et al. 1997). They were contaminated either by taking food from an oil-covered sea surface or by eating oiled seabirds. This is a situation, which is also expected to occur in Greenland.

5.1 Wildlife response

When an oil spill is reported, the question of what to do, especially with oiled dead or living wildlife, soon emerges. In this situation it is crucial to be prepared — a wildlife response contingency plan shall be at hand.

There are in principle three alternative actions when wildlife has been exposed to oil:

1. To do nothing, except to collect as much as possible of the dead wildlife
2. Euthanasia of oiled and still alive seabirds and marine mammals
3. De-oiling and rehabilitation of oiled seabirds and marine mammals.

Preventing wildlife from being exposed to spilt oil is also an option, and some methods have been implemented. Seabirds have been scared away from areas threatened by a drifting oil spill, a method termed as *hazing* or *deterrence*, and in South Africa threatened penguins have been caught and relocated to areas not threatened by the actual oil spill (Wolfaardt et al. 2009). The methods applied are many and for a more detailed account see Gorenzel & Salmon (2008).

An important activity during wildlife response is to record biological information on the impacted birds and mammals. As far as possible, the impacted individuals shall be numbered, identified to species and also to sex and age. Such knowledge is important in order to evaluate how the affected populations are impacted, how they may recover and how they should be managed. Furthermore, it can often be informative and / or of scientific value to link the affected birds to specific populations by genetic ore morphometric analysis.

The three oiled wildlife response alternatives

Alternative #1 is the minimum solution. As far as possible, dead wildlife shall be collected, studied and disposed of. The purpose is to get biological information (see above) and to prevent other wildlife to feed on oiled birds and mammals.

Alternative #2 is the deliberate killing of oiled wildlife (euthanasia). This action implies organization and systematic search for oiled animals along the coast if it shall be effective. During oil spills in Danish waters in the 1970s, the police, the state forest, official game advisors and wildlife research institutions organized the response. Later also county offices and the Nature Agency were included (Joensen 1972a, b; Joensen & Hansen 1977; Clausager 1979; Lyngs 1985; Naturstyrelsen 2012).

Hunters from the local game organizations were supplied with ammunition and systematically searched the affected beaches for seabirds still alive. They were subsequently shot and collected. The birds were then recorded and studied by researchers from ‘Game Biology Station, Kalø’ (today part of Department of Bioscience, Aarhus University).

Nowadays the response is organized and carried out by the Danish Navy, the Home Guard, the police, the Danish Nature Agency (especially the regional offices), the Natural History Museum of Denmark, the Fisheries and Maritime Museum (Esbjerg), the National Veterinary Institute (Danish Technical University) and researchers from Department of Bioscience, Aarhus University.

Alternative #3, de-oiling and rehabilitation of oiled wildlife, is the most comprehensive and time-consuming response action; alive wildlife is caught, de-oiled and released back to their natural environment. This response requires preparation, organization, experience, logistics, manpower and funding.

De-oiling is usually washing with detergents (POSOW 2013), and an alternative method using oil-sequestering magnetic particles is under development (Dann et al. 2015).

De-oiling and rehabilitation have been most extensively carried out in South Africa, where several oil spills have threatened the small and vulnerable population of African penguin (*Spheniscus demersus*). During the most recent spill event in 2000, approx. 20,000 oiled penguins were caught and about 18,000 were de-oiled and released (Barham et al. 2006). Moreover, chronic oil spills cause that up to 700 penguins are cleaned annually. During the period 1970 to 2005, a total of 45,000 penguins have been treated and released (Wolfaardt et al. 2009).

In addition to the de-oiling in 2000, approx. 19,500 penguins were relocated to areas not threatened by the oil spill and about 3,500 orphaned chicks were collected and reared in captivity for subsequent release (Wolfaardt et al. 2008).

Monitoring of the de-oiled and released penguins proved that they had the same survival rate, but up to 26 % of the de-oiled birds did not breed afterwards and that breeding success was reduced among the de-oiled birds (Wolfaardt et al. 2008, 2009).

Another seabird has been de-oiled in South Africa - the Cape gannet (*Morus capensis*). In 1983, 1,500 oiled birds were caught, cleaned and 65 % of these were subsequently released. These birds were ringed and later studies have proved that they had the same survival rate as non-oiled Cape gannets (Altwegg et al. 2008).

However, the experiences of de-oiling programmes from other parts of the world are less encouraging. During the *Exxon Valdez*-spill in Prince William Sound in Alaska in 1989, approx. 1,600 oiled seabirds were caught. Of these about 800 survived and were released (Sharp 1996), although their fate is unknown.

Other studies in the US also included monitoring of the released birds, and generally they showed much reduced survival rates compared to non-oiled control bird (Williams et al. 2012). These studies included surf scoters (*Melanitta perspicillata*) (De la Cruz et al. 2012), common murres (*Uria aalge*) (Newman et al. 2004) and brown pelicans (*Pelecanus occidentalis*) (Anderson et al. 1996). A study of de-oiled and released western gulls (*Larus occidentalis)* in California indicated that they had a survival rate comparable to a reference population (Golightly et al. 2002).

The experiences with de-oiling marine mammals are much fewer than for seabirds. During the *Exxon Valdez* spill, a total of 361 oiled sea otters (*Enhydra lutris*) were caught and cleaned. Of these 54 % survived and were released to the wild (Jessup et al. 2012). Based on this experience, a rehabilitation programme for oiled sea otters has been developed in California.

Besides the sea otters, 19 harbour seal (*Phoca vitulina*) young were treated after the *Exxon Valdez* spill, and 16 were released to the wild. These low numbers reflect the facts that even heavily oiled seals had a better survival rate than treated seals and that adult seals and sea lions were too big to handle (Zimmerman et al. 1994).

De-oiling and rehabilitation are time-consuming, as captured and cleaned wildlife has to be kept in captivity until they are fit for release (post-stabilization), a period which can last for several weeks. Indeed, the actual washing (by two persons) of a single bird has in Australia been estimated to two hours on average (NSW 2012).

De-oiling and rehabilitation are moreover cost-intensive. The costs for a de-oiled and released sea otter from the above-mentioned programme in California are today estimated at approx. 5,000 USD, while they were estimated at 80,000 USD during the *Exxon Valdez* spill in 1989 (Estes 1991; Jessup et al. 2012).

The costs for a cleaned and released penguin in South Africa were in 1994 (during the *Apollo Sea* spill) estimated at 112 USD; and 238 USD for each penguin restored (meaning that it actually started breeding again after the cleaning). During the *Treasure* spill, also at the South African coast, in 2000, the cost of a cleaned and released penguin was reduced to 90 USD (Wolfaardt et al. 2009).

In the US, the costs for a cleaned and released seabird were in the mid-1990s estimated at 5,000 USD (Boersma 1995, quoted from Wolfaardt et al. 2009), while they, during the previous *Exxon Valdez* spill in 1989, were estimated at 10,000 USD (Monaham & Maki 1991, quoted from Wolfaardt et al. 2009). Another estimate from the *Exxon Valdez* spill gives expenses of 41 million USD to clean and release 800 birds (Sharp 1996). These costs from the US do not include efforts of numerous volunteers who contributed to the cleaning activities.

Finally, the handling and cleaning of wildlife require strict procedures and guidelines to be successful. Several guidelines for handling oiled wildlife have been developed around the world, e.g. Australia (NSW 2012), California (OWCN 2000) and summarized in a note to the Danish Nature Agency (Nielsen & Petersen 2015).

The South African effort with cleaning and release of African penguins and Cape gannets has, seen from a nature conservation point of view, been successful. The de-oiled birds have contributed to the reestablishment and survival of the affected populations (Wolfaardt et al. 2009). In contrast to these examples, the experiences from the northern hemisphere have been disappointing. Sharp (1996) concluded, i.a. based on the *Exxon Valdez* experience, that cleaned and released seabirds and marine mammals are unfit and do not contribute to the rehabilitation of the populations, and that the efforts ‘cannot be considered as even partial restoration of the damage’. Or in other words, the effort is useless seen in a nature conservation context.

These different results of the rehabilitation activities are mainly caused by the biology of the birds, and also by the efforts allocated to the activities.

The South African penguins are very robust birds, which endure even rough handling and they are adapted to long periods of starving. Contributing to the success in South Africa is also a high degree of preparedness (including a large contingency of volunteers) and experience from previous spill incidents.

De-oiled and released seabirds on the northern hemisphere were mainly gulls, auks and diving ducks, which are smaller and less robust birds making them less suitable for cleaning and release (Wolfaardt et al. 2009).

Rehabilitation and release of oiled wildlife certainly has an ethical significance: animal welfare, positive media exposure, etc. But is the effort worthwhile if the ecological / conservational results are lacking? Even though rehabilitated birds may survive, the negative impacts on breeding success, as shown for African penguins, are also important to include, if rehabilitation of oiled birds is considered.

Other management initiatives such as reducing other mortality factors on the affected populations (in Greenland primarily hunting pressure) may be a more efficient tool for the reestablishment of oil-affected wildlife populations.

5.2 Wildlife response in Canada, Alaska and Norway

In Canada, it is the responsibility of the polluter to take care of wildlife response, and Canadian Wildlife Service (CWS) shall approve activities which involve the handling or disturbance of birds during oil spill incidents. CWS has prepared guidance to wildlife response planning (Link to document). This plan includes for instance hazing by different methods, oil dispersion, wildlife monitoring, rehabilitation and euthanasia. The operating companies have to develop specific wildlife response plans, for example this from Shell: Link to document.

In Alaska, the US Fish and Wildlife Service's *Best Practices for Migratory Bird Care During Oil Spill Response* is applied (Link), and there is also a more detailed local guideline (Link). Euthanasia, rehabilitation and hazing (deterrence) are possible actions.

Norway has so far no specific guidelines for wildlife response.

5.3 Review of wildlife response actions in a Greenland perspective

A marine oil spill in Greenland will, especially during winter in the open water region, have the potential to reach areas with very high seabird densities (Frederiksen et al. 2012; Merkel et al. 2012; Boertmann et al. 2013). Such an incident may cause thousands of dead and still alive seabirds to beach with the oil spill. Seals and whales may also be impacted, but they are considered less sensitive to direct oiling, and only few are expected to strand on the coasts (Frederiksen et al. 2012, Merkel et al. 2012, Boertmann et al. 2013). Finally, also polar bears (*Ursus maritimus*) are sensitive to oiling and may occur dead or weakened in areas affected by oil spills.

Based on the experiences described above and the limitations the Arctic conditions pose on a wildlife response (Nijkamp et al. 2014), it seems unrealistic that de-oiling and rehabilitation of oiled wildlife in Greenland will have any effects on the affected populations. Moreover, the activities require manpower, which may be very difficult to find in remote Greenland areas. Therefore de-oiling and rehabilitation of oiled wildlife cannot be recommended in a Greenland oil spill situation. This alternative is also explicitly excluded in the Danish wildlife response (Jepsen 1997, Naturstyrelsen 2012).

Hazing may be tried. Especially species occurring at predictable areas (for instance common eider) may effectively be scared away by helicopters or boats. However, the weather conditions, especially in winter, may limit the effectiveness of this method.

Collection and euthanasia of oil-impacted seabirds should be initiated in case of an oil spill in Greenland. This shall be carefully organized and carried out systematically to be efficient. But extensive coastlines and archipelagoes, short daylight periods and harsh weather conditions in winter may limit the efficiency of the search. Moreover, low temperatures in winter will probably imply that euthanasia will be irrelevant, because most seabirds may die before they are found (Nijkamp et al. 2014).

But if possible, local hunters should be engaged, organized, and equipped with ammunition and guided to search, euthanize and collect oiled seabirds. This requires moreover the establishment of reception and storing facilities.

Oiled marine mammals have a much better chance to survive oiling, and should not be euthanized unless obviously suffering or they are very heavily oiled.

5.4 Species likely to be affected by a marine oil spill in Greenland

All seabird species occurring in Greenland could potentially be exposed to a marine oil spill as they spend time at the sea surface. The different populations and species have varying vulnerability to oiling, depending on their biology and on their temporal occurrence in Greenland (Boertmann et al. 2013), and for instance auks and seaducks are most vulnerable as they spend most of their time on the sea. The species most likely to be oiled in large numbers will be those which occur in large aggregations and especially in coastal environments, for instance thick-billed murres (*Uria lomvia*), little auks (*Alle alle*), gulls of different species, great cormorants (*Phalacrocorax carbo*) and many species of ducks (common and king eiders (*Somateria mollissima* and *spectabilis*), red-breasted mergansers (*Mergus serratos*), long-tailed ducks (*Clangula hyemalis*), harlequin ducks (*Histrionicus histrionicus*) and mallards (*Anas plathyrhynchos*)). As mentioned above, also white-tailed eagles can be impacted.

Among the marine mammals, seals and polar bears will be most vulnerable to marine oils spills (Boertmann et al. 2013).

5.5 Wildlife response strategy frame for Greenland

The most applicable actions to be taken as part of wildlife response in Greenland will be collection of dead seabirds and euthanasia of still living oiled seabirds (and potentially marine mammals). This should be carried out in close collaboration with local hunters.

In order to be prepared, a wildlife response strategy / plan for Greenland should be prepared. Such a plan must be considered and approved by relevant stakeholders and authorities as well as have public acceptance. *Appendix 1* gives (in Danish) an outline to a wildlife response plan for Greenland.

Moreover, the responsible authorities shall be prepared, if NGOs or other volunteer organisations plan activities such as hazing or rehabilitation of oiled wildlife.

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Appendix 1 - Forslag til indhold i en beredskabsplan for håndtering af olieforurenede fugle og pattedyr

David Boertmann

Baseret på IPEICA (2004), organisationen Sea Alarms web-side (link) og den danske beredskabsplan (Jepsen 1997) gives der her forslag til en indholdsfortegnelse for en 'wildlife response' beredskabsplan i tilfælde af oliespild, der forårsager, at olieforurenede fugle og havpattedyr driver ind på en kyst i Grønland. De emner, der kan / bør behandles, er nævnt i stikordsform. Flere forhold skal afklares ved konsultationer mellem de forskellige parter (se nedenfor) og en ansvarlig myndighed skal udpeges. Desuden skal listen betragtes som en bruttoliste, som skal tilpasses lokale / aktuelle forhold:

Indledning
- Formål
- Ansvar
- Juridiske forudsætninger
- Bemyndigelse til aktiviteterne (aflivning)
- Afgrænsninger — geografisk og tidsmæssigt
- Sammenhæng med andre planer — Oil spill response plan
- Involverede parter

Beredskabets struktur
- Centralt beredskab — decentralt beredskab
- Koordinering
- Kontaktpersoner, lister over adresser og telefonnr.
- Kompetencer og kommandostruktur
- Tier 1-3 klassificering af spild og indsats

Aktiviteter — overordnet
- Klassificering af indsats (Tier 1-3)
- Mulige metoder
- Rehabilitation?
- Euthanasi
- Bortskræmning (*Hazing*)?
- Potentielt påvirkede arter

Aktiviteter — konkret
- Overvågning af olie og dyrebestande i de ramte områder (retningslinjer skal udarbejdes)
- Vurdering af muligheder for bortskræmning
- Håndtering af levende olieindsmurte fugle og pattedyr (retningslinjer skal udarbejdes)
- Håndtering af døde olieindsmurte fugle og pattedyr (retningslinjer skal udarbejdes)
- Bortskaffelse af affald og døde dyr
- Retningslinjer for indsamling af biologisk viden — skal udarbejdes
- Rapportskemaer for aflivede fugle og havpattedyr — skal udarbejdes

Udstyr og faciliteter

- Krav til logistik
- Lokaler til håndtering af døde / levende fugle og pattedyr
- Opsamlingssteder
- Kontorfaciliteter
- Fangstudstyr
- Ammunition til fangere
- Leverandører af udstyr

Bemanding

- Nøglepersoner
- Organisering
- Involverede parter
- Frivillige
- Træning
- Sikkerhedsvurdering af aktiviteter

Kommunikation

- IT
- Kommunikationsudstyr
- Rapporteringsudstyr / skemaer
- Kort
- Pressehåndtering
- Instruktioner på dansk og grønlandsk

Økonomi

- Udgifter
- Ammunition
- Transportudgifter
- Udstyr
- Rejser
- Løn?
- Finansiering

Operationel plan

Når et oliespild opstår i grønlandske farvande, skal beredskabet træde i kraft og følgende skal ske med det samme:

Aktiviteter

- Klassificer spildet - tier 1-3
- Udpegning af nøglepersoner
- Indsamling af al relevant information
- Hvor er uheldet sket
- Hvor mange dyr er i farezonen
- Olietype
- Vejrforhold
- Oliens drift etc.
- Vælg metoder og prioriter indsatsen
- Vurder muligheder for bortskræmning
- Udpeg opsamlingssteder
- Etabler evt. et kommunikationscenter
- Leverandører af udstyr kontaktes

Desuden skal der

- rapporteres dagligt, der skal føres en central log
- føres kontrol med udgifterne
- briefes til involverede og presse
- besluttes kriterier for, hvornår operationen skal afsluttes
- foretages biologiske undersøgelser af døde dyr

Mobilisering skal omfatte

- mandskab
- infrastruktur - bygninger, transport, opbevaringsfaciliteter
- udstyr
- rådgivere og forvaltere

Afslutning

- oprydning - affaldshåndtering, herunder døde fugle og pattedyr
- rapportering
- antal involverede personer / parter
- antal aflivede dyr
- regnskab
- rapport over aflivede dyr (biologiske data)
- validering af indsats, ”lessons learned”

Handlingsplan for udarbejdelsen af en beredskabsplan

- Ansvarlig myndighed identificeres
- Scope udarbejdes
- Parter, der skal involveres, udpeges
- Scope diskuteres blandt involverede parter
- Selve beredskabsplanen udvikles
- Planen diskuteres blandt involverede parter
- Planen sendes i offentlig høring?

Involverede parter kan være:

- KNAPK
- Kommuner
- Brandvæsen
- Naturinstituttet
- DCE
- EAMRA
- Direktoratet for fangst, fiskeri og landbrug
- Søværnet SOK / GLK
- Jagtbetjente
- Politiet
- Greenland Oil Spill Response.

OIL SPILL RESPONSE IN GREENLAND: NET ENVIRONMENTAL BENEFIT ANALSIS, NEBA, AND ENVIRONMENTAL MONITORING

This review describes the state-of-the-art techniques for combating marine oil spills: mechanical recovery, chemical dispersants and *in situ* burning, and their applicability in the Arctic (Part I). The derived environmental effects from the techniques are described in Part II. Monitoring programme of the fate and effect of the oil spill/response methods is suggested in Part III. This includes monitoring at spill location, monitoring in the trajectory and the spreading/dispersion of the oil slick and analysis of the oil itself to identify changes in the physical and chemical properties due to weathering (e.g. evaporation, degradation) of the oil. Furthermore, wildlife response methods and strategies are described in Part IV. This includes prevention of animals from exposure to oil, and when wildlife has been exposed, collection, euthanasia and/or rehabilitation of oiled wildlife.

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