# Net Environmental Benefit Analysis as a Decision Tool for Greenlandic Oil Spill Response

Janne Fritt-Rasmussen[1], Susse Wegeberg[1], David Boertmann[1], Daniel Spelling Clausen[1], Kasper Lambert Johansen[1] and Anders Mosbech[1]

[1]DCE - Danish Centre for Environment and Energy
Department of Bioscience, Aarhus University
Roskilde, Denmark
jafr@dmu.dk

**Abstract**

One of the tasks of the Danish Centre for Environment and Energy (DCE) and Greenland Institute of Natural Resources in the Greenlandic oil spill contingency planning is to secure that environmental impacts, due to oil exploration activities, are minimized and limited as much as possible. DCE is developing strategies for oil spill response by combining analysis of efficiency and impact of potential response options with distribution and sensitivity of environmental components. An oil spill sensitivity atlas serves as an important background for performing a robust Net Environmental Benefit Analysis (NEBA) by identifying resource at risk and establishing the protection priorities. Furthermore, as part of the NEBA, research knowledge about the different countermeasures and their environmental impacts will be included before the selection of the most appropriate response set-up for a certain oil spill situation. The long-term goal is to continuously improve oil spill response efficiency by improving the information available for making place and time specific informed decisions on response actions. The research knowledge base of the oil spill sensitivity atlas also adds information to the ecological baseline knowledge needed for assessing the impact of an oil spill and the recovery of an oil impacted ecosystem.

## 1 Introduction

The development in oil exploration in Greenland is the result of a dedicated governmental strategy, which has included several licencing rounds since 2002 (Bureau of Minerals and Petroleum, 2009). Most recently (in 2012/13) a license round was carried out for an area in the Greenland Sea, and in the sea off West Greenland there are now several active licence blocks, where so far 8 exploration drillings have been carried out since 2010. Figure 1 illustrates the current license areas in Greenland.

Large accidental oil spills are generally considered as the most harmful effect on the environment of oil exploration in the Arctic (AMAP, 2010), and with the strong increase in oil exploration, the risk of oil spills are increased in Greenland waters. This risk is stressed by Arctic environmental factors such as winter darkness, sea ice in some areas even during the summer period and by the presence of icebergs. Most of the licence blocks are moreover situated in very remote areas with limited or even no supporting infrastructure. The lack of infrastructure is a challenge for planning an efficient oil spill response.

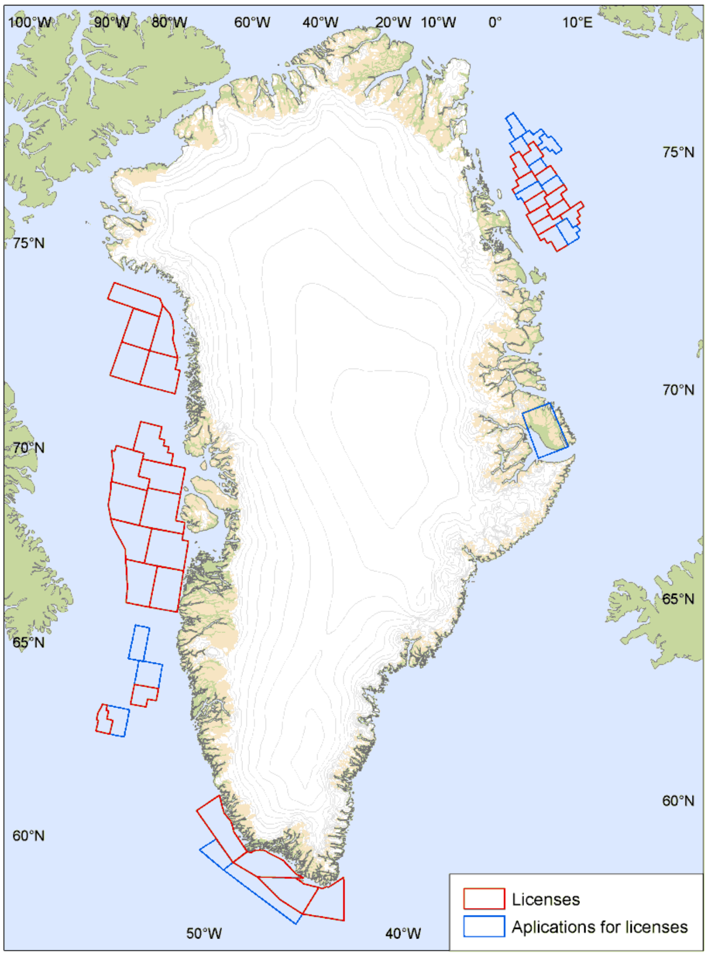


**Figure 1 Map of Greenland with the license areas marked**

Danish Centre for Environment and Energy (DCE) and Greenland Institute of Natural Resources (GINR) act as advisors to the Greenland authorities regarding environmental matters related to mineral and oil activities (exploration and exploitation), and one of the tasks is to contribute to optimise the efforts and select the oil spill response techniques in the case of an oil spill. This includes general advisory tasks, preparation of strategic environmental impact assessments of oil activities, developing oil spill sensitivity atlases and guidelines to Net Environmental Benefit Analysis (NEBA) as well as performing NEBA in the case of oil spill. This paper will provide information about the current development and knowledge base for a NEBA process to be used in the case of an oil spill in Greenland waters with focus on the offshore response options.

## 2 Greenlandic Oil Spill Sensitivity Atlas

The first part of the Greenlandic oil spill sensitivity atlas covered the central part of the southwest coast between 62 and 68° N, and was issued in 2000 (Mosbech et al., 2000) . The coverage has gradually been extended in step with the licencing rounds now to cover the entire West Greenland area as far north as the Nares Strait (Mosbech et al., 2004a; b; Stjernholm et al., 2011; Clausen et al., 2012; Clausen et al., in prep).

The development of sensitivity atlas is based on the principle s used in the Canadian analogue (Dickins, 1988), however, adapted to the unique conditions of Greenland (Mosbech et al., 2004). The atlas compiles biological information obtained from numerous baseline studies and research on the biological resources (marine mammals, fish, seabirds, etc.)

including special status areas protected by national and international legislation (e.g. Ramsar areas and UNESCO World Heritage areas) of Greenland. In addition, the atlas includes knowledge on natural resource use (fishery and hunting) from fishery statistics and interview surveys in local communities. Archaeological remains close to the shoreline are also included. All this knowledge is compiled in a Geographical Information System (GIS).

This information is integrated into two corresponding maps of the same coast segments; a map showing the relative sensitivity of approximately 50 km coastline segments classified as low, medium, high and extreme sensitivity to oil spill. Furthermore, the most important oil spill sensitive elements as well as areas of particular sensitivity is designated and indicated on the maps. The associated map shows physical properties of the coasts and operational oil spill response information such as recommended booming locations and safe havens (Figure 2).

The offshore waters to the limit of the Greenland EEZ are also included. These offshore areas have been divided into a number of blocks and the sensitivity for each block is shown for the four seasons (Figure 3).

An environmental sensitivity ranking system has been applied to determine and illustrate the relative sensitivity of shoreline and offshore areas. This ranking system gives each shoreline segment and offshore area a single numeric value, which represents the relative sensitivity of that area to a marine oil spill. This numeric value is ranked as extreme, high, moderate or low and is illustrated on the sensitivity maps by the use of a colour code (see Figure 2). The sensitivity ranking system incorporates the biophysical and social elements of the region that are important from an oil spill perspective. These elements are assigned to and ranked on a relative scale within three major categories: 1) resource (human use), 2) species occurrence/biological resources and 3) oil residence index (ORI). The latter category considers the oil residence time associated with various coastal types, and the effects of exposure to wind and waves, as well as the differences in ice and open water zones for the shoreline and offshore areas respectively. Each of the categories is assigned a weighting factor (WF), which is based on their relative importance within the region. The elements within each of the categories are ranked based on their relative sensitivity to potential effects of oil spills, called assigned value (AV). These assigned values are then multiplied by the weighting factor to produce a single numeric value, the priority index (PI). It is the sum of the priority indices that determines the overall sensitivity (S) of a specific shoreline or offshore area (Clausen et al., 2012). The sensitivity is calculated in the following way:

$$S_{segment} = PI_1 + PI_2 + \ldots + PI_n$$

$$PI = AV \times WF$$

Where S= sensitivity value, AV = assigned value of the element and WF = weighting factor of the category (Clausen et al., 2012).

The assigned value (AV) of the biological resources is calculated for each species individually. This is based on the relative sensitivity of the species (RS), which is determined by the species mortality and sub-lethal potential, recovery period and the vulnerability to an oil spill. A relative abundance (RA) score, ranging from 1 to 5, is used to determine the numbers of animals present in the area or segment. Since each species may, or may not be present in the area throughout the year, a temporal modifier is added to account for the species temporal presence. Oil residence index (ORI) is used as a measure of oil longevity in an area/segment, and thus how long it is expected to have an influence on the species in question. Thus, the assigned value of the biological resources is calculated as follows:

$$AV = RS \times RA \times TM \times ORI$$

Where RS = relative sensitivity of the species, RA = relative abundance of the species, TM = temporal modifier and ORI = oil residence index (Clausen et al., 2012).

Some examples from the oil spill sensitivity atlas are showed in Figure 2.

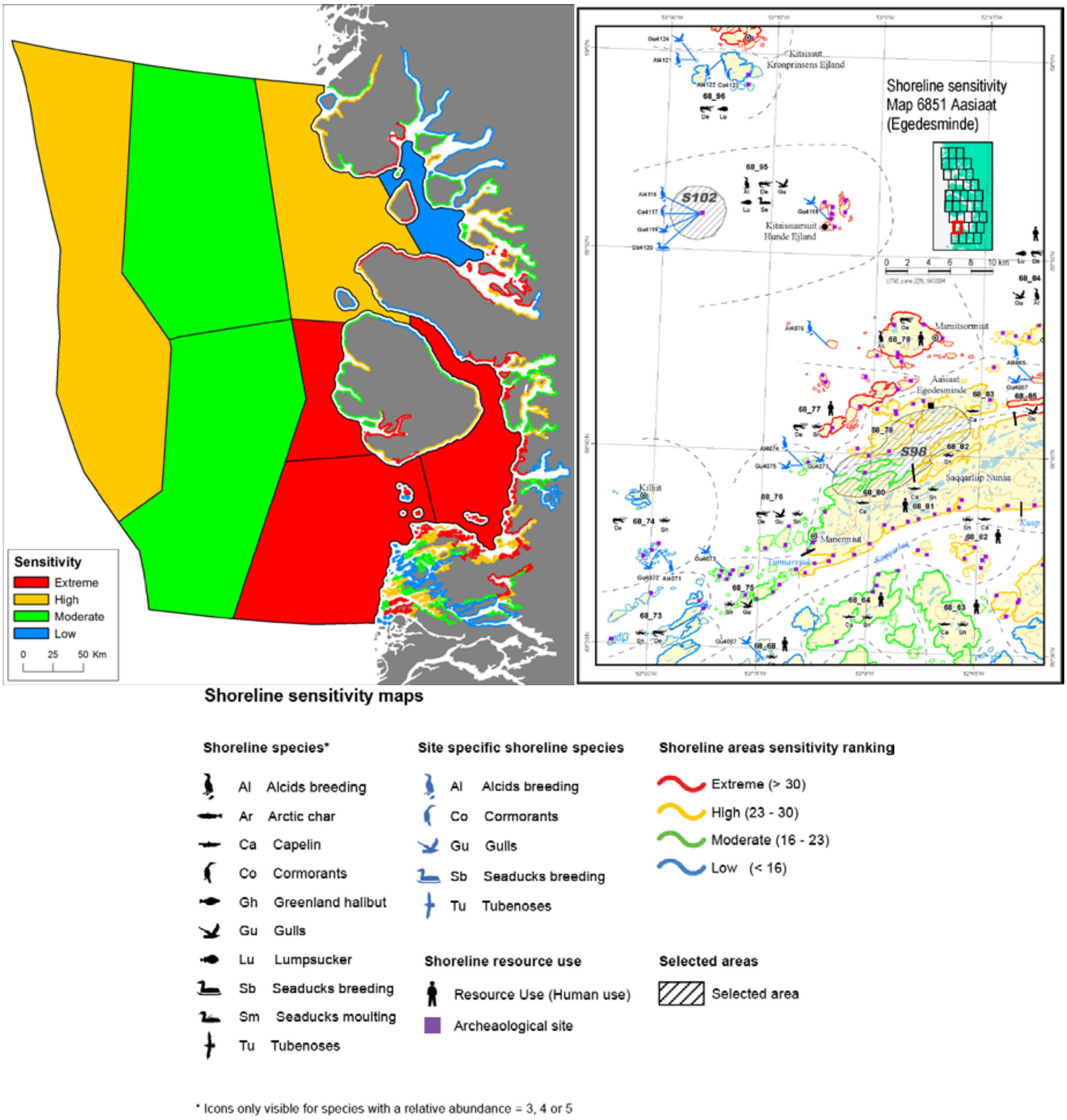


**Figure 2** **Examples of the sensitivity ranking offshore (left) and on the shorelines (right), color-coded according to oil spill sensitivity: Extreme (red), High (yellow), Moderate (green) and Low (blue). The black icons specifies which species are present in important numbers along the shoreline, and if any human resources is exploited along the shoreline. The blue icons points to specific sites with high concentrations of a specific species.**

As indicated in the calculations the seasonal variations for the offshore areas are also taken into consideration, and example of this is given in Figure 3.

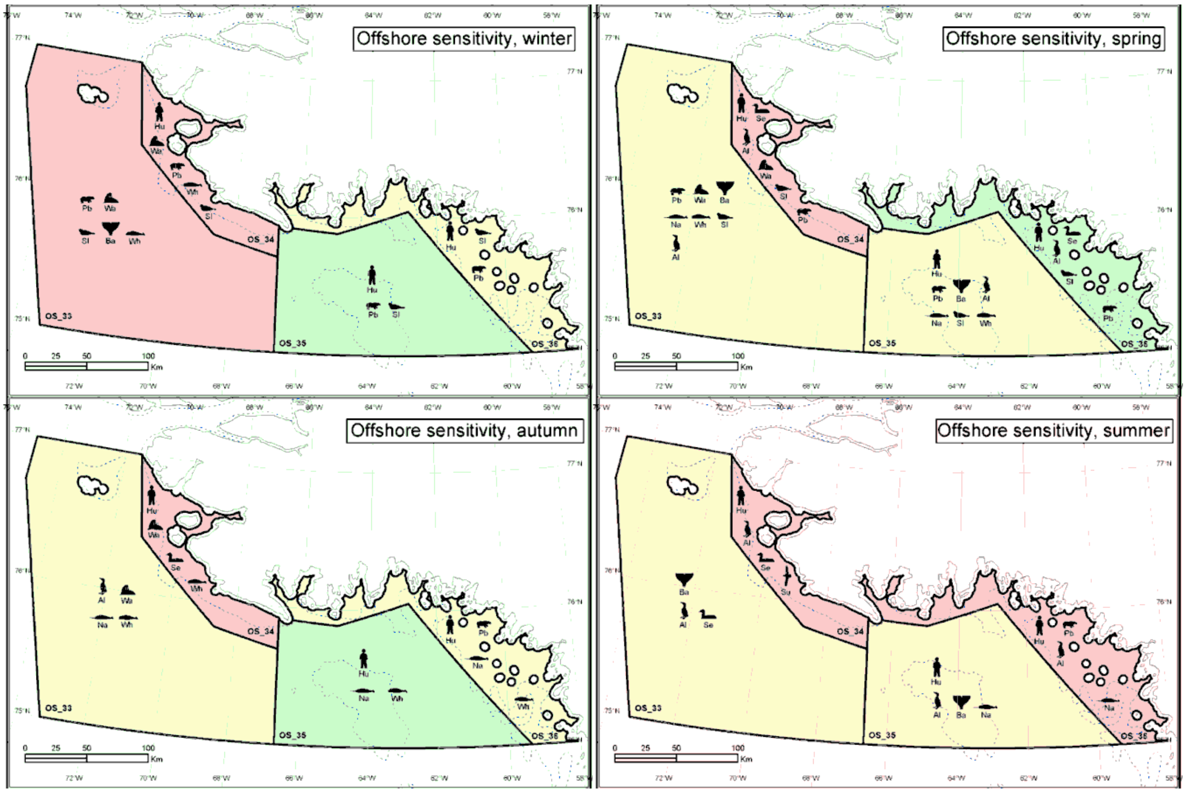


**Figure 3** **Example of offshore sensitivity seasonal variation, color-coded according to oil spill sensitivity: Extreme (red), High (yellow), Moderate (green) and Low (blue). The black icons specifies which species is present in important numbers in the areas (a relative abundance (RA) value between 3-5), is shown on the map, and if any human resources is exploited in important amounts.**

The sensitivity ranking system is supplemented by pinpointing of selected areas (see Figure 2 – hatched areas). The basis for the selected areas is that the areas, compared to the relative sensitivity of shoreline and offshore areas have a high value either environmentally or for resource use, are sensitive to oil spills and are of a size and shape that may allow effective protection in an oil spill situation. In the event of an oil spill, the selected areas are used to identify areas to be prioritised during oil spill response operations (Clausen et al., 2012).

## 3 Net Environmental Benefit Analysis (NEBA) for Greenland

A Net Environmental Benefit Analysis (NEBA) is a tool for assessing pros and cons between different active oil response techniques and a passive no-response alternative (natural attenuation). Also a combination of the different alternatives can be assessed. The principles of the NEBA have been used in an oil spill remediation context since the Exxon Valdez oil spill incident in Prince William Sound, Alaska 1989 (NOAA,1990). The result of a NEBA for a response option might be 1) positive effects for the environment, 2) no effects (or alternatively ineffective) or 3) cause unwanted additional environmental impact to those already expected from the contamination (spill).

As the NEBA is an analysis where the different response techniques, including alternative response techniques (see later) and passive no response alternative, are compared, it is important that the alternatives have the same spatial extents; comparable scenarios and that both chemical and physical stressors are included (Efroymson et al., 2004). However, this is often difficult to meet due to limitations in the available knowledge base, thus focus should be put on operational conditions such as weather and windows of opportunities. Also regarding the combined effects from different response options little knowledge exists. The length of a NEBA should cover the response period for the different alternatives along with the effects (Efroymson et al., 2004).

The concept of NEBA has been introduced in the Greenland context in order to ensure the selection of the most efficient response technologies with least environmental effects (Wegeberg et al., 2011a; b). Prior to an oil spill response operation the responsible must perform a robust NEBA for the specific case, following specific schemes/guidelines. The following response alternatives and the environmental benefits/impacts are compared for the Greenlandic conditions: The containment and recovery of the oil, no response and the alternative response technologies (ART), chemical dispersions and in situ burning (ISB). The ART can only be recommended if based on a NEBA with a positive result. A conceptual outline of the structure for the NEBA is given in Figure 4.

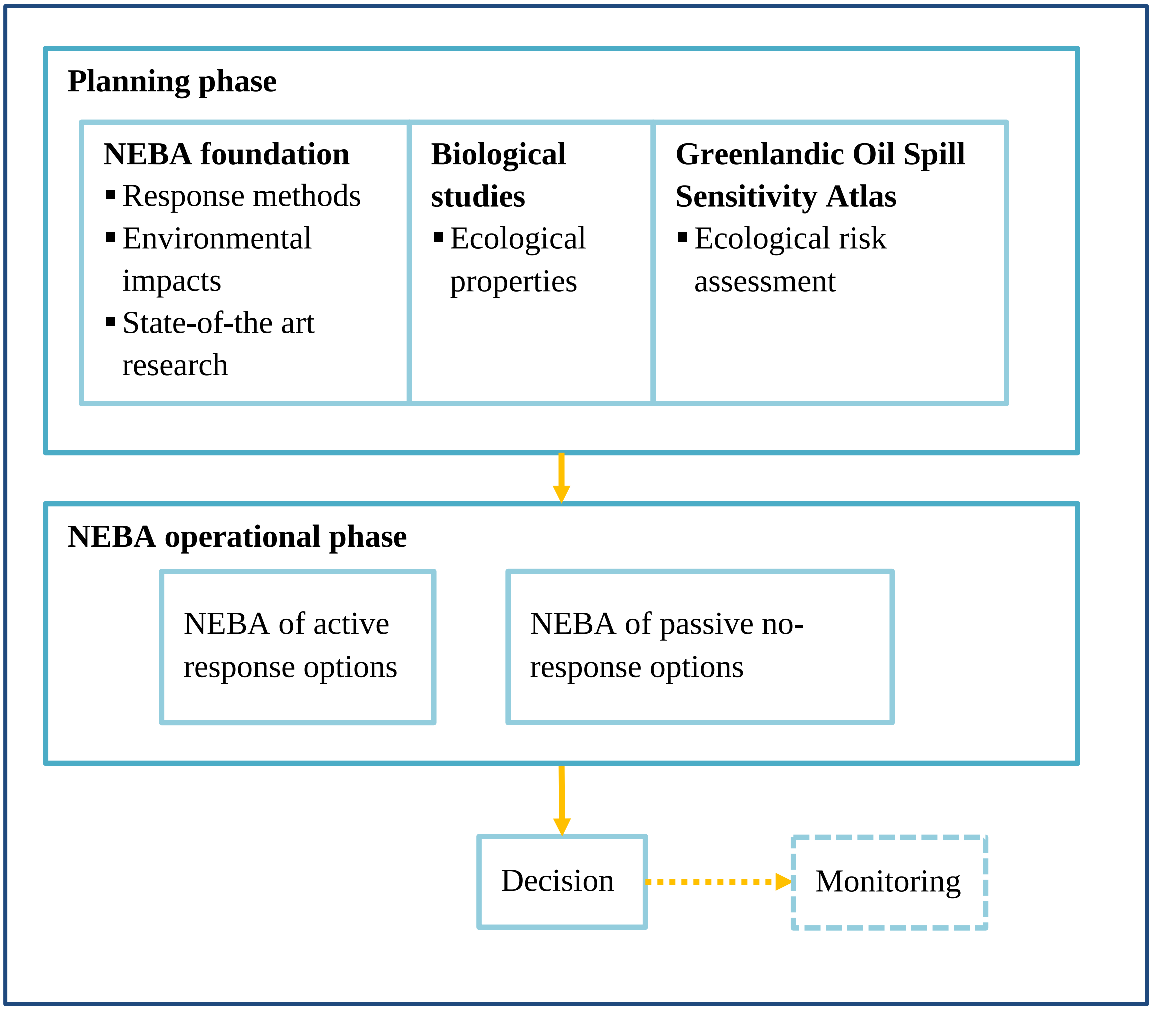


**Figure 4** **Conceptual outline of the structure for the NEBA: the planning phase and the operational phase.**

## 3.1 Passive No-Response Alternative

The passive approach is the alternative where the oil is left in place of the incident and left for the natural processes to take place (drifting, dilution, dispersing, degradation, dissolution, photo oxidation etc.). The passive approach is nonintrusive and has no additional remedial hazardous other than those associated with the spreading of the original contamination and the subsequent weathering, dilution, degradation and release of metabolites (Efroymson et al., 2004).

The passive approach might be chosen as the best alternatives in the cases where the other active alternatives are less efficient and/or compose additional unwanted environmental impacts, than those already seen from the oil spill. The passive approach might also be included in a combined approach together with the active approaches. For very large oil spills the active response is often focused at protecting the most valuable and vulnerable environments and other parts of the spills is left for natural processes. However, if oil ends up on the shoreline it may be targeted with active response and remediation at a later stage and a separate NEBA for shoreline cleaning should be conducted.

Knowledge about the potential impacts (operational oil spill drift model giving risk of oil at the coast, toxicity, weathering data, fate etc.) from the oil contamination, oil / ART products (chemical dispersed oil, in situ burning residues) and degradations products is crucial and should be established and assembled in the planning phase.

### 3.2 Containment and Recovery at Sea

Containment, recovery and storage of the oil are the only active approach where the oil is nearly totally removed from the marine environment. Besides the physical disturbances (vessels, pumps, booms) no additional impacts are added to the environment other than those already imparted from the oil spill it self. Thus, containment and recovery is the method of first choice in Greenland and can be used in Greenland without further assessments regarding the environmental consequences. However, the method is labour intense and requires heavy materials including ocean going vessels (Guenette, 1997), and often the amount of oil recovered are a small fraction of the initial spilled oil (MacNaughton et al., 2003). In particular for the Arctic the containment and recovery are also challenged by the presence of ice and limited infrastructure.

### 3.3 Chemical Dispersants

Chemical dispersants are products that enhance the natural dispersibility of an oil spill, thus the oil is removed from the water surface and dispersed into the water column for subsequent degradation. The method requires mixing energy, which can be inhibited by the presence of ice. Several possible, negative environmental impacts exists that should be considered in a NEBA: the effects from the applied chemical dispersants, the dispersed oil products and related degradation products spread in the water column.

The positive effects from dispersant application are that the oil is being removed from the sea surface and that the increased dispersion results in a potential increased degradation of the oil in the water column due to the enlarged surface area of the oil. The weathering and oil type are factors that affect the time window for a beneficial application of the dispersants.

In the Greenlandic context the application of dispersants is assessed case-by-case, and can only be recommended upon a NEBA for the specific scenario and if the result of the NEBA for the application of dispersants in total will make the spilled oil cause less harm to the environment than no response, mechanical measures or in situ burning. Evaluation criteria are presented in Figure 5 (Wegeberg et al., 2011a). A levels give a positive evaluation for the use of the countermeasure, whereas the C levels in Figure 5 are conditions which do not call for the use of dispersant as the sole or primary response option.

The first of the evaluation criteria focuses on the fate of the oil at sea. If the oil will evaporate and/or naturally disperse within a short period of time (3 hours), it is not meaningful to use dispersants. However, if the expected life time at sea is less than 24 hours the specific circumstances will decide if dispersant could be used or should be avoided.

Finally, it is defined that if the expected life time at sea is longer than 24 hours dispersant could be considered.

As written above the weathering and type of oil are important factors for an effective dispersion of the oil. The expected time window for the dispersibility should thus be hold against the time window needed for the response operation.

The third point in the NEBA derives from the Greenlandic oil spill sensitivity atlas. Three main ecological areas are defined for consideration in relation to the NEBA for the dispersant application: if there are seabird congregations, sensitive shorelines and pelagic spawning areas. Most affected to dispersant are the pelagic environment with important concentrations of spawning/egg/larvae. If such are expected to be present at the time of the operation the use of dispersants could not be recommended. In the other scenarios dispersant could be considered depending on specific situation.

For the dispersants to work properly and reduce the toxicity of the dispersant and oil products a high dilution factor of the dispersed oil is needed. Therefore as seen from point 4 in Figure 5 the sea depth and distance to shore are factors that should be assessed, where less than 10 km to shore and less than 50 m water depth calls for avoidance of dispersants as countermeasure. However, in use situations might exist for dispersants (4. $B_2$).

The final evaluation criteria are the potential stranding of the oil, which in general should be avoided to protect the marine communities along the coast. Therefore the application of dispersant should lead to a prevention of the oil/treated oil to strand including sedimentation in shallow waters.

| **Evaluation criteria** | **Rating criteria** |
|---|---|
| 1. Expected life time of oil on sea without use of dispersants | A: > 24 hours<br>B: < 24 hours<br>C: < 3 hours |
| 2. Oil dispersible | A: Oil is dispersible within possible time for operation<br>B: Reduced dispersibility of oil within possible time for operation<br>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.<br>B: Seabird congregations and / or sensitive shorelines and important concentrations of pelagic eggs / larvae<br>C: Important pelagic spawning area and season – seabird concentrations rare or absent |
| 4. Sea depth and distance to land | A: Depth > 50 m and distance to land > 10 km<br>$B_1$: Depth > 50 m and distance to land < 10 km<br>$B_2$: The criteria in A and $B_1$ is not met, but specific conditions justify use of dispersants (seabirds, wind / currents direction)<br>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<br>$B_1$: Stranding of treated oil can be significantly reduced<br>$B_2$: Stranding of treated oil on exposed / semi-exposed coast<br>C: Stranding of treated oil on sheltered coast / sandy beach |

**Figure 5 Criteria to be evaluated in NEBA for dispersants (Wegeberg et al., 2011a)**

The above criteria are defined from an environmental point of view. A recommendation of a dispersant operation presuppose that necessary operational conditions are met to ensure that the dispersant will work efficiently e.g. sufficient mixing energy, dispersible oil slick etc.

### 3.4 In Situ Burning

In situ burning (ISB) is a method where the oil is ignited and burned at the spill site. By this method the oil is removed from the surface and converted into combustion products and also a burn residue is left on the surface at the end of the burning. The positive sides of ISB are that in the best scenarios the method is very efficient (>90 % are being removed from the water surface) and little labour demanding and can be used in remote areas with drifting ice. For a successful burning to occur there are some conditions that needs to be met, i.e. a continuous slick with a certain slick thickness. Therefore in some cases it is necessary to use fire resistant booms or chemical herders to meet these requirements. The use of chemical herder has not been considered for use in Greenlandic waters, but should also be included in the NEBA if incorporated in the Greenlandic oil spill response as part of ISB.

As for the use of dispersant the use of ISB in Greenland is assessed case-by-case, and can only be recommended upon a NEBA for the specific scenario, the evaluation criteria are given in Figure 6 (Wegeberg et al., 2011b). The first criterion is related to the expected life time for the oil on sea. If it is less than 3 hours due to rapid dilution and/or evaporation ISB as a countermeasure will not be relevant. For an expected life time of less than 24 hours of the oil on the surface ISB could be considered and for longer life time than 24 hours ISB could be an effective response option.

The window of opportunity for ISB is related to the ignitability of the oil. As the weathering of the oil occur, due to impacts from the ambient environment (wind and waves), the oil becomes more difficult to ignite as a result of primarily the emulsification (water-in-oil emulsions) and evaporation of light components in the slick. Highly emulsified oil will be difficult to ignite due to the water content that must be broken or boiled out before the oil can be ignited (Guenette et al., 1995). Also high evaporation result in oil which requires more energy to ignite as the fire/flame point has increased (Nordvik et al., 2003). Therefore the operational window of opportunity for ISB is crucial when considering the use of the method. Thus, if the oil is considered not ignitable and burnable within the possible time for an operation other options should be considered. The window of opportunity varies with oil type (Fritt-Rasmussen et al., 2012) and could be analysed beforehand when the oil type is known or assessed by use of model output (Brandvik et al., 2010).

The ISB result in generation of a smoke plume that will dilute in different pace/distance, depending on the terrain and meteorological conditions. The smoke plume contains different particles including soot, PAHs, dioxins, BTEX, oil etc. The Greenland oil spill sensitivity atlas serves as a background for identifying environmental sensitive areas for e.g. smoke plume. When setting these criteria a precautionary principle has been taken into consideration due to lack of knowledge regarding the potential impact of the smoke plume. Therefor the distance from land should be more than 10 km or if shorter, certain criteria (e.g. offshore wind, no sensitive shorelines or populated land in wind direction) should be met to recommend ISB as a response option.

A final consideration that should be included in the NEBA is regarding the burn residue and potential residual oil, if the burning has not been efficient. Very little knowledge exists about the composition and toxicity of the residue (Holland-Bartels and Pierce, 2011). In the literature it has also been stated that when the residue cools down it could sink. However, this topic has not been completely investigated yet. Therefore, as part of the NEBA, a description of the available approach for containment, recovery and storage of the residue should be included to make sure that the residue can be recovered and disposed.

| Evaluation criteria | Rating criteria |
|---|---|
| 1. Expected life time of oil on sea without ISB | A: > 24 hours<br>B: < 24 hours<br>C: < 3 hours |
| 2. Oil ignitable and burnable | A: Oil is ignitable and burnable within possible time for operation<br>B: Reduced ignitability and combustibility of oil within possible time for operation<br>C: The operation cannot be performed within the operational window |
| 3. Distance to land and wind direction | A: Distance to land > 10 km<br>$B_1$: Distance to land < 10 km – but offshore wind<br>$B_2$: Distance to land < 10 km – but seabirds aggregations or sensitive shoreline in oil slick trajectory and no populated land in wind direction<br>C: The criteria in A, $B_1$ and $B_2$ are not met |
| Additional information | |
| 4. Collection of residues/residual oil<br>*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 residues/residual oil<br>*Collection plan* | Please describe the plan for collection of residuals/residual oil |
| 6. Storage and disposal 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 |

**Figure 6 Criteria to be evaluated in NEBA for in situ burning (ISB) (Wegeberg et al., 2011b)**

## 3.5 Comparison to other Countries

A comparison is made to the neighbouring countries to Greenland i.e. Canada, Iceland and Norway regarding their choice and background for response options.

According to AMAP (2010) all the countries have mechanical containment and recovery as their primary choice – as for Greenland.

From AMAP (2010) is it also stated that Canada is the only country of the three mentioned that under certain conditions allow the use of in situ burning. As for Greenland also Canada has large areas with presence of sea ice; conditions that often favour in situ burning and hinder the other response alternatives. With the right ice concentrations, the ice cover can even put out for a natural containment of the oil.

The use of dispersants is allowed without remarks in Norway and Canada, but for Iceland the situation is the same as in Greenland – the use should be approved prior to use (AMAP, 2010).

These differences in the acceptance and allowance of the response technologies are thus an evidence of the different local policies and local physical and environmental conditions.

# 4 Conclusions

The unique marine environment in Greenland calls for a prompt and efficient action in the unfortunate event of an oil spill. The NEBA serve as a valuable tool for assessing the different available oil spill response techniques. Combined with the oil spill sensitivity atlas for Greenland it is ensured that all available knowledge is included in the selection of countermeasure, and which will lead to the least impact of the environment.

To minimize the environmental risk it is a long-term goal is to continuously improve the knowledge base for oil spill response selection by improving the information available for making place and time specific informed decisions on response actions along with the development of efficient Arctic response techniques for oil in sea ice

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