EOS

Environment &
Oil Spill Response

ENVIRONMENT & OIL SPILL RESPONSE (EOS)

An Analytic Tool for Environmental Assessments to Support Oil Spill Response Planning

The Handbook

Technical Report from DCE – Danish Centre for Environment and Energy No. 172 2020

AARHUS
UNIVERSITY
DCE – DANISH CENTRE FOR ENVIRONMENT AND ENERGY

GRACE

ENVIRONMENT & OIL SPILL RESPONSE (EOS)

An Analytic Tool for Environmental Assessments to Support Oil Spill Response Planning

The Handbook

Technical Report from DCE – Danish Centre for Environment and Energy No. 172 2020

Susse Wegeberg,
Janne Fritt-Rasmussen
Kim Gustavson

Aarhus University, Department of Bioscience

AARHUS UNIVERSITY
DCE – DANISH CENTRE FOR ENVIRONMENT AND ENERGY

Data sheet

Series title and no.:	Technical Report from DCE – Danish Centre for Environment and Energy No. 172
Title:	Environment & Oil Spill Response (EOS)
Subtitle:	An Analytic Tool for Environmental Assessments to Support Oil Spill Response Planning. The Handbook
Authors:	Susse Wegeberg, Janne Fritt-Rasmussen, Kim Gustavson
Institution:	Aarhus University, Department of Bioscience
Publisher:	Aarhus University, DCE – Danish Centre for Environment and Energy ©
URL:	http://dce.au.dk/en
Year of publication:	June 2020
Editing completed:	May 2020
Referees:	David Blockley, Greenland Institute of Natural resources, Ander Mosbech, DCE, Aarhus University
Quality assurance, DCE:	Kirsten Bang
Linguistic QA:	Georgina Elizabeth Scholes
External comment:	The Danish Environmental Protection Agency. The comments can be found here: http://dce2.au.dk/pub/komm/TR172_komm.pdf
Financial support:	EU H2020 GRACE grant no 679266
Please cite as:	Wegeberg, S., Fritt-Rasmussen, J. & Gustavson, K. 2020. Environment & Oil Spill Response (EOS). An Analytic Tool for Environmental Assessments to Support Oil Spill Response Planning. The Handbook. Aarhus University, DCE – Danish Centre for Environment and Energy, 42 pp. Technical Report No. 172 http://dce2.au.dk/pub/TR172.pdf

Abstract: The EOS is a desktop analysis based on oil spill scenarios and published as well as expert knowledge on the environment in the assessment area. The EOS tool can support decisions of inclusion of mechanical recovery, in situ burning and chemical dispersants in national oil spill contingency plans in relation to minimizing and mitigating the environmental impacts. In addition, the results obtained through the EOS tool can be used for establishment of cross-border and trans-boundary co-operation and agreements on oil spill response. The EOS tool is based on an Excel spreadsheet, with references to explanatory boxes provided in the EOS Handbook. The EOS analysis goes through 5 steps for each of the oil spill response methods and for each season: Gathering basic environmental data and information for the assessment area; Assessments of basic data and oil spill modelling results; Indices calculations; Decision trees for each oil spill response technology; Interpretation and dissemination of EOS results.

Keywords:	EOS, Environment & Oil Spill Response, handbook, oil spill response, environment, contingency, mechanical recovery, chemical dispersants, in situ burning, decision tool, interactive.
Layout:	Graphic Group, AU Silkeborg
ISBN:	978-87-7156- 493-8
ISSN (electronic):	2245-019X
Number of pages:	42
Internet version:	The report is available in electronic format (pdf) at http://dce2.au.dk/pub/TR172.pdf

Contents

Introduction

The priorities for oil spill response (OSR) are to protect people, prevent or mitigate environmental damages, and minimise the long-term impact. This includes the assessment of oil spill response measures with respect to the overall mitigation of the environmental impact by burning the oil on the sea surface (in situ burning, ISB) and / or chemically disperse the oil slick into the water body as supplement to or substitution of mechanical recovery.

It is evident that planning and operational implementation of oil spill response with several optional measures includes processing of complex information to achieve the optimal mitigation of the environment. It must be a balance between presence and sensitivity of organisms in the oil slick trajectory, both on sea surface, in the water column and seabed as well as along the shoreline impacted by potential beaching oil.

For years, the use of dispersants and in situ burning was based on a case-by-case environmental assessment in the acute oil spill situation. The original concept of such an assessment was a Net Environmental Benefit Analysis (NEBA). The NEBA was developed in connection with the *Exxon Valdez* oil spill in Prince William Sound, Alaska, in 1989. Since then, the spill impact mitigation assessment (SIMA), an assessment framework, evolved from the NEBA and besides the consideration of mitigation of environmental impact, also includes socioeconomic and cultural impacts (Baker 1995; Wenning et al. 2018 and references herein).

Nonetheless, in preparation for an acute oil spill, and for an un-hesitated and resolute oil spill response operation, decisions regarding the operational response strategy, including national contingency plans and international / trans-boundary agreements, must be in place. For that, pre-selection of the best response technologies to achieve the optimal mitigation of the environment should have been accomplished.

Hence, EOS; Environment & Oil Spill Response - an analytic tool for environmental assessments to support oil spill response planning - was developed. We present the EOS tool here:

https: / / bios.au.dk / raadgivning / greenland / olie-og-miljoe / eos-environment-oil-spill-response /

The EOS is a planning tool and a desktop analysis for environmentally assessing the oil spill combating potential for a selected area in relation to minimize and mitigate the environmental impact of an oil spill. The results of the analysis reveal whether mechanical recovery, in situ burning and chemical dispersants should be included in oil spill contingency plans by a gen-eral assessment of the environmental pros and cons of the methods.

The EOS results advance the qualified framework on which a national oil spill strategy and capacity building can be based. The EOS results can also be used for establishment of transboundary co-operation and agreements.

An EOS analysis is based on oil spill scenarios as well as published and expert knowledge on the environment for a selected area. It includes, as indicated in the EOS conceptual model (Figure 1), that all biological information regarding oil ecotoxicology, sensitivity, biodiversity, production and ecosystem should be included in the analysis. The biological information is related to the positive and potential negative effects on the environment from the oil spill response technologies by spatial compartment (sea surface, seawater, seabed, shoreline). The entire analysis is based on oil spill scenarios and modelled fate of the oil.

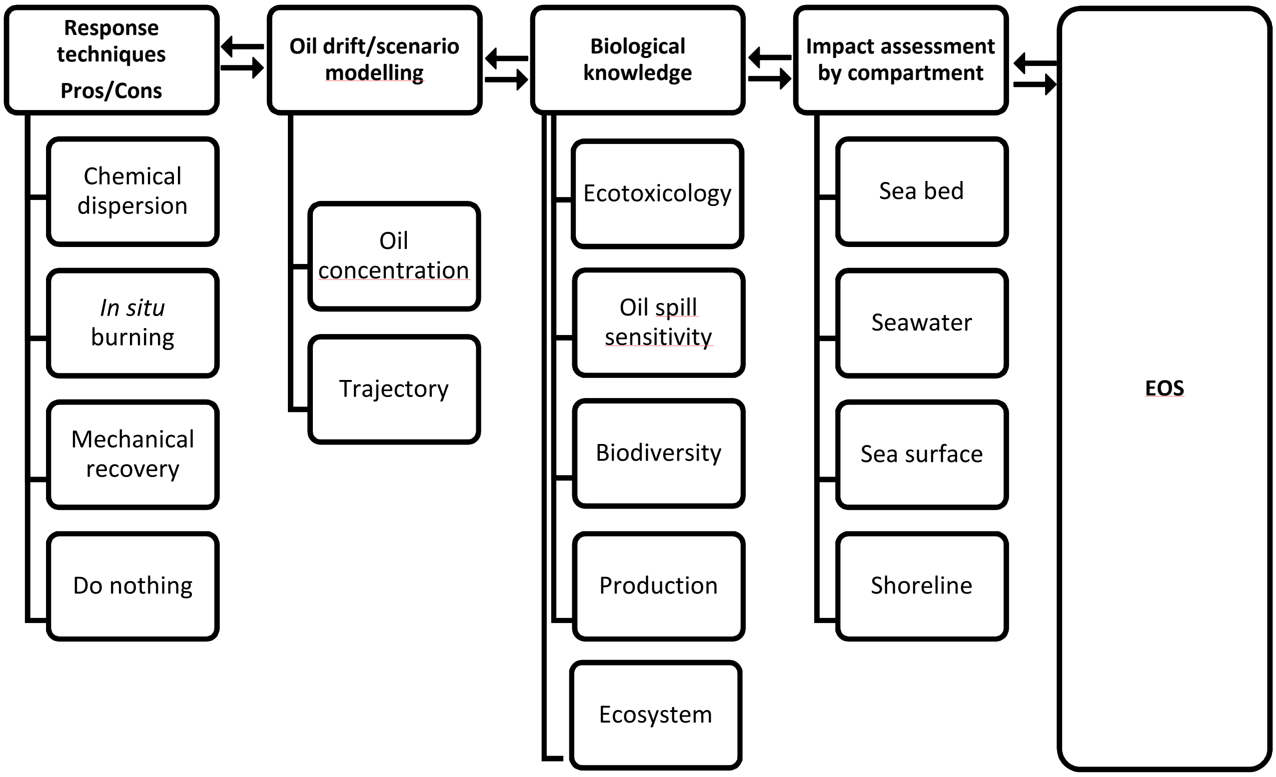

Figure 1. Conceptual illustration of the EOS input and processing complexity. For each oil spill response technique and based on oil spill scenarios for oil drift and oil concentration in seawater, pros and cons are assessed for each spatial compartment based on biological knowledge such as biodiversity, production (e.g., hot spots), ecosystem (e.g. potential cascadal effects) as well as oil spill sensitivity and ecotoxicological data. All information feeds into the EOS analysis, which results indicate if the environment will benefit from a specific oil spill response method. The EOS input are built on an iterative process (indicated by two-direction arrows), where new knowledge can continuously be incorporated in all steps..

New knowledge in all steps of the analysis process can continuously be incorporated.

The EOS tool is based on an Excel spreadsheet for gathering and assessment of input data as well as calculations of indices. The data and indices are finally used in decision trees, to evaluate the possible use of the oil spill response methods for different seasons. The results are given with the traffic light colours; "green" where it is assessed as ok to use the response method in the assessment area for the particular season; "red" where the oil spill technology is not recommended and "yellow" where the oil spill response methodology can be considered but further expert judgement is needed.

The Handbook provides an overview of the process and more detailed descriptions of the steps involved in order to guide the user through the EOS tool:

Chapter 1 provides and overview and brief description on the steps in the EOS process, Chapter 2 contains a list of the common abbreviations and acronyms used,

Chapter 3 collects information boxes that provide more detailed information on each of the steps and what is needed when filling in the EOS tool in the Excel spreadsheet,

Chapter 4 describes each of the decision trees associated with the different types of responses to an oil spill.

Chapter 5 describes how the results of the assessment should be interpreted and communicated.

The EOS tool has been developed under the EU H2020 GRACE grant no. 679266.

1 EOS process

The process of the EOS analysis steps are summarised below, with more detailed descriptions of each contained within explanatory boxes (Chapter 3). A guide to which boxes relate to each step is provided in Table 1.1. The data and indices are eventually used in the decision trees for each of the oil spill response methods (Chapter 4). The results obtained from the decision trees are finally compiled for the different seasons (Chapter 5).

Thus, the EOS process includes the following five steps (see also Table 1.1):

1) Basic data and information. Collection and compilation of data and information of the assessment area as basis for the analysis
2) Assessment. Processing of data and information
3) Indices for the EOS analysis. Calculation of indices for decision trees
4) Analysis through decision trees, one for each oil spill response method and season
5) Interpretation and dissemination of analyses results.

Table 1.1. Steps in EOS, with reference to information boxes for compilation of data, information and indices, decision trees and presentation of results.

Step title	Chapter	
1) Basic data and information The first step in the EOS analysis includes collection and compilation of basic data and information for the calculations and index systems in Step 2) and 3), respectively. A crucial part of Step 1) is to have performed oil spill modelling simulations for obtaining data for the further process:	**3**	***Box***
Selection of assessment area, including examples of definitions to be used, natural limits/borders and examples of areas suitable for an EOS analysis		1-1
Characterisation of the assessment area and water body, including sea surface area and volume of waterbody. Oxygen and nutrient conditions for natural biodegradation potential in the water body are evaluated		1-2
Ecotoxicological data necessary for evaluating impact from untreated and treated oil on species/organism groups of concern and effects of oil sheen or oil slick on seabird feather structure are included in this box		1-3
Selection criteria of species/organism groups of concern in the assessment area, Valued Ecosystem Components (VECs). Species or organism groups must be selected for the four spatial compartments; sea surface, seawater, seabed, shoreline and for each season		1-4
Persistence of oil. For evaluation of the severity of the oil reaching the shoreline and/or ice edge, persistence of the oil on shoreline or in ice edge is included in the analysis based on shoreline morphology, wave energy and presence of sea ice		1-5
Selection of oil spill scenarios and characterisation of the oil type(s) selected. This includes basic parameters for oil spill scenarios, selection of oil spill sites, oil types, size of oil spills, season and weather conditions as well as number of scenarios for covering the objectives of the EOS analysis		1-6
Models for oil spill simulations are described as well as their output with relevance for EOS analysis. This includes oil spill trajectory results, fate of oil with regard to the spatial compartments (sea surface, seawater, seabed, shoreline)		1-7

Characterisation of the assessment area's surroundings, including distance to cities/towns, animal congregation at sea or on land, prevailing wind direction and ice coverage. These parameters are of specific relevance to smoke development and soot deposition in connection with in situ burning		1-8
2) Assessment The second step in the EOS analysis includes assessments and calculations based on the data compiled in Step 1:	***3***	***Box***
Assumptions and criteria behind calculations of sea surface area and seawater volume polluted from oil spill simulation results for use in Box 2-2		2-1
Calculations of polluted sea surface area and seawater volume based on the assumptions from Box 2-1		2-2
Descriptions and estimation of oil spill response technology efficiency which include mechanical recovery, chemical dispersants and in situ burning as well as estimation of their efficiencies		2-3
Definitions of dispersion including natural oil dispersion caused by the weather and tidal energy, chemical dispersion as obtained from dispersants (Box 2-3) and mechanical dispersion		2-4
Assessment of environmental pros and cons of oil spill response methods with respect to species of concern associated with the different spatial compartments (sea surface, seawater, seabed, shoreline)		2-5
3) Indices for the EOS The third step in the EOS analysis includes calculations of indices to be used in next step (Step 4), the decision trees for mechanical recovery, chemical dispersants, in situ burning and do nothing:	***3***	***Box***
Index for environmental effects (E) related to spatial compartment and oil spill response technology. E is calculated from presence of VEC (Box 1-4) and the effect on the VEC from the oil spill response technology (Box 2-5)		3-1
Soot pollution index (SP) for in situ burning. The index includes distance to inhabitation, animal congregations, wind direction and ice cover for protection against particles in smoke (soot).		3-2
Recover potential of VEC. The recover potential of VEC can be based on population modelling, if available, or generation time.		3-3
Potential VEC recruitment related to fractions of sea surface area and seawater volume polluted (Box 2-2) in relation to the total surface area/water volume of the assessments area's waterbody (Box 1-2).		3-4
4) Analysis – by decision trees for each oil spill response methods and for each season Step 4 includes completion of decision trees for each oil spill response method to reach the EOS result, is based on the values and indices obtained in Step 1-3, and must be performed for each of the seasons relevant for the assessment area:	***4***	***Decision tree***
Mechanical recovery		MR
Chemical dispersion		CD
In situ burning		ISB
Do nothing		DN
5) Interpretation and dissemination of analyses results From the decision trees the final result for each oil spill response method for each season is obtained. The results are presented with traffic light colours; green for ok, red for not recommendable, and yellow for further consideration.	***5***	***Results***

2 Abbreviations

List of abbreviation used in the EOS:

MR	EOS decision tree for Mechanical Recovery.
CD	EOS decision tree for Chemical Dispersants
ISB	EOS decision tree for In Situ Burning
DN	EOS decision tree for "Do Nothing"
E	Effect index
EOS	Environment & Oil Spill response
NEBA	Net Environmental Benefit Analysis
sb	seabed
SIMA	Spill Impact Mitigation Analysis
sl	shoreline
SP	Soot Pollution index
ss	sea surface
sw	seawater
VEC	Valued Ecosystem Component

3 EOS explanatory boxes

The explanatory boxes, that the EOS tool interactive part refers to, follow below. The path through the decisions trees for each of the oil spill response technology assessed is explained in Chapter 4 and the interpretation of the results is given in Chapter 5.

Step 1. Basic data and information

BOX 1-1 SELECTION OF ASSESSMENT AREA

EOS is an analytic tool for national or cross-border decision makers for oil spill response planning, capacity building or contingency development. Hence, the assessment area must be defined in accordance with the objectives of the analysis.

The area/region may possess natural limits, like in cases with enclosed sea water basins. If the area is defined in other respects, e.g., within Arctic Council, UN, considered a particular sensitive sea area (PSSA), or is designated important for wildlife, these borders may be respected and used for defining the assessment area.

Examples of areas/regions suitable for EOS:

- Enclosed sea basins; fjords, gulfs, inlets, (e.g. White Sea, Black Sea, The Aegean Sea, The Persian Gulf, Gulf of Finland)
- Regions of particular concern (e.g. sections of the Polar Sea , the Seas around Antarctica)
- Areas at risk of cross border pollution (e.g. Barents Sea, Baffin Bay/Davis Strait, Bay of Biscay, Baltic Sea).

BOX 1-2 CHARACTERIZATION OF THE ASSESSMENT AREA AND WATER BODY

The assessment area included in the EOS must be a defined physical oceanographic unit to estimate/calculate sea surface area and seawater volumes.

Sea surface area of the waterbody
The sea surface area of the assessment area may be defined by shorelines, depth/bathymetry, sill for fjords or other relevant borders.

The sea surface area of the assessment area (km^2) can be estimated by using digital maps e.g., Google Earth or through other GIS (Geographic Information System) tools.

The sea surface area is used for calculation of the fraction of sea surface area polluted (BOX 3-4) and the total seawater volume of the assessment area.

Seawater volume of the waterbody
Delimitation of (active) waterbody depth can be defined by a thermo- and/or halocline, or other hydrodynamic borders, besides those already used for defining the sea surface area.

The seawater volume of the assessment area is used for calculation of the fraction of seawater volume that is polluted (BOX 3-4).

Seabed area of the waterbody of the assessment area
The seabed area of the assessment area (km^2) can be set as equal to sea surface area if seabed topography is not known. This will most likely be an underestimate of the seabed area.

Shoreline length of the waterbody of the assessment area
It is suggested that the length of the shoreline polluted is estimated from a map of approximately scale 1:250,000. The assessment area and case study should, however, be taken into consideration for selecting the map scale to achieve sufficient/restrained resolution.

Biodegradation

The limiting factors for biodegradation of oil may be oxygen as well as the level of nutrient available.

Biodegradation and oxygen conditions

When oil is dispersed into the water column, biodegradation of the oil will be initiated by bacteria. Hazen et al. (2010) identified a plume of oil in app. 1 km depth after the Macondo blow-out in the Gulf of Mexico in 2010. This was based on a significant consumption of oxygen revealed in vertical oxygen profiles of the waterbody, together with identification of an oil degrading microbial flora in the same depth.

The level of oxygen available depends on advection and in situ primary production as well as consumption for degradation. Oxygen can be depleted in the bottom water because new oxygen is not advected from upper waters due to a halo- or thermocline. Depletion of oxygen may harm pelagic, demersal and benthic organisms. Oxygen depletion may thus occur repeatedly in certain seasons. Degradation of oil may add to these potential oxygen depletions in following seasons/years.

Hence, it must be assessed whether oxygen may be depleted at any time of year in the waterbody, and whether the oxygen conditions are considered to be sufficient to facilitate biodegradation of the potential volume of dispersed oil without the environment becoming oxygen depleted.

This evaluation must include consideration of potential for advection of oxygen and biodegradation rates, which may be dependent on temperature as well as nutrient conditions (Wegeberg et al. 2018, Johnsen et al. 2019).

Biodegradation potential with respect to nutrient concentration levels

The rate of biodegradation of oil may depend on several factors, e.g., oil type, temperature (season, depth), nutritional conditions, stratification of water masses, oxygen conditions and presence of oil degrading microbial flora (Wegeberg et al. 2018, Vergeynst et al. 2018).

If oil degrading microorganisms are present, and have the potential to instantly bloom in connection with an oil dispersion operation, the potential for degradation of such an oil plume may be much higher than if poor microbial adaptation to oil degradation is present (Hazen et al. 2010, Vergeynst et al. 2018). In some cases, the presence of an oil degrading microbial flora is well-known and documented for the waterbody, like for the Gulf of Mexico, where natural seeps of oil sustain a natural oil degrading microbial flora (Hazen et al. 2010). In Greenland, only a poor microbial adaption of oil degradation has been observed so far (Kristensen et al. 2015, Vergeynst et al. 2018). However, sufficient nutrients are crucial for the biodegradation potential.

Hence, an assessment of presence of a natural degradation potential should also be included in the basic data and information together with estimates of N and P concentration levels.

Anaerobic microbial degradation of oil is considered insignificant and hence not included in the analysis (Wegeberg et al. 2018).

BOX 1-3 ECOTOXICOLOGICAL DATA

Ecotoxicological data are necessary for evaluating impacts from untreated and treated oil on species/organism groups of concern. In this context acute and chronic toxicity of dispersed oil in seawater are particular relevant. Default values obtained from literature are given for zooplankton, bivalves and fish for the no effect concentrations (NEC) and median concentrations (LC50) of physically dispersed oil in Table 1.3.1. Chemically dispersed oil may be more toxic than physically dispersed oil, though (Singer et al. 1998; Otitoloju 2010), due to increased bioavailability (Østby et al. 2002; Fingas 2008). However, the default values are considered applicable, but if more detailed information is available for the assessment area, these values should be used instead.

Effects of oil sheen or oil slick on sea surface on seabird feather structure and water uptake are included in Table 1.3.2. If more detailed information is available for the assessment area, these values should be used instead.

Table 1.3.1. Effect concentrations of physically dispersed oil in seawater.

	No Effect Concentration (NEC) (mg total petroleum hydrocarbons /L)	**Effect concentration (LC50-96 h) (mg total petroleum hydrocarbons /L)**	**Reference**
Zooplankton	<0.5*	0,7-1**	* Ecotox – US EPA **Hansen et al. (2012)
Bivalves	<1	2	Dupuis and Ucan-Marin (2015)
Fish	<0.15*	1**	*Dupuis, A. and Ucan-Marin (2015) ** Ecotox – US EPA

Table 1.3.2. Effect of oil sheen/slick on sea surface on seabird feathers.

	Oil sheen/slick thicknesses for damage /change in feather microstructure (µm)	**Oil sheen/slick thicknesses for uptake of seawater of feathers (µm)**	**Reference**
Seabird feathers	0.1	3	Morandin & O'Hara (2014)

BOX 1-4 SELECTION OF SPECIES/ORGANISM GROUPS OF CONCERN IN THE ASSESSMENT AREA, VALUED ECOSYSTEM COMPONENTS (VECs)

For selection of species/organism groups of concern in the assessment area, criteria that can be used are listed in Table 1.4.1. However, there may be other specifications for designating species/organisms groups as VECs in the assessment area, which are not listed here, but thus can be included.

The species/organism groups are selected for each season, as the presence of the species of concern may vary throughout the year.

Table 1.4.1. Suggested criteria for species to be included in the EOS analysis, Step 1, VEC selection. Each criteria is described and examples from the Arctic are provided

Species status	Description	Arctic examples
Key species to ecosystem	Impact on key species may lead to cascade effects, by, e.g., food web effects, change in habitats or conditions (loss of structure, wave energy easing, etc.)	Ex. arctic copepod *Calanus hyperboreus* and capelin (Boertmann et al. 2013) Macroalgae and seagrasses
Red list species	Species on national red lists, that are considered vulnerable and hence threatened	Ex. walrus (Boertmann and Bay 2018)
National responsibility species	Impacts on national species population may effect global population	Ex. bowhead whale, common eider (Boertmann and Bay 2018)
Commercial important species	Species that contribute to national economy	Greenland halibut, Northern shrimp (Boertmann et al. 2013)
Stakeholder selected/iconic species	Species of public concern and international attendance	King eider, walrus, bowhead whale, polar bear (Christensen et al. 2016)
Species particular sensitive to oil	Species that may be impacted by smothering	Smothering of eider feathers disrupts feather structure and results in reduced insulation (Fritt-Rasmussen et al. 2016). Effects of smother of the tidal macroalgae depend of oil type (Wegeberg et al. 2020)
	Species exposed to toxic oil concentrations	The oil compound, pyrene, had ecotoxicological effects on *Calanus finmarchicus* and *C. glacialis* from Greenland (Jensen et al. 2008). Tairova et al. (2019) observed adverse developmental effects on the vulnerable early life stages of Arctic capelin
	Species which may accumulate oil compounds	Accumulation of oil compounds in the lipid rich Arctic copepod *Calanus hyperboreus* (Nørregard et al. 2015, Agersted et al. 2018).

BOX 1-5 PERSISTENCE OF OIL ON SHORELINE

When oil lingers on the shore due to a shoreline's low self-cleaning potential, the toxic and/or smother effect of the oil may persist for an elongated period. The retaining capacity of the shoreline and hence the persistence of oil on the shoreline may depend on shoreline morphology, wave energy and presence of ice (Table 1.-5.1).

Table 1.5.1. List of parameters influencing persistence of oil on shore including description and Arctic examples.

Persistence parameter	**Description**	**Arctic examples**
Shoreline morphology	Smooth rocky shores may have a low retaining capacity unless covered by marine vegetation and dependent on oil type viscosity (Gustavson et al. 2020). Presence of boulders, stones and pebbles can cause the oil to drain into crevices and hence avoid the mechanical wash from water motion (Shigenaka 2014). Sandy beaches may have a high retaining capacity due to mix of oil and sand. However, sandy beaches can be cleaned by heavy machinery if accessible (ITOPF 2011a, b).	For instance in the Disko West area in Greenland, there are mostly remote exposed shores, but also shorelines protected from wave exposure with littoral vegetation of fucoid species (*Ascophyllum nodosum, Fucus distichus, F. vesiculosus*) (Boertmann et al. 2013).
Ice (incl. soot pollution)	Ice along the shore complicates oil spill response and may catch and incorporate oil, which will be released in spring (next season) (EPPR 2015). Soot particle deposits on ice may reduce the reflective effect of ice, and hence lead to warming and melt of ice (reduced albedo effect)	For instance in the Disko Bay, Greenland, both sea and land ice are present (Boertmann et al. 2013).
Water energy	Provide mixing energy for dispersing oil (ITOPF 2011b). High degree of wind/wave exposure may cause corresponding high degree of self-cleaning of rocky coasts, depending on oil type. If driven beyond highest water level the self-cleaning potential is greatly reduced.	Self-cleaning potential of two oil types from slate tiles on Arctic rocky coasts showed that cleaning depended on degree of wave wash, rain and sun light degradation processes as well as oil type (Gustavson et al. 2020).

.

BOX 1-6 DEFINITION OF OIL SPILL SCENARIOS

The aim of the oil spill modelling is to help understand the potential distribution, dispersion and fate of the spilled oil in the assessment areas/waterbody based on realistic scenarios with respect to probability and size of oil pollution. In general, it is recommended that distribution, dispersion and fate of the oil in the environment is evaluated using hydrodynamic models (see box 1-7 for more details) that include sea currents, wind, bathymetry, density/salinity, weathering of the oil etc. However, in cases where modelling is not possible or relevant, hydrodynamic modelling may be substituted by less complex estimations based on:

- dominant wind direction and sea current
- oil specific solubility, evaporation etc.
- worst case calculations from total oil volume, that
  - forms slick on sea surface
  - disperses into seawater
  - reaches seabed
  - reaches shoreline

The following basic parameters must be defined for oil spill scenarios:

1) Oil spill sites (e.g. locality, release point (sea surface vs. seabed))
Oil spill sites must be selected in order to cover the defined assessment sea area with respect to heterogeneity in met ocean data and biology.

2) Oil type
Oil types must be selected in order to cover realistic and/or actual activities in the assessment sea area. Each selected oil type must be characterised with respect to density, viscosity, and fraction of oil potential evaporated and soluble in water.

Oil types could be e.g. light/heavy crude oil, bunker oil, diesel oil etc. Oil types selected for oil spill scenarios should include crude oil types if the objective of the EOS is oil exploration/exploitation activities or shipping route for transportation of crude oil. Also, fuel oil types should be included in case of shipping and hence credible fuel oil types for fuel should be included, such as marine diesel and heavy fuel oil (HFO) types or hybrid fuels.

3) Size of oil spill (e.g. amount, volume per time, duration)
For worst-case scenarios from oil exploration/exploitation activities, blow-out oil volumes sizes may be based on those used in oil spill contingency planning by the oil companies.

With regard to shipping, both transported oil volumes (cargo) as well as fuel volumes should be considered. These volumes may be based on realistic carried volumes in the assessment area.

The spill volumes are size categorised in small, medium and large, based on ITOPF (2019) as default (Table 1.6.1), but optionally one's own size categories can be selected.

Table 1.6.1. Size categories of oil spill based on ITOPR (2019).

Category	**Small**	**Medium**	**Large**
Volume (tonnes)	<7	7-700	>700

4) Dates for different time of the year - seasons
For areas, with variating seasons, oil spill scenarios must cover all seasons or seasons of relevance. Seasons of relevance may be those seasons where there are activities from which an oil spill may occur. For instance, during winter in ice-covered waters, oil exploration activities and shipping are not likely to occur, unless icebreakers are used. The weather conditions for the oil spill must be characteristic for the season including differences in wind and current.

5) Weather conditions

To achieve data for worst-case scenarios, model simulations must be run for a suite of weather conditions; calm and stormy weather, different wind directions, potential sea ice, etc.

6) Number of scenarios

An appropriate number of scenarios must be run to cover the heterogeneity of the area with respect to met-ocean data and biology at different times of the year.

From the model simulations, the worst-case values are used for the further EOS assessments (BOX 2-2).

BOX 1-7 MODELS FOR OIL SPILL SIMULATIONS

Models for oil spill simulations may provide a wide range of information ranging from oil spill trajectory to chemical and physical fate of the oil, including change in density, viscosity, natural dispersion and fraction of oil soluble in seawater. This information is needed for later calculations of sea surface and seawater volumes impacted by the oil spill.

An example of such a modelling tool and the resulting data is given below. However, any other oil spill model may be used.

Seatrack Web

The Seatrack Web (STW) is the official HELCOM model used for calculating the drift/dispersion/fate of oil spills in the sea. It is available online for national authorities and certain research organisations. The model uses forecasted wind and current fields to simulate drift/dispersion/fate of oil in three dimensions in the sea. Seatrack Web has been implemented for the Baltic Sea, parts of the North Sea and coastal waters around Greenland. A number of different oils are handled by the model, from gasoline to asphalt. The Seatrack Web model includes state-of-the-art oil weathering algorithms for calculating evaporation, emulsification, density and viscosity of these oils over time. The results of a models simulation include trajectories, changes in the oil properties and the overall fate. Results of the model include estimates of amounts of oil on sea surface, in seawater, on seabed and on shoreline over time, as well as numbers for evaporation, emulsification, density and viscosity of the oils. (http://www.helcom.fi/action-areas/response-to-spills/helcom-seatrackweb-and-oil-drift-modeling).

Oil spill trajectories

Seatrack Web model simulations include three dimensions drift/dispersion/fate of the oil in sea over time after the spill. The simulations indicate whether the oil will reach seabed and shoreline. Please notice in the Gulf of Finland trajectories in Figure 1.7.1-1.7.3, that marine diesel will evaporate and disperse naturally before reaching the shoreline (Figure 1.7.1), while Statfjord crude oil (Figure 1.7.2) and the heavy fuel oil IFO180 reaches the shoreline (Figure 1.7.3).

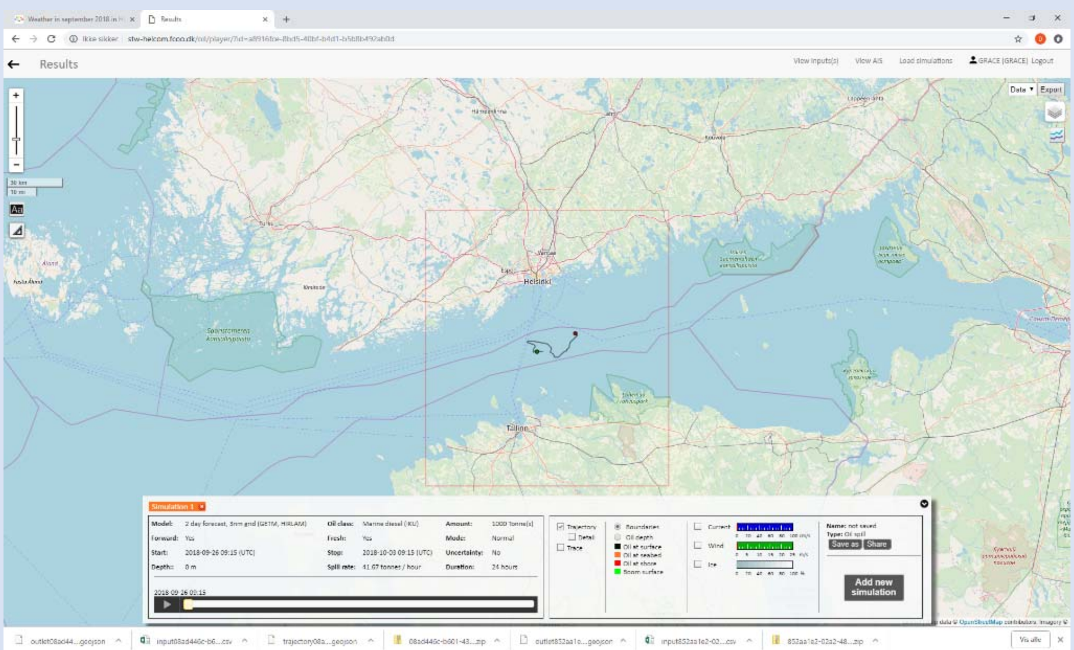

Figure 1.7.1. Seatrack Web: Simulation of drift, dispersion and fate of a Marine diesel oil spill, September 24-27, 2018.

P

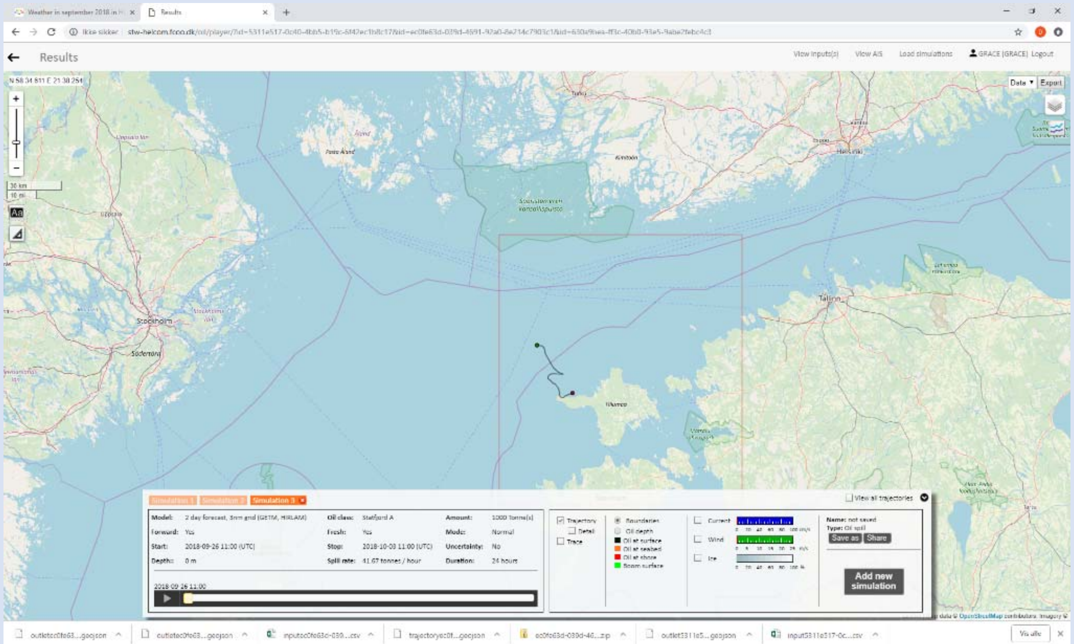

Figure 1.7.2. Seatrack Web: Simulation of drift, dispersion and fate of a crude oil spill (Statfjord), September 24-27, 2018.

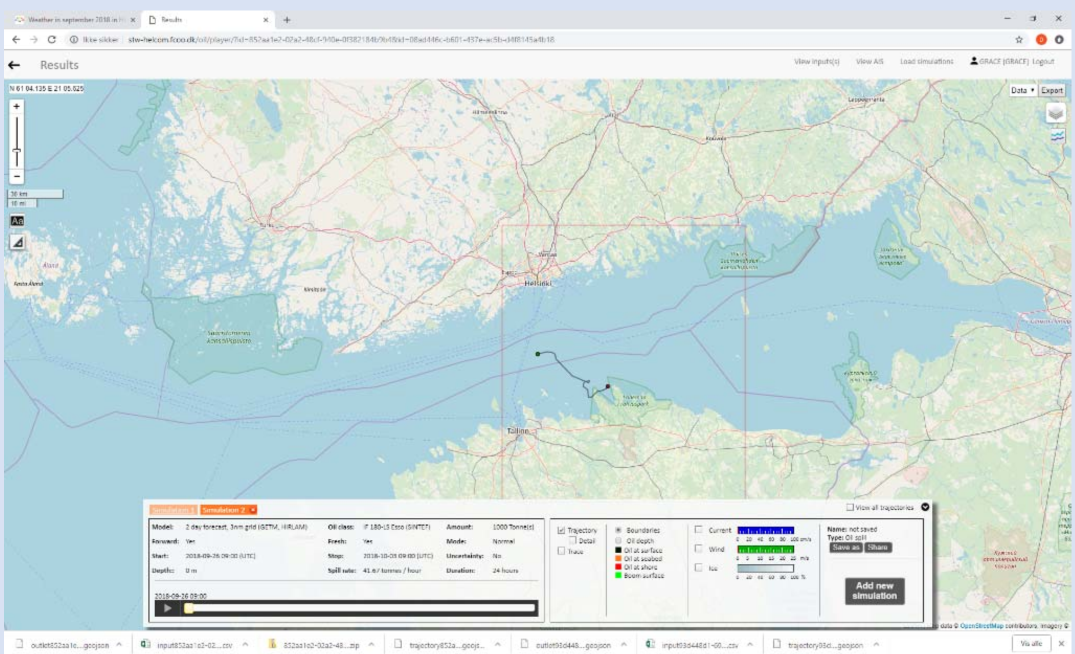

Figure 1.7.3. Seatrack Web: Simulation of drift, dispersion and fate of a heavy fuel oil spill (IFO180), September 24-27, 2018.

Seatrack Web model results

A list of data, which can be obtained from Seatrack Web simulations is shown in Table 1.7.1.

Table 1.7.1. List of data for fate of oil spill, and which can be obtained from Seatrack Web simulations.

Amount of oil in volumes or percent (%)	Fate
m^3	Sea surface
m^3	Seawater
m^3	Seabed
m^3	Shoreline
%	Seawater
%	Seabed
%	Shoreline
%	Evaporated
%	Naturally dispersed
%	Water content

Data from other oil spill model simulations

Models with even more detailed results regarding, e.g., chemical dispersion of oil and fate of the plume, may be available. Models may include half-life of the dispersed oil and more detailed data on plume depth like modelled results provided by ClimateLab in Denmark and SINTEF in Norway (Figure 1.7.4 and 1.7.5). If more detailed data are available, these may be used in the further calculations (BOX 2-2).

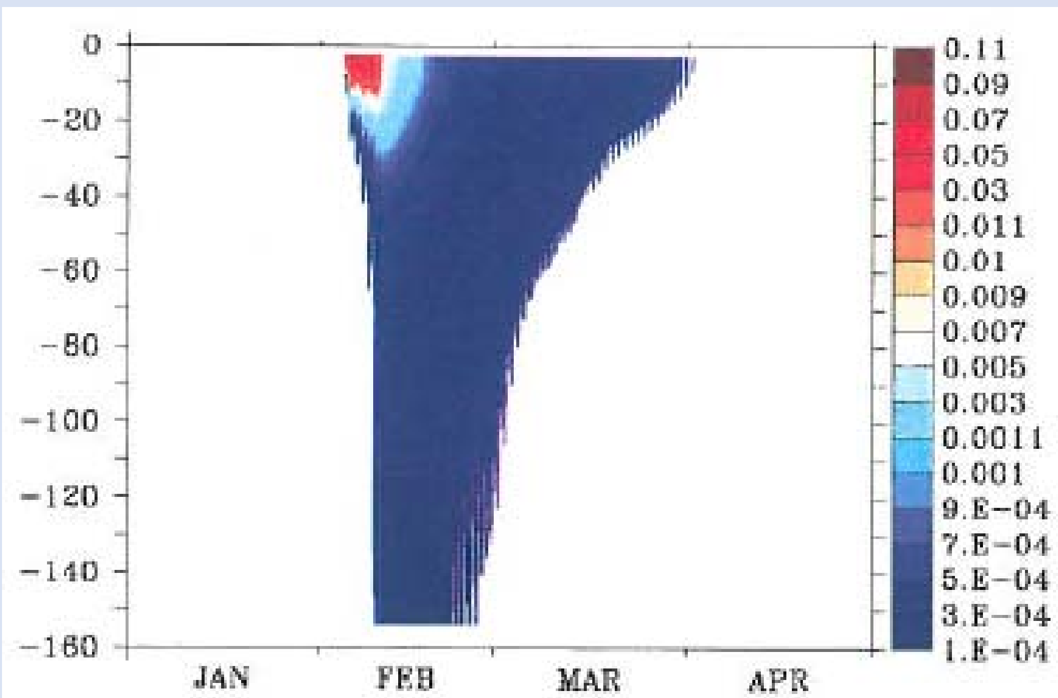

Figure 1.7.4. The vertical distribution of oil concentration with time for simulated chemically dispersed oil from an oil spill of 6000 T in 6 days integrated over a period of 4 months. ClimateLab (2014).

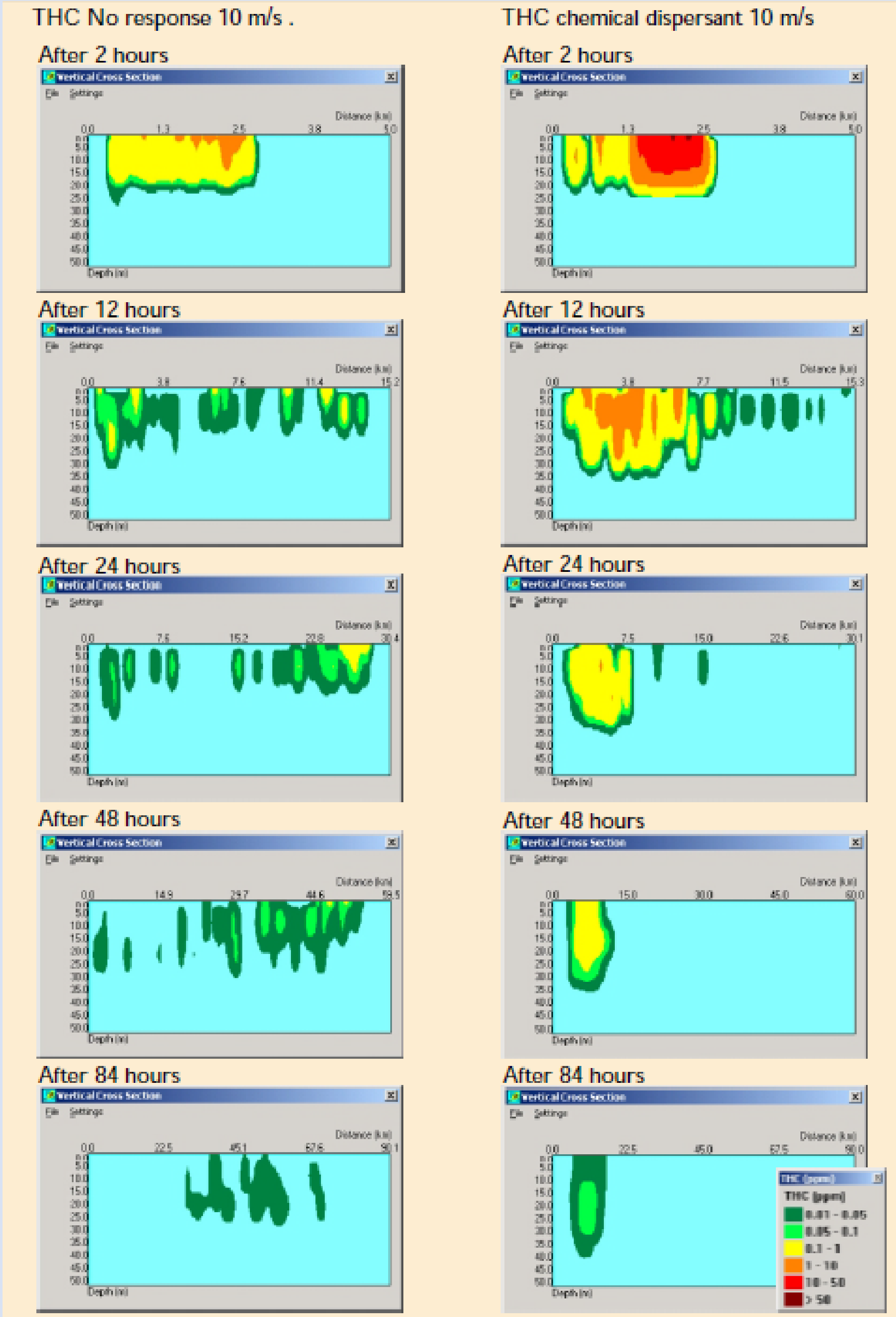

Figure 1.7.5. Naturally (left column) and chemically (right column) dispersed oil distribution and dilution with time. Oil on the surface is not shown in the figure. From Lewis & Daling (2001).

BOX 1-8 DISTANCE TO CONGREGATIONS OF CONCERN IN THE ASSESSMENT AREA'S SURROUNDINGS

To avoid impact from soot from in situ burning (ISB), distance to cities and residents (distance to inhabitation), wildlife and livestock (animal aggregations) must be determined in order to establish a safety zone.

Furthermore, as soot particle deposits on ice may reduce its reflective effect, and hence lead to warming and melt of ice (reduced albedo effect), ice coverage for the assessment area per season must be estimated.

The distance between scenario sites and inhabitation/potential animal congregations may be obtained from measurement on digital maps or through a GIS (Geographic Information System) tool.

Prevailing wind direction may be obtained from metocean data also used as input to the oil spill modelling simulations.

Step 2 – Assessments

BOX 2-1 ASSUMPTIONS AND CRITERIA BEHIND CALCULATIONS OF POLLUTED AREAS/ VOLUMES

For calculating the sea surface and seawater oil pollution (see BOX 2-2), the resultant volumes after 3 days of model simulation run are used. Three days are suggested as default as it is assumed that the window of opportunity for the oil spill methods under prevailing weather conditions will be open.

Sea surface pollution (SSP)
For calculations of the potential sea surface area polluted with an oil slick of a thickness that may harm/change seabird feather structure, the threshold limit is set at 0.1µm as default herein. The 0.1µm threshold value is based on literature values (BOX 1-3, Table 1.3.1).

3µm oil sheen/slick thickness is considered the threshold value for risk of uptake of seawater in seabird feathers (Table 1.3.2).

In the case where oil spill modelling is not available/possible, the sea surface area polluted can be calculated by use of the following estimates and rules of thumb. It is assumed that 90% of the oil on the sea surface will cover 10% of the area polluted, and 10% of the oil on the sea surface will cover 90% of the area polluted (Mackay et al. 1980). The slick thickness is set to:

- 10 % of the oil polluted area has an oil slick thickness of 30 mm
- 90 % of the oil polluted area has an oil slick thickness of 3 mm.

and it is considered to be homogenously distributed on the sea surface.

Seawater pollution (SWP)
For calculations of the potential volume of seawater polluted with naturally dissolved and dispersed oil and calculations of chemical dispersed oil in the seawater, the default threshold values are based on those given in Table 1.7.1 for no effect concentration (NEC). However, if more detailed and specific data are available for the assessment area's organism(s) of concern for each spatial compartment and season, these should be used for the calculations.

The depth of the dispersed oil plume is set to 15 m as default herein. The 15 m depth limit is based on the rule of thumb that the mixing layer of the sea is 1.5 times wave height, which results in a max. depth of the mixing layer corresponding to 10-20 m (BOX 2-2).

If more detailed and specific model results are available for mixing layer or for the depth of dispersed oil in the assessment area, these results should be used for the calculations.

BOX 2-2 CALCULATION OF POLLUTED SEA SURFACE AREA

The oil spill values used in the below calculations are worst case values, which are obtained from oil spill simulations of each oil type and gathered in the Excel document sheet Step 1 – Oil Spill Modelling.

The volume of oil remaining on the sea surface depends on the natural processes of evaporation and natural dispersion of the oil into the water column and the oil type. To which degree these processes naturally remove the oil is important for assessing mechanical recovery as oil spill measure and the option of doing nothing. As such, gas and marine oil has a relatively high natural evaporation and/or dispersion degree corresponding to at least 90 % according to SINTEF oil spill weathering modelling (Moldestad & Daling 2006). The limit for categories of low and high degree of evaporation and natural dispersion to be used in the decision trees for mechanical recovery (MR) and doing nothing (DN) is thus set to 90 % as default. Optionally one's own categories of percentage can be selected (Table 2.2.1).

Table. 2.2.1. The categories (low/high) for degree of removal of oil on surface from the natural processes of evaporation and dispersion

Percentage (%) of evaporated + naturally dispersed oil	Category
< 90	LOW
> 90	HIGH

The polluted sea surface area and seawater volumes are calculated in the Excel document sheet Pollution Assessment.
Calculation of area with oil contamination on sea surface with a slick thickness that may damage seabird feather structure

Calculation for estimating the potential sea surface area that may be polluted to a level of damaging effect on seabird feather structure (Eq. 1). For the rationale behind these assessments, see BOX 2.1.

$$\text{Polluted area of sea surface (km}^2) = \frac{\text{Oil on sea surface (m}^3)}{\text{Damage in feather microstructure (µm)}} \tag{1}$$

The polluted sea surface area is displayed in the cell of Sea Surface Area Exposed in km^2.

The spreading of the oil is rarely uniform, but with large variations in oil film thickness, the oil film will break up and form wind rows parallel to the wind direction (ITOPF 2019). This complex distribution pattern is, however, not included in the calculations, and hence estimations, of polluted sea surface area.

Calculation of polluted seawater volume
Calculations for estimating the potential volume of seawater with a contamination amount of dissolved and naturally dispersed oil (Eq. 2) and chemically dispersed oil (Eq. 3) above No Effect Concentration (NEC) for acute and chronical toxic effects.

$$\text{Sea water volume exposed (nat.)}\ (m^3) = \frac{\text{Nat. dispersed oil}\ (m^3) \times \rho \left(\frac{g}{cm^3}\right) \times 10^6}{\text{EC50 or NEC (mg THC/L)} \times 1000} \tag{2}$$

$$\text{Sea water volume exposed (chem.)}\ (m^3) = \frac{\text{Chem. dispersed oil}\ (m^3) \times \rho \left(\frac{g}{cm^3}\right) \times 10^6}{\text{EC50 or NEC (mg THC/L)} \times 1000} \tag{3}$$

Please note that volumes for naturally dispersed oil and for chemically dispersed oil must be obtained for the decision trees for "Do Nothing" and "Dispersants", respectively.

Data for input to the algorithms (2) and (3) for natural dispersion can be obtained from Table 1.9.1, and input for chemically dispersed oil is the total amount of oil from the oil spill scenarios.

Calculations if no model data is available
If no oil spill modelling data is available the assumptions described in Box 2-1 could be used as input data in the calculation of the sea surface area polluted and the seawater volume polluted.

BOX 2-3 DESCRIPTION OF THE OIL SPILL RESPONSE TECHNOLOGY, EFFICIENCY AND POTENTIAL ENVIRONMENTAL SIDE EFFECTS

Mechanical recovery

Mechanical recovery consists of a wide range of different physical methods all with the overall purpose of collecting and removing (skimming, pumping) the oil directly from the water surface. By this method the oil is removed from the water surface and the side effect is expected to be the increased oil dispersion forced by the activity during the mechanical recovery, the activity itself and possible oil escaping from the containment.

The containment of the oil is typically completed by use of containment booms. In certain situations with pack ice in the range of 60-90 %, the ice can function as the containment.

The removing of the oil from the surface is completed by use of some kind of skimmer system (brush, drum etc.) followed by pumping of the oil/oil-in-water emulsion to a storage tank on the response vessel.

The limitation of the method is the capacity of the booms, oil-water ration of the skimmer, storage capacity and vessel capacity etc. (e.g. see http://www.ipieca.org/resources/good-practice/at-sea-containment-and-recovery/ for more details).

The efficiency of the method varies a lot depending on the specific spill situation. However, often mechanical recovery for spill in open water is reported as less than 15 % of the oil volume and most often less than 5 % of the oil (EPPR 1998). These low efficiencies for spills in open water led to the impacts from mechanical recovery being assumed comparable to those seen for natural removal (do nothing) in the report: http://neba.arcticresponsetechnology.org/report/chapter-4/42/423/. Higher recover efficiencies are expected for oil recovery in, e.g., harbours.

IPIECA (http://www.ipieca.org/resources/good-practice/at-sea-containment-and-recovery/) suggest a recovery efficiency between 5 and 20 % of the initially spilled oil volume.

Conclusively, mechanical recovery removes oil from the environment, but the efficiency may be relatively low.

Chemical dispersion

Dispersion is the process where the natural dispersion of oil into the water column is increased by application of a chemical dispersant. Various products exists, with different formulas adapted to different oil types, salinities, temperatures etc.

Thus, by this method the oil is removed from the surface. The side effects from chemical dispersants are related to the increased toxicity to the organisms in the water column (Box 1-3, Wegeberg et al. 2017 and Fritt-Rasmussen et al. 2018, and references herein). Hence, the effects depend on whether there is sufficient depth or water exchange to achieve adequate dilution of the dispersed oil (ITOPF 2011b) to reach non-toxic concentrations in the seawater.

Further, the dispersability of the oil spill is highly influenced by the viscosity of the oil, as well as the pour point and the ability to form stable water-in-oil emulsions. In the case of heavy fuel oils (HFOs), it may be possible to perform a successful dispersion in some cases, but successive application of the chemical dispersant might be needed, depending on the stability and viscosity of the water-in-oil emulsion. Thus, if the oil slick is missed during the possibly several needed application operations, or the weathering state of the spilled HFO makes it not dispersible, a comparitively larger volume of dispersants is added to the environment without the desired effect (Fritt-Rasmussen et al. 2018).

In the assessment of the dispersion efficiency, it is assumed that the selected chemical dispersant is able to disperse the oil and that the application is done within the window of opportunity.

In situ burning (ISB)

ISB can be effective in rapidly removing large quantities of oil from the marine environment. Ideally, about 85 to 95% of the burned oil becomes carbon dioxide and water (Arctic Response Technology, http://neba.arcticresponsetechnology.org/report/chapter-4/42/423/:). The rest, 5 to 15% which is not burned efficiently is converted into particulates (soot) and a few percent is converted into organic compounds and combustion products that remain in the marine environment – the burn residue (Potter et al. 2012). The burn residue from a typically efficient ISB operation is in the order of less than 15% (SL Ross 2010). After flameout, however, the residues remain. In general terms, the in situ burning residues are highly viscous and sticky and may sink out. The knowledge regarding the potential environmental hazards associated with these residues when sunk to the seabed or as particles in the seawater is still limited (Fritt-Rasmussen et al. 2015). Until now, little effort has been put into recovery of the residue, hence there might be a risk to the environment from the residue. However, if the residue is collected this risk could be eliminated.

BOX 2-4 DEFINITIONS OF DIFFERENT TYPES OF OIL DISPERSION

Spilled oil at sea will usually stay on the sea surface as most oil types' density is less than seawater. For oil to disperse into the water column, energy is needed in the system to break the oil into smaller units (droplets), to be mixed with the seawater. Such energy may be provided naturally or mechanically. The dispersion process can be enhanced by using chemicals that break the oil into smaller droplets.

Natural dispersion
Natural dispersion of spilled oil into the sea is dependent on the water mixing energy from currents, waves and tidal dynamics but also the physical characteristics of the oil types.

Oil broken into droplets of different sizes, and hence different buoyancies, will create a mixing layer. Laboratory experiments and theoretical calculations have estimated the depth of this mixing layer to be 1.5 times wave height (Tkalich & Chan 2002). Below the mixing layer, the oil concentration will decline gradually with water depth, but max. down to 10 to 20 m depth (Li et al. 2013).

Chemical dispersion
An oil slick can also be aided to disperse into the water column by adding chemicals (dispersants) that break the oil into smaller droplets. The oil droplets, however, are again dependent on mixing energy to disperse into the water column.

It is critical, that a sufficient degree of mixing energy and water exchange is available in the system for the oil to reach concentrations below toxic limits quickly. In this way the potential effects on pelagic organisms may be mitigated.

Further details about chemical dispersion see Box 2-3

Mechanical dispersion
Mechanical energy may be added to the system to enhance dispersion and down-mixing of oil, e.g., by thrusters. But also new technology is under development where water jets are used to pulverise oil into microscopic droplets that will stay suspended in the water for possible bacterial degradation. However, mechanical dispersion of oil may also be a result of the activities in connection with mechanical recovery of oil spill. The size of this (side) effect, and potential environmental impact from the oil spill response activities, seems not to have been estimated. Mechanical dispersion from mechanical recovery operations' energy to the seawater system has not been considered, but needs evaluation with respect to proportion in the future.

BOX 2-5 ASSESSMENT OF ENVIRONMENTAL PROS AND CONS OF THE OIL SPILL RESPONSE TECHNOLOGIES

As part of the strategic net environmental benefit analysis, pros and cons of the oil spill response technologies must be assessed for each spatial compartment and season.

Default pros and cons of response technologies are given in Step 2 - Assessment of response methods and the methods are described in Box 2-3. If the oil spill technology overall mitigates the impact on organisms in the spatial compartment in question, it is indicated with a score of 1. If the technology is considered not to mitigate the organisms in the spatial compartment, it is indicated with a score of ÷1. If the impact on the organisms in the spatial compartment is neither mitigated nor impacted by the oil spill technology in question the score of 0 is given. In a few situations, there might be doubts about the negative impact on the organisms in a spatial compartment. In these situations, ÷1 is suggested as default score, until new knowledge is available. For instance, potential effects on seabed organisms from sunk residues is not well elucidated (Fritt-Rasmussen et al. 2015), and more knowledge may change the impact assessment. This may also be the case with sedimentation of oily floc from a dispersion operation as observed in the deep sediments of *Macondo* oil (Stout & Paynes 2016).

The evaluation of pros and cons of the different response technologies are based on Box 2-3 and 2-4, and the references herein. Please be aware that primary source information may be updated with time, and thus present-day literature should be consulted at all times.

Step 3 – Indices for the EOS

BOX 3-1 INDEX FOR ENVIRONMENTAL EFFECTS (E) RELATED TO SPATIAL COMPARTMENT AND TECHNOLOGY

If a VEC is present in a spatial compartment in a specific season, the potential mitigation or negative effect from an oil spill response technology will be indicated by a score of 1 or ÷1 (as described in BOX 2-5):

$$\text{Effect index (E)} = \text{VEC present (1)} \times \text{OSR pros or cons (1 or } \div 1) \qquad (4)$$

If no VECs are present in the specific spatial compartment and season, VEC = 0, and E = 0.

The Effect index (E) is automatically calculated for each season and compartment in Excel document sheet Effect Index (E).

BOX 3-2 SOOT POLUTION INDEX (SP) FOR IN SITU BURNING

Soot Pollution index (SP) is an index to be used with respect to in situ burning (ISB) due to the development of smoke as part of the burning. Therefore, this air pollution may lead to health issues for humans or animals as well as deposition of soot particles.

SP thus is an index that takes into consideration whether distance to land, inhabitation and potential animal congregations of concern, e.g., herds of muskoxen or reindeer, or seabird colonies, is sufficient to avoid health issues. Further, the index includes soot deposition on permanent ice, which may potentially result in reduced albedo and increased ice melt. Finally, the Soot Pollution index includes wind direction compensation.

Distance to inhabitation or animal congregations
The distances to inhabitation or animal congregations are based on ARRT (2008). The safety zone, i.e., the minimum distance to inhabited areas or animal congregations, is given as 3-4 miles (5-6.5 km) in the downwind direction. This is based on standards for air pollution of the US Environmental Protection Agency (US EPA) and modelling of particle concentration in the smoke in wind direction. This distance also corresponds, however, a bit more conservatively, 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. See also Wegeberg et al. (2016) for further explanation.

The default distance limit is hence 5 km.

Ice conditions
The premise is that loss of permanent ice may result from soot particle deposition. This deposition may reduce albedo and hence increase ice melt.

The distance limit of 5 km to permanent ice is also based on information in ARRT (2008) and the above rationale.

Prevailing wind direction
In the EOS analysis, Step 3, Soot Pollution Index, the distance from the burn to congregations of concern or permanent ice must be more than 5 km. If the distance is too short, it can be compensated for if the prevailing wind direction is away from congregations of concern and/or ice. E.g. if the wind direction does not lead the smoke plume towards inhabitation or animal congregations, ISB may be an option, despite being close to either inhabitation or congregations of animals.

BOX 3-3 VEC RECOVERY POTENTIAL, R

The potential for recovery or rehabilitation of VECs is expressed as the time needed for a population to restore or re-establish, and depends on generation time and density of population after acute mortality. For instance, modelling of king eider population dynamics in Greenland showed that rehabilitation may take several decades, if able to rehabilitate at all, in case mortality was comprehensive (Wegeberg et al. 2016).

It is suggested that rehabilitation time is modelled, and the resulting modelled number of years are entered into the EOS analysis, Step 3, VEC recovery potential, R, and the output will be short or long recovery time.

As a default in the EOS analysis, the recovery time is considered to be short if it is less than 1 year, otherwise the recovery time is considered to be long. It is possible to enter a threshold limit of one's own choice if more relevant for the assessment area or more detailed knowledge is available. The threshold limit of 1 year is based on the rationale that a population is able to reproduce within the same year and establish a population for the succeeding year, if generation time is less than one year.

However, if modelling results cannot be obtained, a guidance for assessing short or long recovery time can be based on generation time of the VEC (Bock et al. 2018). See Bock et al. (2018, table S4) for examples of generation time for VECs in Gulf of Mexico.

BOX 3-4 POTENTIAL VEC RECRUITMENT ASSESSED RELATED TO FRACTIONS OF SEA SURFACE AREA AND SEAWATER VOLUME POLLUTED

Recruitment is the potential for a species to re-establish after acute mortality and depends on, e.g., influx, re-colonisation and demography.

Here the influx potential of organisms is estimated by calculating the fractions of polluted sea surface and seawater volume in relation to the total sea surface area and volume of the assessment area's water body (see Eq. 5 and 6 below). This fraction is used as proxy for recruitment potential based on the assumption that if a small fraction is polluted then there is a higher influx potential of non-affected organisms. In contrast, a high fraction may result in lower potential for influx of non-affected organisms, and hence a lower recruitment potential.

Fraction of sea surface area polluted as a function of total sea surface area in the specified area

From the value of sea surface area polluted by oil at a thickness that may harm seabird feather structure (Box 1-3, Step 1 – Basic data and information, Step 2 – Assessment of potential pollution), a fraction of sea surface area polluted in relation to the entire sea surface area for the waterbody of the assessment area (Box 1-2, Step 1 – Basic data and information) can be calculated:

$$\text{Fraction of polluted sea surface area (\%)} = \frac{\text{Sea surface area polluted}}{\text{Sea surface area of assessment area}} \times 100 \quad (5)$$

Fraction of seawater volume polluted as a function of total seawater volume in the specified area

The fraction of water volume polluted as a function of total water body (to the depth of halocline) in the specified area is calculated as follows in the EOS:

$$\text{Fraction of polluted seawater volume (\%)} = \frac{\text{Seawater volume polluted}}{\text{seawater volume of assessment area}} \times 100 \quad (6)$$

For seawater volume polluted with oil concentration above LC_{50} or No Effect Concentration (NEC), see Box 1-3, Step 1 – Basic data and information, Step 2 – Assessment of potential pollution. For the volume of the waterbody of the assessment area see Box 1-2, Step 1 – Basic data and information.

The fractions (Eq. 5 and 6) are automatically calculated for each season in Step 3 - VEC Recruitment and fractions.

Evaluation of the fraction size
The fractions are evaluated as "small" or "large". The rationale behind this is that the smaller the fraction the higher the potential for recruitment by "dilution" of healthy organism in the seawater. The limits for the fractions being considered as "small" or "large" are listed in Table 3.4.1. If the nutrient levels are assessed as *not* limiting for the natural degradation process of the oil in the seawater (Box 1-2), a higher fraction of seawater volume with oil contamination may be accepted (15 % as default). As dispersed oil initially is restricted to the mixing layer and hence above a potential boundary layer (Box 2-1), oxygen is considered as not limited for the biodegradation process in this layer. However, degradation of settling dispersed oil particles below the mixing layer may influence oxygen concentration levels in this spatial compartment.

Presence of a sustained microbial flora for oil degradation from, e.g., natural seeps, is not included in the analysis, as this flora and potential bacterial growth will be predominantly nutrient dependant (Johnsen et al. 2019), which is a parameter already included in the analysis. Note that pristine areas might exists where the intrinsic potential for microbial degradation of oil potentially requires years of adaptation for degradation to occur, if at all (Wegeberg et al. 2018).

The default limits are assessed values, which are based on considerations in connection with a strategic environmental assessment for the use of oil spill response technologies at Store Hellefiskebanke in western Greenland (Wegeberg et al. 2016). However, it is possible to enter a threshold limit of one's own choice if more relevant for the assessment area or more detailed knowledge is available.

Table 3.4.1. Threshold limit values for the calculated fractions being considered as "small" or "large".

	Sea surface area polluted	**Seawater volume fraction polluted**	**Seawater volume fraction polluted if oxygen and nutrients not limiting**
Fraction (%)	2	10	15

4 Decision trees

Through step 1-3, all necessary data and information is at hand for finding the paths through the decision trees for the oil spill response technologies for each season.

4.1 In situ burning (ISB) decision tree

With respect to in situ burning, soot development and deposition is the first branch in the decision tree. If soot is considered a problem, if the oil spill is comprehensive, and where many burns may be expected, evacuation or displacement needs to be addressed. If soot is not considered a problem, the Effect Index (E) for each compartment is used as well as the option for in situ burning residue recovery.

4.2 Chemical dispersant (CD) decision tree

First, it is assessed, on the basis of information from the oil spill scenario modelling, if there is sufficient mixing energy in the waterbody system for a dispersant operation to work as intended.

If it is considered that the mixing energy in the water system is adequate, the Effect Index (E) for each compartment is used for assessing if chemical dispersion of the oil will mitigate, overall, the effect of oil on the environment.

If the outcome of pros and cons for the spatial compartments affected by chemically dispersing the oil is ambiguous due to presence of VECs in these compartments, the analysis enters a guidance matrix. The guidance matrix includes population recovery and recruitment potential in the assessment.

4.3 Mechanical recovery (MR) decision tree

Mechanical recovery is considered to have no environmental side effects, but the efficiency of oil recovery may be relatively low (Box 2-3).

To evaluate if action is gainful, the decision tree initiates with the assessment of the size of the oil spill and the ability of the oil to evaporate or naturally disperse. It is recommended to take action when an oil spill is designated as large (Step 1 – Oil spill modelling). Independent of oil spill size, presence of VECs in the spatial compartments effected by the oil spill (E_{ss}, E_{sw}, $E_{sl} > 0$) calls for action.

4.4 "Do nothing" (DN) decision tree

Doing nothing is not an oil spill response method, but a no-action which may be the result of difficult operational conditions or oil spills of smaller size that may evaporate or disperse naturally within too short time for action.

Therefore, if it has a negative effect on the VECs in the spatial compartments affected by the oil spill (E_{ss}, E_{sw}, $E_{sl} < 0$), then it is not recommendable to do nothing. The decision tree, thus, includes size of oil spill, degree of natural evaporation, and the summed values for organisms on the sea surface and on shoreline.

5 Interpretation and dissemination of EOS results

From the decision trees the final result for each oil spill response method for each season is obtained in relation to an overall mitigation assessment of the environmental impact of an oil spill in the selected water body.

The results are presented with colours from traffic light:

Green/OK The oil spill response method is considered “ok” as an oil spill measure option in the assessment area for the specific season in order to obtain an overall environmental mitigation from the oil spill.

Yellow/Consider The oil spill response method may be considered as an oil spill measure option in the assessment area for the specific season, however, expert judgement may be needed in the specific oil spill situation and season in order to clarify if an overall environmental mitigation from the oil spill is expected.

Red/Not recommended The oil spill response method is not recommended as an oil spill measure option in the assessment area for the specific season as it will most likely not result in an overall environmental mitigation from the oil spill.

It is important to emphasise that the EOS results *indicate* which oil spill response methods *might* **mitigate** the environmental effects from an oil spill in the different seasons. However, the EOS results **do not compare** the oil spill response methods in order to select the best option. Often more than one oil spill response method may be optimal from an operational point of view. Please consult appropriate information for operational assessment.

6 References

Agersted MD, Møller EF, Gustavson K (2018) Bioaccumulation of oil compounds in the high-Arctic copepod Calanus hyperboreus. Aquatic Toxicology 195: 8-14.

ARRT (Alaska Regional Response Team) (2008) In situ burning guidelines for Alaska. Revision 1. iv + 66 pp.

Baker JM (1995) Net environmental benefit analysis for oil spill response. International Oil Spill Conference Proceedings, 611-614.Bock et al. 2018

Boertmann B, Mosbech A, Schiedek D & Dünweber M (eds) (2013) Disko West. A strategic environmental impact assessment of hydrocarbon activities. – Scientific Report from DCE – Danish Centre for Environment and Energy, nr. 71. Aarhus University, 306 pp.

Boertmann D, Bay C (2018) Grønlands Rødliste 2018: Fortegnelse over grønlandske dyr og planters trusselstatus. Grønlands Naturinstitut, 2018.

Christensen T, Aastrup P, Boye T, Boertmann D, Hedeholm R, Johansen KL, Merkel F, Rosing-Asvid A, Bay C, Blicher M, Clausen DS, Ugarte F. Arendt, K, Burmeister A, Topp-Jørgensen E, Retzel A, Hammeken N, Falk K, Frederiksen M, Bjerrum M, Mosbech A (2016) Biologiske interesseområder i Vest- og Sydøstgrønland. Kortlægning af vigtige biologiske områder. – Teknisk rapport fra DCE – Nationalt Center for Miljø og Energi, Aarhus Universitet, nr. 89.

ClimateLab (2014) Dispersion analysis I-IV. Oil spill scenario in the central part of St. Hellefiske bank. In: Wegeberg S, Rigét F, Gustavson K, Mosbech A. 2016. Store Hellefiskebanke, Grønland. Miljøvurdering af oliespild samt potentialet for oliespildsbekæmpelse. Aarhus University, DCE – Danish Centre for Environment and Energy, xx pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 216 http://dce2.au.dk/pub/SR216.pdf.

EPPR (1998) Field Guide for Oil Spill Response in Arctic Waters. Emergency Prevention, Preparedness and Response (EPPR), Arctic Council, 362 pp. https://oaarchive.arctic-council.org/bitstream/handle/11374/109/Field%20Guide%20for%20Oil%20Spill%20Response%20in%20Arctic%20Waters.pdf?sequence=1&isAllowed=y

EPPR (2015) Guide to Oil Spill Response in Snow and Ice Conditions. Emergency Prevention, Preparedness and Response (EPPR), Arctic Council, 2015 ISBN: 978-82-999755-7-5, 185 pp. file:///C:/Users/au188113/Downloads/ACMMCA09_Iqaluit_2015_EPPR_Guide_to_Oil_Spill_Response_Report.pdf

Fingas M (2008) A review of literature related to oil spill dispersants, 1997-2008: Report for the Prince William Sound Regional Citizens' Advisory Council (PWSRCAC). 168 pp.

Fritt-Rasmussen J, Wegeberg S, Gustavson K (2015) Review on Burn Residues from In Situ Burning of Oil Spills in Relation to Arctic Waters. Water Air Soil Pollution, 226: 329. DOI 10.1007/s11270-015-2593-1.

Fritt-Rasmussen J, Linnebjerg JF, Sørensen MX, Brogaard NL, Rigét FF, Kristensen P, Jomaas G, Boertmann DM, Wegeberg S, Gustavson, K (2016) Effects of oil and oil burn residues on seabird feathers. Marine Pollution Bulletin 109: 446-452. DOI: 10.1016/j.marpolbul.2016.05.029

Fritt-Rasmussen J, Wegeberg S, Gustavson K, Sørheim K R, Daling PS, Jørgensen K, Tonteri O, & Holst-Andersen JP 2018. Heavy Fuel Oils (HFO) A review of fate and behaviour of HFO spills in cold seawater, including biodegradation, environmental effects and oil spill response. – TemaNord report in publication

Gustavson K, Hansson SV, van Beest FM, Fritt-Rasmussen J, Lassen P, Geertz-Hansen O, Wegeberg S (in prep.) Natural removal of crude and heavy fuel oil on rocky shorelines in Arctic climate regimes.

Hazen TC, Dubinsky EA, DeSantis TZ, Andersen GL, Piceno YM, Singh N, Jansson JK, Porbst A, Borglin SE, Fortney JL, Stringfellow WT, Bill M, Conrad ME, Tom IE, Chavarria KL, Alusi TR, Lamendella R, Joyner DC, Spier C, Baelum J, Auer M, Zemla ML, Chakraboty R, Sonnenthal EL, D'haesleer P, Holman H-YN, Osman S, Zhenmei L, van Nostrand JD, Deng Y, Zhou J, Mason OU (2010) Deep-sea oil plumes enriches indigenous oil-degrading bacteria. Science 330: 204-208.

ITOPF (2011a). Fate of marine oil spills. Technical Information Paper 2. The International Tanker Owners Pollution Federation Limited,12. pp. https://www.itopf.org/fileadmin/data/Documents/TIPS%20TAPS/TIP_2_Fate_of_Marine_Oil_Spills.pdf

ITOPF (2011b) Use of dispersants to treat oil spills. Technical information paper 4. The International Tanker Owners Pollution Federation Limited, 12 pp. http://www.itopf.com/information-services/publications/documents/TIP4UseofDispersantstoTreatOilSpills.pdf

ITOPF (2019) Handbook. The International Tanker Owners Pollution Federation Limited, 56 pp. http://www.itopf.org/fileadmin/data/Documents/Company_Lit/ITOPF_Handbook_2019_web.pdf

Jensen MH, Nielsen TG, Dahllöf I (2008) Effects of pyrene on grazing and reproduction of Calanus finmarchicus and Calanus glacialis from Disko Bay, West Greenland. Aquatic Toxicology 87: 99-107

Johnsen AR, Christensen JH, Poulsen KG, Hansen LH, Ellegaard-Jensen L, Fritt-Rasmussen J (2019) A study of microbial crude oil degradation in water and sediment from the Greenland Sea. Aarhus University, DCE – Danish Centre for Environment and Energy, 90 pp. Scientific Report No. 347. http://dce2.au.dk/pub/SR347.pdf

Kristensen, M., A R. Johnsen, and J. H. Christensen (2015) Marine biodegradation of crude oil in temperate and Arctic water samples. J. Hazard. Mat. 300: 75-83.

Lewis A, Daling PS (2007) A review of studies of oil spill dispersant effectiveness in Arctic conditions. (JIP Project 4, Act. 4.11). SINTEF Materials and Chemistry, Marine Environmental Technology, SINTEF report A 16086, 22 p.

Li Y, Zhu J, Wang H (2013) The Impact of Different Vertical Diffusion Schemes in a Three-Dimensional Oil Sill Model in the Bohai Sea. Adv. Atmos. Sci. 30(6): 1569-1586

Mackay D, Buist I, Mascarenhas R, Petersen S (1980) Oil spill processes and models. Environmental Protection Service, Canada Report EE-8.

Moldestad MO, Daling PS (2006) Vurdering av forvitringsegenskapene til ulike Marine Gassoljer. Kriterier for fastsettelse av drivstoff kvalitet ut fra egenskaper ved et eventuelt utslipp. SINTEF report no. STF80MK A06170, 52 pp.

Morandin lA, O'Hara, PD (2014) Fish oil disrupts seabird feather microstructure and waterproofing. Science of the Total Environment 496: 257-263.

Nørregaard RD, Gustavson K, Møller EF, Strand J, Tairova Z, Mosbech A (2015) Ecotoxicological investigation of the effect of accumulation of PAH and possible impact of dispersant in resting high arctic copepod Calanus hyperboreus. Aquatic Toxicology, doi:10.1016/j.aquatox.2015.07.006.

Otitoloju AA. 2010. Evaluation of crude oil degradation under a no-control and dispersant-control settings, based on biological and physical techniques. International Journal of Environmental Resources 4: 353-360.

Potter S, Buist I, Trudel K, Dickins D, Owens E (2012) Spill Response in Arctic Offshore, Prepared for the American Petroleum Institute and the Joint Industry Programme on Oil Spill Recovery in Ice, Edited by Scholz, D.; SEA Consulting Group; i-144.

Shigenaka G (2014) Twenty-Five Years After the Exxon Valdez Oil Spill: NOAA's Scientific Support, Monitoring, and Research. Seattle: NOAA Office of Response and Restoration. 78 pp.

Singer MM, George S, Lee I, Jacobson S, Weetman LL, Blondina G, Tjeerdema RS, Aurand D, Sowby ML (1998) Effects of dispersant treatment on the acute aquatic toxicity of petroleum hydrocarbons. Archives of Environmental Contamination and Toxicology 34: 177-187.

SL Ross Environmental Research Ltd., DF Dickins Associates LLC, Envision Planning Solutions Inc (2010) Beaufort Sea Oil Spills State of Knowledge Review and Identification of Key Issues. Environmental Studies Research Funds Report No. 177. Calgary. 126p.

Stout SA, Payne JR (2016) Chemical composition of floating and sunken in situ burn residues from the Deepwater Horizon oil spill. – Marine Pollution Bulletin 108, 186–202.

Tairova Z, Frantzen M, Mosbech A, Arukwe A, Gustavson K (2019) Effects of water accommodated fraction of physically and chemically dispersed heavy fuel oil on beach spawning capelin (Mallotus villosus). Marine Environmental Research 147: 62-71.

Tkalich P, Chann ES (2002) Vertical mixing of oil droplets by breaking waves. Marine Pollution Bulletin 44: 1219-1229.

Vergeynst L, Wegeberg S, Aamand J, Lassen P, Gosewinkel U, Fritt-Rasmussen J, Gustavson K, Mosbech A (2018). Biodegradation of marine oil spills in the Arctic with a Greenland perspective. Science of the Total Environment 626, 1243-1258.

Wegeberg S, Rigét F, Gustavson K, Mosbech A (2016) Store Hellefiskebanke, Grønland. Miljøvurdering af oliespild samt potentialet for oliespildsbekæmpelse. Aarhus Universitet, DCE – Nationalt Center for Miljø og Energi, 98 s. - Videnskabelig rapport fra DCE - Nationalt Center for Miljø og Energi nr. 216. http://dce2.au.dk/pub/SR216.pdf

Wegeberg S, Frit-Rasmussen J, Boertmann D (2017) Oil spill response in Greenland: Net Environmental Benefit Analysis, NEBA, and environmental monitoring. Aarhus University, DCE – Danish Centre for Environment and Energy, 92 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 221 http://dce2.au.dk/pub/SR221.pdf

Wegeberg S, Johnsen A, Aamand J, Lassen P, Gosewinckel U, Fritt-Rasmussen J, Rigét F, Gustavson K, Mosbech A (2018) Arctic marine potential of microbial oil degradation. Aarhus University, DCE – Danish Centre for Environment and Energy, 54 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 271 http://dce2.au.dk/pub/SR271.pdf

Wegeberg S, Hansson SV, van Beest FM, Fritt-Rasmussen J, Gustavson K (2020) Smooth or smothering? The self-cleaning potential and photosynthetic effects of oil spill on arctic macro-algae Fucus distichus. Marine Pollution Bulletin 150: 110604.

2020,Wenning RJ, Robinson H, Bock M, Rempel-Hesterc MA, Gardinerd W. 2018. Current practices and knowledge supporting oil spill risk assessment in the Arctic. Marine Environmental Research 141:289–304.

Østby C, Brude OW, Moe KA (2002) Netto miljøgevinst analyse. Akutt oljeforurensning; mekanisk bekjempelse – kjemisk dispergering. NOFO rapport 1113-01. 52 pp.

ENVIRONMENT & OIL SPILL RESPONSE (EOS)

An Analytic Tool for Environmental Assessments to Support Oil Spill Response Planning

The Handbook

The EOS is a desktop analysis based on oil spill scenarios and published as well as expert knowledge on the environment in the assessment area. The EOS tool can support decisions of inclusion of mechanical recovery, in situ burning and chemical dispersants in national oil spill contingency plans. In addition, the results obtained through the EOS tool can be used for establishment of cross-border and trans-boundary co-operation and agreements on oil spill response. The EOS tool is based on an Excel spreadsheet, with references to explanatory boxes provided in the EOS Handbook.The EOS analysis goes through 5 steps for each of the oil spill response methods and for each season: Gathering basic environmental data and in-formation for the assessment area; Assessments of basic data and oil spill modelling results; Scores and indices calculations; Decision trees for each oil spill response technology; Interpretation and dissemination of EOS results.

ISBN: 978-87-7156- 493-8
ISSN: 2245-019X