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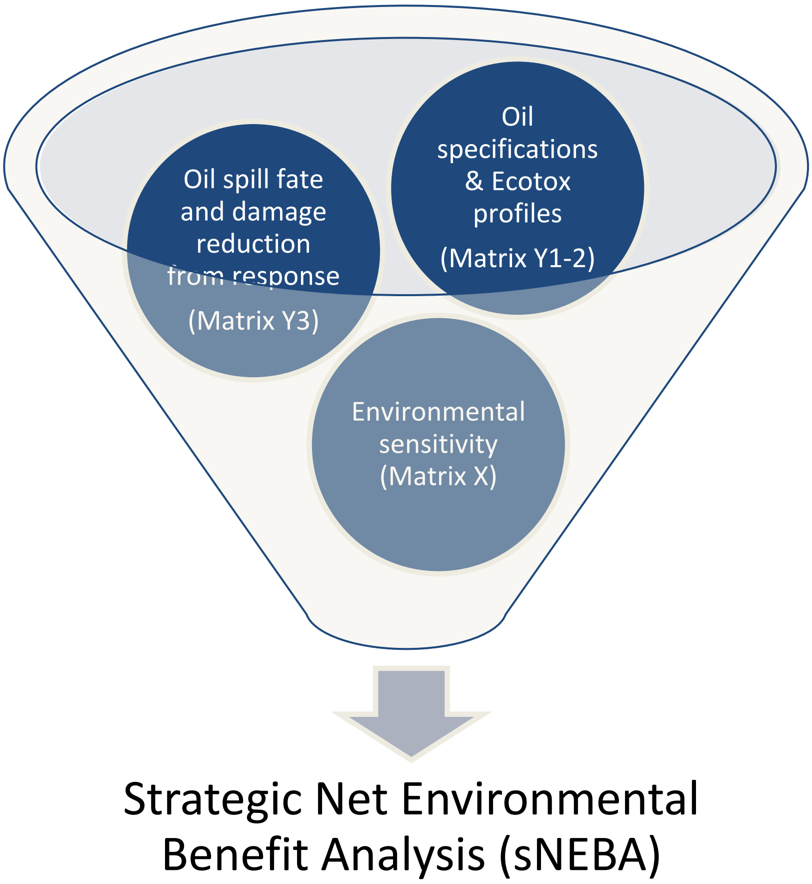
GRACE grant no 679266

Strategic Net Environmental Benefit Analysis (sNEBA) for combat of oilspill in open waters – Matrices for environmental sensitivity and effects



D5.5

WP5: Strategic Net Environmental Benefit Analysis (sNEBA)

Prepared under contract from the European Commission

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Research and Innovation Action

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1.0	draft	24th April 2018	Susse Wegeberg (AU), Janne Fritt-Rasmussen (AU) and Kim Gustavson (AU)	WP5 members
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Executive summary

A Strategic Net Environmental Benefit Analysis (sNEBA) is a planning tool for oil spill response preparedness. The overall aims of the analysis are to identify the most environmental beneficial methods for combating an oil spill in a specific sea area. sNEBA compiles information and data on 1) sensitivity of ecological important organisms in selected sea area, 2) estimates for fate and distribution of oil spill in the selected sea area.

Evaluation of oil spill combat techniques at sea can been performed for, e.g., a location, sea area or a region. This evaluation focuses on minimization of the combined environmental impacts of both oil spill and oil spill response techniques. Present available oil spill response techniques include mechanical recovery, chemical dispersion of oil and *in situ* burning (burning of oil directly on the sea surface), but also doing nothing, and leave the oil to be natural dispersed and degraded, may be the (only) option. This evaluation can be completed by assessing the environmental pros and cons of the different oil spill response techniques, and for which the concept of a strategic Net Environmental Benefit Analysis (sNEBA) was developed.

Based on the model simulation results (or estimates) from the oil spill scenarios, identification of sensitive and ecological important organisms at risk to potential oil exposure can be performed, and the sensitivity of the organisms associated to sea surface, water column, seabed, coast and ecosystems characteristic of these spatial compartments can be assessed.

Generic matrices for the knowledge components that needs to go into the analysis are developed and presented.

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Introduction

A Strategic Net Environmental Benefit Analysis (sNEBA) is a planning tool for oil spill response preparedness. The overall aims of the analysis are to identify the most environmental beneficial methods for combating an oil spill in a specific sea area. sNEBA compiles information and data on 1) sensitivity of ecological important organisms in selected sea area, 2) estimates for fate and distribution of oil spill in the selected sea area.

Evaluation of oil spill combat techniques at sea can been performed for, e.g., a location, sea area or a region. This evaluation focuses on minimization of the combined environmental impacts of both oil spill and oil spill response techniques. Present available oil spill response techniques include mechanical recovery, chemical dispersion of oil and *in situ* burning (burning of oil directly on the sea surface), but also doing nothing, and leave the oil to be natural dispersed and degraded, may be the (only) option. This evaluation can be completed by assessing the environmental pros and cons of the different oil spill response techniques, and for which the concept of a strategic Net Environmental Benefit Analysis (sNEBA) was developed.

Information regarding environmental (side) effects can be obtained from, e.g., IOGP database (www.neba.arcticresponsetechnology.org) and Wegeberg et al. (2017, and references herein).

The sNEBA includes an analysis, which is based on oil spill scenarios and published as well as expert knowledge on the environment in the area in question. The environmental knowledge included in the sNEBA, to achieve the overall environmental optimal oil spill combating strategy, is knowledge on sensitivity of ecological important organisms for oil pollution in all marine spatial compartments; sea surface, water column, seabed, and coast for all seasons, biology, and ecotoxicology of oil (naturally and chemically dispersed as well as oil burning residues). Furthermore, the reduction in environmental damage is assessed according to oil spill response method efficiencies.

Matrices for the knowledge components that needs to go into the analysis are developed (Matrix X1-3, Y1-3) (Figure 1). The matrices are thought to be generic and can be used for sNEBAs performed for sea areas/ regions not within the GRACE sea areas. The information on the fate and distribution of the oil spill in the specific sea area can be obtained from model simulations of dispersion of dissolved oil components during an oil spill as well as oil slick trajectories, or estimates based on trends in oil types fate and behavior at sea. If a sNEBA is performed for an area of high oil spill risk or for an area considered to particular sensitive to oil spill, oil spill model simulations are required. If the sNEBA is performed for, for instance, a very large area, less detailed estimates may be sufficient and more meaningful.

Background for sNEBA components and input

Based on the simulation results (or estimates), identification of sensitive and ecological important organisms at risk to potential oil exposure can be performed, and the sensitivity of the organisms associated to sea surface, water column, seabed, coast and ecosystems characteristic of these spatial compartments can be assessed. To explain the sNEBA process and the input requirements, a short and generic description for each spatial compartment is given below based on Wegeberg et al. (2016, 2017 and references herein).

Considered consequences and benefits by oil dispersion and ISB for seabirds on sea surface

To the benefit of the organisms associated to the sea surface, removal of the oil from the sea surface will prevent smothering of feathers and fur. Removal or significant reduction of the spilled oil in open water will also prevent or reduce impacts on the coast.

The response techniques, chemical dispersal and ISB, are thus considered as beneficial in protection of seabirds congregated on the sea surface for feeding or moulting. However, it should be noted that burning residues from ISB also may possess a risk for smothering of seabird feathers, but by ensuring a high burning efficiency this risk can be further reduced.

Analysis of potential effects of dispersed oil on copepods in the water column

The dispersion model simulations may indicate dilution capacity and hence how oil concentrations are dispersed into the water column, and how it distributes horizontally. Calculations of water volumes with toxic oil concentrations, based on the simulations of dissolved oil components dispersion, indicate the OMFANG of the risk of effects on the organisms in the water column. The vertical distribution of toxic oil concentrations covers the upper part of the water column, which also may be occupied by a high fraction of plankton. Hence, there can be an overlap between the zones with toxic concentrations (acute lethal and sublethal) and high density of plankton. Besides the toxic concentrations of oil components, dispersal of oil may result in oil droplets, which can be perceived as food items and taken up by, for instance, copepods. This may pose a risk, especially during summer, when the copepods are feeding and lead to accumulation of oil components in these organisms. However, dispersal of oil during wintertime may not pose the same risk as the copepods do not feed during this season.

Calanus-species and larger crustaceans in the water column provide an important food resource for higher trophic levels, but also for pelagic larvae of potentially key species for an area. Oil spill in, for instance, high productive areas may thus have direct and indirect impacts on the ecosystem due to the toxic effects on organisms at lower trophic levels and the derived impact on the higher trophic levels due to changes in food availability. The toxic effects of oil components may hence be transmitted through the food web and cause so called cascade effects.

In such a case, dispersion of large oil spills may not be recommended in the summer time, as it may provide a risk of impacting ecosystem key species, for instance, copepods (*Calanus* spp.) by relatively large water volumes and areas with toxic oil concentrations depending of the dilution capacity of the water body. During winter month, the, e.g., copepods may be less sensitive to oil exposure and hence dispersion may be a solution for combating oil spill during that season.

It may also be expected that dispersion of smaller oil volumes may have only insignificant effects on the environment as earlier simulations results show that concentrations of dispersed oil in the water column is positively correlated with the volume of oil spill dispersed.

Analysis of potential effects of dispersed oil and ISB residues on seabed organisms

The seabed organisms (benthos), e.g., bivalves, corals, brittle stars, sea anemones, polychaetes etc., and demersal fish may not be impacted by toxic concentrations of dispersed oil if the area has sufficient depth. The plume of dispersed oil in toxic concentration will most often not reach greater depths than app. 20 m, according to earlier simulations and depending on dilution capacity of the water body. Oil spill from a well head at the seabed is not expected to cause stronger effects, as simulations of such oil spill show that the oil, due to oil's buoyancy and not very deep waters, will be transported to the sea surface at a fast rate.

However, if dispersed at the wellhead at great depths, it had been seen, in connection with the oil spill response strategy from the Macondo blow-out, that buoyant plume of dispersed oil can may be formed at greater depths.

The risk of indirect effects of toxic oil concentrations through food web impacts may be more imminent. If the biomass from the primary and secondary production in the water column above the seabed is reduced, food propagated to the benthic organisms will decline and the benthic community is less sustained. Bivalves, for instance, may provide food for seabirds and marine mammals.

From in situ burning, residues or particles may pose a risk of more direct effect on the benthos if they sink. Mats of partly burned oil may lie on the sea bottom. Environmental effects of these residues on benthos and, in particular, demersal fish has only been sporadic elucidated, but studies have been initiated.

Another factor, which may be relevant in areas with oxygen depletion, is the effect of the oxygen consuming degradation process of oil in the sediment. This is an impact yet to be investigated.

Analysis of potential effects of dispersed oil on the coastal ecosystems

If present, the richest part of the kelp forest is often in the upper part of the subtidal zone at wave exposed coastlines, which is also the depths where concentrations of dispersed oils may be highest, as shown in earlier simulations.

If an oil spill is not combated offshore and drifts towards a wave protected coast, and where the oil hence not will be dispersed naturally, it may beach. On such coasts, the richest tidal communities are found, which thus may be impacted by the beaching oil.

Protected coasts, may moreover have very limited self-cleaning potential, why there is risk of preserving oil for example buried in the beach sediment or between boulders and in crevices. Such oil may pose a source of continuous contamination to the environment. In connection with the *Exxon Valdez* accident in 1989, small amount of buried oil is still present on the coast, also surprisingly far away from the location of the accident.

Beaching oil will furthermore pose a risk for coastal fish spawning areas.

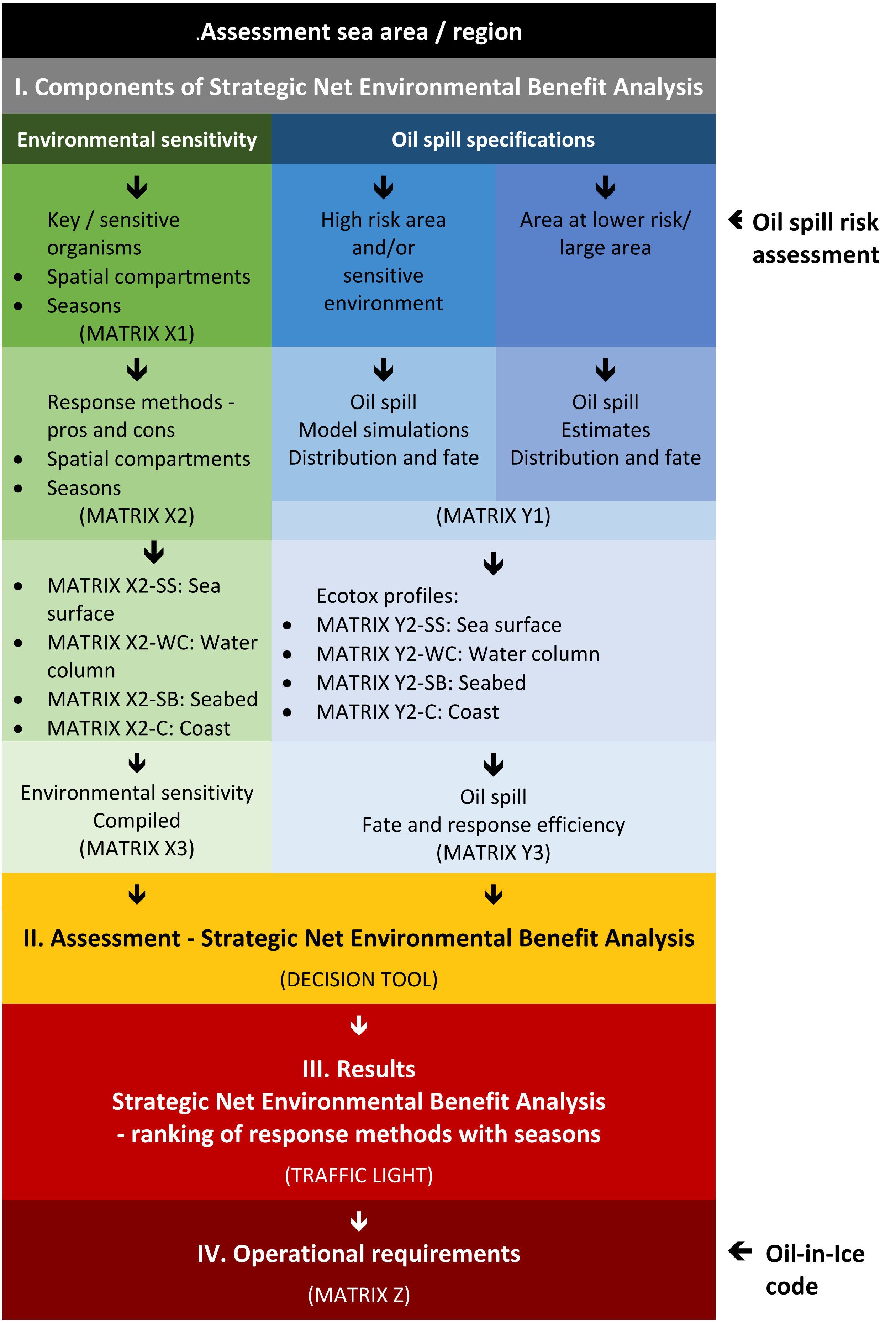

Figure 1. Flowchart for sNEBA components, assessment and results followed by operational requirements including oil-in-ice code.

Damage reduction

The damage reduction (Matrix X3) is defined as the reduction in negative environmental effect by the oil spill and oil spill responses. It is given in percent (%) for each oil spill response method and for each spatial compartment calculated from the efficiency estimates. The efficiency estimates of each response method are given for optimal use and conditions and based on Fritt-Rasmussen & Wegeberg (2017, and references herein).

sNEBA process

The components and steps in the strategic net environmental benefit analysis (sNEBA) for oil spill in a specific sea area is presented in Figure 1.

When an assessment area/region has been selected (0, black), the flow-chart shows the components and input to go into the analysis and form base for the assessments (I, grey). The gathering of this knowledge, which follows two tracks, 1) the environmental information needs (green); and 2) oil specifications, characterization and ecotoxicology (blue), is based on 6 matrices (X1-3 and Y1-3), including 8 sub-matrices (X2-SS, WC, SB, C and Y2-SS, WC, SB, C).

Hereafter the assessment – the strategic net environmental benefit analysis (sNEBA) – will follow (II, yellow), based on a decision tool.

At present, it is planned, that the results from the sNEBA (III, red) will be ranked with traffic light colours for intuitive comprehending and for each oil spill response method for each season (Figure 2). Please note as the development of the sNEBA tool now is on-going, changes to the matrices, including number, input and order, may occur after this deliverable.

FULL STOP The use of the oil spill response methods will not give an overall environmental benefit for this season
EXPERT JUDGEMENT The use of the oil spill response methods will have to be assessed by experts to evaluate the overall environmental benefit for this season
GO The use of the oil spill response methods will give an overall environmental benefit for this season

Figure 2. Traffic light to indicate the environmental recommendation of using a particular oil spill response method in a selected assessment area and for each of the four seasons, spring, summer, autumn and winter.

The results from the sNEBA will answer the question regarding "will we?" when considering using a particular oil spill response method, and then lead straight into the assessment of "can we?" by the operational requirements (IV, brown) (Figure 1). The matrix for the operational requirements is presented in D5.4.

Environmental matrices

Environmental sensitivity

MATRIX X1 – Key / sensitive organisms according to seasons

<table>
<tr><th>Season</th><th>Sea surface</th><th>Water column</th><th>Seabed</th><th>Coast</th></tr>
<tr><td>Spring</td><td>• Seabirds; migrating
• Marine mammals
• Marine turtles</td><td>• Plankton
• Pelagic fish; spawning, larvae
• Benthos spawning</td><td>• Benthos; bivalves, crustaceans, polychaetes, echinoderms
• Demersal fish
• Kelp</td><td rowspan="2">• Intertidal community organisms
• Kelp forest organisms
• Coastal fish</td></tr>
<tr><td>Summer</td><td>• Seabirds; migrating
• Marine mammals
• Marine turtles</td><td>• Plankton
• Pelagic fish; larvae
• Benthos spawning</td><td>• Benthos; bivalves, crustaceans, polychaetes, echinoderms
• Demersal fish
• Kelp</td></tr>
<tr><td>Autumn</td><td>• Seabirds; migrating
• Marine mammals
• Marine turtles</td><td>• Plankton
• Pelagic fish</td><td>• Benthos; bivalves, crustaceans, polychaetes, echinoderms
• Demersal fish
• Kelp</td><td rowspan="2">• Intertidal community organisms
• Kelp forest organisms
• Coastal fish</td></tr>
<tr><td>Winter</td><td>• Seabirds; migrating
• Marine mammals
• Marine turtles</td><td>• Pelagic fish</td><td>• Benthos; bivalves, crustaceans, polychaetes, echinoderms
• Demersal fish
• Kelp</td></tr>
</table>

MATRIX X2 - overview

Oil spill response method	Season	Sea surface (X2-SS)			Water column (0-50 m) (X2-WC)			Seabed (X2-SB)			Coast (X2-C)		
		Key organisms	Potential environmental effects		Key organisms	Potential environmental effects		Key organisms	Potential environmental effects		Key organisms	Potential environmental effects	
			Pros	Cons		Pros	Cons		Pros	Cons		Pros	Cons
Mechanical recovery	Spring												
	Summer												
	Autumn												
	Winter												
Dispersion	Spring												
	Summer												
	Autumn												
	Winter												
ISB	Spring												
	Summer												
	Autumn												
	Winter												
Do nothing	Spring												
	Summer												
	Autumn												
	Winter												

See text in separate matrices (X2-ss, wc, sb, c)

MATRIX X2 – SS (sea surface)

Oil spill response method	Season	Sea surface		
		Key organisms	Potential environmental effects	
			Pros	Cons
Mechanical recovery	Spring	• Seabirds; migrating • Marine mammals • Marine turtles	• Oil is removed from the environment	• Smother and toxic effects from non-recovered oil
	Summer	• Seabirds; breeding, moulting • Marine mammals • Marine turtles	• Oil is removed from the environment	• Smother and toxic effects from non-recovered oil
	Autumn	• Seabirds; moulting, migrating • Marine mammals • Marine turtles	• Oil is removed from the environment	• Smother and toxic effects from non-recovered oil
	Winter	• Seabirds; aggregations • Marine mammals • Marine turtles	• Oil is removed from the environment	• Smother and toxic effects from non-recovered oil
Dispersion	Spring	• Seabirds; migrating • Marine mammals • Marine turtles	• Oil is removed from sea surface	• Impact from dispersant on feather structure • Increased combined effects on feather structure from oil+dispersant
	Summer	• Seabirds; breeding, moulting • Marine mammals • Marine turtles	• Oil is removed from sea surface	• Impact from dispersant on feather structure • Increased combined effects on feather structure from oil+dispersant
	Autumn	• Seabirds; moulting, migrating • Marine mammals • Marine turtles	• Oil is removed from sea surface	• Impact from dispersant on feather structure • Increased combined effects on feather structure from oil+dispersant
	Winter	• Seabirds; aggregations • Marine mammals • Marine turtles	• Oil is removed from sea surface	• Impact from dispersant on feather structure • Increased combined effects on feather structure from oil+dispersant
ISB	Spring	• Seabirds; migrating • Marine mammals • Marine turtles	• Oil is removed from sea surface • Acute toxic volatile oil compounds are combusted	• Smoke and soot deposition • Burning residues • Hazardous compounds; dioxin, PAHs
	Summer	• Seabirds; breeding, moulting • Marine mammals • Marine turtles	• Oil is removed from sea surface • Acute toxic volatile oil compounds are combusted	• Smoke and soot deposition • Burning residues • Hazardous compounds; dioxin, PAHs

	Autumn	• Seabirds; moulting, migrating • Marine mammals • Marine turtles	• Oil is removed from sea surface • Acute toxic volatile oil compounds are combusted	• Smoke and soot deposition • Burning residues • Hazardous compounds; dioxin, PAHs
	Winter	• Seabirds; aggregations • Marine mammals • Marine turtles	• Oil is removed from sea surface • Acute toxic volatile oil compounds are combusted	• Smoke and soot deposition • Burning residues • Hazardous compounds; dioxin, PAHs
Do nothing	Spring	• Seabirds; migrating • Marine mammals • Marine turtles	• Some oil types may evaporate and/or naturally degrade relatively fast	• Oil smother • Toxic effects
	Summer	• Seabirds; breeding, moulting • Marine mammals • Marine turtles	• Some oil types may evaporate and/or naturally degrade relatively fast	• Oil smother • Toxic effects
	Autumn	• Seabirds; moulting, migrating • Marine mammals • Marine turtles	• Some oil types may evaporate and/or naturally degrade relatively fast	• Oil smother • Toxic effects
	Winter	• Seabirds; aggregations • Marine mammals • Marine turtles	• Some oil types may evaporate and/or naturally degrade relatively fast	• Oil smother • Toxic effects

MATRIX X2 – WC (water column)

Oil spill response method	Season	Water column (0-50 m)		
		Key organisms / processes	Potential environmental effects	
			Pros	Cons
Mechanical recovery	Spring	• Plankton • Pelagic fish; spawning, larvae • Benthos spawning	• Oil is removed from the environment	• Dispersion forced by mechanical activities
	Summer	• Plankton • Pelagic fish; larvae • Benthos spawning	• Oil is removed from the environment	• Dispersion forced by mechanical activities
	Autumn	• Plankton • Pelagic fish	• Oil is removed from the environment	• Dispersion forced by mechanical activities
	Winter	• Pelagic fish	• Oil is removed from the environment	• Dispersion forced by mechanical activities
Dispersion	Spring	• Plankton • Pelagic fish; spawning, larvae • Benthos spawning	• Dilution below toxic concentrations • Potential increase of degradations rate	• Oil is not removed from environment • Potential toxic oil concentrations • Chemicals are added to the effect of oil + cocktail effects of dispersant+oil • Uptake of oil droplets • Oxygen consumption
	Summer	• Plankton • Pelagic fish; larvae • Benthos spawning	• Dilution below toxic concentrations • Potential increase of degradations rate	• Oil is not removed from environment • Potential toxic oil concentrations • Chemicals are added to the effect of oil + cocktail effects of dispersant+oil • Uptake of oil droplets
	Autumn	• Plankton • Pelagic fish	• Dilution below toxic concentrations • Potential increase of degradations rate	• Oil is not removed from environment • Potential toxic oil concentrations • Chemicals are added to the effect of oil + cocktail effects of dispersant+oil • Uptake of oil droplets
	Winter	• Pelagic fish	• Dilution below toxic concentrations • Potential increase of degradations rate	• Oil is not removed from environment • Potential toxic oil concentrations • Chemicals are added to the effect of oil + cocktail effects of dispersant+oil • Uptake of oil droplets
ISB	Spring	• Plankton • Pelagic fish; spawning, larvae • Benthos spawning	• Acute toxic water soluble oil • compounds are combusted	• Sinking residues and particles from combustion
	Summer	• Plankton • Pelagic fish; larvae • Benthos spawning	• Acute toxic water soluble oil • compounds are combusted	• Sinking residues and particles from combustion

	Autumn	• Plankton • Pelagic fish	• Acute toxic water soluble oil • compounds are combusted	• Sinking residues and particles from combustion
	Winter	• Pelagic fish	• Acute toxic water soluble oil • compounds are combusted	• Sinking residues and particles from combustion
Do nothing	Spring	• Plankton • Pelagic fish; spawning, larvae • Benthos spawning	• Buoyant and surface drifting oil slick may not affect water column organisms	• Toxic concentrations from natural dispersion
	Summer	• Plankton • Pelagic fish; larvae • Benthos spawning	• Buoyant and surface drifting oil slick may not affect water column organisms	• Toxic concentrations from natural dispersion
	Autumn	• Plankton • Pelagic fish	• Buoyant and surface drifting oil slick may not affect water column organisms	• Toxic concentrations from natural dispersion
	Winter	• Pelagic fish	• Buoyant and surface drifting oil slick may not affect water column organisms	• Toxic concentrations from natural dispersion

MATRIX X2 – SB (seabed)

Oil spill response method	Season	Seabed		
		Key organisms / processes	Potential environmental effects	
			Pros	Cons
Mechanical recovery	Spring	• Benthos; bivalves, crustaceans, polychaetes, echinoderms • Demersal fish • Kelp	• Oil is removed from the environment	• In more shallow areas oil may reach seabed fauna from mechanical activities
	Summer	• Benthos; bivalves, crustaceans, polychaetes, echinoderms • Demersal fish • Kelp	• Oil is removed from the environment	• In more shallow areas oil may reach seabed fauna from mechanical activities
	Autumn	• Benthos; bivalves, crustaceans, polychaetes, echinoderms • Demersal fish • Kelp	• Oil is removed from the environment	• In more shallow areas oil may reach seabed fauna from mechanical activities
	Winter	• Benthos; bivalves, crustaceans, polychaetes, echinoderms • Demersal fish • Kelp	• Oil is removed from the environment	• In more shallow areas oil may reach seabed fauna from mechanical activities
Dispersion	Spring	• Benthos; bivalves, crustaceans, polychaetes, echinoderms • Demersal fish • Kelp	• Potential increase of degradations rate	• In more shallow areas dispersed oil may reach the sea bed fauna in toxic concentrations
	Summer	• Benthos; bivalves, crustaceans, polychaetes, echinoderms • Demersal fish • Kelp	• Potential increase of degradations rate	• In more shallow areas dispersed oil may reach the sea bed fauna in toxic concentrations
	Autumn	• Benthos; bivalves, crustaceans, polychaetes, echinoderms • Demersal fish • Kelp	• Potential increase of degradations rate	• In more shallow areas dispersed oil may reach the sea bed fauna in toxic concentrations
	Winter	• Benthos; bivalves, crustaceans, polychaetes, echinoderms • Demersal fish • Kelp	• Potential increase of degradations rate	• In more shallow areas dispersed oil may reach the sea bed fauna in toxic concentrations
ISB	Spring	• Benthos; bivalves, crustaceans, polychaetes, echinoderms • Demersal fish • Kelp	• Oil volume reduced and removed from the environment	• Uptake of sinking residues and water surface deposited particles from combustion by, e.g., filtration • Covering thallus surface may inhibit photosynthesis
	Summer	• Benthos; bivalves, crustaceans, polychaetes, echinoderms • Demersal fish • Kelp	• Oil volume reduced and removed from the environment	• Uptake of sinking residues and water surface deposited particles from combustion by, e.g., filtration • Covering thallus surface may inhibit photosynthesis

	Autumn	• Benthos; bivalves, crustaceans, polychaetes, echinoderms • Demersal fish • Kelp	• Oil volume reduced and removed from the environment	• Uptake of sinking residues and water surface deposited particles from combustion by, e.g., filtration • Covering thallus surface may inhibit photosynthesis
	Winter	• Benthos; bivalves, crustaceans, polychaetes, echinoderms • Demersal fish • Kelp	• Oil volume reduced and removed from the environment	• Uptake of sinking residues and water surface deposited particles from combustion by, e.g., filtration • Covering thallus surface may inhibit photosynthesis
Do nothing	Spring	• Benthos; bivalves, crustaceans, polychaetes, echinoderms • Demersal fish • Kelp	• Buoyant and surface drifting oil slick may not affect seabed organisms	• In more shallow areas untreated oil may smother seabed fauna
	Summer	• Benthos; bivalves, crustaceans, polychaetes, echinoderms • Demersal fish • Kelp	• Buoyant and surface drifting oil slick may not affect seabed organisms	• In more shallow areas untreated oil may smother seabed flora and fauna
	Autumn	• Benthos; bivalves, crustaceans, polychaetes, echinoderms • Demersal fish • Kelp	• Buoyant and surface drifting oil slick may not affect seabed organisms	• In more shallow areas untreated oil may smother seabed flora and fauna
	Winter	• Benthos; bivalves, crustaceans, polychaetes, echinoderms • Demersal fish • Kelp	• Buoyant and surface drifting oil slick may not affect seabed organisms	• In more shallow areas untreated oil may smother seabed flora and fauna

MATRIX X2 – C (coast)

Oil spill response method	Season	Coast		
		Key organisms / processes	Potential environmental effects	
			Pros	Cons
Mechanical recovery	Spring / summer	• Capelin • Intertidal community organisms • Kelp forest organisms	• Oil is removed from the environment	• Low efficiency may allow oil to reach coast • Risk for effects on growth and reproduction
	Autumn / winter	• Intertidal community organisms • Kelp forest organisms	• Oil is removed from the environment	• Low efficiency may allow oil to reach coast • Risk for effects on growth and reproduction
Dispersion	Spring / summer	• Capelin • Intertidal community organisms • Kelp forest organisms	• Oil is combated offshore	• In more shallow areas dispersed oil may affect kelp and associated fauna
	Autumn / winter	• Intertidal community organisms • Kelp forest organisms	• Oil is combated offshore	• In more shallow areas dispersed oil may affect kelp and associated fauna
ISB	Spring / summer	• Intertidal community organisms • Kelp forest organisms	• Oil is combated offshore	• Floating residues may reach the coast and leak toxic compounds
	Autumn / winter	• Intertidal community organisms • Kelp forest organisms	• Oil is combated offshore	• Floating residues may reach the coast and leak toxic compounds
Do nothing	Spring / summer	• Capelin • Intertidal community organisms • Kelp forest organisms		• Smother and toxic effects on organisms
	Autumn / winter	• Intertidal community organisms • Kelp forest organisms		• Smother and toxic effects on organisms

MATRIX X3 (Environmental sensitivity, compiled and commented)

Oil spill response method	Season	Sea surface	Score	Water column	Score	Seabed	Score	Coast	Score
Mechanical recovery	Spring								
	Summer								
	Autumn								
	Winter								
Dispersion	Spring								
	Summer								
	Autumn								
	Winter								
ISB	Spring								
	Summer								
	Autumn								
	Winter								
Do nothing	Spring								
	Summer								
	Autumn								
	Winter								

Oil spill specifications

Oil spill characteristics

MATRIX Y1

Oil type	Oil volume released (rate/total)	Sea water volume oil contaminated	Sea surface area oil contaminated (km^2)	Evaporation (%)	Weathering: water content	Weathering: viscosity	Weathering: density	Trajectory
Crude oils								Map
Raffinated oils								Map

Ecotoxicological profiles and information for each spatial compartment

MATRIX Y2

	Smother effects	Exposure effects	Effects by uptake	Effect concentration EC_{50} mg / L[1]	Lethal concentration LC_{50} mg / L[2]	Population effects	Cascade effects	Sea water volume of EC_{50} conc.	Sea water volume of LC_{50} conc.	Sea surface area effected by EC_{50}/LC_{50} conc. (km^2)	Shoreline potentially effected by smothering (m/km)
Organism(s) for each spatial compartment, e.g.: Seabirds Copepods Pelagic larvae Macroalgae											

[1]Concentration at which tested population is 50% effected compared to maximal effect. [2]Concentration at which 50 % of tested population is dead.

Oil spill fate and damage reduction from response

MATRIX Y3

Oil spill resp. methods	Efficiency (%)	Season	Sea surface	Damage red. (%)	Water column	Damage red. (%)	Seabed	Damage red. (%)	Coast	Damage red. (%)
Mechanical recovery	20-30	Spring	• Bouyancy • Slick thickness • Sea ice incapsulation		• Oil dispersed forced by mechanical activity					
	20-30	Summer	• Bouyancy • Slick thickness		• Oil dispersed forced by mechanical activity					
	20-30	Autumn	• Bouyancy • Slick thickness		• Oil dispersed forced by mechanical activity					
	20-30	Winter	• Bouyancy • Slick thickness • Sea ice incapsulation		• Oil dispersed forced by mechanical activity					
Dispersion	80-100	Spring	• Bouyancy • Slick thickness • Sea ice incapsulation		• Dilution capacity • Sea ice		• Depth of dispersion • Dilution capacity • Sedimentation			
	80-100	Summer	• Bouyancy • Slick thickness		• Dilution capacity		• Depth of dispersion • Dilution capacity			
	80-100	Autumn	• Bouyancy • Slick thickness		• Dilution capacity		• Depth of dispersion • Dilution capacity			
	80-100	Winter	• Bouyancy • Slick thickness • Sea ice incapsulation		• Sea ice		• Depth of dispersion • Dilution capacity			
ISB	70-90	Spring	• Bouyancy • Slick thickness • Sea ice incapsulation		• Sinking of residues		• Sedimentation of residues			
	70-90	Summer	• Bouyancy • Slick thickness		• Sinking of residues		• Sedimentation of residues			
	70-90	Autumn	• Bouyancy • Slick thickness		• Sinking of residues		• Sedimentation of residues			
	70-90	Winter	• Bouyancy • Slick thickness • Sea ice incapsulation		• Sinking of residues		• Sedimentation of residues			
Do nothing	0-100	Spring	• Oil in icePhoto oxidation		• Microorganisms					
	0-100	Summer	• Photo oxidation		• Microorganisms					
	0-100	Autumn	• Photo oxidation		• Microorganisms					
	0-100	Winter	• Oil in ice		• Microorganisms					

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