

ERA Acute

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The ERA Acute methodology will be the new industry standard environmental risk assessment (ERA) method on NCS in 2019, replacing the currently used MIRA method.

ERAs are carried out with the purpose to assess and ensure acceptable environmental risk for oil and gas offshore operations, aiming to minimize the risk to the environment. ERA Acute has been developed by leading ERA experts, and provides the mean to evaluate the potential risk from an acute oil spill in the marine environment.

The ERA Acute method includes four environmental compartments: the sea surface, shoreline, water column and seafloor. ERA Acute uses input data from an oil spill trajectory model and biological resource data, and calculates the potential environmental risk (impact and recovery time) for biological resources in all compartments.

The ERA Acute software tool provides relevant visualization of the output results from the ERA Acute method, such as maps, graphs and tables. The tool has applications for environmental risk management, such as a risk matrix and a comparison tool which may support a spill impact mitigation analysis (SIMA).

Report 1: EIF Acute Damage and restoration modelling (2006)

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The report (2006) presents the EIF Acute damage and restoration modelling for environmental risk assessment of acute discharges, as a precursor of the ERA Acute method development.

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STATOIL ASA

EIF ACUTE DAMAGE AND RESTORATION
MODELLING 2005

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Summary: <p>The EIF Acute model has been developed in cooperation between Statoil, Hydro, SINTEF and DNV. This report describes the finalised damage and restoration modelling carried out by Hydro and DNV in 2005, based on the work by Hydro and Alpha in 2004. The theory of function of the three levels of EIF calculations, as well as the implementation into a GIS (ArcView EIF Extension) and a user guide is described. EIF is a three-compartment impact assessment model, used for assessing impacts of acute oil spills. It has three levels of increasing level of detail.</p>		

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1 CONCLUSIVE SUMMARY

The EIF Acute model has been developed in cooperation between Statoil, Hydro, SINTEF and DNV. This report describes the finalised damage and restoration modelling carried out by Hydro and DNV in 2005, based on the work by Hydro and Alpha in 2004. The theory of function of the three levels of EIF calculations, as well as the implementation into a GIS (ArcView EIF Extension) and a user guide is described. EIF is a three-compartment impact assessment model, used for assessing impacts of acute oil spills. It has three levels of increasing level of detail.

Level I is a simple analysis of the area where exposure exceeds a threshold level considered to be critical to the most sensitive resources in each compartment. The Level I EIF value is area of the sum of all grid cells where the Level I criterion is met.

Level II includes the probability of presence of resource in the calculation. The Level II EIF value is area of the sum of all grid cells where the Level II criterion is met.

Level III is different from the other two. The EIF value is called Resource Impact Factor (RIF) and is calculated based on population losses, impact-, lag- and restoration times. It is resource specific.

2 INTRODUCTION

2.1 DNV and Hydro work 2005

The compartment-specific damage-functions initially developed in 2004 and finalised in 2005 have been finalised and implemented in the EIF ArcView model tool.

Norsk Hydro and DNV have cooperated to finalise damage functions in the sea surface and shoreline compartment. The damage parameters $p_{r,let}$ and $p_{r,ex}$ suggested in 2004 are further described and developed in this document, and restoration parameters for sea surface and shoreline have been finalised in cooperation between DNV and Hydro. Available knowledge of relationships between oil amounts, accident circumstances, area coverage as well as damage extent and duration, have been studied and compiled for input to the damage functions, although there are no identifiable relationships between dose and response for acute oil spills, as is the case when lethality is caused by toxic action alone. The relationships between oil amounts and damage levels that are implemented in the EIF model are therefore based on practical adaptations of the literature data.

Results from the DamEShore-model are implemented in EIF by carrying out a pre-calculation of potential “restoration-time” factors from the DamEShore model applicable for each 10x10 km grid cell. In connection with work carried out regarding implementing use of Pi-values in MIRA (OLF, 2005), the cut-off of Pi-values at 0.5 has been revised, and a dataset of sensitive shoreline segments with Pi-values exceeding 0.33 has been chosen, thus including more segments. This cut-off has been implemented into the EIF-model as well, in order to obtain conformity between the two models.

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The probability of lethality for fish resources, the two parameters “injury-96h” and “injury-total” supplied by the oil spill trajectory model OSCAR (SINTEF) are the two $p_{r,let}$ –values for water-soluble components and oil droplets respectively for water column (calculated lethality as a function of the dose). These values have been implemented into the damage and restoration model in EIF at level III. The rationale behind choice of threshold values and dose-response-functions are the scope of SINTEF/Statoil work, and are therefore not described further in this document.

The restoration modelling of impacted resources for the most frequently used resource groups has been revised and finalised at level III. The resources have been grouped with respect to common restoration parameters, and adequate restoration growth models have been selected for the resources for which distribution data are developed. Experience from oil spills shows that restoration may be impaired and/or delayed by oil residues in the environment. The model theory allows for calculation of lag-times before restoration begins, but it was decided by the project not to include this parameter in the currently implemented datasets.

Theoretical restoration models have been adjusted to reflect empirical observations of restoration time, this introducing overshoot into the logistical restoration model.

The model has been finalised with respect to implementation in ArcView, and the restoration parameters previously presented as Excel worksheets in 2004 (Brude, 2004b and Spikkerud & Brude, 2004b) are now implemented in the ArcView EIF Extension.

This document also contains a user guide for the ArcView EIF Extension.

2.2 Background

2.2.1 Prerequisites and previous work

Basic assumptions and prerequisites for development of EIF are described in the EIF Concept design and “Risk Functions and Model Design” (Johansen et al., 2003; Østby et al., 2003). Additional assumptions that are made are described in the relevant sections describing model development. The EIF level III model is a compartment-based model, based upon the common principles of ERA’s, in which risk is characterized on grounds of exposure characterisation and hazards characterisation. The extent of acute lethal effects and duration of the following population impacts are considered (not chronic sub-lethal effects of acute oil exposure directly, although a lag-time for recovery may be assessed, causing failure to recover). Currently, lag-times are not implemented, but the model and ArcView application allows for later inclusion of such parameters. An important prerequisite for EIF is that it should work in a robust and transparent manner. Although the best quality data sets available to the project team at present are data covering the Norwegian coast and waters, it is important that EIF should be globally applicable. Resource data detail and level will decide whether EIF Level II or III may be used.

3 THEORETICAL FUNCTIONS OF EIF – ALL LEVELS

3.1 Overall damage functions

The damage functions quantify the loss of individuals on basis of exposure to oil and the physiological sensitivity and ecological vulnerability of the resource in question. A resource may be a species or a habitat. For further information about the choice of model resources, the reader is referred to Spikkerud *et al.* (2004).

Theory and functioning of pilot versions of risk functions of EIF Level I, II and III have previously been described in Spikkerud & Brude (2004). On finalisation of the functions, adaptations and adjustments are made in the current document, based on previous reports and updated where relevant.

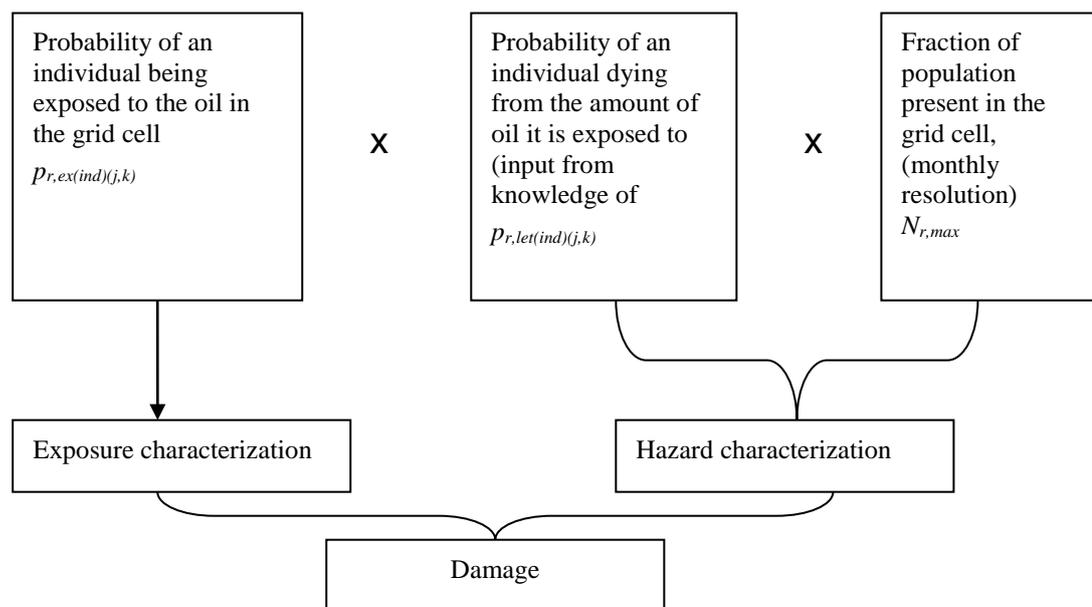


Figure 3-1 Overall sketch of the EIF/RIF damage calculation process.

The three-level model implies that there are three levels of increasing detail and sophistication: Levels I and II are iterations of each other, in that the resulting EIF value is an “area of impact” – quantified as the area where damage occurs and identified by geo-referencing of the area. By adding data on probability of presence of resources, the results will be more sophisticated at level II compared with level I. The difference between these two levels are that in the first level – the resource is indirectly present (i.e. probability of presence = 1), and in the second level, the probability of presence is included in the formula, and is a probability between 0 and 1. Level III brings the assessment a step further by further refining the probability of lethality to any individual organism as a function of exposure probability (tendencies to be exposed due to behavioural factors) and lethal effect given exposure (physiological sensitivity)

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to define the damage extent. The function at level III also includes restoration times for the resources involved, the level III calculation is thereby resource specific and has been denominated “Resource Impact Factor “ (RIF). It can be calculated for each resource in a grid cell, thereby the contribution of any given cell to the overall damage (calculated as population loss) can be georeferenced, but the total RIF-value (as EIF-value at levels I & II), is given as a total potential statistical “risk” value that is expected to impact the resource in the case that an oil spill of the size of the DSHA should occur.

An EIF-project will be carried out as follows:

- 1) Scoping of the EIF assessment project – which questions are to be answered? E.g.
 - a) Risk level for alternative options with different DHSAs
 - b) Quantification of risk reduction potential of different risk reducing options
 - c) Risk level to individual resources or representatives of resource groups
 - d) etc.
- 2) Resource selection and data collection/adaptation (distributions, damage and restoration parameters). (Spikkerud & Brude 2004b). EIF/RIF can be calculated for as many resources as desired, a technical minimum is one resource per compartment.
- 3) Oil drifts data simulation. The oil drift data should be in the format specified in Johansen (2006).
- 4) Post-processing of oil drift data and resource data in ArcView (See user guide for ArcView EIF Extension).
- 5) Calculation of EIF and RIF values.
- 6) Interpretation of results and reporting

The steps 3) and 5) are described in this document. Discussion point for interpreting the results are also given throughout the current document.

3.2 Level I EIF Functions

3.2.1 Input data necessary for EIF level I – threshold values

Input data necessary at level 1 are in addition to oil drift data, the threshold values for harmful effects. Because the resources are only “indirectly” present at level I, the threshold values are chosen for the assumed most sensitive resources, and no resource data are necessary. Where in previous reports, a PNEC value was used, the work carried out at level III has been used in level I and II using 1 % lethality as the lower threshold value for damage. In the work of 2005, we therefore introduce the concept of p_{let} at level I, although any applicable value of a threshold may be used.

Threshold values are:

Water column: The dose that gives a lethal response of 1 % is used. Since the p_{let} values for toxicity due to water soluble components at 96 hours and water-dispersed oil droplets are provided as separate values by the oil drift model, based on the dose-response-curves of these two different oil “fractions” and the concentrations of soluble components (time-averaged) and droplets, a check is performed to see which of these values leads to the higher damage. Implicitly, at this level it is assumed that all individual organisms will be equally affected by lethal action when the concentration is above the threshold value, denoted “TV.”

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Shoreline: At 14 mm oil film thickness, 100 % lethality is observed, and a linear increase in mortality from 0 – 100 % between 0 and 14mm is assumed (Hoell, Espen, *pers. comm.* 2004). This is used with full detail in level III. At level I the threshold value TV of 1 % mortality equalling 0.14 mm is used. The film thickness is calculated from the parameter oil amount (tonnes)/ km coastline and assuming a shoreline average width of 10 m. This leads to a threshold value of $Q_{oil} = 1$ tonne/km coastline. In the intertidal zone, damage can also occur from toxic effects in the water column. Intertidal crustaceans are equally sensitive as fish eggs and larvae (Hoell, Espen *pers.comm.*, 2004), and a check is therefore performed to see whether either of the two p_{ter} -values from the water column compartments lead to a 1 % mortality or higher in addition to a check of the film thickness.

Sea surface: In the sea surface compartment, sea bird plumage soiling sensitivity is used as the most sensitive endpoint. A film thickness of 10 μm is considered to be the highest film thickness that can be tolerated by swimming birds (Hoell, Espen, *pers. comm.*, 2005). As a threshold for exposure probability, area coverage of 1 % of the grid cell together with film thickness > 10 μm is used.

3.2.2 Level I calculation and output

EIF Level I is basically a calculation of the influence area of the oil exposure. The unit is km^2 . A prerequisite of the project, the level I EIF value is calculated in line with the PEC>PNEC-approach of the EU-Technical Guidance Document on Risk Assessment (EU-TGD <http://ecb.jrc.it/Technical-Guidance-Document/>), but has been changed slightly from the EU-TGD as the threshold value for when damage occurs in EIF is not identical to PNEC in all compartments, as the damages are not solely the results of toxic action(s), but are also the result of mechanical mechanisms of harm such as oiling of fur/plumage and smothering. The values used in EIF/RIF are therefore denoted “threshold values” (see above), although the basic principles are the same.

At Level I, the value of EIF is:

$$EIF(I) = n_I \times 100 \text{km}^2$$

Where: n_I = number of grid cells, j , where the probability $p(\text{PEC} > \text{Threshold value}) > 0.05$ in at least one compartment.

All grid cells are checked for all scenarios from the post-processed oil drift modelling for whether the oil concentration/amount (depending on compartment) in the grid cell and compartment exceeds the threshold(s). The number of times (scenarios) where this is true is counted and the percentage is recorded as the value “Exposure probability” for this grid cell. The grid cells where this “Exposure probability” > 0.05 are included in the summarisation of n_I . Thereby, the EIF level I area represents the area where there is a more than 5 % probability of exceeding the threshold value(s) for damage.

3.3 Level II EIF Functions

3.3.1 Input data for EIF level II – threshold value and resource data

At level II, the same input data should be used as for level I with respect to threshold values and oil drift parameters. In addition, the probability of presence of a sensitive resource is included (See Spikkerud *et al.* 2004). These probability data should have a monthly resolution and in the following format:

ID: Unique 10x10 km grid cell id

Pjan-Pdec: Monthly values for probability of presence in each grid cell

3.3.2 Level II calculations and output

Level II is also grid-referenced, but also refines the exposure characterisation by adding data on the probability of presence of oil-sensitive natural resources (Østby *et al.*, 2003b). It identifies “overlap” between the probability of presence of resources and the area with more than 5 % probability that $PEC > TV$ in at least one compartment. The unit in level II is km^2 .

$$EIF(II) = n_{II} \times 100km^2$$

Where n_{II} = number of grid cells, j, where: $p(PEC > TV) \times p(presence) > 0.05$

This cut-off ensures that in the outer parts of the influence area, the probability of presence of a sensitive resource must be higher for a grid cell to be included, than in the inner parts where there probability of exposure is higher.

For each 10x10 km grid cell, the resource with the highest potential impact is registered and can be shown for each compartment. An *exposure probability* value showing the value of the product: $p(PEC > TV) \times p(presence)$ can be shown for each grid cell, illustrating the contribution of each compartment to the total EIF level II value.

3.4 Level III functions – overall functions

3.4.1 Level III specifics

The 2005 EIF ArcView Extension has implemented both the level III damage functions and the compartment and resource-group specific restoration functions, following exposure and hazard identification.

Level III calculations are carried out in two distinct steps – calculation of damage by population losses, and assessment of restoration. This chapter therefore has a different structure than the previous description of the other two levels.

3.4.2 Output from EIF Level III – Resource Impact Factor

The final end point of EIF level III is the resource-specific impact factor, the RIF. It is shown summarised as the total RIF for each resource in the compartments, and partial population losses in individual 10 x 10 km grid cells may be shown in a map.

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The theoretical process of damage and recovery is illustrated in Figure 3-2, the rationale for choice of this model is further described in Østby *et al.* (2003).

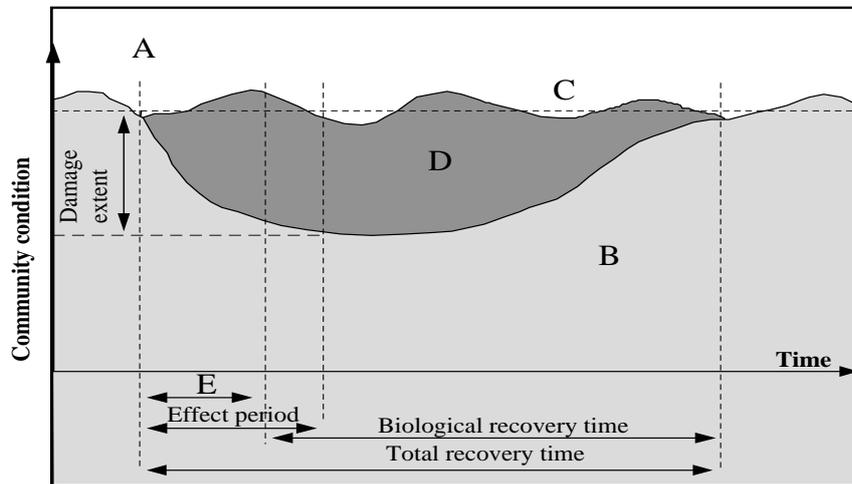


Figure 3-2 The impact of an oil spill on the condition of the community (or population). The sensitivity is expressed as the shaded area (D). A: the time at which the contaminant strikes the resource; B: recovery process after the initial exposure; C natural conditions, including fluctuations without contamination; E: initial impact period. Modified from Lein *et al.* (1992).

3.4.2.1 Linearization of the functions of RIF

The above complex functions were linearized and simplified during the work of 2004. For each resource (or resource group where applicable), there are parameters of impact and restoration that must be given as input. In the 2005 implementation, the resources have been grouped with respect to common parameters, and the process was therefore also automated, where the pilot version depended on manual input.

The parameters describe the affected population and the corresponding theoretical recovery function. Recovery rates could vary with the fractions of a population that was affected (i.e. density dependent recovery rates). Recovery functions, although continuous in a biological sense, have been simplified to a linear relationship between damage extent and damage duration. The potential resource impact expression for a resource could be expressed as:

$$\text{RIF} = \text{Rf}(b)$$

Where:

b = Affected population (%)

Rf = Theoretical recovery function

RIF = Damage integral (area) i.e. potential impact from the given dose of oil

The affected population b will give the initial damage extent, (fraction of initial population, $N_{max}=1$) in the linearized expression of the recovery function (see figure below). Affected population b can be calculated as an average value for a single grid cell over all scenarios and as a sum of all the average values for all cells.

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In order to provide simplification enough for EIF modelling purposes, the approach in Figure 3-2 has been simplified as shown in Figure 3-3. An important prerequisite for EIF level III is that the model should be possible to run also when there are limited data on many of the biological parameters necessary for complex calculations of fluctuating recovering and declining populations shown in Figure 3-2. Providing that adequate data are available for resource distributions other parameters may be simplified to match more available restoration data.

At Level III, the population density distribution given as fraction of population present in a 10 x 10 km grid cell at a monthly resolution is needed to calculate the initial level of damage (i.e. proportion of original population that is affected, b (%)). In addition, in order to express the potential total impact this has on the resource at risk, duration of damage must be given in terms of the theoretical recovery potential for the resource. For some resources at risk, for instance some shoreline communities and species whose restoration is prohibited by residual oil, a response time lag will occur before the initial damage extent is reached and recovery can commence. This can be accounted for by adding the integral within this time lag (t_{lag} in Figure 3-3) in addition to the integral from the impact (t_{imp}) and recovery time (t_{res}) periods. The potential impact, the area formed by the functions, is the RIF value for each resource. Currently, common restoration parameters have been implemented in the ArcView EIF Extension, but the parameter t_{lag} has not been assigned a value. The model is programmed so that this parameter may easily be implemented at a later stage.

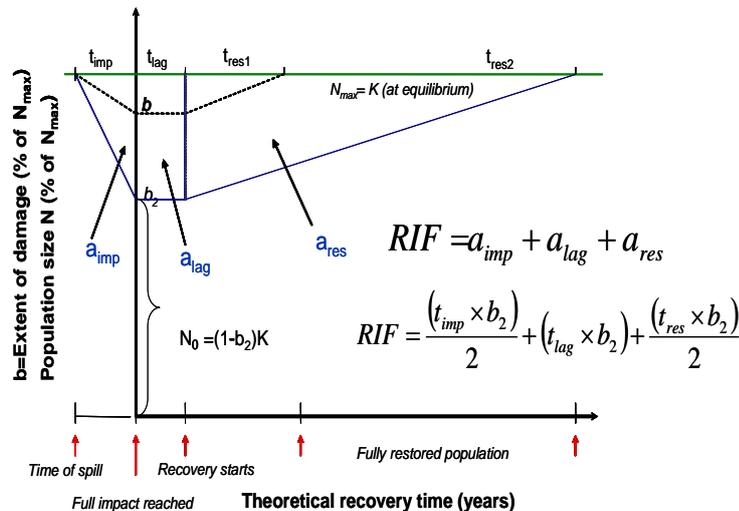


Figure 3-3 Resource Impact Factor (RIF) calculated from the linear functions of damage and recovery of an oil-sensitive resource. RIF is calculated for a resource as a total over all grid cells, using an average population loss b over all scenarios. Here, two examples are shown, with two levels of impact. N_{max} = Size of population before impact assumed to be at ecological equilibrium (denoted K), N_0 = Population left after full impact, b = size of impact (relative loss of population), t_{imp} = duration of impact, t_{lag} = duration of lag-phase before restoration can begin, t_{res} = duration of restoration time (years).

EIF is calculated in two steps, firstly calculation of population loss b , and secondly, modelling of restoration time as a function of population loss, and thereafter the impact factor for the given resource, denoted RIF.

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Implementation of the method on an individual resource level implies theoretical knowledge of damage and population dynamics for the selected sensitive resources, therefore rates of recovery suitable for identification of the extent and duration of the damage must be found for all these resources. Theoretically, for each sensitive resource chosen on bases of the criteria outlined in Spikkerud *et al.* (2004a), there must be enough data in a data set to provide the parameters of restoration and impact, however, the resource groups have been grouped according to best available knowledge, and the parameters implemented as resource attributes or formulas in the model.

3.4.3 Calculating the size of impact –b

The size of the impact is determined by exposure and hazard characterisation, i.e. by determining the environmental dose, the probability of an individual being exposed to oil if present in the grid, and the quantitative relationship between dose and lethality.

EIF Acute Level III is a compartment model (Johansen *et al.*, 2003), where resources (species or species groups) are exposed in one compartment to which they are ascribed with a monthly resolution. Like Level I and II, step one of Level III is grid based, allowing geographical visualisation of contribution of each cell to total impact.

In step 1, two impact parameters are calculated for *each resource at a monthly resolution*.

- N_{max} is the pre-spill population. The theoretical assumption is made that this population is “stable” at the carrying capacity, usually denoted K in ecological literature. N_0 is the population post-spill, when full impact has been reached, and before restoration is begun or completed back to 100 % of N_{max} . Overshoot is included in the restoration equation. This will be explained in Section 3.5.4.
- b_j = affected fraction of present population of a resource, in a given grid cell j , ($N_{max,j}$ = fraction of $N_{max} = 1$ present in the grid cell j before the spill occurs) calculated by the model by input of parameters outlined in Section 3.4.6. This value of population loss in each grid cell is registered by the ArcView EIF Extension, and the cells where this $b_j > 0$ contribute to the total sum of b . The size of b_j is calculated as an average over all scenarios, and it’s contribution to the total impact size b can be visualised in a map.
- b = affected fraction of total population of a resource, ($N_{max} = 1$) calculated by the model by input of parameters outlined in Section 3.4.7. N_0 is the remaining fraction of the population immediately after impact. The value of b is simply calculated as the sum of all grid cell b -values.
- All individuals in a grid cell will not be subjected to a lethal effect, and the end point RIF value should be based on statistics, therefore the probabilities of exposure and lethality are introduced:
 - For a resource, certain behavioural aspects will determine the biologically inherent tendency to be exposed. This is denoted p_{exp} . Its value is a 0-1 probability.
 - For the same resource, intra-species variation in physiological sensitivity is represented by p_{let} , the probability of lethal effect for any given individual within

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a population of the resource, given the same exposure. Its value is also a 0-1 probability.

- The numerical values of threshold lethality values cut-offs and the function and p_{let} . for the water column is within the scope of Statoil/SINTEF: (Johansen, 2005)>.
- Sea surface and shoreline p_{let} and p_{ex} are given in this document, based on the work carried out at Hydro (Hoell *pers. comm.* 2005)). Threshold values (TV) are obtained from various parameters of the oil drift data as in levels I and II.

Combined the above parameters form the first step – calculation of b . The parameters are further described in the following sections.

Differently from the Levels I and II, a grid cell is included in the further calculations if $p(\text{PEC}>\text{TV})>0.05$.

3.4.4 Probability of an individual organism being exposed p_{exp}

3.4.4.1 p_{exp} water column

The probability of a pelagic resource (e.g. fish) being exposed to hydrocarbons (HC) in the water column is dependent on the coincident presence of HC over the threshold level and presence of resource. Data on vertical distribution of HC within the water column of a grid cell and the vertical distribution of resource in the same column will determine this. E.g. fish larvae may be phototactile in certain periods, in which case they will not be evenly distributed within the water column. Currently, such information is lacking, the probability of exposing a resource in the water column is therefore set = 1.

3.4.4.2 p_{exp} sea surface

Probability that any given individual of the resource (i.e. bird, seal etc.) will be exposed to oil in the grid cell should be calculated in order to modify the assumption that all individuals in any exposed grid cell are affected. Probability of exposure of an individual is seasonally dependent, and also dependent on movements and area coverage of oil:

$$p_{exp} = f(\text{area coverage})$$

If the cell is 100 % covered with the oil spill, the probability of exposure of individuals present can be set to 100 %. However, if the cell is covered with x % of the area this will reduce the probability of exposure of each individual. Animals may be grouped on basis of their behaviour (French-McCay, 2003) and their probability of oil encounter estimated. French-McCay uses a threshold thickness of oil equalling 10 microns (approx. $10\text{g}/\text{m}^2$) thick oil, based on data on minimum dose to impact a bird and calculations. French-McCay (2003) provides a table of the probabilities of oil mortality for several species (Table 3-1). Biologically, the value is a combination of the encounter-probability *and* the physiological sensitivity, but since the two factors p_{exp} and p_{let} are to be multiplied the values given by French-McCay may be regarded as being p_{let} -values. The p_{exp} is therefore proportional to the area coverage, producing same numerical result (see Section 3.4.5.2).

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3.4.4.3 p_{exp} shoreline

p_{exp} in the shoreline compartment should theoretically vary with the substrate's ability to sequester oil, degree of exposedness with respect to location in the outer, exposed coastal areas or in the more sheltered areas etc. However, for the data set of the Norwegian coastline included, these two parameters are already integral parts of the $P_i > 0.33$ cut-off. p_{exp} is therefore set = 1. Oil amounts Q_{oil}/km coast are used for calculations of lethal effects given exposure has taken place, modifications regarding different types of coastal segments are attributes of the data set, and are included in the p_{let} calculations of the shoreline compartment. In other geographical areas, the p_{exp} factor may be used differently and independently, e.g. if substrate data are available, and the necessary impact and time factors must be ascribed to the certain substrate types and/or wave-exposure degrees.

3.4.5 Probability of lethal effect on an individual exposed organism p_{let}

The values determining the probability of an individual of a resource suffering a lethal effect has been denote p_{let} . As described in Spikkerud & Brude (2004), it's value represents the physiological sensitivity to oil, either due to chemo toxic effects or mechanical soiling effects of plumage or fur, or smothering effects on organisms in the inter-tidal zone/shoreline.

3.4.5.1 p_{let} water column

This parameter is provided by the oil drift simulations as the parameter "injury", representing the probability of lethal effect towards any individual of the sensitive representative species (fish eggs and larvae). In the water column, two values are provided. As mentions under level I, the p_{let} values for toxicity due to water soluble components at 96 hours and water-dispersed oil droplets are provided as separate values by the oil drift model (Johansen, 2006), based on the two dose-response-curves of these two different oil "fractions" and the concentrations in each grid cell of soluble components (time-averaged) and droplets of total hydrocarbons. At level III the total "dose-response" curve is used, whereas at levels I and II, the dose that gives 1 % lethality is used as a threshold value, denoted TV, above which the lethality is set to 100 %, At level III the picture is modified according to the theoretical probability of each individual suffering a lethal effect, simplified by assuming that sensitivity is normally distributed within the population. For level III, p_{let} is given directly by the oil drift data, for both components and oil droplets. The highest value of the two, implying the highest lethal probability is used in the calculations of b .

3.4.5.2 p_{let} sea surface

French-McCay (2003) states the combined probabilities of encountering and dying from oil exposure of certain sea birds and mammalian species to be the values given in Table 3-1. In the work of 2005, the sea surface exposure probabilities p_{exp} were not finalised, and it was suggested to use French-McCay's values as p_{exp} , e.g. for sea birds, and $p_{let} = 1$. However, finalisation of the work at Hydro indicates that p_{exp} should be a function of area coverage as suggested in section 3.4.4.2, therefore the combined values are in the current model implemented as p_{let} -values.

Mammals: Furbearing marine mammals have a combined mortality value of 0.75 (French-McCay, 2003). Since these animals depend on their fur for insulation, we may expect the probability of dying if oiled to be $p_{let} = 0.75$. Grey seal and harbour seal pups are dependent on fur in the earliest life stages, and p_{let} is therefore set to 0.75 for this part of the population in the breeding period. For cetaceans, pinnipeds such as adult grey seals and harbour seals, manatees

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and sea turtles, the combined mortalities (p_{exp}) \times p_{let} have been estimated to be 0.01 (French-McCay, 2003), but based on an evaluation of other data available, it was decided to use a p_{let} value of 0.35 for adult seals (Hoell, Espen, *pers. comm.*, 2005). However, the resource data include both pups and adults, and therefore the p_{let} is weighted according to the partition between adults and pups in the breeding season. In breeding season months, the p_{let} -value for pinnipeds is 0.42, in the other months the value is 0.35.

Sea birds: For mechanical oiling effects, the probability of death once oiled, p_{let} is set = 0.99 for pelagic diving species of sea birds such as alcids, and other sea birds/water fowl with a high exposure probability. For birds any amount of oil is potentially lethal once the threshold thickness has been exceeded. It should therefore be noted however, that the values in the table are combined values of exposure- and sensitivity, and that sea birds' physiological sensitivity is expected to be the same between species. However, since the probability of exposure within a grid cell also is a function of area coverage, and the product of the factors is the same for mathematical reasons, the biological fact has academic relevance, but is simplified for mathematical implementation in the ArcView EIF Extension, and the below table is implemented as p_{let} .

A film thickness of 10 μ m is considered to be the highest film thickness that can be tolerated by swimming birds, a check is therefore performed to determine the film thickness on the sea surface (Hoell, Espen, *pers. comm.*, 2005) at level III also.

Table 3-1 Mortalities of various wildlife species as combined function of p_{exp} \times p_{let} . Values from French-McCay (2003), with the exception of pinnipeds, for which modifications have been carried out (see text)*.

Bird species group	Probability	Habitat
	Error! Objects cannot be created from editing field codes.	
Dabbling waterfowl	0.99	Intertidal and landward subtidal
Nearshore aerial divers	0.35	Intertidal and landward subtidal
Surface seabirds	0.99	All intertidal and subtidal
Aerial seabirds	0.05	All intertidal and subtidal
Wetland waders and shorebirds	0.35	Wetlands, shorelines, seagrass beds
Surface birds in seaward only	0.99	All seaward intertidal and subtidal
Surface diving birds in seaward only	0.35	All seaward intertidal and subtidal
Surface birds in landward only	0.99	All landward intertidal and subtidal
Surface diving birds in landward only	0.35	All landward intertidal and subtidal
Aerial divers in landward only	0.05	All landward intertidal and subtidal
Surface diving birds in water only	0.35	All subtidal
Aerial divers in water only	0.05	All subtidal
Furbearing marine mammals	0.75	All intertidal and subtidal
Cetaceans	0.001	Seaward subtidal
Manatee, sea turtles	0.01	All intertidal and subtidal
Pinnipeds*	0.42	All intertidal and subtidal

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3.4.5.3 p_{let} for shoreline

The probability of lethal effects in the shoreline and intertidal compartment has been assessed as follows, for implementation in the ArcView EIF Extension: At a film thickness on the shoreline $<10 \mu\text{m}$, $p_{let} = 0 \%$ (Hoell, Espen, *pers. comm.* 2005), i.e. this is the threshold film thickness as in levels I and II, below which there is “no lethal risk”. At a film thickness $>14 \text{ mm}$; literature indicates that lethal probability $p_{let} = 100 \%$. Between these to extreme values, the lethality will lie between 0 and 100 %, with no indications in literature from oil spills, that there is a general “dose-response” curve as may be derived from toxicological experiments. For the sake of simplicity, a linear function between $10 \mu\text{m}$ and 14 mm has been assumed. The whole curve is used, calculating the value of p_{let} from the film thickness calculated from the amounts of stranded oil (in tonnes/km coast).

Since all coastal types are not equally sensitive, the different segments have different P_i -values in the DamE –Shore-model. The oil amounts are distributed between the different types of shoreline types in the grid cell, and the proportion of each substrate type present is used to calculate an average film thickness for each of the coastal segments. The number of km where $P_i > 0.33$ is used to give weight to the segment with respect to its contribution to the total p_{let} of the grid cell, which varies with both the oil amounts and the composition of the coastline, leading to a modification of p_{let} , because not all coast is equally vulnerable and sensitive. This may be illustrated by the following example, where in a single $10 \times 10 \text{ km}$ grid cell we have (Table 3-2):

Table 3-2 Example of calculation of p_{let} contribution for shoreline segments.

Substrate type	Tonnes/km	Km with $P_i > 0.33$	Film thickness	p_{let}	p_{let} contribution
Artificial	10	0			
Cobble	20	3	2	20 %	$20\% \times \frac{3}{10}$
Mud	30	2	3	30 %	$20\% \times \frac{2}{10}$
Sand	30	3	3	30 %	$30\% \times \frac{3}{10}$
Rocky shore	5	2	0.5	5 %	$5\% \times \frac{2}{10}$
Sum (km)		10			22 %

Shoreline water column: In the inter-tidal zone, damage can also occur from toxic effects in the water column. To cover toxic and other lethal effects towards inter-tidal crustaceans, a check is therefore performed to see whether either of the two p_{let} -values from the water column compartments leads to mortality higher than the one calculated for the stranded oil as described in the example above. The highest value is used as representative p_{let} .

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3.4.6 Average impact on a resource in a single grid cell, b_j

The size of the impact on one resource in a specific grid cell, b_j , is calculated by exposure and hazard characterisation, following the compartmentalisation of oil exposure (as) carried out in Levels I and/or II (Johansen, 2003, Østby et al., 2003). The calculation has a monthly resolution.

For each grid cell where $p(\text{PEC} > \text{Threshold value}) > 0.05$, b_j is calculated for each resource, from the following formula*:

$$b_j = p(\text{PEC} > \text{TV}) \times p_{\text{exp}} \times p_{\text{let}} \times N_{\text{max},j}$$

Where $N_{\text{max},j}$ is the pre-spill population given in the resource data with a monthly resolution:

- Water column: Fraction of a population of eggs/larvae.
- Sea surface: Fraction of a population of individuals.
- Shoreline: Fraction of vulnerable coastline.

$p(\text{PEC} > \text{TV})$ is the probability that PEC exceeds the threshold value in the statistical analysis of all scenarios

p_{let} and p_{exp} are statistical averages of lethal and exposure probabilities over all scenarios

Note that p_{exp} and p_{let} are average values for each grid cell, using only the scenarios where $\text{PEC} > \text{TV}$, therefore the probability that $\text{PEC} > \text{TV}$ is included in the expression, to obtain the statistical average impact over all scenarios, this is a change from the revised report from 2005. The resulting b_j (output from the model) is the proportion of $N_{\text{max},j}$ that is impacted (average). Its value is 0-1.

In the ArcView EIF Extension, this population loss in an individual 10x10 km grid cell may be shown in the map, using the b_j -values from each grid cell.

3.4.7 The $\sum b_j$ – Total Impact on a Resource

The affected fraction of the resource in a grid cell j is denoted b_j and is calculated as an average population loss in a grid cell, as described above. This value is registered in order to show individual losses in a map, but is also summarised to calculate the total impact to the vulnerable resource, denoted b . Only b_j -values from 10 x10 km grid cells where $p(\text{PEC} > \text{PNEC}) > 0.05$ are included in the summarisation.

$$b = \sum_{j=1}^n b_j$$

It is this b -value that is used to calculate t_{res} -values from the implemented functions of restoration as a function of population loss, as well as the RIF-value.

3.4.8 RIF endpoint calculation

Total RIF for a resource is a function of the degree of impact on a resource, and the duration of the impact, calculated by the simplified risk function:

$$\text{RIF} = \frac{b t_{\text{imp}}}{2} + b t_{\text{lag}} + \frac{b t_{\text{res}}}{2}$$

* The equation is changed from the equation in the revised version of the 2004-report, as it was there assumed that the calculation would be based on *all* scenarios. However, on implementation, the sequence was changed and since the p_{exp} and p_{let} are averages, the probability of PEC exceeding TV was reintroduced to modify RIF statistically.

3.5 RIF restoration modelling – calculation of time factors

Three time-factors are necessary to calculate the duration of effect, and thereby also RIF for a resource:

3.5.1 Impact time t_{imp}

The time necessary to achieve full impact (in years) must be given as best scientific judgement of the time that is necessary to realise the potential impact: For fish eggs and larvae, the value of t_{imp} is set to 0 years, as the restoration time for the whole spawning stock (i.e. of mature individuals) is calculated based on loss of fractions of a year class, and the exposure time necessary to give full impact on eggs/larvae/juveniles is a matter of a few weeks. In the sea surface compartment, t_{imp} is also expected to be of a few weeks' duration, hence the impact-time is set to 0 for the same reason. In the shoreline compartment, t_{imp} is implemented. Impact-time is a factor in the DamE-Shore-model, and this factor has been implemented as t_{imp} into the dataset of shoreline segments with sensitivity index $P_i > 0.33$. The DamE-Shore model is described in Appendix 2.

3.5.2 Lag-time t_{lag}

Time-lag between full impact is reached and restoration growth can start is dependent on duration of growth inhibiting exposure to oil that is present on the environment. This factor should be inserted on basis of scientific judgement, e.g. on basis of knowledge of inter-dependencies between compartments (see discussion in Spikkerud & Brude, 2004). E.g. an estimate of continued shoreline oiling which may contaminate the food sources of near-shore seabirds. In such cases, an expected lag-phase determined by the expected duration of exposure should be added based on scientific judgement, sequestering properties of the shoreline substrate, mussels etc. These values are currently not used, but are implemented with the restoration times.

3.5.3 Restoration time t_{res}

Restoration times for e.g. sea bird populations are generally dependent on the size of impact b . Restoration times once restoration growth/recovery has initiated, until the population level (N) again equals population level without perturbation from oil spill impact (N_{max}), i.e. the time from restoration starts to the population is restored (100% of N_{max}), t_{res} is either calculated by input of b into the *logistical* or the *exponential* growth model implemented in the ArcView EIF extension.

The other time-factors; impact factor t_{imp} and t_{lag} are currently not used in all compartments, as will be described in the next chapters. Impact time may be longer for some resources, this is then included as an attribute of the resource data sets. Some resources may also experience a lag-phase before restoration starts. This should also be part of resource data adaptations. For sea birds and mammals, the growth rate r must be included if the value is different from what is implemented in the model.

Currently, full impact is assumed to occur within the first year. The ArcView EIF extension inserts the value of b into the restoration modelling equations that were developed for EIF and RIF in the work of Spikkerud & Brude (2004), modified and implemented in the work of 2005.

The value of b for each resource is used to calculate restoration time t_{res} along with a growth rate, r , for the resources. The below given time-factors are implemented based on the described

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models that are implemented in ArcView EIF extension, although not all are currently implemented.

3.5.4 Compartment-specific time-parameters

3.5.4.1 Compartment water column

The following parameters decide the impact and restoration parameters (t_{imp} , t_{lag} and t_{res}) of the three fish resources Atlantic cod (*Gadus morhua*), Atlantic herring (*Clupea harengus*) and Capelin (*Mallotus villosus*). Input parameter is the percentage of loss of larvae after exposure to oil. There is a time lag from full impact on eggs and larvae through reduced future recruitment until the full extent of the damage to the spawning biomass is shown after several years. For e.g. cod, the maximum damage (lowest spawning biomass) is seen after 5 years. The end point of the “restored” population for fish resources is the restored spawning stock biomass.

Time-to full impact on fish larvae is matter of days or weeks in the case of acute oil spills (t_{imp} =days-weeks), compared to the years until final restoration of the spawning stock is reached (t_{res} =years) (a maximum t_{res} of 12 years in the case of herring). The model is simplified by omitting the area that is formed by $(t_{imp} \times b)/2$, by simply saying that $t_{imp} = 0$, the same is done for t_{lag} . The complex impact functions of the Oil-Fish model include both these factors as well as the restoration time (Brude & Moe, 2002). t_{lag} is therefore an integral part of t_{res} in the Oil-Fish model. It could be argued that this underestimates the RIF-value, however, there is little information to determine a split between the lag- and restoration parameters, and this choice was made. For EIF-modelling purposes, we may therefore eliminate t_{lag} , (set = 0) and only use the “prolonged” t_{res} . See discussion in Spikkerud & Brude (2004).

Values of t_{imp} , t_{lag} and t_{res} are implemented in a Fish – Oil impact model (Brude & Moe, 2002), and restoration times for use in EIF have been extracted from the mentioned work. For cod, results presented in Brude & Moe, (2002) from applying the integrated damage and restoration model for oil and fish (Moe et al. 2000) show a near normal distribution of the restoration times, when the model is applied to 100 projections. Each projection represents the developments of year classes of larvae on the spawning stock, and thereby the t_{res} for the spawning stock to recover from an impact b to the population of cod larvae. The mean restoration times at certain values of b are shown in Table 3-3, together with the maximum restoration (including lag-time) time from any projection. For Atlantic herring, the results presented in Brude & Moe (2002) show a frequency distribution of the restoration times with two peaks when the Oil-Fish model (Moe et al. 2000) is applied to 100 projections. Each projection represents the developments of year classes of larvae on the spawning stock from applying the integrated damage and restoration model for oil and fish (Moe et al. 2000). The pattern is interpreted to mean that there are year classes that are less “important” with respect to recruitment to the spawning stock, and others whose losses have a higher impact on the future spawning stock. Nevertheless, the mean restoration time for all projections is used, as it is the impact to the average year class that should be used. The mean restoration time is shown in Table 3-3, together with the maximum restoration time from any projection. For Capelin the life-span is three years, and the maximum restoration time for any impact size b is 6 years, also shown in Table 3-3.

The values are examples, in the ArcView EIF Extension, the regression lines have been implemented in order to calculate t_{res} directly from any value of b : To provide a continuous

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function of these restoration time distributions as a function of b , the following functions have been implemented into the ArcView EIF extension based on Linear regression-analysis:

Cod: $y = 1.6617 \ln(x) + 8.1762$
 $R^2 = 0.988$

Herring: $y = 1.6652 \ln(x) + 8.5692$
 $R^2 = 0.9263$

Capelin: $y = 0.988 \ln(x) + 7.5901$
 $R^2 = 0.9711$

Table 3-3 Restoration parameters for spawning stock of Cod (*Gadus morhua*), Atlantic herring (*Clupea harengus*) and Capelin (*Mallotus villosus*), based on fractional losses of larvae year classes.

Fraction loss of year class larvae	Common parameters		Cod (<i>G. morhua</i>)		Herring (<i>Cl. harengus</i>)		Capelin (<i>Mallotus villosus</i>)	
	b (as fraction of N_{max})	t_{imp} (years)*	t_{lag} (years)*	Max. rest. time in any projection (years)**	Mean rest. time for spawning stock t_{res} (years)	Max. rest. time in any projection (years)**	Mean rest. time for spawning stock t_{res} (years)	Max. rest. time in any projection (years)**
0.01	0	0	0	0	2	2	3	3
0.02	0	0	5	2.1	2	2	6	3.87
0.05	0	0	6	3.22	5	2.25	6	4.55
0.10	0	0	7	4.42	10	4		
0.11							6	5.1
0.15	0	0	8	5.16	10	5.35		
0.2	0	0	8	5.58	11	6		
0.3	0	0	9	6.32	12	7.12		
0.5	0	0	10	6.98	12	7.56		
1	0	0	11	8.01	12	8.84		

Where:

b = affected fraction of total population (in fraction of $N_{max}=1$)

t_{imp} = duration of impact period (years) (time to full impact is reached, mortality > fertility),

t_{lag} = lag phase from full impact until restoration occurs. In the Oil – Fish Model (Brude & Moe, 2002), this is included in t_{res}

t_{res} = duration of restoration time (years) time to population level equals population level without perturbation from oil spill impact

* Time-lag from oil spill to full impact on the spawning stock is implemented in the fish-oil model of Brude & Moe (2002). Time-to full impact on fish larvae is matter of days-weeks, compared to the years until final restoration is reached (years) and is therefore omitted.

** In any projection run of the model in (Brude & Moe, 2002)

3.5.4.2 Compartment shoreline

In the shoreline compartment, a data set has been prepared, using DamE-Shore (Moe *et al.*, 2000b,c; Moe & Brude, 2002,) a model developed to assess the potential impact of oil on the shoreline. The sensitivity of the various communities and substrates towards oil pollution is a function of several parameters. Substrate type and wave exposure determine important parameters of damage and recovery, and thereby also the potential for a given type of shore to be rendered biologically barren, comparable to “population loss” in other compartments. A brief description of DamE-Shore is given in Appendix 2. Impact times of the shoreline substrate types are not a function of the fraction b of total shoreline length (N_{max}) that is affected, but restoration of the communities are density dependent. In the DamE-Shore model, which is used as basis for the data set of the Norwegian coastline, the parameter effect period t_{imp} is a parameter of the substrate type, whereas the lag-phase, t_{lag} and biological restoration period, t_{res} are functions of the biological communities that may typically be present.

As for fish spawning stocks, restoration times for shoreline communities and substrate types have been subject to modelling of the complex relationships determining impact, lag-times and restoration in DamE-Shore. The shoreline compartment as a resource is an ecosystem, not a single species, and oil may persist for a longer time than on the water surface and in the water column. The restoration-time in DamE-Shore (denoted t_p) is a combination of lag- and restoration-time ($t_p = t_{imp} + t_{res}$). Several communities may be present on the same substrate type, and P_i is calculated using the community that gives the maximum values, and the restoration time t_p is obtained from the slowest-restored community that may be present on the given substrate. However, Brude *et al.* (2003) does not state how long the lag-period is, compared to the restoration. For EIF purposes, t_p was split into t_{imp} and t_{res} where information has been found to support the split. Brude *et al.*, 2003 gives a full overview of the community distribution model for each substrate type. The EIF value will be different according to the division between the two components t_{lag} and t_{res} , as the contributions are calculated as the areas of a rectangle and triangle, respectively. Restoration times for other shoreline habitats are typically (roughly) 3 years for other benthic and inter-tidal habitats, 10 years for sea grass beds, 15 years for salt marshes and 30 years for mangroves (French-McCay, 2003).

As EIF shall be valid for other areas than the Norwegian mainland coast and Svalbard, the *functions* of DamE-Shore have not been implemented in EIF directly. However, the restoration-specific restoration time factors are grid specific, and have been implemented in the data set. In other areas, the time-factors of different substrate types should be implemented in data sets as an attribute of a grid cell, based on the substrate type or combination of substrate types within the cell. The substrate-specific information in the DamE-Shore model has been used to ascribe values of t_{imp} , t_{lag} and t_{res} to the different segments of various shoreline types within the 10x10 km grid cells, providing a detailed data set along the Norwegian coast. The weighted time-parameters have thereafter been calculated for each grid cell based on the proportion of each substrate type in the grid cell. These weighted, grid-specific $t_{imp,j}$, $t_{lag,j}$ and $t_{res,j}$ values are included in the data set of the distribution of sensitive shoreline types. Each of the grid cell b_j values contribute to the total b of the shoreline compartment, corresponding to a fraction of b . This fraction is used as the grid cell-specific weight of the contribution from each $t_{imp,j}$, $t_{lag,j}$ and $t_{res,j}$ value of segments with a $P_i > 0.33$ to the total t_{imp} , t_{lag} and t_{res} values which are then used to calculate RIF as a function of b . This means that if the 10x10 km grid cell is impacted with a

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fully triggered $b_j = N_{max,j}$, the vulnerable areas in the cell have an impact time that equals the weighted impact time, and a restoration time that equals the weighted restoration time.

The implemented time-factors are shown in Table 3-4. The substrate types were assigned impact times based on a data set query. The maximal t_{res} – values were calculated by a special routine for hard substrates, based on the abundance of key species in the coastal segment. For soft substrate key species, the parameters were set to 4 or 7 years, based on experience and depending on wave exposure.

Table 3-4 Time parameters from DameE-Shore implemented in EIF.

Substrate		t_{imp} (years)	$t_{lag} + t_{res}$ (years) implem. as t_{res}
	Bare rock faces	2	*
	Boulder shores	2	*
	Sea cliffs	2	*
	Sandy beaches	6	4 (7 if high wave exposure)
	Rocky shores	10	*
	Muddy beaches	10	5
	Man-made structures	0	0
	Tidal flats	+ 2	
Community (key species)			
(Hard substrate)	<i>Ascophyllum nodosum</i>		15
(Hard substrate)	<i>Corralina officinalis</i>		5
(Hard substrate)	<i>Patella vulgata</i>		6
(Hard substrate)	<i>Fucus vesicolucus</i>		10
(Hard substrate)	<i>Littorina littorea</i>		5
(Hard substrate)	Filter feeders		5
(Hard substrate)	Kelps		3

The choice of $P_i = 0.5$ or 0.33 as a cut-off for shoreline vulnerability was assessed in the MIRA 2005 development project (Brude *et al.*, 2006 *in. prep*). Where the effects of choosing the two different values as a lower limit for inclusion into the dataset of vulnerable shoreline segments was assessed. The Norwegian coastline was divided into regions corresponding to the NOFO oil spill combat regions, and the P_i -values values of the various segments were analysed. By setting the cut-off at 0.33 , above average sensitive shoreline segments are included.

3.5.4.3 Compartment sea surface

The model resources in the sea surface compartment are divided into sea birds (represented by the pelagic diving species, e.g. the alcids) and marine mammals, where seals are used as model organisms.

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t_{imp} : In most cases the rate of decline due to acute oil spills will be high (i.e. a short time to full impact). Default value of t_{imp} may in most cases be set to 1 year or less, in the model t_{imp} has been set to 0. Time to full impact can be estimated from experience data from spills, whereas more complex inter-dependencies suggest a t_{imp} which may be longer than the follow-up period after a historical oil spill (which might still be ongoing).

t_{lag} : In those cases where restoration of a sea surface resource is inhibited by slow degradation of oil in the grid cell in the same compartment, or a different compartment of the environment (see discussion in Spikkerud & Brude, 2004). It should be noted, however, that only oil-induced time-lags, such as continued oil contamination of benthic feeding shoreline birds from prolonged oil contamination of the shore, should be added, as it is the oil-induced impact that is of interest.

For certain birds, future data sets may be adapted as follows: t_{lag} for certain sea birds, depending on ecological group of seabird (based on theories from experience of non-recovery): Time-lag of oil persistency on shore could be added to the restoration time of benthic feeders. The rationale for this is that benthic organisms are cleaned fairly quickly after exposure is ended, it can therefore be suggested that the theoretical recovery of seabirds calculated in Level III is “postponed” by adding a time-lag from compartment shoreline corresponding to the t_{lag} of the shoreline compartment resources. For piscivorous seabird species, an impact to a year-class of prey fish species could be expected to give an additional impact on chick survival (increased perturbation factor on immature survival, in addition to direct chick mortality from parent death). However, the impact from an acute oil spill is considered to be a small factor compared to other reasons for prey-fish stock-collapses, and sea bird populations are generally adapted to fluctuating prey-fish stocks (although a lasting collapse is thought to be the cause of general decline of certain sea bird species in many areas). The additional contribution from oil may be considered small and theoretical and will not be explored further, but could form the principles for adaptation of future data sets for species where such interactions may be valid, in which case, the use of such factors should be considered.

t_{res} : A simplified approach to seabird, mammalian and reptile growth is chosen by applying a simple logistic population model (K.I. Ugland, *pers comm.*), although the logistic model is developed for continuously breeding populations, and not for species/species groups with discrete breeding seasons (Begon *et al.*, 1990), the logistic model provides a continuous function.

$$\frac{dN}{dT} = rN \frac{(K - N)}{K}$$

Where:

K = Carrying capacity – population size at equilibrium, the maximum number of individuals (population level) at which the birth and death rates of a species are equal, producing a stable population over time.

N = Population size at time T

r = intrinsic (per capita) growth rate. If r is positive, the population is increasing, if r is negative, the population is declining, i.e. during t_{imp} r is negative, during t_{res} , r is positive.

Solved, the growing population at time t is:
$$N(t) = \frac{KN_0}{N_0 + (K - N_0)e^{-rt}}$$

Logistic growth is sigmoidal, i.e. when the intrinsic rate of natural increase r is the average rate of increase per individual (per capita rate of increase), the population total growth rate varies dependent on the size of N , and rN is the tangent of the curve. The model also incorporates

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density dependence (competition) on growth, for each individual in the N population number there is $(N-1)$ competitors. Taking into consideration the possible numbers of encounters, the result is a sigmoidal curve. If r is positive the population grows, if r is negative the population declines.

The population before impact equals K if the population is at equilibrium before impact. For sea birds such as alcids, the current population trends show that many species are declining, whereas they are increasing in numbers elsewhere. A decline could be interpreted as a reduced carrying capacity (deterioration of the environment) with respect to e.g. fish resources for feeding chicks. N may therefore be assumed to have been equal to K before impact, but the carrying capacity could be changing due to external environmental factors. The simple logistic model “works” as long as the initial population in the model is below the carrying capacity, which for EIF purposes is assumed to be valid for the decline and restoration phase after impact. When density N approaches the carrying capacity K , *restoration time* approaches ∞ in the logistical growth model. In the work carried out by Spikkerud & Brude (2004) we stated that a fully restored population should be defined as a fraction X of K , and it was discussed whether this fraction should be 90 % or 99%. I was concluded that if the model was to be able to calculate RIF values based on the generally obtained low population, a fully restored population would have to be at least 0.99, as it would imply an indirect acceptance criterion of 1 % loss. Using a fully restored population of 0.99 N_{max} causes the asymptotic growth to lead to $t_{res} = 0$ for all b 's smaller than 1 %, as long as the time-steps are in whole years. However, acute oil-pollution ERAs carried out by other methods such as the MIRA method rarely gives higher losses than 5% of the national population, EIF must therefore be able to handle small losses as long as the data sets are national populations. The use of the logistical growth model as initially suggested was not very sensitive at low values of b , but gave long restoration times when there was a small but significant loss.

Re-growth of the population using the concept of “overshoot” of the carrying capacity at restoration is therefore used as a mathematical adaptation to bring the population back to 100 % without the t_{res} becoming artificially long due to fact that the sigmoidal growth curve will never reach 100% of the initial population. This is used as a technical solution to the mathematical problem, although it is questionable in some cases whether growth rates will be as high as inherently possible, depending on whether there is residual oil left in the environment. However, due to the general tendency for species to grow until the growth-inhibiting factors exceed the growth stimulating factors, this is assumed to have biological validity enough to give robustness enough for EIF purposes. Actual growth rates of sea bird species vary with the other external environmental factors.

Different growth rates were also discussed in the work of 2004, and $r = 0.12$ was suggested for sea birds such as alcids. However: For alcids, annual growth rates in Norwegian colonies have been reported to be up to 12-14 %, but also as low as 5 % (Hoell, Espen, *pers. comm.* 2006). Modelling of Brünnich's guillemot (*Uria lomvia*) (Am.E.: “thick-billed murre”) using a stochastic growth model without density dependence and a $\lambda = 1.057$ resulted in an estimated growth of a population from 300,000 to 900,000 in a 20 year period (Wiese *et al.*, 2004). This was assumed to be the inherent growth rate of a population growing without the perturbation of acute oil spills and hunting. If we use these parameters in the exponential model (non-density dependent), we would achieve the same using a growth rate $r = 0.058$. However the logistical model is for EIF purposes somewhat more conservative with respect to restoration times, and it is therefore suggested that a growth rate of 0.06 should be used for sea birds with low

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reproduction rates such as alcids, as a practicable approach. A growth rate of 0.10 could be used for other sea birds, such as cormorants/shags and common eiders.

For cases where growth is known to be *exponential* at present, such as is reported for grey seals in Norway, it could be assumed that this means that the current population size N is so far below K that the population is currently growing below the critical density for when inhibiting factors start to become evident. Use of the exponential mathematical model is not inhibited by approaching K asymptotically as time, t approaches ∞ . (Bowen *et al.*, (2003) reported a growth rate of 0.12 in a population of grey seals showing exponential growth. The same growth rate for grey seals of 0.12 has been used by Nilssen *et al.*, (2004), and has been stated to be a valid inherent reproductive rate (lower range) for pinnipeds and sea otters (*Enhydra lutris*) (Wade & Angliss, 1996). For otter (*Lutra lutra*) no data were found, but it is suggested that a logistical growth curve (density dependent) and a growth rate of 0.12 be used as for *E. lutris*. A lower range inherent growth rate $r = 0.04$ can be used for cetaceans and manatees (Wade & Angliss, 1996).

Where it is not known that the growth at present is exponential (as for some reports on grey seal colonies), it is suggested that the logistical growth model be used, as it is slightly more conservative. However, it should be noted that growth rates might be lowered after an oil spill due to chronic impacts of the oil on the environment. E.g species that forage on mussels may be subject to a growth rate reduced by chronic exposure to toxic oil components from oil contaminated fodder (see e.g. Lance *et al.* 2001). Mussel beds may sequester oil and many species may be subjected to chronic exposure through contaminated mussels. It is therefore only when the external environment is restored (no growth-inhibiting factors due to oil) that the inherent r value becomes true.

Sea surface resource	Model	Inherent growth rate r	“Overshoot (%)”
Sea birds, alcids	Logistical	0.06	5 %
Sea birds, other (cormorants/shags, eiders, ducks)	Logistical	0.10	5 %
Pinnipeds (grey seal and harbour seal in Norway)	Exponential until density dependent	0.12	-
Sea otter	Logistical	0.12	5 %
Manatees, cetaceans	Logistical	0.04	5 %

Currently, only sea birds (alcids) and pinnipeds have been implemented in the model.

Example of re-growth of sea birds using the above parameters, and compared with the damage keys used in MIRA (OLF 2005) for sea birds and mammals with a low restoration potential with and without a negative population trend is shown in table Table 3-5. Note that the damage key of MIRA is a distribution of the probable damage category at various population losses (values of b).

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Table 3-5 Values of t_{res} with population loss b compared with probability distribution of restoration times used in MIRA.

Popu- lation loss b	RIF t_{res} (years) ($r=0.1$) and “over- shoot” to $N(t_{res}) =$ $K+0.05K$	Consequence category – environmental damage Theoretical restoration time (years) (OLF 2005) (species with low restoration potential and negative population trend)				Consequence category – environmental damage Theoretical restoration time (years) (OLF 2005) (species with low restoration potential)			
		Proba- bility of t_{res} (0.1-1 yr)	Proba- bility of t_{res} (1-3 yr)	Proba- bility of t_{res} (3- 10yr)	Proba- bility of t_{res} (>10 yr)	Proba- bility of t_{res} (0.1-1 yr)	Proba- bility of t_{res} (1-3 yr)	Proba- bility of t_{res} (3-10 yr)	Proba- bility of t_{res} (>10 yr)
<5 %	8	40 %	50 %	10 %	-	50 %	50 %	-	-
5-10 %	8-13	10 %	50 %	30 %	10 %	25 %	50 %	25 %	-
10- 20%	13-19	-	10 %	50 %	40 %	-	25 %	50 %	25 %
20- 30%	19-24	-	-	20 %	80 %	-	-	50 %	50 %
≥ 30 %	>24	-	-	-	100 %	-	-	-	100 %

As can be seen from the above table, EIF restoration values are more conservative than the restoration time distributions that are used with MIRA.

4 DISCUSSION

4.1 What are EIF and RIF?

The numerical value of EIF level III (RIF) is the area formed by the functions shown in Figure 3-1.

The numerical value of RIF is therefore a conceptually different value than EIF levels I and II, which are geo-referenced “geographical areas”. The sum of the areas of 10x10 km grid cells where $p(PEC>TV) \geq 0.05$ (Level I), and the sum of the areas of 10x10 km grid cells where $p(PEC > Thr.) \times p(presence) > 0.05$ (Level II). The unit is km². The resulting values of running EIF level I and II can therefore be compared directly; adding data on the probabilities of presence of resource data will reduce the “potential risk area” from Level I to Level II. By geo-referencing b -values (population losses (average)) at Level III for *resources* some of the same visual strength is preserved, although the RIF value is different from the EIF-area values of levels I and II.

However, the total RIF for an individual resource is in the unit of “fraction of a population x years”, a unit that has no direct biological equivalent, but is a measure of the size of impact to that resource. The strength lies in comparability with other resources, and by using *fractions* of populations, and not numbers of individuals, it is the status of the population that is addressed, and both rare and abundant vulnerable species are treated the same. Rare and threatened species

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may be given a higher priority in the selection of species (Spikkerud *et al.* 2004a), and any resource may be entered in the EIF model if special documentation of certain resources is required. By using both Levels II and III, a depth in the analysis is achieved. Level II provides the size of the area of impact, and gives a measure of the geographical spread of impact, whereas Level III is well suited for addressing issues relating to valued resources, comparing the impact to them and identifying special potential risk areas for individual resources by showing the average grid *b*-values. All levels are suitable for illustrating the effects of oil spill combat, but level III will give a higher level of information for this application also.

4.2 Visibility of data quality

Preliminary testing of EIF / RIF calculations shows that the model has a high degree of transparency with respect to the input data. There are no weightings or adjustments carried out in the calculations that may mask results and “smooth out” non-covered areas between grid cells with data. The outcome of the EIF model is therefore (as for most risk assessment models) very susceptible to poor data quality with respect to oil drift modelling or resource data coverage, as well as data distributions and the adaptation technique that is used for ascribing probabilities of presence or population fractions within the grid cells. It is therefore important that the number of scenarios should be sufficient to provide statistical strength and that resource data should be as well founded as possible.

5 IMPLEMENTATION – DESCRIPTION OF THE EIF ARCVIEW EIF EXTENSION

5.1.1 Level I

Oil drift data (EIFFILE) are prepared by running a separate function in the ArcView EIF extension that prepares the oil drift data for EIF calculations. The routine will import the data if the correct EIF format is used for the oil drift data (Johansen, 2006).

Post-processing of oil drift scenarios is carried out as follows:

DAT/TXT file is converted to a dBASE file, and subsequently joined with:

- 1) ContAct 10x10 grid to calculate oil per km coastline for use as a part of the calculation for the shoreline compartment. In addition, oil pr. km coastline for different substrate types (Artificial, Cobble, Mud, Sand and Rock) is calculated.
- 2) The scenario-description (SFILE) to extract the start month for the model scenario.

EIFFILE is summarized so that all unique grid cells (in one or more scenarios) are reported to a new dBASE file for further EIF calculation and compartment-based reporting.

EIF level I calculations are then carried out as follows, and the results are presented as shown in Figure 5-1.

The probability that $PEC > \text{Threshold Value (TV)}$ is calculated for each grid cell and for each compartment, by counting the number of single oil drift scenarios in which $PEC > \text{Threshold Value}$. The probability is reported as the exposure probability, r , for each compartment i .

The EIF value is calculated as the area of grid cells where the exposure probability (previously called “risk value”) r for at least one compartment exceeds 5 % ($R > 5\%$). The output of EIF level I in ArcView EIF extension is thereby a map showing the area with a more than 5 % probability of PEC exceeding Threshold Value in at least one compartment. The EIF value can have contributions from all three compartments; these contributions could be visualized in pie charts.

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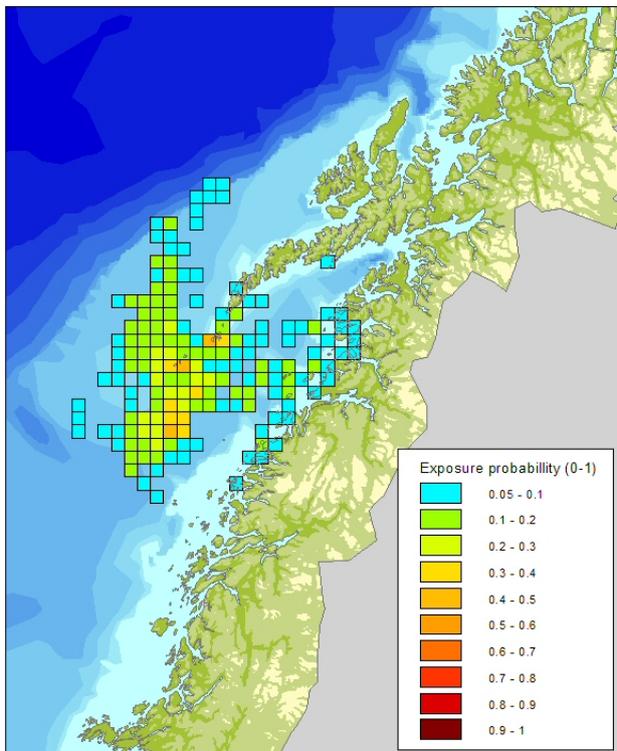


Figure 5-1 Example of output from EIF Level I. (ArcView EIF Extension).

5.1.2 Level II Implementation

The same preparation of oil data is carried out as in level I. No new adaptation of oil drift is necessary if a level I-calculation has already been carried out. Data on sensitive environmental resources at level II are prepared as described in Section 3.3.1 and Spikkerud *et al.*, 2004). As in level I, the lowest Threshold Value -values, reflecting the most sensitive resource in the compartment is used. EIF level II calculations are performed for a specified month (this is optional in level I).

The EIF level II calculations are performed as for level I with the following changes:

The *exposure probability* of level II is calculated for each environmental resource and grid cell by multiplying the probability of presence of the resource with the probability that $PEC > \text{Threshold value}$. $p(PEC > TV) \times p(\text{presence})$

The resource exposure probability is compared for each respective compartment, and the highest value is registered. This allows for later identification of the most sensitive environmental resource in each compartment and grid cell.

Results are presented as total EIF value i.e. the area in which exposure probability $> 5\%$. Compartment based EIF values are recorded separately.

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5.1.3 Level III implementation

The level III (calculation of Resource Impact Factor – RIF) is implemented for one month at a time, this implies that in order to perform a whole-year analysis, one has to perform 12 model runs. For each month, input data both from oil drift simulations and resource data distributions must be available. Input data sets are further described in the Appendix to Spikkerud *et al.* (2004a). Changes have been made for shoreline dataset that must have the following additional parameters at level III:

- ArtP – Relative distribution [0-1] of Artificial shore in the shoreline dataset
- CobP – Relative distribution [0-1] of Cobble in the shoreline dataset
- MudP – Relative distribution [0-1] of Muddy shore in the shoreline dataset
- RockP – Relative distribution [0-1] of Rocky shore in the shoreline dataset
- SandP – Relative distribution [0-1] of Sandy shore in the shoreline dataset
- Timp – impact time (in years)
- Tlag – lag time (in years)
- Tres- restoration time (in years)

Changes for the Sea surface compartment is comprised by and additional parameter Plet, with values from 0-1 according to French-McCay (see Table 3-1).

Once the input data are available, the user will select “EIF level III – monthly” and the calculation will begin. Input from the user is required to specify the input data sets. There is currently no limit to the number of data sets that can be handled for each compartment, although the different compartments should preferably be treated as similarly as possible.

Once the input data are specified, the model will calculate the affected fraction of each resource (data set) in each grid cell by taking into account the following parameters:

- Probability that $PEC > \text{Threshold value}$.
- Probability of exposure (p_{exp}).
- Probability of dying (p_{let}) given exposure.
- Fraction of population present ($N_{r,max}$) in each grid cell (from resource data sets).

The results will be a 10x10 km grid (ArcView shapefile) which contains the affected fraction in each grid cell for each resource (see example in Figure 5-2).

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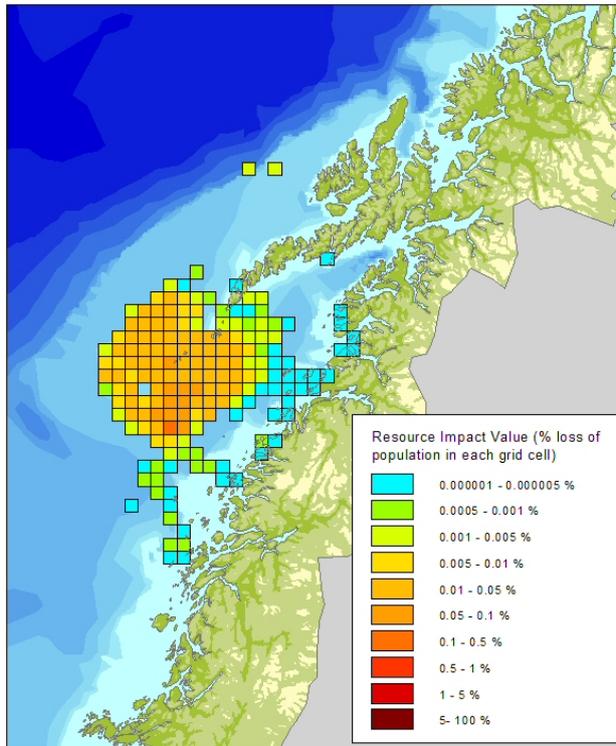


Figure 5-2 Example of EIF level III results showing percentage loss of Puffin population in each grid cell in May. The sum over all grid cells will represent the overall loss of Puffin.

The total affected fraction for each resource is then summarized for all grid cells for which there is a 5 % probability that $PEC > \text{Threshold}$ value. The RIF calculation is then performed by applying the restoration parameters for each resource. RIF results can be visualized in the map by showing exposure value for each compartment or resource impact value (figure 5.2) for each resource individually. Overall RIF results are presented by default as a chart when the computing stops (Figure 5-3).

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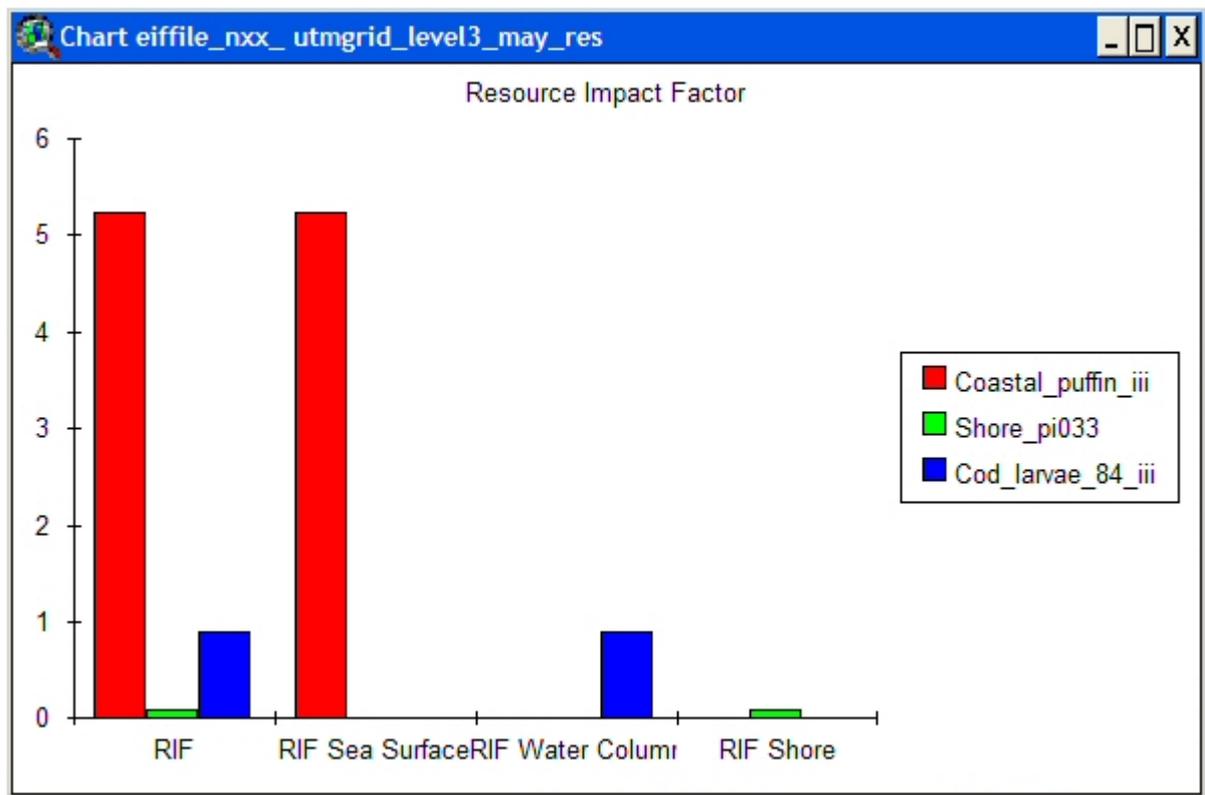


Figure 5-3 Example of RIF (EIF level III) result showing RIF values for each compartment and each resource data set individually.

5.1.3.1 Implementation notes

In the sea surface compartment, only sea birds and pinnipeds have been implemented in the current version of the ArcView EIF Extension. With the automatization of the restoration modelling carried out in 2005, each resource group and its restoration parameters must be programmed individually, and resources such as mangroves, turtles etc. have not been included. However, given necessary data available, these adjustments may be carried out at a later stage, alternately, the input of restoration factors may be given in a dialog window, suggesting default values and restoration model, but with the option of changing the model (logistical/exponential), r -values or “overshoot” values.

In the shoreline compartment, the model has been implemented using the data and information present or adapted from the DamE-Shore-model, which is valid for most of the Norwegian Coastline. Other places, the necessary data are substrate data for shoreline segments and grid cell-specific values of the potential impact- lag- and restoration times given full impact. Applicability here lies in the data adaptation.

6 EIF ARCVIEW EXTENSION – USER GUIDE

6.1.1 Installation

The following procedure must be performed to install the EIF extension (for ArcView 3.x) and prepare for calculations:

1. Place all data in a separate folder
2. Add the appropriate legend files (avl-files) to this folder.
3. Place EIF extension into the /ESRI/AV_GIS30/ARCVIEW/EXT32/ folder
4. Start ArcView – add appropriate themes such as land contour etc. (*Add Themes*)
5. Add 10x10 km grid files: cont_10comp.shp and cont_10eif.shp (*Add Themes*)
6. Add oil drift data tables (eiffile*.txt and sfile*.txt) into the ArcView project (*Add Tables*)
7. Add resource data sets (Shapefiles) for running EIF level II or III (*Add Themes*)
8. Load EIF extension
9. Save the ArcView project

You are now prepared to run the EIF calculations.

Please notice that all result files will be placed into the last used folder. If you want to select a specific folder for the results, use “Add themes”, select the appropriate folder and then press cancel.

6.1.2 Data set naming conventions

For practical purposes, a naming convention is suggested for input data sets as follows:

Oil drift simulations file: EIFFILE_<NAME>_<TYPE>.txt

Oil drift simulations description file: SFILE_<NAME>_<TYPE>.txt

Oil drift scenario description file: DFILE_<NAME>_<TYPE>.txt

NAME should indicate name of oil field or exploration well

TYPE should be type of event (e.g. Sub for subsea or Surf for surface blowout)

6.1.3 EIF menu choices

The EIF extension will when activated in ArcView 3.x bring up one EIF menu with 14 menu choices. The different choices are explained in brief below. Sections 6.1.6.1-6.1.6.4 deals with calculations, whereas 6.1.6.5 – 6.1.6.8 deals with presentation of results.

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EIF
Prepare Oildrift
Run EIF Level I
Run EIF Level I - Monthly
Run EIF Level II - Monthly
Run EIF Level III - Monthly
Make Chart with EIF results (Level I and II)
Make Chart with RIF results (Level III)
Show Exposure Probability
Show Exposure Probability Sea Surface
Show Exposure Probability Shore
Show Exposure Probability Water Column
Make Pie Chart in grid cells
Make Column Chart in grid cells
Show Impact Value (Level III)

6.1.3.1 Prepare oildrift

Input: oil drift scenario files (eiffile_*.txt and sfile_*.txt) and 10x10km grid (cont_10eif.shp).

Output: dBase files for oil drift scenario files + new statistics file (eiffile_*_stat.dbf)

The routine will convert the input oil drift scenario files from txt to dbf files with additional information from the 10km grid (oil mass pr km coastline) and the scenario description (sfile). In addition a statistics file (*_stat.dbf) is created for later reporting of EIF values.

6.1.3.2 EIF Level I & EIF Level I monthly

The routine calculates EIF values from all three compartments based on implemented threshold values and PEC-values from oil drift for all simulations in the input oil drift. The calculation can also be performed monthly. The resulting file is automatically joined with 10x10 km grid (cont_10comp.shp) to visualize results.

Input: statistics file created in the above routine (eiffile_*_stat). The scenario file must also be present (*.dbf from first step) in the ArcView project.

Output: result file (_level1_<month>.dbf) for reporting on P(PEC>Threshold values) and an additional summary file (*_level1_<month>_res.dbf) for the overall compartment based results. The table contains the following attributes:

- Eif – Overall EIF value for all three compartments
- Eif_ss – EIF value for compartment 1 (sea surface)
- Eif_s – EIF value for compartment 2 (shoreline)
- Eif_wc – EIF value for compartment 3 (water column)

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In addition a shapefile with resulting grid cells (10x10 km) is produced (*_level1_<month>_grid.shp). The attribute table contains the following fields:

- Pexp - Total exposure probability for all compartments
- Pexp_ss- exposure probability for compartment 1 (sea surface)
- Pexp_s - exposure probability for compartment 2 (shoreline)
- Pexp_wc - exposure probability for compartment 3 (water column)

6.1.3.3 EIF Level II - monthly

The routine calculates EIF values for one month for all compartments based on PEC values from oil drift and implemented thresholds values. The resulting file is automatically joined with the 10x10 km grid (cont_10comp.shp) for visualization of results.

Input: statistics file created in the prepare oildrift routine (*_stat) together with one or many resource data sets covering all three compartments. The scenario file must also be present (*.dbf from first step) in the ArcView project.

Output: A resulting ArcView shapefile with user selected name (_level2_<month>_grid.shp) for reporting of risk values and an additional summary table (*_level2_<month>_res.dbf) for the overall compartment based EIF results. The summary table contains the EIF values as in EIF level I. The shapefile attribute table contains the following fields in addition to the fields from level 1 (see 6.1.6.2 above):

- Ss_max - the dataset with the highest exposure probability for compartment 1 (sea surface)
- S_max - the dataset with the highest exposure probability for compartment 2 (shoreline)
- Wc_max - the dataset with the highest exposure probability for compartment 3 (water column)
- Pexp_<resource> - exposure probability for each resource data set

6.1.3.4 EIF Level III - monthly

The routine calculates *b* values for a resource for one month for all compartments based on oil drift results and implemented threshold values. The resulting file is automatically joined with the 10x10 km grid (cont_10comp.shp) for visualization of results.

Input: statistics file created in the “prepare oildrift” routine (*_stat) together with one or many resource data sets covering all three compartments. The scenario file must also be present (*.dbf from first step) in the ArcView project.

Output: A resulting ArcView shapefile with user selected name (_level3_<month>_grid.shp) for reporting of exposure probability and affected fractions and an additional summary table (*_level3_<month>_res.dbf) for the reporting of the RIF of each resource data set and compartment. The shapefile attribute table contains affected fraction in each grid cell in addition to risk values as for level I (see above):

- Imp_<species_name> - the affected fraction in each grid cell for each resource

6.1.3.5 Make Chart with EIF results (level I and II)

The routine generates a chart showing the calculated EIF values for each compartment.

Input: result table from EIF level I or II calculations (*_res.dbf)

Output: Chart window showing EIF values for each compartment

6.1.3.6 Make Chart with RIF results (level III)

The routine generates a chart showing the calculated RIF values for each resource and each compartment.

Input: result table from EIF level III calculations (*_res.dbf)

Output: Chart window showing RIF values for each compartment

6.1.3.7 Show Exposure Probability

For the resulting grids on all levels one can classify the results by selecting the appropriate menu choice for each compartment. Activate the theme and select the compartment you want to classify by. Overall exposure probabilities can be classified with the menu *Show Exposure Probability*.

Input: resulting shapefile from all levels as active theme

Output: on screen theme classification of exposure probability

6.1.3.8 Make Pie Chart in grid cells

The routine generates pie charts in each 10km grid cell showing the relative distribution of exposure probabilities for each compartment.

Input: resulting shapefile from all levels as active theme

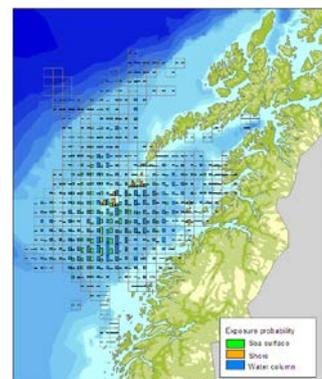
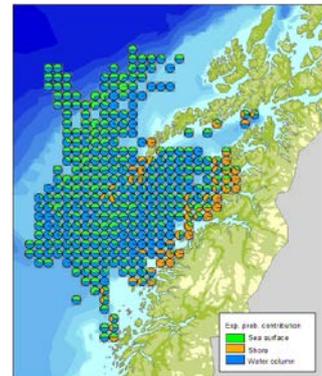
Output: on screen theme classification of exposure probability

6.1.3.9 Make Column Chart in grid cells

The routine generates column charts in each 10km grid cell showing the relative distribution and value of exposure probabilities for each compartment.

Input: resulting shapefile from all levels as active theme

Output: on screen theme classification of exposure probability



6.1.3.10 Show Impact Value (level III)

For the resulting grids on level III one can classify the results by selecting a resource to show impact values for.

Input: resulting level III shapefile as active theme

Output: on screen theme classification of impact values for user selected resource data set

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APPENDIX A: RESTORATION NOTES (UPDATED FROM 2004-REPORT)

Without growth-inhibiting factors such as competition for food and breeding/nesting sites, a population may well show exponential growth, at a rate determined by the species inherent instantaneous rate of growth r . An example of this was shown by Bowen *et al.* (2003), where Grey seals (*Halichoerus grypus*) showed an $r=0.1203$, and continuous *exponential* growth for four decades. If we assume that there is a limit to the growth of a population, we might deduce that the population's present size is below a critical level where density dependent growth-inhibiting factors become apparent, and far below the equilibrium state K . It should be noted, however, that according to Bowen *et al.* (2003) there is little evidence that the populations of large, long-lived carnivorous mammals fluctuate around an equilibrium level (original references in Bowen *et al.*, 2003). From this, we may draw the conclusion that if there is evidence that a population was growing exponentially before the oil spill, it may recover exponentially after an oil spill as well, if the environment is fully restored and the animals' diet is not contaminated, and that the environment's carrying capacity K is at least the size of the previous population size, unless the oil has permanently impacted the seals' habitat.

On the other hand, a population that is declining may be doing so because the carrying capacity of the environment, K , is being lowered for some reason, and that it may be difficult to estimate what the new equilibrium population will be. This should be explored further, as declining species may not recover at all after an oil spill (Lance *et al.*, 2001).

Colony-bound species such as alcids, that rely on high adult survival, and have a slow growth rate are not expected to grow exponentially, but will show some critical density level at which density-dependent growth-inhibiting factors become evident. For species where the primary strategy of growth is high adult survival rate, an impact to mature individuals could be expected to have a long-term impact.

For sea birds, recruitment of breeding birds from unimpacted colonies will shorten the restoration time, whereas "self-recruiting", isolated colonies are more vulnerable to long-term impacts. Adult sea birds show a high degree of nest-site fidelity, whereas younger birds may disperse to new colonies (Hanssen *et al.*, 1998). Although these parameters vary between species, most alcids that have been studied show a high degree of breeding bird nest-site fidelity: Razorbills (91,5 %), Common guillemot (96 %), Atlantic Puffins (93.2 %), Black guillemot (57 % for failed pairs -95 % for successful pairs), Pigeon guillemot (86 %), Ancient Murrelet (78 %) (Original references in: Divoky & Horton, 1995). Natal dispersal, which is the dispersal from the fledging site to a nesting site (age of maturity 3-7 years for alcids) is similar between alcids (Divoky & Horton, 1995), and is common for the group. Alcid breeding dispersal is dependent on the rate of creation or destruction of a breeding habitat, mortality of breeding birds, and availability of nest-sites. Loss of a breeding site, e.g. by oil contamination, will result in displaced breeding birds prospecting for new nest-sites (Divoky & Horton, 1995). The site-fidelity may also depend on what kind of nest site the species uses. For example, Brünnich's guillemots (*Uria lomvia*) nest on cliffs, and falling rocks are stated to destroy or create nest sites in Brünnich's guillemot colonies more frequently than for some other species. Burrow-nesting species may also show a higher rate of dispersal, if burrows have a tendency to collapse (Divoky & Horton, 1995). Breeding site fidelity is expected to be dependent also on overwinter mortality. A high adult mortality increases the likelihood of vacancies in the colony, as well as single

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survivors prospecting for new mates, and thereby dispersal (Divoky & Horton, 1995). Alcids generally have a high adult survival-strategy for population growth, long life-spans and late maturation ages, which counteracts population susceptibility to the high variations in breeding success between years, but also slow down the time of restoration if adult mortality suddenly is high in an oil spill. In a population of Cassin's Auklet (*Ptychoramphus aleuticus*), an adult survival rate of 65 % was found, this is lower than what is usual for most alcids (survival rate of more than 85 %). The lowered adult survival rate is expected to be the cause of a decline in the worlds largest colony of the species (Bertram *et al.*, 2000). The importance of adult survival for population status is evident for other species of sea birds than alcids. Population modelling of European Shag (*Phalacrocorax aristotelis*) and a study of shags on Cíes Island (Galicia Spain) showed that in order for the population to be stable, the annual survival rate of adults must be 73.5 %, and that the multiplication rate was more dependent on the annual adult survival rate than on reproductive success. In the study, site-fidelity of European shags was 61 %. Reproductive rate in the study peaked at 15 % in the two colonies studied (Valando & Freire, 2002), suggesting a high inherent reproductive potential if the conditions are otherwise favourable.

Other colony-related factors affecting restoration times are e.g. competition between species, and the "effective colony size" which is the sum of all species with overlap with respect to diet and/or nest-sites.

A caution point should be noted that using inherent theoretical recovery potential of a species of sea bird, when estimating the potential impact to a resource provides a measure of the oil induced impact potential of the incidence, but does not necessarily estimate the true time for recovery. It was decided by the project not to focus on lack of recovery of sea bird populations that has been observed in many cases. Following the *Exxon Valdez*, and *Braer* oil spills, an estimated total number of 35,467 and 1,536 birds were killed, respectively (Kingston, 2002). Several authors report on lack of restoration of impacted sea bird populations, both at-sea fish-eating species and near-shore benthos feeding species (e.g. Lance *et al.*, 2001).

This theoretical approach also assumes that the community returns to the same state as prior to the spill. However, this may not be the case, as competing species that have suffered a lower impact may well take over a niche previously occupied by the higher impacted species.

There seems to a high inherent resiliency of seabirds to survive severe, short-term perturbations of the populations in years with low fledging success, due shortage of food, severe weather conditions etc. In a study of the Atlantic puffin (*Fratercula arctica*) - population at Røst (Anker-Nilsen & Aarvak, 2004), the fledging success -rates (number of fledging chicks per hatched egg) from 1978-2003 are summarised. From one year to another, fledging success may vary between 0 and 96 %, with the mean being 36.7 % of the chicks fledging. The fledging success necessary for a stable population i.e. equilibrium is 54 %. A strong year-class of herring (0-group) (measured in the Barents Sea) is correlated by a high fledging success of Puffins at Røst (corrected for the drift time of herring larvae to the Barents Sea) (Anker-Nilsen & Aarvak, 2004), The puffin colonies at Røst are declining, in this region, the reason is also thought to be shortage of prey. The variability of prey is increasing, and shifting from energy-rich capelin, sand-eels and herring towards higher proportions of gadoids. This trend causes the birds to consume more energy in catching less energy-yielding food, reducing the fledging success. Common Guillemot (*Uria aalge*) is also declining on the Norwegian Coast due to increased adult mortality and low reproduction because of capelin stocks reduction. Sea birds are long-

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lived, and delay breeding until they are several years old, and display high annual rates of adult survival, but low rates of post fledgling survival rather than breeding success and post-fledgling survival, unless such effects are sustained over several years (Mitchell *et al.*, 2004). However, relevant for oil spills is that long-lived species that rely on high adult survival, such as alcids, is the high “populational value” of each breeding adult. Restoration may take long both to set on and to identify in the field. Re-colonization would depend on the general range of the species, dispersal ability (of adults and juveniles) (Gaston and Blackburn, 2002). A wide-ranging, generally well distributed species may, although the tendency is lowered to colonise *new* areas – because there are few vacant habitats, more easily be replaced by nearby colonies. However, dispersal ability would be a critical factor in this respect.

Pigeon Guillemot (*Cephus columba*) had suffered a 67% decline since 1970's before the *Exxon Valdez* Oil Spill (EVOS) in March 1989, and the numbers were still declining 9 years after the spill (Kuletz, 1998). Even given the background decline, a higher rate of decline was found for oiled areas than for unoiled areas (Lance *et al.*, 2001). Marbled Murrelet (*Brachyramphus marmoratus marmoratus*) had also suffered a 67 % decline since 1972 (Kuletz, 1997). Minimum 8400 Marbled murrelets (*Brachyramphus marmoratus*) and Kittlitz' murrelets were killed directly by the EVOS, estimated to be approximately 7 % of the population. The population trends were analysed and found not to be recovering after more than 10 years (Lance *et al.*, 2001), although the population has been stable since 1990 (Kuletz, 1997). Analysis of population trends post-EVOS showed that guillemots of *Uria spp.* (Am.E. “Murre”), cormorants, Mew gulls, Glaucus-winged gulls, Black Oystercatchers, grebes and terns were not found to be recovering either, when the trends of oiled and unoiled areas were compared. After EVOS, comparison of surveys from 1972 with post-spill surveys from 1989-1991 and 1993 showed a general decline (independent of the EVOS) in species that *feed on fish* (divers (Am. E: “Loons”), cormorants, mergansers, Bonapart's Gull, Glaucus-winged Gull, Black-legged Kittiwake, Arctic Tern, Pigeon Guillemot, murrelets, Parakeet Auklet and puffins) (Original references to be found in Lance, *et al.* 2001). Of these fish-eating species for which a decline had been registered, several suffered impact by the EVOS, and as mentioned above, *none* of them showed signs of population recovery, in the comparison between oiled and non-oiled areas. 6 years after the *Amoco Cadiz* oil spill, populations of razorbill, Atlantic puffins and Common guillemot (murre) had not recovered (Lance *et al.*, 2001).

Harbour seals (*Phoca vitulina richardsi*) in Prince William Sound (PWS) were declining by 12 % p.a. prior to EVOS (1984-1989). In the oiled areas, the decline was 43 % in oiled areas and 11 % in unoiled areas. There seem to be no additional long-term effects of oil on the seal populations, as the decline between 1990-1994 was the same in oiled and unoiled areas, 6 %, although tissue samples from the animals showed that they were still being exposed to elevated levels of hydrocarbons from food source such as fish, and the shoreline (Frost, 1997). The reasons for decline of harbour seals in PWS are not yet fully understood.

For both Pacific and Atlantic alcids (who have in common that they are (primarily) fish-eating diving species highly vulnerable to oil spills) general declines in populations are observed in many areas. Shortage of prey is generally thought to be a major cause. A shift from high-energy prey to lower-energy prey has been launched as one hypothesis for the background decline of many species; another was that prolonged contamination of the intertidal food sources used by predators cause a shift of predation intensity towards higher predation on guillemots by other predators (Kuletz, 1998). For fish-eating species, a hypothesis to explain the decline has been

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that a shift of prey species from high-energy prey species such as sand-lance (Pacific sand lance, *Ammodytes hexapterus*), sand-eels, capelin and herring to lower-energy yielding species such as gadoids, resulting in lower breeding success. For some species the decline may be ascribable to habitat loss (e.g. Marbled murrelets in some areas). Such pre-spill declines that are not caused by oil contamination may be indicative of a changing background level that will inhibit recovery. However, there are indications that North American Atlantic Puffin (*Fratercula arctica*) populations are on the increase (Canada), due to cessation of exploitation (hunting, eggging and habitat loss), which previously lowered the numbers. The numbers of colonies are said to be increasing as well as the number of birds, suggesting they are dispersing and establishing new colonies, and that shortage of food does not seem to be an issue for these populations (Chardine, J., CWS Canada), contrary to what they are in Europe, e.g. at Røst, Norway.

The species that feed on benthic invertebrates (goldeneyes, Harlequin Duck and Black Oystercatcher) did not show “background” declines prior to the spill. Of the benthos-feeding sea bird species, Black oystercatchers were disturbed in the breeding season of 1989/1990 because of clean-up after EVOS (Lance *et al.*, 2001). In 1992 and 1993, effects of persistent shoreline oil on breeding success were negligible, and by 1998, they had reoccupied nesting sites, indicating that oiling had not impaired breeding success. However, the species abundance did not increase, and breeding success was significantly lower in oiled than in unoiled areas. Predation was attributed to be the driving mechanism, though the link between oil and predation was unclear (Lance *et al.*, 2001). There might also be influence from food web-mediated effects, and background (non-spill) population development trends. Failure to recover has been ascribed to continuous oiling of shorelines for those species that are most dependent on intertidal zone foraging. Clam populations were reduced after the spill, and had not recovered by 1997. Harlequin Ducks, Barrow’s Goldeneye and Pigeon Guillemot all had elevated levels of cytochrome P450 1A, an enzymatic induction response giving evidence of contaminant exposure. Contaminated Pigeon guillemots had more organ damage than non-contaminated ones. (Original references to be found in Lance, *et al.* 2001).

In EVOS, there was also an impact on the Pacific Herring (*Clupea palasi*), which had not recovered by 2000 (Lance *et al.*, 2001), although there is no strong evidence for continued long-term reproductive impact to the population. Prior to the spill, Pacific Herring has been increasing (Brown & Carls). The spill occurred at a time when Pacific herring were gathering in Prince William Sound (PWS) to spawn, and the spill had a large adverse effect on the success of hatching and larval development. However, the population is slowly increasing (Brown & Carls, 1998) and the background variability of spawning stock recruitment is high, just as for the Atlantic herring (*Clupea harengus*). The year class of 1989 failed largely to recruit to the spawning stock of 1993, however the long-term effects on the spawning population is unclear, as the 1989 year class in general was a relatively small recruitment cohort to the 1993 spawning stock (Brown & Carls, 1998), as could be interpreted as being an example of a impact to a year – class of lesser importance.

Summarized: For some of the species discussed above, failure to recover after EVOS was ascribed by Lance *et al.* (2001) to have several possible causes:

1. Persistent effects of continued ingestion of oil through feeding on benthic organisms, on a persistently contaminated shoreline (Benthic-feeding shorebirds).
2. Pre-spill/background declines are preventing the species from recovering, because the breeding success is lowered through a background lack of prey species of fish (Fish-eating seabirds).

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3. Density dependent mechanisms may change if the carrying capacity of the environment is changed (reduced K compared to pre-spill conditions).
 - If the change in the environment's carrying capacity is temporary, the inherent recovery potential in the population could be triggered when the carrying capacity is back to the previous level
 - If the change in the environment's carrying capacity is chronic, the inherent recovery potential in the population will not be triggered and the population may not be expected to recover.
4. Recovery could be occurring though fecundity, survival or immigration, but the increase in population is not yet detectable, as seabirds are k -selected; intrinsic rates of recovery may be slow.
5. Recovery may be occurring, but the size of the initial oil spill impact may be relatively small compared to population size, so that the natural fluctuations are masked.

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APPENDIX B: USE OF THE DAME-SHORE MODEL IN EIF

Moe *et al.* (2000b) introduced the principal index P_i as a quantified potential for both damage and recovery, a function that needs to be triggered by oil exposure to be realised – in the model DamE-Shore the dose-response principle is implemented in the model as a relationship between dose and realisation of damage, effects and damage extent is combined through the principle index P_i , *an inherent potential for damage in DamE-Shore*. P_i is not the same as EIF, but a damage potential that needs to be triggered by an amount of oil that decides the proportion of shoreline (equalling “part of population” for other compartments). The value of P_i lies between 0 (no damage) and 1 (damage d larger than or equal to a critical level of damage, over a period of time T longer than or equal to a critical time T_{cr}). The principle index is the relationship between the level of damage D (as a function of damage-time) and the critical level of damage D_{cr} (as a function of damage-time) ($P_i = D/D_{cr} = D/T_{cr}$) and is calculated on basis of the function:

$$P_i = \frac{D}{T_{cr}} = \frac{d_{\max}}{T_{cr}} \left(\gamma_m \left(\frac{t_{m,ref1}}{E} + t_{m,ref2} \right) + \gamma_p t_p \right)$$

- P_i = Principal sensitivity index
 d_{\max} = The maximum level of damage
 T_{cr} = Period of time, considered superior to or overarching the periodicity of the natural fluctuations of the resources. The factor is species specific and introduced to compensate for natural variations in community status between the moment of fall (i.e. at time t_0 when oil strikes the resource) and the moment of rise (i.e. at time $t_{recovered}$ when the resource is back to “normal” state)
 γ_m = the form factor of the effect period [0, 1], i.e. the rate of $d(t)$ approaching d_{\max}
 γ_p = the form factor of the recovery period [0, 1], i.e. the rate of $d(t)$ approaching “normal” level
 t_m = the effect period
 $t_{m,ref}$ = the effect interval in time t_m
 t_p = the biological recovery period, and equalling the sum of t_{lag} and t_{res} in EIF
 E = the wave exposure

For periodically ice-covered areas the period of ice-cover modifies the equation, and the inherent restoration rates of biological communities may be higher (the communities are “constantly” in a restorations state due to ice scouring). Here, E = the wave exposure as a function of ice-cover.

$$P_i = \frac{d_{\max}}{T_{cr}} \left(\gamma_m \left(\frac{t_{m,ref1}}{E_{NoIce} \frac{T_{NoIce}}{T}} + t_{m,ref2} \right) + \gamma_p t_p \right)$$

P_i is ascribed to a segment of shoreline, on basis of knowledge of substrate and expected abundance of shoreline communities. The abundance distribution of shoreline communities is a function of wave exposure and geographical region (south-north gradient). The biological exposure scale model is valid for hard substrates. For soft substrates, experiences from various local investigations of soft substrate communities have been used and included in the concept (references in Moe & Brude, 2002).

γ_m and γ_p are the rates of decline and growth of communities respectively. $t_{m,ref1}$ and $t_{m,ref2}$ are two parameters of t_{imp} , respectively, they denote the period when oil exposure is the primary recovery-inhibiting factor, and the period when oil exposure is less important. t_p is the recovery

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time. $t_{m,ref1}$ and $t_{m,ref2}$ are characteristics of the substrate type, whereas γ_m , γ_p and t_p are parameters of the community. Since several communities may be present on the same substrate type, P_i is calculated using the community that gives the maximum values.

The different substrates have varying ability to accumulate oil (thereby varying exposure time) (Moe *et al.*, 2000b; Moe & Brude, 2002). “All” properties of the shoreline are quantified and integrated in the P_i function of DamE-Shore. Through Moe & Brude (2002), Moe *et al.* (2000c) and Brude *et al.* (2003), the concept has been applied to most of the Norwegian coastline (where data on substrate and wave exposure are available, and the tidal differences are compliant with the wave exposure – abundance model of <hold references, and P_i -values have been ascribed as shown in Figure II.1.



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