ERA Acute Report

WP2a – Seafloor Compartment Norwegian Sea Test Case level A.1, A.2, A.3 and B

ERA Acute Report ERA Acute – WP2a – Seafloor Compartment - Norwegian Sea test case level A.1, A.2, A.3 and B	
Authors: ***Cathrine Stephansen, APN*** ***Verified by Tom Sørnes, APN***	***Version/Date: 21.12.2017*** ***Number of pages****: 58* ***Distribution: Project members*** ***Document ID: ERA Acute 2A-4***
Summary: *Using updated recommended parameters based on sensitivity testing in WP2a (Document ID 2A-3), a case study was carried out for the seafloor compartment for a single blowout scenario in the Norwegian Sea. The case study was carried out at level A.1, A.2 and A.3 impact modelling, and included level B restitution modelling*	
Task lead: Odd Willy Brude/Anders Bjørgesæter	***Project Manager:*** Cathrine Stephansen

The ERA Acute project is carried out by a consortium of industry partners (Statoil, Total, Norwegian Oil and Gas Association) and experts in environmental risk analysis (Acona, Akvaplan-niva (Project Manager), DNV-GL and SINTEF), supported also by the Research Council of Norway.

ERA Acute is developed to provide a globally applicable, transparent method for quantitative environmental risk assessment of oil spills in four compartments: Sea surface, shoreline, water column and sea floor.

1 Test 6 Norwegian Sea Surface Blowout Case

1.1 Oil drift simulations and parameter values used

A series of tests were carried out in WP 2a to investigate the sensitivity of the soft and hard substrate calculations to variations in the input parameters used. During the course of the sensitivity testing, parameters were adjusted, and data were obtained for the Norwegian Sea region, that have been used in a case study of impacts and restitution to sea floor VECs following a surface blowout scenario of 9000 Sm3/day Oseberg Øst crude for 65 days. The oil drift simulations were used in the sensitivity tests (WP2A), as were the dummy data generated using MAREANO results. The oil drift simulations, data sets and input parameters are described in the WP2A Sensitivity Testing Report (Stephansen and Bjørgesæter, 2017).

The datasets are described in section 9 of the WP2A Sensitivity Testing Report, denoted "Sensitivity Report" in the following sections.

Oil drift simulations are described in section 2, Using the oil drift data sets (see section 2.1 in the Sensitivity Report) the three levels of impact -based risk assessment were tested. This includes levels A.1, A.2 and A.3 and following A.3, full risk assessment for level B with restitution endpoints and RDF was included.

1.2 Influence areas

The influence areas for the Norwegian sea test case were presented in Sensitivity Report section 2.1 In test 5c (Sensitivity Report section 8.4), it was found that with the current recommended setup of VECs and substrate parameters (the oil amount that gives a restitution time in mud > 0 years is 0.0015 kg/m^2 input values from the oil drift simulations.

A probability map of cells using 0.0015 kg/m^2 is shown in Figure 1, Figure 2 shows a close-up of the same, and Figure 3 shows the C_{THCtot} value in the cells (ppb) relevant for FMs 1,4 and 6.

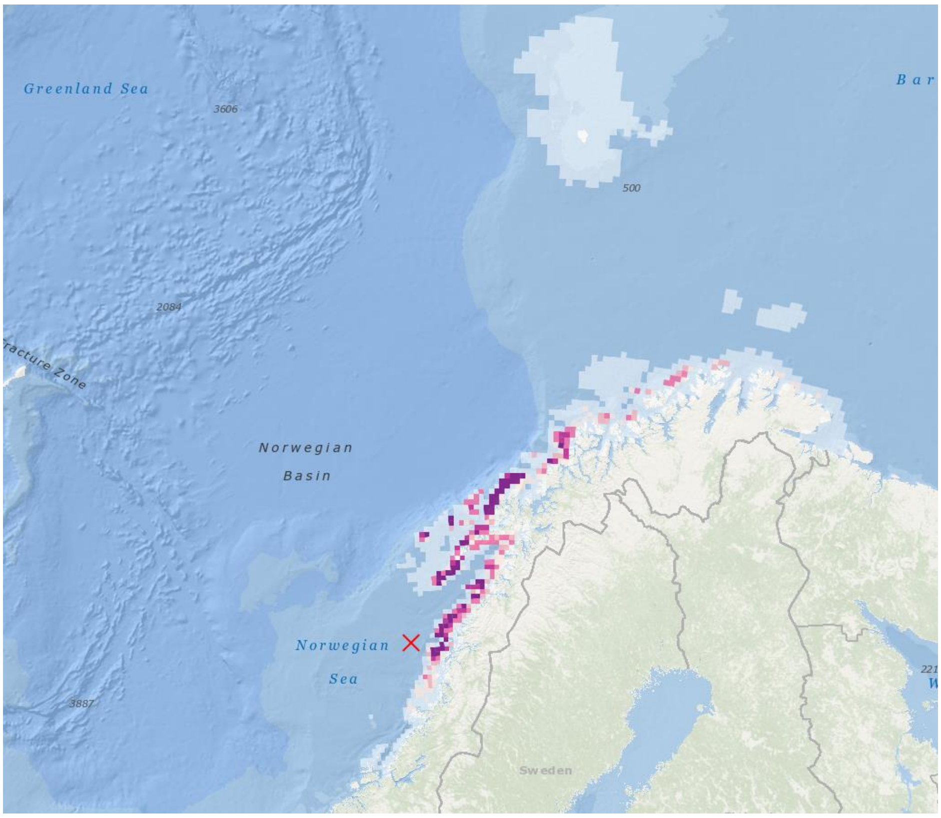

Figure 1. Probability of oil amounts above 0.0015 kg/m² sediment following 21 simulations of a surface release of 9000 Sm³/day for 65 days, Oseberg Øst crude.

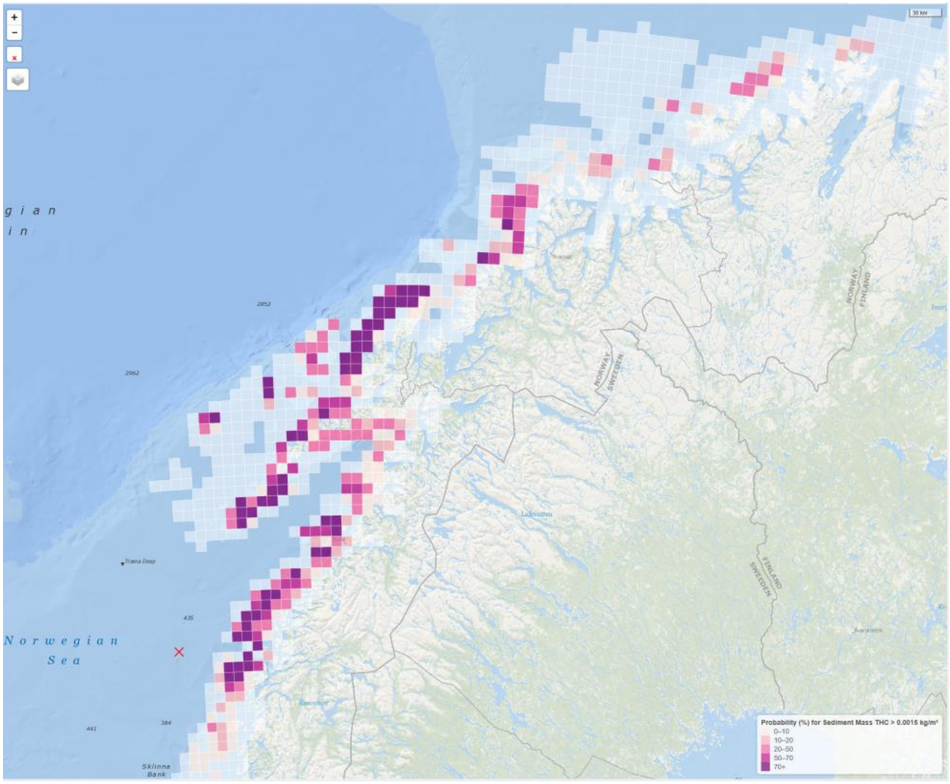

Figure 2. Closer view of probability of oil amounts above 0.0015 kg/m² sediment, 21 simulations of a surface release of 9000 Sm3/day for 65 days, Oseberg Øst crude.

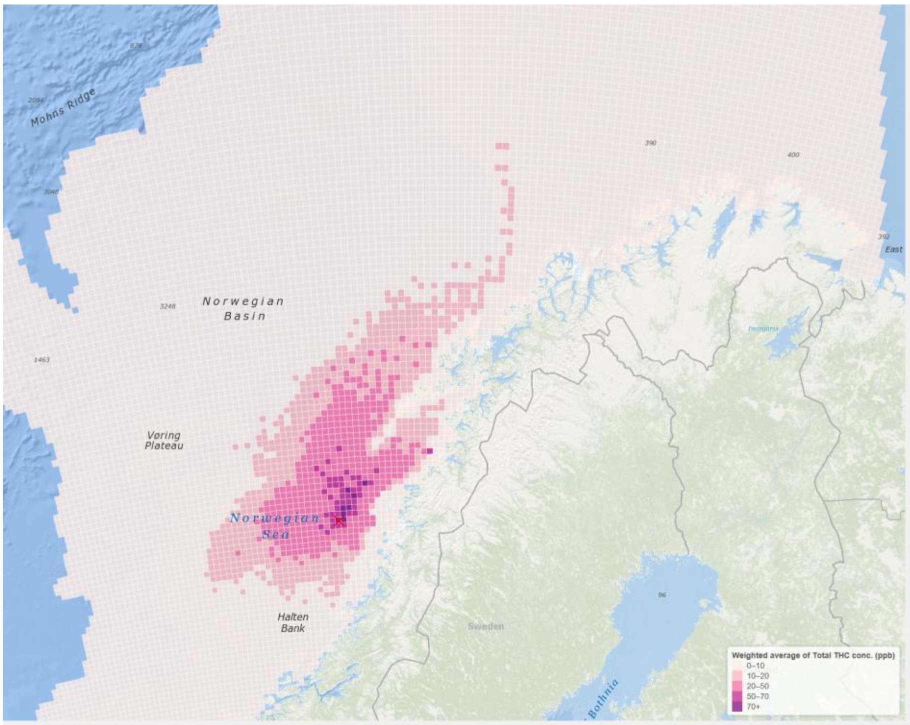

Figure 3. Weighted average total THC concentration (ppb) in the water column 21 simulations of a surface release of 9000 Sm3/day for 65 days, Oseberg Øst crude.

2 Level A1 Impact Assessment

2.1 Introduction

Level A1 was designed originally to use just one (most) sensitive species/resource for which the presence was 100 % (N=1) in every cell within the analysis area (Spikkerud *et al.,* 2006). However, the calculator and software tool have been implemented in such a way that a choice of several VECs is possible, by using a pre-defined setup of the resource setup file. The user can select a single VEC, but will then have to know which VEC is the most sensitive.

As we in the sea floor compartment have combinations of properties of the substrates and feeding modes which for example make mud the most sensitive substrate with respect to restitution time, but the coarse sands the substrates that give the highest impacts, the feature in the tool allows us to use several VECs in the A.1 screenings and test which VECs that are the potentially most sensitive, just given exposure.

The basic impact equation at level A1 is, where p_{exp} in the sea floor = 1, therefore the potential mortality to any given cell is p_{let} calculated from the oil amount in the cell, either from water column (for FMs 1 and 4) or from sediment interstitial water (FMs 2 and 5,7) or from both (FM 6).

$$Impact = plet \times pexp \times 1$$

The potential mortality (in %) is the same as the probability for a lethal effect to any given organism of the FM in the cell, and also the % of the total cell area to be impacted. In this study the cell area is 100 km^2. The resource setup from level A.2 was used to calculate potential mortalities for all possible VECs. In the sea floor, because the sensitivity of species may be different, thereby leading to different restitution times, we introduced the SF to adjust the impact. In course of the finalisation of the calculator and tool, the same SF was decided to be used for the A1 impact calculation as was used in the Level B restitution calculations for different substrates. Although the impacts are calculated from the THC concentration in the water column, use of the SF which is different for each of the soft substrates, the impacts are calculated differently for FM1 and FM4 in the soft substrates. FM1 and FM4 on hard substrates and sand will thereby be the same, whereas FM1/4 in substrates coarse sand and mud will be different. This is done to add conservativeness due to the prolonged contamination of mud compared to coarse sands.

$$Impact = plet \times pexp \times 1 \, x \, SF$$

2.2 Results – Impact levels

In the simulation with the highest potential impact to each VEC, the monthly impact for the different VECs is as shown in Table 1 for level A.1. The values of impacts are low in each cell, meaning that the potential mortality (fraction of the cell area impacted) is low compared to the cell area of 100 km^2. In each cell, the potential mortality is calculated as a fraction of the cell area that is potentially impacted ("potential mortality"). Table 1 shows the sum of potential mortalities over all cells. This number also represents the number of whole cells the impact corresponds to, even though the impact is distributed over a larger number of cells.

Table 1. Level A.1 impact for the VECs in the seafloor compartment following simulations of a surface release of 9000 Sm^3/day for 65 days, Oseberg Øst crude. (100-percentile)

VEC	Sum of potential mortalities in all cells in simulation with highest impact	Equivalent area of Impact (km^2)	SF
	(Equals No. of 10x10km cells)		
FM1/FM4 hard bottom. demospongia. glass sponges. hard bottom corals and sponges	18.7	1870	1 (none)
FM4+5 seapens. Umbellula.soft bottom corals	22.7	2270	1.2
FM1&4 bioclastic coarse sand	7.5	750	0.4
FM1&4 coarse sand	7.5	750	0.4
FM1&4 mud	45.0	4500	2.4
FM1&4 sand	18.7	1870	1
FM1&4 muddy sand	22.5	2250	1.2
FM2&5 bioclastic coarse sand	0.69	69	0.4
FM2&5 coarse sand	0.66	66	0.4
FM2&5 Mud	4.1	410	2.4
FM2&5 sand	1.5	150	1
FM2&5 Sandy mud	3.4	340	1.2
FM6 Mud	45.4	4540	2.4
FM6 Sandy mud	27.0	2700	1.2
FM7 Sandy mud (e.g. burrowing with seapens)	18.9	1890	1.2
FM7 Mud	9.9	990	2.4

2.3 Risk maps

Visual interpretation of sea floor results requires combining the influence areas of both the water column and the sea floor.

The highest potential impact in the simulations, given that the VEC is present in all the exposed cells is found for FM1,4 and 6 for mud, given the higher exposure in water column, and the high SF due to the high TOC which increases the restitution time. Looking at the average impacts over all the simulations, the cells in the areas with the highest impacts have average impacts of just in excess of 50 % i.e 50 km^2 on a yearly average for the FMs exposed in the water column. The highest impact to the organisms exposed in water column is found in February (weather conditions favour natural dispersion of surface oil into the water column). The figures below do not show the full extent of the influence area, but in each case closes in on the most relevant part to better show the values in the central part of the influence area. The area with a very low probability is larger, a cut-off level is recommended when using figures in reports.

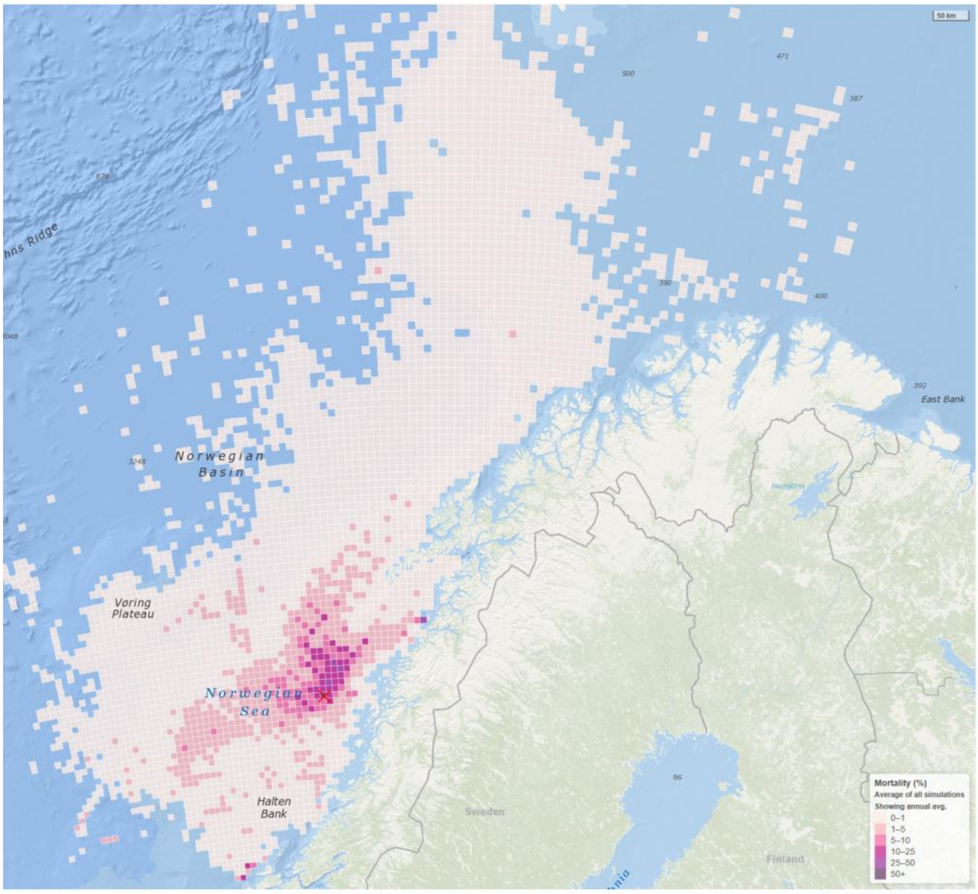

Figure 4. Level A1: Central parts of the influence area with average impact to FM1 & 4 if the substrate is mud (exposure through water column) showing potential mortality (%).

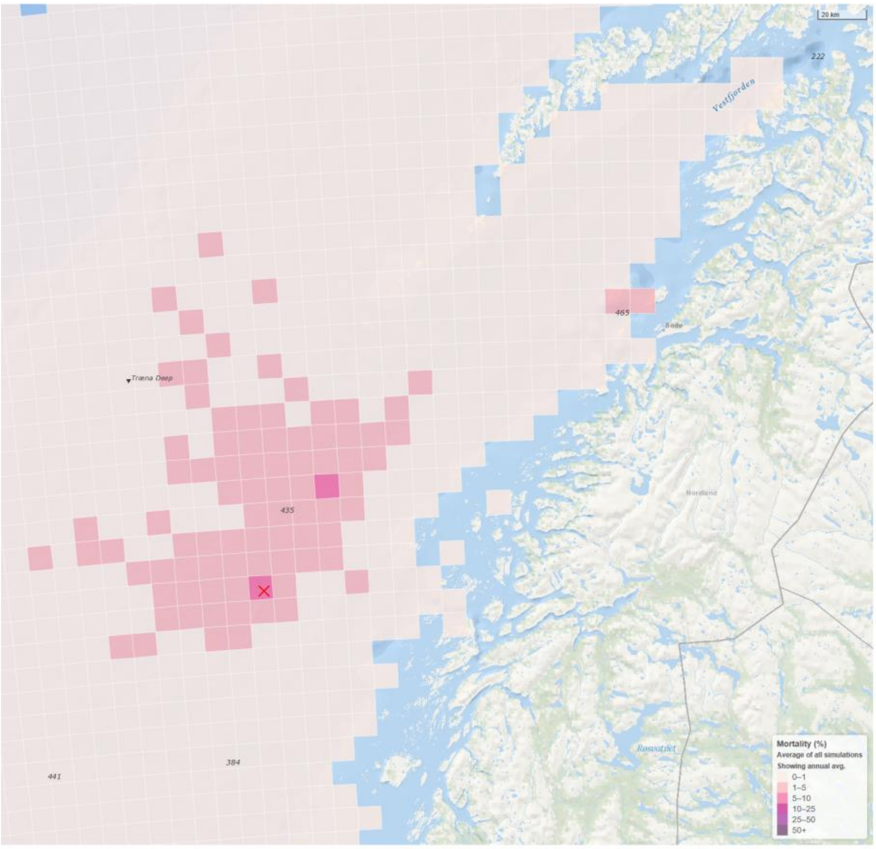

Figure 5. Level A1: Central parts of the influence area with impact to FM1 & 4 if the substrate is coarse sand (exposure through water column).

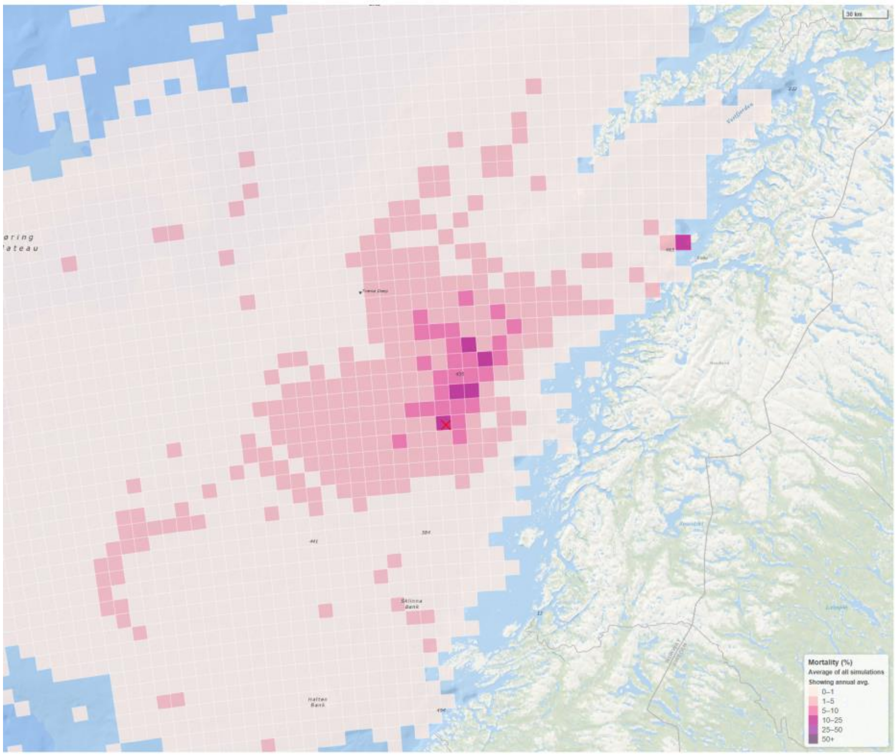

Figure 6. Level A1: Central parts of the influence area with impact to FM1 & 4 if the substrate is sand or hard bottom (exposure through water column).

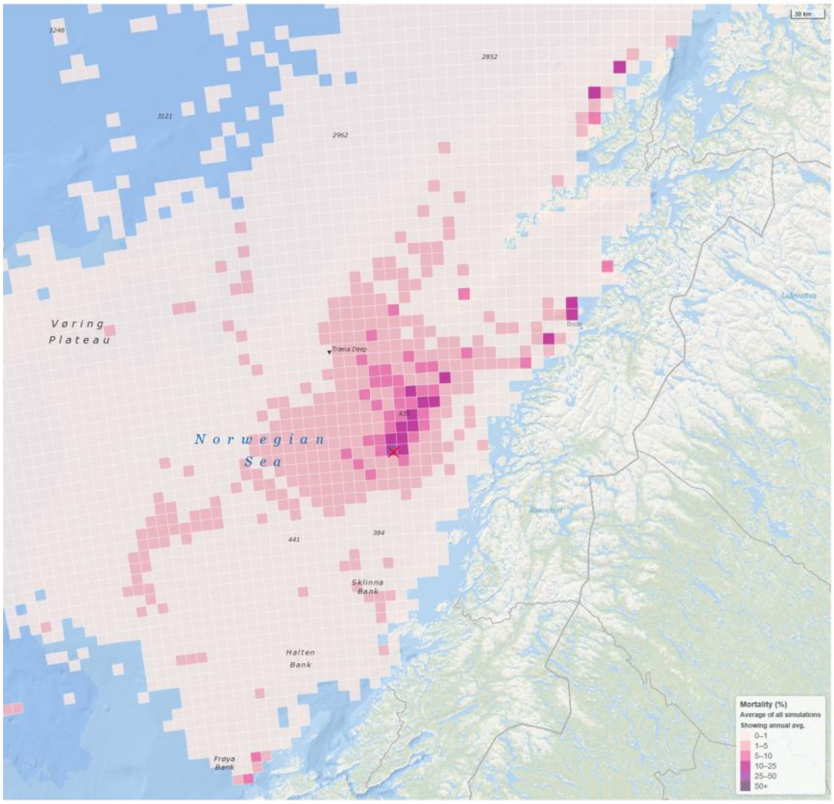

Figure 7. Level A1: Central parts of the influence area with impact to FM4 & 5 as additive effect (e.g. seapens) if the substrate is sandy mud exposure through water column and interstitial water).

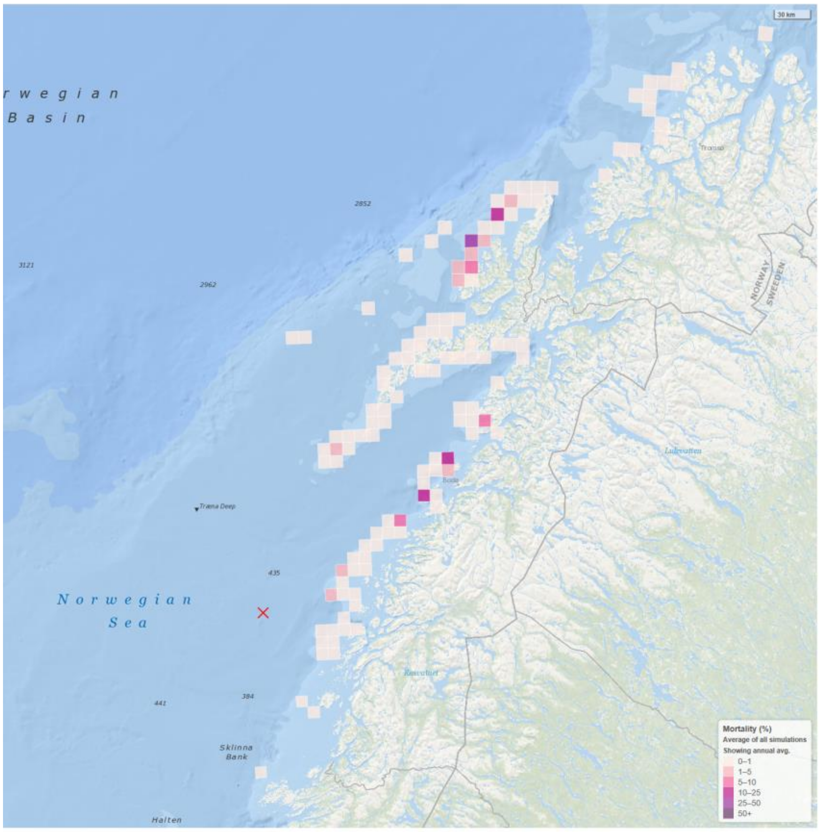

Figure 8. Level A1: Central parts of the influence area with impact to FM2 & 5 if the substrate is mud (exposure through water column). Oil is deposited on the sea floor at a distance from the spill site.

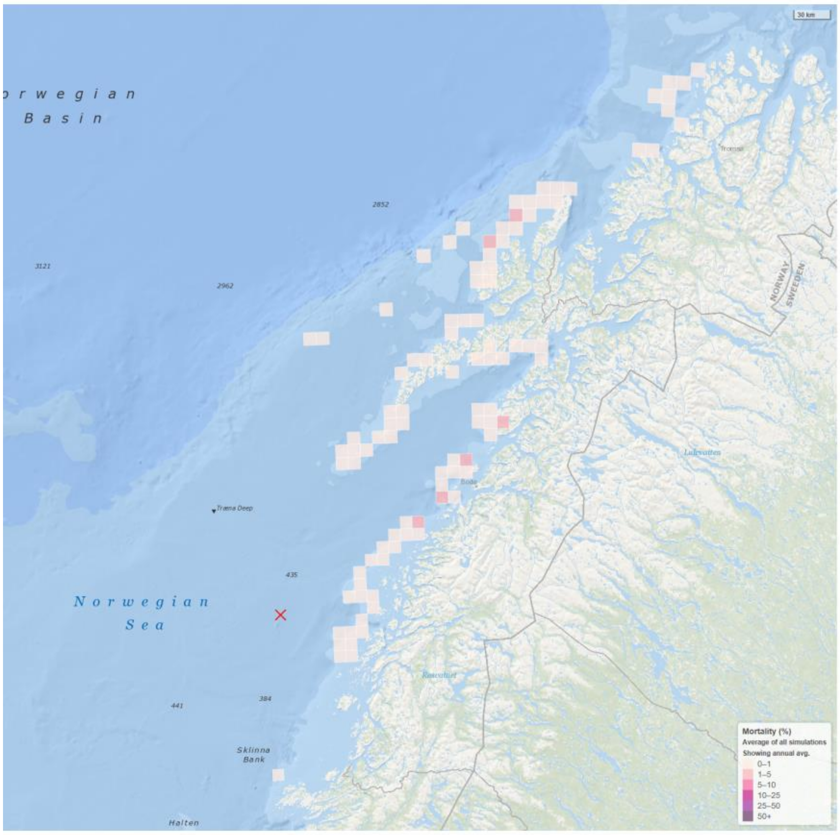

Figure 9. Level A1: Central parts of the influence area with impact to FM2 & 5 if the substrate is coarse sand (exposure through water column). Oil is deposited on the sea floor at a distance from the spill site.

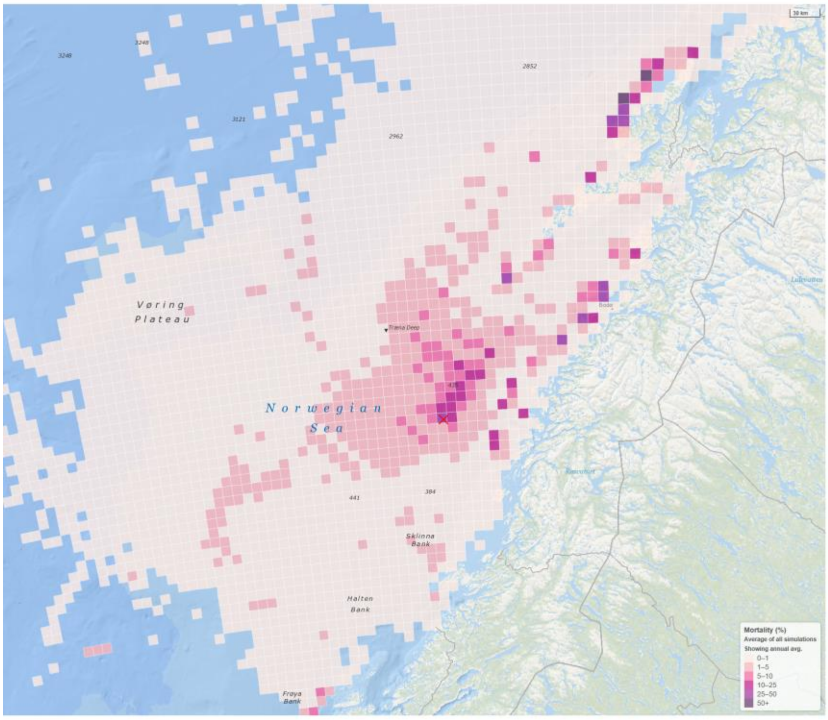

Figure 10. Level A1: Central parts of the influence area with impact to FM6 if the substrate is sandy mud (exposure through water column and through ingested particles of contaminated deposits).

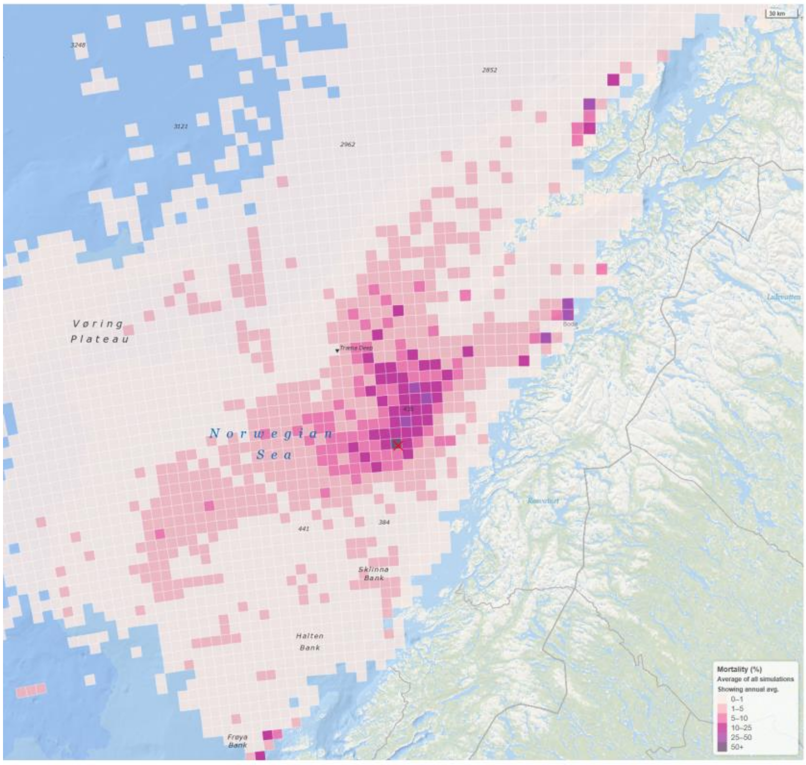

Figure 11. Level A1: Central parts of the influence area with impact to FM6 if the substrate is mud (exposure through water column and through ingested particles of contaminated deposits).

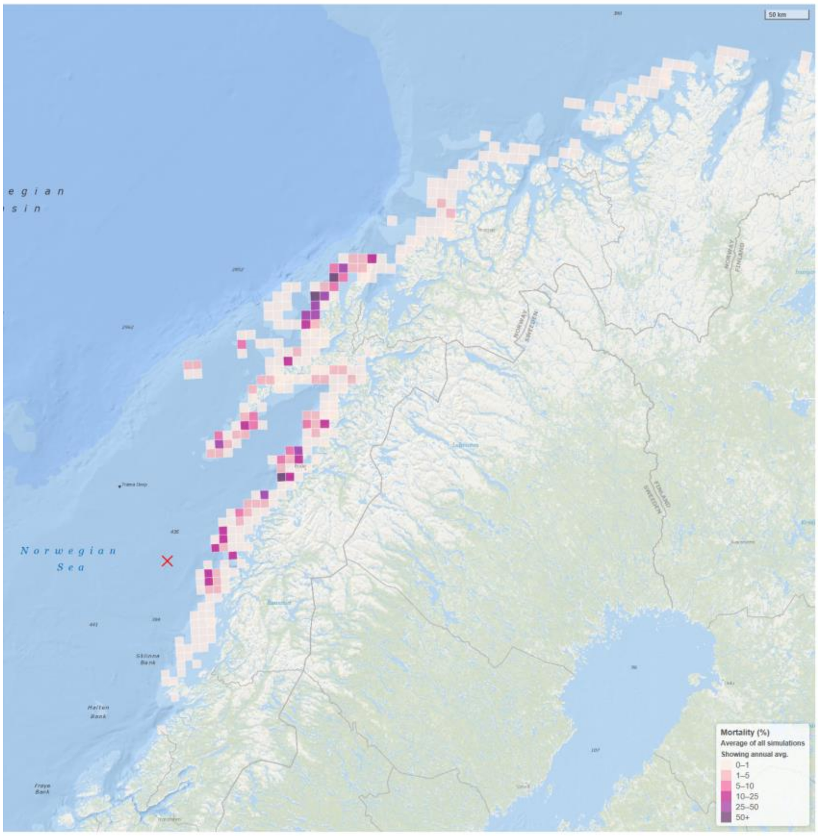

Figure 12. Level A1: Central parts of the influence area with impact to FM7 if the substrate is sandy mud (exposure through interstitial water and through ingested particles of contaminated deposits).

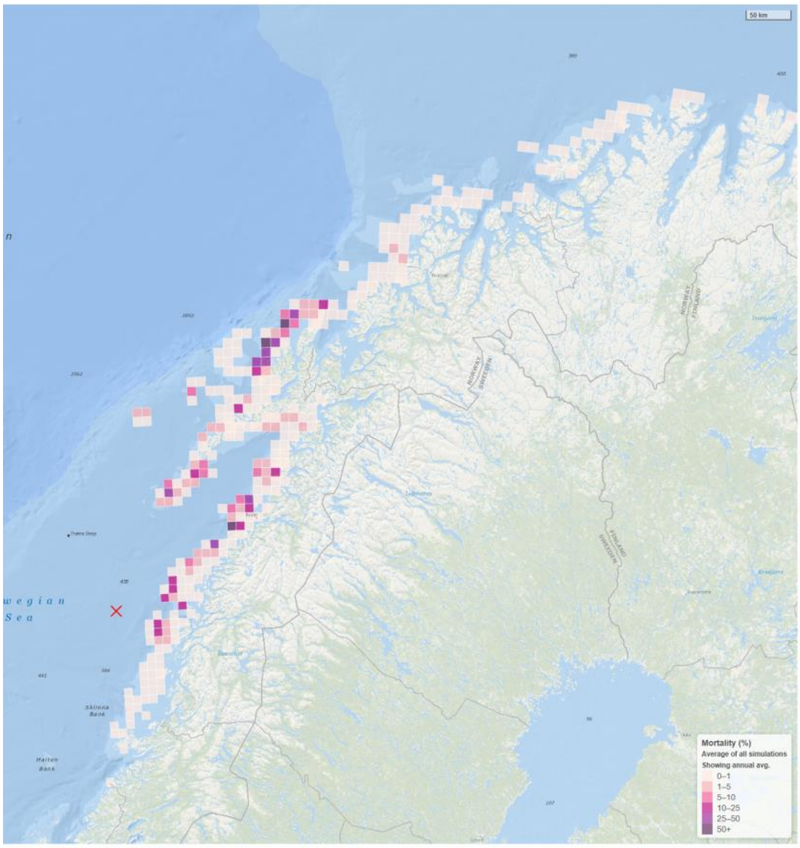

Figure 13. Level A1: Central parts of the influence area with impact to FM7 if the substrate is sandy mud (exposure through interstitial water and through ingested particles of contaminated deposits).

Figure 14. Level A1: Central parts of the influence area with impact to FM7 if the substrate is mud (exposure through interstitial water and through ingested particles of contaminated deposits).

2.4 Discussion and conclusions – test of A.1 ERA Acute screening analyses for the Norwegian Sea

The results of the A1 impact assessment show clearly the significance of the feeding modes and substrate parameters in the levels and areas of potential impact at level A1.

Level A1 is particularly useful for the sea floor compartments, as the different modes of exposure mean that the search for detailed data in a new area can be time-consuming. However, finding data on the presence or non-presence of the substrates with the highest impact potential for the FM as well as regional values of TOC and mixing depths (see sensitivity tests 1-4) may well be worth the effort.

3 Level A.2 Impact Assessment

3.1 Introduction

At level A2, ERA Acute calculates the same potential impact as at level A1. However, at A2 it is assumed that the user has data that verifiably exclude some cells from the calculations, because it is known which areas the VEC inhabits, but not necessarily the fraction of the VEC present in the cells. This type of data would be useful for polygons of Special Protected Areas (SPAs) for specific VECs, e.g. coral reefs (hard bottom, FM4).

For this test, the data from MAREANO that were developed for A3, were modified so that cells with VEC are given N=1, for other cells, there is no value.

For cells with a value for the VEC:

$$Impact = \ plet \ \times pexp \ \times 1 \ x \ SF$$

For cells without VEC, the impact is 0.

3.2 Results – Impact levels

In the simulation with the highest overall impact to areas with presence of VEC (different simulations) the highest monthly impact for the different VECs is as shown in Table 2 for level A.2. The impact areas are reduced by 70-100% for the VECs analysed, using A2 data based on the Mareano data.

Table 2. Level A.2 impact for the VECs (100 percentile) in the seafloor compartment following simulations of a surface release of 9000 Sm^3/day for 65 days, Oseberg Øst crude, and comparison to A1 results in sums of potential impacts[2], reductions in sum of potential impacts (equivalent number of 10x10km cells and %.

VEC	**Sum of potential mortalities in all cells in simulation with highest impact** A2	SF	**Sum of potential mortalities in all cells in simulation with highest impact** A.1	Difference from A1-A2 (sum of potential impacts)	% reduction from A1 to A2
FM1/FM4 hard bottom. demospongia. glass sponges. hard bottom corals and sponges	0.0155	1 (none)	18.7	18.6845	99.9
FM4+5 seapens. Umbellula.soft bottom corals	0.085	1.2	22.7	22.615	99.6
FM1&4 bioclastic coarse sand	1.57	0.4	7.5	5.93	79.1
FM1&4 coarse sand	2.2	0.4	7.5	5.3	70.7
FM1&4 mud	0.46	2.4	45.0	44.54	99.0
FM1&4 sand	2.9	1	18.7	15.8	84.5
FM1&4 sandy mud	3.9	1.2	22.5	18.6	82.7
FM2&5 bioclastic coarse sand	0	0.4	0.69	0.69	100.0
FM2&5 Sandy mud	0.003	0.4	0.66	0.657	99.5
FM2&5 Mud	0	2.4	4.1	4.1	100.0
FM2&5 sand	0.0051	1	1.5	1.4949	99.7
FM2&5 Sandy mud	0.0052	1.2	3.4	3.3948	99.8
FM6 Mud	0.46	2.4	45.4	44.94	99.0
FM6 Sandy mud	3.93	1.2	27.0	23.07	85.4
FM7 Sandy mud (e.g. burrowing with seapens)	0.13	1.2	18.9	18.77	99.3
FM7 Mud	0	2.4	9.9	9.9	100.0

3.3 Risk maps

The reduced risk areas at level A2 are shown in the following figures Figure 15 to Figure 23. See the table of reductions in % Table 2 for reference. The legends used are the same as used in level A1 risk maps, for easier reference.

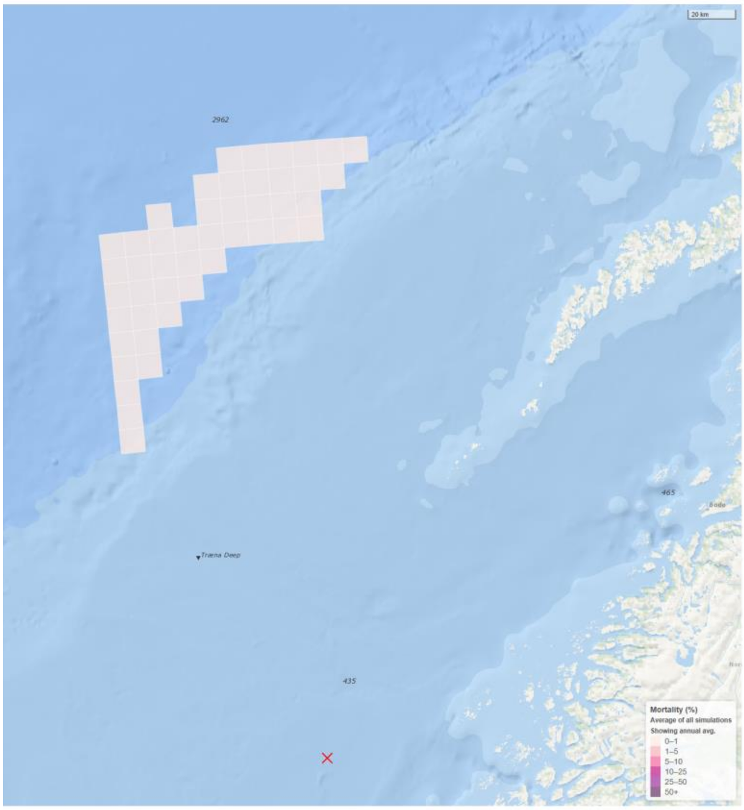

Figure 15. Level A2: Central parts of the influence area with impact to FM1 & 4 if the substrate is mud (exposure through water column). Highlighted is the statistics for the cell of the spill site. The reduction in area compared to A1 is 99 %.

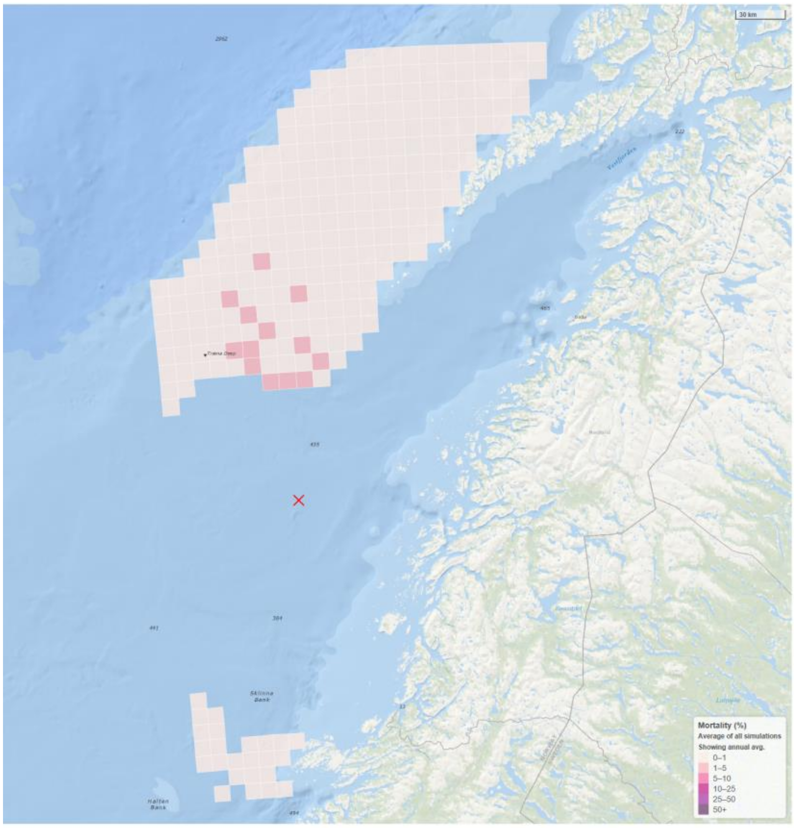

Figure 16. Level A2: Central parts of the influence area with impact to FM1 & 4 if the substrate is coarse sand (exposure through water column). Highlighted is the statistics for the cell of the spill site. The reduction in area compared to A1 is 70.7 %.

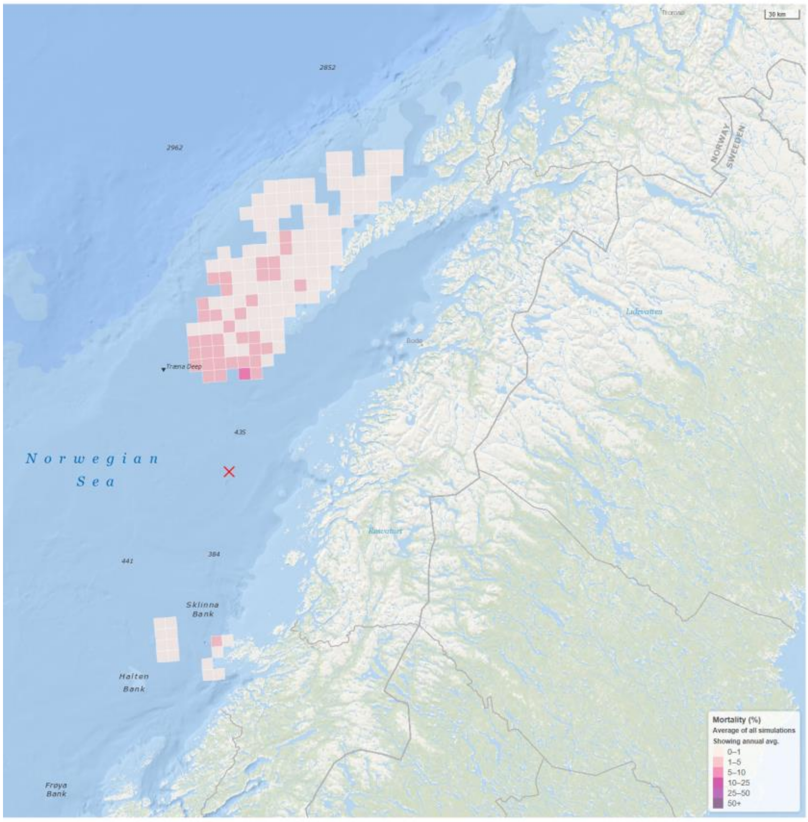

Figure 17. Level A2: Central parts of the influence area with impact to FM1 & 4 if the substrate is sand (exposure through water column). The reduction in area compared to A1 is 84,5 %.

Figure 18. Level A2: Central parts of the influence area with impact to hard bottom coral gardens (exposure through water column). (In A1 same risk area as for F1 & 4 on hard substrates.

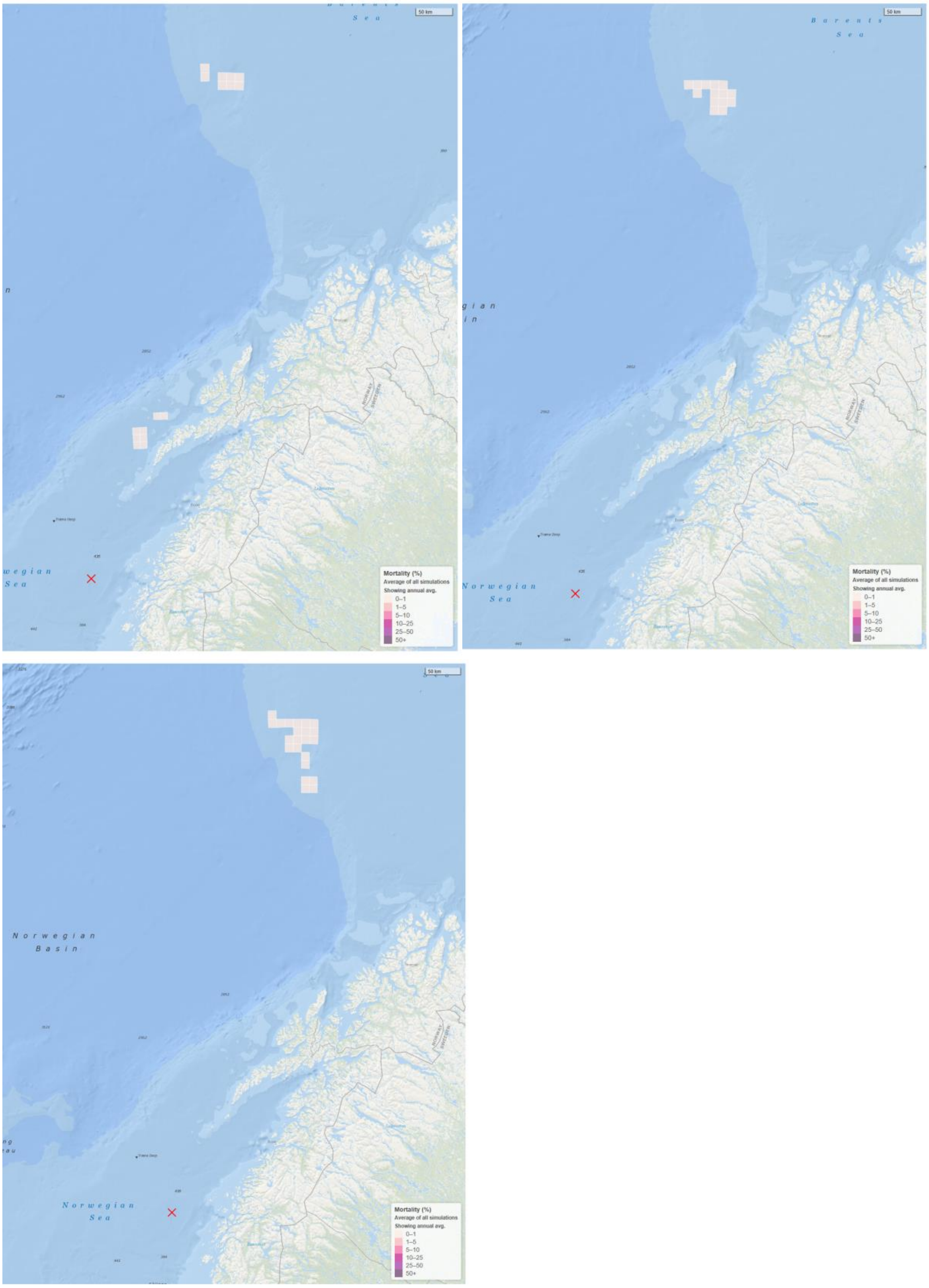

Figure 19. Level A2: Central parts of the influence area with impact to FM4 & 5 as additive effect (e.g. seapens, upper left, soft bottom coral garden upper right and *Umbellula* stands lower left) if the substrate is sandy mud exposure through water column and interstitial water).

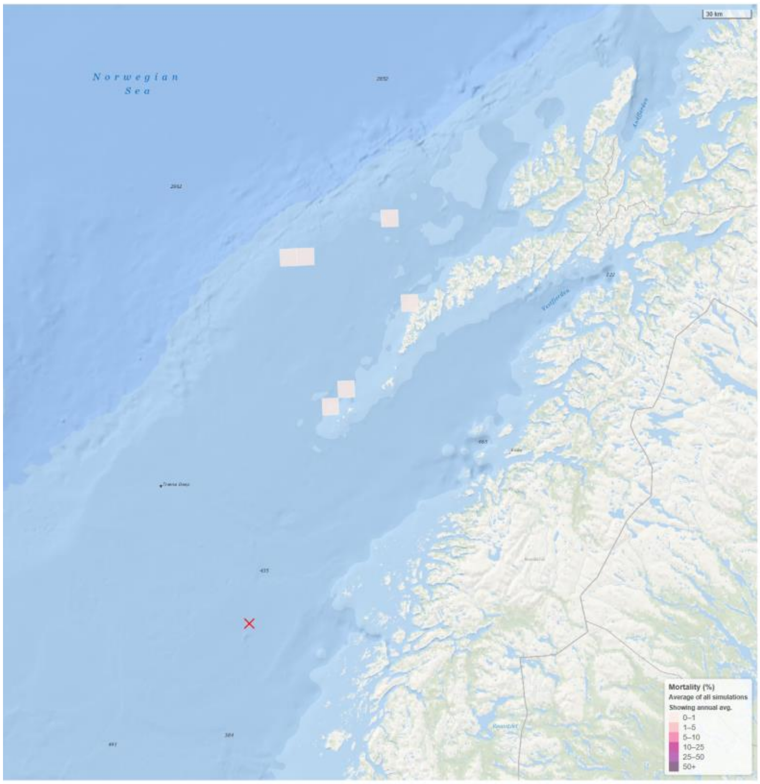

Figure 20. Level A2: Central parts of the influence area with impact to FM2 & 5 if the substrate is coarse sand (exposure through water column). Oil is deposited on the sea floor at a distance from the spill site.

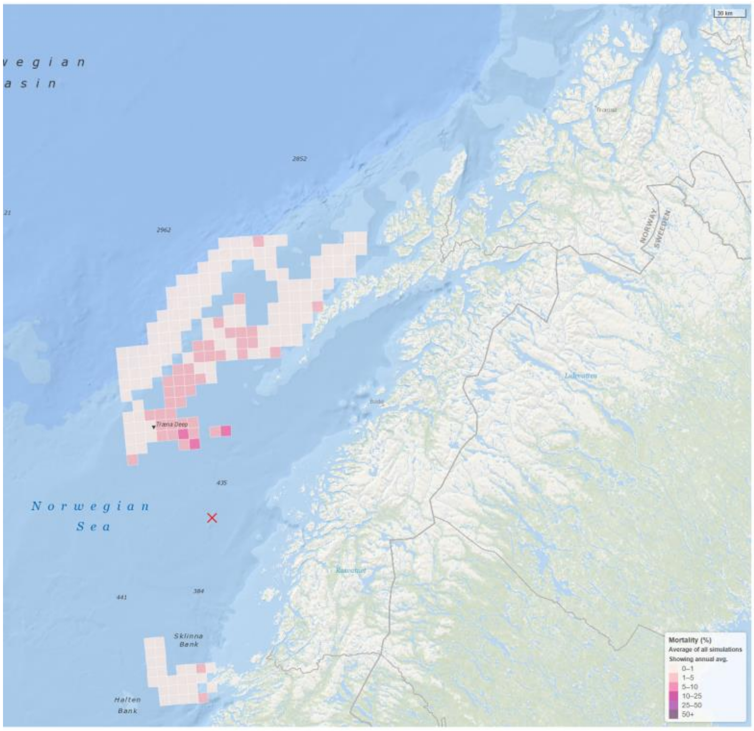

Figure 21. Level A2: Central parts of the influence area with impact to FM6 if the substrate is sandy mud (exposure through water column and through ingested particles of contaminated deposits).

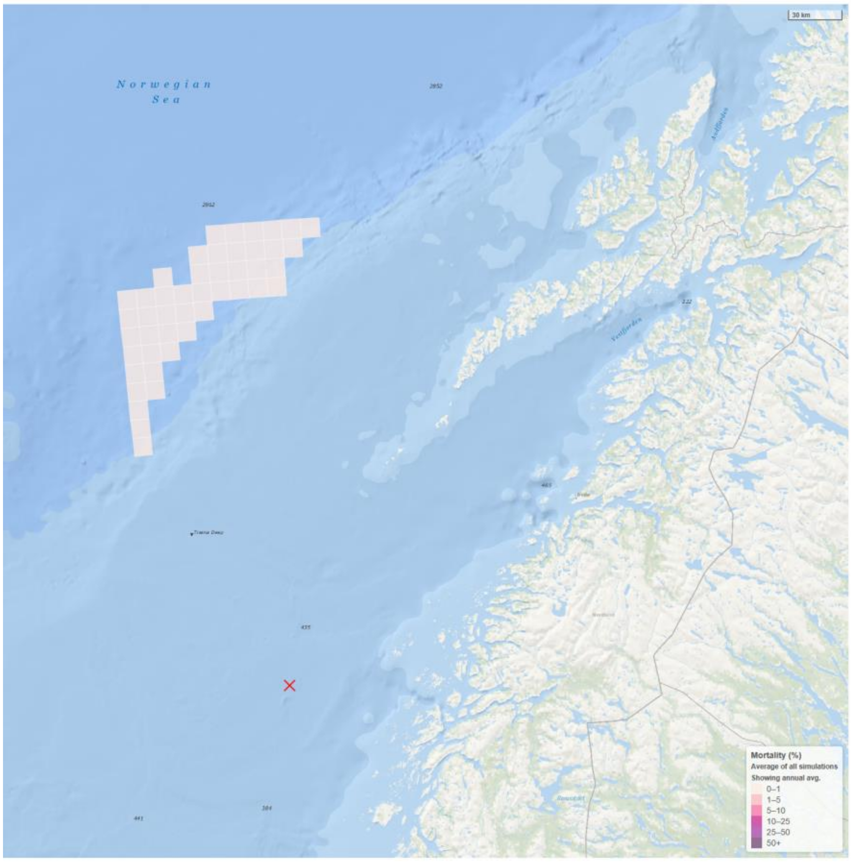

Figure 22. Level A2: Central parts of the influence area with impact to FM6 if the substrate is mud (exposure through water column and through ingested particles of contaminated deposits).

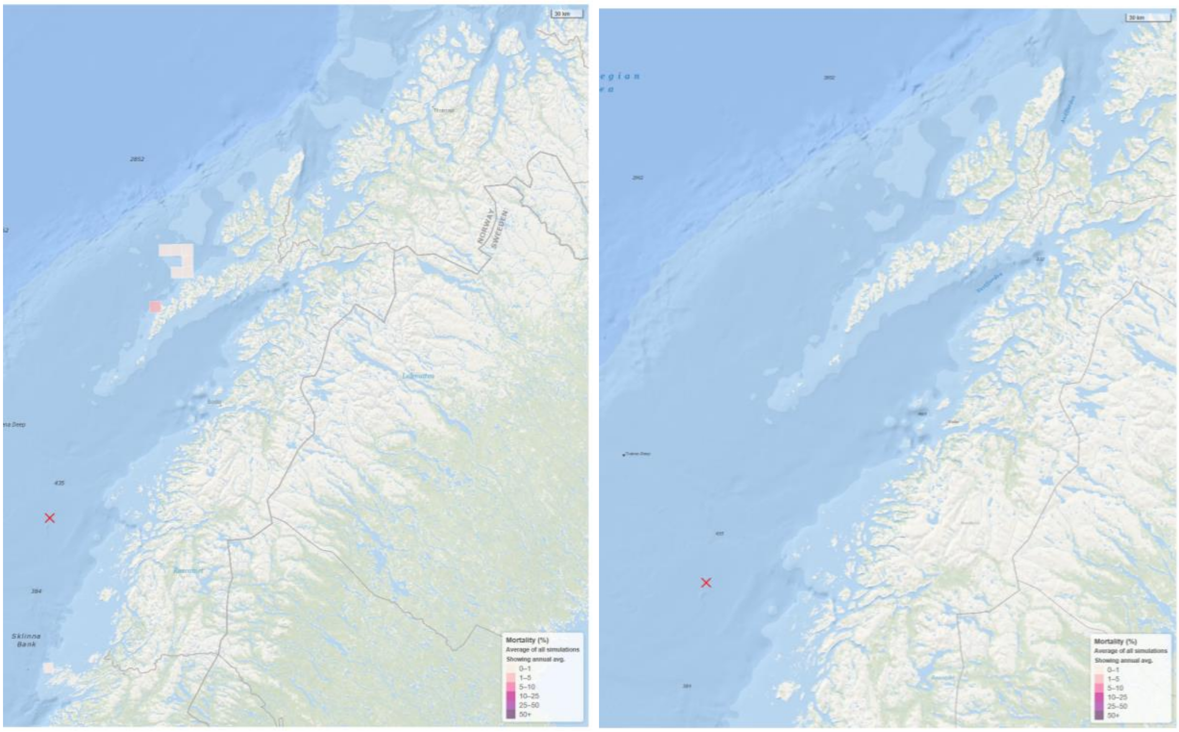

Figure 23. Level A2: Central parts of the influence area with impact to FM7 if the substrate is sandy mud (left), burrowing fauna assoc. with seapens (upper right) (exposure through interstitial water and through ingested particles of contaminated deposits). Burrowing associated with *Umbellula* habitats are not impacted.

3.4 Discussion and conclusions – Level A.2

The results of the A2 impact assessment compared to the impact assessment in A1 show clearly the benefit to documenting risk reduction if it can be verified that a specific habitat or community is not present in an area. Especially for high-risk substrates and FMs identified at level A1, the effort of data-mining will give improved results for decision making. Especially for comparative studies like Spill Impact Mitigation Assessments SIMAs, where the presence of a seafloor VEC of FM1 or FM4 in an area that has increased water column exposure following use of dispersants may comprise a risk that indicates that dispersants should be avoided. The verified absence of the same VEC would then reversely indicate that dispersants may be used safely.

However, it is important to use and interpret level A2 results with caution as cells with 0 values should represent the verified absence of the resource. Be aware of lack of data.

4 Level A.3 Impact assessment and level B restitution modelling

Using the oil drift data sets (see section 2.2 of Part 1) the three levels of impact -based risk assessment were tested, as well as a full risk assessment for level A3 with restitution endpoints and RDF.

At level A3 a full risk assessment can be carried out involving impact assessment and restitution modelling.

For cells with a value for the VEC the impact is calculated by:

$$Impact = \ plet \ \times pexp \ \times N$$

Where N is the number of km^2 present in the 10x10 km cell of that VEC. The SF is not used in the impact calculation at level A3, instead it is used in the restitution calculation. The same substrate parameters were used as for levels A1 and A2. See chapter 5 of Part 1 for details. It is important to remember that the data unit for the N-value is different in level A3 compared to A2. The two datasets are based on the same data on substrates, however, the impacts at level A3 will have different numerical values than on Level A.2. Impacts at level A2 are shown as % mortality, which represents the potential for lethal effect to a VEC in the cell, based on the parameter values of the VEC. At level A.3, the impacted area is shown in km^2 within the cell, which can be converted to fractions of the cell or other relevant measures.

4.1 Overview – Impact levels

4.1.1 % of simulations within categories of impact, time factors and RDF

The fraction (%) of the simulations that resulted in different categories of impact areas (km^2) for the different VECs are shown in Figure 24. The same statistics for the endpoint RDF are shown in Figure 25, lag times (for hard substrates) in Figure 26, restitution times in Figure 27 and total recovery times in Figure 28. The highest impact levels are for VECs exposed through the water column. Note that the water column concentrations are from the stochastic simulations that use THC-concentrations from the upper water column as a proxy for the lower water column (see 7.2) The highest impacts in single simulations are in the range of 200-500 km^2 as a sum of impacts over all the affected cells. The impacts in each cell are lower.

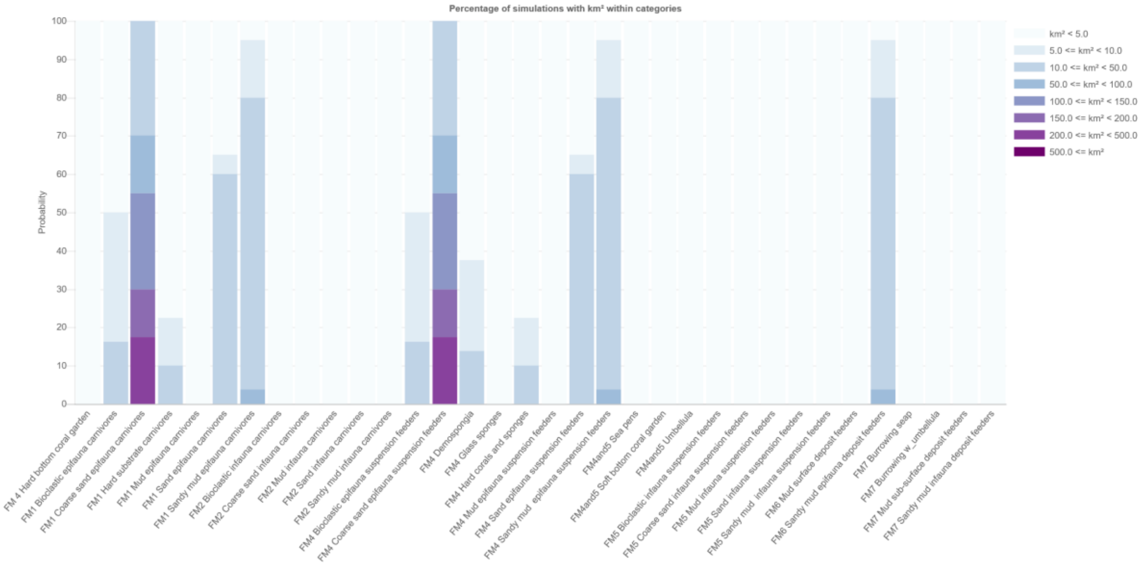

Figure 24. Probabilities as % of the simulations that gave an impact in area categories (km²).

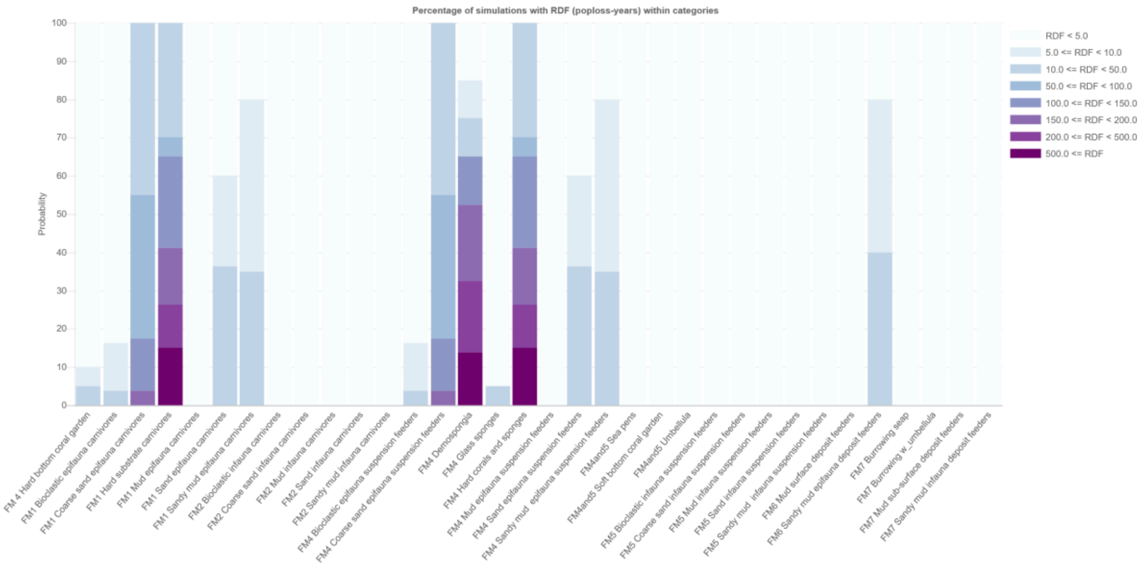

Figure 25. Probabilities as % of the simulations that gave an RDFs in categories (km²years).

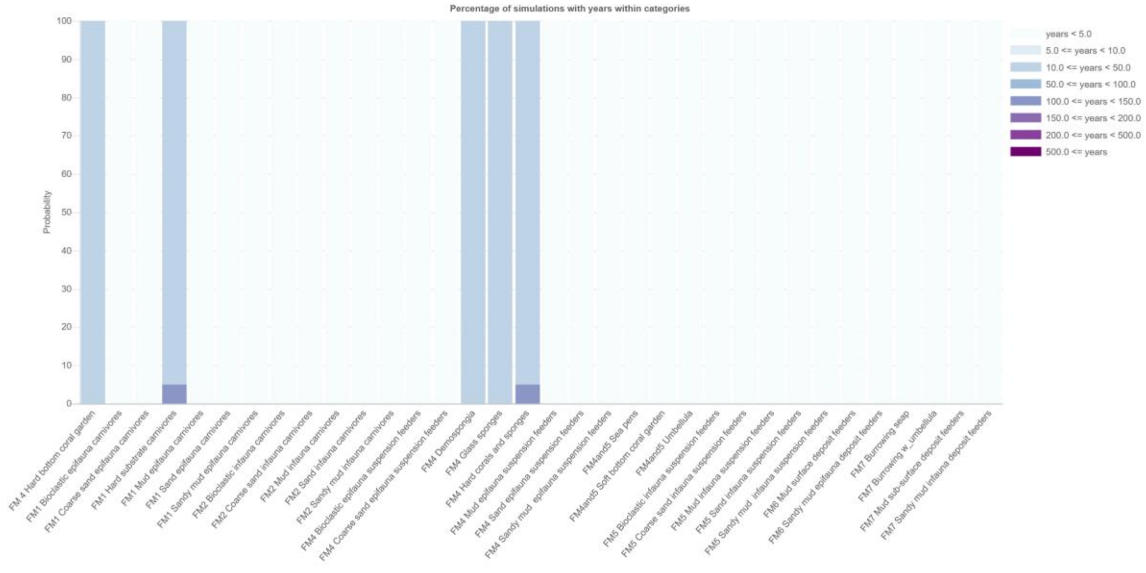

Figure 26. Probabilities as % of the simulations that gave lag times in year categories.

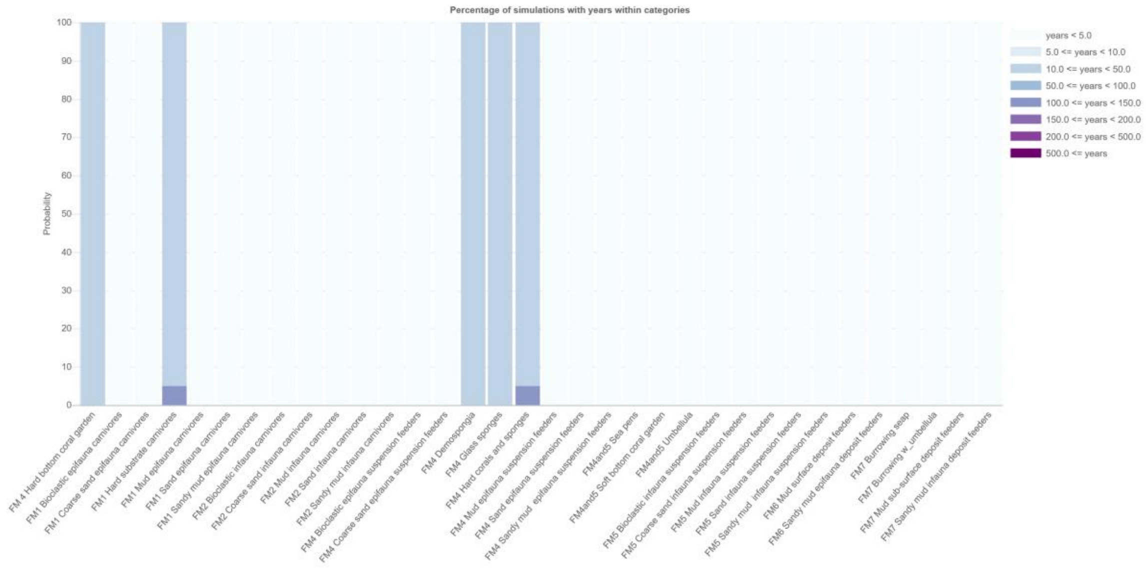

Figure 27. Probabilities as % of the simulations that gave restitution times in year categories.

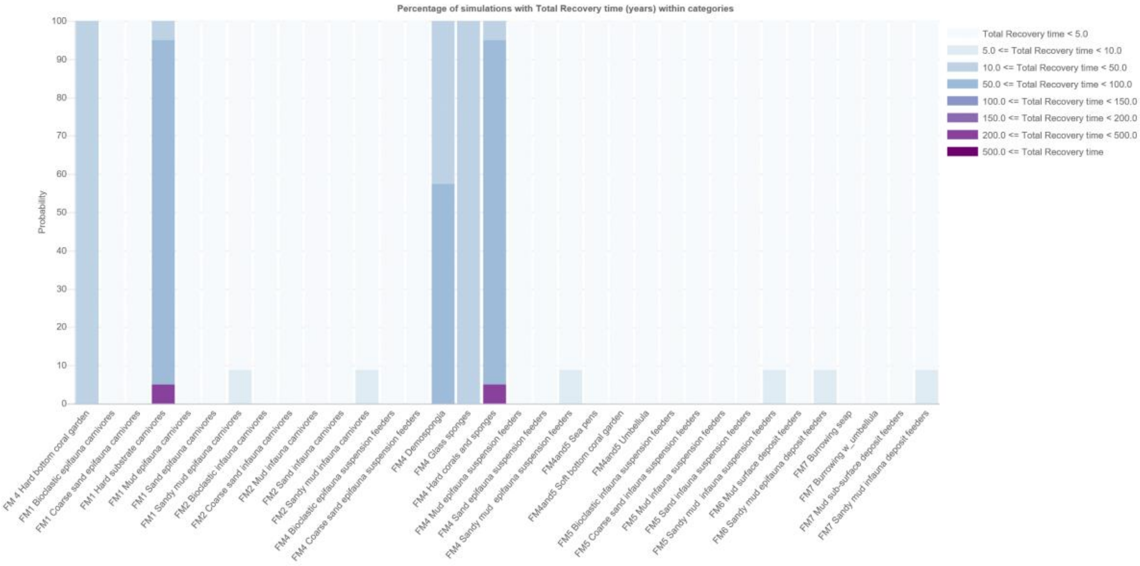

Figure 28. Probabilities as % of the simulations that gave total recovery times in year categories.

For each VEC we have available results of the average and maximum impacts in km^2 for each month for all VECs, risk maps for individual VECs, percentile values of individual simulations and probabilities per scenario when the case is a multi-scenario case. For the individual substrates, we will investigate the results that are relevant for the single scenario.

4.2 Mud

4.2.1 Monthly maximum and mean impacts, RDFs and restitution times

As can be seen from Figure 29, only VECs of FMs 1,4 and 6 are impacted in mud substrates. The average sum of impacts over all cells per month is very low, around 0.5 km^2, and the maximum in the summer months just above 2 km^2 in total. Each cell is 100 km^2. Due to the fact that mud, as a soft substrate, has a restitution time dependent on the THC-amount in the sediment, and the cells are not hit by oil in the sediment, there is no calculation of restitution time. Impact-time is by default 1 year, the RDF-values can therefore be calculated and are seen Figure 30.

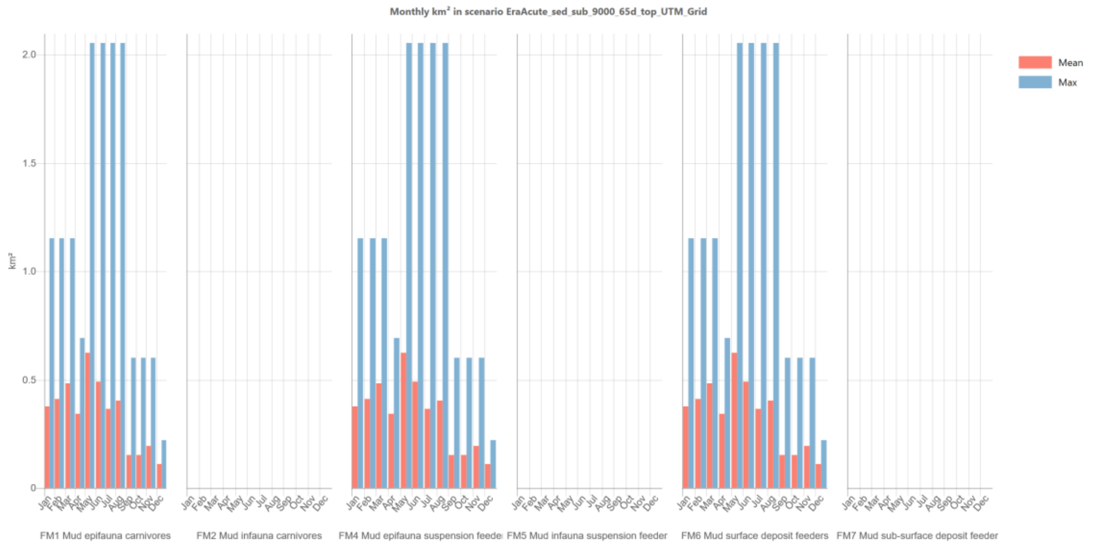

Figure 29. Mean and maximum impact areas (km²) for VECs in substrate mud with different FMs.

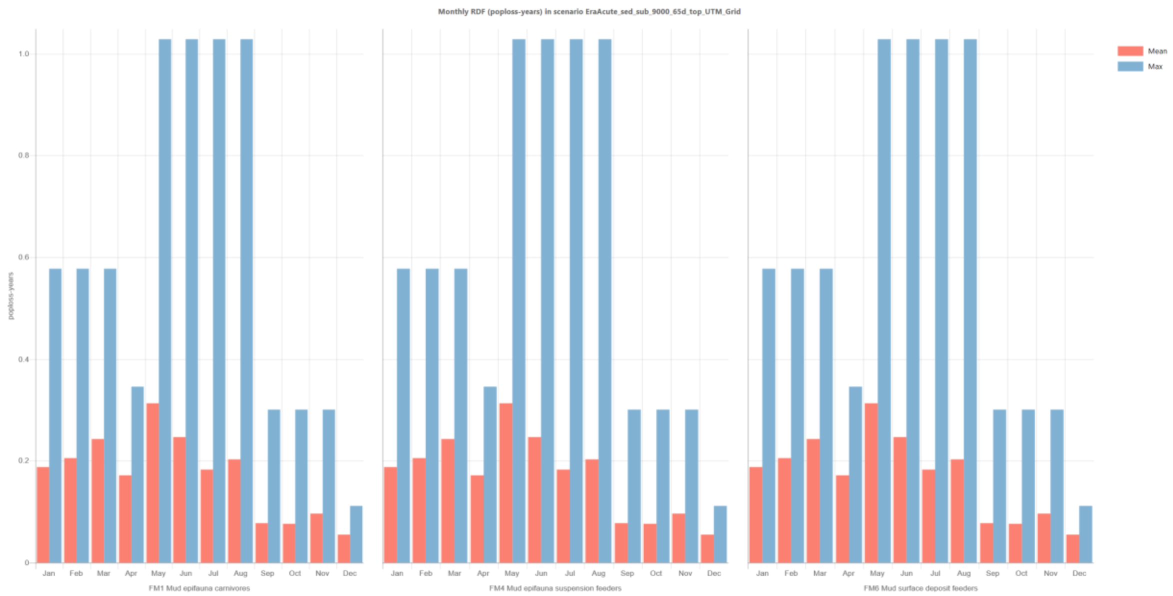

Figure 30. Mean and maximum RDF values in km²years for VECs in substrate mud with FMs that had an impact.

4.2.2 Risk maps for impacted VECs

There is no impact to FM2 and FM5 in mud, as the cells are not hit by oil in the sediment. FM1 and FM4 are impacted by oil in the water column, but values are low. FM 6 impacts are identical to FM1 and 4 when there is no sediment exposure. As was seen in Figure 29, the total mean impact as the sum over all cells was around or below 0.5 km². The cells with the highest impact have an average impact of less than 0.05 km² within a 100 km² cell. (Figure 31). The THC-values in sediment are too low to give restitution time of > 0 years. T_{imp} is by default 1 year and the RDF values in each cell are shown in Figure 32.

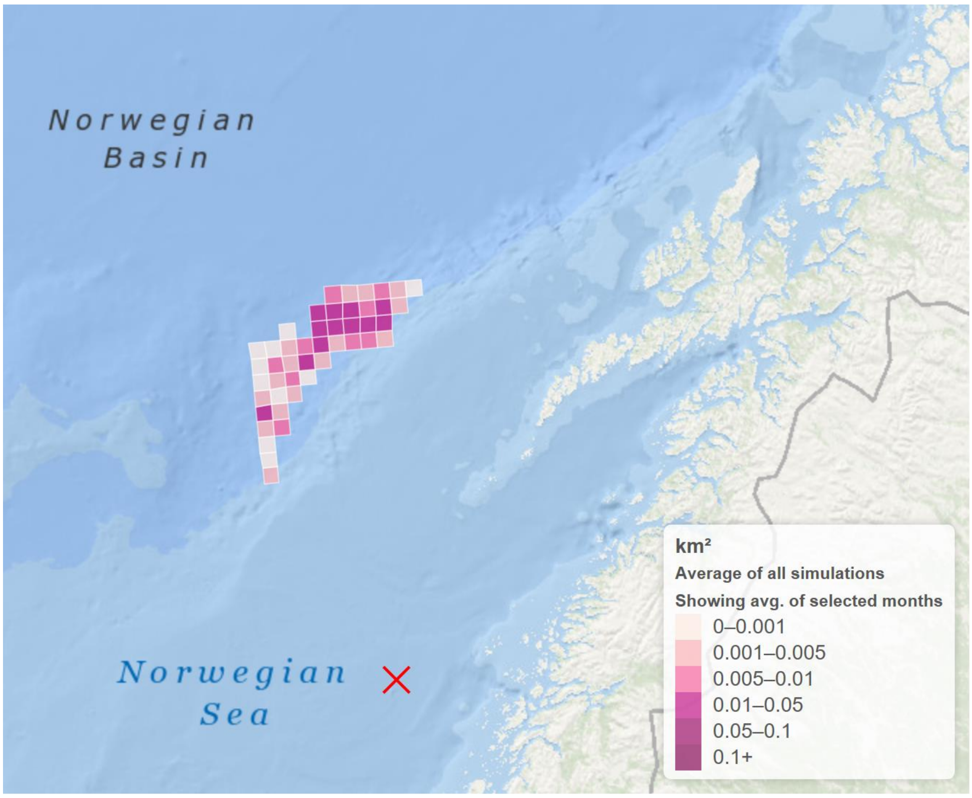

Figure 31. Average km² impacted for FM1, FM4 and FM6 in mud substrate (all months).

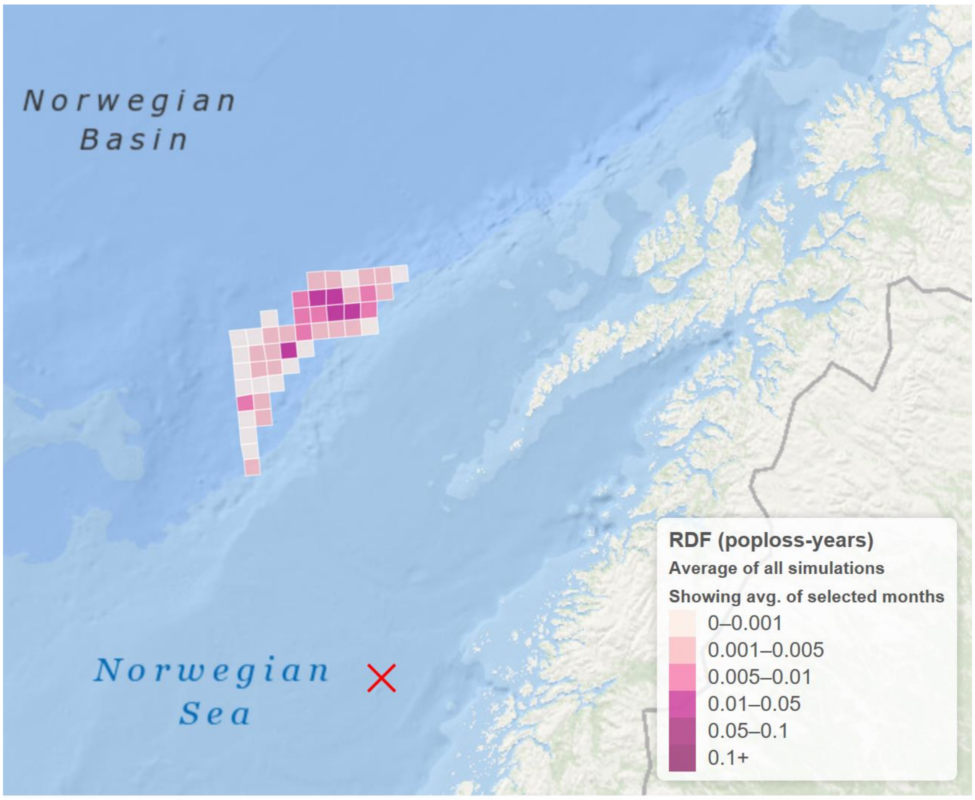

Figure 32. Average RDF for FM1, FM4 and FM6 in mud substrate (all months).

4.2.3 Results in single simulations

Simulation 17 gave the highest impact in the cells that hit the mud substrate VECs, water column compartment. The 100-percentile value is shown in Figure 33 for impacts and in Figure 34 for RDFs. With more simulations run, a 95-percentile value can be used to indicate a more moderate worst case scenario than the absolute maximum value.

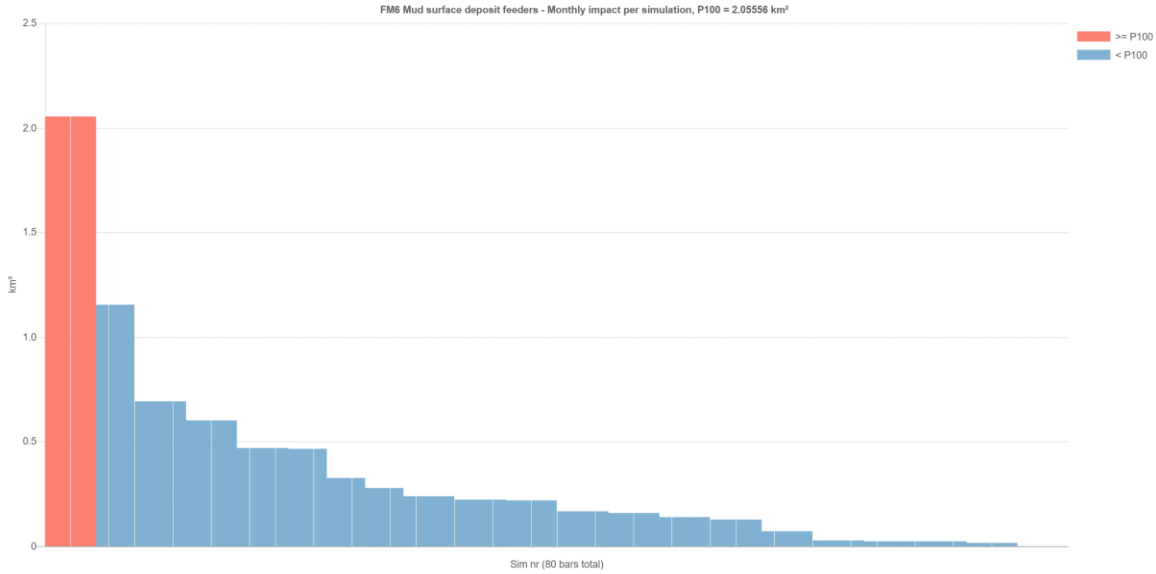

Figure 33. Single simulation results for sum of impacts over all cells (km^2) for mud substrate VECs with FMs 1,4 and 6.

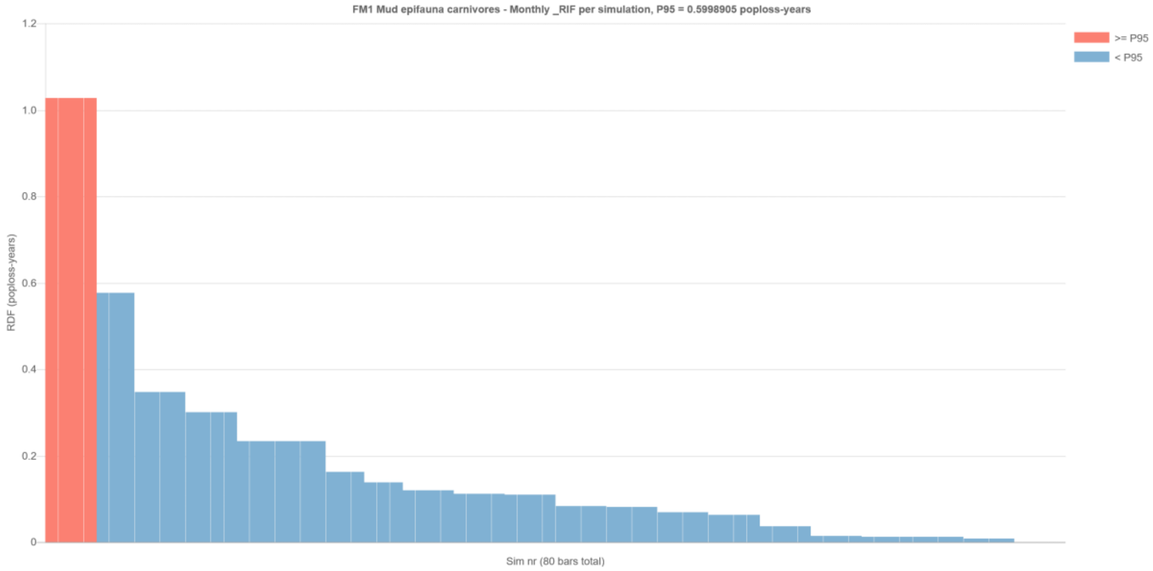

Figure 34. Single simulation results for sum of RDF over all cells (km^2years) for mud substrate VECs with FMs 1,4 and 6.

4.3 Sandy mud

4.3.1 Monthly maximum and mean impacts, RDFs and restitution times

As can be seen from Figure 29, VECs of FMs 1,4, 6 are impacted more than FM 2,5 and 7 in sandy mud substrates, due to a higher exposure in the water column than in sediment. The average sum of impacts over all cells per month are low, around 20 km^2, for FM1, 4 and 6 exposed in the water column, for these VECs the maximum in the summer months is just above 56 km^2 in total. The impacts to VECs that are exposed in the sediment interstitial water (calculated from oil in the sediment) is much lower, (Figure 36) although the ingestion of deposit particles increases exposure through gut water, increasing the impact. RDF values are seen in Figure 37 and Figure 38. As for mud, the restitution times for all VECs are calculated based on the oil amount in sediment in the current implementation. The restitution times are therefore the same for all VECs independent of feeding mode.

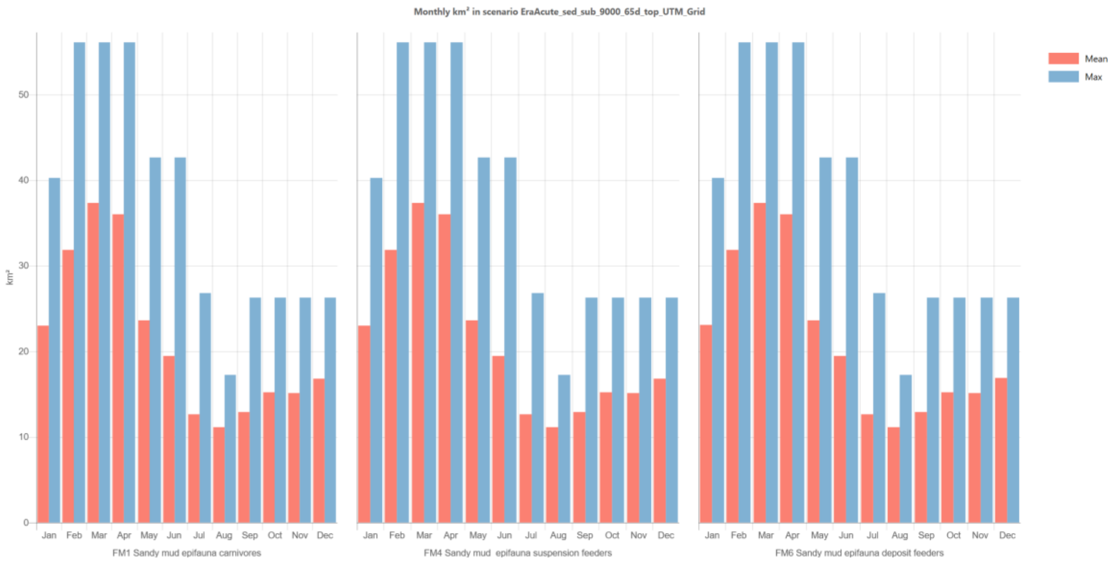

Figure 35. Mean and maximum impact areas (km^2) for VECs in substrate sandy mud with FM 1,4 and 6.

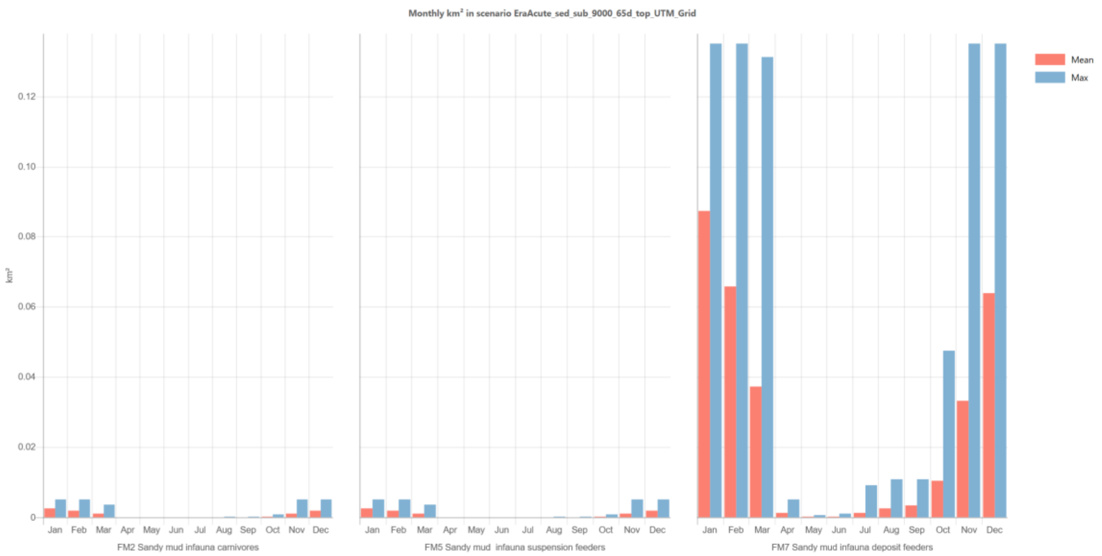

Figure 36. Mean and maximum impact areas (km^2) for VECs in substrate sandy mud with FM 2, 5 and 7.

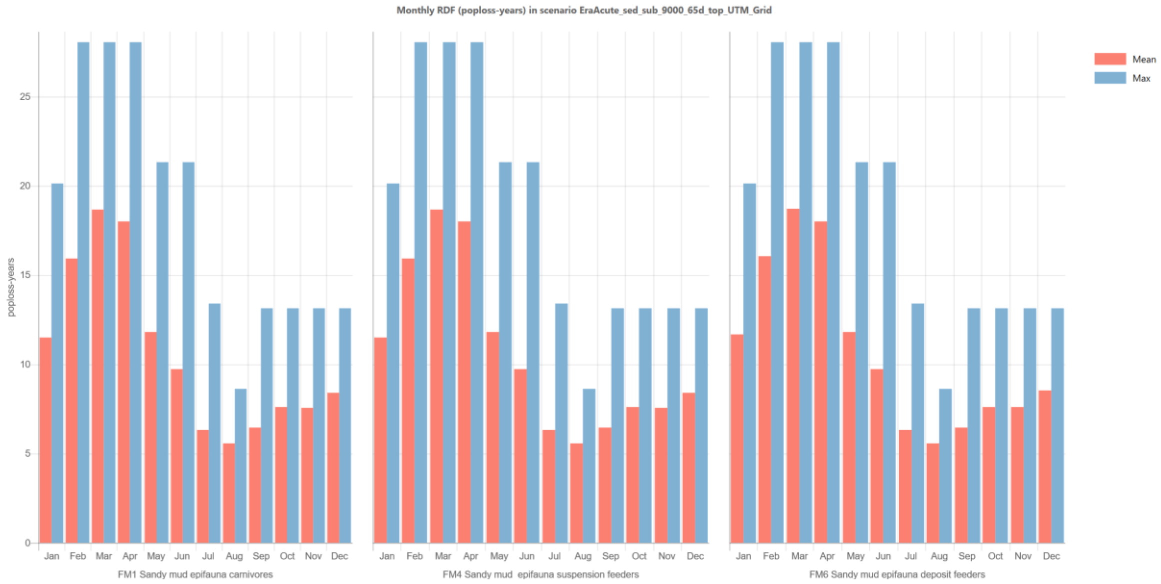

Figure 37. Mean and maximum RDF values in km²years for VECs in substrate sandy mud with FM 1,4 and 6.

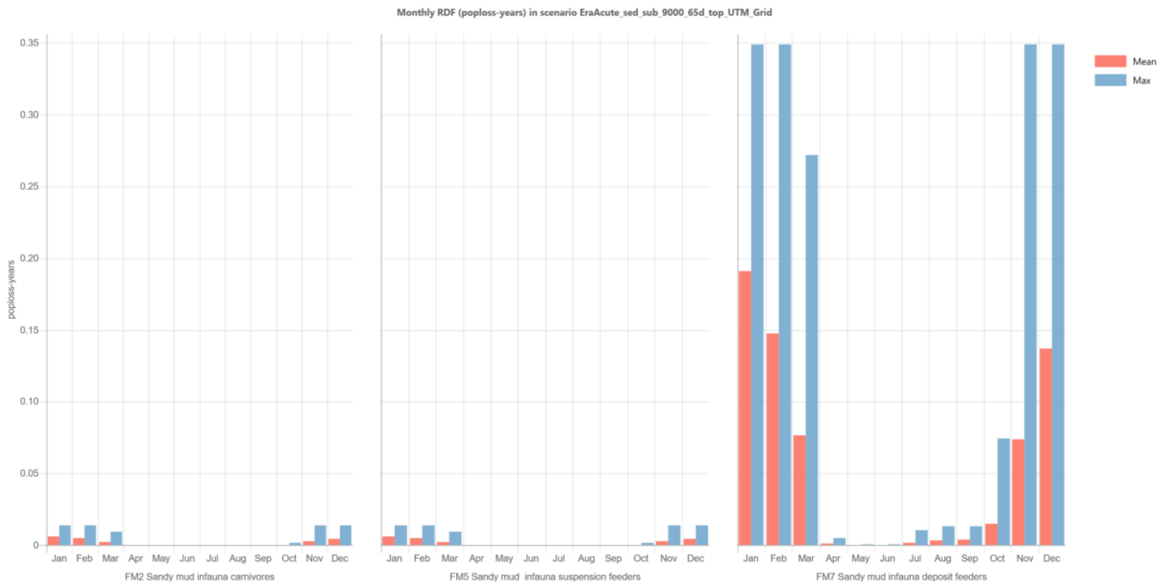

Figure 38. Mean and maximum RDF values in km²years for VECs in substrate sandy mud with FM 2,5 and 7.

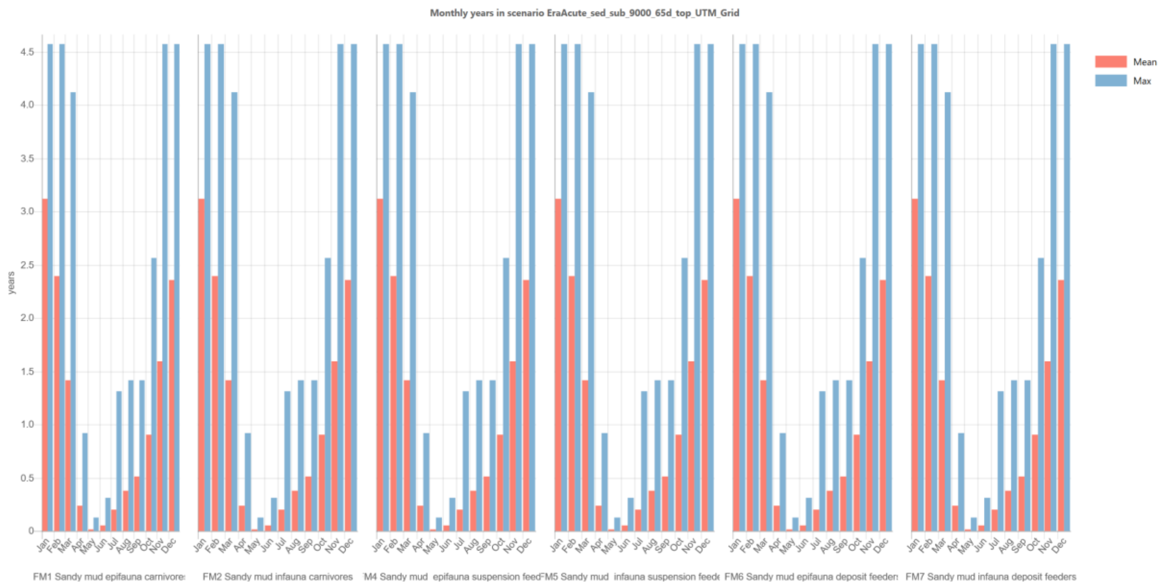

Figure 39. Mean and maximum restitution time in years for all VECs in substrate sandy mud.

4.3.2 Risk maps

Average impacted cells for FM1/4 and FM6 can be seen in Figure 40. Comparing the effects of ingestion between FM1/4 and FM6, it can be seen very clearly that adding the effect of ingestion of contaminated deposited material does not increase the exposure compared to the exposure through water column in this case, as the ingestion of oil through deposits only affects a few cells. These cells are the ones also seen in the risk map of FM7 (Figure 41, right). For FM7, however, exposure through ingestion exceeds exposure through interstitial water (FM2 and 5). Comparing the effects of ingestion between FM 6 and FM7, this dominance of exposure through the water column for this case is clear. Restitution time is only above 0 years for four cells (Figure 42). Impact time is 1 year for all. The highest average restitution time for a cell is 1.09 year, the highest in a single month is 3.12 years in January.

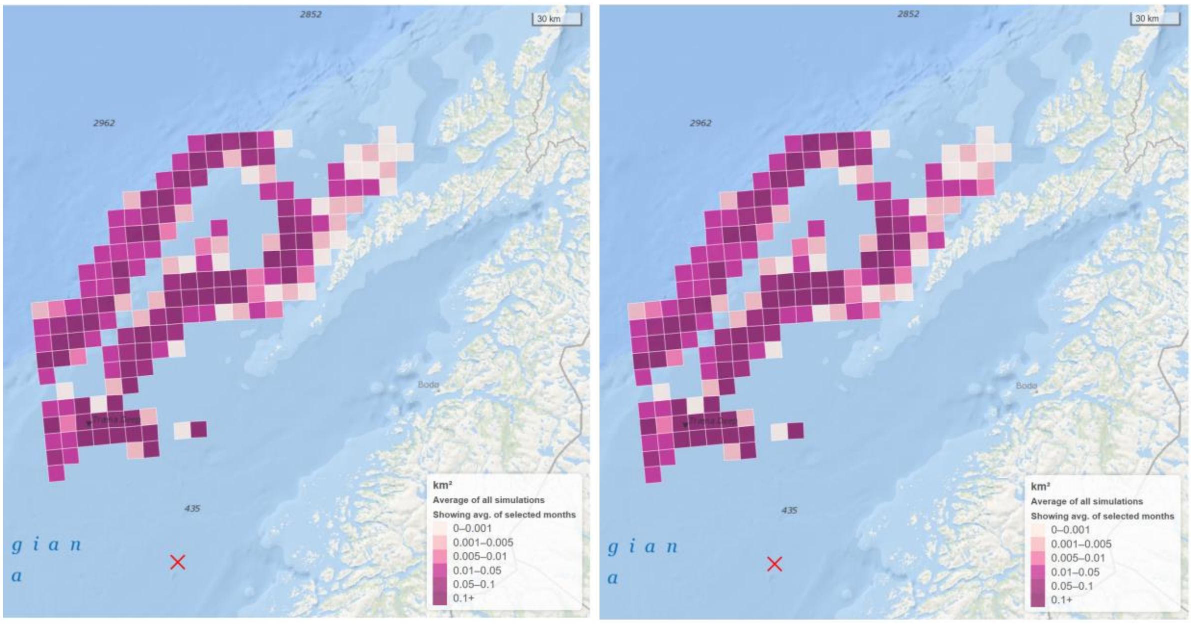

Figure 40. Average km² impacted for FM1, FM4 (left) and FM6 (right) in sandy mud substrate (all months).

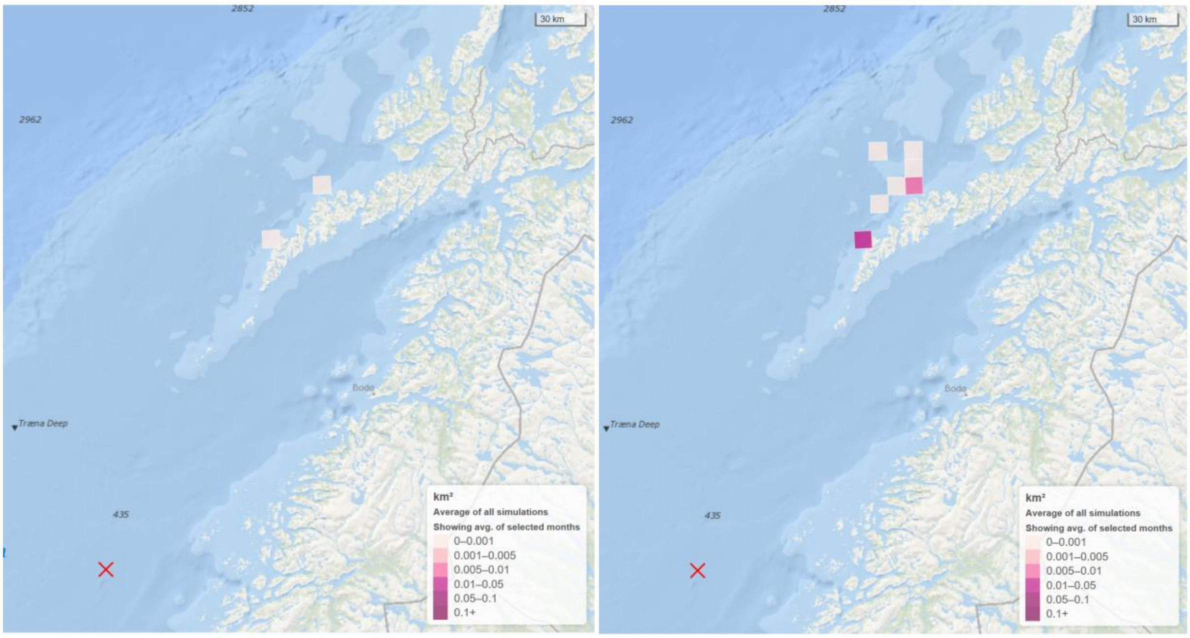

Figure 41. Average km² impacted for FM2 and FM5 (left) and FM7 (right) in sandy mud substrate (all months).

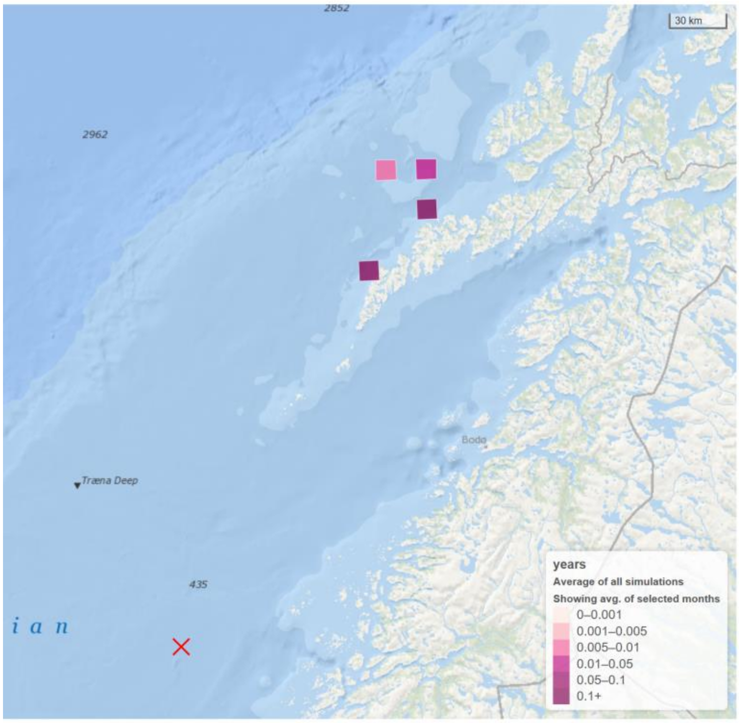

Figure 42. Average restitution time (years) in sandy mud substrate (all months).

4.3.3 Results in single simulations

Simulation 2 gave the highest impact in the cells that hit the sandy mud substrate VECs, water column compartment. The 100-percentile value is shown in Figure 43 for impacts and in Figure 44 for RDFs. With more simulations run, a 95-percentile value can be used to indicate a more moderate worst case scenario than the absolute maximum value. The values for the other FMs are much lower

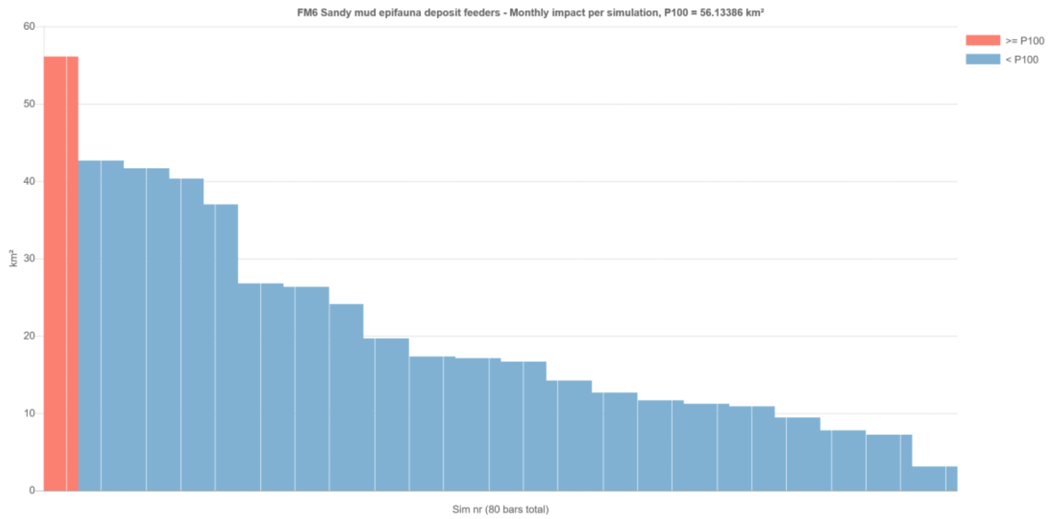

Figure 43. Single simulation results for sum of impacts over all cells (km^2) for sandy mud substrate VECs with FMs 1,4 and 6.

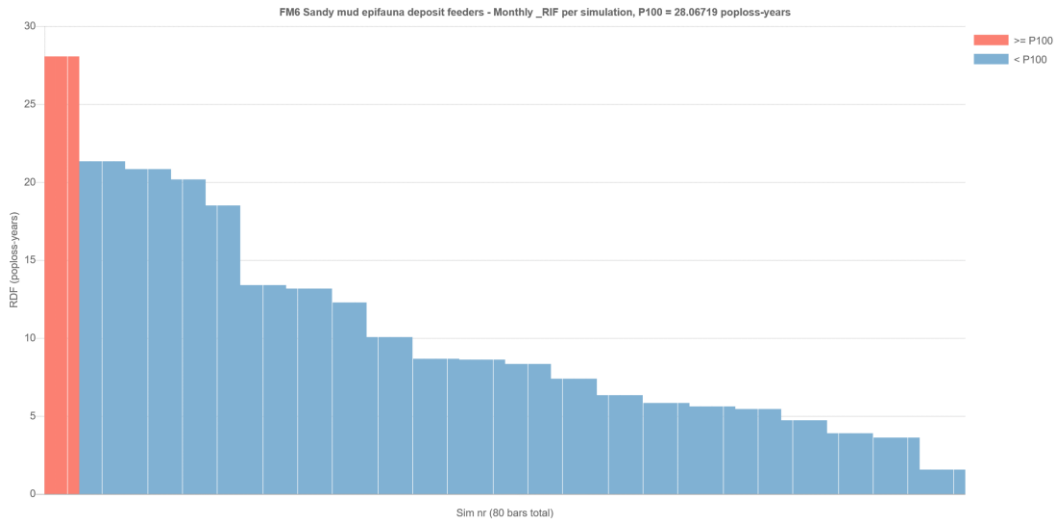

Figure 44. Single simulation results for sum of RDF over all cells (km^{2}years) for sandy mud substrate VECs with FMs 1,4 and 6.

4.4 Sand

4.4.1 Monthly maximum and mean impacts, RDFs and restitution times

As can be seen from Figure 45, VECs of FMs 1 and 4 are impacted more than FM 2 and 5 in sand substrates, due to a higher exposure in the water column than in sediment. The average sum of impacts over all cells per month are low, around 7-27 km^2, for FM1 and 4 exposed in the water column, for these VECs the maximum in the late winter/spring months is just below 29 km^2 in total. The impacts to VECs that are exposed in the sediment interstitial water (calculated from oil in the sediment) is much lower, (Figure 46). RDF values are seen in Figure 47 and Figure 48. As for the other soft substrates, the restitution times for all VECs are calculated based on the oil amount in sediment in the current implementation. The restitution times are therefore the same for all VECs independent of feeding mode. Figure 49.

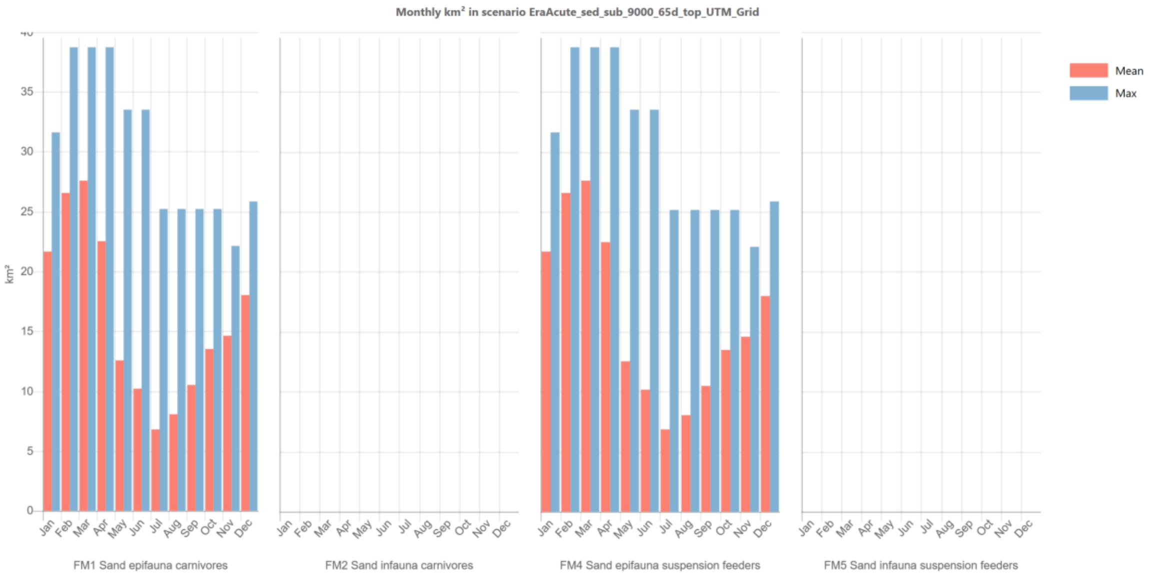

Figure 45. Mean and maximum impact areas (km²) for VECs in substrate sand with FM 1 and 4. 2 and 5 are included for comparison.

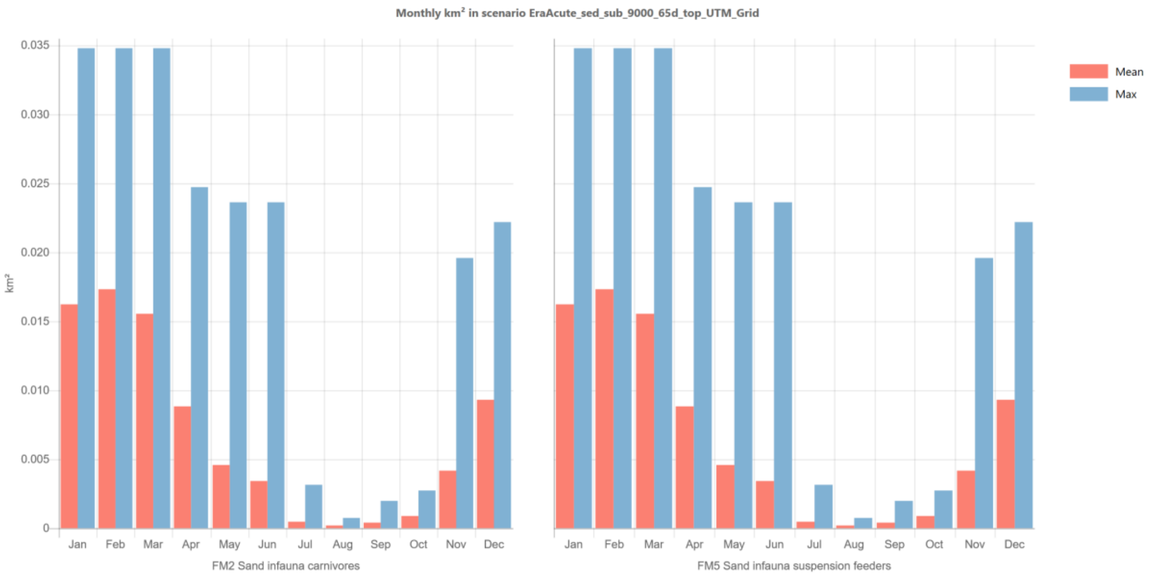

Figure 46. Mean and maximum impact areas (km²) for VECs in substrate sand with FM 2 and 5.

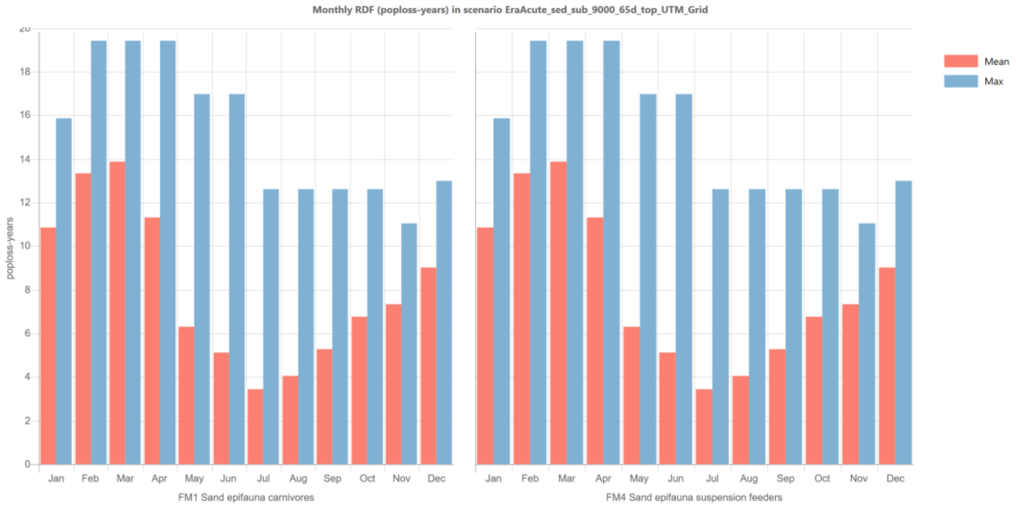

Figure 47. Mean and maximum RDF values in km²years for VECs in substrate sand with FM 1 and 4.

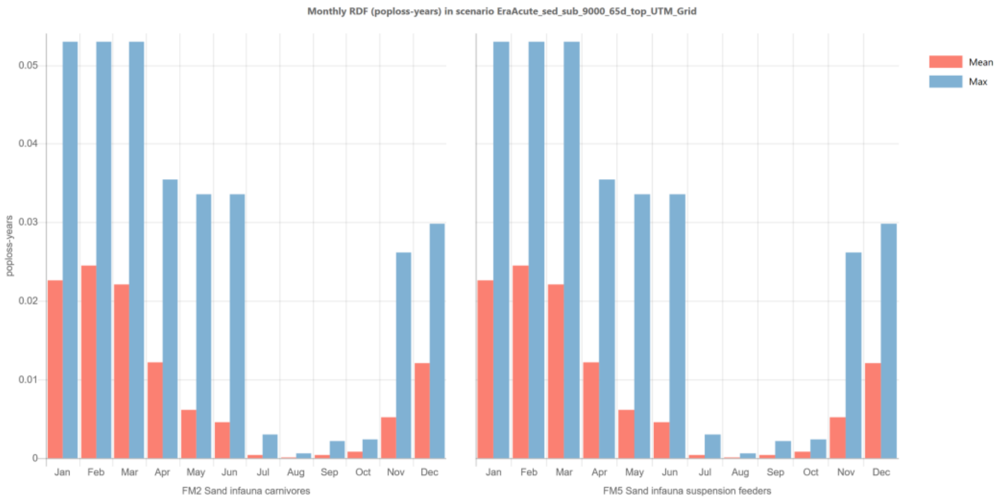

Figure 48. Mean and maximum RDF values in km²years for VECs in substrate sand with FM 2 and 5.

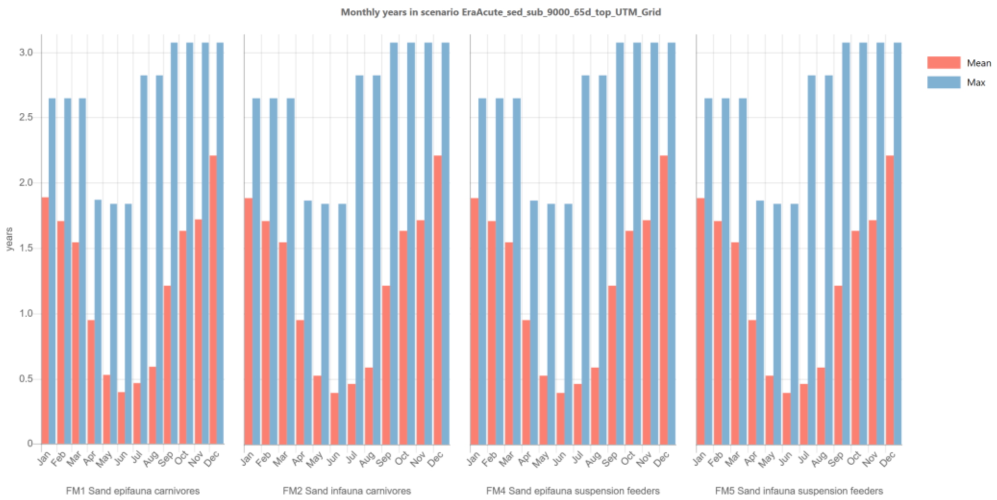

Figure 49. Mean and maximum restitution times in years for all VECs in substrate sand (FM 1,2, 4 and 5).

4.4.2 Risk maps

Average impacted cells for FM1/4 (left)and 2/5 (right) can be seen in Figure 50. Comparing the effects between the feeding modes, it can be seen very clearly that the exposure through water column in this case is much higher than in the sediment, as the sedimentation of oil only affects a few cells. Restitution time is only above 0 years for nine cells (Figure 51). Impact time is 1 year for all. The highest average restitution time for a cell is 0.99 years, the highest in a single month is 2.2 years in December.

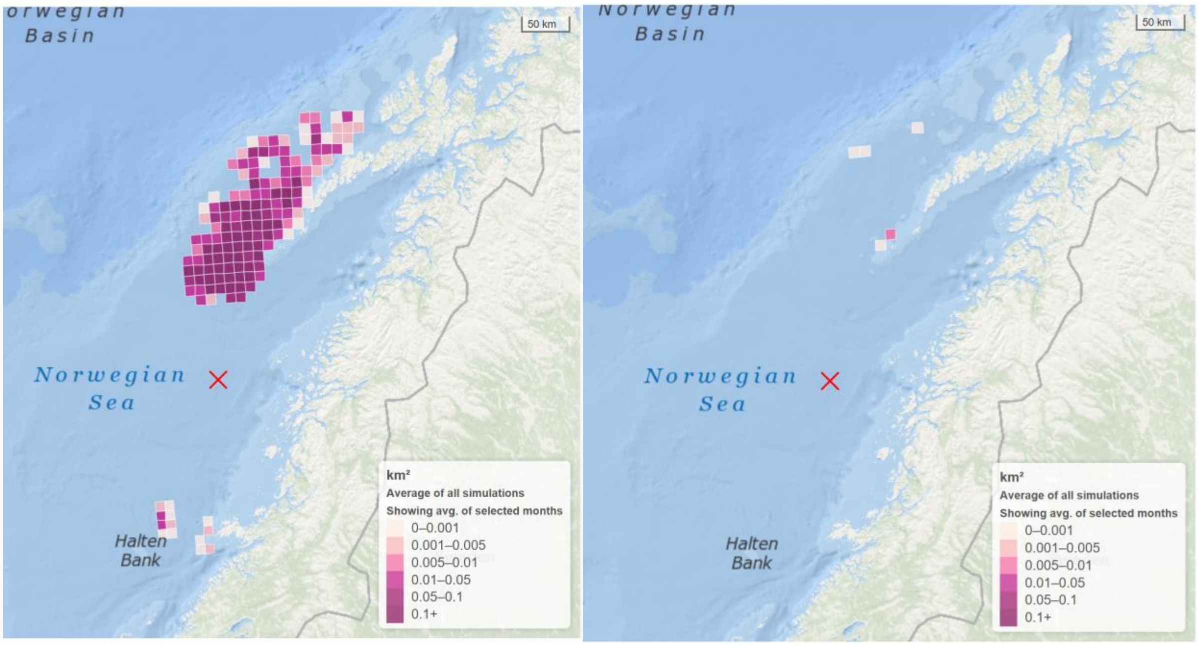

Figure 50. Average km² impacted for FM1 and FM4 (left) and FM2 and 5 (right) in sand substrate (all months).

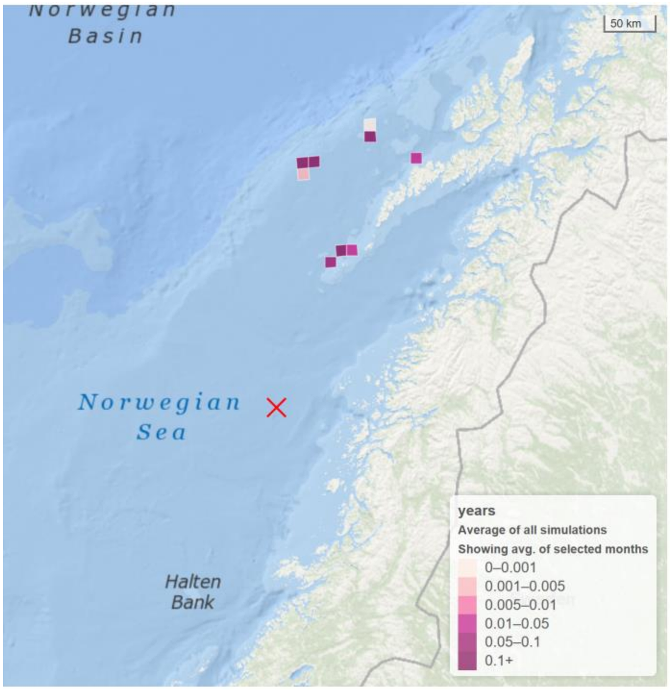

Figure 51. Average restitution time (years) in sand substrate (all months).

4.4.3 Results in single simulations

Simulation 2 gave the highest impact in the cells that hit the sand substrate VECs, water column compartment. The 100-percentile value is shown in Figure 52 for impacts and in Figure 53 for RDFs.

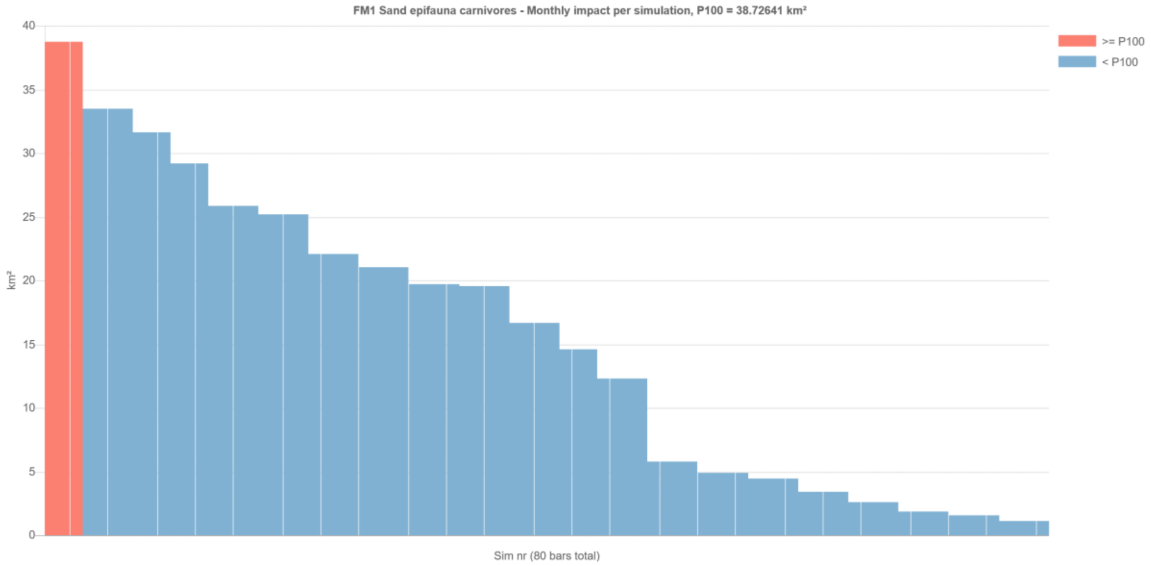

Figure 52. Single simulation results for sum of impacts over all cells (km^2) for sand substrate VECs with FMs 1 and 4.

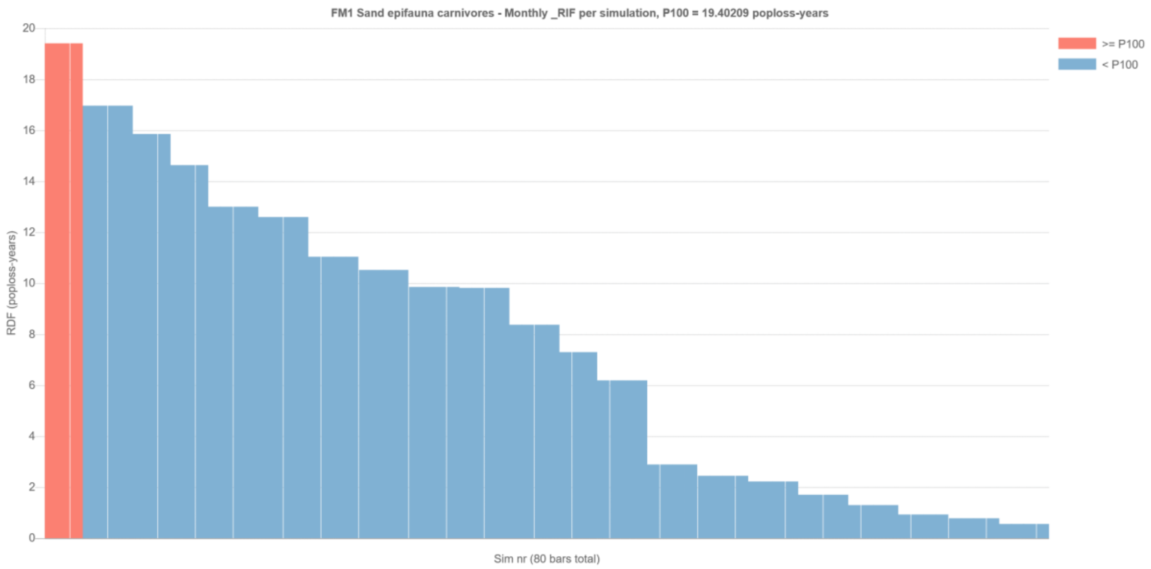

Figure 53. Single simulation results for sum of RDF over all cells (km^{2}years) for sand substrate VECs with FMs 1 and 4.

4.5 Coarse sand

4.5.1 Monthly maximum and mean impacts, RDFs and restitution times

As can be seen from Figure 54, VECs of FMs 1 and 4 are impacted more than FM 2 and 5 in coarse sand substrates, due to a higher exposure in the water column than in sediment. The average sum of impacts over all cells per month are moderate, between 50-217km^2, for FM1 and 4 exposed in the water column, for these VECs the maximum in the late winter/spring months is just below 377 km^2 in total. The impacts to VECs that are exposed in the sediment interstitial water (calculated from oil in the sediment) is much lower, (Figure 55). RDF values are seen in Figure 56 and Figure 57. As for the other soft substrates, the restitution times for all VECs are calculated based on the oil amount in sediment in the current implementation. The restitution times are therefore the same for all VECs independent of feeding mode (Figure 58).

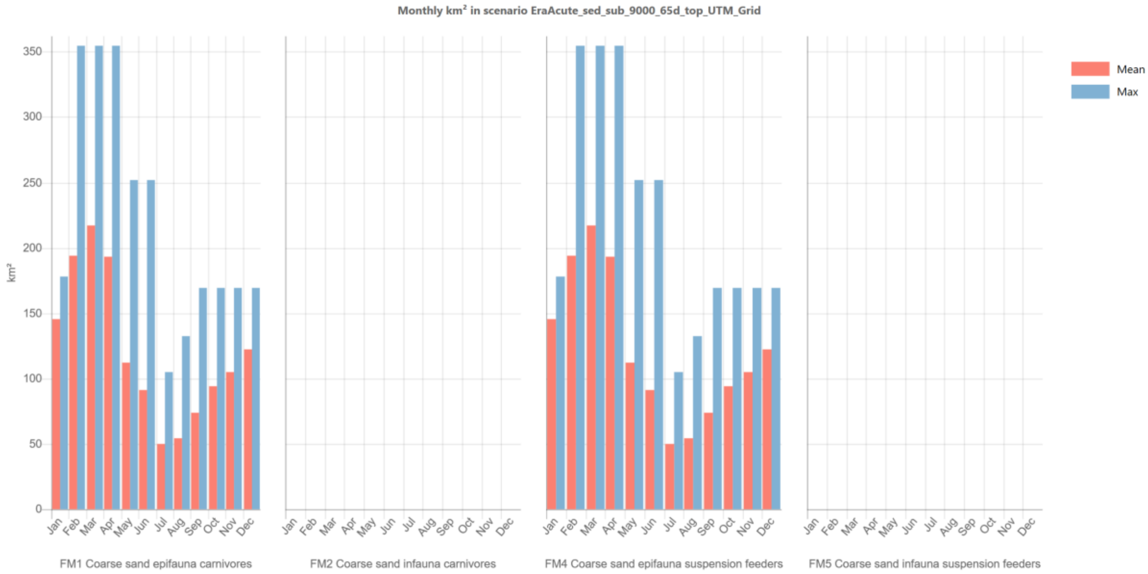

Figure 54. Mean and maximum impact areas (km²) for VECs in substrate coarse sand with FM 1 and 4. 2 and 5 are included for comparison.

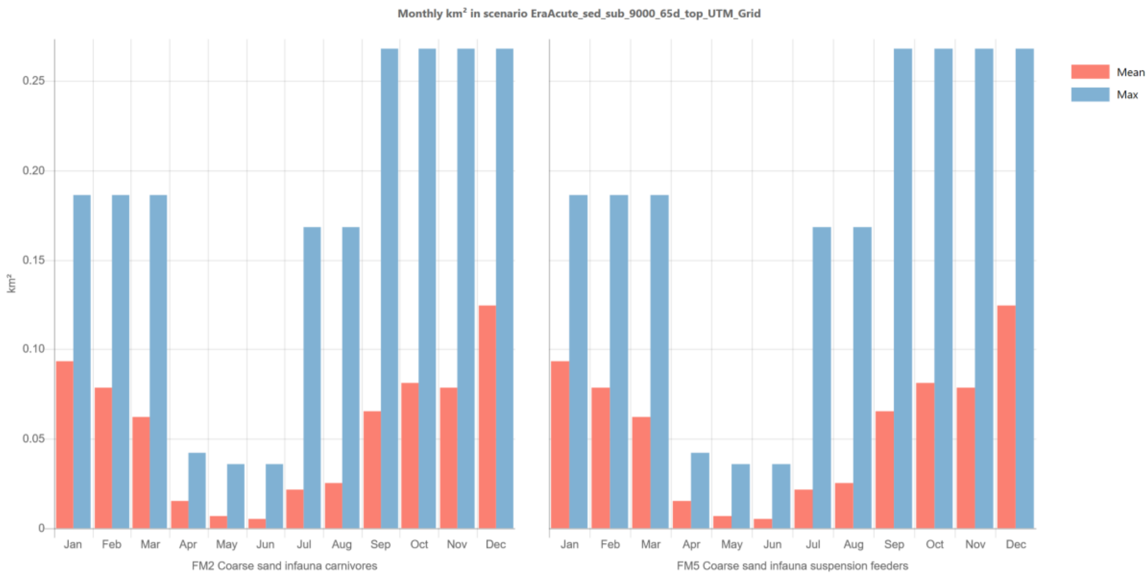

Figure 55. Mean and maximum impact areas (km²) for VECs in substrate sand with FM 2 and 5.

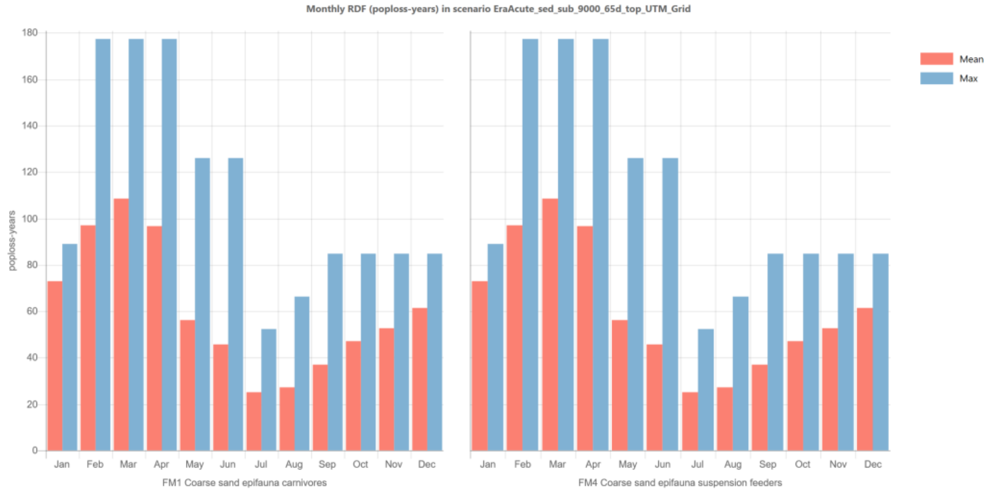

Figure 56. Mean and maximum RDF values in km²years for VECs in substrate coarse sand with FM 1 and 4.

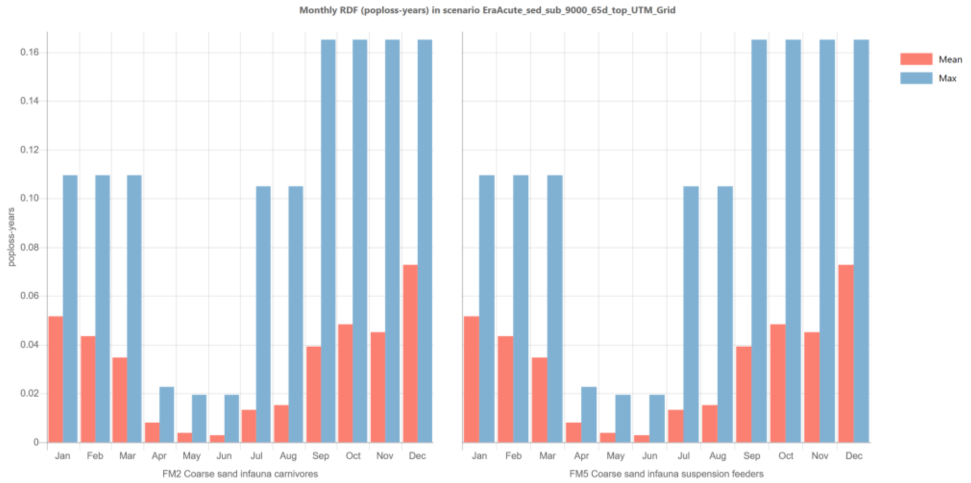

Figure 57. Mean and maximum RDF values in km²years for VECs in substrate sand with FM 2 and 5.

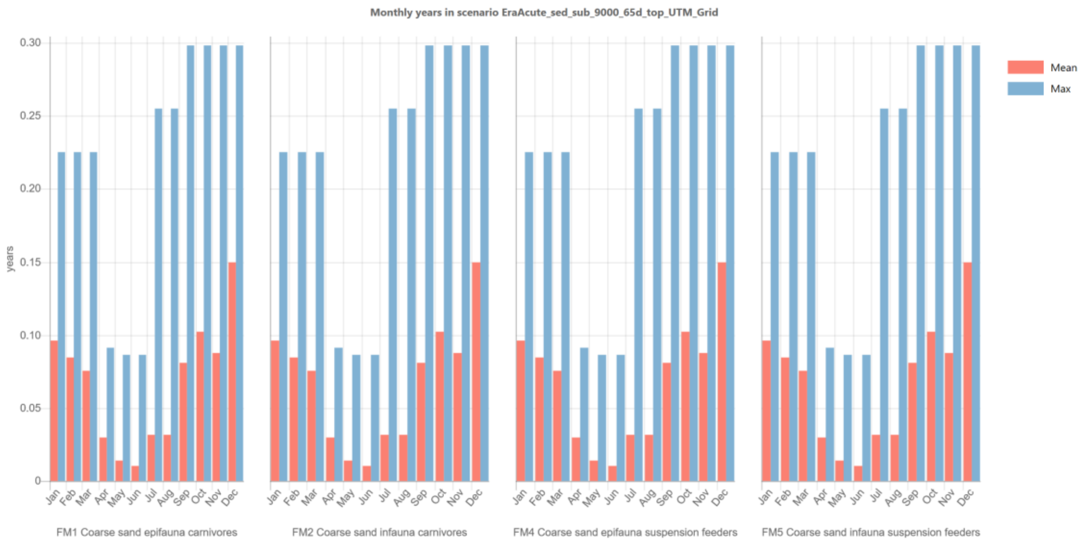

Figure 58. Mean and maximum restitution times in years for all VECs in substrate sand (FM 1,2, 4 and 5).

4.5.2 Risk maps

Average impacted cells for FM1/4 (left)and 2/5 (right) can be seen in Figure 59. Comparing the effects between the feeding modes, it can be seen very clearly that the exposure through water column in this case is much higher than in the sediment, as the sedimentation of oil only affects a few cells. Restitution time is only above 0 years for three cells (Figure 60). Impact time is 1 year for all. The highest average restitution time for a cell is 0.055 years, the highest in a single month is 0.14 years in December.

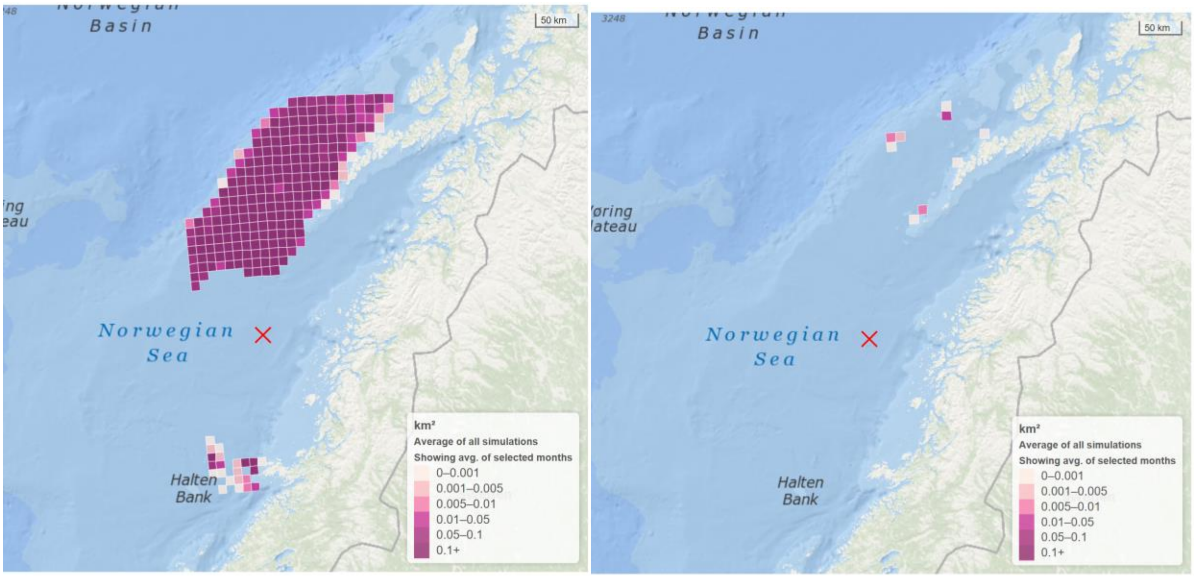

Figure 59. Average km² impacted for FM1 and FM4 (left) and FM2 and 5 (right) in coarse sand substrate (all months).

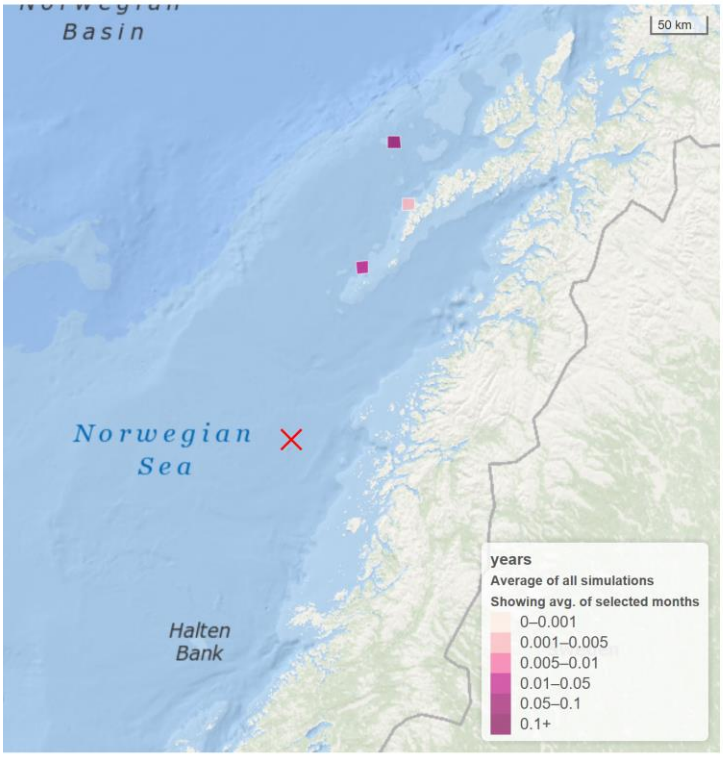

Figure 60. Average restitution time (years) in coarse sand substrate (all months).

4.5.3 Results in single simulations

Simulation 2 gave the highest impact in the cells that hit the coarse sand substrate VECs, water column compartment. The 100-percentile value is shown in Figure 61 impacts and in for RDFs.

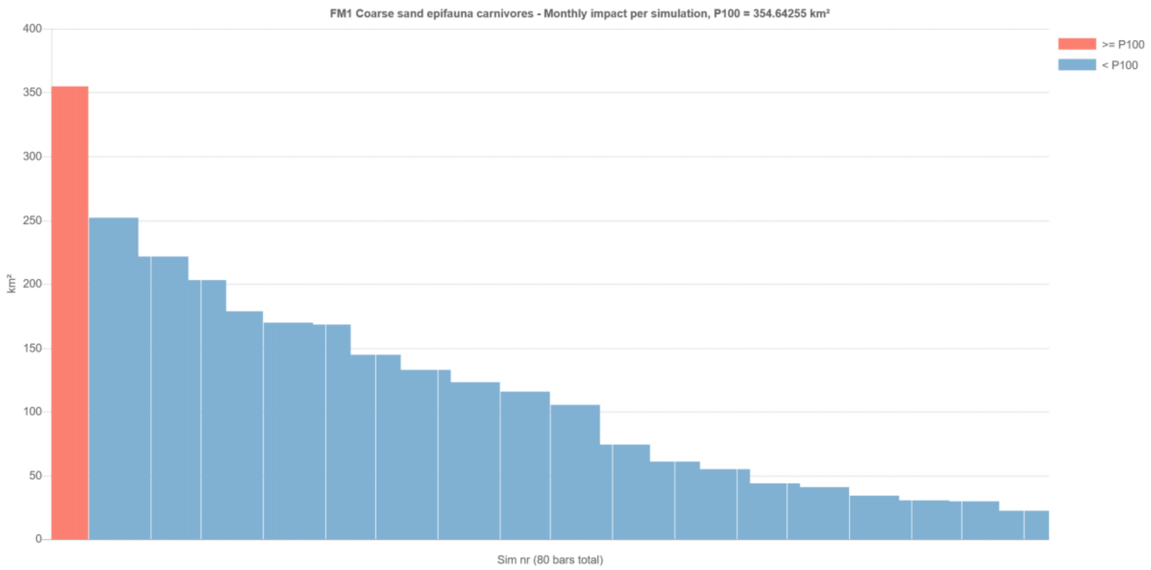

Figure 61. Single simulation results for sum of impacts over all cells (km²) for coarse sand substrate VECs with FMs 1 and 4.

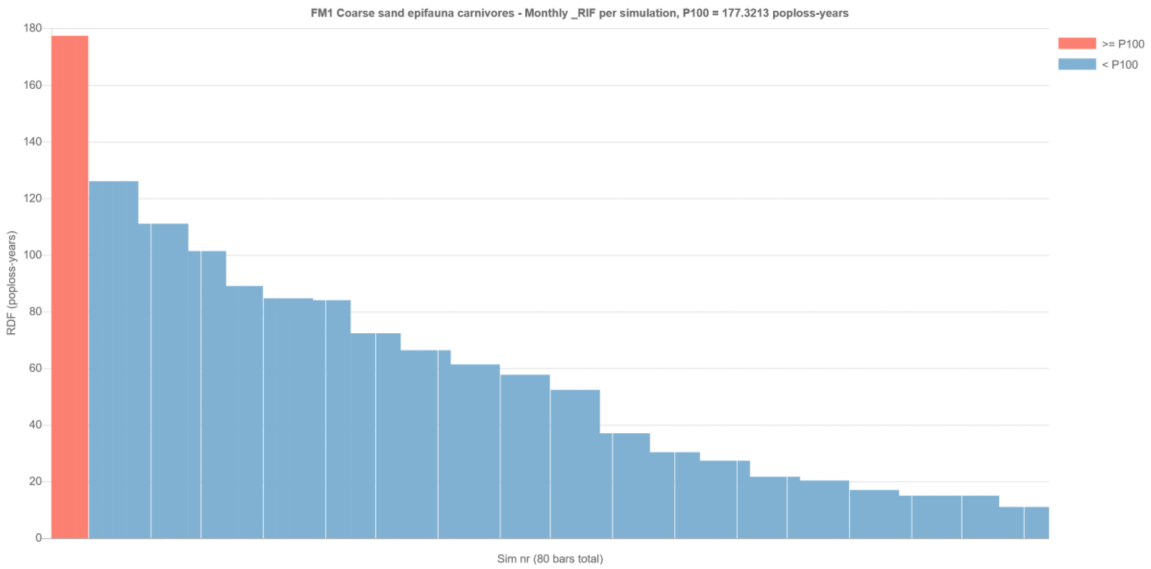

Figure 62. Single simulation results for sum of RDF over all cells (km²years) for coarse sand substrate VECs with FMs 1 and 4.

4.6 Bioclastic coarse sand

4.6.1 Monthly maximum and mean impacts, RDFs and restitution times

As can be seen from Figure 63, VECs of FMs 1 and 4 are impacted in bioclastic 5 in coarse sand substrates, whereas FM 2 and 5 are not, as sedimentation of oil does not hit the cells of this substrate. The average sum of impacts over all cells per month are low, between 3-13 km^2, for FM1 and 4 exposed in the water column, for these VECs the maximum in the late winter/spring months is just below 29.5 km^2 in total. RDF values are seen in Figure 64. As for the other soft substrates, the restitution times for all VECs are calculated based on the oil amount in sediment in the current implementation. The RDF-value is therefore only based on the impact time of 1 year, as there is no restitution time calculated for the bioclastic coarse substrate in this case.

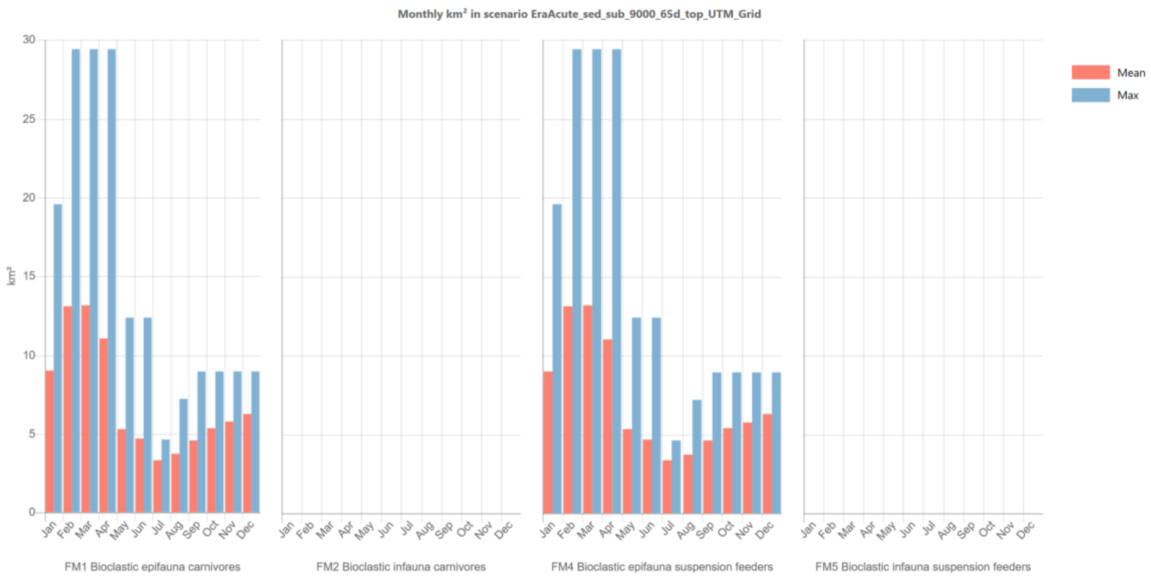

Figure 63. Mean and maximum impact areas (km^2) for VECs in substrate bioclastic coarse sand with FM 1 and 4. FM 2 and 5 have no impact.

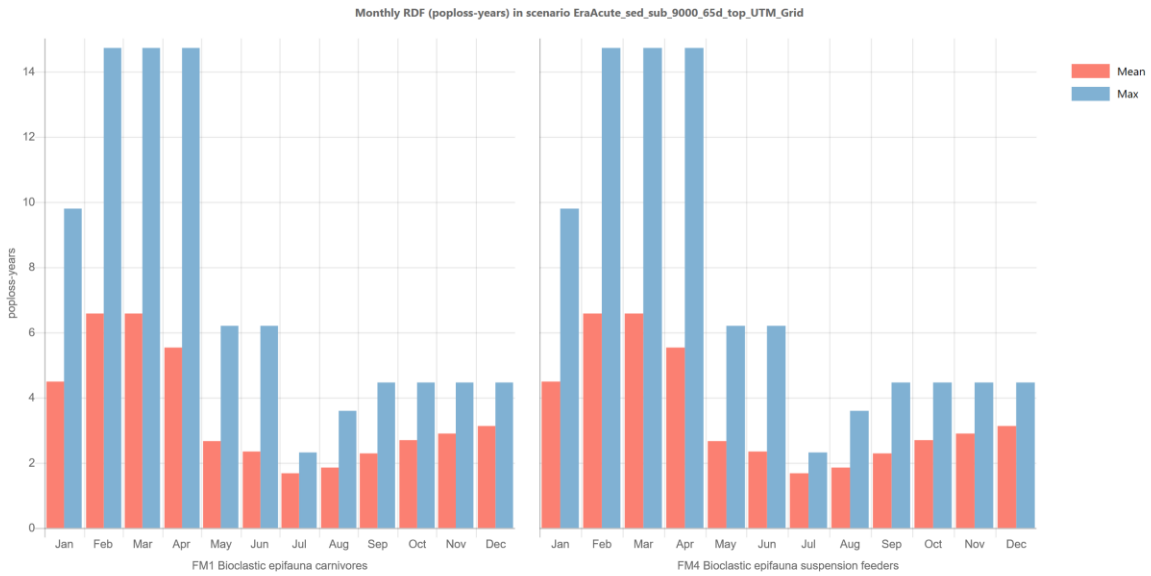

Figure 64. Mean and maximum RDF values in km^{2}years for VECs in substrate bioclastic coarse sand with FM 1 and 4.

4.6.2 Risk maps

Average impacted cells for FM1/4 (left)and 2/5 (right) can be seen in Figure 59. Comparing the effects between the feeding modes, it can be seen very clearly that the exposure through water column in this case is much higher than in the sediment, as the sedimentation of oil only affects a few cells. Restitution time is only above 0 years for three cells (Figure 60). Impact time is 1 year for all. The highest average restitution time for a cell is 0.055 year, the highest in a single month is 0.14 years in December.

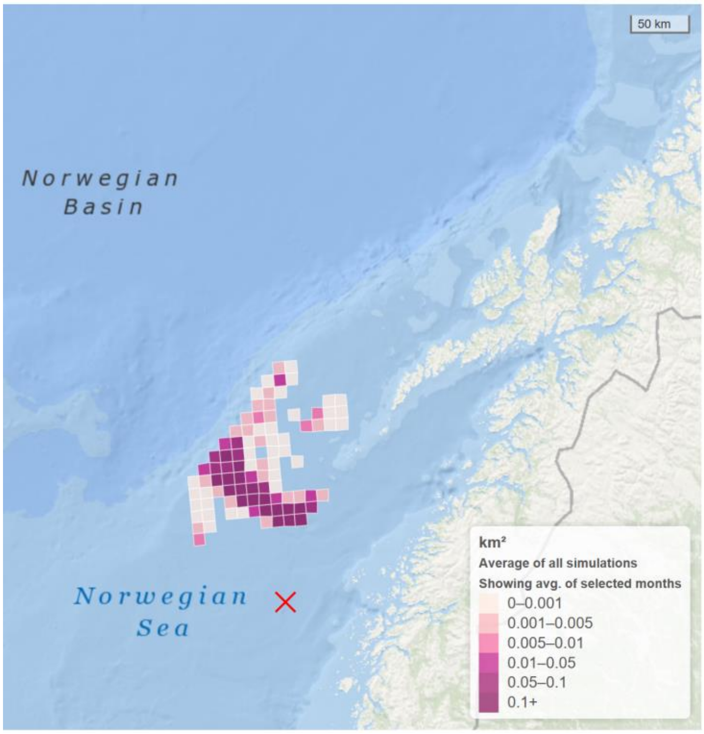

Figure 65. Average km² impacted for FM1 and FM4 bioclastic coarse sand substrate (all months).

4.6.3 Results in single simulations

Simulation 2 gave the highest impact in the cells that hit the bioclastic coarse sand substrate VECs, water column compartment. The 100-percentile value is shown in Figure 66impacts and in Figure 67 for RDFs.

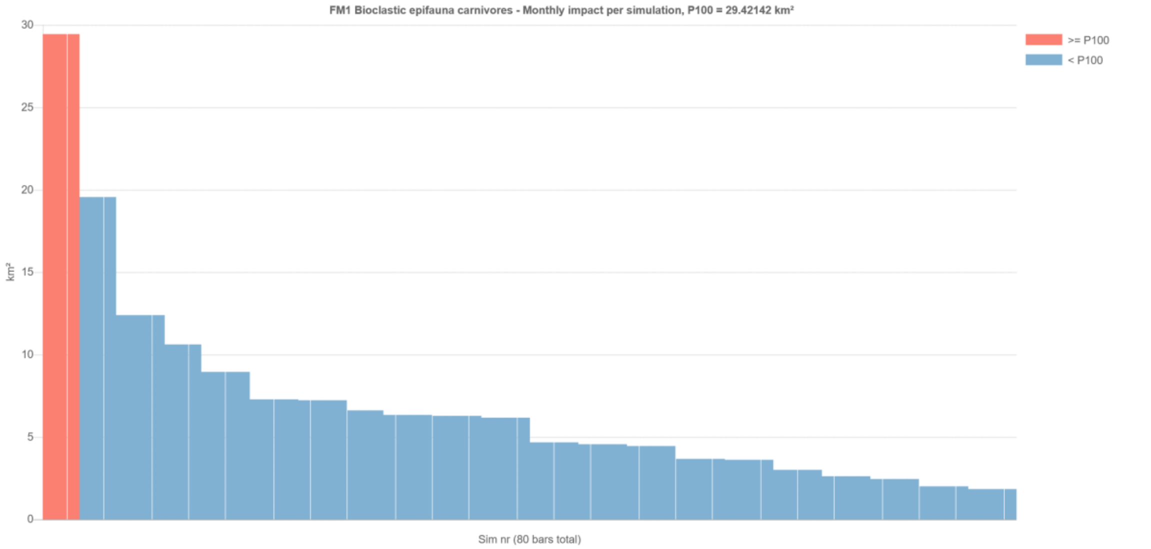

Figure 66. Single simulation results for sum of impacts over all cells (km²) for bioclastic coarse sand substrate VECs with FMs 1 and 4.

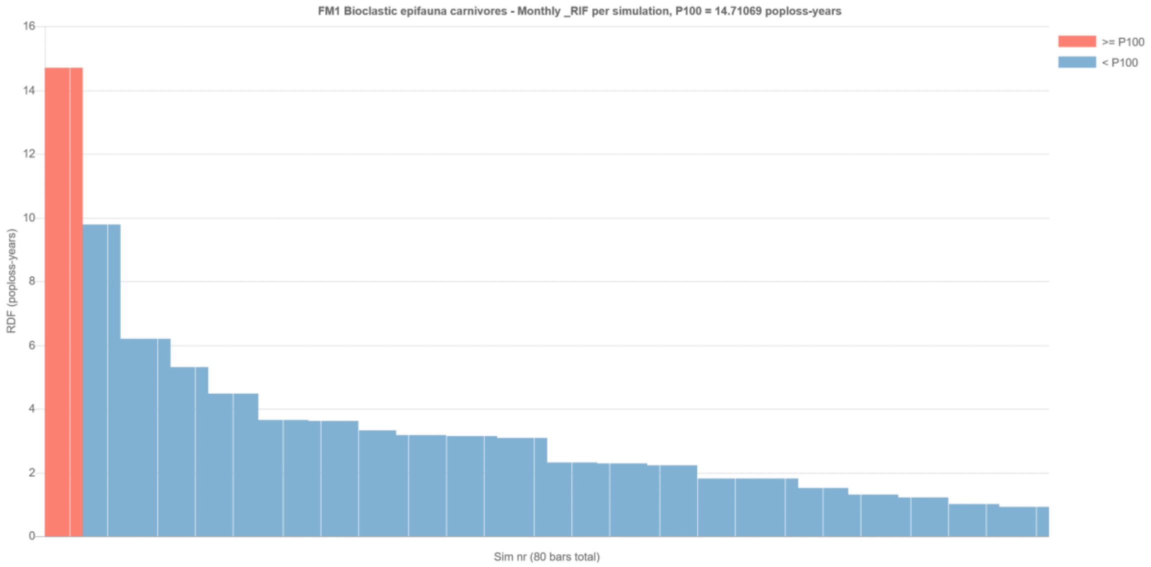

Figure 67. Single simulation results for sum of RDF over all cells (km²years) for bioclastic coarse sand substrate VECs with FMs 1 and 4.

4.7 Hard substrate Carnivores and Corals/sponges

4.7.1 Monthly maximum and mean impacts, RDFs and lag- and restitution times

Figure 68 shows the impact to VECs of FMs 1 (carnivores) and 4 (corals and sponges) on hard substrates. The average sum of impacts over all cells per month are low, between 2-8 km^2, for FM1 and 4 exposed in the water column, for these VECs the maximum in April is 13.3 km^2 in total. RDF values are seen in Figure 69. In hard substrates, the restitution times for all VECs are calculated based on the magnitude of the impact. The RDF-value is therefore based on the impact time of 1 year, as well as the lag- and restitution times.

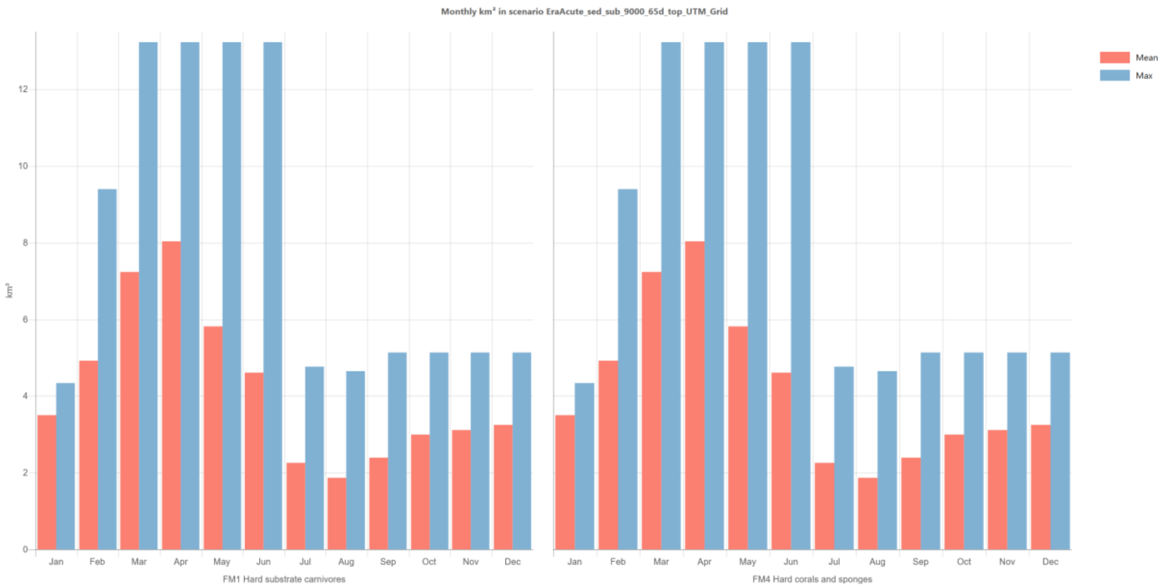

Figure 68. Mean and maximum impact areas (km²) for VECs in for hard substrate carnivores (FM 1) and corals/sponges on hard substrate (FM4).

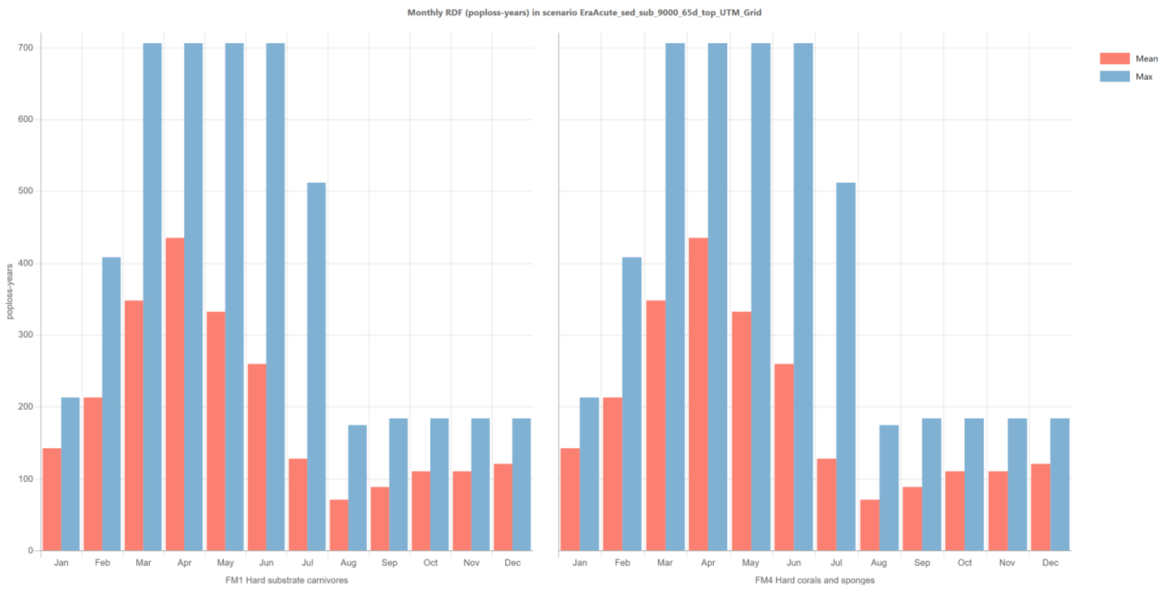

Figure 69. Mean and maximum RDF (km²years) for VECs in for hard substrate carnivores (FM 1) and corals/sponges on hard substrate (FM4).

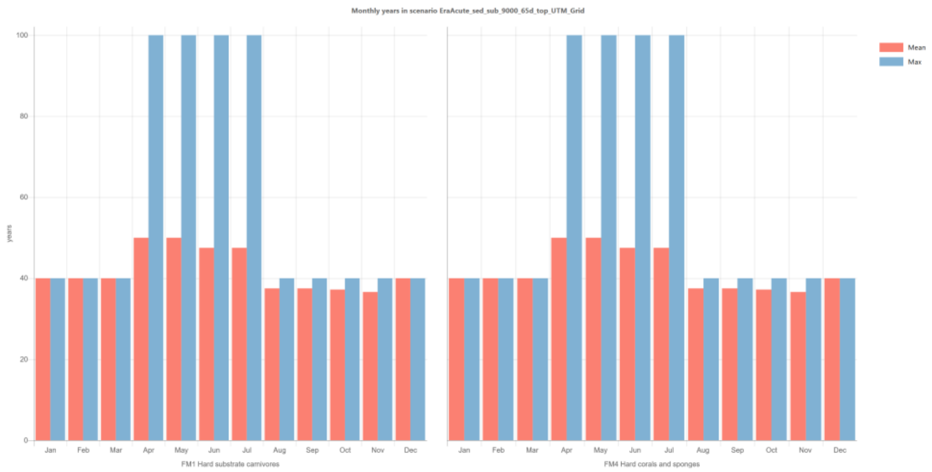

Figure 70. Mean and maximum lag times (years) for VECs in for hard substrate carnivores (FM 1) and corals/sponges on hard substrate (FM4).

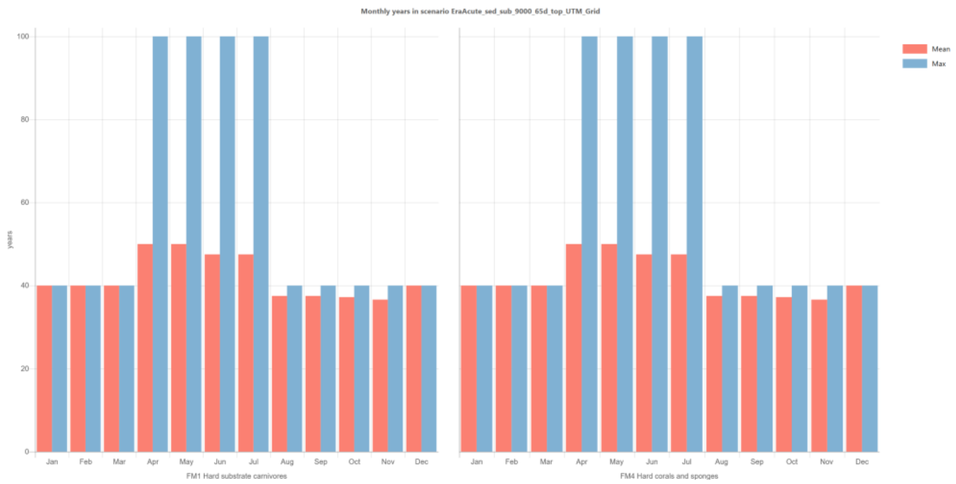

Figure 71. Mean and maximum restitution times (years) for VECs in for hard substrate carnivores (FM 1) and corals/sponges on hard substrate (FM4).

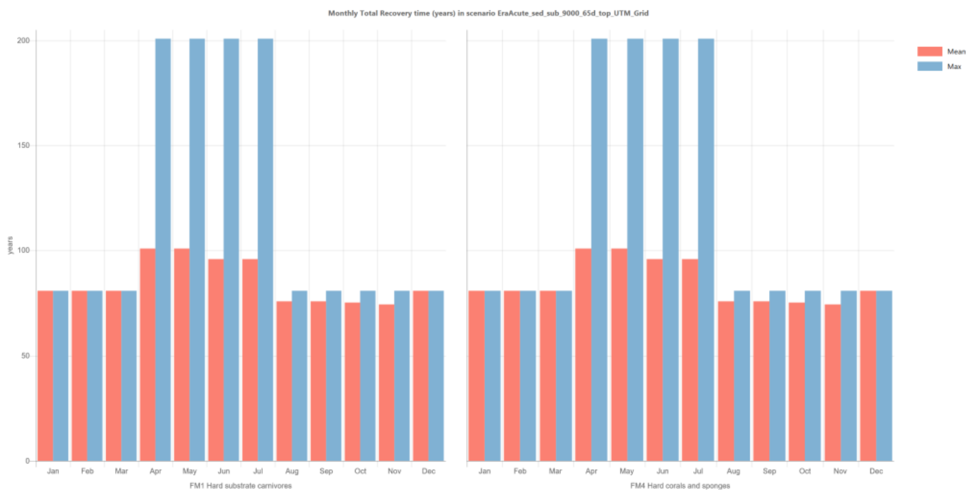

Figure 72. Mean and maximum total recovery times (years) for VECs in for hard substrate carnivores (FM 1) and corals/sponges on hard substrate (FM4).

4.7.2 Risk maps

Average impacted cells for FM1/4 can be seen in Figure 73. Average RDF-values in cells are shown in Figure 74).

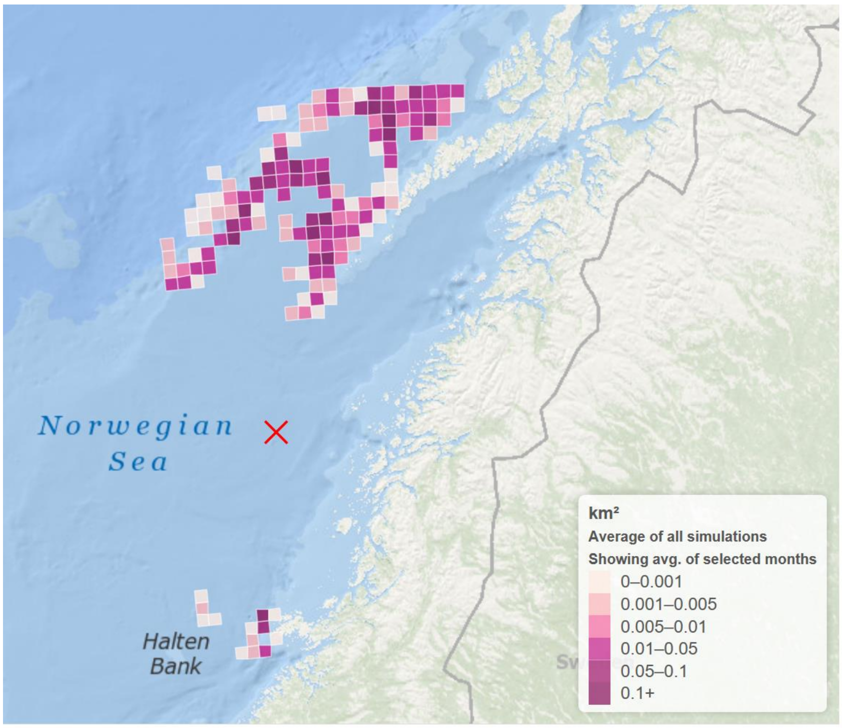

Figure 73. Average km² impacted for FM1 and FM4 bioclastic coarse sand substrate (all months).

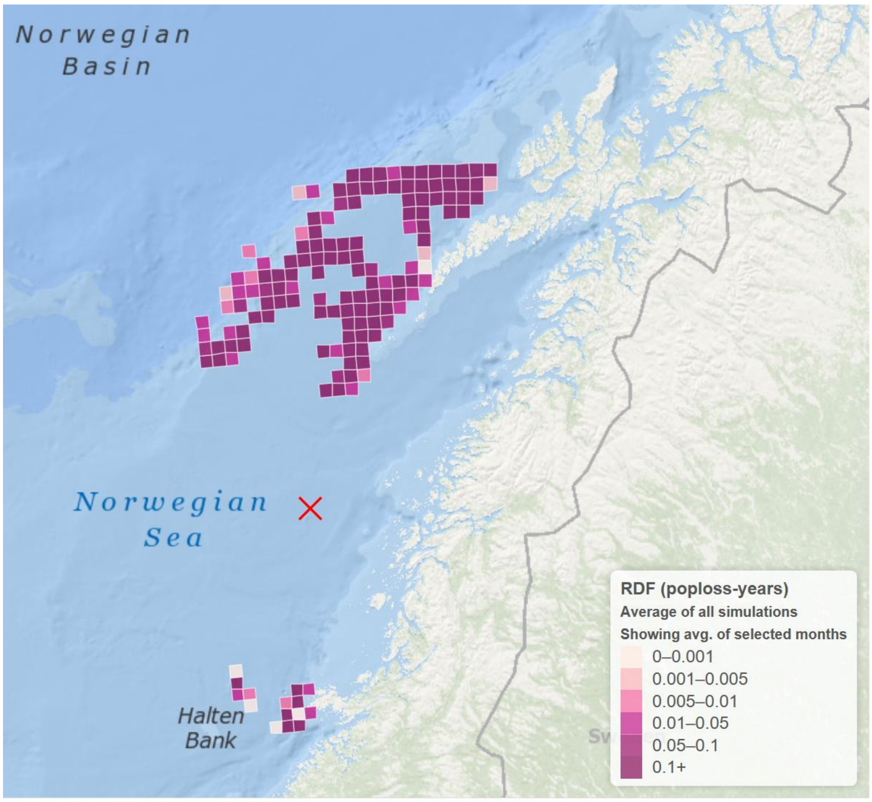

Figure 74. Average RDF (km²years) for FM1 and FM4 bioclastic coarse sand substrate (all months).

4.7.3 Results in single simulations

Simulation 13 gave the highest impact in the cells that hit the hard substrate VECs, water column compartment. The 100-percentile value is shown in Figure 75 for impacts and in Figure 76 for RDFs.

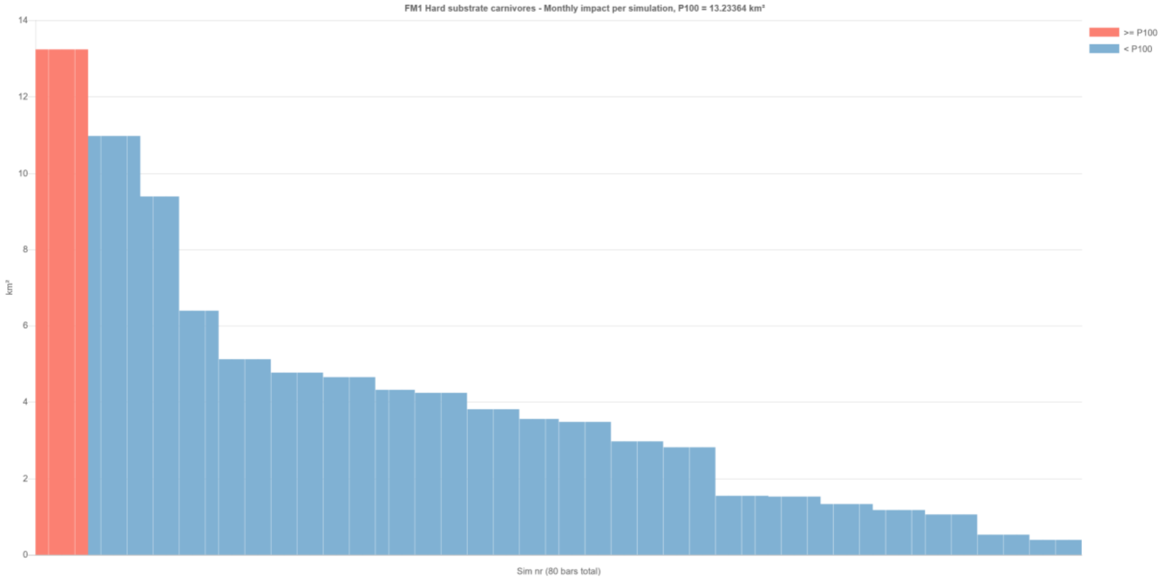

Figure 75. Single simulation results for sum of impacts over all cells (km²) for hard substrate carnivores (FM1) and corals/sponges (FM4).

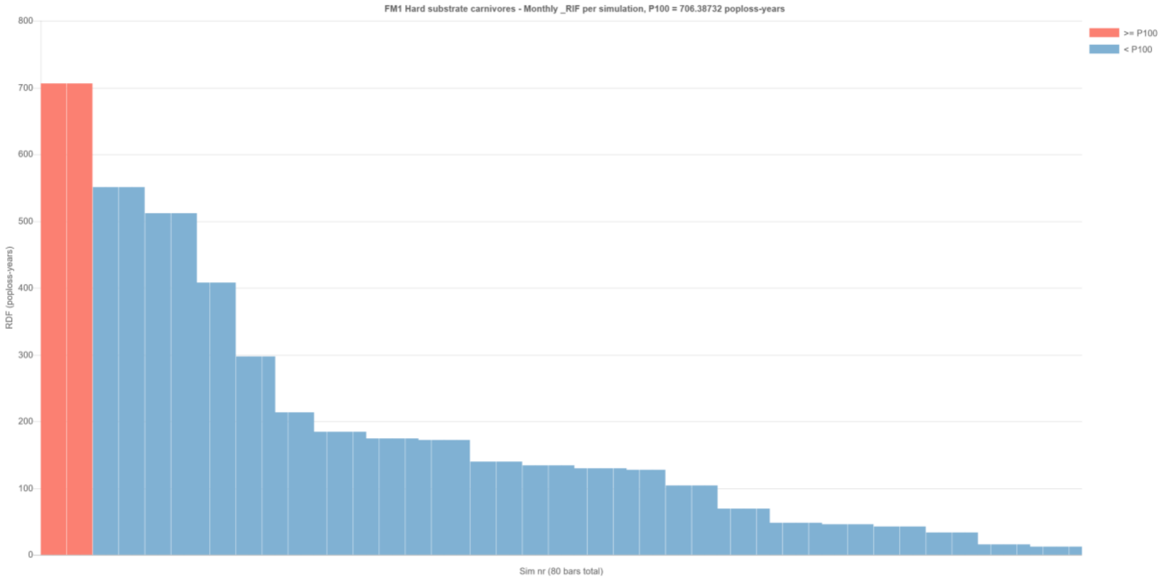

Figure 76. Single simulation results for sum of RDF over all cells (km²years) for hard substrate carnivores (FM1) and corals/sponges (FM4).

4.8 Seapens and burrowing organisms

Seapens and burrowing megafauna are a separate dataset in the MAREANO data. The data set has been split into two VECs, seapens (FM 4+5 as additive effect) and burrowing megafauna (FM7). The two VECs are reported together, as they are derived from the same dataset.

4.8.1 Monthly maximum and mean impacts, RDFs and lag- and restitution times

Figure 77 shows the impact to seapens and the burrowing organisms associated with the seapen habitats. The average sum of impacts over all cells per month are very low, between 0.2-1.3 km^2, for seapens and extremely low for the burrowing fauna. For the seapens the maximum just above 2 km^2 in total. RDF values are seen in Figure 78. Total recovery times include 1 year impact time, and are seen in Figure 79.

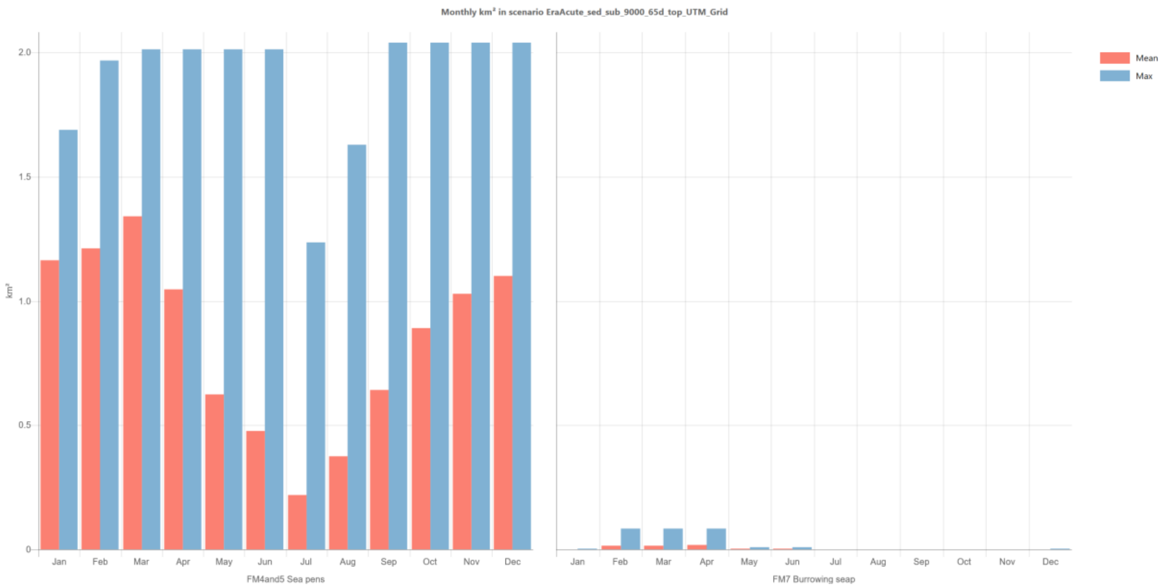

Figure 77. Mean and maximum impact areas (km^2) for seapens (FM 4 + 5) and burrowing fauna (FM7).

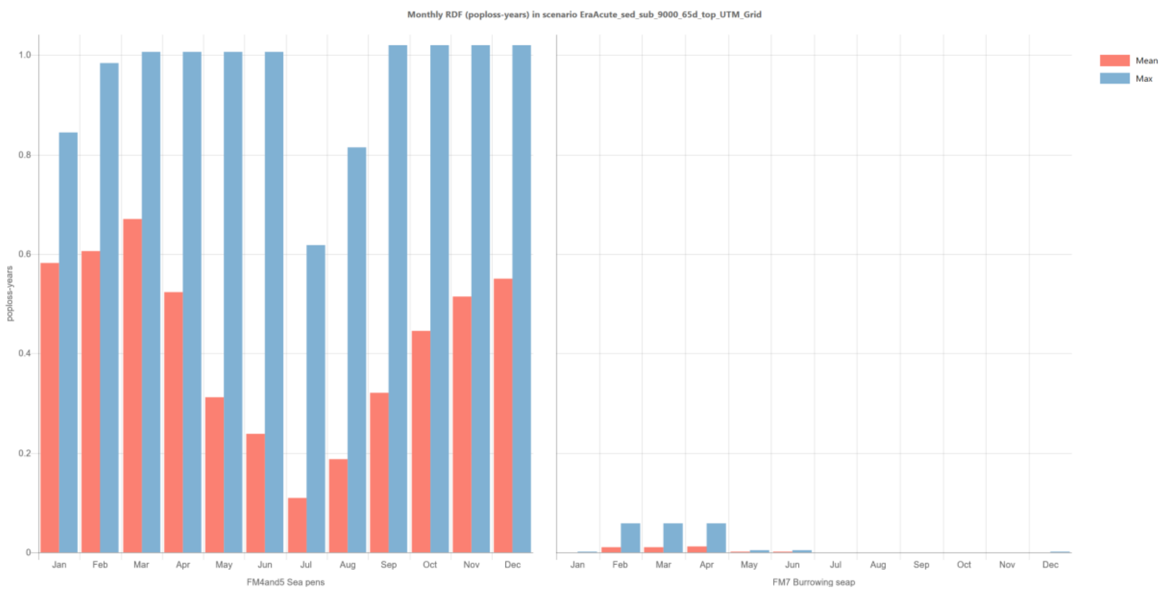

Figure 78. Mean and maximum RDF (km^{2}years) for seapens (FM 4 + 5) and burrowing fauna (FM7).

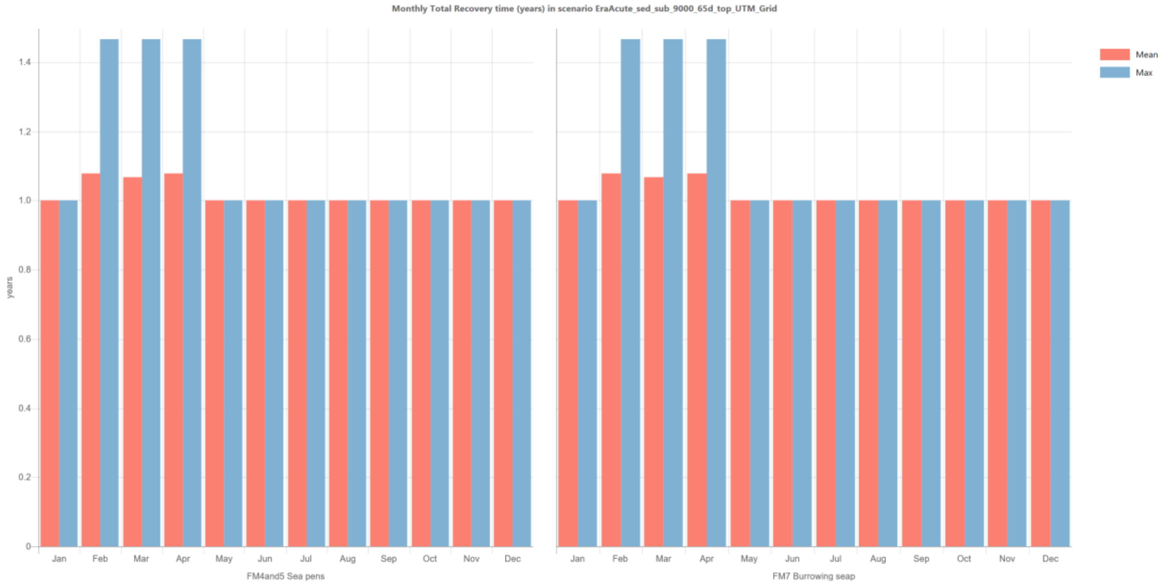

Figure 79. Mean and maximum total recovery times (years) (including 1 year lagtime) for seapens (FM 4 + 5) and burrowing fauna (FM7).

4.8.2 Risk maps

Average impacted cells for seapens and associated burrowing fauna can be seen in Figure 80. Average RDF-values in cells are shown in Figure 81.

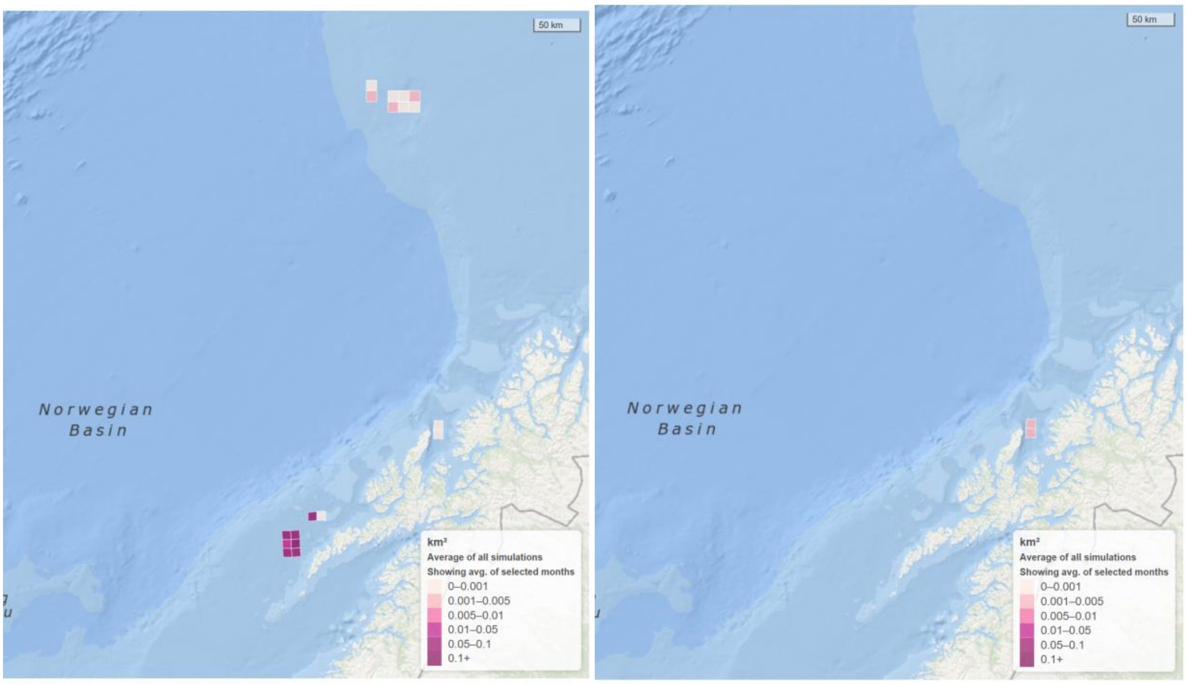

Figure 80. Average km² impacted for seapens (left) and associated burrowing fauna (right) all months).

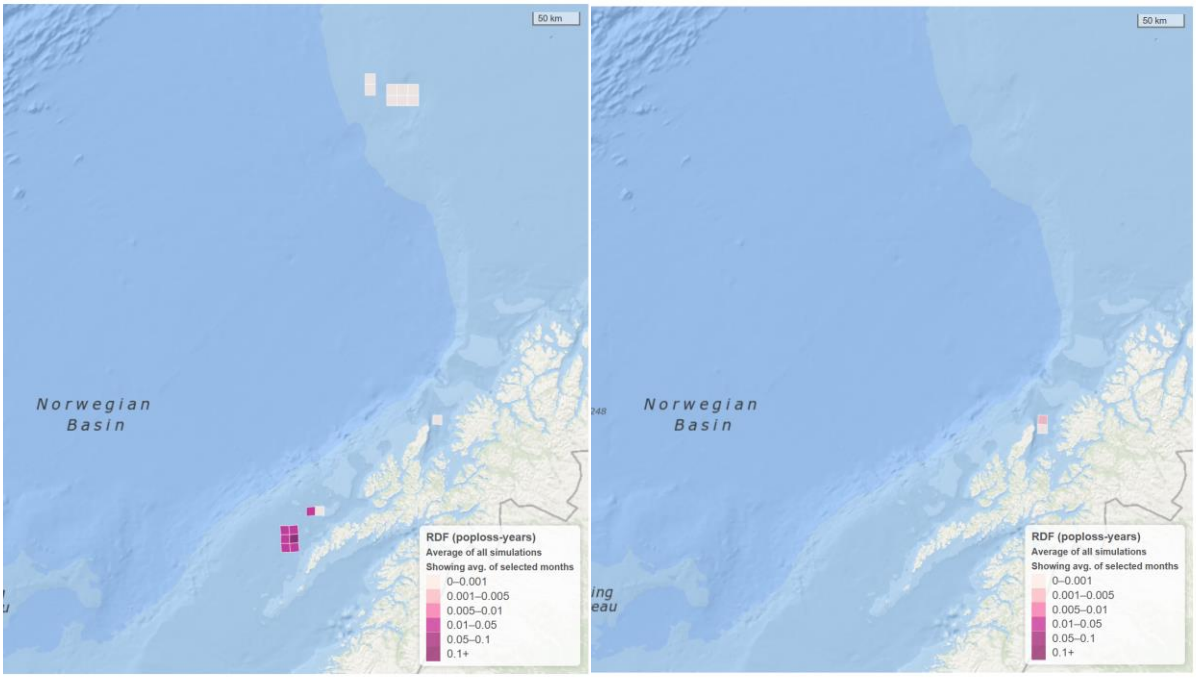

Figure 81. Average RDF (km²years) for seapens (left) and associated burrowing fauna (right) all months).

4.8.3 Results in single simulations

Simulation 9 gave the highest impact in the cells that hit the seapens, water column and interstitial water compartment. The 100-percentile value is shown in Figure 75 for impacts and in Figure 76 for RDFs. For the burrowing organisms, the impacts are much lower.

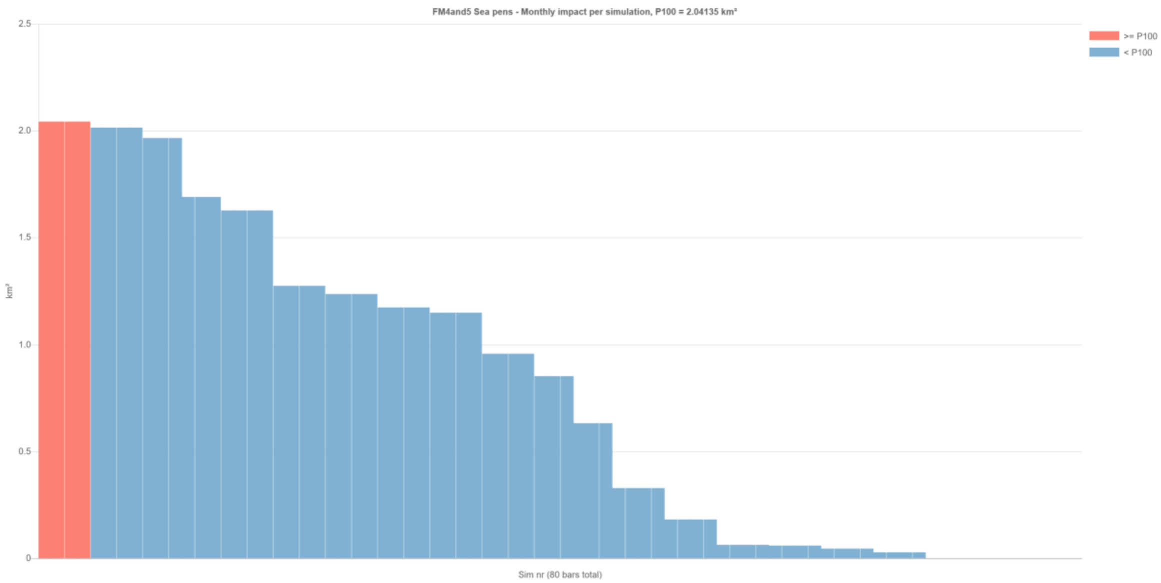

Figure 82. Single simulation results for sum of impacts over all cells (km²) for seapens (FM4+5).

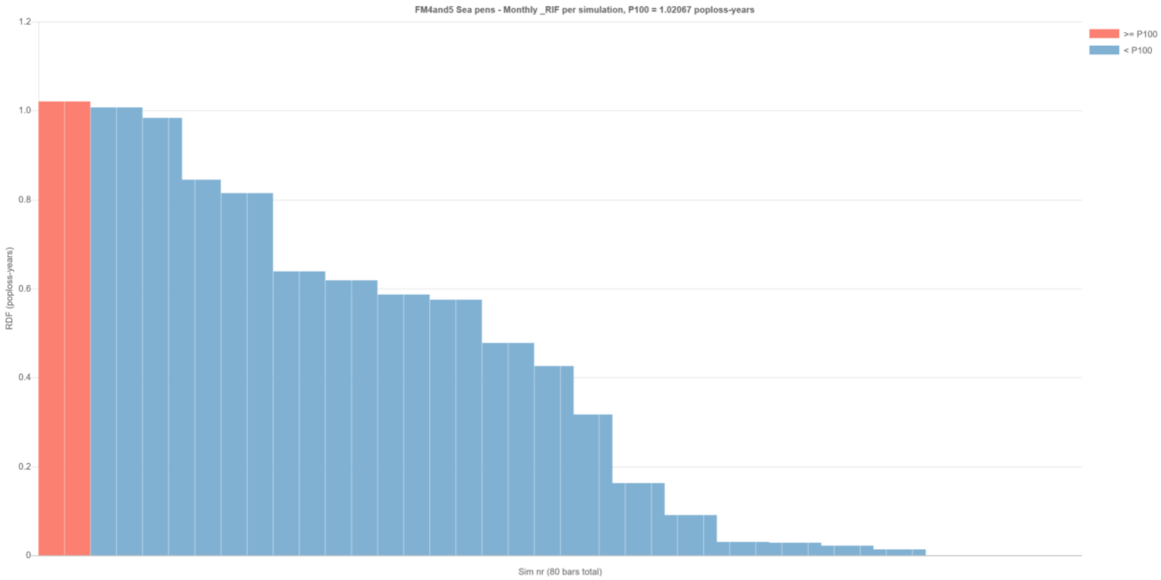

Figure 83. Single simulation results for sum of RDF over all cells (km²years) for seapens (FM4+5).

4.9 Umbellula and burrowing organisms

4.9.1 Monthly maximum and mean impacts, RDFs and lag- and restitution times

Figure 77 shows the impact to *Umbellulas* and the burrowing organisms associated with the *Umbellula* habitats. The highest average sum of impacts over all cells in all month is very low, approximately 0.05 km^2 for seapens in April-May, and there is no impact to the burrowing fauna. For the seapens the maximum is less than 0.35km^2 in total. RDF values are seen in Figure 78. Total recovery times is 1 year as for impact time.

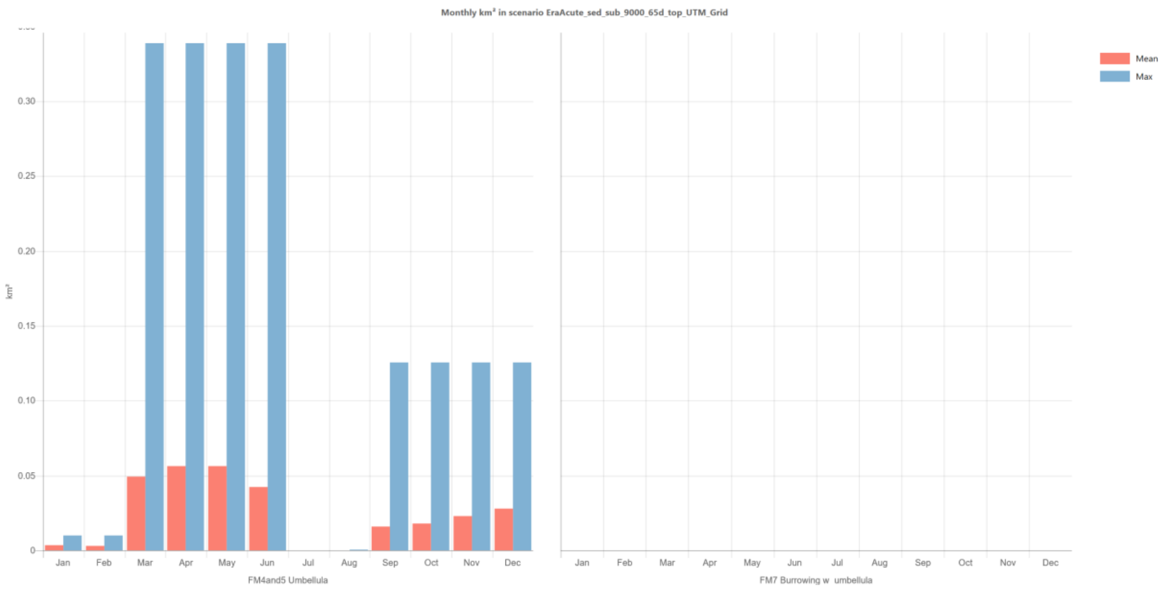

Figure 84. Mean and maximum impact areas (km²) for Umbellula stands (FM 4 + 5) and burrowing fauna (FM7).

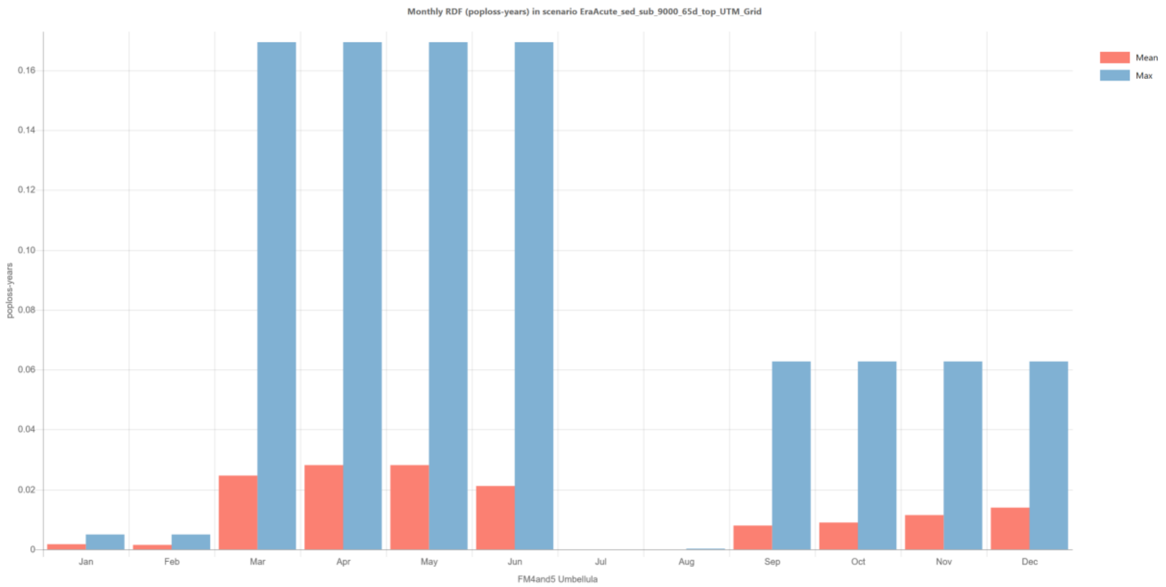

Figure 85. Mean and maximum RDF (km²years) for *Umbellula* (FM 4 + 5).

4.9.2 Risk maps

Average impacted cells for *Umbellulas* and associated burrowing fauna can be seen in Figure 86 on the left, and the average RDF-values in cells are shown in the same figure (right).

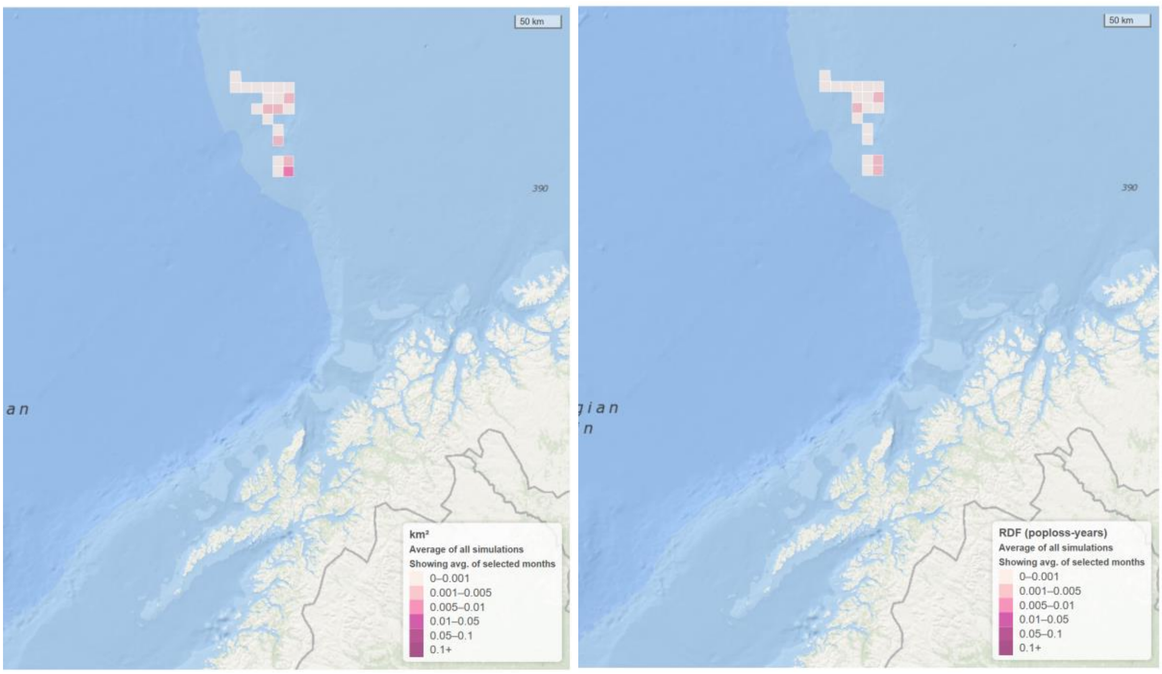

Figure 86. Average km² impacted for Umbellula (left) and RDF (right) (all months).

4.9.3 Results in single simulations

Simulation 15 gave the highest impact in the cells that hit the *Umbellulas*, water column and interstitial water compartment. The 100-percentile value is shown in Figure 87 for impacts.

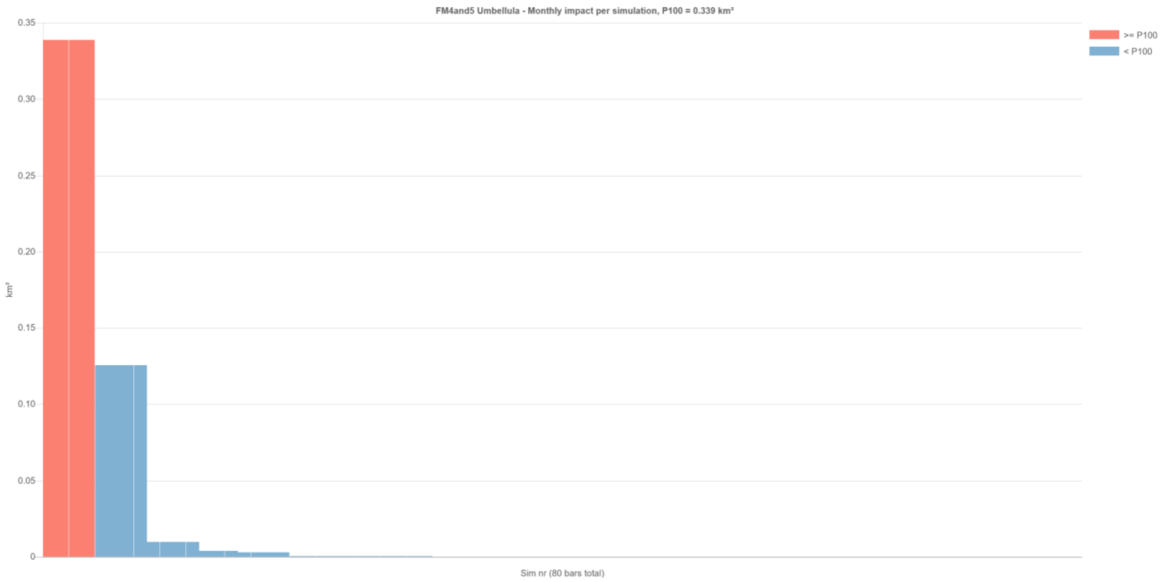

Figure 87. Single simulation results for sum of impacts over all cells (km²) for Umbellulas (FM4+5).

4.10 Soft bottom coral gardens

4.10.1 Monthly maximum and mean impacts, RDFs and lag- and restitution times

Figure 77 shows the impact to soft bottom corals. The highest average sum of impacts over all cells in all month is very low, approximately 0.05 km^2 for soft bottom corals in April-May. The maximum is just above 0.35km^2 in total. RDF values are seen in Figure 88. Total recovery times is 1 year as for impact time.

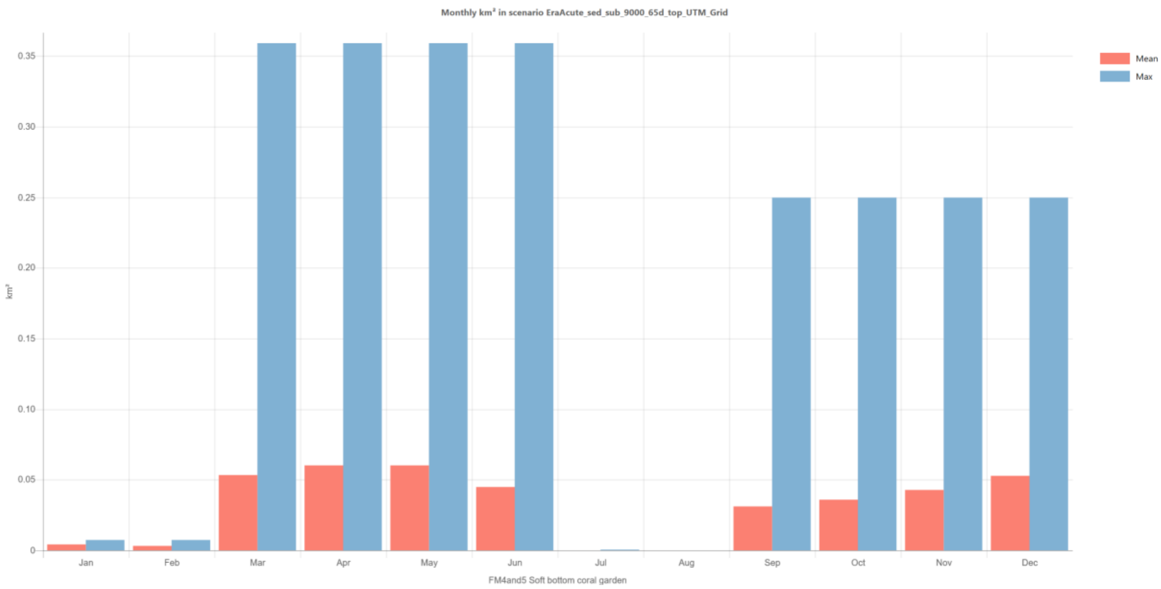

Figure 88. Mean and maximum impact areas (km²) for soft bottom corals (FM4+5).

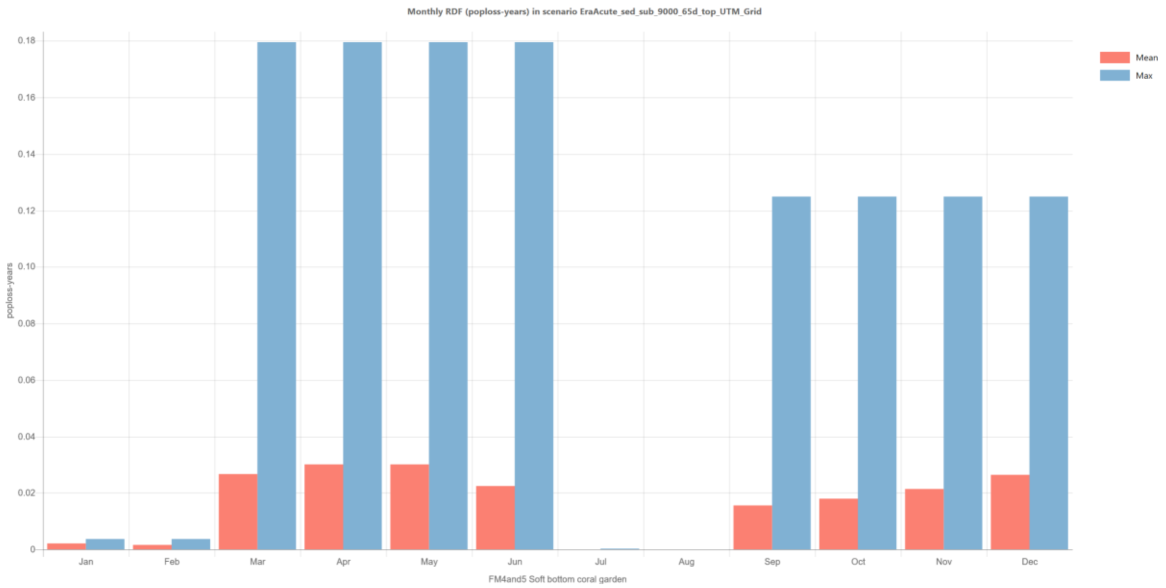

Figure 89. Mean and maximum RDF (km²years) for soft bottom corals (FM4+5).

4.10.2 Risk maps

Average impacted cells for soft bottom corals can be seen in Figure 90on the left, and the average RDF-values in cells are shown in the same figure (right).

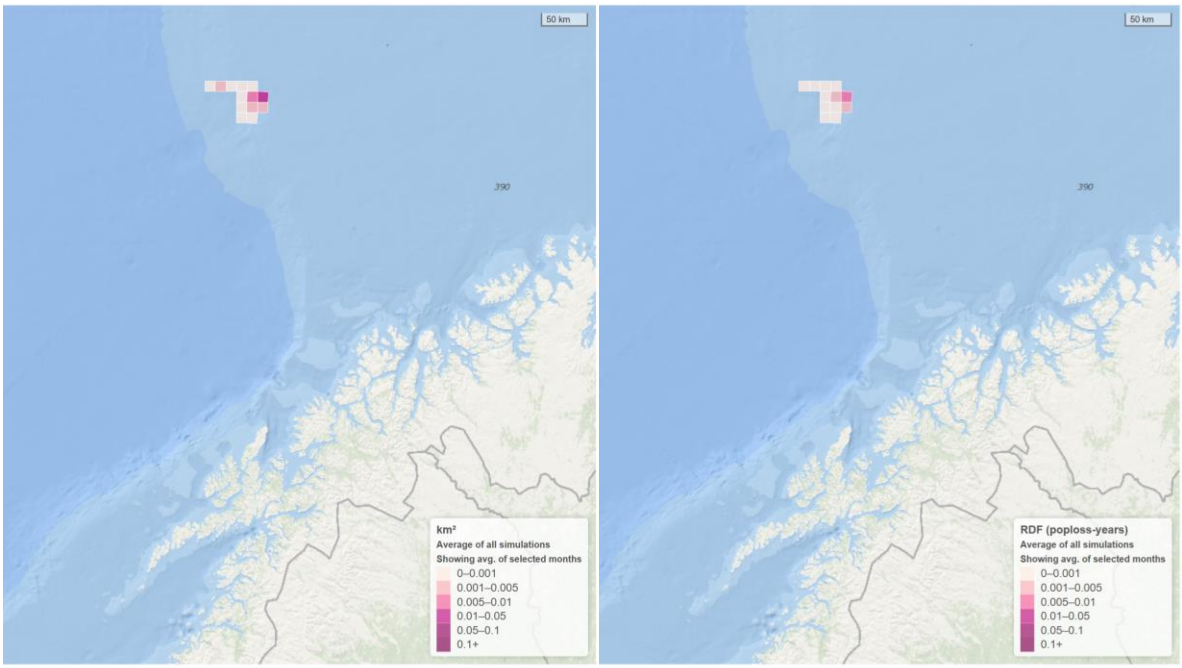

Figure 90. Average km² impacted for soft bottom corals (left) and RDF (right) (all months).

4.10.3 Results in single simulations

Simulation 15 gave the highest impact in the cells that hit the soft bottom corals, water column and interstitial water compartment. The 100-percentile value is shown in Figure 91 for impacts.

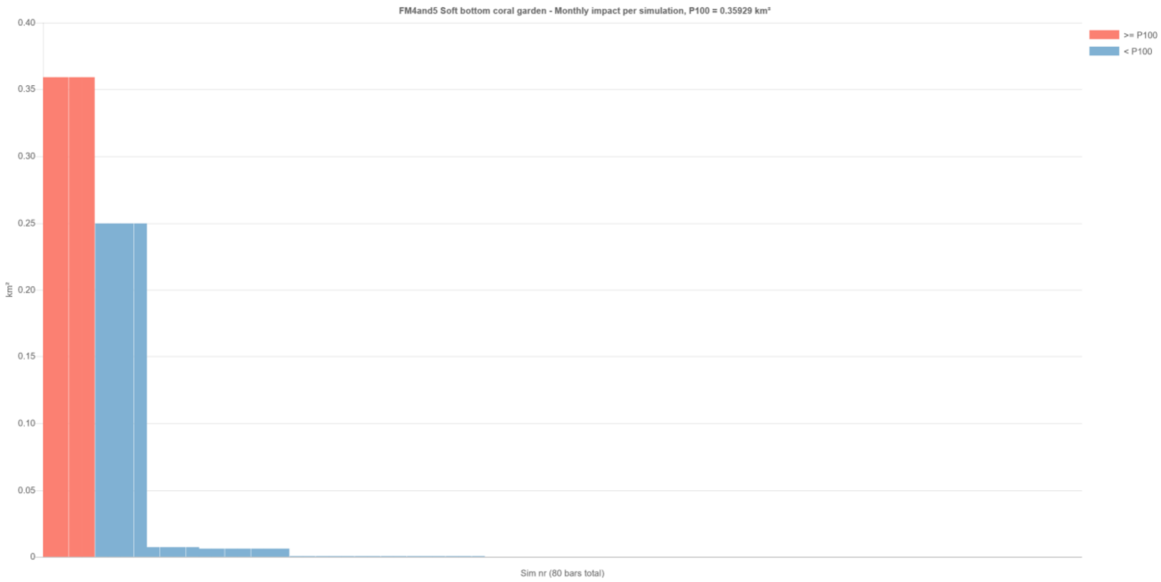

Figure 91. Single simulation results for sum of impacts over all cells (km^2) for soft bottom corals (FM4+5).

4.11 Hard bottom coral garden

The hard bottom coral garden is a separate VEC data set, not based on the substrate types. It has been ascribed the same parameters as corals and sponges on the substrate hard bottom, but the cells are in different locations.

4.11.1 Monthly maximum and mean impacts, RDFs and lag- and restitution times

Figure 92 shows the impact to hard bottom coral gardens. The highest average sum of impacts over all cells in all month is very low, between 0.01-0.07 km^2. The maximum is just above 0.4 km^2 in total. RDF values are seen in Figure 93. Lag-time and restitution times, are from the cell with the highest impact (20 years for each). The total recovery time is 41 years. Note that the time factors are from the cells with the longest times. In the hard substrate VECs the values are based on the impacts in a single cell.

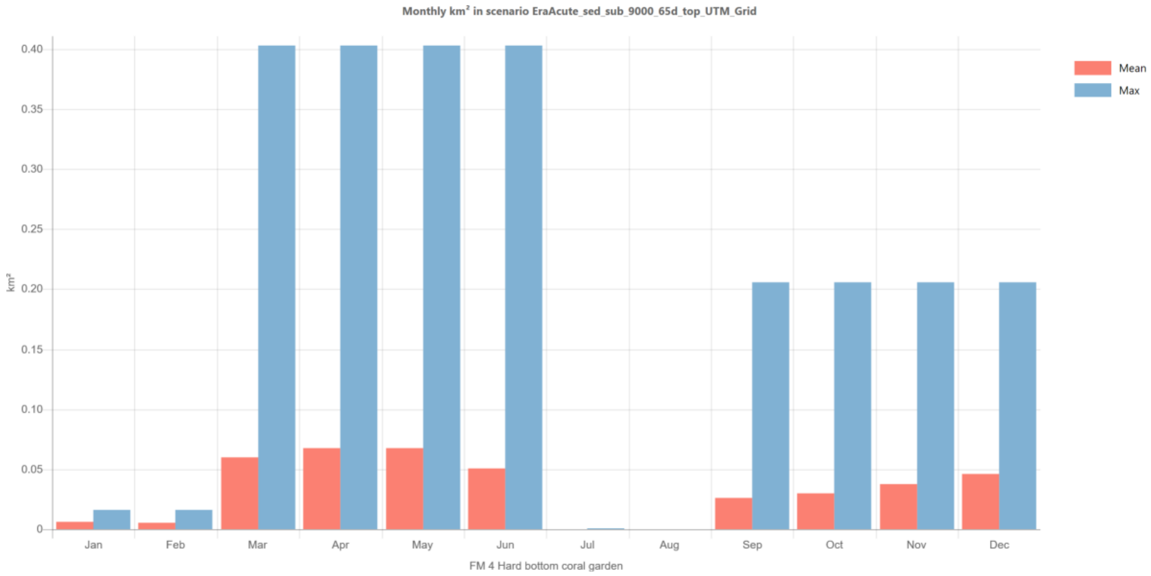

Figure 92. Mean and maximum impact areas (km²) for hard bottom coral garden (MAREANO) (FM4).

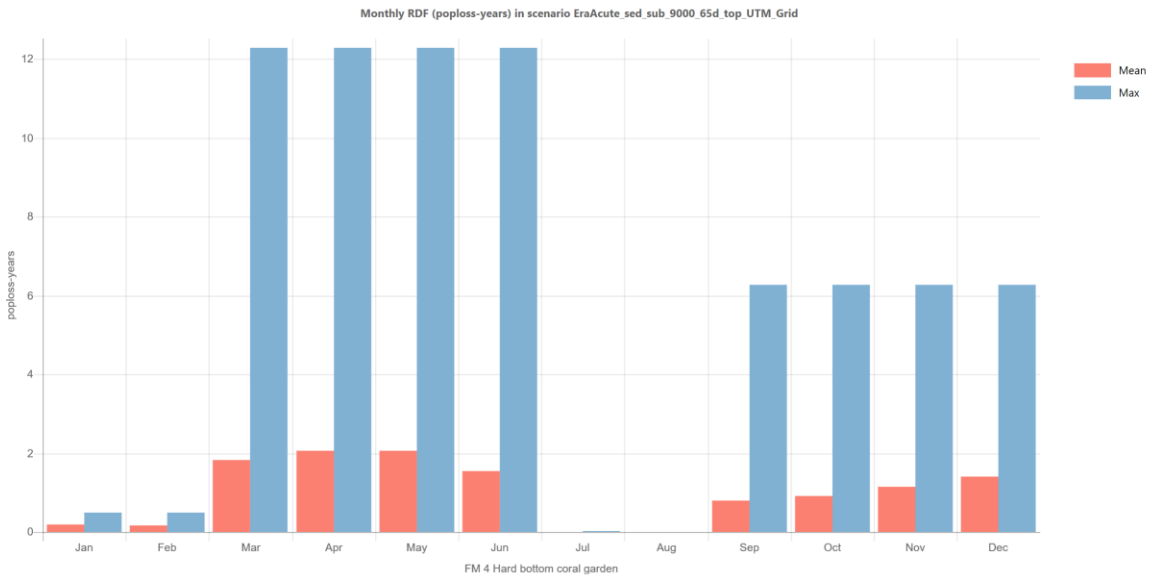

Figure 93. Mean and maximum RDF (km²years) for hard bottom coral garden (MAREANO) (FM4).

4.11.2 Risk maps

Average impacted cells for soft bottom corals can be seen in Figure 94 on the left, and the average RDF-values in cells are shown in the same figure (right).

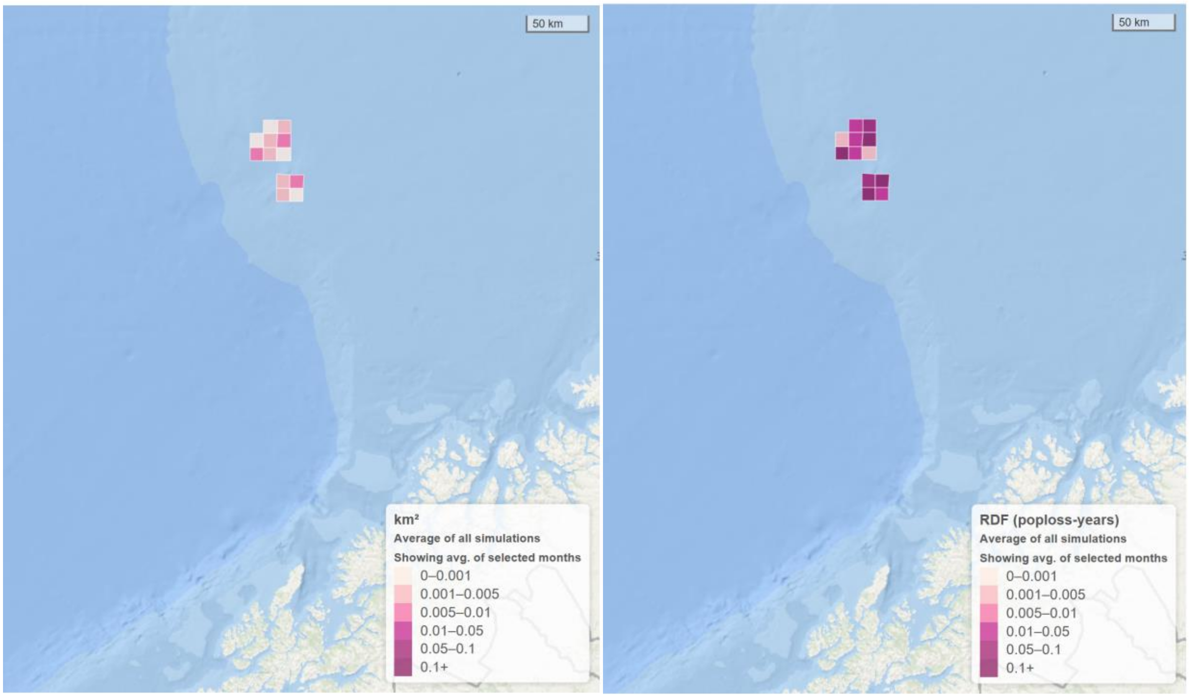

Figure 94. Average km² impacted hard bottom coral garden (MAREANO) (left) and RDF (right) (all months).

4.11.3 Results in single simulations

Simulation 15 gave the highest impact in the cells that hit the hard bottom coral gardens, water column compartment. The 100-percentile value is shown in Figure 95 for impacts.

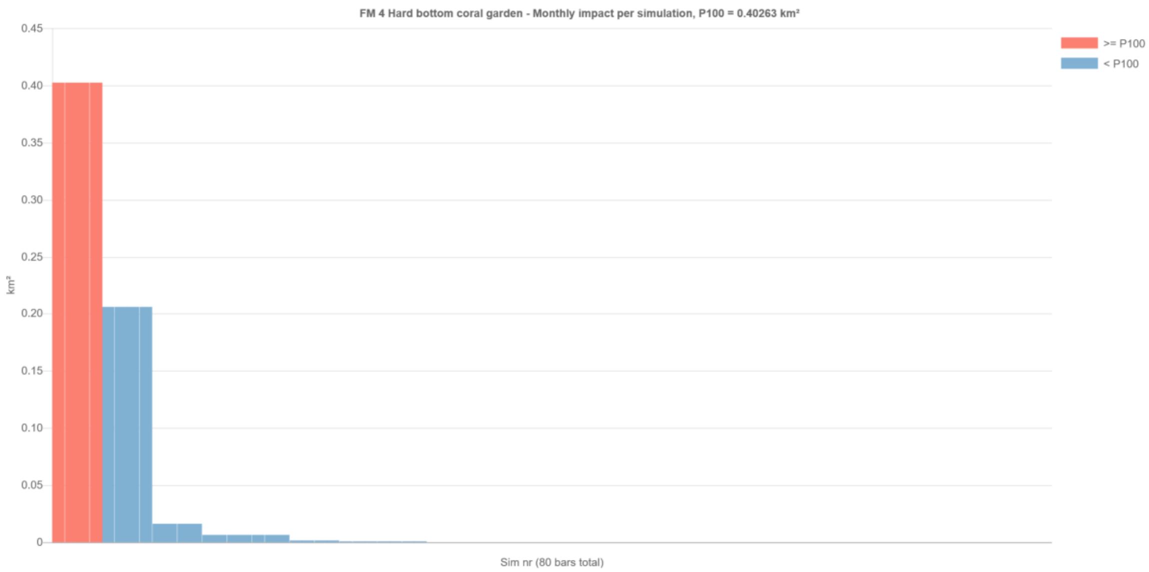

Figure 95. Single simulation results for sum of impacts over all cells (km²) for hard bottom coral garden (MAREANO) (FM4).

4.12 Discussion and conclusions for Level A.3

At level A.3, full risk assessments using fractions of the VEC present in a cell to calculate more accurate impact levels, as well as to calculate the time factors necessary to establish RDFs can be carried out. In the 21 simulations carried out for the surface spill of 9000 Sm^3/day of Oseberg Øst crude oil for 65 days, the impacts were higher in the water column than in the soft substrate sediments, due to higher exposure. The influence areas are described in Part 1.

Level A.3 and B results are well in line with the model theory. See the rest of the discussions and conclusions in Part 1.

5 Conclusion

More case studies are needed to determine appropriate risk levels for ERA acute for use in acceptance-based decisions and risk matrixes. The results of the single case study cannot be used to set these acceptance limits. However, it has need determined that risk can be measured in the sediments (soft substrates) as well as for hard bottom substrates in the sea floor compartment using the currently available oil drift modelling and impact mechanisms that are currently possible to include.

6 Reference

Stephansen, C. and Bjørgesæter, A. 2017: ERA Acute – WP2c – Seafloor Compartment Sensitivity Testing and Norwegian Sea Test Case Data. ERA Acute Report