

ONE-Dyas B.V. F06-IJssel Pipeline Release OSCAR Modelling Report

Version Control

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Abbreviations

API	American Petroleum Institute
BAOAC	BONN Agreement Oil Appearance Code
IBCAO	International Bathymetric Chart of the Arctic Ocean
mt	Metric ton (tonne)
Oil	Petroleum in any form including crude, condensate, fuel oil, sludge oil, oil refuse and refined products – such as diesel
OSCAR	Oil Spill Contingency and Response
ppb	parts per billion
µm	micrometre

1.0 MODELLING

The SINTEF Oil Spill Contingency and Response (OSCAR) modelling package was used to examine the potential impact of a release of crude from the F06-IJssel pipeline. Several scenarios have been modelled to assist in quantifying the risk to the local marine and coastal environment.

The aims of the modelling were to understand:

Stochastic Modelling

- Surface Oiling
 - probability of surface oiling (with an applied threshold of $\geq 0.1 \mu\text{m}$)
- Shoreline Contamination
 - probability of shoreline impact (no threshold applied)

Deterministic Modelling

- The fate of the crude (the amount that has dispersed, evaporated, and beached) and the potential impact on environmentally sensitive areas.

1.1. OSCAR

SINTEF's OSCAR modelling package, which has undergone extensive scientific research and validation (Reed M. F., 1995), (Reed M. A., 1996), was selected to undertake the simulation.

The OSCAR modelling package developed by SINTEF, is a three-dimensional oil spill model which calculates and records a range of water surface, subsurface and shoreline oiling possibilities over a stipulated period of release. OSCAR is a fully validated and calibrated model using a variety of field observations from several experimental oil spills.

The model accounts for weathering, the physical, biological, and chemical processes affecting oil at sea. OSCAR addresses the following surface processes: surface spreading and advection, entrainment in the water column, emulsification (mousse formation), and volatilisation (dissolution). Particles entrained in the water column are modelled with horizontal and vertical advection and dispersion.

OSCAR's range of predictions includes:

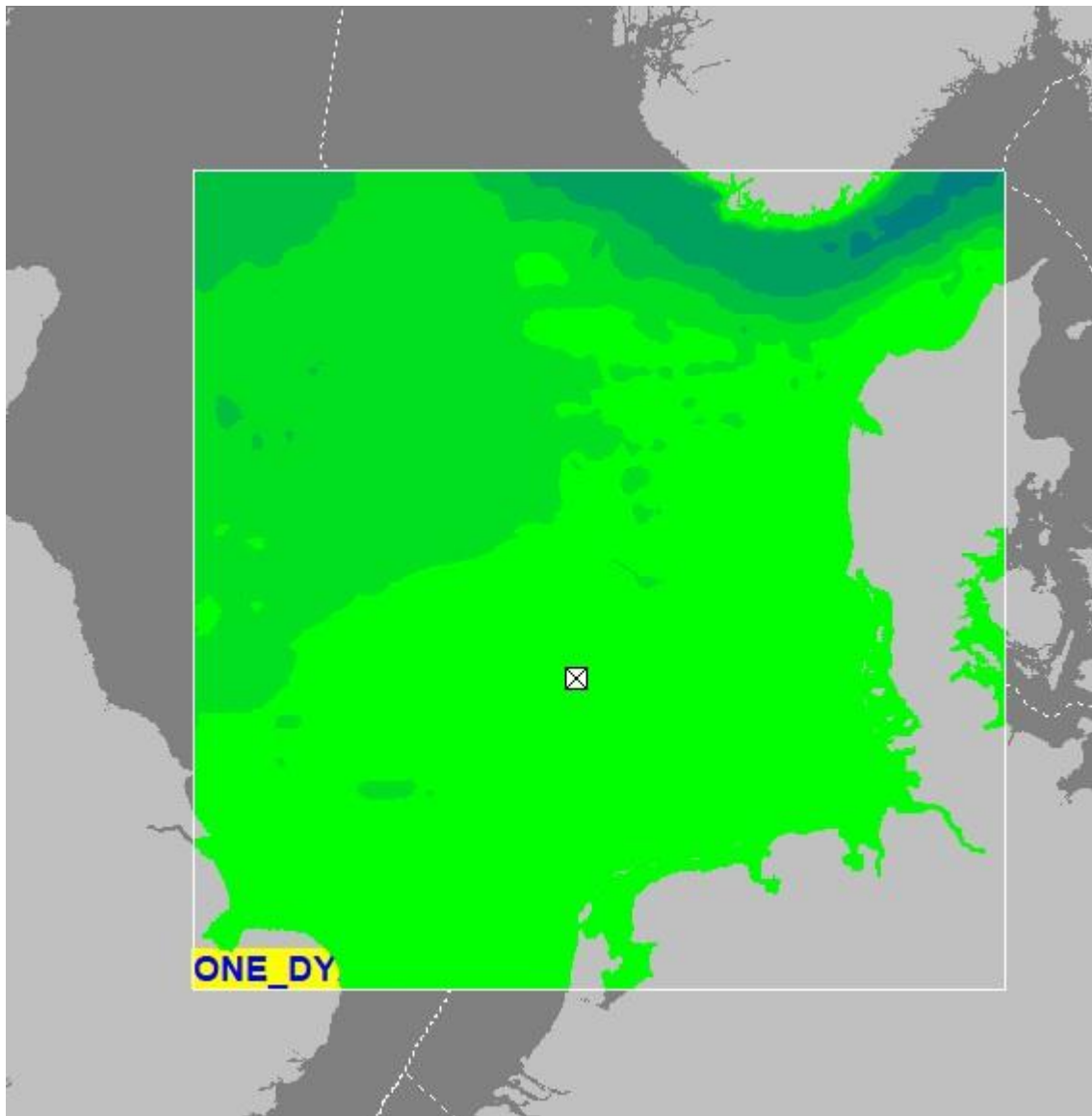
- probability of contamination - surface, sediment, shoreline, and water column
- time of arrival - oil on surface, in the water column and shoreline beaching
- maximum likely concentrations - in the water column and on water surface
- emulsified mass - of oil reaching shoreline and surface.
- exposure time - of surface oil, water column and concentration thresholds
- fate processes - including evaporation, dispersion, dissolution, sedimentation, beaching and decay.

2.0 MODEL INPUT DATA

This section summarises the input data used for the OSCAR simulations.

2.1. Study Area (Habitat Grid)

A 650 km by 650 km (422,500 km²) habitat grid was considered as an appropriate resolution to establish potential surface oiling, water column concentrations and shoreline impact. Each grid cell covers an area of approximately 650 m x 650 m (0.4225 km²).



The shoreline type has a bearing on the amount of hydrocarbon that may beach and re-mobilise – this was chosen to be ‘Sandy Beach’. This shoreline type is a reasonable approximation to determine the quantities beached.

2.2. Environmental Data

Hydrodynamic Data	Daily average representative 3D current data used in the model was taken from the Hybrid Coordinate Ocean Model (HYCOM) (2008- 2014).	
Wind	Representative wind data used in the model was taken from the European Centre for Medium-Range Weather Forecasts (2008 - 2014) and provided at 3 hourly intervals.	
Air Temperature	The air temperature is not used by the evaporation model in OSCAR	
Sea Temperature¹	Winter	Summer
Depth 0m	6.9°C	14.4°C
Salinity	34 ppt	34 ppt

2.3. Modelled Parameters

F06-IJssel Pipeline	
Release location	Subsurface
Latitude / Longitude	54° 49' 12.8" N / 04° 42' 51.4" E
Release amount	850 m ³ – released over one hour
Simulation duration	20 days ²

¹ NOAA, WOA 2018 Data Access: Statistical mean of temperature on 1° grid

² An additional 20 days was added to the release duration to allow for additional surface oil tracking once the release ceased.

2.4. BONN Agreement Oil Appearance Code

The BONN Agreement Oil Appearance Code (BAOAC) states that under most viewing conditions, oil layers below 0.04 μm in thickness cannot easily be detected by the human eye and appear silvery / grey up to a thickness 0.3 μm (Lewis, 2013).

BONN Agreement Oil Appearance Code				
Code	Description - Appearance	Layer thickness Interval		Litres per km ²
		μm	mm	
1	Sheen (silver/grey)	0.04 - 0.30	4e-005 - 0.0003	40 - 300
2	Rainbow	0.3 - 5.0	0.0003 - 0.005	300 - 5,000
3	Metallic	5.0 - 50	0.005 - 0.05	5,000 - 50,000
4	Discontinuous true oil colour	50 - 200	0.05 - 0.2	50,000 - 200,000
5	Continuous true oil colour	≥ 200	≥ 0.2	$\geq 200,000$

2.4.1. Applied Thresholds

- Based on the report finding of 'Effects of Sheens Associated with Offshore Oil and Gas Development on the Feather Microstructure of Pelagic Seabirds' (O'Hara & Morandin, 2010) and for the purpose of this study report, a surface thickness threshold of 0.1 μm (0.0001 mm) was applied to surface oiling.
- Based on acceptable oil in water discharges for onshore waters within 12nm territorial water limits, a 50-ppb threshold was set for water column concentrations.
- No threshold set for shoreline mass accumulations onshore.

2.5. Shoreline Oiling

Based on the 2011 ITPOF Technical Information Paper No. 6 “Recognition of oil on shorelines” the extent of shoreline oiling described as Light, Moderate or Heavy oiling is shown below. Where shoreline oiling is registered within the models, an overview of shoreline classification for oiling is provided.

Shoreline Oiling Classification	Volume (litres / m ²)	Avg. oil Thickness (mm)	Oiling (kg / m ²)
Light Oiling	0.1 - 1	0.1 - 1	0.0914 - 0.914
Moderate Oiling	1 - 10	1 - 10	0.914 - 9.14
Heavy Oiling	>10	>10	>9.14

Light Oiling example	Moderate Oiling example	Heavy Oiling example
		

Images courtesy of ITPOF – ITPOF Technical Information Paper No. 6 “Recognition of oil on shorelines”

2.6. Oil Profile

OSCAR’s standard oil database does not hold F06-IJssel pipeline crude. Svalde crude was chosen as a suitable representation for modelling purposes through hydrocarbon matching based on known properties.

Oil Matching Comparison						
Name	ITOPF Group	SG	Viscosity	Pour Point (°C)	Wax Content (%)	Asphaltene Content (%)
F06-IJssel	III	0.914	100	-42	4.7	0.25
Svalde	III	0.914	257	-33	2.12	0.32

2.7. Response Activities

To provide a better understanding of the fate of the crude, the simulations did not incorporate any oil spill response activities.

2.8. Modelled Scenarios

2.8.1. Stochastic Scenarios

Scenario		Release Rate	Release Duration	Modelled Duration
S01	F06-IJssel Pipeline Release (Winter)	850 m ³	1 hour	20 days
S02	F06-IJssel Pipeline Release (Summer)	850 m ³	1 hour	20 days

2.8.2. Deterministic Scenario

Results from stochastic model outputs have been analysed to identify the worst-case beaching scenario - this being the simulation with the single largest beaching volume.

Scenario		Release Rate	Release Duration	Modelled Duration
D01	F06-IJssel Pipeline Release (Winter)	850 m ³	1 hour	20 days
<i>Month of modelled release – February 2009</i>				
D02	F06-IJssel Pipeline Release (Summer)	850 m ³	1 hour	20 days
<i>Month of modelled release – July 2009</i>				

3.0 OSCAR SIMULATIONS

3.1. Stochastic Simulation

In a stochastic simulation, a series of release trajectory simulations are run repeatedly with a start date that is within the time period covered by historical wind and/or hydrodynamic data. The results of the trajectories are combined to illustrate the predicted probabilities of oil pathways in defined time periods. Running multiple release simulations during a single season should provide a reliable prediction of the oil pathways and oiling probabilities for a release starting during that season and extending into subsequent seasons.

In excess of 100 simulations spanning the release period were run using a wind time series, which started on a randomly selected date. In this approach, a sufficient number of simulations should adequately model the variability in the wind speed and direction in the area identified within the simulation.

The results of the stochastic model were analysed to determine the date with the highest beaching volume. This date and time were used for the deterministic model.

3.2. Deterministic Simulation

Deterministic or trajectory models are used to predict the path of an oil slick over time. The model estimates the weathering profile under the specified hydrodynamic and meteorological conditions by using temporally, and spatially varying, numerically computed ocean currents and winds.

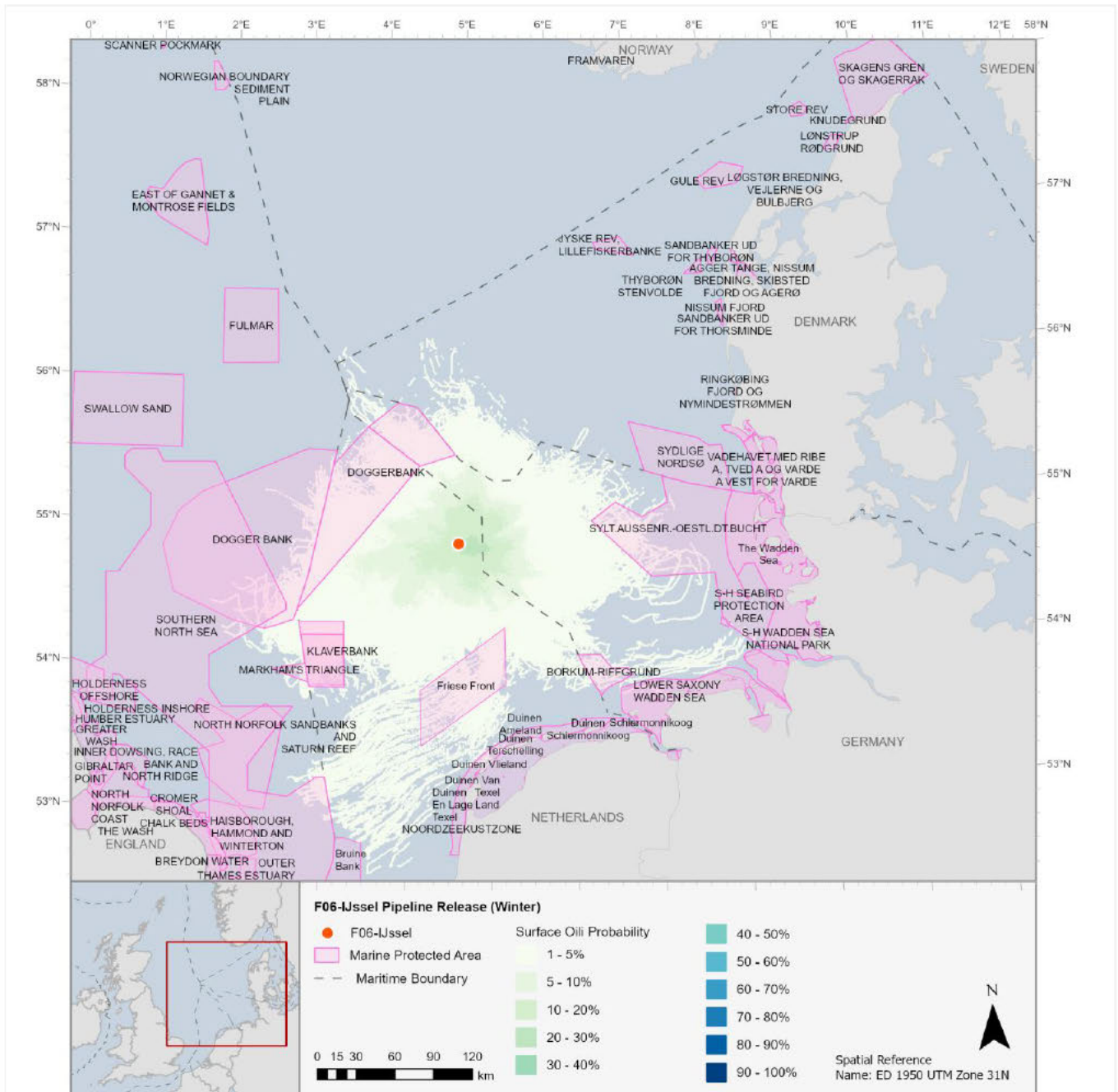
The results were analysed to determine:

- the predicted slick trajectory
- estimates of slick area
- changes to the crude properties over time
- potential impact to environmentally sensitive areas and the length of coastline impacted.
- sediment concentrations
- estimates of the total amount of beached crude.

4.0 RELEASE OUTPUTS

4.1. STOCHASTIC OUTPUTS

4.1.1. S01 – F06-IJssel Pipeline Release Surface Oiling Probabilities

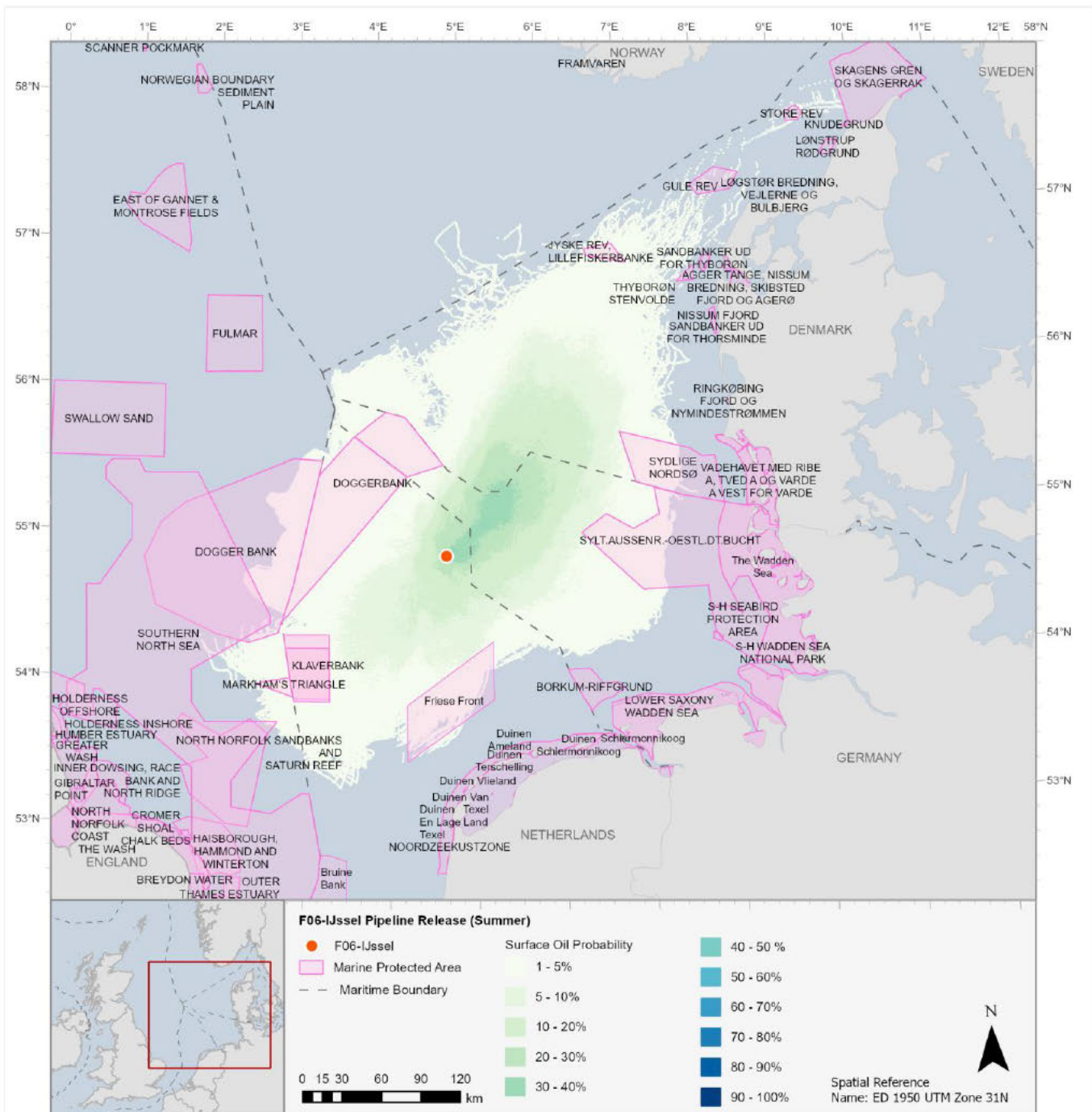


The picture does not depict the real extent of the spill; instead, it provides a statistical representation employed for risk assessment, drawing from approximately 100 distinct simulated trajectories. The anticipation of oil pathways involves amalgamating all trajectories from the simulation and illustrating them as a unified probability-density map. The plot illustrates the likelihood (>1%) of surface crude thickness being equal to or greater than 0.1µm.

Summary of S01 Surface Oiling Probabilities

- The highest probability of occurrence in a single grid cell is shown to be 90 – 100%. This area is directly above the release site. A 20 – 30% probability extends circa 10 km from the release site across into German waters.
- There is a 1- 5 % probability of surface oil crossing into UK waters.

4.1.2. S02 – F06-IJssel Pipeline Release Surface Oiling Probabilities

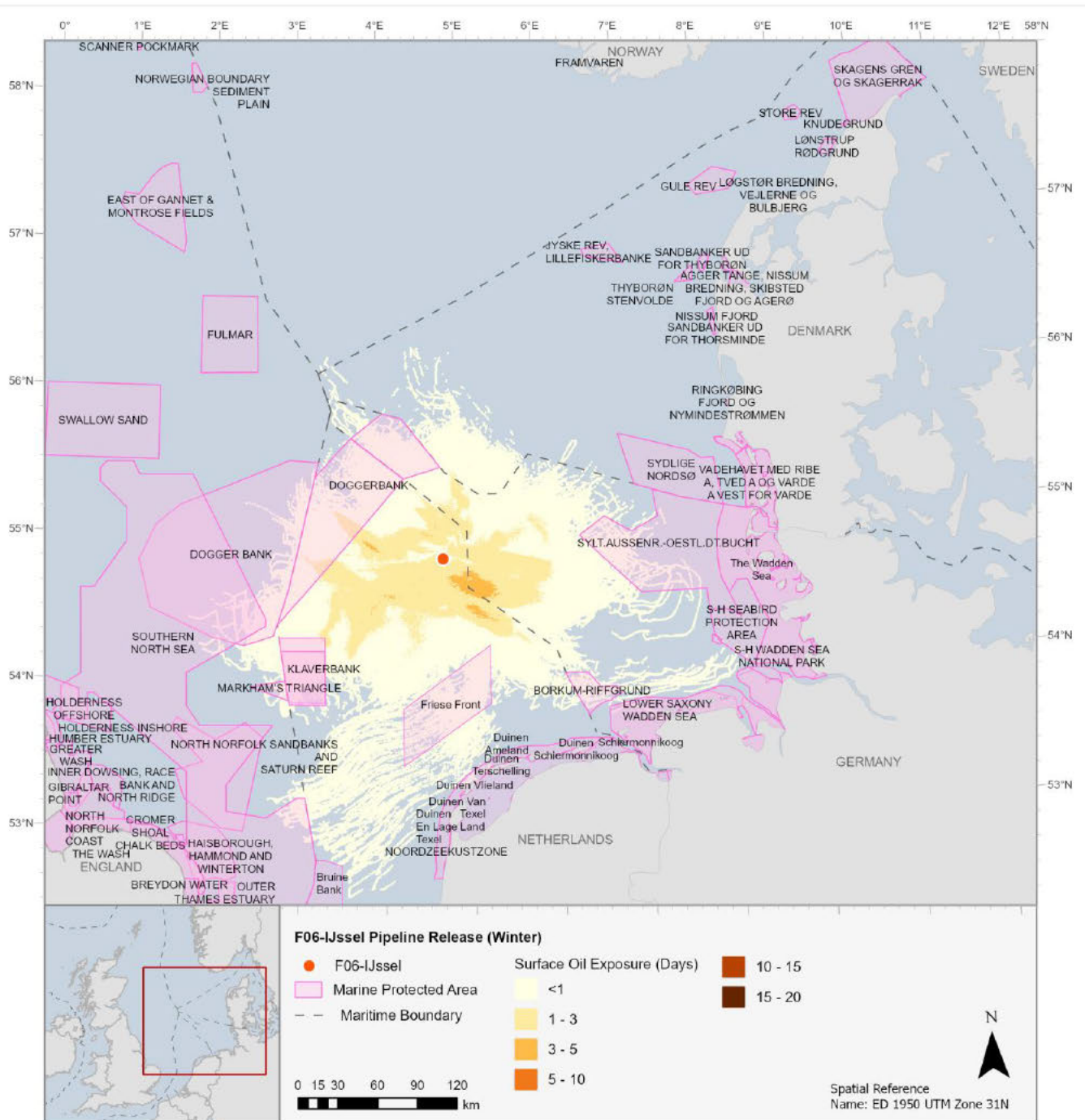


The picture does not depict the real extent of the spill; instead, it provides a statistical representation employed for risk assessment, drawing from approximately 100 distinct simulated trajectories. The anticipation of oil pathways involves amalgamating all trajectories from the simulation and illustrating them as a unified probability-density map. The plot illustrates the likelihood (>1%) of surface crude thickness being equal to or greater than 0.1µm.

Summary of S02 Surface Oiling Probabilities

- The highest probability of occurrence in a single grid cell is shown to be 90 – 100%. This area is directly above the release site. A small area of 40 – 50% probability extends circa 50 km from the release site across into German waters.
- There is a 30 - 40 % probability of surface oil crossing into Danish waters.

4.1.3. S01 – F06-IJssel Pipeline Release Maximum Exposure Time

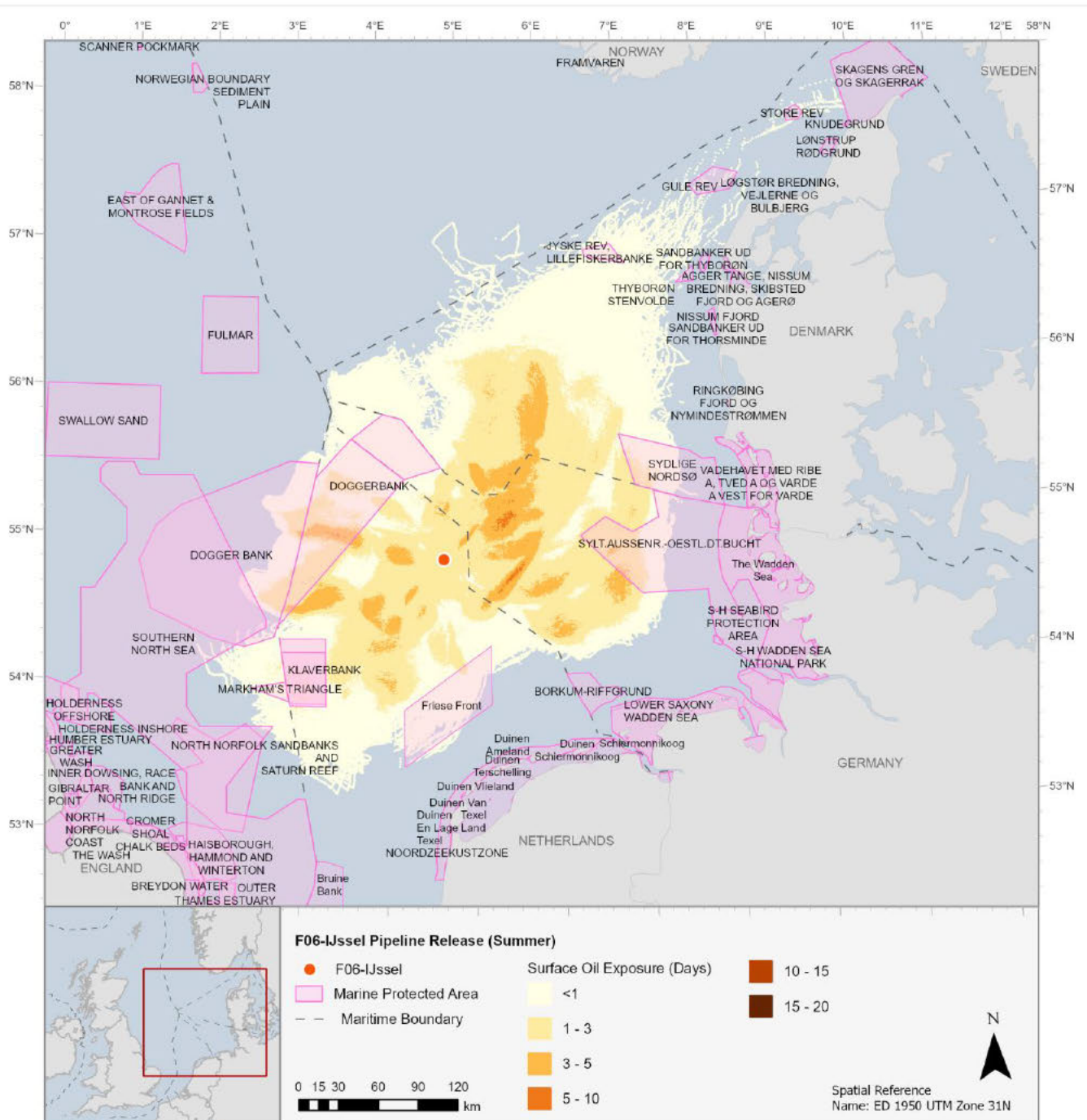


The picture does not depict the real extent of the spill; instead, it provides a statistical representation employed for risk assessment, drawing from approximately 100 distinct simulated trajectories. The image illustrates the longest duration of exposure in all simulations. Exposure time denotes the number of days a specific area has experienced oiling during a simulation.

Summary of S01 Surface Oiling Exposure Time

- The maximum exposure time indicated by the model is 4 days.
- The exposure time reduces to ≤ 2 days approximately 100 km from the release site, indicating that the surface oil is unlikely to persist for more than a week.

4.1.4. S02 – F06-IJssel Pipeline Release Maximum Exposure Time

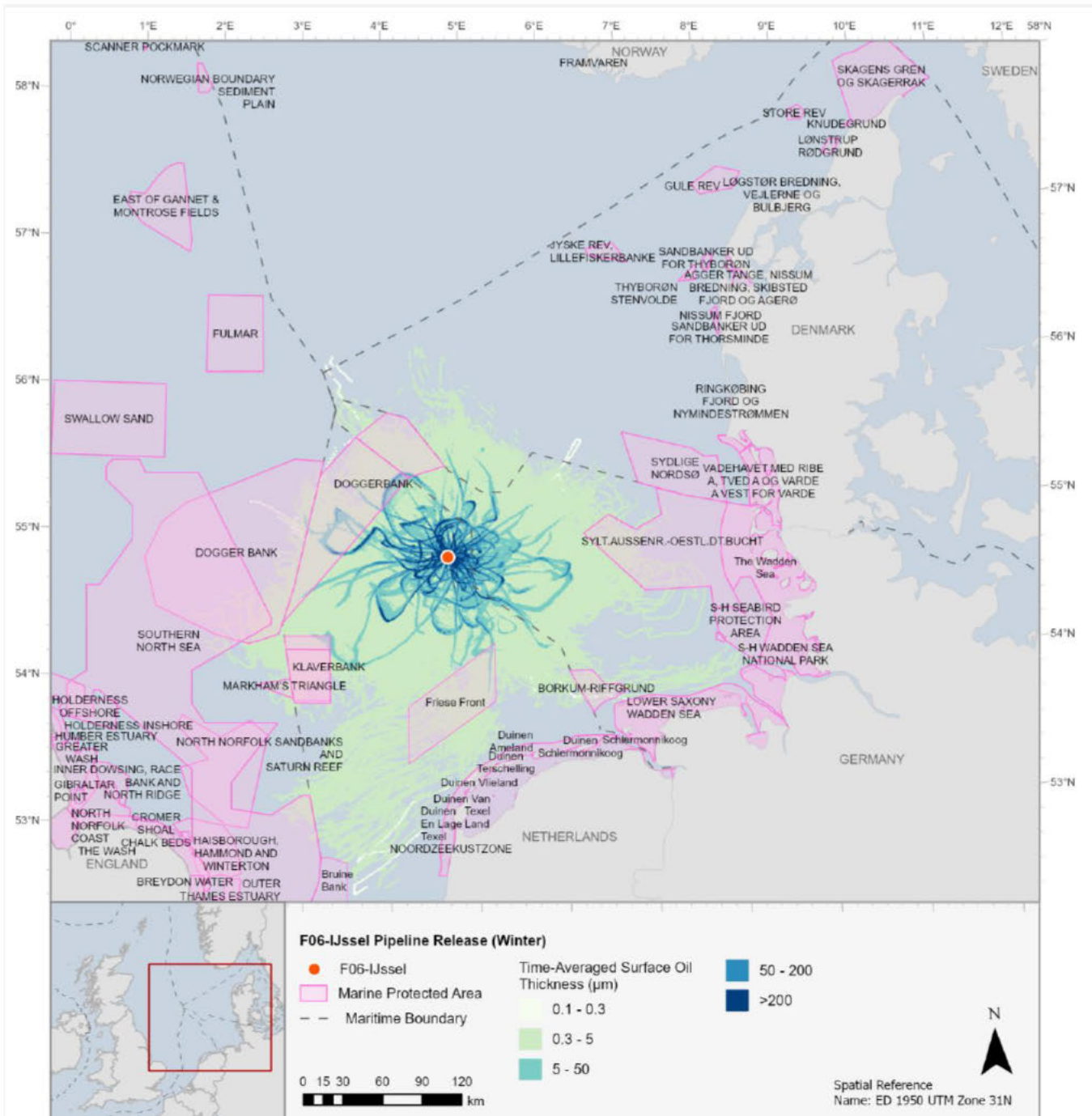


The picture does not depict the real extent of the spill; instead, it provides a statistical representation employed for risk assessment, drawing from approximately 100 distinct simulated trajectories. The image illustrates the longest duration of exposure in all simulations. Exposure time denotes the number of days a specific area has experienced oiling during a simulation

Summary of S02 Surface Oiling Exposure Time

- The maximum exposure time indicated by the model is 5 days.
- The exposure time reduces to ≤ 2 days approximately 150 km from the release site, indicating that the surface oil is unlikely to persist for more than a week.

4.1.5. S01 – F06-IJssel Pipeline Release Maximum Time-averaged Emulsion Thickness

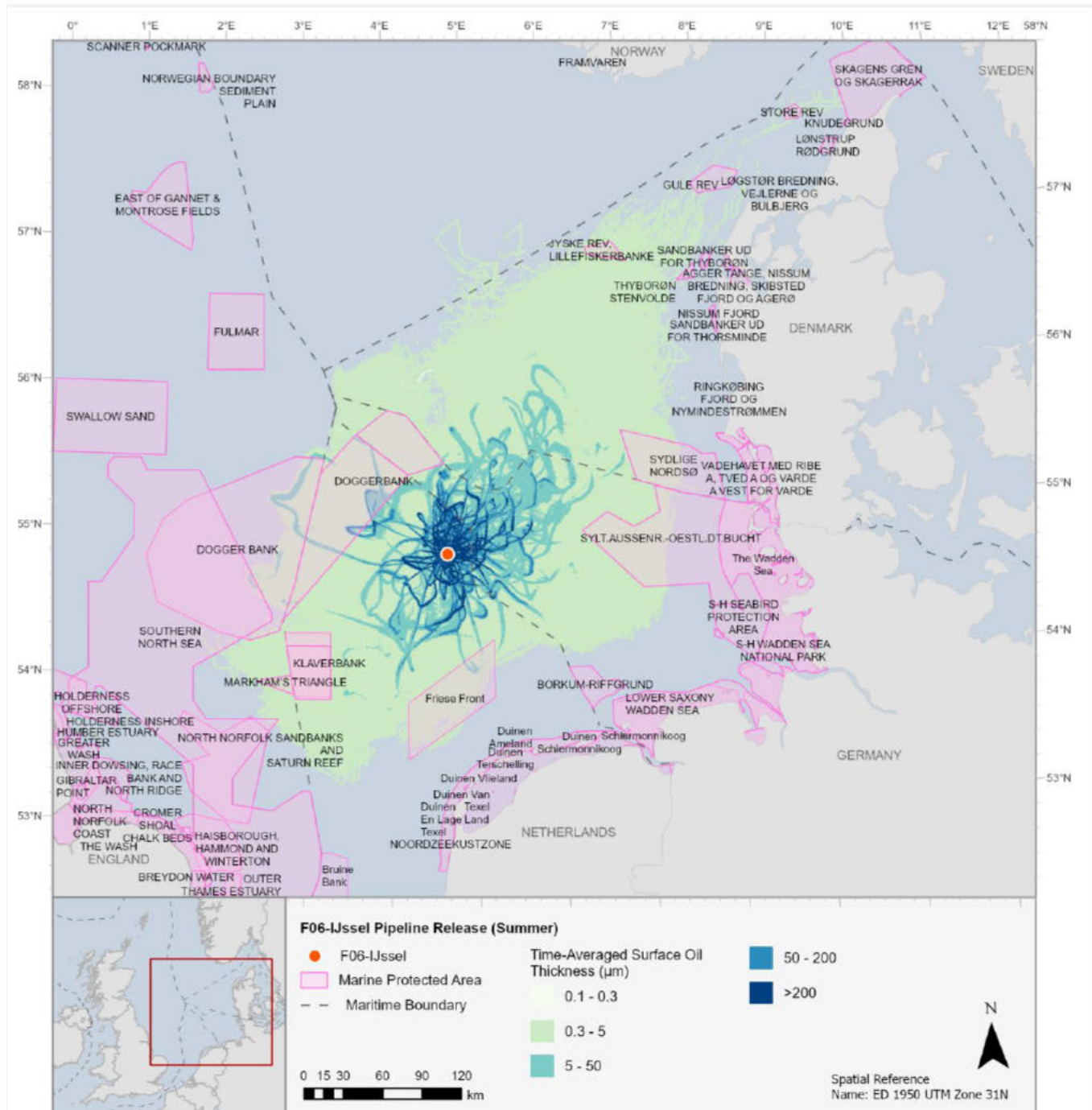


The picture does not depict the real extent of the spill; instead, it provides a statistical representation employed for risk assessment, drawing from approximately 100 distinct simulated trajectories. The image shows the maximum time-averaged thickness of surface crude over all simulations.

Summary of S01 Maximum Time-averaged Emulsion Thickness

- The maximum time-averaged emulsion thickness is indicated to be >200 µm (Continuous True colour).
- Areas of crude with a thickness of >200 µm (Continuous True colour) extend into German waters.
- The average thickness is predominantly between 0.3 µm and 5 µm (Rainbow colour) which is likely to reach UK and Danish waters.

4.1.6. S02 – F06-IJssel Pipeline Release Maximum Time-averaged Emulsion Thickness

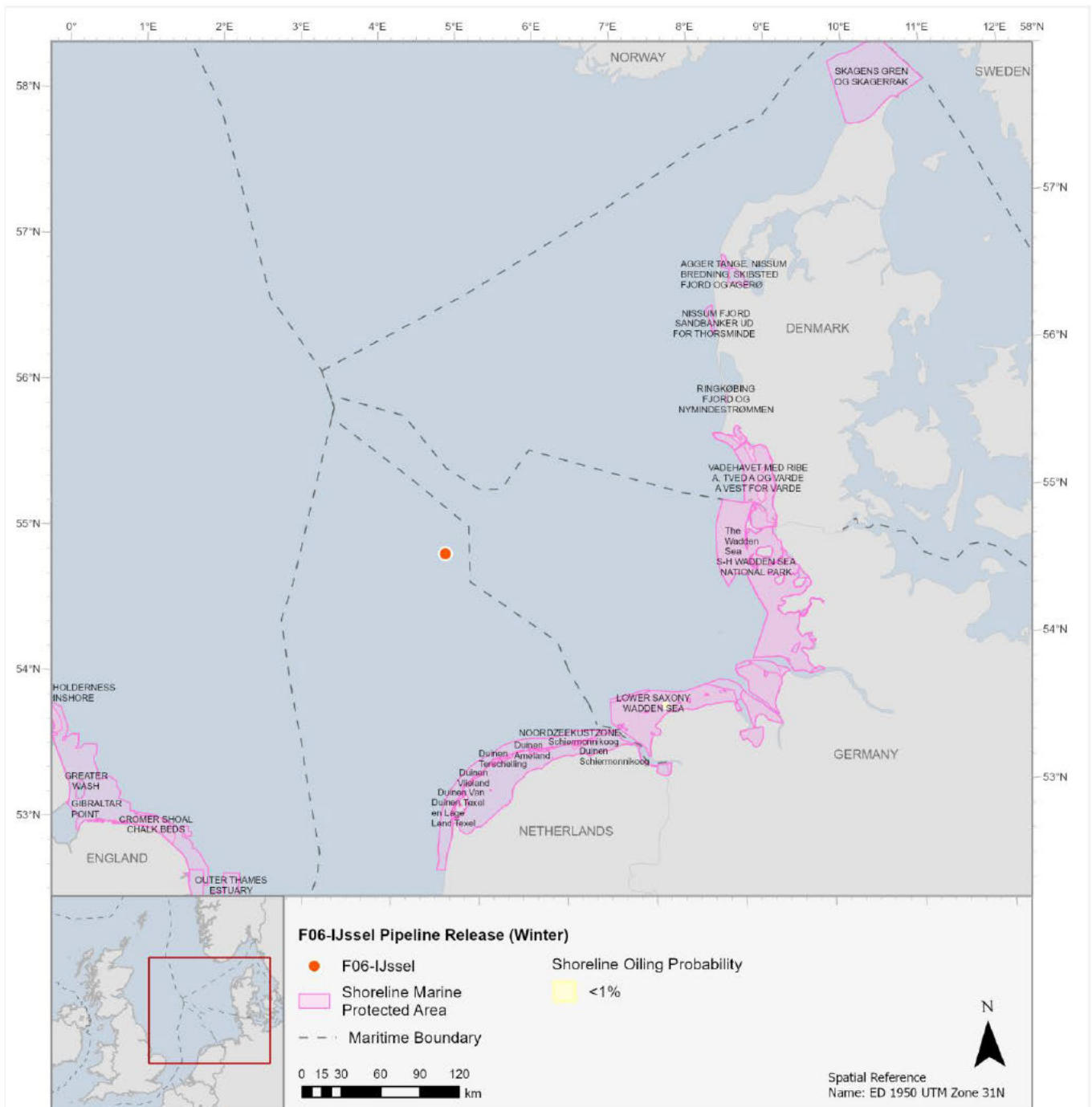


The picture does not depict the real extent of the spill; instead, it provides a statistical representation employed for risk assessment, drawing from approximately 100 distinct simulated trajectories. The image shows the maximum time-averaged thickness of surface crude over all simulations.

Summary of S02 Maximum Time-averaged Emulsion Thickness

- The maximum time-averaged emulsion thickness is indicated to be >200 µm (Continuous True colour).
- Areas of crude with a thickness of >200 µm (Continuous True colour) extend into German and Danish waters.
- The average thickness is predominantly between 0.3 µm and 5 µm (Rainbow colour) which is likely to reach UK and Danish waters.

4.1.7. S01 – F06-IJssel Pipeline Release Shoreline Oiling Probabilities

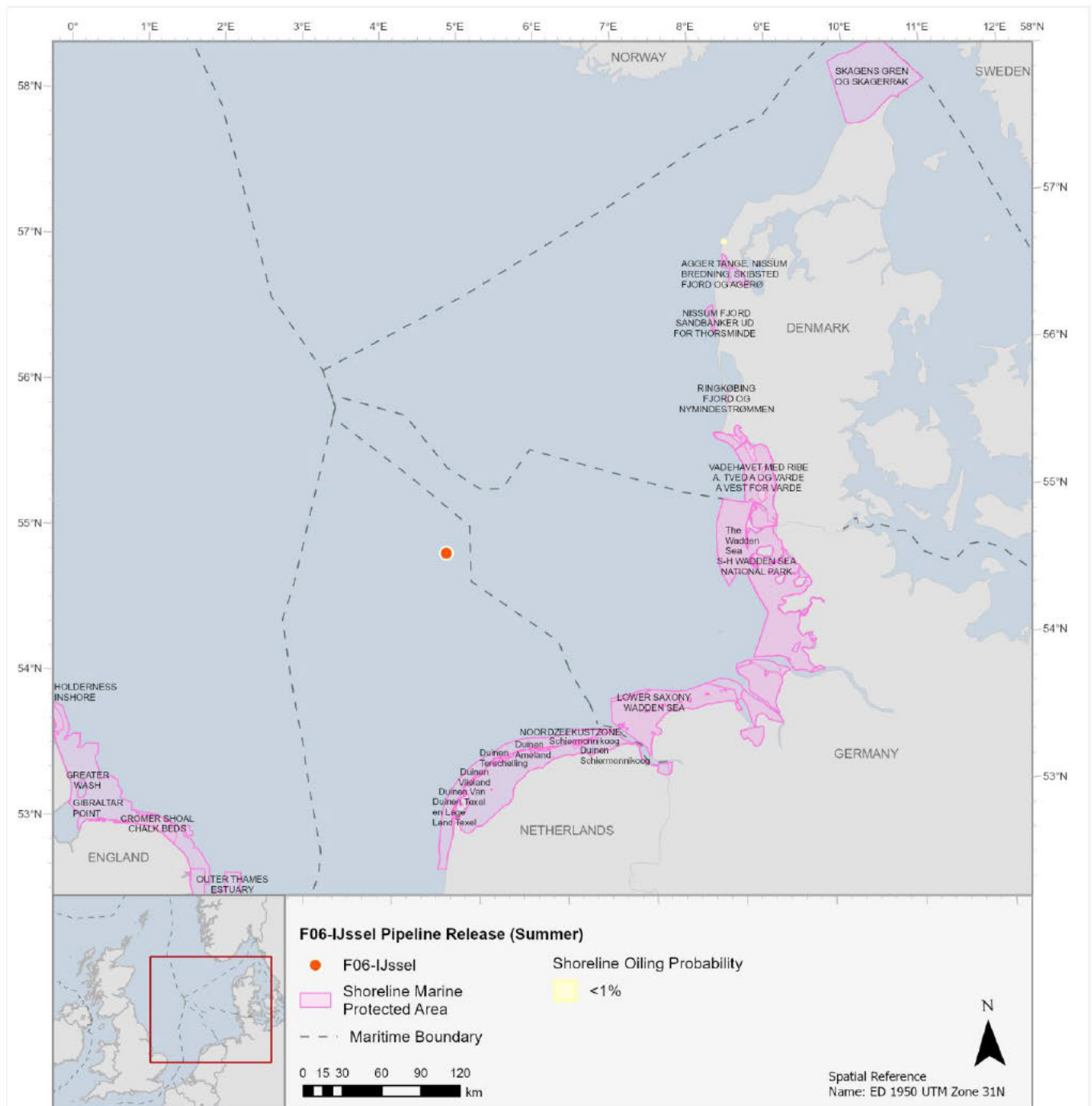


The picture does not depict the real extent of the spill; instead, it provides a statistical representation employed for risk assessment, drawing from approximately 100 distinct simulated trajectories. Oil pathways are predicted by combining all trajectories from the simulation and presented as a combined probability-density map. The plot shows the probability of shoreline oiling to <1%. No threshold set for shoreline mass accumulations onshore.

Summary of S01 Shoreline Oiling Probabilities

- The highest probability for shoreline impact is <1% along the German coastline.
- The shortest time for beaching is predicted to be 19 days.

4.1.8. S02 – F06-IJssel Pipeline Release Shoreline Oiling Probabilities

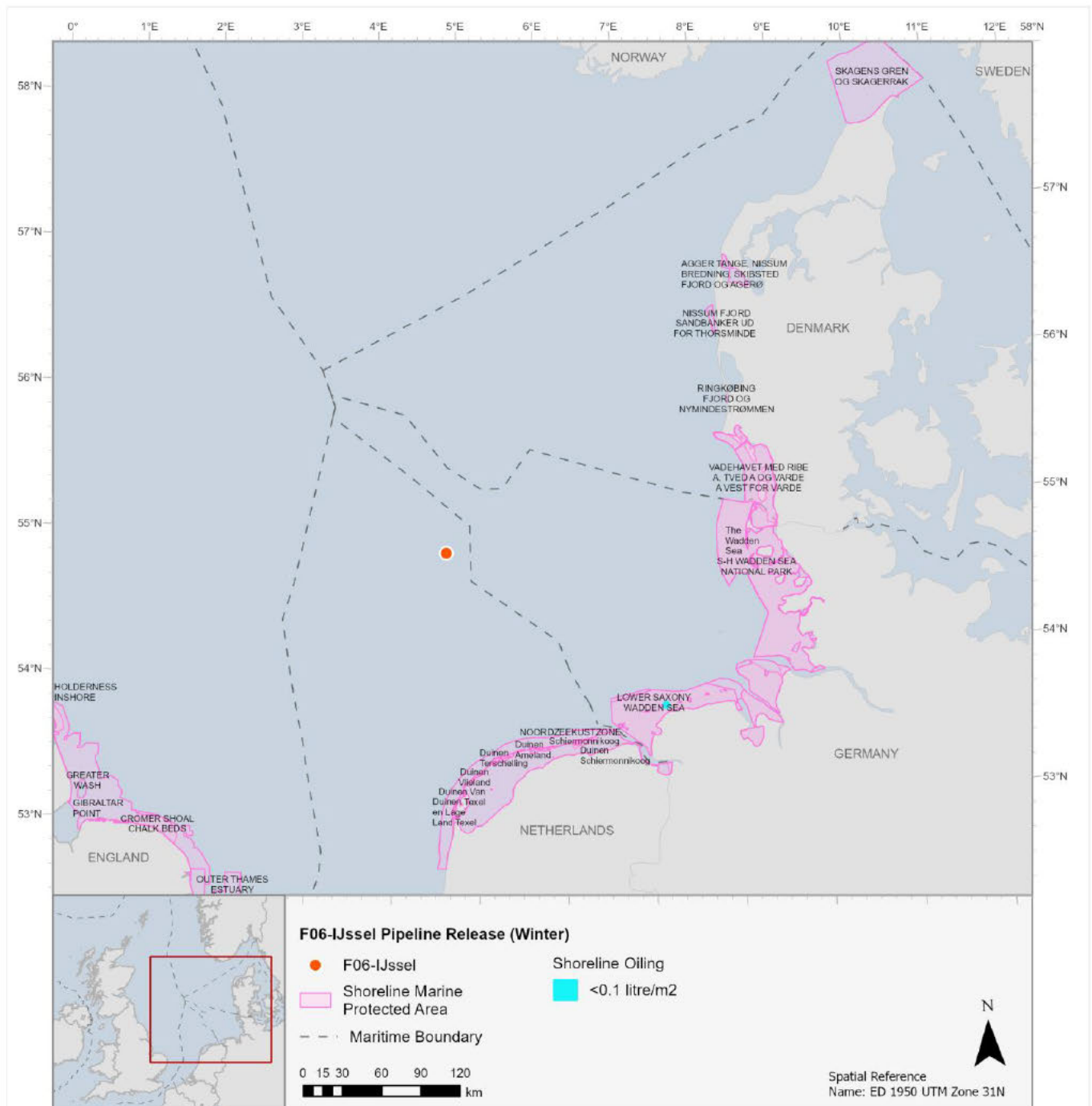


The picture does not depict the real extent of the spill; instead, it provides a statistical representation employed for risk assessment, drawing from approximately 100 distinct simulated trajectories. Oil pathways are predicted by combining all trajectories from the simulation and presented as a combined probability-density map. The plot shows the probability of shoreline oiling to <1%. No threshold set for shoreline mass accumulations onshore.

Summary of S02 Shoreline Oiling Probabilities

- The highest probability for shoreline impact is <1% along the Danish coastline.
- The shortest time for beaching is predicted to be within 16 days.

4.1.9. S01 – F06-IJssel Pipeline Release Extent of Shoreline Oiling

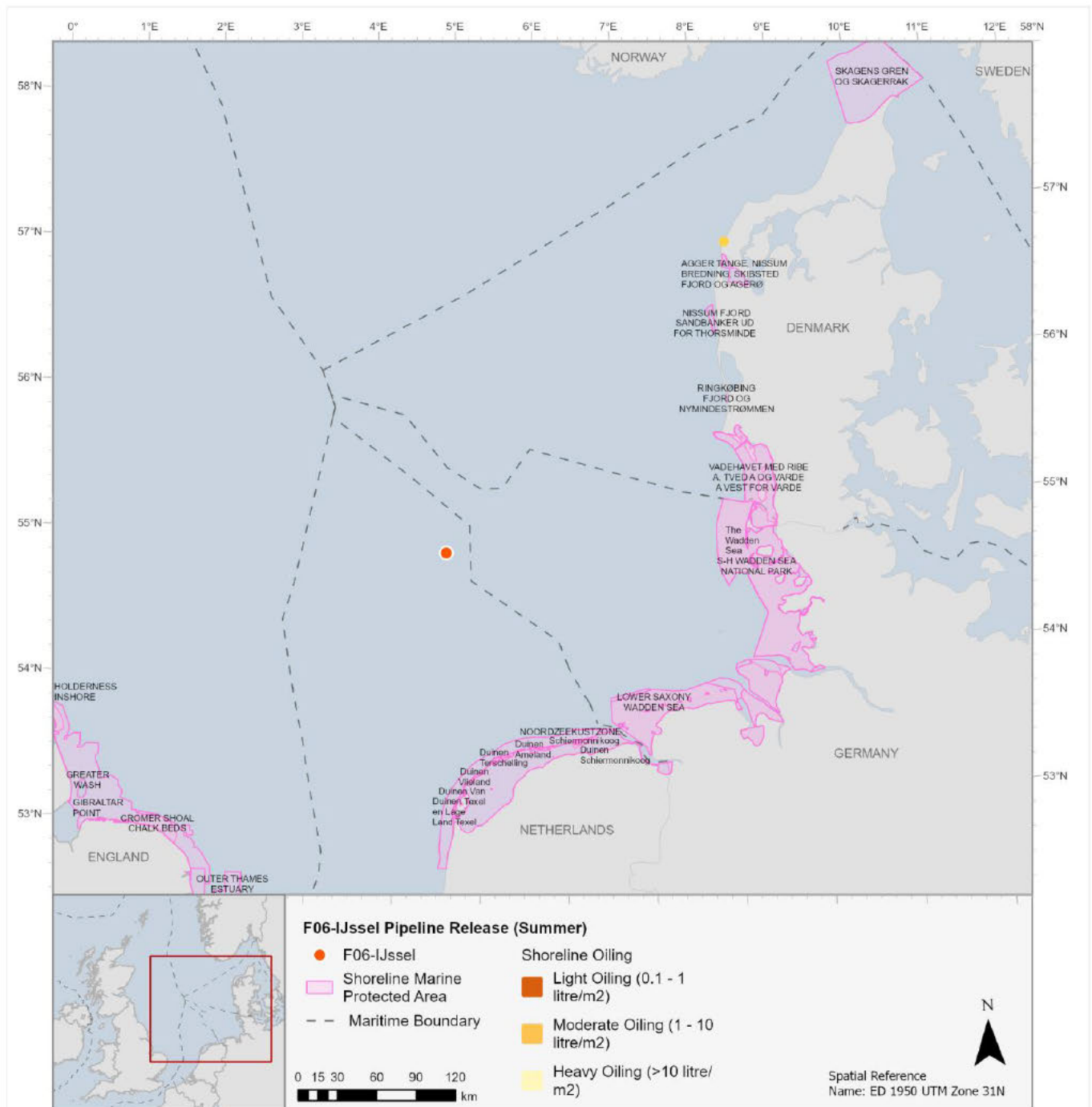


The image DOES NOT SHOW the actual footprint of a spill, they present a statistical picture used for assessing risk, based on circa 100 independently simulated trajectories. Oil pathways are predicted by combining all trajectories from the simulation and presented as a combined density map. The plot shows the extent of oiling.

Summary of S01 Shoreline Impact

- A small area of oiling <0.1 litre/m² is predicted along the German coastline.

4.1.10. S02 – F06-IJssel Pipeline Release Extent of Shoreline Oiling



The image DOES NOT SHOW the actual footprint of a spill, they present a statistical picture used for assessing risk, based on circa 100 independently simulated trajectories. Oil pathways are predicted by combining all trajectories from the simulation and presented as a combined density map. The plot shows the extent of oiling.

Summary of S02 Shoreline Impact

- A small area of Moderate oiling (0.1 - 1 litre/m²) is shown to affect the Danish coastline.

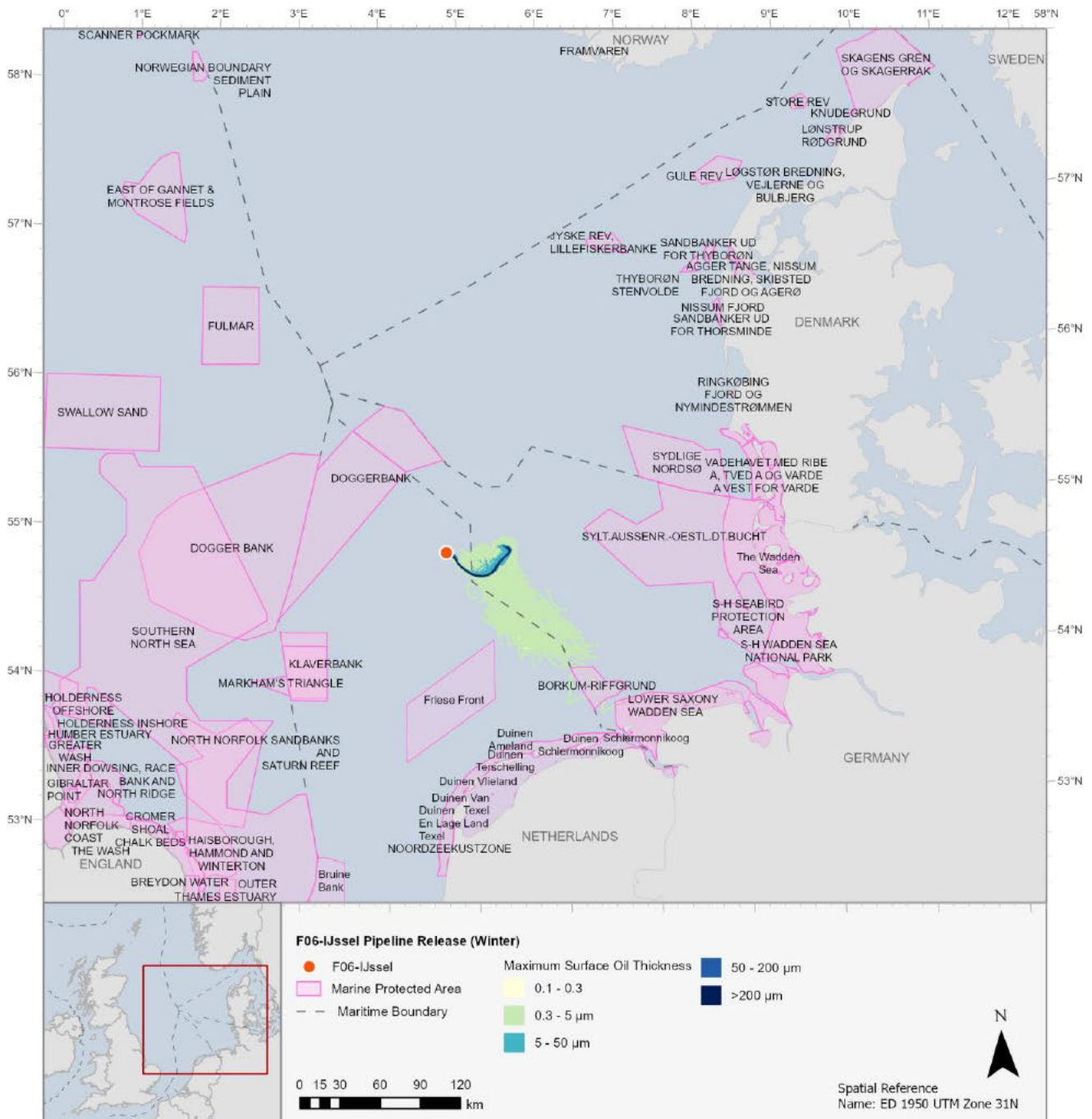
4.2. Summary of Shoreline Oiling Stochastic Outputs

Sensitivity	Shoreline Oiling Probability		Extent of Oiling	
	Summer	Winter	Summer	Winter
Germany				
Lower Saxony Wadden Sea	No oiling	<1 %	N/A	Oiling amount is less than the Light oiling threshold of 0.1 litres/m2

4.3. D01 - DETERMINISTIC OUTPUT

4.3.1. D01 – Surface Impacted Area

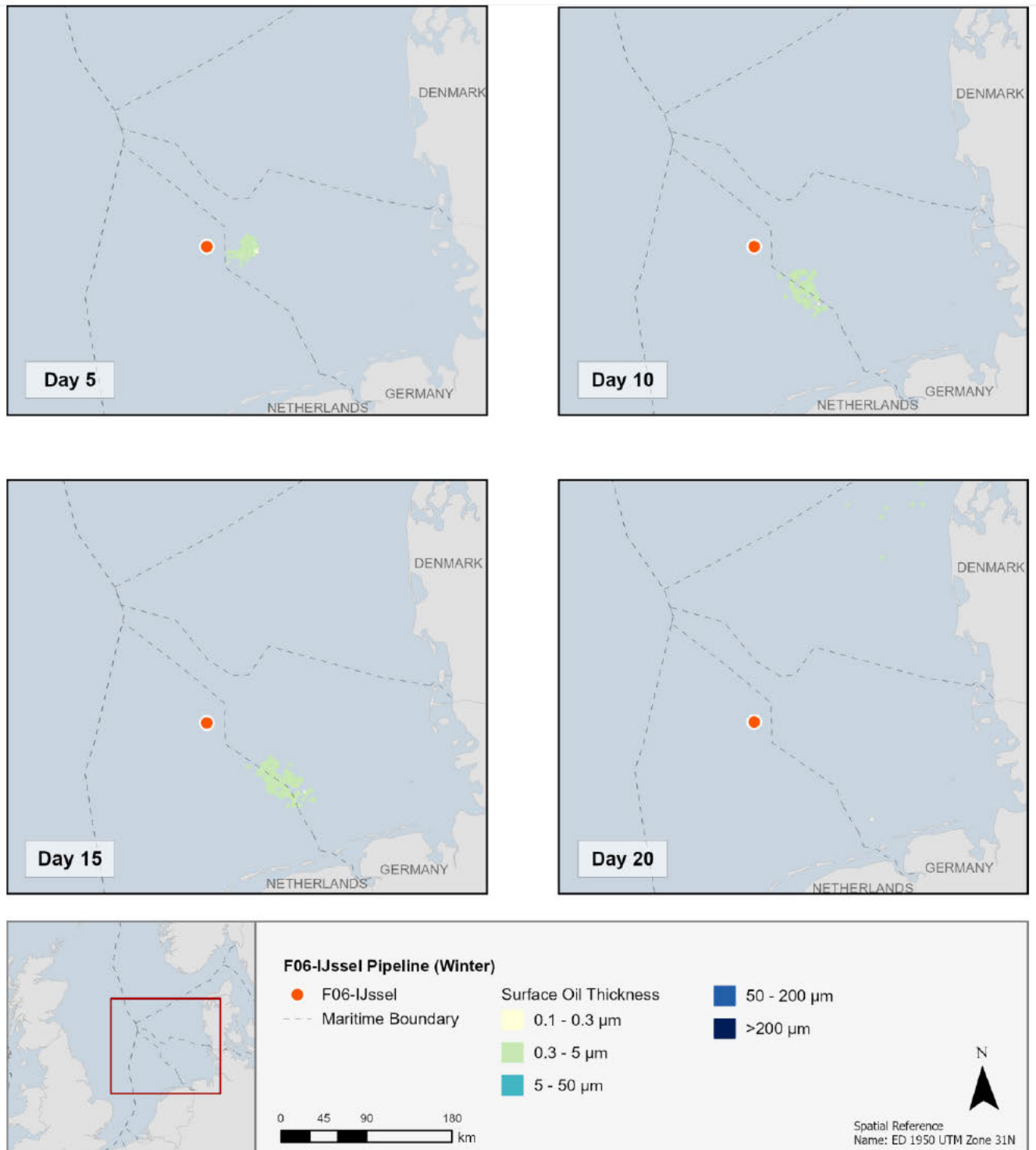
D01 – Surface Oil Impacted Area Map over 20 days



Summary of Surface Impact

- The image does not depict the specific size of the release at a single point; instead, it highlights the probable locations of the thickest crude throughout the 20-day scenario.
- Crude with a thickness of >200 µm (Continuous True colour) is indicated cross into German waters.
- Crude with a thickness of 0.3 – 5 µm (Rainbow) extends circa 170 km.

4.3.2. D01 – Surface Oiling Over Time



Surface Oiling Over Time Summary

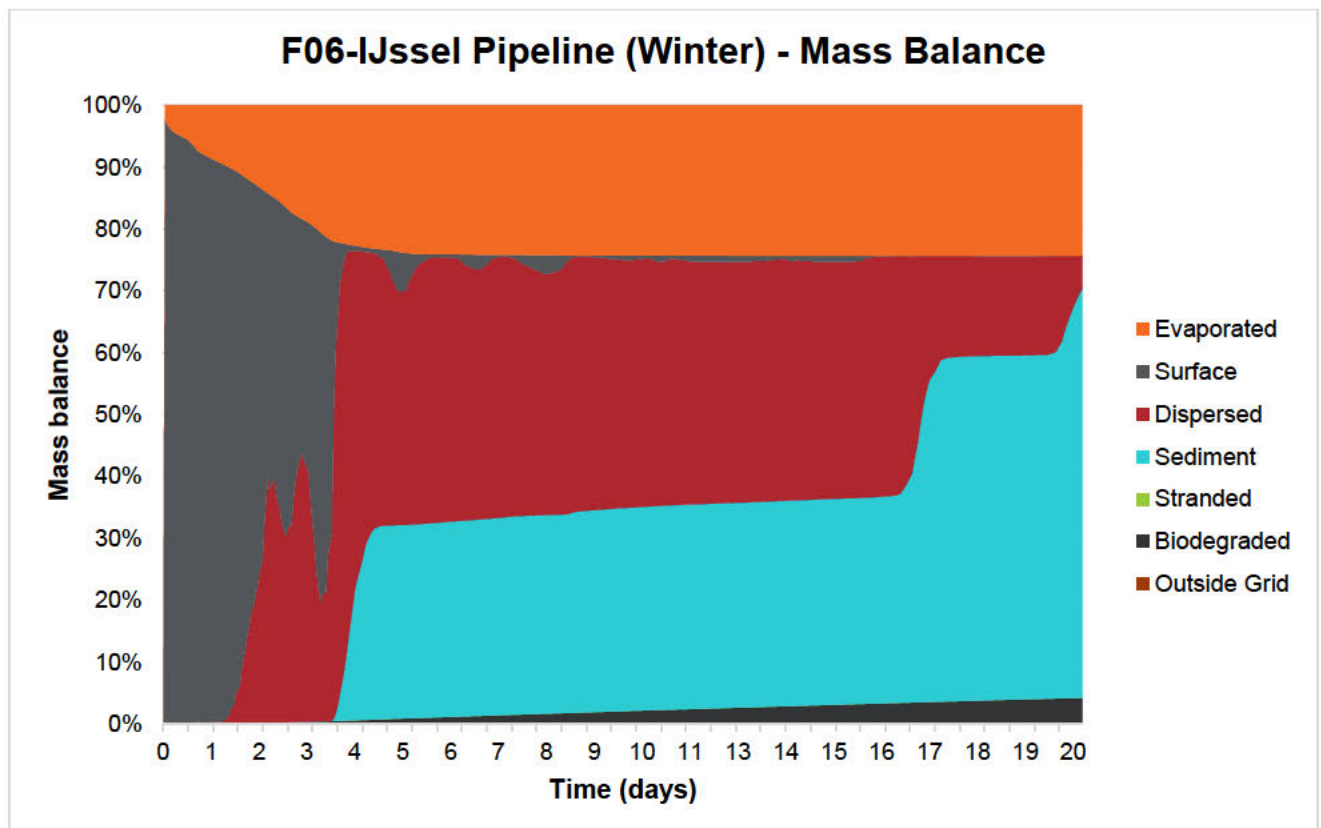
- The above series of images display surface oiling at various timeframes during the 20-day release.
- By day 20, surface oil has reduced to small, isolated areas of 'Sheen' appearance.

4.3.3. D01- Fate of Crude after 20 days

Fate	Value (mt)	Percentage (%)
Surface	0.08	0.0
Atmosphere	182.5	24.3
Water Column	39.1	5.2
Sediments	496.7	66.2
Stranded	0	0.0
Biodegraded	31.65	4.2
Outside Gridded area	0	0
Total length of coastline oiled (km)	0	
Maximum crude ashore (mt)	N/A – oil was not predicted to beach within the 20-day model	

4.3.4. D01 - Mass Balance

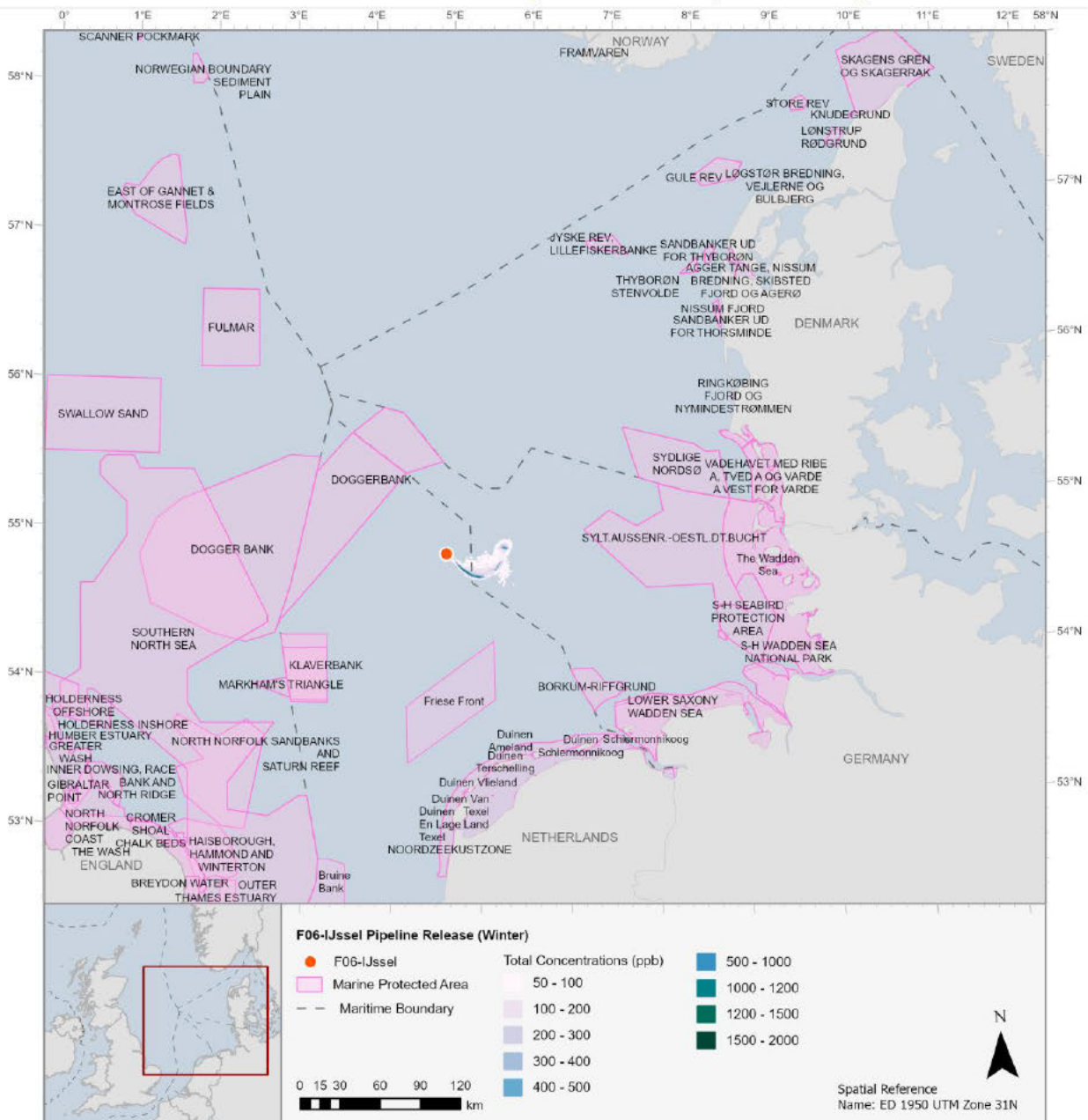
Graph shows the fate of the crude release over time.



By day 20, 0 % of the hydrocarbon remains on the surface, 24.3% has evaporated, 5.2% has dispersed into the water column, 66.2% has deposited on the sediment and 4.2% has biodegraded, 0% has stranded (beached).

4.3.5. D01 - Total Water Column Concentrations

D01 – Total Water Column Concentrations Impacted Area Map over 20 days

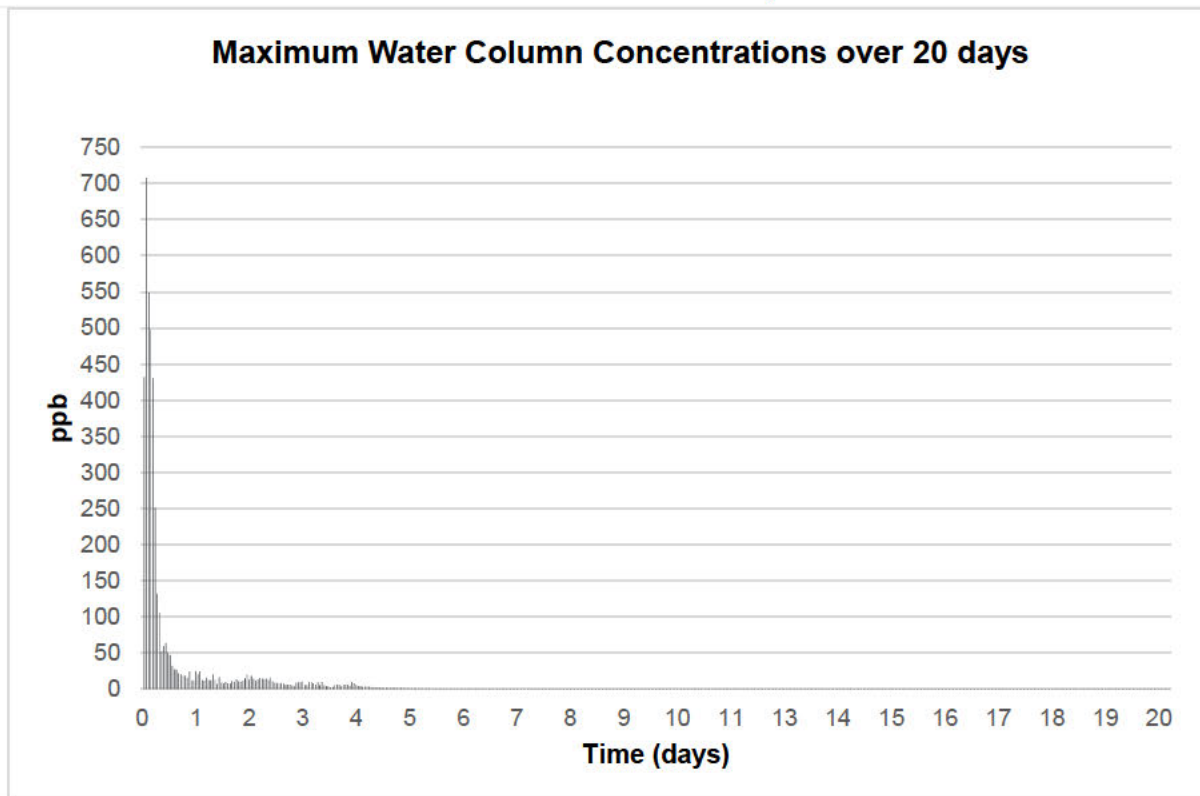


Summary of Total Water Column Concentrations

- The image DOES NOT SHOW the size of the release at any one point. The image illustrates the total concentrations (both dissolved and droplets) likely to be present in the water column across the 20-day scenario.
- The highest total concentration is not predicted to exceed 2,000 ppb.
- Water column concentrations of liquid particles remain below 50 ppb throughout the 20 day scenario.

4.3.6. D01 – Maximum Water Column Concentrations Over Time

D02 - Maximum Water Column Concentrations over 20 days

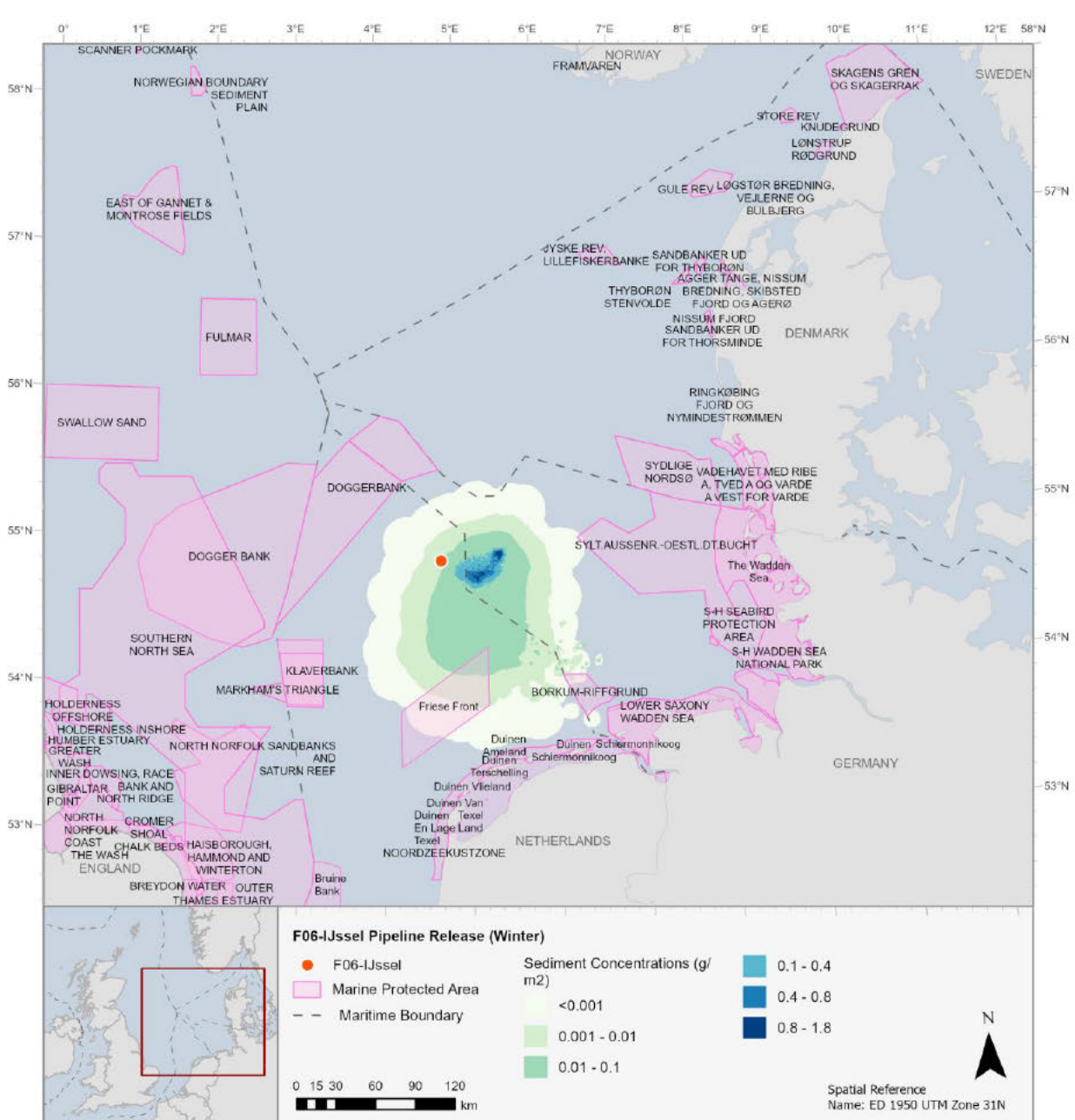


Summary of Water Column Concentrations

- During day 1 of the release, water column concentrations of liquid particles drop below 50 ppb and remain below 50 ppb throughout the 20 day scenario.

4.3.7. D01 - Sediment Concentrations

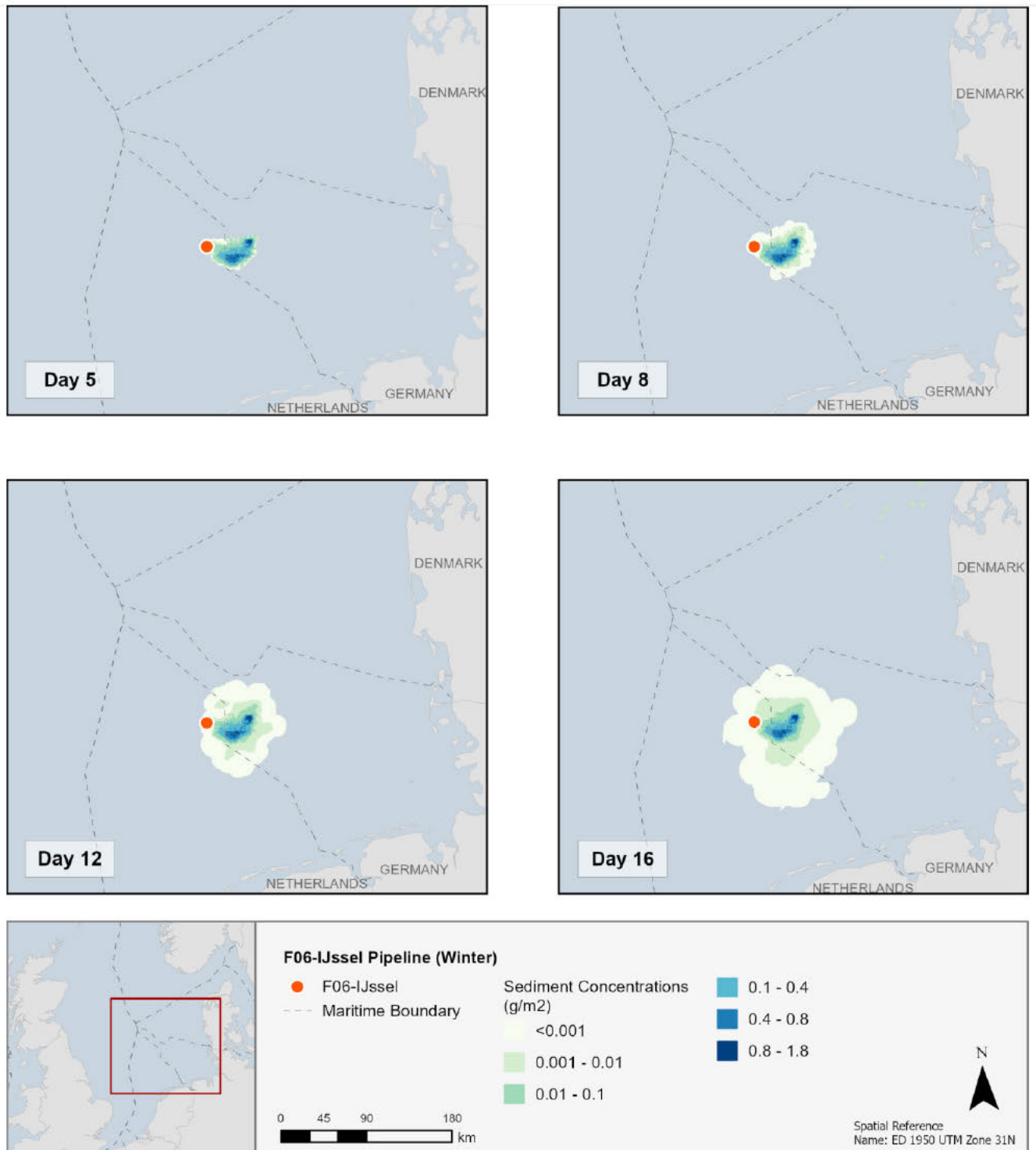
D01 – Sediment concentrations after 20 days



Summary of Sediment Concentrations

- The image shows the extent of sediment concentrations at day 20.
- The highest concentrations of up to 1.8 g/m² extend into German waters.

4.3.8. D01 – Sediment Concentrations Over Time



Sediment Concentrations Over Time Summary

- The following series of images display sediment concentrations at various timeframes during the 20-day release.

4.3.9. D01 - Shoreline Oiling

D01 –Shoreline oiling concentrations after 20 days

Shoreline oiling was not predicted by the model.

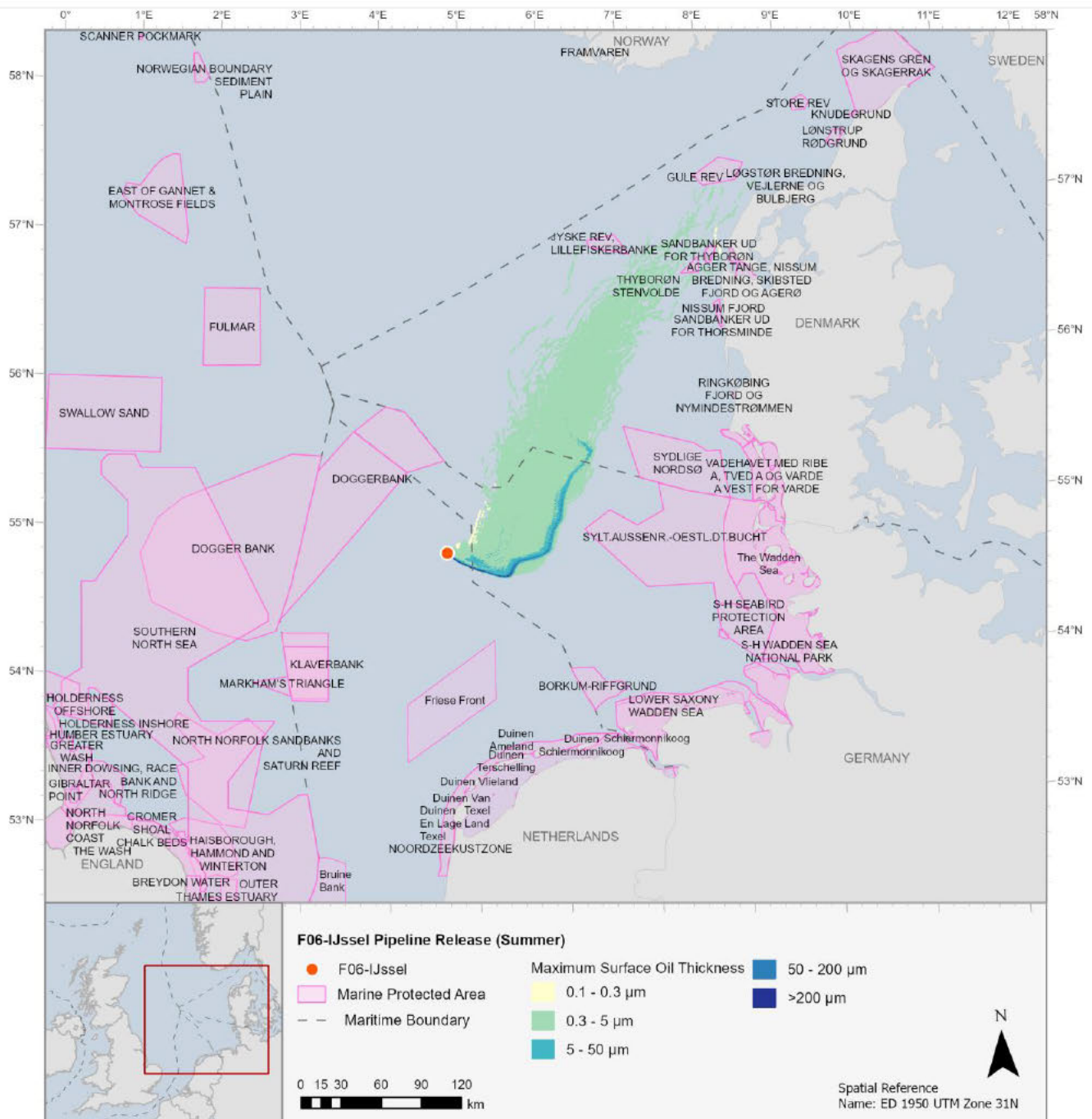
4.3.10. D01 - Impacted Shoreline Environmental Sensitivities

The model did not predict the oiling of environmentally sensitive shoreline areas during the 20-day release.

4.4. D02 - DETERMINISTIC OUTPUT

4.4.1. Release D02 – Surface Impacted Area

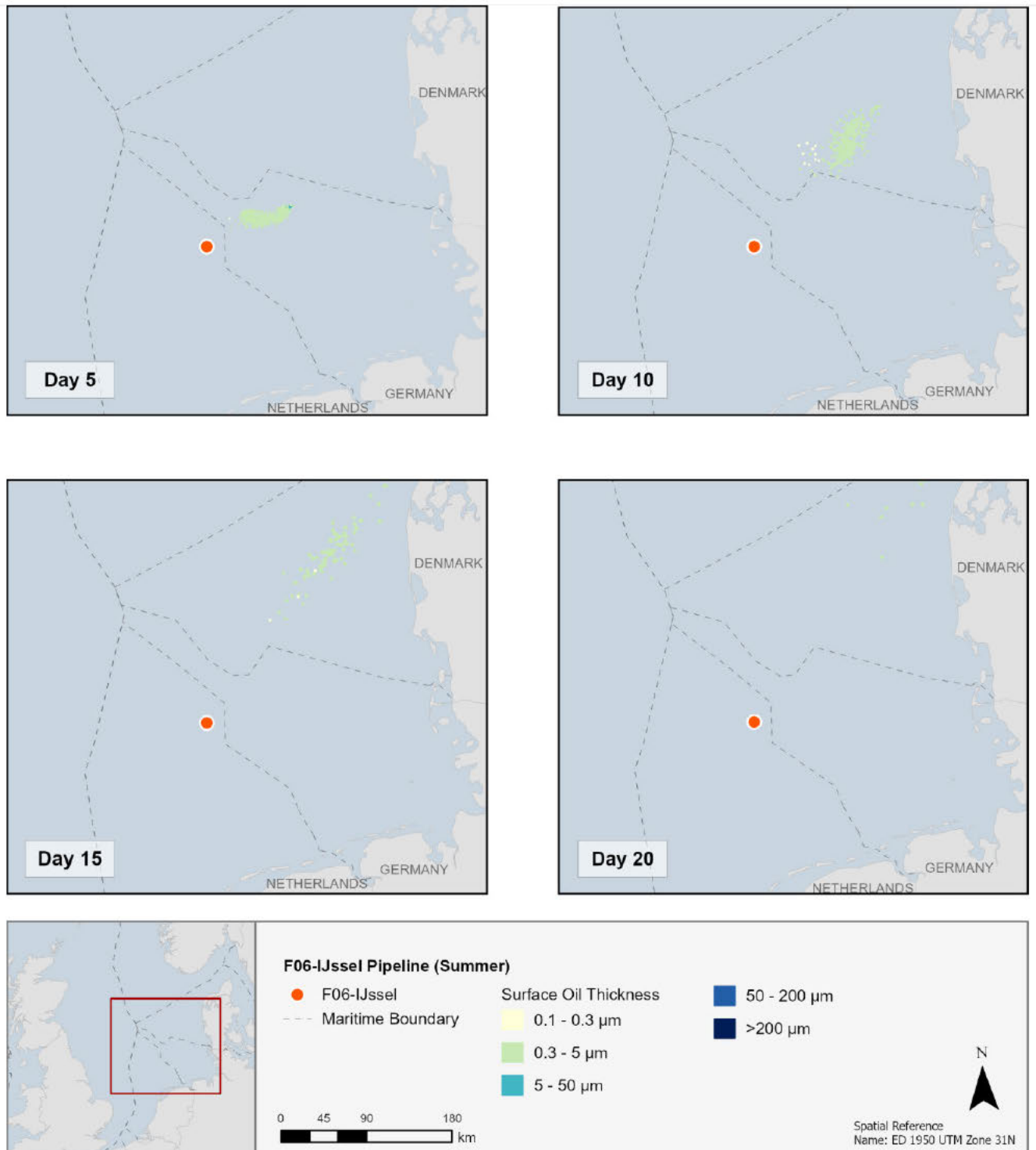
D02 – Surface Oil Impacted Area Map over 20 days



Summary of Surface Impact

- The image does not depict the specific size of the release at a single point; instead, it highlights the probable locations of the thickest crude throughout the 20-day scenario.
- Crude with a thickness of >200 μm (Continuous True colour) is indicated to remain at sea and extend into German waters.
- Oil between 50 - 200 μm (Discontinuous True colour) extend into Danish waters.

4.4.2. D02 – Surface Oiling Over Time



Surface Oiling Over Time Summary

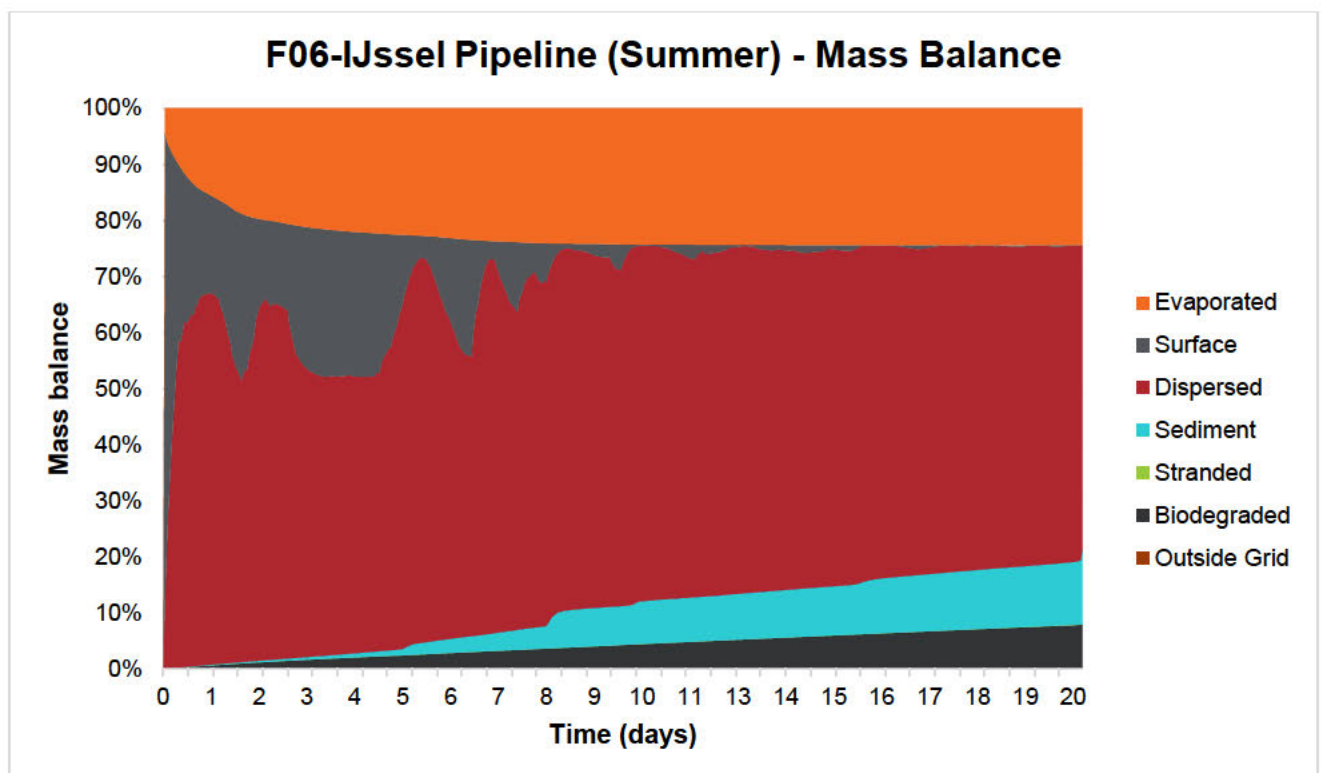
- The above series of images display surface oiling at various timeframes during the 20-day release.
- By day 20, surface oil has reduced to small, isolated areas of 'Rainbow' appearance.

4.4.3. D02 - Fate of Crude after 20 days

Fate	Value (mt)	Percentage (%)
Surface	0.77	0.1
Atmosphere	183.4	24.5
Water Column	405	54.0
Sediments	101.7	13.6
Stranded	0.08	0.0
Biodegraded	59.0	7.9
Outside Gridded area	0	0.0
Total length of coastline oiled (km)	0	
Maximum crude ashore (mt)	0.08 (day 17)	

4.4.4. D02 - Mass Balance

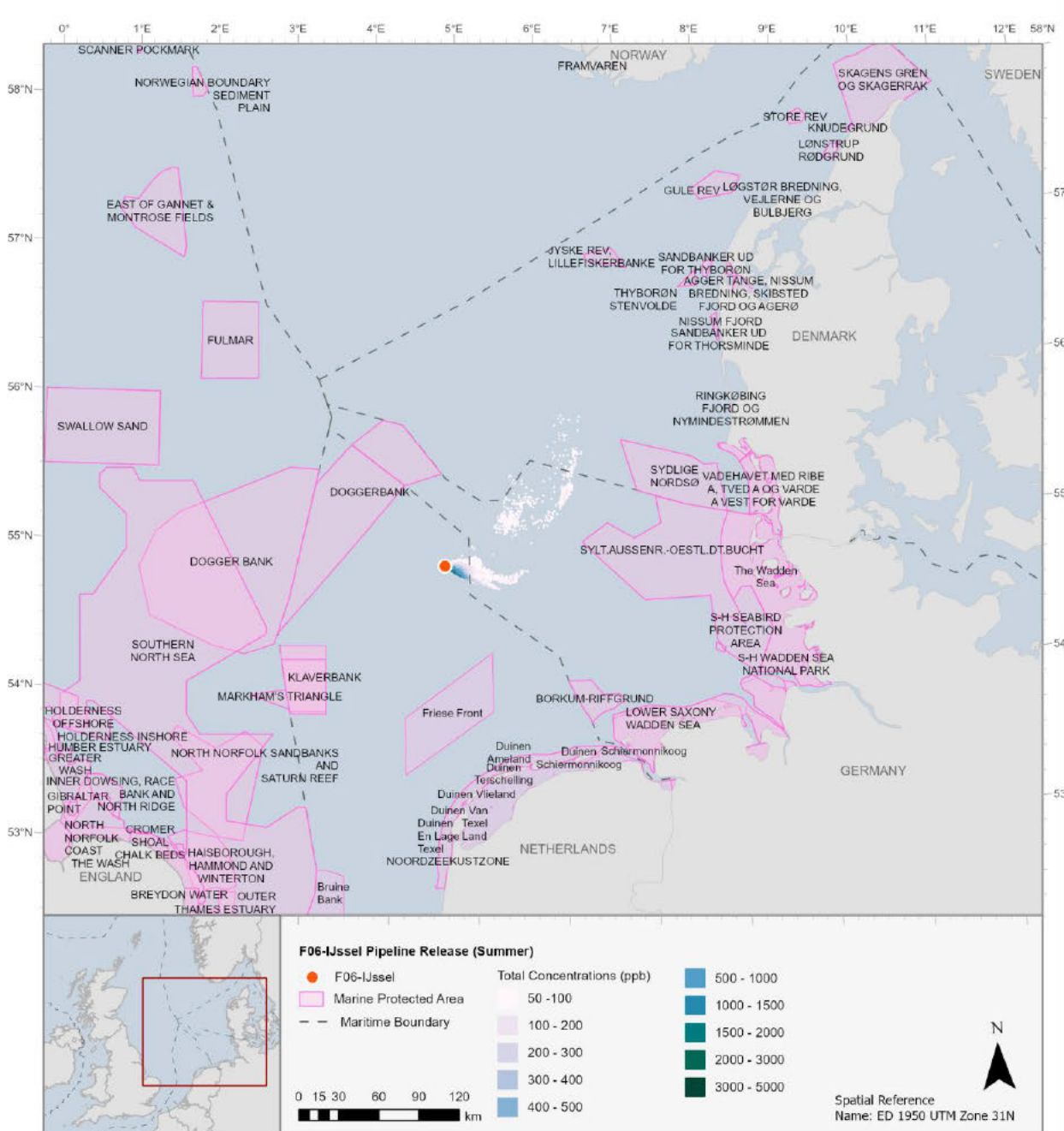
Graph shows the fate of the crude release over time.



By day 20, 0.1% of the hydrocarbon remains on the surface, 24.5% has evaporated, 54.0% has dispersed into the water column, 13.6% has deposited on the sediment and 7.9% has biodegraded, 0.0% has stranded (beached).

4.4.5. D02 - Total Water Column Concentrations

D02 - Total Water Column Concentrations Impacted Area Map over 20 days

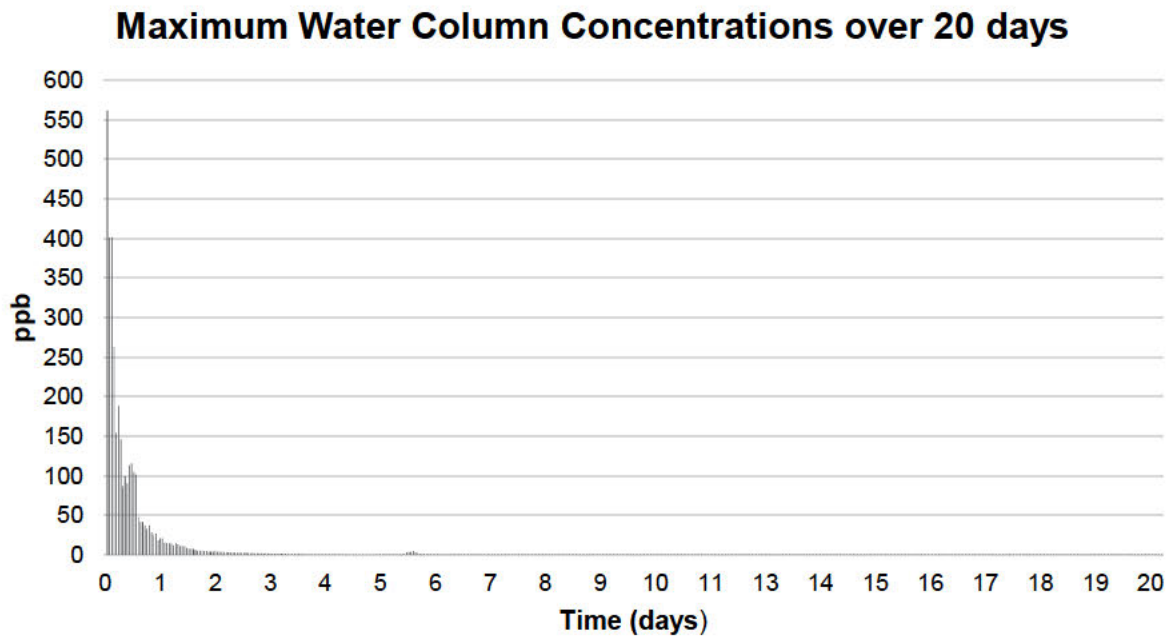


Summary of Total Water Column Concentrations

- The image DOES NOT SHOW the size of the release at any one point. The image illustrates the total concentrations (both dissolved and droplets) likely to be present in the water column across the 20-day scenario.
- The highest total concentration is not predicted to exceed 5,000 ppb.
- Water column concentrations of liquid particles remain below 50 ppb throughout the 20 day scenario.

4.4.6. D01 – Maximum Water Column Concentrations Over Time

D02 - Maximum Water Column Concentrations over 20 days

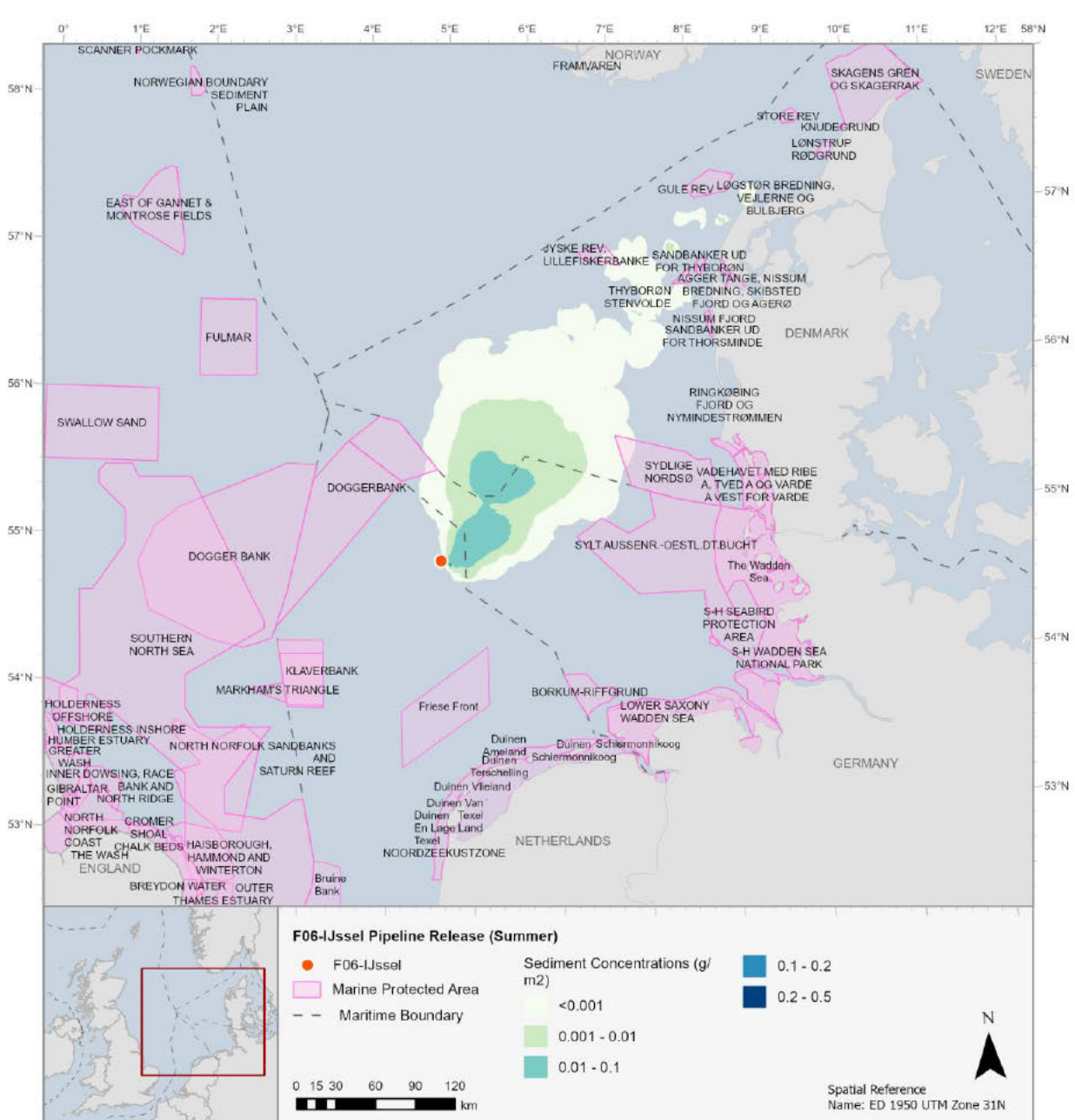


Summary of Water Column Concentrations

- During day 1 of the release, water column concentrations of liquid particles drop below 50 ppb and remain below 50 ppb throughout the 20 day scenario.

4.4.7. D02 - Sediment Concentrations

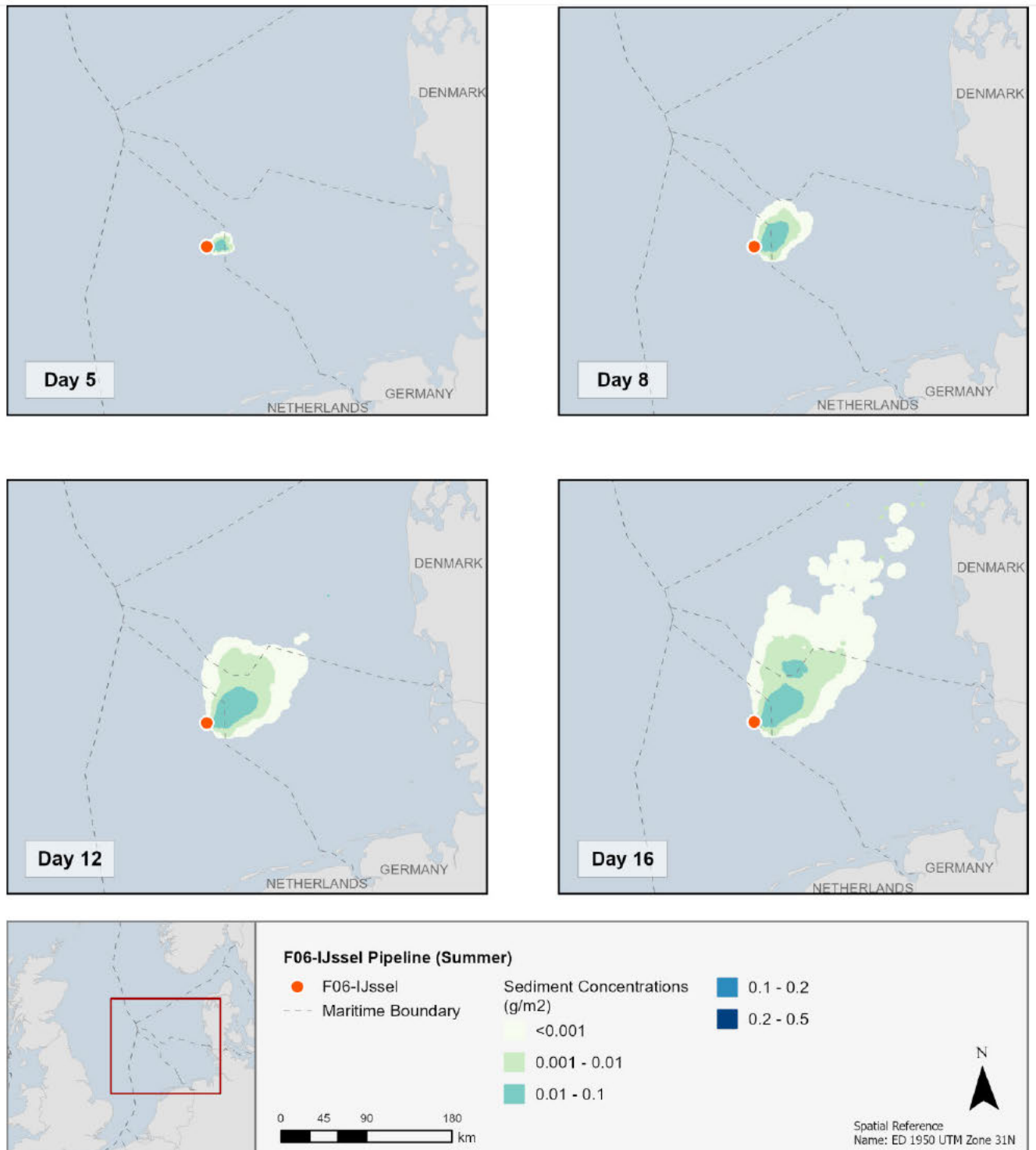
D02 – Sediment concentrations after 20 days



Summary of Sediment Concentrations

- The image shows the extent of sediment concentrations at day 20.
- The highest concentration is predicted not to exceed 0.5 g/m².
- The highest concentrations are predominately around the release site, with concentrations of up to 0.1 g/m² extending into German and Danish waters.

4.4.8. D02 – Sediment Concentrations Over Time

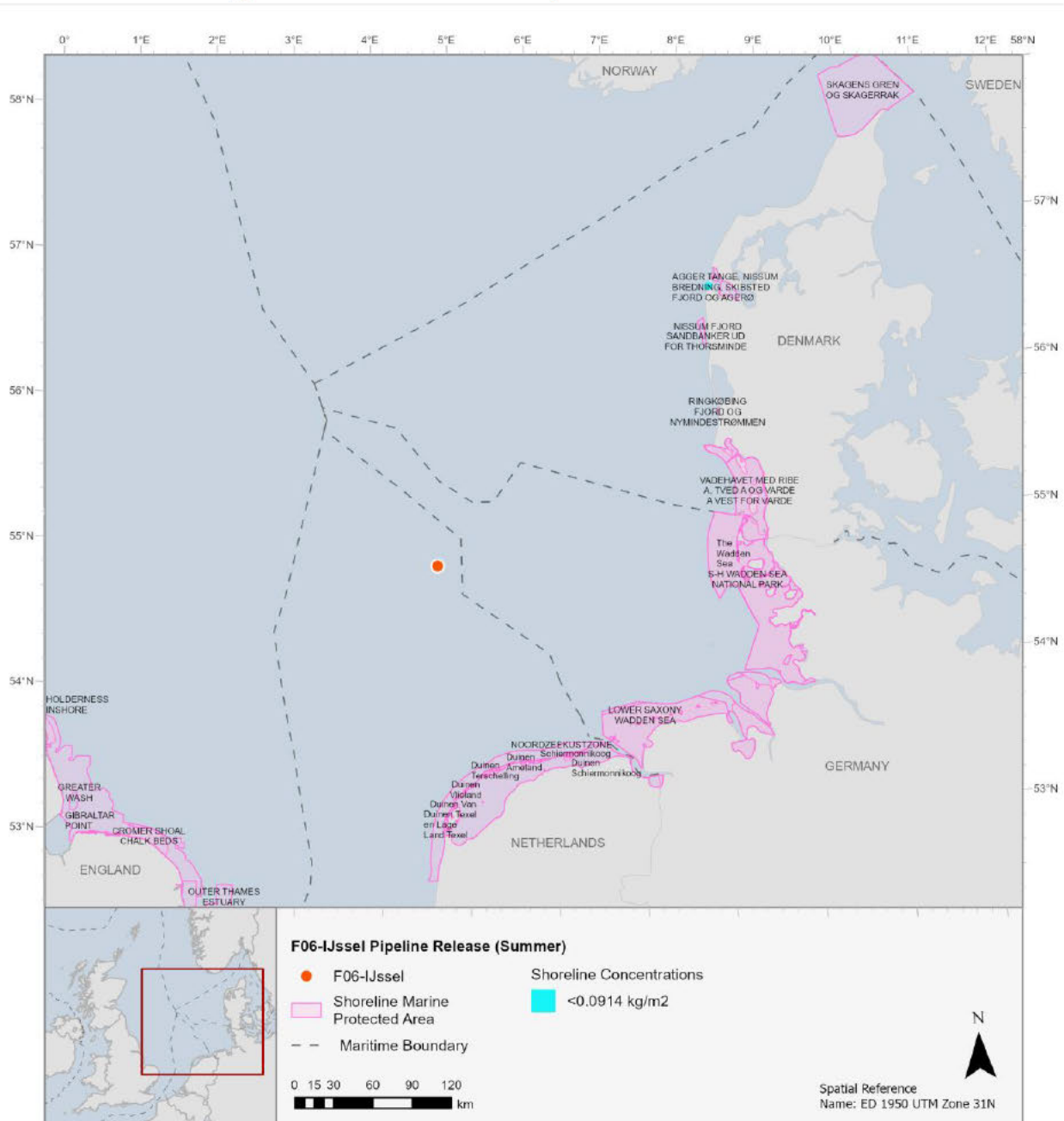


Sediment Concentrations Over Time Summary

- The following series of images display sediment concentrations at various timeframes during the 20-day release.

4.4.9. D02 - Shoreline Oiling

D02 –Shoreline oiling concentrations after 20 days



Summary of Shoreline Concentrations

- The image shows shoreline concentrations at day-20. The highest concentration is predicted to impact the Danish coastline.
- The total mass of oil beaching in this scenario is 0.08 tonnes

4.4.10. D02 - Impacted Shoreline Environmental Sensitivities

Sensitivity	Extent of Oiling
Denmark	
Agger Tange, Nissum Bredning, Skibsted Fjord Og Agerø	Oiling amount is less than the Light oiling threshold of 0.1 litres/m ²

5.0 RESULTS SUMMARY

The most effective means of identifying the risks is to view OSCAR's outputs concurrently. These include:

- Probability of impact
- Scale / extent of impact.

Probability of Impact

- The highest probability of surface oiling $\geq 0.1 \mu\text{m}$ is up to 90-100% (see S01 / S02 Sections 4.1.1 and 4.1.2).
- Maximum exposure time of surface crude in the immediate vicinity of the release site is indicated as 4 to 5 days (see S01 / S02 Sections 4.1.3 and 4.1.4). The exposure time reduces to ≤ 2 day beyond a radius of approximately 100 - 150 km from the release site.
- Maximum time-averaged emulsion thickness of surface oiling is indicated to be $>200 \mu\text{m}$ – equivalent of 'Continuous True colour' in appearance (see S01 / S02 Sections 4.1.5 and 4.1.6).
- The highest probability of shoreline impact along the German coastline is predicted to be $<1\%$ (see D02 Section 4.1.7).
- The highest probability of shoreline impact along the Danish coastline is predicted to be $<1\%$. (see D02 Section 4.1.8).

Water column Concentrations

- Total concentrations in the water column reach up to 5000 ppb. (see D02 Section 4.4.5).
- The maximum concentration of liquid particles remain predominantly below 50 ppb. (see D01 Section 4.3.6 and D02 Section 4.4.6).

Sediment Concentrations

- The highest concentration is predicted not to exceed 1.8 g/m^2 . (see D01 Section 4.3.7).

Shoreline Impact

- Section 4.2 provides a summary of the probability and extent of oiling affecting sensitive areas.
- In the winter release scenario outlined in D01 Section 4.3.9, shoreline oiling is not predicted.
- In the summer release scenario outlined in D02 Section 4.4.9, a small amount of oil is predicted to reach the Danish coastline.

6.0 REFERENCES

Lewis, A. (2013, January 2007). *BONN Agreement*. Retrieved July 2013, from <http://www.bonnagreement.org/eng/doc/Microsoft%20Word%20-%20CURRENT%20STATUS%20report%20final%2019Jan07.pdf>

O'Hara, P., & Morandin, L. (2010). *Effects of Sheens Associated with Offshore Oil and Gas Development on the Feather Microstructure of Pelagic Seabirds*.

Reed, M. A. (1996). *Calibration and testing of IKU's oil spill contingency and response (OSCAR) model system*.

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