EMODnet North Sea Checkpoint

EMODNET Oil Platform Leak Bulletin

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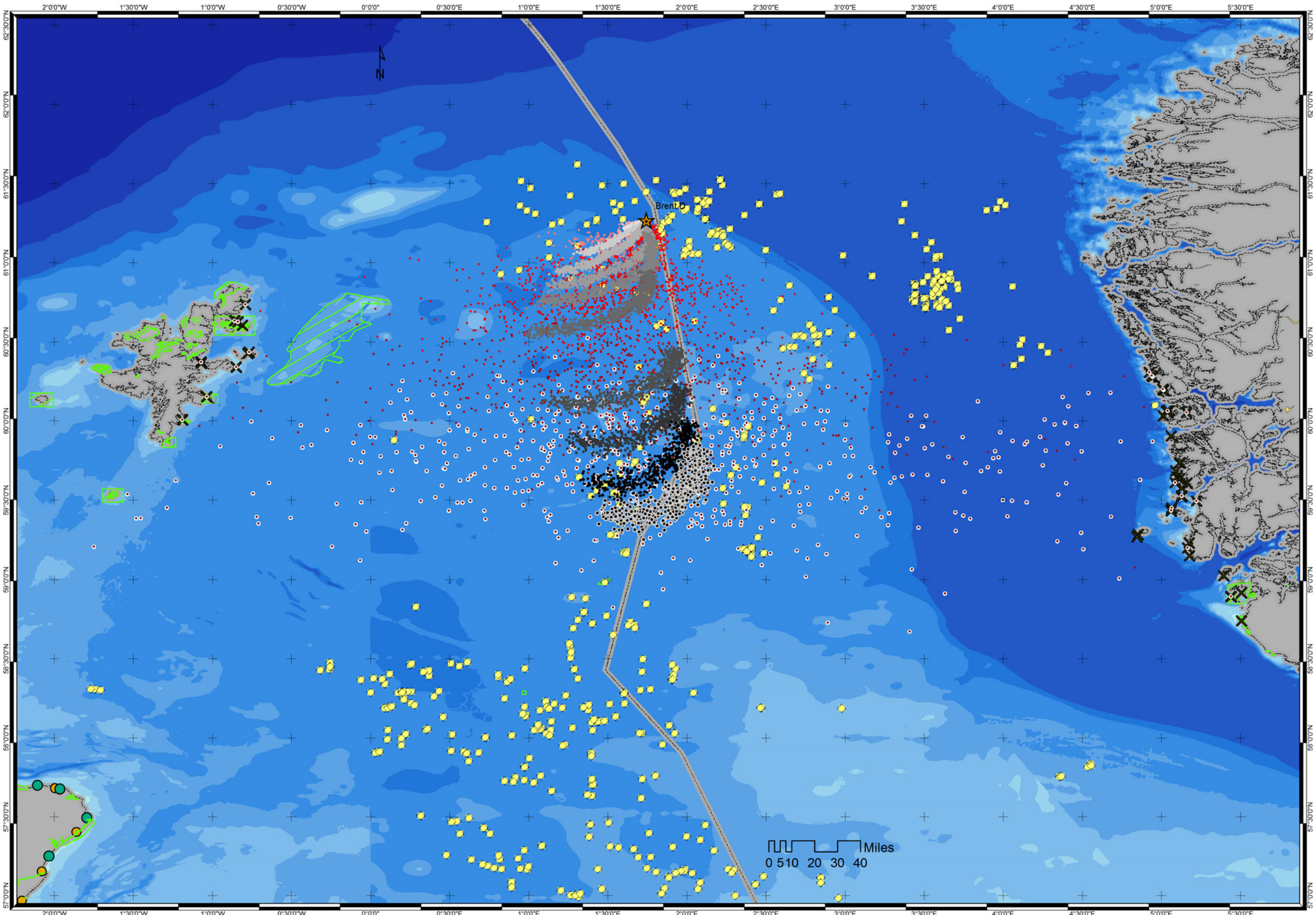
European Commission

Executive Summary

An "Oil Platform leak" challenge was performed by IMARES with the objective to test the adequacy of data currently available for the North Sea basin for impact assessment of an oil spill as part of emergency response. On Tuesday, May 10, 2016 11:24 AM, we received an email from DG MARE with the notification that about 5000m3 of oil per day leaked from the Brent Delta Platform with an expected duration of 48 hours. A preliminary report on the potential impact was delivered 24h after the spill, followed by a 48h summary update. This document is a refined impact assessment, provided within 72 hours after the spill.

Based on oil spill simulation modelling it is predicted that, 132 hours after the spill, 42% is evaporated and dispersed, and 58% remains floating on the sea. As a worst case, 4% (400 m^3) of the total amount of spilled oil could beach, posing a threat to coastal habitat/species in the UK and Norway, as indicated by the crosses (beached oil) in the figure below. Main identified gaps limiting this refined assessment are: Tourist beaches (especially the locations of tourist beaches at the Shetlands); Shipping lanes; Fisheries activity on a time scale shorter than a whole year; Distribution data of birds and sea mammals, and possibly other biological distribution data.. These issues will be addressed within the main data adequacy report.



Overview of the impacted location after the Brent Delta spill according to the best guess and no regret simulation.

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1. Introduction

This document is part of a project for the European Commission Directorate-General for Maritime Affairs and Fisheries (DG MARE): “Growth and innovation and ocean economy – gaps and priorities in sea basin observation and data”. The objective of the project is to "examine the data collection, observation and data assembly programmes in a sea basin, analyse how they can be optimised and deliver the findings to stakeholders through an internet portal". It covers the Greater North Sea, including the Kattegat and the English Channel. As part of this project, a series of challenges are undertaken, designed to test the adequacy of data currently available for the North Sea basin across a range of applications. This report is part of “Challenge 3: Oil Platform leak” (work package 4). The objective of this challenge is to test the adequacy of data currently available for the North Sea basin for impact assessment of an oil spill as part of emergency response.

The challenge will deliver:

- A preliminary assessment, providing a document within 24 hours describing a first indication of impact. The executive summary of the preliminary assessment is provided in Annex 1 . This assessment was followed by a 48h summary update (Annex 2);
- Complete impact assessment, providing a document within 72 hours describing a refined impact assessment (underlying document);
- Main assessment, providing an understanding of whether suitable datasets are available to provide input for emergency response to pollution incidents, including limitations of severe time pressures.

The main goal of this refined impact assessment is to:

- Acquire predicted weather patterns (mainly wind fields) to improve the accuracy of the predicted trajectory of the oil slick;
- Include a more detailed description of the characteristics of the predicted impacted locations (habitat or species found there etc.);
- Contact experts, depending on the characteristics of the impacted sites, to determine whether the identified risk of predicted impact have been correctly identified.

2. Challenge description

This section recites the information of the oil spill challenge which IMARES received from DG MARE.

On Tuesday, May 10, 2016 11:24 AM CET, we received an email with the following notification:

"*At 8:15 CET this morning (10/05/2016), an accident took place while dismantling the Brent Delta Platform. About 5000m3 of oil per day leaked from the platform at a depth 229ft. It is anticipated that the leak will be sealed after 48 hours.*"

Assumptions made in the formulation of a scenario

To arrive at a scenario that can be assessed with the selected model, the following assumptions were required:

- The GNOME model used, can only model spills at the sea surface. The oil spilled is relatively light and we will assume that it reaches the surface rapidly (see Annex 3).
- Brent Crude is a major trading classification of sweet light crude oil that serves as a major benchmark price for purchases of oil worldwide. This grade is described as light because of its relatively low density, and sweet because of its low sulphur content (ca. 0.37%). GNOME can only simulate a few oil types. We use the "medium crude" oil as specified in the GNOME model as this is the closest match.

Scenario description

Based upon the provided details and assumptions described above, the following scenario is formulated:

- We assume in the model scenario that the oil is released at the sea surface instantaneously at the start of the spill and at the location of the platform. For the underlying refined assessment we calculated the time for oil to reach the surface from the depth of 70 meters (see Annex 3) in order to validate this assumption. It is likely the oil will reach the surface in a matter of minutes (or hours when droplets are very small), thus the above assumption can be maintained.
- The physical structure of the Brent Delta platform was also studied, a.o. based on the Decommissioning Program (SHELL, 2015) to ascertain how a spill of this size could happen. More on this can be found in Annex 4.

3. Model description

This chapter provides the reasoning for selecting a model (section 3.1), a brief description of the model applied in the oil spill challenge (section 3.2) and the (parameter) settings used (section 3.3). Input data (and processing thereof) form an important part of the overarching aim of the project (i.e., addressing data adequacy for specific purposes). The model requires input data: to indicate where water bodies and coastlines are situated (i.e. a map, section 3.4); and to drive the movement of oil particles in the model (i.e. wind, water current and diffusion, section 3.5). Some of the model details and limitations are described in section 3.7. Section 3.8 describes the model output and section 3.9 describes the option of the GNOME model to address data uncertainty.

3.1. Model selection

There are plenty models that can be used to simulate an oil spill. Some highly sophisticated models are available for this purpose, but come with a commercial license. As for the present exercise a preference for publically available data exists, a publically available model was selected as well. MEDSLIK would qualify, but is already selected for the Mediterranean challenge. In contrast the GNOME model was selected for the North East Atlantic challenge. The main report will present a more detail analysis of available models and the selection procedure.

3.2. GNOME model

GNOME (General NOAA Operational Modeling Environment) was developed by the Emergency Response Division of NOAA's Office of Response and Restoration to predict the possible route, or trajectory, a pollutant might follow in or on a body of water, such as in an oil spill. The GNOME model is a straightforward instrument with easy to use graphical user interface. As a down-side, the nice interface does not allow for case specific modifications of the model and some predefined settings (such as oil composition) have to be used.

The model represents spilled oil as so-called Langrangian particles, where each particle reflects a certain amount of oil. The particles are simulated to move around in space, drive by wind, current and random processes. By tracing these particles, information about the oils fate can be obtained. For such a simulation GNOME requires four essential elements:

- Model settings
- Model map
- Movers
- Spill information

Each element will be discussed in separate sections.

3.3. Model settings

Model settings are overall settings that are required for the simulation to run. Essential is the start time of the simulation (usually the same as the start time of the spill), and the duration of the simulation. The duration of the simulation is limited by the availability of wind and water currents forecasts.

Also essential is the computational time step. This is the time interval between model calculation steps. For each time step, the model will calculate the new positions of the particles. Smaller time steps would increase the accuracy of the predictions, especially when conditions (currents and winds) are changeable. However, it's not very meaningful to set this time step to much smaller intervals than the interval for which wind (6 hour interval) or water currents (1 hour interval) are available. Note that the output interval can be larger than the computational time step to save storage space for the output file. The table below (Table 1) shows the settings used in the present study.

Table 1 Model settings used for the current situation

Parameter	**Value (and unit)**
Simulation start time	2016-10-05 6:15 UTC
Simulation duration	132 hours
Computational time step	0.25 hours

3.4. Model map

The GNOME model requires a map that provides information on where water bodies and coastlines are situated. The model uses this information to determine whether a particle is beached or not. Note that beaching is a reversible process in the model.

The coastline map was extracted from the Global Self-consistent, Hierarchical, High-resolution Shoreline database (GSHHS) and converted to the GNOME compatible bna-format. This process is facilitated by NOAA with the GNOME Online Oceanographic Data Server (GOODS1). To achieve sufficient cover for the study area, the downloaded extent was from 45° to 65° North and from 20° West to 20° East.

For (re-)use in GIS the bna-format was converted to GIS-dataset using a self-developed Python-script, based on the format specifications available in Zelenke *et al.* (2012b).

3.5. Movers

Movers can be considered as layers in the model that drive the movement of oil particles in the model. Wind is included as a 'mover' by specifying the northward and eastward components of the wind

[1] GNOME Online Oceanographic Data Server (GOODS) coastal subset page http://gnome.orr.noaa.gov/goods/tools/GSHHS/coast_subset

speed in a spatially gridded file for a 6 hour interval. Details on the source of the wind data and pre-processing before use in the model are described below. A similar ‘mover’ is required for the water currents. Details on the source and pre-processing of water current data are also given below.

Finally, a ‘mover’ is required that simulates random processes such as diffusion. This mover is simply added to the model by specifying a single diffusion coefficient (following Fick’s laws on diffusion). The model’s default value of $D = 2\ 10^5\ cm^2/s$ is used. This constant is used in the model in the so-called ‘random walk’ principle, which is described in detail in the GNOME technical documentation.

Water current data

Water current data are retrieved from the marine.copernicus.eu website and are based on the Forecasting Ocean Assimilation Model 7km Atlantic Margin model (FOAM AMM7). This is a coupled hydrodynamic-ecosystem model, nested in a series of one-way nests to the Met Office global ocean model. The hydrodynamics are supplied by the Nucleus for European Modelling of the Ocean (NEMO) with an Analysis Correction (AC) data assimilation scheme for sea surface temperature. This is coupled to the European Regional Seas Ecosystem Model (ERSEM), developed at Plymouth Marine Laboratory (PML). The hourly instantaneous water current data (product id: NORTHWESTSHELF ANALYSIS FORECAST PHYS 004 001 b; METO NWS PHYS HI AGG) holds a top, bottom and middle layer with a 1/15° latitudinal resolution and 1/9° longitudinal resolution (approximately 7km square).

The data is in a netcdf file format and needs some minor modifications before it can be used in the GNOME model (which also requires a netcdf file). An R (The R Foundation for Statistical Computing, Vienna) script is used to extract the required variables (northward and eastward components of the currents in the top layer) from the original file and rename the variable names to what the GNOME model expects.

The water current data only provides data for grid cells that are situated in the water body (left in Figure 1). Note that there are some grid cells near the coastline without water current data. This will pose a problem in the GNOME model as simulated oil particles that end up in these grid cells (without current data), will no longer move (i.e., the simulated particles get trapped in those grid cells). Therefore the function ‘na.approx’ from the ‘zoo’ library in R is used for simple inter and extrapolation of the water current data to grid cells with missing data. This extrapolation step also produces current data on land (right in Figure 1). Although this is not realistic, this is not a problem as simulated particles are not able to move further on land once they are beached. Furthermore, it is a necessity to inter- and extrapolate the currents, to avoid particles getting trapped in void grid cells. It should be noted that the water currents near the coast and estuaries are not very reliable.

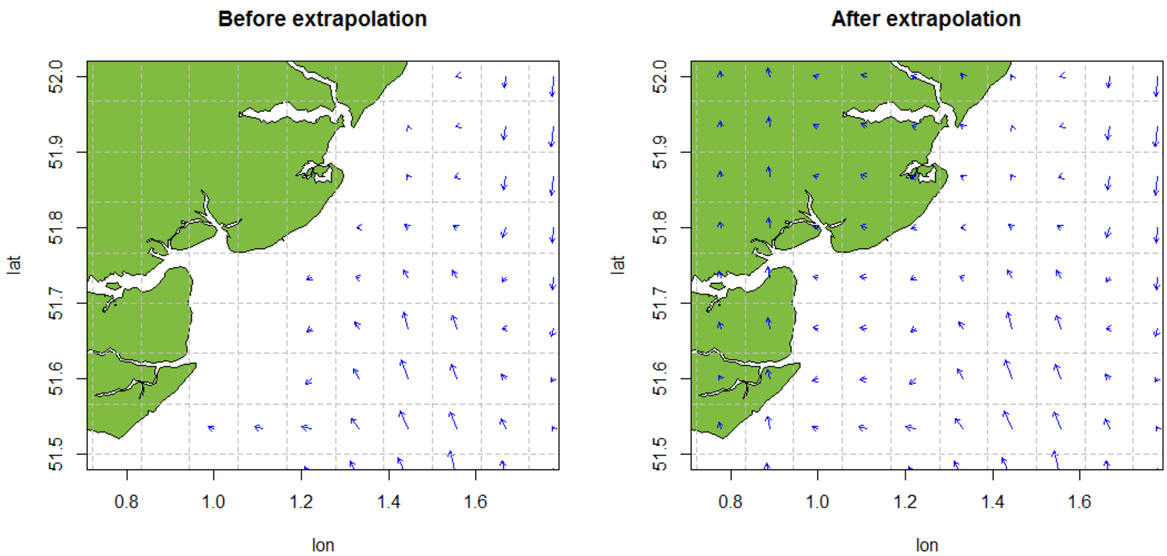

Figure 1 An example of the extrapolation of current data. Green represents land, white represents water. Dashed grey lines mark the grid cells. The blue arrows in the left panel represent the data as extracted from marine.copernicus.eu. The blue arrows in the right panel represent the data after extrapolation.

Wind data

In contrast to the water current data, it was challenging to retrieve wind data with complete spatial coverage and covers both hind- and forecasts. Surely there are commercial products available, however, in the current project we chose to work with publically available information. This means that the hind- and forecast had to be retrieved from different sources.

Hindcast data

The hindcast wind data is retrieved from marine.copernicus.eu (product identifier: WIND GLO WIND L4 NRT OBSERVATIONS 012 005). These Global Ocean- The IFREMER CERSAT Global Blended Mean Wind Fields include wind components (meridional and zonal), wind module, wind stress. They are estimated from scatterometers ASCAT and OSCAT retrievals and from ECMWF operational wind analysis with a spatial resolution of 0.25° by 0.25° and a 6 hour time interval. The data is provided as a netcdf file.

Note that at the time of the 72h simulation the hind cast data was only available for the day of the spill and backwards.

Forecast data

For the forecast data, the automated mailing service provided by www.globalmarinenet.com is used. This service automatically mails a seven day forecasts on a daily basis. The data are provided in the GRIB file format and are based on the National Weather Service, NOAA, Wave Watch III model yielding forecasts at 6 hour intervals and at a 1.25° by 1° (longitude and latitude) spatial resolution.

Although all routines for reading and processing data are implemented in R, third party software (WGRIB v1.8.1.2a) is used together with the 'rgdal' package in R to read the GRIB file format. Further processing of the file is described below.

Combining hind- and forecast data and further processing

The following steps (implemented in R) are executed in order to combine and pre-process the wind data for the use in the simulation (details are given below this list):

- Resample the forecast data to higher resolution to match the hindcast data resolution
- Merge the hindcast data with the most recent forecast data file
- Fill gaps in time between hind- and most recent forecast data with older forecast data
- Inter- and extrapolate wind data onto land
- Save the data in a netcdf format conform GNOME's requirements

The spatial resolution of the forecast data is artificially increased to 0.25° by 0.25° to match the resolution of the hindcast, using the 'resample' function from the 'raster' package in R. After merging the hindcast with the most recent forecast file, there is a gap of approximately a day in the wind data. This is because the most recent hindcast is approximately a day old. This gap is filled with older forecast files. As with the water current data, where data is only provided in the water body, wind data is only given above seawater. In order to avoid simulated particles to get trapped in grid cells with no wind data, a procedure (identical to that applied to water current data, see above) is applied to inter- and extrapolate the data to those cells.

Finally, the variable names are adjusted to match what the GNOME model expects and the file is saved as a netcdf file.

3.6. Spill information

Finally the model requires information on the spill that needs to be simulated. First of all the spill start time needs to be specified. Note that this time does not necessarily need to be equal to the start time of the simulation (but should at least be equal or later). Also the end time and the amount spilled need to be specified and the number of simulated particles (or 'splots' as they are referred to by GNOME). A spill position is also required.

Also the type of oil needs to be selected here. Only a limited selection of oil types is available in the model:

- Gasoline
- Kerosene
- Diesel
- Fuel oil #4
- Fuel oil #6
- Medium crude
- Non-weathering

These oil types are used to estimate the weathering of the oil except for the 'non-weathering' type, for which weathering is not simulated. This type can be used in conjunction with separate weathering modelling afterwards (not part of GNOME), such as ADIOS 2 (Lehr et al., 2000; http://response.restoration.noaa.gov/oil-and-chemical-spills/oil-spills/response-tools/adios.html). For this particular case study, ADIOS 2 was used. The ADIOS 2 calculations are described in more detail in Section 4. GNOME uses relatively simplistic 3-phase evaporation algorithm where the pollutant is treated as a three-component substance with independent half-lives. The properties of the oil types cannot be edited in the model. Windage of the oil is set to the model's default value of 3%.

Table 2 The spill information as used in the present challenge

Parameter	Value (unit)
Spill start time	2016-05-10 6:15 UTC
Spill end time	2016-05-12 6:15 UTC
Spill amount	10,000 m^3
Spill location	LongLat: 61.26838 N 1.744306 E
Oil type	Medium crude
Number of particles ('splots')	1000

3.7. Model details and limitations

This section describes some of the model's details. For a more in depth description we refer to the technical documentation provided with the model (Zelenke et al., 2012a and 2012b; NOAA 2002). The GNOME model is general and applies to trajectory problems. It is an Eulerian/Lagrangian model that is two-dimensional (2-D) in space. The third dimension (depth) is currently not included, limiting the model mostly to surface drift of the oil. Accurate near field modelling (including jet characteristics of momentum flux, buoyancy flux, and outfall geometry) of a spill (e.g., resulting from a blow-out) is not possible with the GNOME model. Third party (commercial) software (such as CORMIX) could be used to achieve this. This was considered out of scope for the present rapid response challenge and was therefore not included.

To get the overall movement the u (east-west) and v (north-south) velocity components from currents, wind, diffusion, and any other movers are added together at each time-step using a forward Euler scheme (a first-order Runge-Kutta method). Although higher order approaches are more accurate (and require more computational time), the uncertainty in input data is expected to be the limiting factor for the model output certainty.

Temperature of neither water nor air is a parameter in the model. Temperature is an important factor that affects oil behaviour (such as evaporation rate). In that respect the GNOME model is limited as it does not address effects of temperature. By applying ADIOS 2, a corrected mass balance can be calculated, taking into account the water temperature. As explained before, the ADIOS 2 model was not applied to the current case.

3.8. Model output

The model generates particle (splot) positions at specific output intervals, where each particle represents a specific amount of oil. Each particle will also contain a ‘flag’ indicating whether a particle has beached or not. These positions can be processed in GIS for presentation and further analysis.

The model will also generate a mass balance at output intervals, specifying how much oil is released, how much is afloat, beached or evaporated or off map.

As the model only indicates the amount of oil in the environmental compartments, additional analyses is required to assess the environmental impact on coastal habitats, species and tourist beaches. This is described in chapter 5.

3.9. ‘Minimum regret’ in the model

The GNOME model has a ‘minimum regret’ option. This option works under the assumption that input data is uncertain and simulated particles may end up elsewhere due to this uncertainty. By specifying the uncertainty in input data, the model is able to estimate extreme positions (less likely, but also not impossible) of the simulated particles (‘splots’). So if you want to have ‘minimum regret’, this setting can be used to identify locations where the spill may end up (although it is unlikely). We used this option, by applying the uncertainties as specified in the table below (Table 3). The selected values aim at a balance between how precautious and how realistic one wants to be.

Table 3 Uncertainties assumed in input for minimum regret calculations

Parameter	Value (unit)
Uncertainty factor in diffusion coefficient	2
Wind uncertainty start time	0 hr
Wind uncertainty duration	132 hr
Wind uncertainty speed scale	2
Wind uncertainty angle scale	0.4
Current uncertainty start time	48 hr
Current uncertainty duration	132 hr
Uncertainty along current	5%
Uncertainty cross current	10%

The ‘minimum regret’ option will be calculated in parallel with the standard run. In the standard run, uncertainties as listed above are not considered.

4. Refined mass balance

ADIOS 2 has a more extensive database of oil types when compared to GNOME. It also has refined routines to estimate the mass balance over time (i.e., the fraction of oil, afloat, evaporated and dispersed; Lehr et al., 2000). The model requires input on the oil type; emulsification; wind and wave conditions; water properties; release information; and the amount beached over time. Each aspect will be described in more detail below.

From the database the BRENT, OIL&GAS oil was selected as the most complete and closest matching oil type in the database. Its main characteristics are given in Table 4.

Table 4 Main characteristics of the selected oil type in ADIOS 2 calculations

Parameter	Value
Product type	Brent, Oil & Gas
API	38.2
Pour point	-3 deg C
Flash point	Unknown
Density at 15°C	NA
Viscosity at 15°C	3.7 cSt at 0 deg C
Adhesion	Unknown
Aromatics	Unknown

For emulsification (the forming of a mousse by the oil on water), the default settings of the model is used.

For wind conditions, the model only allows for a single point estimate. For this purpose, the average wind speed and direction is calculated from the wind data obtained (Section 3.2) at the release site. The wave conditions are calculated by the ADIOS 2 model based on the provided wind data.

Also for the water currents, only a single point estimate can be entered. This too is calculated from the obtained water current data (Section 3.2), as the mean over time at the release site. In addition, water temperature and salinity are required inputs for the model. These are parameters are also available from the obtained water current data set and are extracted from it, as the mean value over time at the release site.

The release information in terms of the amount of oil spilled over time are copied from the settings of the GNOME model (Section 3.2). The amount of oil beached is ignored in the ADIOS model as the GNOME simulation shows that it is unlikely that (much) of the oil will beach in within the simulated period.

5. Data used in post-analyses

The model simulation output requires post analyses in order to assess the potential impacts of the spill, i.e. a description of the characteristics of the predicted impacted locations (habitat or species found there etc.). This section describes the data used in these analyses. For the post-analyses in GIS (ESRI ArcMap) datasets were collected that cover the area and that give pertinent information in relation to the aspects expected of the challenge. Most of the datasets have been sourced from European Union servers.

- Coastline: European Coastline 2013, downloaded from the EEA website. The website of the EEA is located at this URL:http://www.eea.europa.eu
- Marine Protected Areas and Coastal Protected Areas: Natura 2000 geographical dataset + accompanying database (version end2013) was downloaded from the EEA website. For use in the challenge a subset was selected for protected areas that are marine or on-land but come closer than 5 km to the shoreline. This selection was made to ensure inclusion of valuable coastal habitats as well as sea bird (breeding) colonies that may not necessarily be directly on the coastline.
- Maritime Boundaries, was downloaded from the EEA website.
- Bathing water directive reports for the period 1990-2014 and the all relevant countries (BE, DE, DK, FR, NL, SE, UK) were downloaded from the EEA website. From the Excel-sheets a geographical dataset was compiled covering the study area.
- For each of these datasets the most recent available version was acquired during the preparation phase of the project. A number of these were updated during the vigilance phase to newer, updated version a.o. : Bathing Water (2014), Oil and Gas Infrastructure (2015).
- Seabed habitat was downloaded as the EU SeaMap from servers at the JNCC in the UK. The datasets is discoverable through the EMODNET dataportal, biology section (http://www.emodnet-seabedhabitats.eu/)
- Bathymetry was downloaded from the EMODNET dataportal, bathymetry section (http://www.emodnet-hydrography.eu/). For complete cover to of the study area both the Greater North Sea and the Celtic Sea datasets are required.

For marine and coastal protected areas the EEA Natura 2000 datasets was augmented with national data from Norway via the Norwegian Environment Agency (http://wms.miljodirektoratet.no/), the United Kingdom via Natural England (http://www.gis.naturalengland.org.uk/pubs/gis/GIS_Register.asp

) and the Netherlands with information from http://www.noordzeeloket.nl/projecten/noordzee-natura-2000/ .

6. Results

6.1. Progress report

In Table 5 a brief report on the progress in time with respect to the challenge is presented. This will give an indication on the effort spend on each task.

Table 5 Effort spend on each task

Task description	Start		End	
	Date	**Time**	**Date**	**Time**
Collect data	2016-05-12	08:30 CEST	2016-05-12	15:30 CEST
Run model	2016-05-12	15:30 CEST	2016-05-12	16:00 CEST
Process model output	2016-05-12	16:00 CEST	2016-05-12	23:00 CEST
Report findings	2016-05-12	14:00 CEST	2016-05-13	10:00 CEST
"Down time" (out of office at night)	2016-05-12	23:00 CEST	2016-05-13	08:00 CEST

6.2. Mass balance

At the end of the simulation (132 hours after the spill) 41% is evaporated or dispersed (Table 6) (using the generic "medium crude" oil in GNOME as a surrogate for Brent oil), the remainder is afloat.

When we look at the worst case/'no regret' simulation, we see that 4% (400 m^3) of the total amount of spilled oil could beach (Table 2).

Table 6 Mass balance at the end of the simulation

Fate	24h prediction		48h prediction		72h prediction	
	Most likely Fraction (%)	**Minimum regret Fraction (%)**	**Most likely Fraction (%)**	**Minimum regret Fraction (%)**	**Most likely Fraction (%)**	**Minimum regret Fraction (%)**
Released	100	100	100	100	100	100
Floating	64	63	59	NA	58	55
Beached	0	1	0	NA	0	4
Evaporated and dispersed	36	36	41	NA	42	41
Off map	0	0	0	0	0	0

The mass balance is also determined with the ADIOS model as indicated earlier. The results are depicted in Figure 2. Note that the results are very similar to those obtained with the GNOME simulation. Also note that the ADIOS model does not include potential beaching of oil.

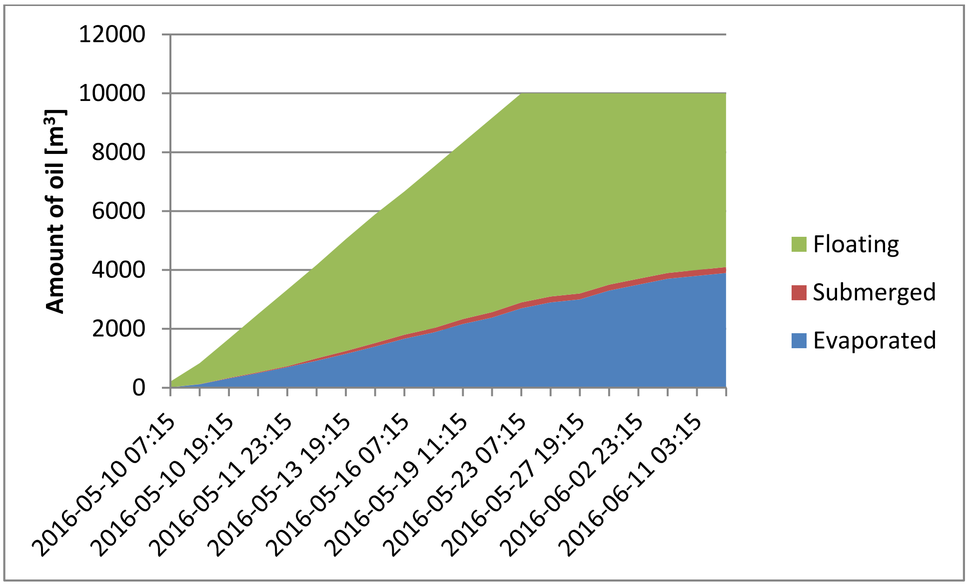

Figure 2 Mass balance calculated with the ADIOS model as described in the main text. Note that these calculations do not include the potential beaching as found in the 'no regret' simulation in GNOME.

6.3. Threatened location

This section describes the locations that are most likely to be under threat, based on an improved predicted trajectory of the oil slick and a more detailed description of the areas.

- Predicted impact on human activities in the area
    - Oil and gas sector
      Most likely, most of the oil will float on waters surrounding other oil and/or gas platforms (Figure 9). Of these Ninian North / Central / South are the first to come under threat, as well as Brent A. With the inclusion of observed current and wind information rather than forecasts, also the Alwyn North platforms are close to the trajectory of the oil slick The platforms at locations Hutton NW and Heather A remain safe.
      With the extended simulation duration further oil and gas platforms are in the path of the oil slick. Table 7 list a total of 24 platforms (above sea level structure) that are in the modelled trajectory or at least are within 1 km of the particle cloud at any time.

      As there remains an oil slick at the end of the simulation, an outlook can be given that further platforms are in locations that are likely to in the path that the oil slick will take in the next days beyond the end of simulation. To name a few: Jotun, Grane, Devenick.

- Shipping
  The available information on shipping lanes was not sufficient to cover the area under threat and only shows the area south of the location (Figure 13). Based on the available data and assuming the shipping lanes will continue in a straight line further north it is expected that the main shipping lane along the west side of the oil spill will hardly be threatened. According to the worst case scenario however, the oil could reach the main shipping route. The final spill location is getting close to crossing the shipping/ferry route between Aberdeen, Scotland and Bergen, Norway. Already threatened is a ferry route that exists between Bergen, Norway and Lerwick on the Shetland Islands (https://www.ferrytravel.com/ferries-ferry-to-norway.htm).
  AIS is a valuable resource to gain knowledge about ships positions, but we currently have no access to or knowledge of datasets that are readily available and processed to a level of detail that would match this type of work. The screenshot from MarineTraffic.com (Figure 3) shows that vessels are active within the area. It should be noted that a considerable part of the visible activity is related to the Oil and Gas platforms. The light blue squares are non-moving vessels within the category of Tugs & Special Craft and very likely these are so called stand-by and guard vessels. Much the same will hold true for those light blue ships-shapes but these are in motion.

- Fishery
  Known fisheries in the area are: otter trawling on demersal roundfish such as Pollack and pelagic trawling on e.g. herring and limited seine fishing on demersal roundfish. In the deeper areas (Norwegian Trench) there is fishery on Nephrops (pers. comm. N Hintzen, IMARES).
  From the data collected for the Fisheries Management Challenge, the datasets that are available from the ICES working group WGSFD (Spatial Fisheries Data) (ICES-WGSGF, 2014) it can be shown – as yearly average fisheries activity – that fisheres from the gear groups: demersal seiners and otter trawlers have been active in the area in 2012 (Figure 4). Nielsen *et al.* (2014) have a map that shows the locations of a mixed fishery using otter trawls that a.o. targets Neprops (Figure 5).

Table 7 Oil+Gas Platforms located within 1 km of a particle at any time during the 120 hours of simulation

Country	Name	Current Status	Primary product
Norway	HEIMDAL	Operational	Gas
Norway	FRIGG TCP2	Decommissioned	Gas
Norway	FRIGG DP2	Decommissioned	Gas
Norway	HEIMDAL HRP	Operational	
Norway	FRIGG DP1	Decommissioned	Gas
Norway	ALVHEIM floating steel	Operational	Oil
United Kingdom	Beryl; SPM3	Operational	Oil
United Kingdom	Alwyn north NAA	Operational	Oil
United Kingdom	Alwyn north NAB	Operational	Oil
United Kingdom	Beryl B	Operational	Oil
United Kingdom	Brent A	Operational	Oil
United Kingdom	Brent flare	Decommissioned	Gas
United Kingdom	Bruce PUQ	Operational	Condensate
United Kingdom	Dunbar	Operational	Oil
United Kingdom	Frigg QP	Decommissioned	Gas
United Kingdom	Ninian north	Operational	Oil
United Kingdom	Ninian south	Operational	Oil
United Kingdom	Beryl A Flare	Operational	Gas
United Kingdom	Beryl A	Operational	Oil
United Kingdom	Brent B	Operational	Oil
United Kingdom	Brent C	Operational	Oil
United Kingdom	Brent D	Closed down	Oil
United Kingdom	Frigg (UK) TP1	Derogation	Gas
United Kingdom	Bruce Phase II Platform	Operational	Condensate

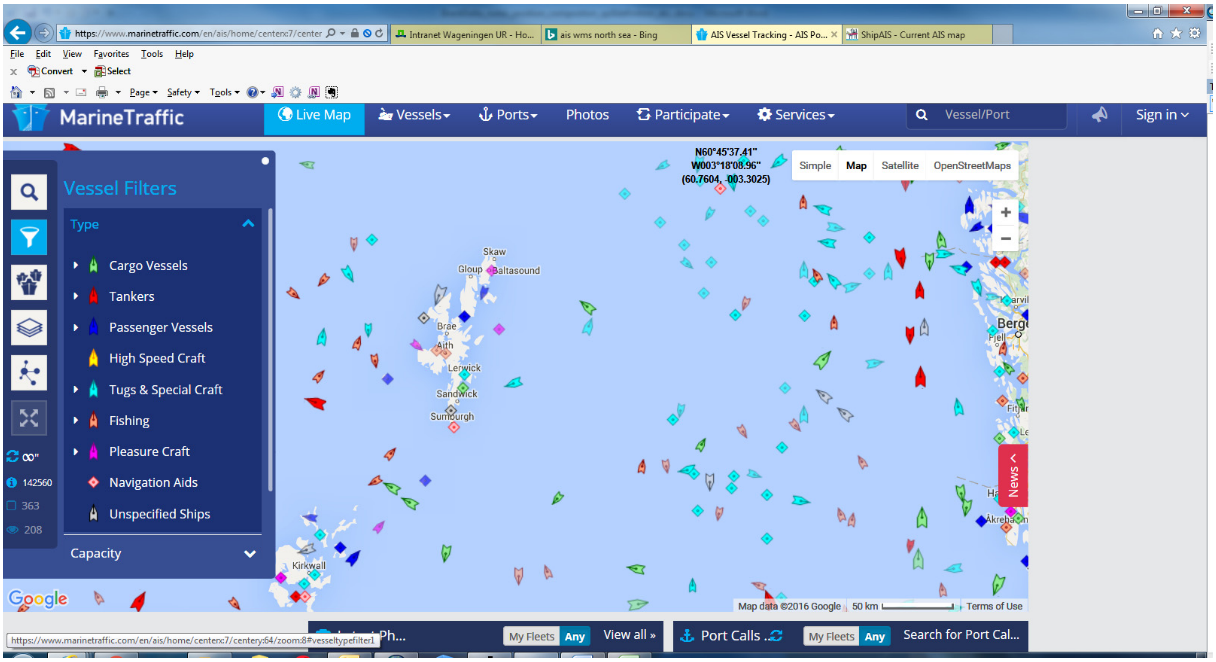

Figure 3 Screenshot showing presence of ships, based on AIS-data, in the area of the simulated oil spill around Brent Delta. (https://www.marinetraffic.com/en/ais/)

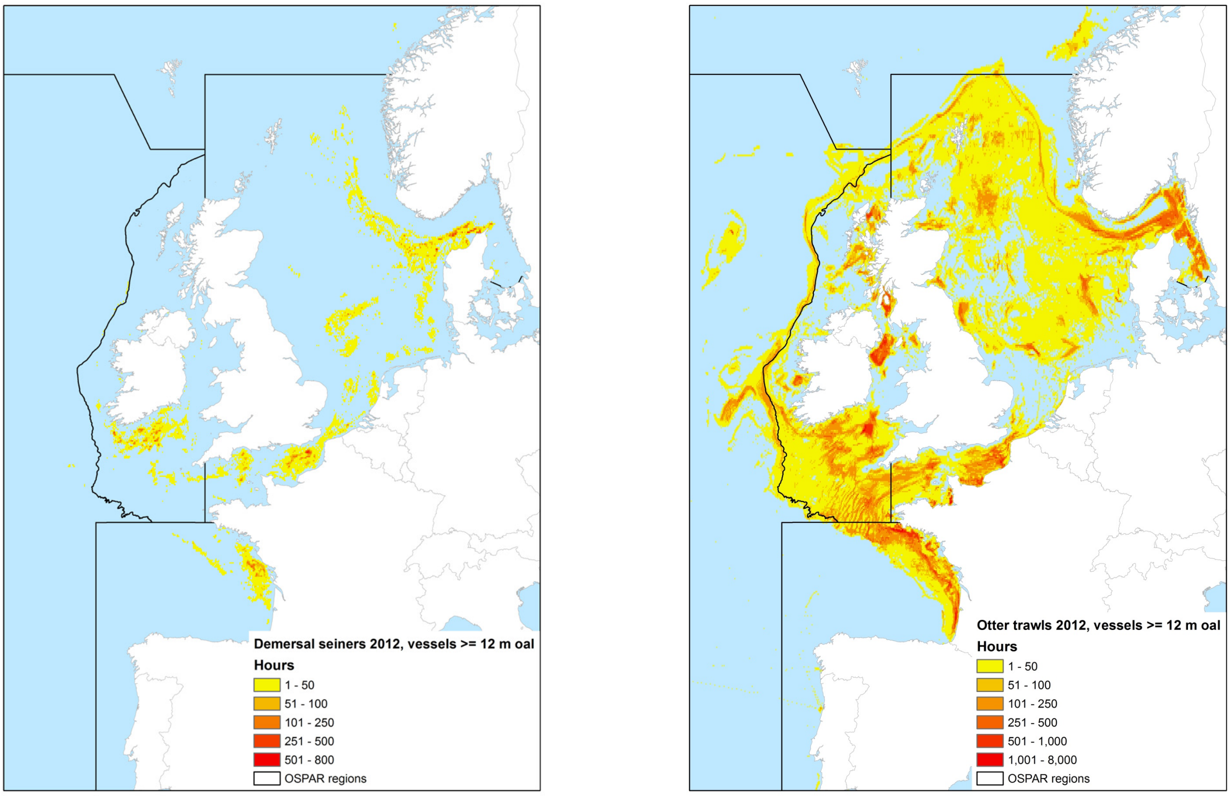

Figure 4 Spatial distirbution of fisheries for two gear groups: left Demersal seiners, 2012 and right Otter trawls, 2012 (ICES-WGSFD, 2012). Data as shown represents a whole year.

OT-MIX-NEP

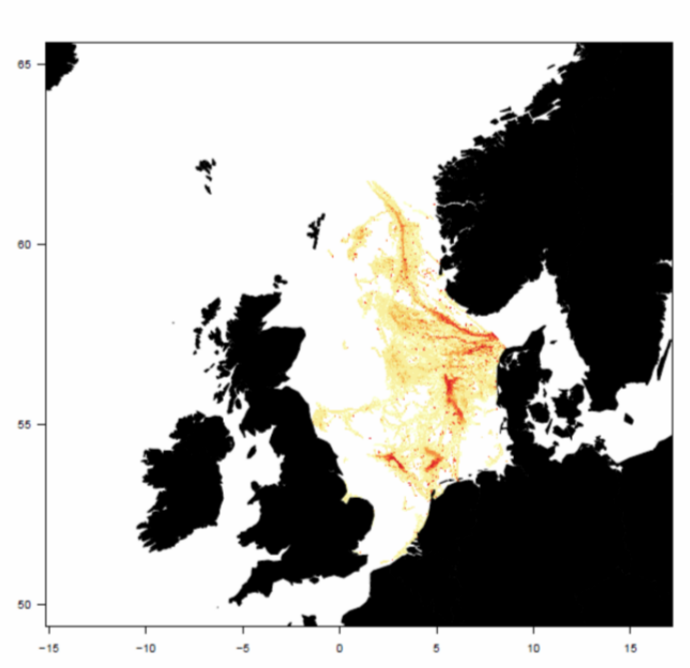

Figure 5 Spatial distribution of mixed fisheries targeting a.o. Neprhops (Nielsen et al., 2014) Data as shown represents a whole year.

- Predicted ecological impact
  - Marine mammals
    At this time of the year the northern North Sea is a very important area for many marine mammal species, especially dolphins, orca, sperm whale and long-finned pilot whale. Seals (grey seal and common seal) and harbour porpoise are permanent residents and for these species the area is always important (pers. comm. H. Verdaat, IMARES). Marine mammals are thus likely to be impacted, regardless of the trajectory of the oil slick. Only for otters, which remain very close to shore, the impact depends on the oil slick trajectory. Also for seals, which use the Shetland Islands as haul out, a higher impact is expected when the oil reaches the shore.
    Presented in Annex 6 are distribution maps for six sea mammals: Sperm whale (Physeter macrocephalus), Killer whale (Orcinus orca), Long-finned Pilot whale (Globicephala melas), Harbour porpoise (Phocoena phocoena), Harbour seal (Phoca vitulina), Grey seal (Halichoerus grypus), taken from the Obis SeaMap website (http://seamap.env.duke.edu/). Obis SeaMap also offers OGC-compliant services such as WMS and WFS, but these where not used due to time constraints. All of the species of sea mammal mentioned in this section do make use of the area, some of them may still be rare. This rarity may however also be a true reflection of the (global) status of the species, thus making it even more important to protect uas much as possible wherever and whenever an option presents itself.

- Birds
  Many bird species are now breeding and very sensitive and use the area for foraging. Thus exposure to the oil slick is likely to have a great impact on populations. Species are known to forage up to 100 km or even 200 km (for northern gannet) from the colony (pers. comm. H. Verdaat, IMARES). This means that, regardless of the exact trajectory of the oil slick, marine bird species are likely to be impacted. Bird species protected in designated areas are listed below (see protected areas).

- Habitats
  The oil is expected to spread over water covering a seabed substrate of muddy sand (Figure 12). This habitat is not likely to be impacted due to the expected low exposure (largest part of the spilled oil remains floating). The same holds for the protected Pobie Bank Reef (rocky and stony reef habitat). Threatened protected coastal habitat types are: vegetated sea cliffs, wet heaths, salt meadows, lagoons, sea caves, kelp forest, mud flats and salt marches (see below under protected areas).

- According to the no regret simulation (i.e. worst case) the oil could reach the Shetlands (Figure 10) and it is possible that oil will reach the shore (Figure 11). This will be further addressed in the text below (see protected areas)
  The same no regret (i.e. worst case) simulation also shows that the oil can beach at the coast of Norway south of Bergen, Storebo / Bekkjarvik. The 120h long simulation done for the 72h bulletin shows that as expected area with potentially beached oil has increased towards the south.

- Are there any protected areas threatened?
  According to the no-regret simulation (i.e. worst case scenario) the Shetlands can be impacted (Figure 11). Under the expected wind and current conditions the oil could even spread further south, where there are Natura 2000 areas (Table 8). If the oil beaches even further south at the coast of Norway, some nationally designated areas at the southern coast could be impacted. At least four protected areas where identified on the Norwegian coast that are home to natural values that are potentially impacted by the oil spill. Urter and Ferkingstadøyene are situated on islets on the outer coast, north of Stavanger fjord, while Heglane og Eime and Kjørholmane are just to the south. The natural values overlap at least partially with the protected areas on the Shetlands and are seabirds that breed on the island but use the sea areas offshore to forage for their own food as well as to feed their young. Most species may range to ca. 100 km away from the breeding colonies, where as some a.o. the Gannet may range even wider to ca. 200 km. The area Jærstrendene is also at risk, but mainly from a no regret point of view. The beaches and

natural values of this area are only under threat once oil is actually about to be stranded there. Annex 5 lists more details with respect to relevant species in these areas.
Figure 6 shows how far afield from the protected areas of Noss on the Shetlands and Kjørholmane in Norway a foraging range of 100 km would extend. As the simulation shows the most likely trajectory (best guess) is beyond that range, but as pointed out earlier the worst case scenario (no regret) does indicate a limited risk that oil could get close enough to foul foraging sea birds.

Table 8 Protected areas (details are provided in Annex 5).

Protected area	**Threatened habitats**	**Threatened species***
Pobie Bank Reef (N2000, UK)	Reefs	Mammals (grey- and common seal, harbour porpoise)
Hermanesss, Saxa vord and Valla Field (N2000, UK)	None	Birds
Keen of Hamar (N2000, UK)	Vegetated sea cliffs	None
Fetlar (N2000, UK)	None	Birds
North Fetlar (N2000, UK)	Not relevant	None
Yell Sound Coast (N2000, UK)	Wet heaths, salt meadows, lagoons, reefs, sandbanks, sea caves	Mammals (otter, common seal)
Noss (N2000, UK)	None	Birds
Mousa (N2000, UK)	Reefs, sandbanks, sea caves	Mammals (common seal, harbour porpoise) and birds
Sumburgh Head (N2000, UK)	None	Birds
Jærstrendene (National, NO)	Rocky seabeds, kelp forest, mud flats, sand flats, saltmarsh	Birds and mammals (grey- and common seal)

*Bird species protected in the UK areas are: *Calidris alpina schinzii* (Dunlin, only threatened when oil reaches the shore); *Catharacta skua* (Great skua); *Fratercula arctica* (Atlantic puffin); *Fulmarus glacialis* (Northern fulmar); *Gavia stellata* (Red-throated loon); *Hydrobates pelagicus* (European storm petrel); *Morus bassanus* (Northern Gannet) ; *Numenius phaeopus* (Whimbrel, only threatened when oil reaches the shore); *Phalacrocorax aristotelis* (European shag); *Phalaropus lobatus* (Red-necked phalarope); *Rissa tridactyla* (Black legged kittiwake); *Stercorarius parasiticus* (Arctic skua); *Sterna paradisaea* (Arctic tern); *Uria aalge* (Common guillemot). Bird species protected in the Norwegian area are: Great Northern Diver (wintering site, thus not under threat); White-billed Diver; Black-throated Diver; Red-throated Diver; Horned Grebe.

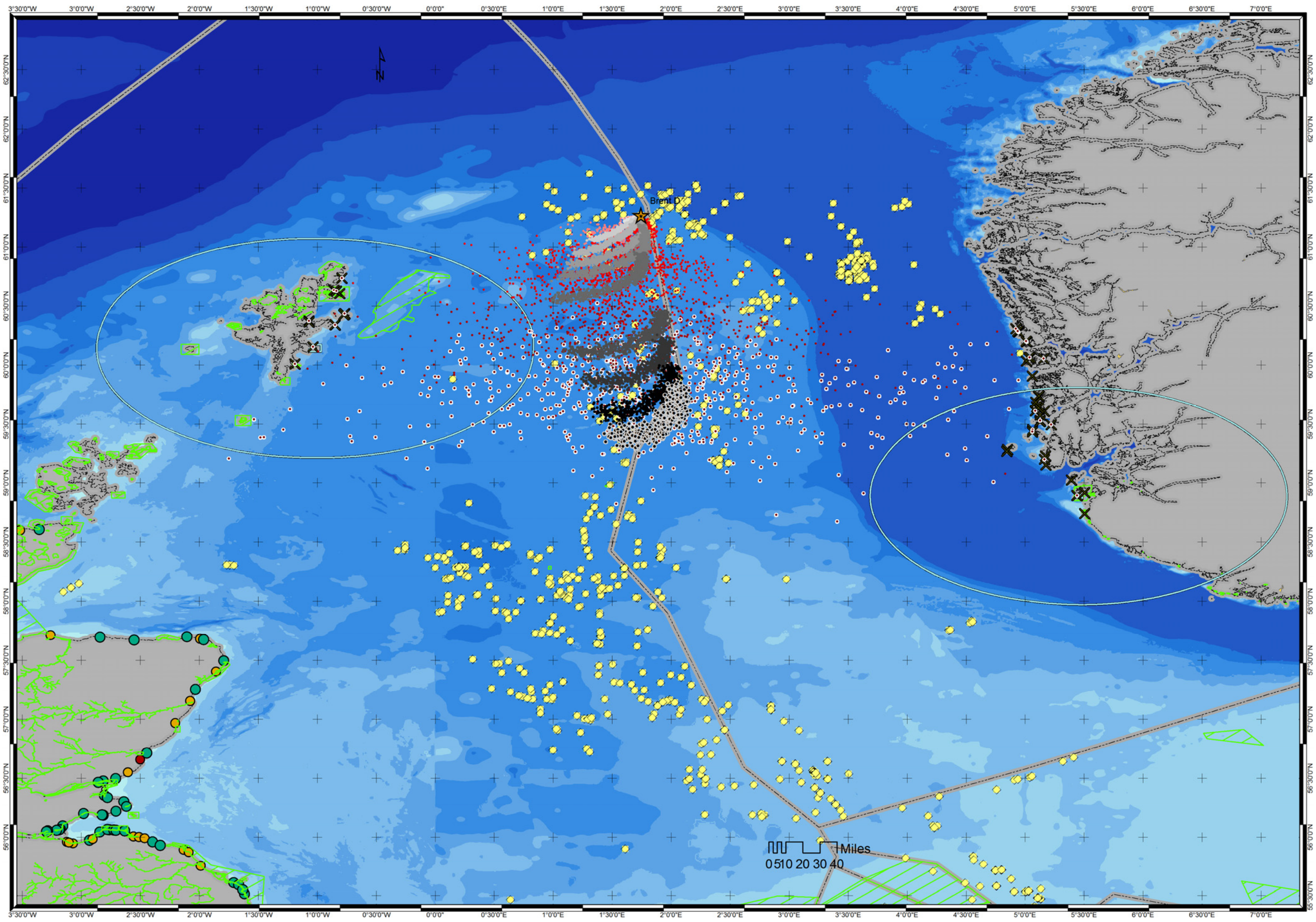

Figure 6 Overview of the impacted location during 120 hours after the beginning of the Brent Delta spill according to the best guess and no regret simulation. The star indicates the position of the spill. The line indicates the EEZ boundary between Norway and the UK. The light grey dots indicate the position of the oil after 6 hours, darker grey dots are later in time. The final predicted position of the oil (at 15 May,14:15 CEST) have a light grey halo (best guess) or a white hale (no regret). The rings showing around the Shetland Islands and on the Norwegian Coast indicate a distance of 100 km that foraging sea birds nesting at Noss or Kjørholmane may travel.

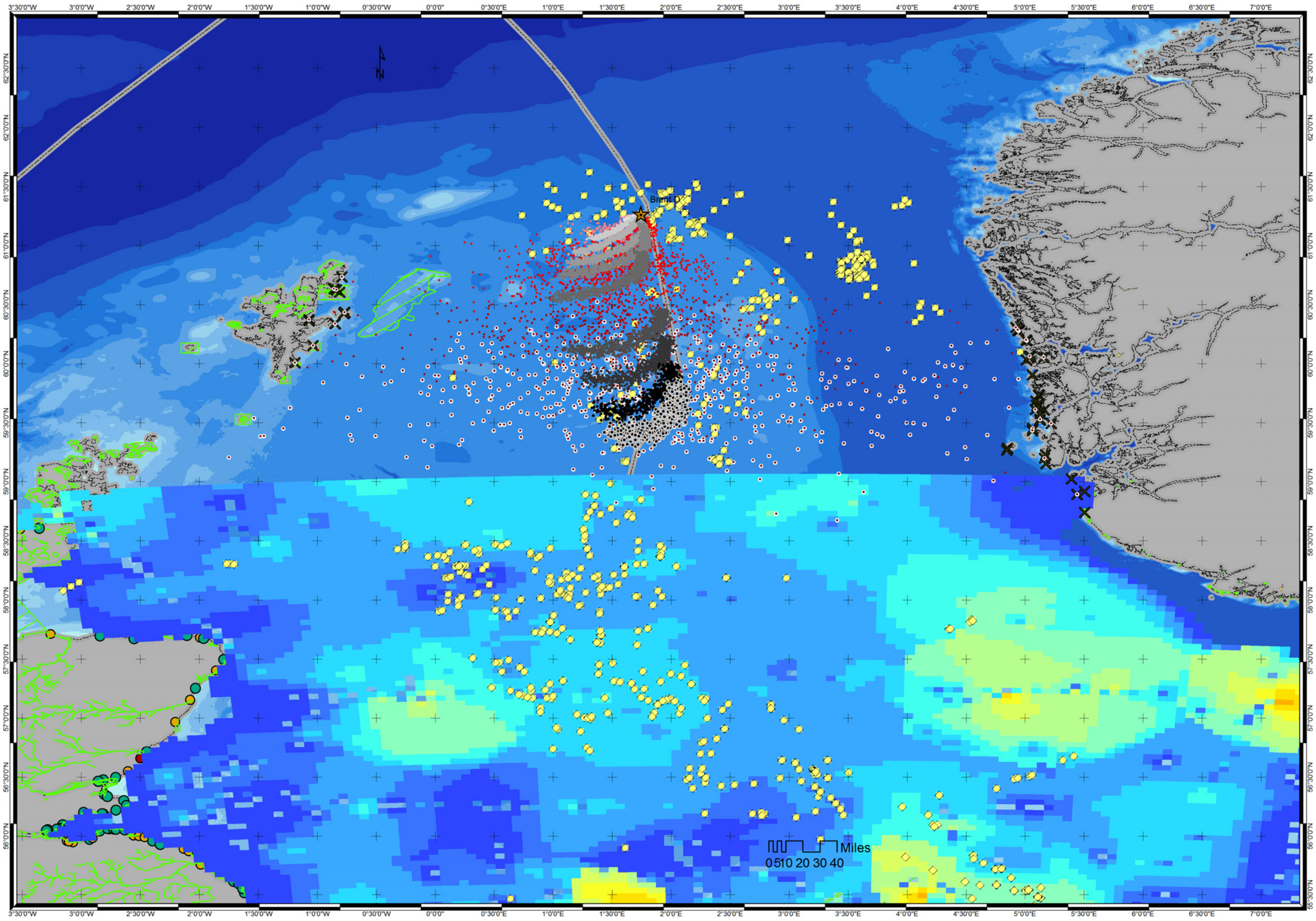

Figure 7 Overview map of oil spill development (upto 120 h from the start of the spill - active spilling lasted 48 h), showing distribution of Northern Fulmar (*Fulmarus glaciali*) during April/May, based on data from Leopold et al., 2015.

- Are there any tourist beaches threatened?
  There are tourist beaches situated at the Norwegian coast (Figure 8). These could potentially be impacted by the spill. Shetland also has tourist beaches which can also be impacted, for which we could not find a map. However, it is unlikely that the tourist beaches are used intensively at this time of year. Further information on tourist beaches can a.o. be found on the website of the Region Stavanger (http://www.regionstavanger.com/en/Attractions/Beaches-and-bathing/). Bathing water quality is monitored in Norway, most often by the municipality and reported by these also on the internet. However there are many municipalities with beaches and they assume local knowledge.

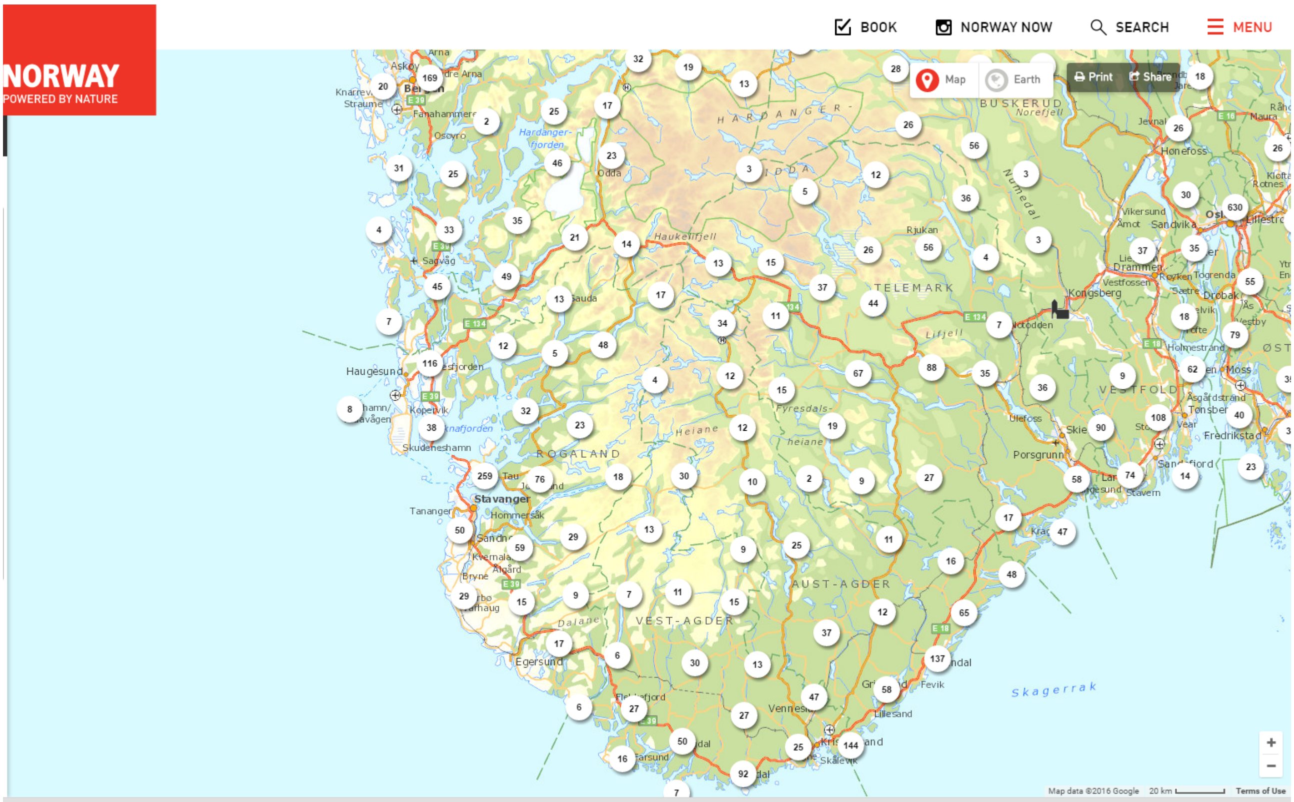

Figure 8 Locations of touris beaches as listed at https://www.visitnorway.com/maps/. The numbers showing inside the white circles indicate the number bathing locations/beaches in that area.

6.4. Graphical output

The figures below show the impacted location from different perspectives.

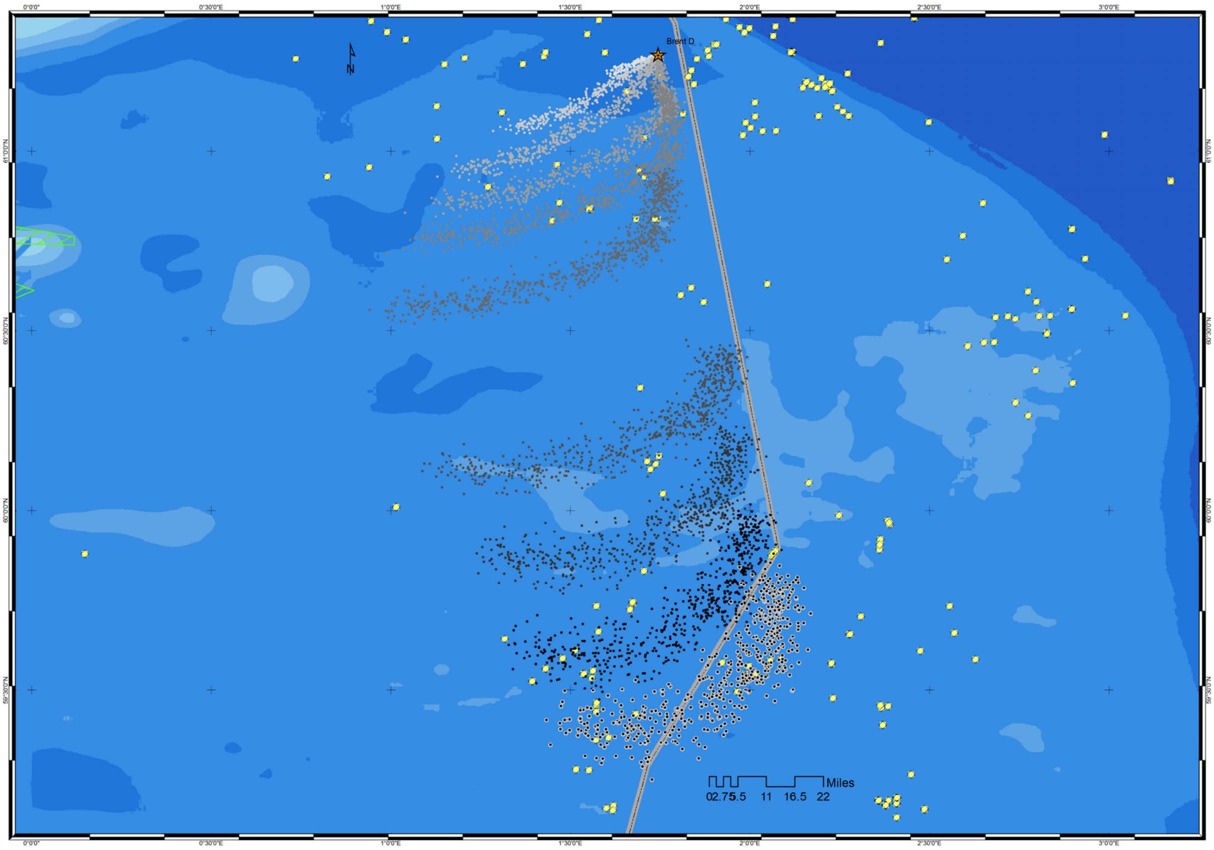

Figure 9 Overview of the impacted location during 120 hours after the beginning of the Brent Delta spill according to the best guess and no regret simulation. The star indicates the position of the spill. The line indicates the EEZ boundary between Norway and the UK. The light grey dots indicate the position of the oil after 6 hours, darker grey dots are later in time The final predicted position of the oil (at 15 May,14:15 CEST) have a light grey halo (best guess) or a white hale (no regret). The figure also indicates the positions of other platforms (yellow diamonds).

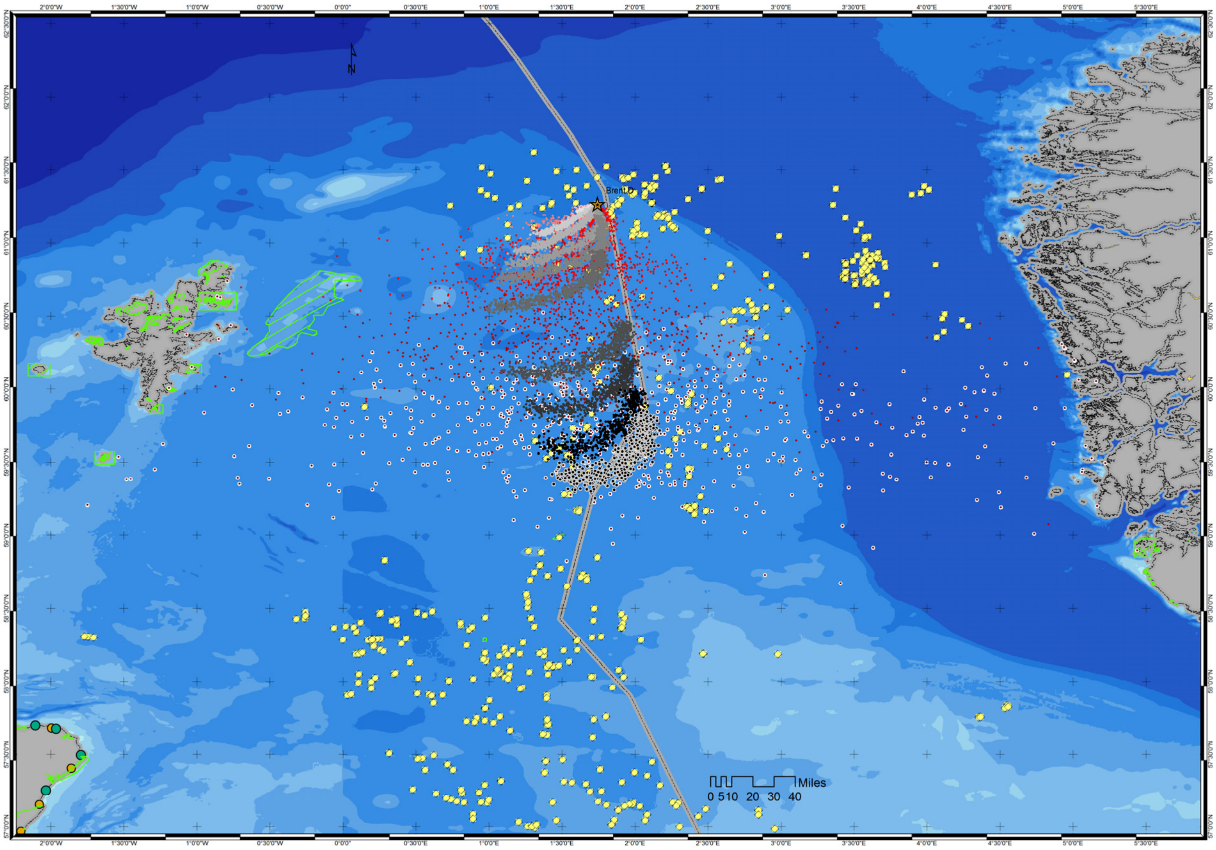

Figure 10 Overview of the impacted location during 120 hours after the beginning of the Brent Delta spill according to the best guess and no regret simulation. The star indicates the position of the spill. The line indicates the EEZ boundary between Norway and the UK. The light grey dots indicate the position of the oil after 6 hours, darker grey dots are later in time. The final predicted position of the oil (at 15 May,14:15 CEST) have a light grey halo (best guess) or a white hale (no regret). The figure also indicates the positions of other platforms (yellow diamonds).

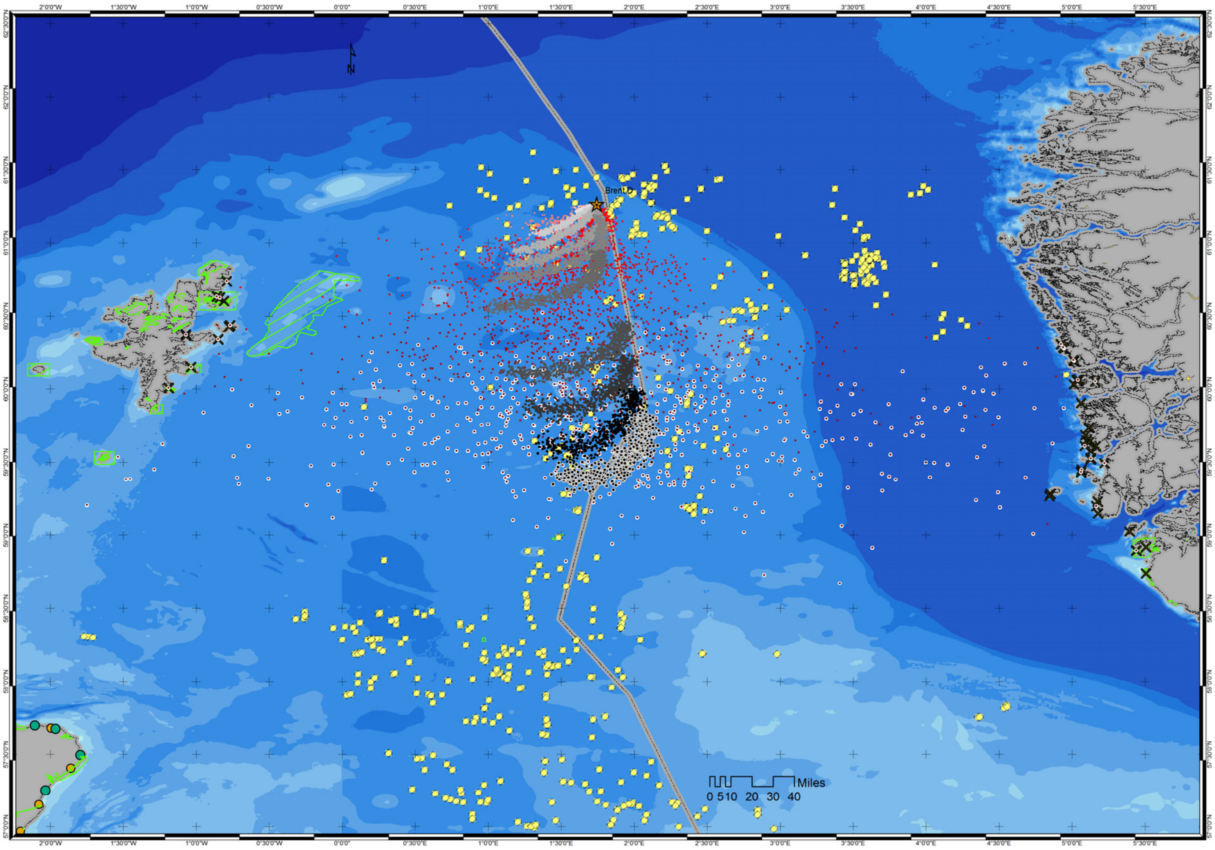

Figure 11 Overview of the impacted location during 120 hours after the beginning of the Brent Delta spill according to the best guess and no regret simulation The star indicates the position of the spill. The line indicates the EEZ boundary between Norway and the UK. The light grey dots indicate the position of the oil after 6 hours, darker grey dots are later in time. The final predicted position of the oil (at 15 May,14:15 CEST) have a light grey halo (best guess) or a white hale (no regret). The figure also indicates the positions of other platforms (yellow diamonds). Black crosses indicate positions of beached oil as a worst case scenario (no regret simulation). Green striped areas indicate protected Natura 2000 areas.

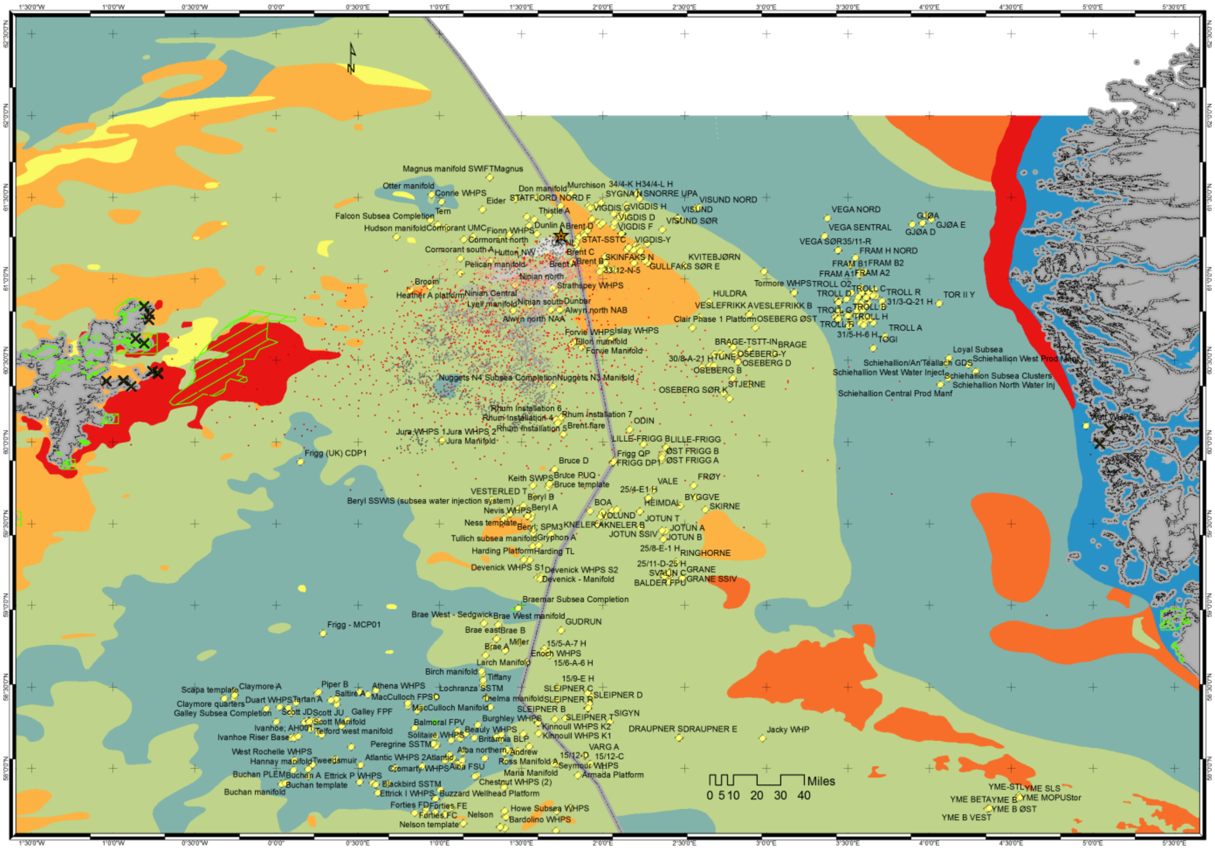

Figure 12 Overview of the predicted impacted location 90 hours after the Brent Delta spill according to the best guess and no regret simulation as assessed during the first 24 hours, showing the seabed substrate with different coloured areas. Most of the seabed substrate of the impacted location consists of muddy sand (indicated by the green area). The star indicates the position of the spill. The line indicates the EEZ boundary between Norway and the UK. The light grey dots indicate the position of the oil after 6 hours, darker grey dots are later in time. The final predicted position of the oil (at 14 May, 00:00 CET) are the green (evaporated/dispersed) and red (in/on water) dots. The figure also indicates the positions of other platforms (yellow diamonds) and subsea structures (olive green diamonds). Black crosses indicate positions of beached oil as a worst case scenario (no regret simulation). Green striped areas indicate protected Natura 2000 areas. [not updated for 72h bulletin]

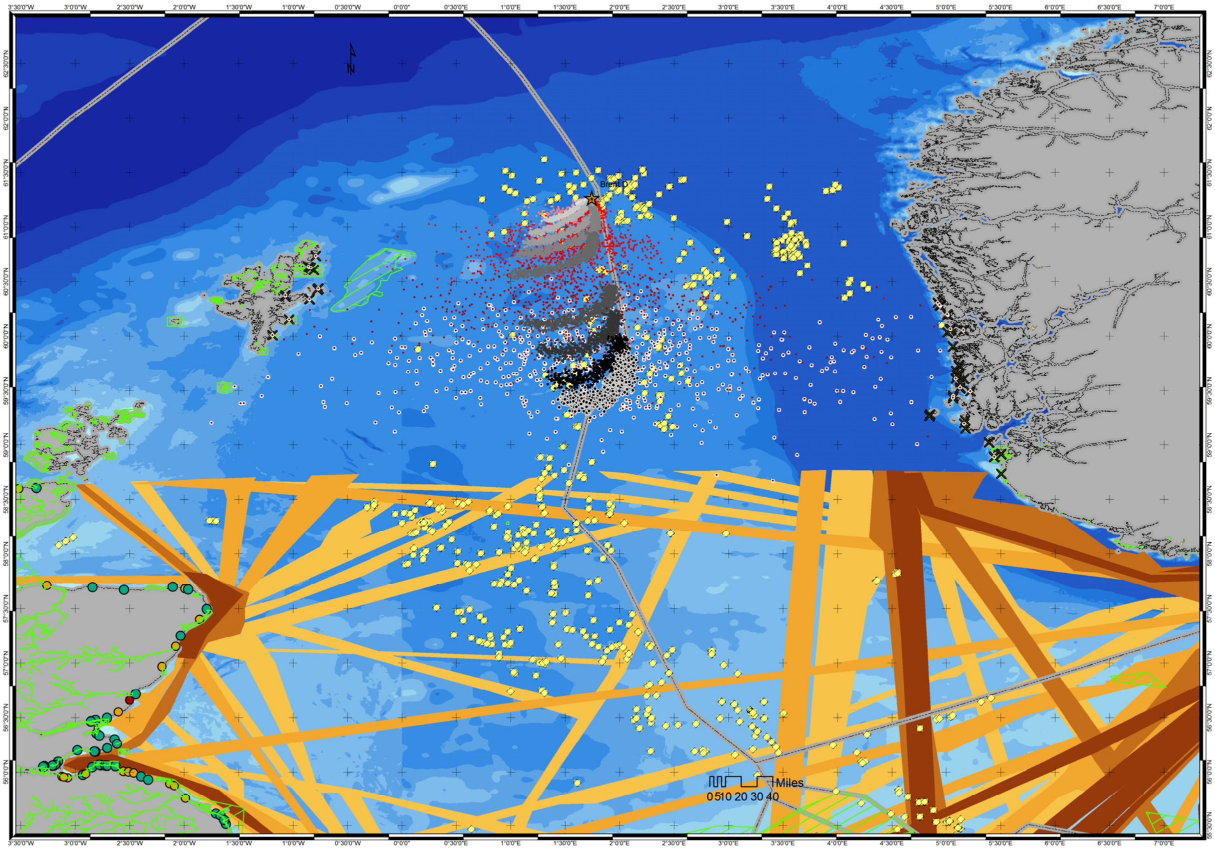

Figure 13 Overview of the impacted location during 120 hours after the beginning of the Brent Delta spill according to the best guess and no regret simulation The star indicates the position of the spill, Also showing available information on shipping lanes (in yellow/brown). NB. The latter data is not covering the impacted area and is limited to the area south of the spill. The star indicates the position of the spill, Brent Delta platofrm.. The line indicates the EEZ boundary between Norway and the UK. The light grey dots indicate the position of the oil after 6 hours, darker grey dots are later in time. The final predicted position of the oil (at 15 May,14:15 CEST) have a light grey halo (best guess) or a white hale (no regret). The figure also indicates the positions of other platforms (yellow diamonds). Black crosses indicate positions of beached oil as a worst case scenario (no regret simulation). Green striped areas indicate protected Natura 2000 areas.

7. Conclusion

7.1. Predicted impact

Based on this refined assessment it is likely that:

- The oil could beach at the southern coast or Norway or at the Shetlands, although this is not the most likely scenario. Most likely, the oil will move further south beyond the period that could be simulated with the available data.
- There is a threat to the following marine mammal species: dolphins, orca, sperm whale and long-finned pilot whale, grey- and common seal, otter and harbour porpoise. Marine mammals are likely to be impacted, regardless of the trajectory of the oil slick. Otters will only be affected when the oil reaches the shore and for seals, a higher impact is expected when the oil reaches the shore (haul out).
- There is a threat to marine bird species which use the area for foraging, especially now they are breeding. Potentially affected bird species protected in the UK areas are: *Calidris alpina schinzii* (Dunlin, only threatened when oil reaches the shore); *Catharacta skua* (Great skua); *Fratercula arctica* (Atlantic puffin); *Fulmarus glacialis* (Northern fulmar); *Gavia stellata* (Red-throated loon); *Hydrobates pelagicus* (European storm petrel); *Morus bassanus* (Northern Gannet) ; *Numenius phaeopus (*Whimbrel, only threatened when oil reaches the shore)*; Phalacrocorax aristotelis* (European shag)*; Phalaropus lobatus (*Red-necked phalarope); *Rissa tridactyla* (Black legged kittiwake); *Stercorarius parasiticus* (Arctic skua); *Sterna paradisaea* (Arctic tern); *Uria aalge* (Common guillemot). Threatened bird species protected in the Norwegian area are: White-billed Diver; Black-throated Diver; Red-throated Diver; Horned Grebe.
- Threatened protected coastal habitat types are: vegetated sea cliffs, wet heaths, salt meadows, lagoons, sea caves, kelp forest, mud flats and salt marches (see below under protected areas).
- Tourist beaches at the Southern coast of Norway and the Shetlands are impacted if the oil beaches there. Exact locations of tourist beaches at the Shetlands are unknown.
- The following locations and activities are threatened (best guess):
    - Platforms surrounding the spill site
    - Fisheries in the area (demersal seine, otter trawl, mainly on demersal roundfish species).

  - Shipping activity may need to avoid some areas, due to the presence of an oil slick. Both shipping moving mainly north-south into and out of the North Sea for intercontinental destinations as well as ships navigating East-West and vv. between Scotland or the Shetlands and Norway.
- The following locations and activities are threatened to a lesser degree (no regret):
  - Tourist beaches (both on the Shetlands as well as on the Norwegian Coast)
  - The Natura 2000 areas: Pobie Bank Reef; Hermanesss, Saxa vord and Valla Field; Keen of Hamar; Fetlar, North Fetlar; Yell Sound Coast; Noss; Mousa; Sumburgh Head.
  - The nationally designated areas Jærstrendene, Urter, Ferkingstadøyene, Heglane og Eime and Kjørholmane.
  - Beyond the period simulated with the available data, the spilled oil is expected to move further south where it could also beach (e.g., at Scotland mainland).

7.2. Limitations

Model limitations are:

- Case specific modifications of the model are not possible and some predefined settings (such as oil composition) have to be used.
- Depth is not included, limiting the model mostly to surface drift of the oil
- Accurate near field modelling (including jet characteristics of momentum flux, buoyancy flux, and outfall geometry) of a spill (e.g., resulting from a blow-out) is not possible with the GNOME model. Third party (commercial) software (such as CORMIX) could be used to achieve this. This was considered out of scope for the present rapid response challenge and was therefore not included. Instead, the time needed for the oil to reach the surface was estimated using basic formulations.
- To get the overall movement the u (east-west) and v (north-south) velocity components from currents, wind, diffusion, and any other movers are added together at each time-step using a forward Euler scheme (a first-order Runge-Kutta method). Although higher order approaches are more accurate (and require more computational time), the uncertainty in input data is expected to be the limiting factor for the model output certainty.
- Temperature of neither water nor air is a parameter in the model. Temperature is an important factor that affects oil behaviour (such as evaporation rate). In that respect the GNOME model is limited as it does not address effects of temperature. By applying ADIOS 2, a corrected mass balance was calculated, taking into account the water temperature.

The following has been identified as data gaps limiting the refined assessment:

- Tourist beaches (especially the locations of tourist beaches at the Shetlands)
- Shipping lanes
- Fisheries activity on a time scale shorter than a whole year
- Distribution data of birds and sea mammals. Possibly also other biological distribution data on e.g. fish and benthic species. This is not caused by absence of survey data (which may be scarce nonetheless), but is caused by the non-existence of (geographically explicit) datasets that are prepared and ready for use. However as the usefulness of such data is also strongly dependent on the specific of e.g. an oil spill incident, getting the details right for both the geographical detail and the correct time scale will remain difficult. Spatial coverage
  For both winds and water currents data covering the region of interest was available. However, both lacked information in some grid cells near the coast, this information had to be extrapolated from the available information. Also, there is no single winds data source covering the region with both a hind- and a forecast, publicly available and free of charge. Therefore different sources had to be used and combined for hind- and forecast winds data.
- Applicability
  - The data needed some (minor) modifications before it could be used in the model considering the format of the available data versus the required data format (i.e. file type, variable names). R scripts were used for extracting and modification of data.
  - Winds and currents data are limited near shore.
  - Current forecasts as available from MyOcean are currently limiting the length of time the simulation of an oil spill can be taken into the future.
  - Lack of data on location of fishery effort and/or importance of areas at sea to fisheries is limiting the possibility to assess the impact that an oil spill accident may have on fisheries in general.
  - Datasets both at MyOcean.eu as well as at GlobalMarineNet.com are updated once per day (around 11:00 in the morning). These processes are themselves reliant on other models being run and completing their updates and reporting. This is important to consider when attempting an update of the assessment e.g. from the 24 hours to the 72 hours assessment (no new forecasts can be made till afternoon). In real spill response events, the reliability of the availability of required data is key. Some of the data on MyOcean was unavailable at one point in time (although not during the challenge).

These issues will be addressed within the main report on data adequacy, including recommendations for improvement.

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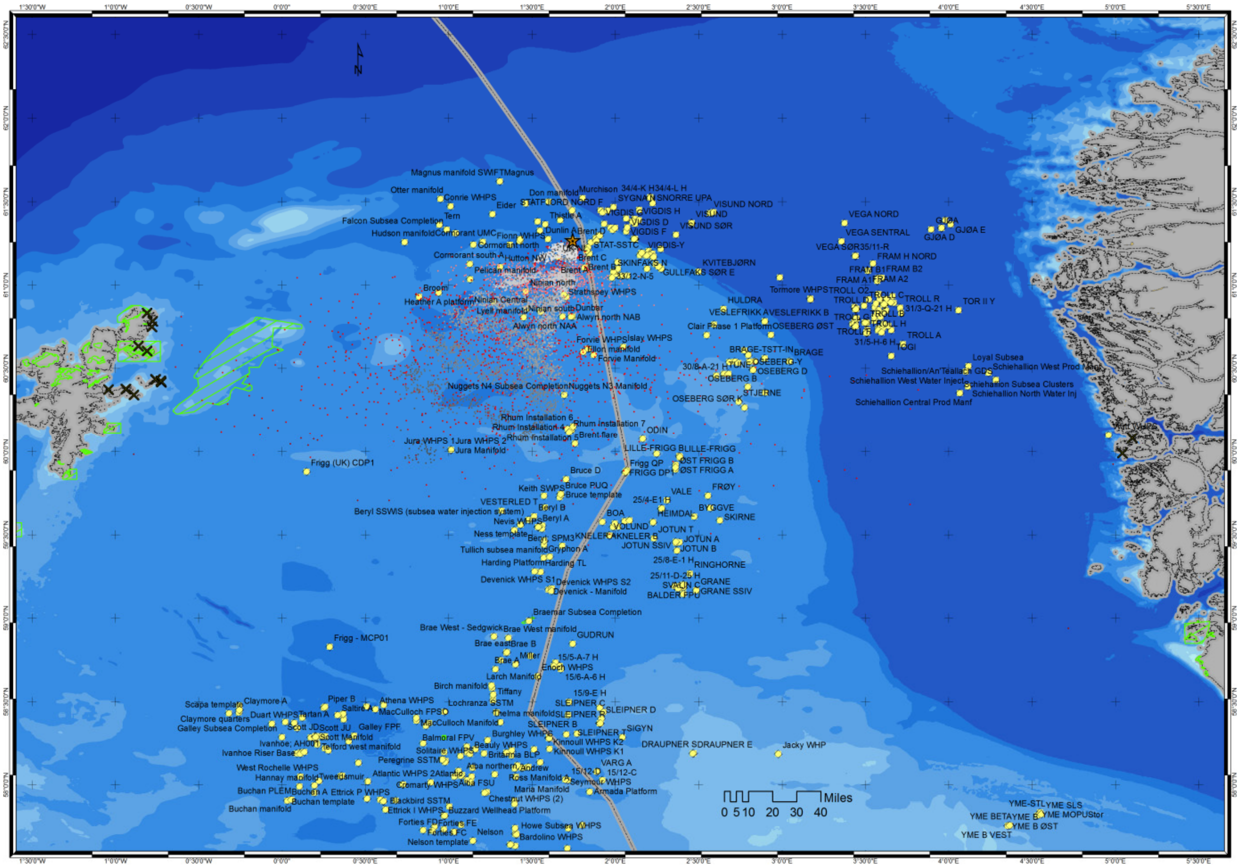
Annex 1 24h executive summary oil leak challenge

An “Oil Platform leak” challenge was performed by IMARES with the objective to test the adequacy of data currently available for the North Sea basin for impact assessment of an oil spill as part of emergency response. On Tuesday, May 10, 2016 11:24 AM, we received an email from DG MARE with the notification that about 5000m3 of oil per day leaked from the Brent Delta Platform with an expected duration of 48 hours.

The GNOME model was used to simulate the oil spill. At the end of the simulation (90 hours after the spill) 36% is evaporated and dispersed, and 64% is floating. As a worst case, only 1% of the total amount of spilled oil could beach, posing a threat to coastal habitat/species in the UK and Norway, as indicated by the crosses (beached oil) in the figure below. Identified data gaps limiting this preliminary assessment are a lack of data on tourist beaches and shipping lanes in the area of concern and details on the Natura 2000 areas are not yet addressed. These issues will be addressed within the complete impact assessment and/or the main report.

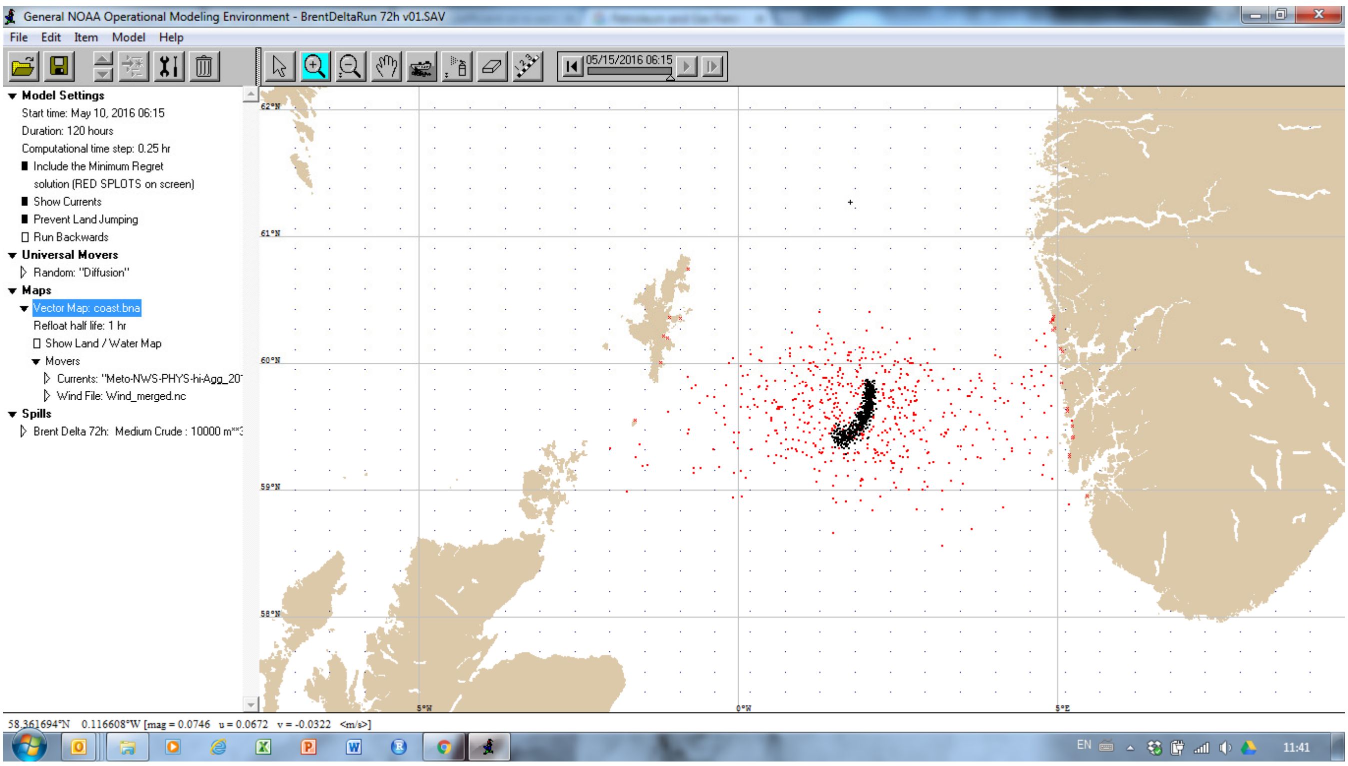


Overview of the impacted location after the Brent Delta spill according to the best guess and no regret simulation.

Annex 2 48h summary update oil leak challenge

An “Oil Platform leak” challenge was performed by IMARES with the objective to test the adequacy of data currently available for the North Sea basin for impact assessment of an oil spill as part of emergency response. On Tuesday, May 10, 2016 11:24 AM, we received an email from DG MARE with the notification that about 5000m3 of oil per day leaked from the Brent Delta Platform with an expected duration of 48 hours. A preliminary impact assessment was provided 24h after the spill. Here we provide a 48h update of the assessment.

Based on model simulations, it is expected that (120 hours after the spill) 41% is evaporated and dispersed, and 59% is floating. As a worst case, a small amount of spilled oil could beach, posing a threat to coastal habitat/species in the UK and Norway, as indicated by the red dots on the coast lines (beached oil) in the figure below. The most notable change is that the best guess trajectory (black dots) for the spill is moving further south, and stays well away from shore. The potential threats (no regret) to the coast are expanding southward. The northernmost locations are the first where increased vigilance is advisable, starting in the afternoon of Thursday 12 May (today).



Screenshot (taken from Gnome) of the impacted location after the Brent Delta spill according to the best guess and no regret simulation. Time shown is 15 May 06:15.

Annex 3 Time for oil to reach the surface

The force exerted on a droplet due to its buoyancy depends on the earth's gravity constant, the density difference between the droplet (ρ_{oil}) and that of the surrounding medium (ρ_w) and the volume of the droplet ($\frac{4}{3}r^3$), and thus the droplet radius (r):

$$F_{buoyancy} = (\rho_w - \rho_{oil})\left(\frac{4}{3}r^3\right)g$$

The drag force on a spherical droplet depends on the density of the medium in which it moves (ρ_w), the drag coefficient (c_d) and the surface area of the droplet (πr^2) and the velocity with which the droplet moves (v).

$$F_{drag} = \frac{1}{2}c_d\rho_w v^2\pi r^2$$

When a droplet is released in the water column, it will accelerate until the drag force is balanced against the buoyancy force:

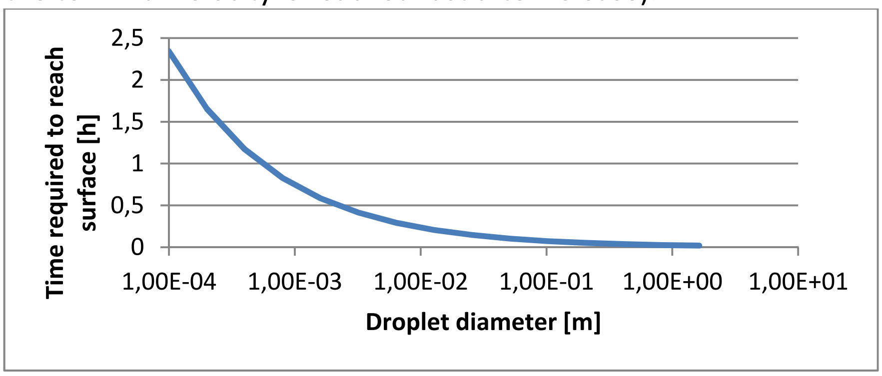
$$(\rho_w - \rho_{oil})\left(\frac{4}{3}r^3\right)g = \frac{1}{2}c_d\rho_w v^2\pi r^2$$

From this equation, we can solve the terminal velocity of an oil droplet:

$$v = \sqrt{\frac{2(\rho_w - \rho_{oil})gr}{3c_d\rho_w}}$$

The terminal velocity is thus dependent on the size of the droplet size (r). When fill in all other parameters ($g = 9.81$ m/s^2, $\rho_w = 1.02$ kg/dm^3[2], $\rho_w = 0.835$ kg/dm^3, $c_d = 0.86$, which had no unit and was found in the book Petroleum and Gas Field Processing, Second Edition).

We don't know the droplet size for the spill scenario at hand, but it is safe to assume that they will likely have a diameter somewhere between 0.1 mm and 1m. The relation between the droplet size and time to reach the surface is visualised in the plot below, using the equation above (and assuming that the terminal velocity is reached fast after release).



[2] In reality density also depends on water depth (and thus pressure), salinity and temperature. As we only intend to get a rough estimate, these terms are neglected.

Under these assumptions, the oil will reach the surface in a matter of minutes (or hours when droplets are very small) from the depth of 70 meters.

Annex 4 Brent Delta Platform, physical structure in relation to the simulated spill

The (simulated) oil spill is located at the Brent Delta platform and has been specified to occur at a depth of 229 feet or 70 meters. It supposedly occurred while work was underway related to the decommissioning of the platform. Oil production ceased at Brent Delta in November 2011. These specifications place the spill about mid-water column as the water depth at the platform location is between 140 and 150 m.

The topside platform stands on a foundation that is a gravity-based substructure from concrete. The size and layout of the platform is presented in Figure 14 (from DNV, 2011). There are two legs, the right leg is referred to as the utility leg and on the inside a water level is maintained at -74m. below sea level. In the left or drill leg the water is at the same level as the outside sea water. The specified spill depth would indicate the drill leg as the most likely source of the spill at a height of a few tens of meters above the ballast tanks or caisson.

From Shell (2015), Figure 15 it becomes clear that the cells of the caisson do not contain large amounts of oil anymore and are therefore unlikely sources for a spill as is currently being simulated. Each cell has an internal free volume that is estimated at 9800 m^3, based on 18 m. diameter, 60 m. height of which ca. 77% is available. The remaining height is taken up by the ballast sand and the concrete diaphragm on top of the sand. The volume is a reasonable match to reported size of the spill, but the release depth would have been deeper at ca. 90 m. However the cells where used as storage for oil, at least SHELL (2015) refer to them as 'GBS oil storage cells'. So a hypothetical spill of this size from a single storage cell failing is possible.

The internal structure of the drill leg as shown indicates that the pipe lines are a potential source of the reported amounts of oil. But in that case a double failure would be needed, not only a leak of one or more pipes inside the leg, but also of the outer shell would have to be compromised. As such the presented scenario for the oil spill leak is clearly a hypothetical case.

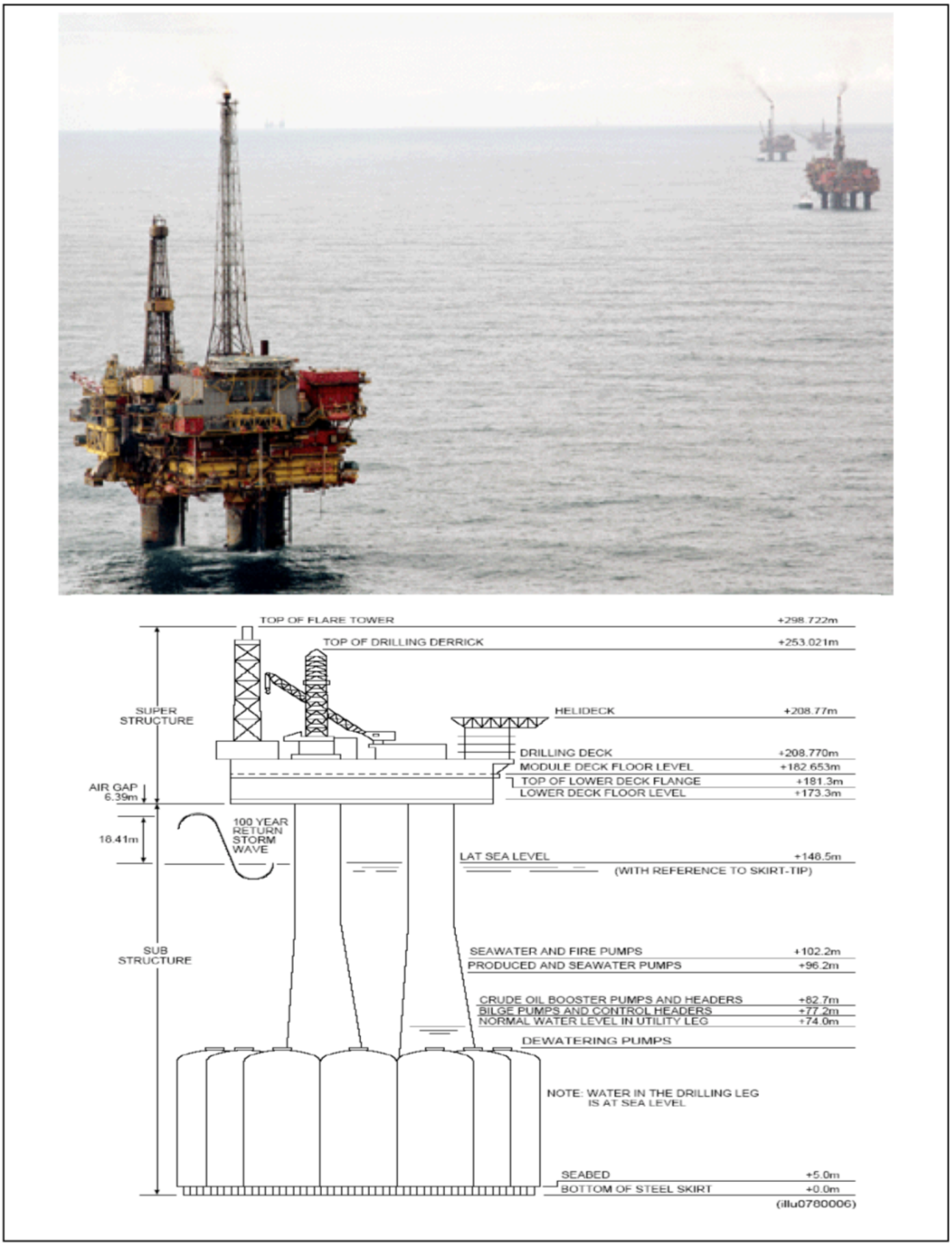


Figure 14 Brent Delta platform, general configuration (from DNV, 2011)

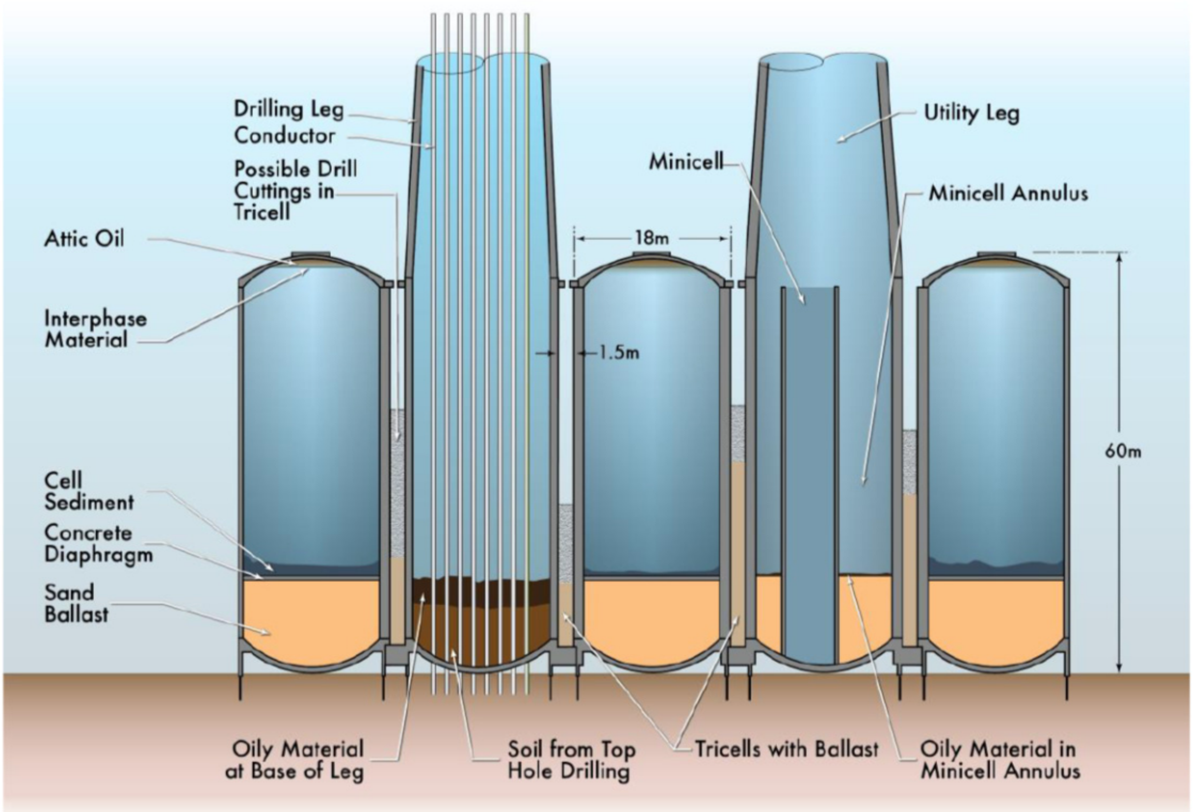


Figure 15 Location of other material and components in the Brent Delta GBS (from Shell, 2015)

DNV (2011) Environmental Scoping Report for Brent Field Decommissioning EIA. DNV Reg.No. EP021428/12NA8UG-7 Shell Brent Decommissioning Report No. BDE-F-GEN-HE-0702-00004 rev. 5, 24 May 2011, Den Norske Veritas Ltd, Aberdeen, UK

SHELL (2015) Brent Delta Topside Decommissioning Programme, Report No. BDE-D-TOP-AA-5580-00001 Final, 22 June 2015

Annex 5 Protected areas information

Data source: http://natura2000.eea.europa.eu/Natura2000

Pobie Bank Reef (Site code UK0030385)

- Longitude: -0.293100; Latitude: 60.529700
- Area: 96575 ha of which 100% is marine area
- Protected habitats:

Habitat type	Description	Area (ha)
1170	Reefs	82032

- Protected species: Mammals (permanent residents)
  - 1364 *Halichoerus grypus* (Grey seal)
  - 1365 *Phoca vitulina* (Common seal)
  - 1351 *Phocoena phocoena (*Harbour Porpoise)

Hermanesss, Saxa vord and Valla Field (Site code UK9002011)

- Longitude: -0.901389; Latitude: 60.828333
- Area: 6832.36 ha of which 75.9% is marine area
- Protected habitats: None
- Protected species: Birds (mainly permanent residents)
  - A016 *Morus bassanus*
  - A204 *Fratercula arctica*
  - A001 *Gavia stellata*
  - A175 *Catharacta skua*
  - A009 *Fulmarus glacialis*
  - A018 *Phalacrocorax aristotelis*
  - A188 *Rissa tridactyla*
  - A199 *Uria aalge*

Keen of Hamar (Site code UK0012815)

- Longitude: -0.820000; Latitude: 60.767500
- Area: 39.8700 ha of which 0% is marine area
- Protected habitats:

Habitat type	Description	Area (ha)
4030	European dry heaths	17.59
8120	Calcareous and calcshist screes of the montane to alpine levels (Thlaspietea rotundifolii)	11.39
1230	Vegetated sea cliffs of the Atlantic and Baltic Coasts	1.04
6130	Calaminarian grasslands of the Violetalia calaminariae	9.31

- Protected species: None

Fetlar (Site code UK9002031)

- Longitude: -0.855556; Latitude: 60.603889
- Area: 16964.69 ha of which 85% is marine area
- Protected habitats: None
- Protected species: Birds (permanent residents)
  - A158 *Numenius phaeopus*
  - A009 *Fulmarus glacialis*
  - A173 *Stercorarius parasiticus*
  - A194 *Sterna paradisaea*
  - A466 *Calidris alpina schinzii*
  - A175 *Catharacta skua*
  - A170 *Phalaropus lobatus*

North Fetlar (Site code UK0030226)

- Longitude: -0.855556; Latitude: 60.616667
- Area: 1585.1800 ha of which 0% is marine area
- Protected habitats:

Habitat type	Description	Area (ha)
4030	European dry heaths	1284
7230	Alkaline fens	47.56

- Protected species: None

Yell Sound Coast (Site code UK0012687)

- Longitude: -1.150000; Latitude: 60.461111
- Area: 1544.44 ha of which 53.2% is marine area
- Protected habitats:

Habitat type	Description	Area (ha)
4010	Northern Atlantic wet heaths with Erica tetralix	0.93
1330	Atlantic salt meadows (Glauco-Puccinellietalia maritimae)	15.44
7130	Blanket bogs (* if active bog)	308.73
4060	Alpine and Boreal heaths	0.93
1210	Annual vegetation of drift lines	0.93
3160	Natural dystrophic lakes and ponds	30.58
1150	Coastal lagoons	14.98
4030	European dry heaths	150.43
1170	Reefs	463.18
1110	Sandbanks which are slightly covered by sea water all the time	14.52
8330	Submerged or partially submerged sea caves	0.93

- Protected species: mammals (permanent residents)
  - 1355 *Lutra lutra* (Otter)
  - 1365 *Phoca vitulina* (Common seal)

Noss (Site code UK9002081)

- Longitude: -1.012222; Latitude: 60.141667
- Area: 3338.38 ha of which 90.4% is marine area
- Protected habitats: None
- Protected species: Birds (mainly permanent residents)
  - A199 *Uria aalge*
  - A175 *Catharacta skua*
  - A016 *Morus bassanus*
  - A009 *Fulmarus glacialis*
  - A188 *Rissa tridactyla*
  - A204 *Fratercula arctica*

Mousa (Site code UK0012711)

- Longitude: -1.172222; Latitude: 60.000000
- Area: 529.7400ha of which 99.5% is marine area
- Protected habitats:

Habitat type	Description	Area (ha)
1210	Annual vegetation of drift lines	0.11
1170	Reefs	79.88
1110	Sandbanks which are slightly covered by sea water all the time	370.39
8330	Submerged or partially submerged sea caves	0.11

- Protected species: Mammals (permanent residents)
  - 1365 *Phoca vitulina* (Common seal)
  - 1351 *Phocoena phocoena* (Harbour Porpoise)

Mousa (Site code UK9002361)

- Longitude: -1.172222; Latitude: 60.000000
- Area: 196.85 ha of which 0% is marine area
- Protected habitats: None
- Protected species: Birds (permanent residents)
  - A194 *Sterna paradisaea*
  - A014 *Hydrobates pelagicus*

Sumburgh Head (Site code UK9002511)

- Longitude: -1.266389; Latitude: 59.860000
- Area: 2478.91 ha of which 98.6% is marine area

- Protected habitats: None
- Protected species: Birds (mainly permanent residents)
    - A194 *Sterna paradisaea*
    - A009 *Fulmarus glacialis*
    - A188 *Rissa tridactyla*
    - A199 *Uria aalge*

The nationally designated area Jærstrendene

Source: http://www.miljodirektoratet.no/old/dirnat/attachment/28/Rapport%202007-1b%20Emerald%20rapport%20engelsk.pdf

- Area: 20.457 ha
- Protected Habitats:
    - Sublittoral rocky seabeds and kelp forest
    - Mud flats and sand flats
    - Atlantic brackish saltmarsh communities
    - Dunes
    - Humid dune-slacks
    - Rich fens.
- Protected species: Birds and mammals
    - Great Northern Diver (Wintering site)
    - White-billed Diver
    - Black-throated Diver
    - Redthroated Diver
    - Horned Grebe
    - Grey Seal
    - Harbour Seal.

Other nationally designated areas in Norway

Source: www.naturbase.no

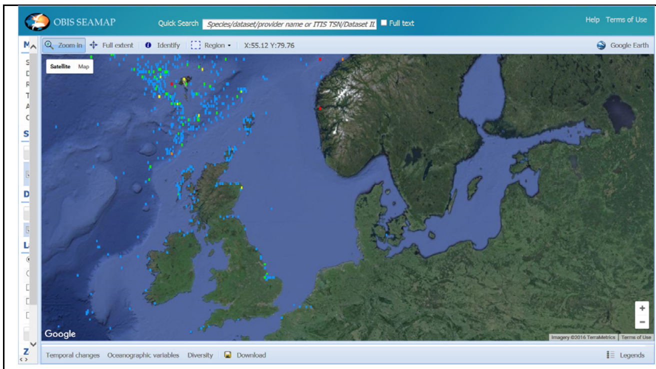
English name	Norwegian name	Latin name	Urter	Ferkingstadøyene	Heglane og Eime	Kjørholmane
European Shag	Toppskarv	*Phalacrocorax aristotelis*	+	+	+	+
Black-legged Kittiwake	Krykkje	*Rissa tridactyla*	+	-	-	+

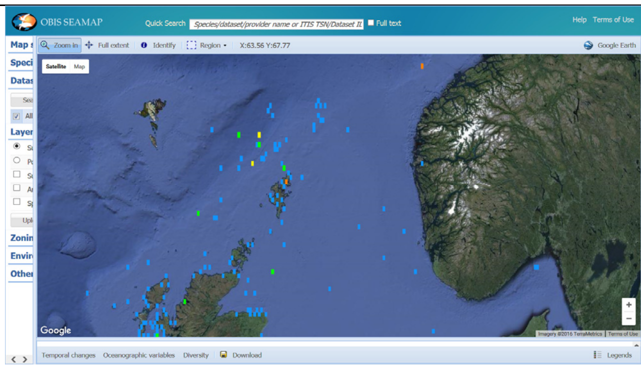
Razorbill	Alke	*Alca torda*		+	-	+
Atlantic Puffin	Lunde	*Fratercula arctica*		+	(+)	+
Black Guillemot	Teist	*Cepphus grylle*	+	+	+	+
Common Guillemot	Lomvi	*Uria aalge*		-	(+)	+
Northern Fulmar	Havhest	*Fulmarus glacialis*	+	+	-	+
Herring Gull	Gråmåke	*Larus argentatus*	(+)	+	+	+
Lesser Black-backed Gull	Sildemåke	*Larus fuscus*	+	+	+	+
Great Black-backed Gull	Svartbak	*Larus marinus*	(+)	+	+	+
Grey seal	Kystsel/Havert	*Halichoerus grypus*		-	-	+
Harbour seal	Steinkobbe	*Phoca vitulina*		-	-	+
Terns	Terner	*Sterna spec.*		(+)	-	-
Greylag goose	Grågås	*Anser anser*	(+)	-	+	+
Eider duck	Ærfugl	*Somateria mollissima*	+	-	+	-

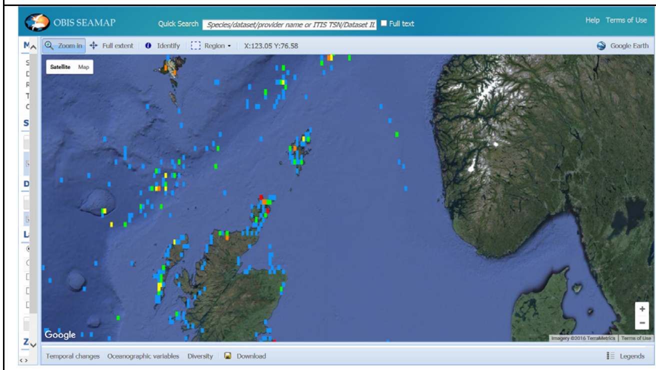
+ = present/mentioned in the factsheet; (+) = as + but as irregular, with low numbers etc.; - = not present/mentioned in the factsheet.

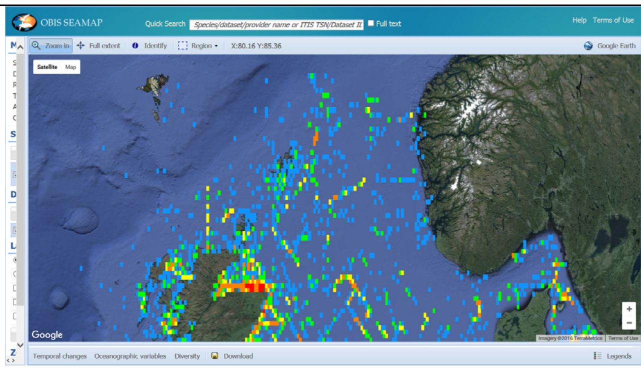
Annex 6 Sea mammal distribution maps

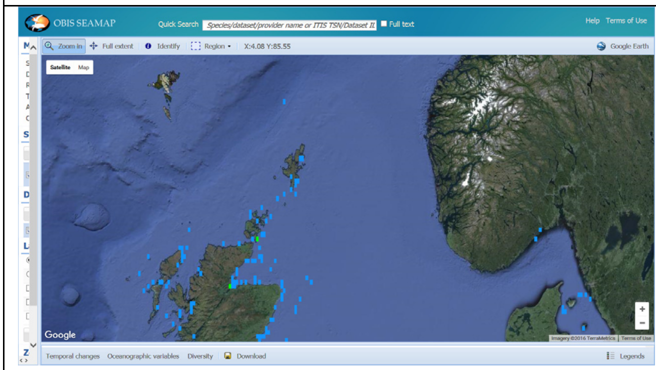
OBIS SeaMap http://seamap.env.duke.edu/

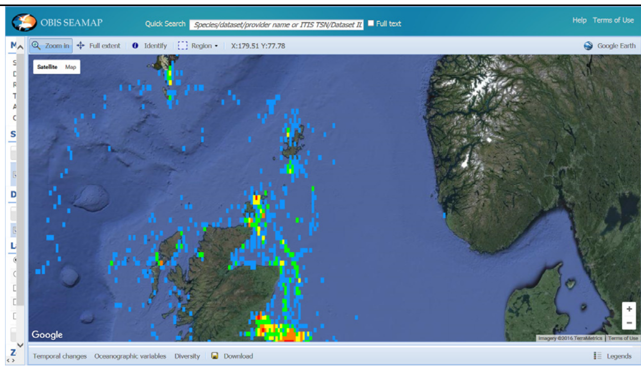

Sperm whale (*Physeter macrocephalus*)


Killer whale (*Orcinus orca*)


Long-finned Pilot whale (*Globicephala melas*)


Harbour porpoise (*Phocoena phocoena*)


Harbour seal (*Phoca vitulina*)


Grey seal (*Halichoerus grypus*)