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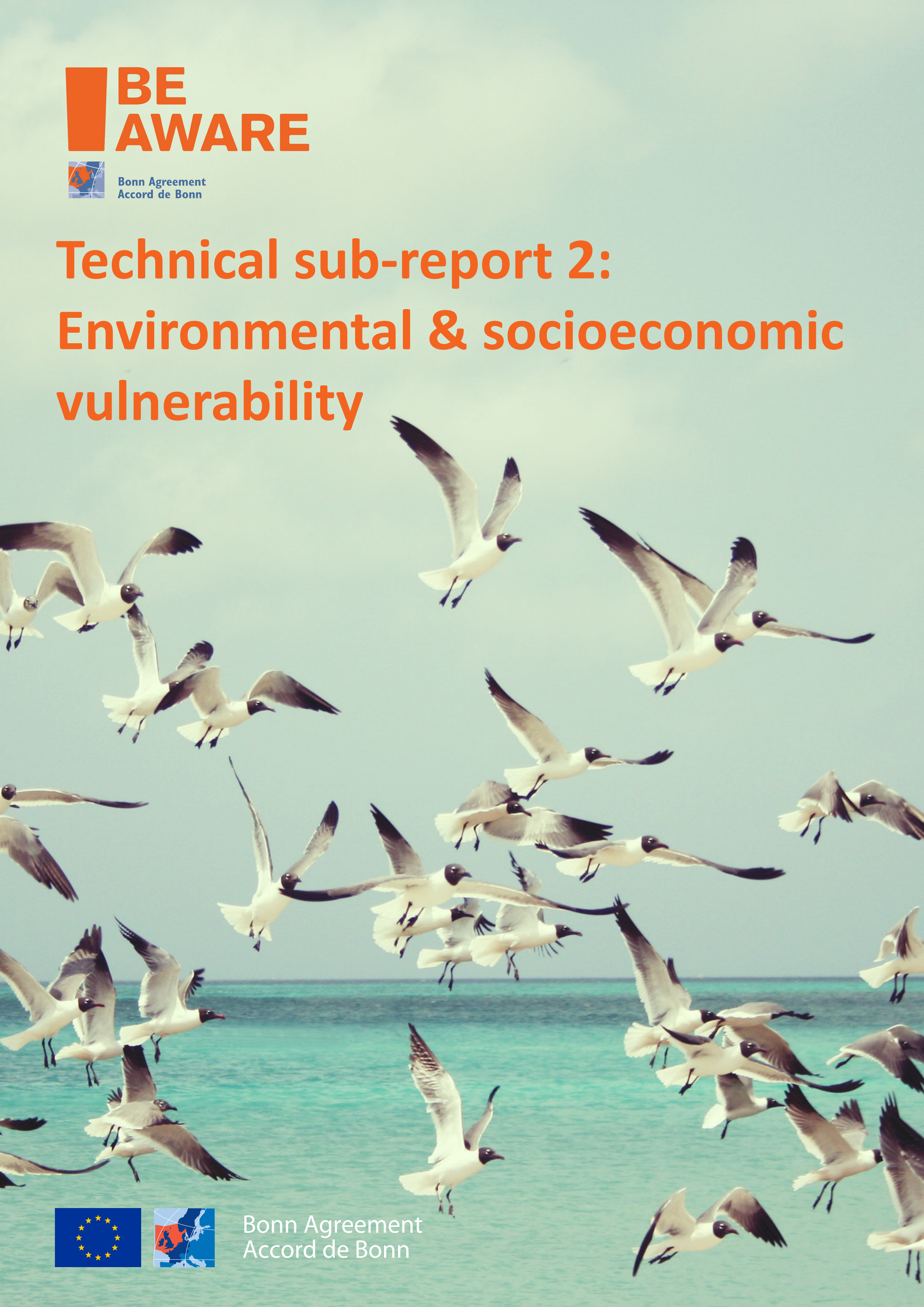
Technical sub-report 2: Environmental & socioeconomic vulnerability



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The Greater North Sea and its wider approaches is one of the busiest and most highly used maritime areas in the world. With the ever-increasing competition for space comes an increased risk of accidents that could result in marine pollution.

Currently the area has no overall risk assessment for marine pollution; risk is mapped with a variety of national risk assessments which are undertaken with differing methodologies; thus reducing comparability.

The BE-AWARE project is therefore undertaking the first area-wide risk assessment of marine pollution using a common methodology that allows the risk to be mapped and compared under different scenarios.

The project outcomes will be sub regional risk management conclusions, which will identify priority future risk reduction and response scenarios for each sub region, oil impact and damage assessments and a region wide environmental and socioeconomic vulnerability analysis.

The project is a two year initiative (2013-2015), co-financed by the European Union (DG ECHO), with participation and support from the Bonn Agreement Secretariat, Belgium, Denmark, France, Germany, Ireland, the Netherlands, Norway, Sweden and the United Kingdom.

Contents

1. Summary

This report describes the results of the vulnerability analysis of oil spills and mapping carried out as part of the BE AWARE II project. The analysis covers the North Sea, the Skagerrak, the English Channel, the Irish Sea and the waters west of Scotland and Ireland.

The report outlines the methodology behind the vulnerability analysis and subsequent ranking of environmental and socioeconomic features. The analysis and ranking are described for each of the identified environmental and socioeconomic features, as well as the scientific knowledge underlying each assessment of vulnerability.

In accordance with the findings and recommendations of the BE AWARE I study, the ranking of the vulnerability of environmental and socioeconomic features to oil spills in the different regions of the Bonn Agreement area was carried out in the following distinct steps:

- Step 1: The identification of environmental and socioeconomic features to be mapped and ranked according to vulnerability to oil spill;
- Step 2: The mapping of the identified environmental and socioeconomic features;
- Step 3: The assessment and definition of rank scores to be allocated to each of the identified environmental and socioeconomic features during spring, summer, autumn and winter;
- Step 4: Vulnerability mapping of the identified environmental and socioeconomic features to oil spill and;
- Step 5: The total seasonal vulnerability mapping by combining the results of Step 4.

2. Introduction

2.1 Background

The BE AWARE I project (2012-2014), assessed the risk of oil pollution both now (2011) and in the future (2020) and the likely size of any spills. However, in order to assess which methods and technologies will be most effective in reducing and responding to oil pollution, further analysis were required, that is the objective of the BE AWARE II project.

The project is a two two-year initiative (2013-2015), co-financed by the European Union (DG ECHO), Ireland and Germany, with participation from the Bonn Agreement Secretariat, Belgium, Denmark, France, Germany, Ireland, the Netherlands, Norway, Sweden and the United Kingdom.

2.2 Content and structure of report

This report describes the results of the oil spills vulnerability analysis and mapping carried out as part of the BE AWARE II project. The analysis covers the North Sea, the Skagerrak, the English Channel, the Irish Sea and the waters west of Scotland and Ireland, described in this report as the BA area.

The report is structured as follows:

- Chapter 3 outlines the methodology applied for the vulnerability analysis and ranking, as developed in BE-AWARE I;
- Chapter 4 describes the oil spill vulnerability analysis and ranking for each of the identified ecological features, which have been described and analysed in terms of:
    - Location and extent in the project area

  - Ecological characteristics
  - Sensitivity to oil spill including:
  - Fate of oil
  - Impacts of oil
  - Classification of vulnerability

- Chapter 5 describes the vulnerability analysis of birds and fish spawning areas, structured as chapter 4
- Chapter 6 describes the vulnerability ranking for Marine Protected Areas
- Chapter 7 describes the vulnerability ranking for each of the identified socioeconomic features, structured as chapter 4
- Chapter 8 sums up the outcome of the vulnerability analysis in terms of scoring matrices, which show the scores allocated to all identified ecological and socioeconomic features
- Chapter 9 presents the vulnerability maps

3. Methodology

3.1 Purpose of vulnerability mapping

Vulnerability mapping for oil spill response is a key element in the planning of oil spill response (IPIECA/IMO/OGP 2012), for several reasons:

- Oil spill vulnerability mapping is essential for developing a response strategy for oil spills (choice of combatting equipment, best suited response strategy and cooperation effort)
- Oil spill vulnerability maps identify the most sensitive environments or resources in relation to oil spills and provide a basis for prioritising areas to be protected or cleaned up following an oil spill. In the BE AWARE II context, the vulnerability maps are used in combination with models of risk of oil spills to assess and map the environmental risks of oil spills in the Greater North Sea and its approaches (the BA area).
- Oil spill vulnerability maps provide oil spill combat teams with essential information on the location of ecologically sensitive areas, economically important resources and the priority areas for protection and clean up;
- Oil spill vulnerability maps can also support the development of a dispersant use policy by providing information on the potential impact of dispersed oil in the water column.

3.2 Terminology

The use of the terms vulnerability and sensitivity can be confusing, particularly in the context of oil spill vulnerability mapping and prioritisation of resources. The following definitions are relevant to this report.

3.2.1 Vulnerability to oil spills

A feature is defined as vulnerable if it is likely that it could be directly exposed to either crude oil slicks or high concentrations of oil compounds for long enough time periods to be affected. Most intertidal features are vulnerable to oil spills because surface oil could strand upon them. However, wave-exposed shores are less vulnerable than sheltered shores because wave action removes the oil quickly on exposed shores, whereas on sheltered shores oil may persist for a long time. Subtidal features are less vulnerable to surface oil spills because most of the oil normally remains on the surface and it is unusual for high concentrations of oil to persist in the water for long time periods. On the other hand, shallow sub-tidal features are more vulnerable than deeper-lying features because concentrations of oil become increasingly diluted with increasing depth. Feature vulnerability can also include consideration of its location in relation to shipping traffic and industrial areas. Features close to shipping lanes, refineries and ports will be more vulnerable to oil spills than features further away.

3.2.2 Sensitivity to oil spills

In its strict sense, a feature is defined as being sensitive to oil if it is likely to be acutely affected by contact with either oil slicks or concentrations of oil compounds in water. However, this definition could include features with a low vulnerability to oil spills, such as biogenic reefs in deep water, or fish farm ponds where water is recycled rather than pumped in from the sea. These features are very sensitive to oil, but for the purposes of this report, they are not considered vulnerable to oil spills, as the risk of actually being hit by oil during an oil spill is small.

3.3 Overall procedure

During BE AWARE I, it was agreed that the vulnerability ranking should be based on a modification of the BRISK methodology (Brisk 2012).

To comply with the findings and recommendations of the BE AWARE I study (Schallier et al 2013) the ranking of the vulnerability of ecological and socioeconomic features to oil spills in the different regions of the BA area was carried out in the following distinct steps:

- Step 1: The identification of environmental and socioeconomic features to be mapped and ranked according to vulnerability to oil spill;
- Step 2: The mapping of the identified environmental and socioeconomic features;
- Step 3: The assessment and definition of rank scores to be allocated to each of the identified environmental and socioeconomic features during spring, summer, autumn and winter;
- Step 4: Vulnerability mapping of the identified environmental and socioeconomic features to oil spill and;
- Step 5: The total seasonal vulnerability mapping by combining the results of Step 4.

3.4 Step 1. Identification of ecological and socioeconomic features to be mapped and ranked

Environmental and socioeconomic features to be mapped and ranked according to vulnerability to oil spill were identified during BE AWARE I (Schallier et al 2013) and revised during the course of the project. The identified Environmental features are listed in Table 3-1 and the socioeconomic features in Table 3-2.

Table 3-1 Sensitive environmental features identified to be mapped and ranked according to vulnerability to oil spill.

Sensitive Environmental features in the BA area	
Shoreline and Coastal Habitats • Exposed rocky shores and reefs on less than 20m depth; • Exposed rocky shores and reefs on more than 20m depth: • Sheltered rocky shores and reefs on less than 20m depth: • Sheltered rocky shores and reefs on more than 20m depth; • Littoral chalk communities; • Sandy beaches; • Shingle beaches; • Tidal sand and mud flats; • Salt marshes; • Underwater sandbanks on less than 20m depth • Underwater sandbanks on more than 20m depth; • Biogenic reefs on less than 20m depth • Biogenic reefs on more than 20m depth • Maerl beds • Seagrass beds (Zostera sp. > 5%) • Estuaries • Coastal lagoons (open to the sea); • Large shallow inlets and bays;	**Open Sea Habitats** • Open water column on less than 20 m depth • Deep sea water column (>20 m depth) • Deep sea floor (>20m depth) • Seamounts • Coral gardens and sponge aggregations • Carbonate mounds • Lophelia pertusa reefs • Sea-pen and burrowing megafauna
Species Features • Spawning areas for fish • Wintering areas for birds • Staging areas for birds • Breeding areas for birds (incl. foraging areas)	**Coastal and marine protected areas** • Natura 2000 areas (EC Habitat and Birds Directive (SACs and SPAs)) • RAMSAR Convention areas • OSPAR Convention areas • Norwegian national plan for protection of marine areas

Table 3-2 Sensitive socioeconomic features identified to be mapped and ranked according to vulnerability to oil spill.

Sensitive Industries and Socioeconomic features in the BA area	
Fisheries • Offshore and coastal fisheries	**Aquaculture** • Fish farms • Shellfish cultures • Algae cultures
Tourism and recreation • Marinas • Overnight stays coastal tourist hotels • Densely populated towns and communities • Main recreational fishing locations • Cruise liner stops	**Other** • Heritage sites • Ports • Mineral extraction site • Offshore windfarms • Water intakes

During the process of selecting features and collecting available data, some additional features were considered and eventually disregarded. These included the ecological features kelp forests, coastal nursery areas for fish, important areas for marine mammals hereunder whales, seals and otters. There was not consistent and comparable datasets available for these features covering the whole region and therefore they were not included. However, the mentioned features are indirectly taken into account in the vulnerability analysis, as they are integral part of other features. Kelp forests, for example, are common in sheltered rocky shores and the presence of marine mammals are often part of the reason behind the protection of selected marine areas. Some socioeconomic features were also omitted due to lack of consistent data. That included harvesting of shellfish and algae from natural stocks and surfing hot spots. Finally, offshore platforms were also not included as a sensitive socioeconomic feature as, based on expert advice, the shut-down periods because of spills were expected to be insignificant.

3.5 Step 2. Preparation of maps of environmental and socioeconomic features

During step 2, COWI prepared maps of the location and extent of each of the agreed environmental and socioeconomic features within the Greater North Sea Area and its Approaches. The maps were based on the data collected by the Project Partner countries, the Bonn Agreement Secretariat and COWI in accordance with specifications outlined in a Data Request Note issued 5 June 2014 (COWI 2014a). Project partner countries and the Bonn Agreement Secretariat subsequently reviewed the maps for quality assurance.

3.6 Step 3. Assessment of the vulnerability to oil spills of the mapped environmental and socioeconomic features

3.6.1 Vulnerability scores and seasons

During BE AWARE I it was agreed to rank the vulnerability to oil spill of each of the identified environmental and socioeconomic features using the scores and seasons applied in the BRISK project (Table 3-3).

Table 3-3 Applied scores and seasons in the BRISK vulnerability ranking

Scores	Seasons
Score 4 = Very high vulnerability	Winter: December, January and February
Score 3 = High vulnerability	Spring: March, April and May
Score 2 = Moderate/medium vulnerability	Summer: June, July and August
Score 1 = Low vulnerability	Autumn: September, October and November.
Score 0 = Not affected	

COWI carried out a literature review of scientific papers and reports, with emphasis on surveys of the effects of particular oil spills on environmental and socioeconomic features in the North Sea and adjacent waters as well as laboratory studies on the effects of oil and dispersants. Based on this a proposal for ranking scores was prepared.

During a workshop in Brussels 11-12 September 2014, project partners discussed and agreed on the vulnerability scores for each of the identified environmental and socioeconomic features for each of the four seasons (winter, spring, summer and autumn) using the COWI proposal as a guideline. Scores were agreed both for a situation combating an oil spill using dispersants and a situation without the use of dispersants. The workshop approach and agenda, the list of participants and the results of the workshop were reported to the Bonn Agreement (COWI, 2014b).

3.6.2 Criteria for ranking

Environmental features

The vulnerability scores for ecological features are based on the following criteria which were decided on during BE AWARE I:

- Fate of oil (exposure, chemical recovery). The fate of oil in terms of oil weathering, natural degradation and removal in the particular ecosystem/ environment, the main factors being:

  - Onshore: Wave and tidal exposure, shoreline slope, substrate type;
  - Open water (3D): Natural energy (waves, currents, winds), depth;
- Potential impact of oil/sensitivity of habitats and organisms and their recovery.

Socioeconomic features

When oil affects a vulnerable socio-economic feature, the extent of damage will depend not only on the fate of the oil in the environment, but also on the sensitivity of the human activity to oil exposure and the potential for recovery of the activity once most of the oil has been removed. In other words, the same three aforementioned 'vulnerability' factors (exposure, sensitivity, recovery) also apply to define socio-economic vulnerability. As a result, any additional socio-economic ranking criterion reflects one or more of these three vulnerability factors in its definition.

The BE AWARE I project examined a set of additional socio-economic ranking criteria and agreed upon the following two additional criteria:

- Length of interruption of an activity or service
- Compensation

Impacts in terms of length of interruption of an activity or service involve important factors such as the possibility (or lack of) of protecting an activity and the possibility (or lack of) of displacing an activity.

Compensation in terms of whether a damaged feature can be economically compensated for or not, this is important when comparing economic vs. environmental vulnerability.

Aspects of the fate of spilled oil and potential impacts of oil on organisms, which were applied for the assessment of the sensitivity of oil spill on different habitats and organisms in the study area for this project are detailed in Appendix A.

The abovementioned criteria for vulnerability scoring of the environmental and socioeconomic features are summarised in Table 3-4.

Table 3-4 Criteria used for allocating vulnerability scores to the identified environmental and socioeconomic features

Criteria	Definition
Fate of oil (exposure; chemical recovery)	The fate of oil in terms of oil weathering, natural degradation and removal in the particular ecosystem/ environment , the main factors being: • Onshore: Wave and tidal exposure, shoreline slope, substrate type • Open water: Natural energy (waves, currents, winds), depth Effect of the use of dispersants has also been included.
Impact of oil (ecological sensitivity; biological recovery)	The impact of oil in terms of physical and toxic effects, tainting and a selection of population and life cycle considerations. Population and life cycle considerations: • The ability of plants and animals to survive and recover from contamination by oil varies significantly. Population of organisms are most at risk from oil spills when: • Large numbers of individuals are concentrated in a relatively small area; • Marine or aquatic species come ashore during special life stages or activities, such as nesting, birthing, resting, or moulting; • Early life stages or important reproductive activities occur in sheltered, near shore environments where oil tends to accumulate; • Limited suitable habitat exists within an area for specific life stages or along critical migratory routes;

	• Specific areas are known to be vital sources for seed or propagation; • A species is threatened, endangered, or rare; or • A significant percentage of the population is likely to be exposed to oil Impacts of the use of dispersants was also included
Social Nuisance (social sensitivity)	Describing the degree of social nuisance
Length of interruption (socio-economic sensitivity)	Describing socio-economic impact in terms of length of interruption of an activity or service. Important factors being: • Possibility (or lack of) of protecting an activity • Possibility (or lack of) of displacing an activity
Compensation potential (economic recovery)	In terms of whether a damaged feature can be economically compensated for or not. Important when comparing economic vs. ecological vulnerability

3.7 Step 4. Vulnerability mapping

During step 4, separate environmental and socioeconomic vulnerability maps for each season were prepared in GIS format. The following maps were prepared:

- Vulnerability maps for habitats for each of the four seasons and for non-dispersed and dispersed oil spills (a total of eight maps per feature);
- Vulnerability maps for species for each of the four seasons and for non-dispersed and dispersed oil spills (a total of eight maps per feature);
- Vulnerability maps for Protected Areas for each of the four seasons and for non-dispersed and dispersed oil spills (a total of eight maps per feature);
- Vulnerability maps for socioeconomic features for each of the four seasons and for non-dispersed and dispersed oil spills (a total of eight maps per feature)

The maps were based on data delivered as GIS layers with location and extent of the ecological and socioeconomic features and the vulnerability scores of each individual feature.

Each of the vulnerability maps was prepared by summing up individual vulnerability scores of all features and reclassifying the total scores into five different overall vulnerability classes:

- Very high vulnerability
- High vulnerability
- Medium vulnerability
- Low vulnerability
- Very low vulnerability

Table 3-5 shows the sum of scores for habitats, species, protected areas and socio-economic features that correspond to each vulnerability class on the vulnerability maps.

Table 3-5 Reclassification of vulnerability maps. Sum of scores of that correspond to each vulnerability class.

Vulnerability class	Habitats (sum of scores)	Species (sum of scores)	Protected areas (sum of scores)	Socioeconomy (sum of scores)
Very high vulnerability	6-8	13-18	16	12-24
High vulnerability	4-5	9-12	12	9-11
Medium vulnerability	3	7-8	8	6-8
Low vulnerability	2	4-6	4	3-5
Very low vulnerability	1	1-3	-	1-2

3.8 Step 5. Total seasonal vulnerability mapping

Integrated total vulnerability maps were prepared from a combination of the four series of seasonal vulnerability maps (habitats, species, protected areas and socio-economic features) based on the use of a weighting ratio. During the workshop in Brussels, 11-12 September 2014 it was decided to apply the series of weighting ratios indicated in Table 3-6.

Table 3-6 Proposed weighting ratios of feature groups.

Groups	Weighting ratios (%)				
	1	2	3	4	Based on feature numbers
1 Habitats	25	35	15	50	48
2 Species	25	25	15	10	15
3 Protected areas	25	30	20	15	8
4 Socio-economy	25	10	50	25	28

The four first options in Table 3-6 were chosen and maps of total vulnerability were made using each ratio to observe variations due to weighting. There were very little variation between vulnerabilities of the different ratios and the analyses proceeded with weighting ratios 1.

4. VULNERABILITY ANALYSIS OF HABITATS

This chapter presents the results of the vulnerability analysis of the selected habitats.

Please notice, the scaling of maps necessary to illustrate the whole Bonn Agreement Area in one map, makes it difficult to see details on a local scale. On the BE AWARE web site (http://www.bonnagreement.org/be-aware/ii), interactive versions of the vulnerability maps are will be made available and can be used to assess local variations in locations and vulnerability.

Each habitat is described and analysed in terms of:

- Ecological characteristics and significance
- Discussion of vulnerability in terms of fate of oil in the habitat type and impact of oil/sensitivity to oil of organisms in the habitat
- Allocation of vulnerability scores of undispersed and dispersed surface oil spill

4.1 Rocky shores and reefs

This habitat was split into the following habitat sub-groups as they differ in terms of fate of oil and vulnerability:

- Sheltered rocky shores and reefs (< 20 m)
- Sheltered rocky shores and reefs (> 20 m)
- Exposed rocky shores and reefs (< 20 m)
- Exposed rocky shores and reefs (>20 m)

4.1.1 Location of rocky shores and reefs

Rocky shores are mainly encountered in Norway, Sweden, Scotland (including the Orkney and Shetland Islands) and Ireland. Rocky shores are also found in England, Wales, and Brittany and scattered along other parts of the French coast. Sheltered rocky shores are mainly found in Norway and the west coast of Scotland (Figure 4-1 and Figure 4-2). Rocky shores are not found in Denmark, Germany, the Netherlands and Belgium.

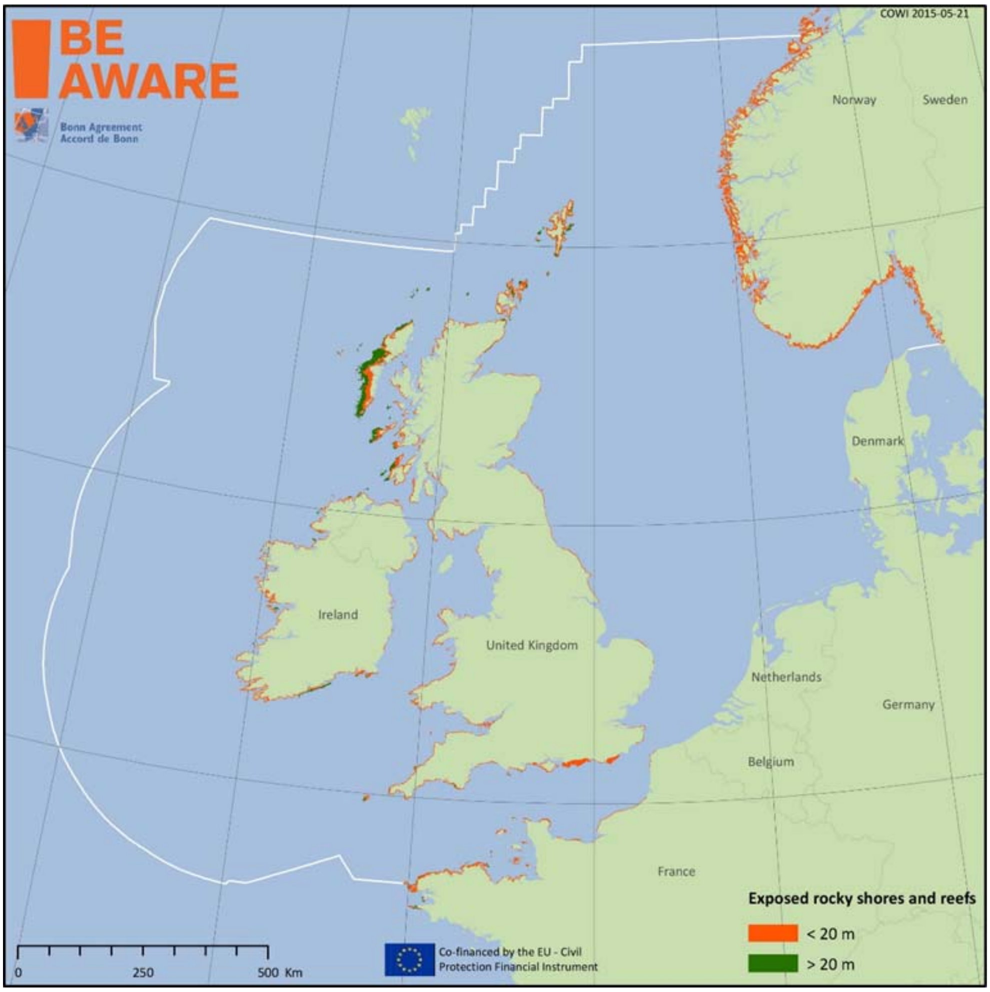

Figure 4-1 Location of exposed rocky shores and reefs on waters < 20 m depth and > 20m depth.

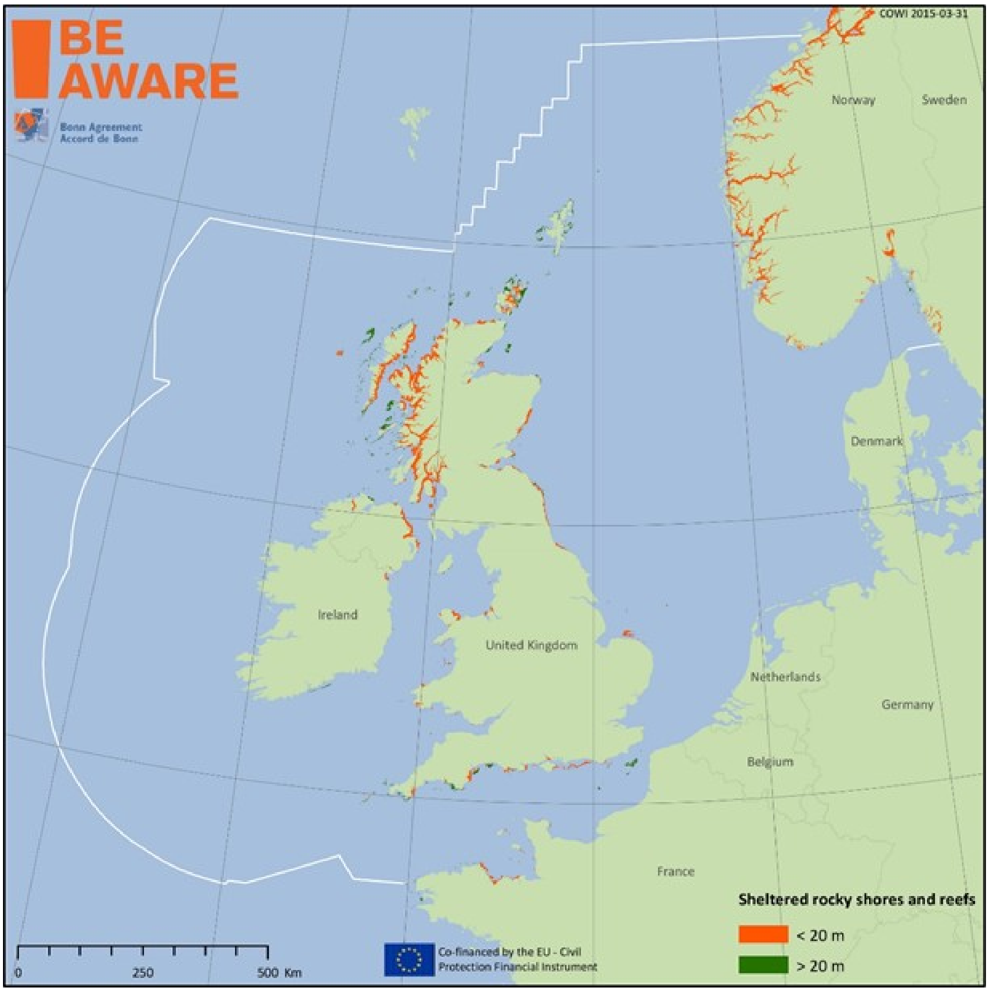

Figure 4-2 Location of sheltered rocky shores and reefs on waters < 20 m depth and > 20m depth.

4.1.2 Ecological characteristics and significance. Rocky shores and reefs

A rocky shore is an intertidal area that consists of solid rocks. Rocky shores are encountered on shores where the effect of waves on the coast is mainly erosive. Softer rocks are worn down, leaving harder rocks exposed. Rocky shores are the most variable coastal habitat. Their character mainly depends on the prevailing rock type and the exposure to wind, waves and currents. The habitat is physically complex, with changes of slope and the presence of rock pools, gullies, crevices and boulders increasing the range of habitats and consequently the number of species present. As rocks are stable, they provide a secure surface for attached organisms such as seaweeds, barnacles, mussels and limpets. Conditions on rocky shores are harsh and organisms have to be able to survive rapidly to changing environmental conditions and to be capable of rapid recolonisation. Despite this, they are important marine habitats with a high biodiversity.

Zonation of seaweed

The physical conditions on rocky habitats are highly variable along the rock profile in terms of light availability, degree of exposure, changes in temperature and salinity, resulting in a characteristic distinct zonation of seaweed. Five different vegetation zones are typically encountered with the following characteristics:

- The eulittoral zone (the splash zone), which is situated on the upper region of the rocky habitat. This zone is only covered by water during storms and extremely high tides and is moistened by the spray of the breaking waves. Organisms are exposed to the drying heat of the sun in the summer and to low temperatures in the winter. Only a few resistant organisms can live in this harsh environment, including lichens, certain species of green algae and cyanobacteria.

- The littoral zone. The littoral zone is the shoreward fringe of the sea, which is affected by the tide. The intertidal zone can be sub-divided in three zones:
  - The high tide zone, which is only flooded during high tides. The brown algae channelled wrack (*Pelvetia canaliculata*) is common in this zone
  - The middle tide zone is covered by water twice a day. This zone is often densely grown with the brown algae flat wrack (*Fucus spiralis*), knotted wrack (*Ascophyllum nodosum*) and Bladder wrack (*Fucus vesiculosus*)
  - Low intertidal zone, which is usually covered with water. This zone is only uncovered when the tide is extremely low. In contrast to the other zones, the organisms are not well adapted to long periods of dryness or to extreme temperatures. Saw wrack (*Fucus serratus*) is common in this zone
- The subtidal zone is situated below the intertidal zone and is continuously covered by water. This zone is much more stable than the intertidal zone. Common seaweed species include the brown algae saw wrack (*Fucus serratus*), oar weed (*Laminaria digitata*), sugar wrack (*Laminaria saccharina*) and a wide variety of red algae.

Characteristic Fauna

Rocks and stones are often substrate for epifauna such as barnacles, limpets, periwinkles (*Littorina* sp.) and common mussel (*Mytilus edulis*). Sub-littoral rocks and stones are important spawning and nursery areas for a number of fish species. Rocky shores are also important breeding areas for seabirds and coastal birds. Important habitats for seals may also be encountered.

EUNIS Classification

The European Nature Information System (EUNIS) habitat classification is a pan-European system that was developed between 1996 and 2001. It was updated in 2004 by the European Environment Agency (EEA) in collaboration with experts from all over Europe. It covers all types of natural and artificial habitats, both aquatic and terrestrial.

Exposed rocky shores and reefs include the following EUNIS habitats:

- A1.1 High energy littoral rock
- A3.1 Atlantic and Mediterranean high energy infralittoral rock
- A4.1 Atlantic and Mediterranean high energy infralittoral rock

Sheltered rocky shores and reefs include the following EUNIS habitats:

- A1.2 Moderate energy littoral rock
- A1.3 Low energy littoral rock
- A3.2 Atlantic and Mediterranean moderate energy infralittoral rock
- A3.3 Atlantic and Mediterranean low energy infralittoral rock
- A4.2 Atlantic and Mediterranean moderate energy circalittoral rock
- A4.3 Atlantic and Mediterranean low energy circalittoral rock

4.1.3 Vulnerability of rocky shores and reefs

Fate of oil

Rocky shores include different types of rocky habitats each differing in terms of the fate of stranded oil (see Table 4-1).

Table 4-1 Fate of oil on different types of rocky shores.

Type of rocky habitat	Fate of oil
Steep exposed rocks (Wave-cut cliffs)	Steep exposed rocks are characterised by regular exposure to high wave energy and tidal currents. The waves are strongly reflected. The slope of the intertidal zone is 30 degrees or greater, resulting in a narrow intertidal and splash zone. The persistence of oil on steep exposed rock is low because they are exposed to large waves, wave reflection tends to keep oil offshore, and waves promote rapid natural degradation of oil. In addition stranded oil remains on the surface because the substrate is impermeable, resulting in quick removal of oil by natural degradation processes. Wave-cut cliffs are often found interspersed with other shoreline types, particularly wave-cut platforms.
Exposed wave-cut rock platform	Wave-cut platforms are flat rock benches formed by erosion within the intertidal zone. Exposed wave-cut platforms are characterised by regular exposure to high wave energy and strong wave-reflection patterns. The lower slope result in a wider intertidal zone compared to vertical rocks. The intertidal zone can be up to hundreds of metres wide. The substrate is impermeable with no potential for subsurface penetration over much of the intertidal zone and the high wave energy tends to remove oil. However, stranded oil may persist longer compared to steep exposed rocks. If beach sediments are encountered behind the wave cut rock platform stranded oil may penetrate and persist longer in these sediments. The oil is removed only when large waves rework the sediment. Secondly, oil may accumulate in tidal pools and crevices on the platform.
Sheltered rocky areas	Due to the general low energy regime of sheltered rocky shores spilled oil will persist for a long time

Impact of oil/sensitivity

Organisms attached to rocks and stones are very sensitive to oil.

Macro algae

Table 4-2 shows selected references from field surveys on the effects on macro algae following oil spills. Although some studies have failed to demonstrate the effects of oil spills on macroalgae, the general experience is that macro algae in coastal areas can be severely affected due to direct toxic effects, smothering and indirect effects derived from the spill. Such indirect effects may delay recovery for a decade or more.

Table 4-2 Selected references from field surveys on the effects on macro algae following oil spills.

Spill	Reported effect	Reference
2006. Extensive oil spill detected in Nova an Keibu Bay in the south-western Gulf of Finland	The oil spill only had a minor effect on the benthic vegetation. The species composition, coverage of *Fucus vesiculosus* and depth distribution of macrophytes were not affected by the spill but the coverage of *Pilayella littoralis* was significantly lower in the impacted area than in the reference areas.	Kotta et al 2007
2002. Oil spill from the shipwrecked tanker "*Prestige"* in the northwest coast of Spain. 64,000 tonnes were spilled	Algal Belts of *Pelvetia caniculata*, *Fucus spiralis Fucus vesiculosus* and *Rhopdothamniella floridla* on the shoreline disappeared	Garcia R 2003
1989 "*Exxon Valdez*" oil spill in Prince William Sound Alaska. 35,360 tonnes of oil spilled	*Fucus gardneri* was heavily affected and recovery took a decade or more	Peterson et al 2003, Driskell et al 200
1977. "*Thesis*", Baltic Sea Sweden; spill of 1,000 tonnes of medium fuel oil	*Fucus vesiculosus* in the area was not affected	Linden et al. 1979; Teal and Howarth 1984.
1973: "*Arrow*" spill in Nova Scotia	The vertical distribution of *Fucus* spp. was dramatically reduced and masses of algae (mostly *Fucus serratus*) washed ashore	Anon 1985, Kotta et al 2007
1971 "C*hryssi P. Goulandris*" spill in Wales	A decrease in *Fucus vesiculosus* coverage was observed following the spill. During the "recovery" phase Fucus decreased in abundance as populations of the limpet, *Patella vulgate* increased.	Crapp 1971
1967. Oil spill from the shipwrecked tanker "*Torrey Canyon*" at Cornwall UK. 120,000 tonnes of oil were spilled	Macroalgae were affected by the spill. Areas that were bare due to toxic effects of the oil and dispersant were initially colonised by ephemeral green alga, which were followed in succession by *Fucus vesiculosus* and *Fucus serratus*.	Southward and Southward 1978

Comprehensive studies carried out following the 1989 "Exxon Valdez" oil spill in Prince William Sound Alaska have shown severe and long-term impacts on rockweed *Fucus gardneri*. The dramatic initial loss of cover by *F. gardneri*, which was the most important habitat provider, triggered a cascade of indirect impacts that lengthened the recovery for a decade or more. (Peterson et al 2003, Driskell et al 2001, DeVogalaere and Foster 1994). The following rather complicated chain of events apparently took place:

- *Fucus* cover at spill-disturbed sites initially decreased dramatically due to toxic effects of oil and clean up. Coverage averaged <1 percent at oiled sites versus 80 percent at un-oiled sites up to 30 months.
- The slow recovery has been explained as follows: Freeing of space on the rocks and the loss of important grazing (limpets and periwinkles) and predatory (whelks) gastropods due to impacts of the oil spill combined to promote initial blooms of ephemeral green algae in 1989 and 1990 and an opportunistic barnacle, *Chthamalus dalli*, in 1991. Absence of structural algal canopy led to declines in associated invertebrates and inhibited recovery of *Fucus* itself, whose recruits avoid desiccation under the protective cover of the adult plants. Those *Fucus* plants that subsequently settled on tests of *C. dalli* became dislodged

during storms because of the structural instability of the attachment of this opportunistic barnacle.

- By 1993, the *Fucus* on previously oiled shores had apparently recovered but in 1994-1995, the rockweed exhibited a mass mortality again. The changes in cover at spill-disturbed sites were dramatic (≥50% decline year to year) and synchronous. In contrast, unaffected reference sites demonstrated little synchrony. The mass mortality was explained as a cyclic instability probably caused by simultaneous senility of the single-aged stand that was recruited some years following the spill.

Apparently, not all populations of algae are affected seriously by hydrocarbons and indeed some appear to be notably tolerant even during their reproductive and early developmental phases. Thus, the oil did not affect beds of Kelp (*Laminaria digitata*) at the Amoco Cadiz spill site (Anon 1985).

Usually, intertidal rocky areas where algae have been affected by an oil spill are readily repopulated once the oil has been substantially removed. The plants have the capacity to grow new leaves (the leaves grow from a relatively protected meristem). Recovery can occur within 6-12 months. Plant mortality has been observed at spills when sediments were contaminated by oil.

Invertebrate epifauna

Invertebrate epifauna organisms are generally very sensitive to oil spills and elevated concentrations of toxic oil components in the water. There are numerous examples of severe impacts on benthic fauna following oil spills. However, impacts have only been observed on shallow water along the coasts where toxic concentrations may reach the seabed. Impacts on benthic fauna in open waters have not been observed. Table 4-3 shows some examples of impacts of oil spills on epifauna observed in coastal waters.

In general, benthic fauna has a high recovery potential. Re-colonisation by most species is quite rapid but the recovery of certain sensitive species may be prolonged (such as species of crustaceans and mussels).

Table 4-3 Selected references from field surveys on the effects on benthic epifauna following oil spills.

Spill	Reported effect	Reference
2002. Oil spill from the shipwrecked tanker "*Prestige*" in the northwest coast of Spain. 64,000 tonnes were spilled	Two years after the spill severe impacts on lysosomes, tissues of digestive glands, health and immune system of the mussel *Mytilus galloprovincialis* were observed.	Basque Research (2009)
1996 oil spill from the "*Sea Empress*" off the coast of Wales	The oil spill caused serious mortalities of rock dwelling invertebrates. Large numbers of limpets were killed on heavily oiled rocky shores with up to 90% mortality recorded. Top shells and periwinkles also died, though in lower numbers. The recovery process of limpet and other mollusc populations started shortly after the spill	Dyrynda, 1996
1993 "*Braer*" oil spill Shetland	Limpets on rocky shores near the spill were heavily affected by oil.	Kingston, et al 1995

Vulnerability scores. Rocky shores and reefs

Exposed rocky shores and reefs < 20 m

Exposed rocky shores and reefs on water depth less than 20 m have been allocated the following vulnerability scores:

- Score surface oil spill: Spring: 3, Summer: 3, Autumn: 2, Winter: 2
- Score dispersed oil: Spring: 3, Summer: 3, Autumn: 2, Winter: 2

The scores were based on the ecological and impacts characteristics described above and the following arguments:

- Exposed rocky shores are typically a mix of steep rocks and rocks with low to moderate slope. The fate of oil differs somewhat on the two types of rock (see Table 4-1)
- Organisms attached to rocks, stones are very sensitive to oil due to direct toxic effects, smothering, and indirect effects derived from the spill. Recovery of algal vegetation is slow. Re-colonization by most species of epifauna is however quite rapid but the recovery of certain sensitive species may be prolonged (such as species of crustaceans and mussels)
- Due to the shorter persistence of oil on exposed rocks compared to sheltered rocks, the score has been set to 3 and to 2 in autumn and winter where the highest wave energy is expected to occur.

The scores and the arguments behind them are identical for surface oil spills and dispersed oil.

Exposed rocky shores and reefs > 20 m

Exposed rocky shores and reefs on water depths of more than 20 m have been allocated the following vulnerability scores:

- Score surface oil spill: Spring: 1, Summer: 1, Autumn: 1, Winter: 1
- Score dispersed oil: Spring: 2, Summer: 2, Autumn: 2, Winter: 2

The scores for surface oil spills have been lowered compared to “Exposed rocky shores and reefs < 20m", because there is a lower risk that spilled oil will reach the reefs on deeper waters. For dispersed oil, the score has been maintained as 2 in all seasons because in general the risk of dispersed oil reaching deeper water is higher.

Sheltered rocky shores and reefs < 20 m

Sheltered rocky shores and reefs on water depths of less than 20 m have been allocated the following vulnerability scores:

- Score surface oil spill: Spring: 4, Summer: 4, Autumn: 3, Winter: 3
- Score dispersed oil: Spring: 4, Summer: 4, Autumn: 4, Winter: 4

The scores were based on the ecological and impacts characteristics described above and the following arguments:

- Sheltered rocky shores and reefs is an important marine habitat with a high biodiversity. There are spawning and nursery areas for fish and crustaceans, and feeding areas for birds.
- Organisms attached to rocks and stones, are very sensitive to oil due to direct toxic effects, smothering and indirect effects derived from the spill.
- On shallow water < 20 m toxic concentrations may reach the organisms and affect them.
- Recovery of algal vegetation is slow. Re-colonization by most species of epifauna is however quite rapid but the recovery of certain sensitive species may be prolonged (such as species of crustaceans and mussels).

- Due to the general low energy regime of sheltered rocky shores spilled oil may persist for a long time.
- The vulnerability scores for dispersed oil during autumn and winter have been elevated compared to surface oil spill because it is less influenced by exposure and is more damaging than surface oil spills in general.

Sheltered rocky shores and reefs > 20 m

Sheltered rocky shores and reefs on water depths of more than 20 m was allocated the following vulnerability scores:

- Score surface oil spill: Spring: 2, Summer: 2, Autumn: 2, Winter: 2
- Score dispersed oil: Spring: 4, Summer: 4, Autumn: 4, Winter: 4

The scores for surface oil spills have been lowered by one compared to “Sheltered rocky shores and reefs < 20 m", because there is less risk of spilled oil reaching the reefs on deeper waters. The scores for dispersed oil remain the same as for shallower sheltered rocky shores and reefs.

4.2 Littoral chalk communities

4.2.1 Location of littoral chalk communities

Littoral chalk communities are relatively rare communities in Europe. They are mainly found on the southern and eastern coasts of England and in Northern Ireland (Figure 4-3).

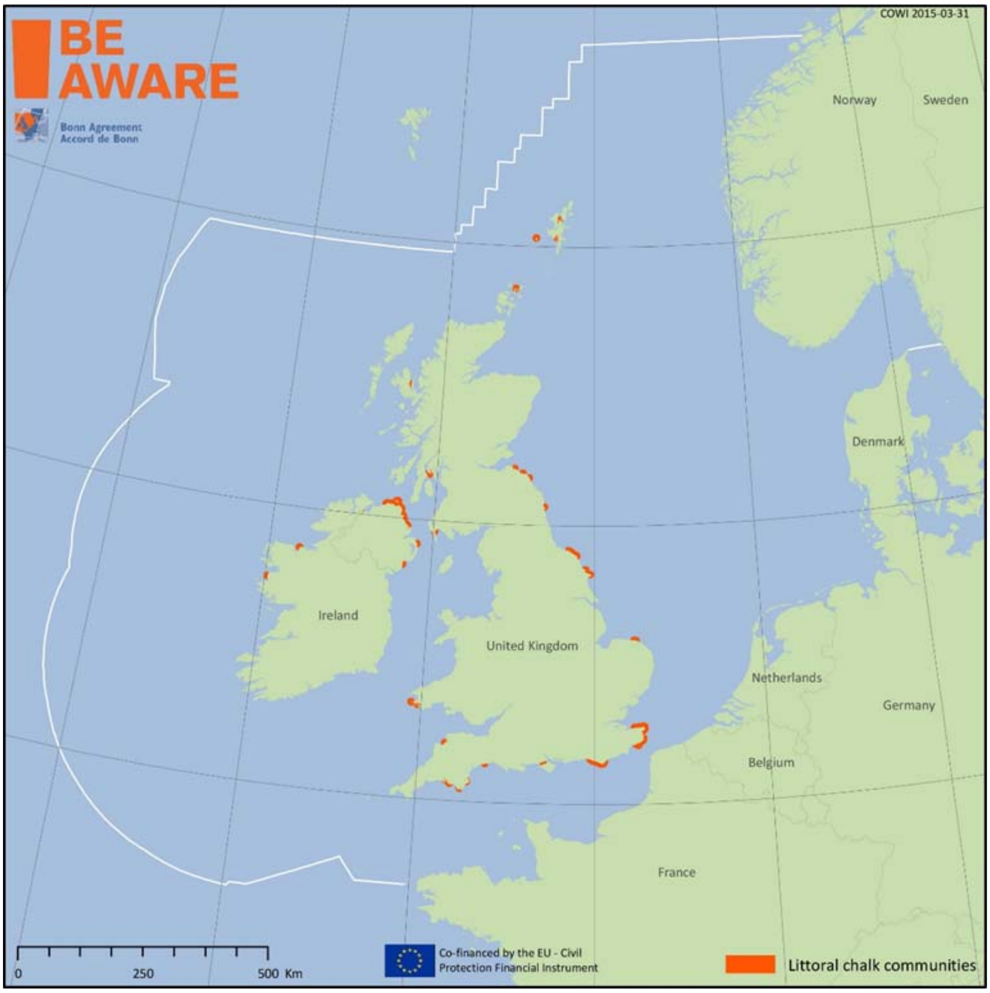

Figure 4-3 Location of littoral chalk communities

4.2.2 Ecological characteristics and significance of littoral chalk communities

Littoral chalk communities have developed as a result of erosion of chalk by the sea, causing the formation of vertical chalk cliffs, sea caves and gently sloping intertidal chalk platforms often many hundreds of metres wide (OSPAR 2008).

Characteristic flora and fauna

The chalk formations house rich and unique communities of seaweed with a characteristic zonation (OSPAR 2009):

- In the supralittoral zone above the high water mark, where the chalk cliffs and sea caves are splashed by waves, orange, brownish or blackish gelatinous bands of algae on the white chalk are encountered including species of Haptophycea (such as *Apistonema* spp, *Pleurochrysis carterae* and *Crysotila lamellose*), *Chrysophycea* and *Prasionophycea*.
- In the lower littoral fringe regularly covered by the tide, dense mats of green seaweeds, such as Enteromorpha spp and *Ulva lactuca* and various red and brown algae (such as *Fucus spiralis*) may occur.

Close to the low water mark, ‘rock-boring’ animals such as piddocks are found overlain by seaweeds (fucoids and red algal turfs).

EUNIS Classification

Littoral chalk communities include the following EUNIS habitats:

- A1.126 *Osmundea pinnatifida* on moderately exposed mid eulittoral rock
- A1.2143 *Fucus serratus* and piddocks on lower eulittoral soft rock
- A1.441 *Chrysophyceae* and *Haptophyceae* on vertical upper littoral fringe soft rock
- B3.114 *Blidingia* spp on vertical fringe chalk
- B3.115 *Ulothrix flacca* and *Urospora* spp on freshwater influenced vertical fringe soft rock

4.2.3 Vulnerability of littoral chalk communities

Fate and impacts of oil

Littoral chalk communities on the shore are vulnerable to pollution and oil spills. They are encountered on shallow water, implying that organisms may be affected by smothering or toxic effects of oil and oil components. In addition, organisms on chalk communities are very sensitive to oil spills. Table 4-4 shows examples of oil spills that have deleteriously affected algae that are typical for littoral chalk communities.

Table 4-4 Selected references from field surveys on the effects of oil spill on species of macroalgae that may be encountered on littoral chalk communities.

Spill	Reported effect	Reference
1969. The Santa Barbara oil spill, which occurred in the Santa Barbara Channel in Southern California. The source of the spill was a blowout on Union Oil's Platform A in the Dos Cuadras Offshore Oil Field. Within a ten-day period, an estimated 80,000 to 100,000 barrels of crude oil spilled into the Channel and onto the beaches of Santa Barbara County in Southern California	*Ulva lactuca, Enteromorpha intestinalis* were damaged and killed with the effects being most severe on the highest occurring *Enteromorpha* where the oil was stranded for long periods. On mid-tidal substrates, where oil was removed relatively quickly by weathering and scouring, Ulva recolonisation was quite rapid.	O`Brien and Dixon 1976
1971. The Panamanian tanker the "*Texaco Caribbean*" collided with the Peruvian freighter the "*Paracas*" in thick fog off the coast of Kent near Dover UK. The Texaco Caribbean exploded, split in two and sank, releasing 600 tonnes of bunker oil and ballast.	The spill resulted in a patchy deposition of oil and oil-detergent mixtures on upper intertidal communities that deleteriously affected algae (Tittley, 1972). Affected algae included the following species that are typical for littoral communities: the green algae *Enteromorpha* spp. and the red algae *Porphyra umbilicalis*, *Gigartina stellate*, *Gelidium crinale*, *Ceramium* spp. and *Calithamnion* spp. Although not specifically stated in the paper, the affected community may very well have been a littoral chalk as these are in the Dover area, where the accident occurred.	Tittley, 1972
2002. Oil spill from the shipwrecked tanker "*Prestige*" on the northwest coast of Spain. 64,000 tonnes were spilled	Algal Belts of *Fucus spiralis* on the shoreline disappeared	Garcia R 2003

Vulnerability scores littoral chalk communities

Based on these ecological and impact characteristics undispersed surface oil spills and dispersed oil spills on littoral chalk communities have both been allocated the following scores: Spring: 4, Summer: 4, Autumn: 3, Winter: 3.

4.3 Sandy beaches

4.3.1 Location of sandy beaches

Large stretches of sandy beaches are found along the coasts of Denmark, Germany, the Netherlands, Belgium, France, UK and Ireland (Figure 4-4). Sandy beaches in Norway are more rare and smaller, compared to the rest of the Bonn Agreement area. However, they are numerous along the Norwegian coastline, often in sheltered bays and with a local high recreational value.

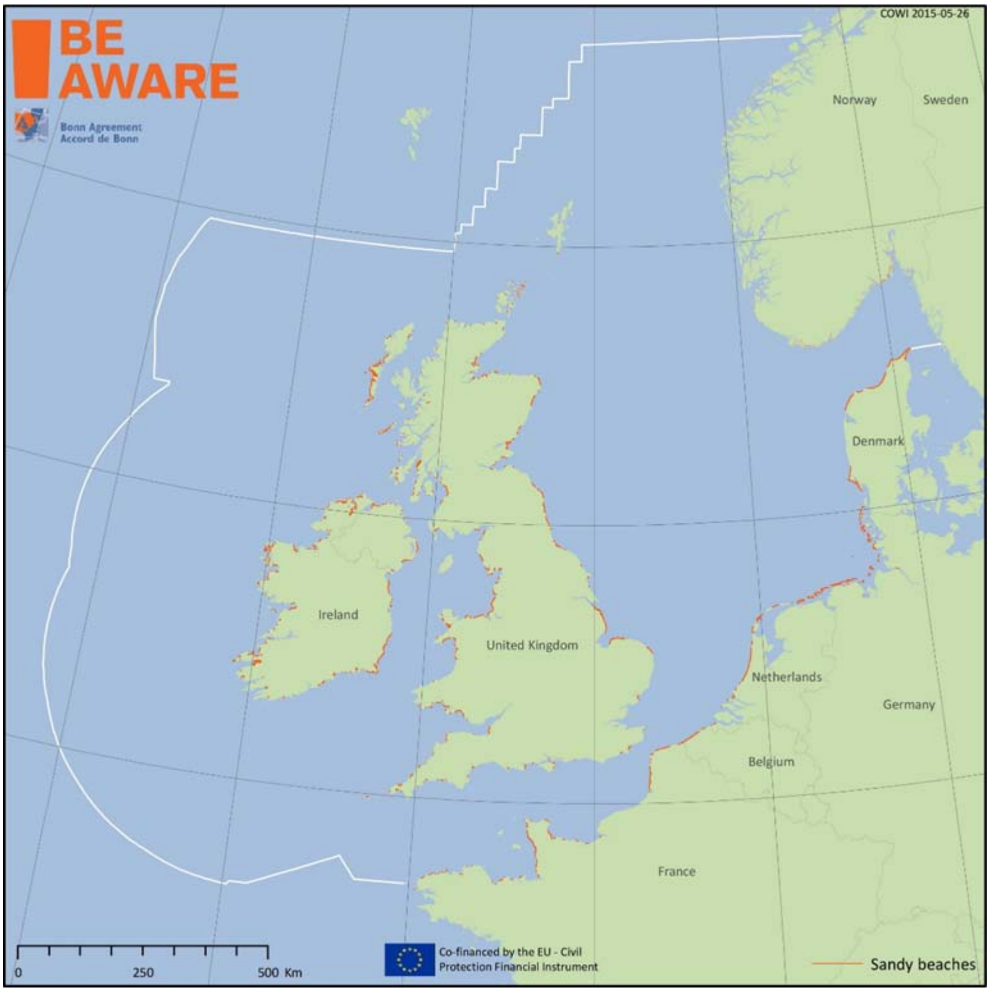

Figure 4-4 Location of sandy beaches.

4.3.2 Ecological characteristics and significance of sandy beaches

Sandy beaches are loose deposits of sand, formed by deposition of material carried by water currents from other areas. The sand mainly originates from land and is transported via rivers to the sea. However, some of the sand is derived from the erosion of shores in other areas. The material includes:

- Quartz (=silica) of terrestrial origin
- Carbonate sands of marine origin (i.e. weathered from mollusc shells and skeletons of other animals) or
- Other material such as heavy minerals, basalt (of volcanic origin) and feldspar.

The grain size of sand varies from very fine to very coarse (Particle diameter is in the range 0.0625 mm to 2 mm).

Characteristic flora and fauna on sandy beaches

Terrestrial insects, spiders and amphipod crustaceans may be encountered in the supralittoral zone above the high water mark on the beach. Certain species of birds use the beach for foraging, nesting or roosting. However, the biodiversity of the beach above the high water mark is generally low.

Often there are tidal sandy flats off sandy beaches covered by water during flood tide and dry during ebb tide. Tidal flats are habitats for a rich, abundant and diverse fauna. This habitat is not included in the vulnerability ranking of sandy beaches. A separate ranking of tidal sand and mud flats has been carried out (see Section 4.5. below).

Beaches also provide important coastal recreational areas for many people.

EUNIS Classification

Sandy beaches include the following EUNIS habitats:

- B1.1 Sand beach drift lines
- B 1.2 Sand beaches above the drift line

4.3.3 Vulnerability. Sandy beaches

Fate of oil

The persistence of stranded oil on beaches with fine-grained sand and low slope is limited due to the following facts:

- The compact nature of fine sand limits oil penetration to a few centimetres
- Fine grained sand beaches generally accrete slowly between storms reducing the potential for burial of oil by clean sand
- The low penetration and low potential for burial facilitates natural degradation processes and mechanical removal
- The beaches are generally highly exposed to waves facilitating the removal of oil from the shoreline.

The persistence of oil on beaches with coarse sand is somewhat higher compared to beaches with fine-grained sand because they have the potential for higher oil penetration due to coarser grained particles with oil penetration up to 25 cm. These beaches can undergo very rapid erosional and depositional cycles, with the potential for rapid burial. The penetration and burial hamper natural degradation.

Impact of oil/sensitivity

Sandy beaches above the high water mark generally have low species diversity and few organisms are likely to be impacted following an oil spill.

Vulnerability scores. Sandy beaches

Based on these ecological and impact characteristics undispersed surface oil spills and dispersed oil spills on sandy beaches have both been allocated the following scores: Spring: 2, Summer: 2, Autumn: 1, Winter: 1.

The general low vulnerability score (of 1) has been increased to score 2 during spring and summer when the biological productivity is highest.

4.4 Shingle beaches

4.4.1 Location of shingle beaches

Single beaches are mainly found in the UK and Ireland (Figure 4-5).

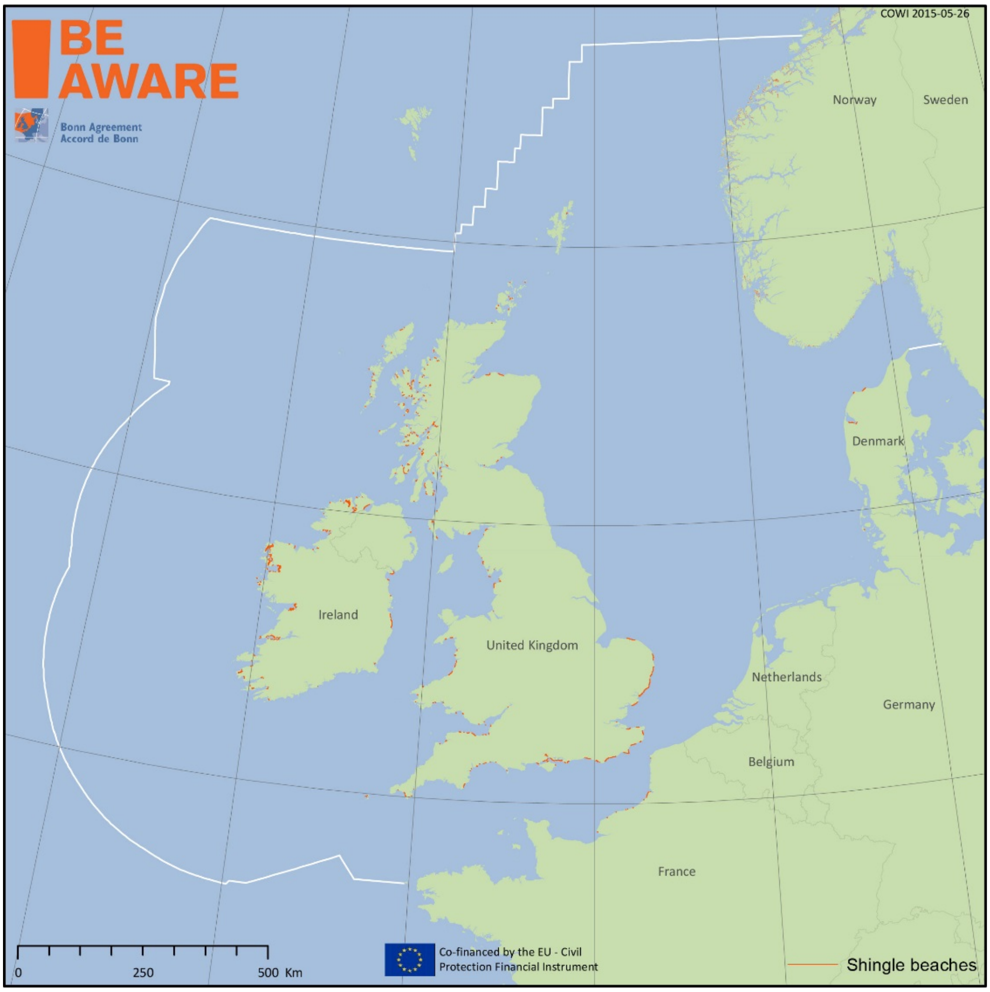

Figure 4-5 **Location of shingle beaches.**

4.4.2 Ecological characteristics and significance of shingle beaches

A shingle beach is a coarse sediment beach, consisting of pebbles or small to medium-sized cobbles, typically ranging from 2 to 200 mm in diameter. All shingle beaches consist of a mixture of these particle sizes, some being well sorted, some poorly sorted.

Characteristic flora and fauna on shingle beaches

Vegetated shingle communities may develop out of reach of the normal tide cover. The development of vegetated shingle communities is dependent upon the stability of the beach, matrix composition and the availability of freshwater and nutrients (Scott, 1963; Fuller, 1987; Walmsley & Davey, 1997; Doody & Randal, 2003). Shingle habitats are often home to many specialist plant species that are unable to survive anywhere else.

They are also extremely important to a range of other species including ground ground-nesting birds such as terns (*Sterna* spp.), the Ringed Plover (*Charadrius hiaticula*), and waders like the Oystercatcher (*Haematopus ostralegus*) and curlews (*Numenius* spp.). These species often nest directly on the shingle or visit the beach to forage for food (Cadbury & Ausden, 2001). A wide variety of invertebrate species relies on shingle habitats (Shardlow, 2001), for example, the wolf spider and the jumping spider, both ground hunting specialists that do not build webs.

EUNIS Classification

Shingle beaches include the following EUNIS habitats:

- A2.11 Shingle (pebble) and gravel shores
- B2 Coastal shingle

4.4.3 Vulnerability of shingle beaches

Fate and impact of oil on shingle beaches

Oil stranded on this type of beach penetrates rapidly and deeply into the coarse sediments and may persist for years.

During the “Uroquiola” oil spill at La Coruna in Spain in 1976, crude oil seeped 60-80 cm into the gravel beach. Lighter processed oil would probably have penetrated further (Gundlach and Hayes 1978).

A solid asphalt pavement may form under heavy oil accumulations. The buried or penetrated oil may seep out slowly generating sheens that can re-contaminate the shoreline and damage the seabed sublittoral benthic fauna community.

A moderately to heavily oiled shingle beach is practically impossible to clean without removal of large amounts of pebbles and cobbles which may reduce the stability of the beach. During the “Arrow” spill, a shingle beach was oiled and a large amount of pebbles and cobbles were removed during the clean-up process. As a result, the beach retreated between 10 and 20 m (Owens and Rashid 1976).

Vulnerability scores. Shingle beaches

Based on these ecological and impact characteristics undispersed surface oil spills and dispersed oil spills on shingle beaches have both been allocated the following vulnerability scores: Spring: 3, Summer: 3, Autumn: 3, Winter: 3.

4.5 Tidal sand and mud flats

4.5.1 Location of tidal sand and mudflats

There are tidal flats along most of the coasts in the BA area except in Norway, the Danish west coast north of the Wadden Sea and parts of the coast of the Netherlands (Figure 4-6). The Wadden Sea at the coast of southern Denmark, Germany and the Netherlands, is a UNESCO World Heritage Site and the largest area of connected tidal flats in the world, extending over a length of some 500 km and an area of 10,000 km^2.

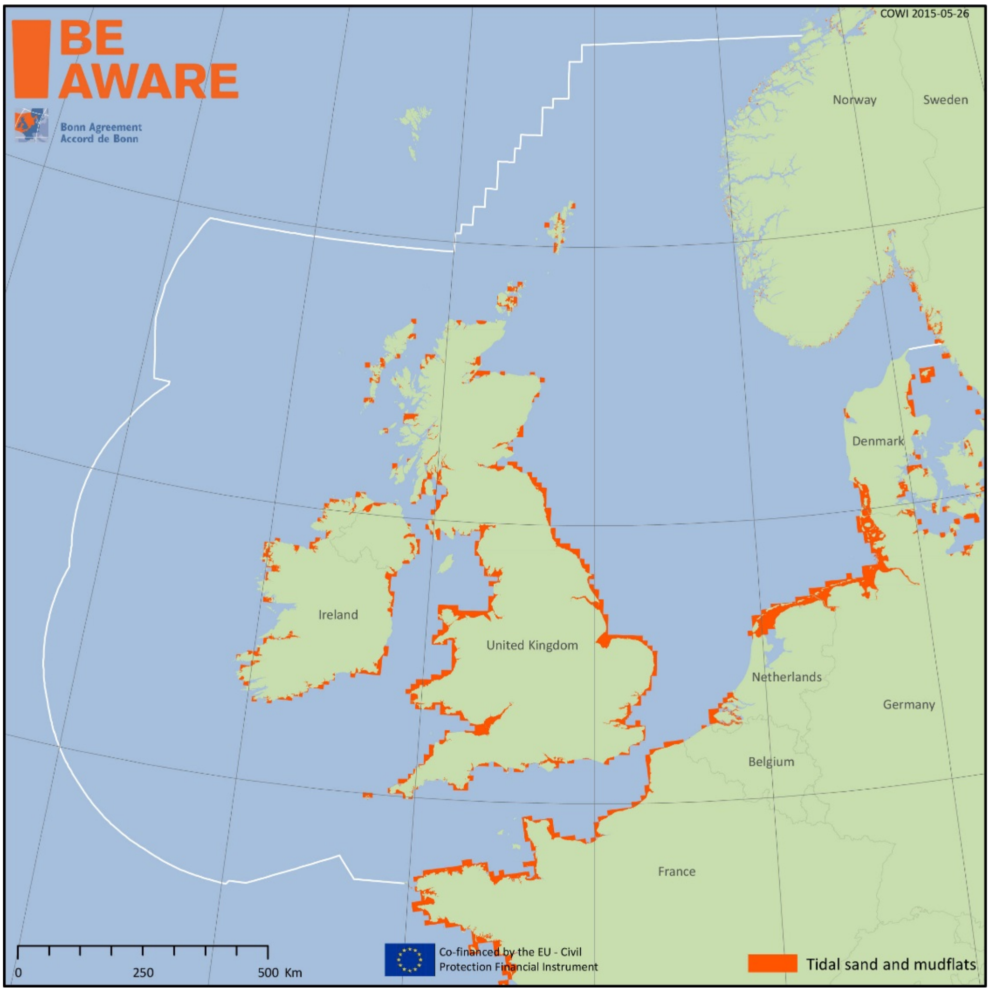

Figure 4-6 **Location of tidal sands and mudflats.**

4.5.2 Ecological characteristics and significance. Tidal sand and mudflats

Tidal flats are found on coastlines and on the shores of lagoons and estuaries in intertidal areas. Tidal flats are always exposed to air and they develop in areas where sediments from river runoff or inflow from tides, deposits mud or sand.

Mud flats develop in intertidal areas where the energy of waves beating on the shore is low, resulting in the deposition of fine -grained sediment. Mudflats comprise fine silts and clays (particle size less than 0.063 mm in diameter) with a high content of organic matter. They are located in sheltered coastal areas such as estuaries. In large estuaries, intertidal mudflats may be several kilometres wide and commonly form the largest part of the intertidal area of estuaries. The upper limit of intertidal sand flats is often marked by saltmarsh, and the lower limit by Chart Datum.

Sand flats develop in more exposed intertidal areas where the wave energy is high resulting in the deposition of coarser grained particles (sand). The upper limit of intertidal mudflats is often marked by saltmarsh, and the lower limit by the lowest astronomical tide.

There are three zones in a tidal flat:

- The supratidal zone, located above high tide mark;
- The intertidal zone, located between high and low tide marks
- The subtidal zone, which occur below low tide mark and is rarely exposed

Characteristic fauna on tidal flats

Tidal sand and mud flats are productive ecosystems. Mudflats are among the most productive ecosystems on earth. Tidal sand and mudflats are characterised by very high density and biomass of organisms, but low diversity with few rare species. Fauna species that live on tidal flats include invertebrates, birds and fish with the following characteristics:

- The composition of the invertebrate fauna varies characteristically with salinity and composition of sediment (grain size and content of organic matter):
    - In areas of lowered salinity and muddy sediment, the macroinvertebrate fauna is predominantly of the Petersen Macoma community, where the characteristic species are: common cockle (*Cerastoderma edule*), sand hopper (*Corophium volutator*), laver spire shell (*Hydrobia ulvae*), ragworm (*Hediste diversicolor*) and, when salinity is low, large numbers of oligochaete annelids (principally *Tubificoides* spp).
    - With an increase in the proportion of sand, other species take over. The abundance of polychaetes like catworm (*Nephtys hombergi*) and lugworm (*Arenicola marina*) will for instance increase together with other species of molluscs, crustaceans and polychaetes. The dominant taxa of tidal sand flat meiofauna are nematodes and harpacticoid copepods with other important groups including turbellarians, oligochaetes, gastrotrichs, ostracods and tardigrades.
    - Where stones and shells provide an initial attachment for byssus threads, beds of the common blue mussel (*Mytilus edulis)* occur
- The abundant invertebrate fauna provide food for a large number of wildfowl and are often feeding and resting areas for internationally important populations of migrant and wintering waterfowl including species such as the brent goose, shelduck, pintail, oystercatcher, ringed plover, godwit, curlew, redshank, knot, dunlin and sanderling. Mudflats are important for migrant and wintering birds: No less than 10-12 million birds visit the tidal flats of the Wadden Sea annually (Reise et al., 2010).
- Intertidal sand and mudflats also provide an important food source for a range of fish species, including plaice, sole, flounder and dab. They are also vital nursery areas for a number of these fish species.

Characteristic vegetation on tidal flats

Tidal flats are mostly devoid of vegetation, although mats of benthic microalgae (diatoms and euglenoids) are common, especially on mudflats. Under nutrient-rich conditions there may be mats of the macroalgae *Enteromorpha* spp. or *Ulva* spp. and in areas with slightly coarser sediments, seagrass (*Zostera* spp) beds may develop. Occasional stones or shells may also provide suitable attachment for stands of fucoid macroalgae such as *Fucus vesiculosus* or *Fucus spiralis*.

EUNIS and other classification

Tidal sand and mud flats include the following EUNIS classification:

- A2.2 Littoral sand and muddy sand
- A2.3. Littoral mud

In addition, the habitat corresponds to the EU Habitats Directive – Annex 1 Habitat type: 1140 *Mudflats and sandflats not covered by seawater at low tide.*

4.5.3 Vulnerability. Tidal flats

Fate of oil on tidal flats

The fate of oil stranded on both exposed and sheltered tidal flats has been studied at several major spills. The general experience is that on most tidal flats, oil persistence is long-term because of low wave energy. The persistence depends on a number of factors with the general exposures to waves and the width of the tidal flat being the main factors, i.e.:

- Oil stranded on tidal flats in sheltered areas will persist for years due to general low wave energy
- Oil stranded on tidal flats in exposed areas with very wide flats, may also persist for years, because the wide flat attenuates the waves and induce low wave energy on the shore-ward parts of the flat
- Oil stranded on exposed flats with relatively narrow flats will persist for shorter time because of the high wave energy

Table 4-5 compares the fate of oil on exposed- and sheltered tidal flats based on observations at many major spills and Table 4-6 provides some examples of fate of oil on tidal flats following oil spills.

Table 4-5 Comparison of the fate of oil on exposed and sheltered tidal flats based on observations at many spills (Michel and Hayes 1992).

Exposed tidal flats	Sheltered tidal flats
• Oil does not usually adhere to the surface of narrow exposed tidal flats, but rather moves across the flat and accumulates at the high-tide line • On wide exposed tidal flats that attenuate nearly all the wave energy, the oil may form into a thin crust that persists for years • Heavy accumulations will cover the flat at low tide • Oil does not penetrate the water-saturated sediments	• Oil does not usually adhere to the surface of sheltered tidal flats, but rather moves across the flat and accumulates at the high-tide line • Very heavy accumulations will cover the flat at low tide • Oil will not penetrate the water-saturated sediments at all • In areas of high suspended sediments, sorption of oil can result in contaminated sediments that can be deposited on the flats • When sediments are contaminated, oil will persist for years

Table 4-6 Examples of fate of oil on tidal flats following oil spills

Spill	Fate of oil	Reference
1974. Metula spill. "Metula" was a super tanker that was involved in an oil spill in Tierra del Fuego, Chile. The tanker grounded in the Strait of Magellan, during severe tidal and current conditions. The tanker released about 47,000 tonnes of Arabian light crude oil and between 3,000 and 4,000 tonnes of heavy fuel oil. The rough sea conditions resulted in the formation of a water-in-oil emulsion, which then landed on the shores of Tierra del Fuego.	Oil slicks moved across wide exposed tidal flats (up to 10 km wide) and accumulated only at the landward edge of the flat. The oil remained on the surface, penetrating only a few centimetres, and there was no burial after 1.5 years. Because the wide flats attenuate nearly all the wave energy, the oil eventually formed into a thin pavement or crust, which remained unchanged for more than six years.	Michel and Hayes 1992
1976 The tanker "Urquiola" struck bottom on entering the port of La Coruña in Spain and began leaking oil. It was estimated that 100,000 tonnes of Arabian Light crude oil was spilt during this incident, most of which burned, and an estimated 25-30,000 tonnes washed ashore.	Oil was observed to pass over exposed tidal flats and accumulate on the adjoining beach. At low tide, heavy oil slicks covered the flat, but the rising tide lifted the oil off and pushed it across the flat. No long-term deposition of oil on the flats was observed, although the surface sediments were lightly stained early in the spill.	Michel and Hayes 1992
1991 The Gulf War oil spill was one of the	Significant contamination of exposed tidal	Michel,

largest oil spills in history, resulting from the Gulf War in 1991. Iraqi forces purposefully opened valves at the Sea Island oil terminal and dumped oil into the Persian Gulf in a strategic wartime move against U.S. forces.	flats was observed. The spill inundated the shoreline for 500 km and the oil coverage on the tidal flats was nearly 100 percent, as of May 1991. This spill was unique in that onshore winds kept extremely large slicks piled up against the shoreline for months. Eventually, the oil adhered to the intertidal sediments, but the oil did not penetrate the sediments very deeply (i.e. less than 5 cm)	1991
1978. Super-tanker, "Amoco Cadiz" spill, Brittany, France, in which 200,000 gallons crude oil was spilled.	During the Amoco Cadiz spill, large waves dispersed the oil into the water column, both as the oil exited the ship and when storm waves eroded the oil from exposed beaches. During the first three weeks, about 20,000 metric tons of oil was released into the water column. This oil adsorbed onto suspended sediments that were then deposited onto sheltered tidal flats; oiled intertidal sediments were found in sheltered bays, which never received any surface slicks. Oil removal and weathering rates were slowest in very fine-grained sediments.	Gundlach et al 1983

Impact of oil on tidal flats

Biological impacts on tidal flats can be severe. Oil spills can cause large scale, direct deterioration of benthic infauna communities and birds. Impacts on benthic infauna may in turn cause secondary effects on fish birds and other predators due to reduced food sources. Oil covering intertidal muds prevents oxygen transport to the substratum and produces anoxia resulting in the death of infauna. Infauna may also be affected directly by smothering or by elevated concentrations of toxic oil components in the water. Table 4-7 shows some examples of impacts of oil spills on previously observed tidal flats.

Although benthic invertebrate fauna in the littoral zone is generally very sensitive to oil spill, benthic fauna has a high recovery potential and in areas where oil has been removed (either naturally or due to clean up) recolonization by most species is quite rapid. However, the recovery of certain sensitive species may be prolonged (such as species of crustaceans and mussels).

Shorebirds and waterfowl that are often concentrated on tidal flats are also very vulnerable to oil spills and severe impacts and mass killing of birds are well documented (see section 5.1.3).

Table 4-7 Selected references from field surveys on the effects on benthic infauna and fish on tidal waters following oil spills.

Spill	Reported effect	Reference
1996 "Sea Empress" oil spill off the coast of Wales. 72,000 tonnes of oil were spilled	Mass kills of amphipods, cockles and razor shells were observed Populations of mud snails recovered within a few months but some amphipod populations had not returned to normal after one year.	SEEEC 1998, Dyrynda 1996 IPIECA 2000
1993 "Braer" oil spill Shetland	No significant changes in benthic infauna community structure, as characterized by species richness, abundance and diversity could be related to the areas of seabed affected by the Braer oil spill. However, sensitive crustaceans such as the Amphipoda which were found in low abundance before the spill, seem to have disappeared	Kingston, et al 1995 Kingston et al 1997

1978. Super-tanker, "Amoco Cadiz" spill, Brittany, France in which 223,000 t of crude oil was spilled.	The invertebrates of the fine sand Abra alba community in the Bay of Moriaix was heavily affected by the spill and the recovery of a sensitive benthic amphipod (Ampelisca spp.) took more than 10 years. A general decrease in the intertidal nematode abundance was obvious in intertidal sand seven months after the pollution in spite of the occurrence of the natural spring bloom. Flat fish and mullets on the intertidal sand flats had reduced growth, fecundity and recruitment; they were affected by fin rot disease.	Dauvin 1998 Conan et al 1982 Boucher 1980
1976 The tanker "Urquiola" struck bottom on entering the port of La Coruña in Spain and began leaking oil. It was estimated that 100,000 tonnes of Arabian Light crude oil was spilt during this incident, most of which burned, and an estimated 25-30,000 tonnes washed ashore.	At several heavily oiled fine-grained intertidal flats, thousands of dead amphipods were found along the tide swash line	Gundlach and Hayes 1978

Vulnerability scores. Tidal sand and mudflats

Based on these ecological and impact characteristics undispersed surface oil spills and dispersed oil spills on tidal sand and mudflats have both been allocated the following vulnerability scores: Spring: 4, Summer: 4, Autumn: 4, Winter: 4.

4.6 Salt marshes

4.6.1 Location of saltmarshes

Saltmarshes are mainly found in Denmark, especially in the Wadden Sea, the Wadden Sea coasts of Germany, the Netherlands, and several areas in England. Saltmarshes are also found in areas of Belgium, France and Ireland (Figure 4-7).

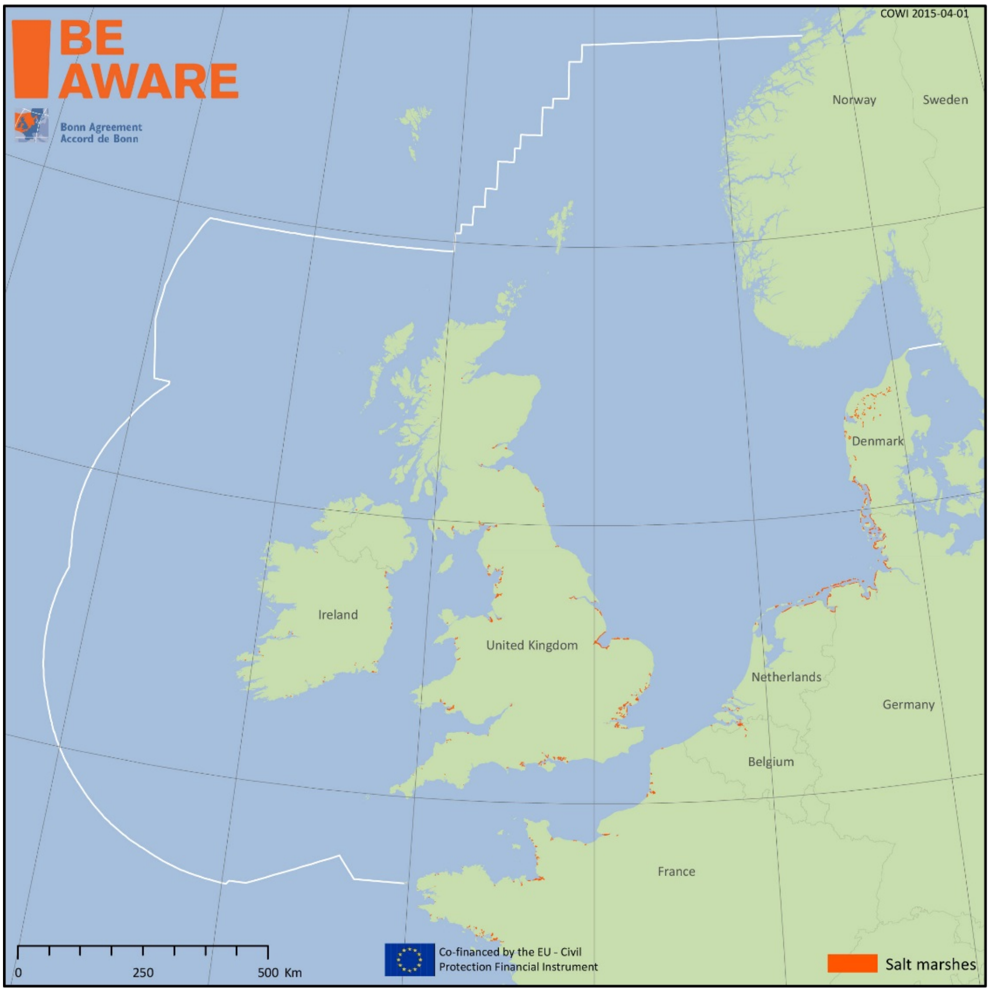

Figure 4-7 **Location of tidal saltmarshes.**

4.6.2 Ecological characteristics and significance. Saltmarshes

Saltmarshes are formed by vegetation occurring on the upper shore of sheltered coasts between mean high water neap tides and mean high water spring tides. The vegetation develops on a variety of sandy and muddy sediment types and may have admixtures of coarser material. Saltmarshes are usually restricted to sheltered locations in estuaries, in saline lagoons, behind barrier islands, at the heads of sea lochs and on beach plains.

Salt marshes are highly productive habitats. They serve as depositories for organic matter, which feeds a broad food chain of organisms from microorganisms and invertebrates, which in turn become food for fish and birds.

Characteristic vegetation

Saltmarsh vegetation include halophytic (salt tolerant) species adapted to regular immersion by the tides. The diversity of plant species is relatively low, since the plants must be tolerant of salt, complete or partial submersion and anoxic mud substrate. The most common salt marsh plants are glassworts (*Salicornia* spp.) and the cordgrass (*Spartina* spp.). The following species may also be encountered common saltmarsh-grass (*Puccinellia maritima*), sea plantain (*Plantago maritima*), sea arrow-grass (*Triglochin maritinum*), sea aster (*Aster tripolium*), English scurvy grass (*Cochlearia anglica*), common sea-lavender (*Limonium vulgare*), sea purslane (*Halimione portulacoides*), the red algae *Bostrychia scorpioides* and *Catenella caespitosa*. *Juncus maritimus* is another species that can occur in salt marshes.

Characteristic fauna

The highly productive saltmarshes is habitat for a rich fauna i.e.:

- They are important areas for wading birds and wildfowl and act as
    - High tide refuges for birds feeding on adjacent mudflats such as waders
    - Breeding sites for waders, gulls and terns and as a source of food for passerine birds particularly in autumn and winter.
    - Feeding grounds for large flocks of wild ducks and geese during winter.
- They are also sheltered nursery sites for several species of fish such as mullet, bass and plaice.

EUNIS and other classification

Saltmarshes correspond to the EUNIS habitat:

- A2.5 *Coastal saltmarshes and saline reed beds*

In addition, the habitat includes the following EU Habitats Directive – Annex 1 habitat types:

- 1310 *Salicornia and other annuals colonising mud and sand*
- 1320 *Spartina swards (Spartinion maritimae)*
- 1330 *Atlantic salt meadows (Glauco-Puccinellietalia maritimae)*.

4.6.3 Vulnerability. Salt marshes

Fate and impacts of oil. Saltmarshes

Saltmarsh plants are sensitive to oil spills and due to the tidal environment they are living in, they are virtual oil traps that may retain oil for a long time. In addition, saltmarshes are very difficult to clean up without causing major destruction of the habitat.

Some plant species are more susceptible to oil. Perennials with robust underground stems and rootstocks tend to be more resistant than annuals and shallow rooted plants. If, however, perennials such as the grass *Spartina* are killed, the first plants to recolonize the area are likely to be annuals such as the glasswort (*Salicornia*). This is because such annuals produce large numbers of tidally dispersed seeds (IPIECA 2000d).

Recovery time from oiling varies from 1-2 years to decades depending on a number of factors (IPIECA 1994) with oil type and degree of weathering being the most important, i.e. the lighter more penetrating oils are more likely to cause acute toxic damage than heavy or weathered oil.

Table 4-8 shows some examples of observed impacts of oil spills on saltmarshes and recovery time for affected saltmarshes.

Table 4-8 Comparison of some scientifically documented oil spills that have affected coastal saltmarshes (Mendelssohn et al. 2012).

Spill	Impacts	Recovery
2010. Oil well blowout, Deepwater Horizon event, northern Gulf of Mexico in April 2010 in which no less than 205,800,000 gallons of Macondo sweet crude oil was spilled	Saltmarsh vegetation from the Chandeleur Islands to Point Au Fer was variably impacted by the oil	Not yet quantified
2000. Pipeline rupture, Swanson Creek, Maryland in April 2000 in which 140,000 gallons of fuel oil was spilled	Saltmarsh vegetation markedly affected. Seven years later stem density and stem height of *S. alterniflora* and underground	The oil had lost 22%–76% of its initial PAH content after seven years; 25% of the soils in the marsh are expected to be toxic

	biomass of S. cynosuroides were significantly lower in oiled sites.	
1985. Pipeline rupture, at Nairn, Louisiana in April 1985 in which 12,600 gallons of crude oil was spilled	64% reduction in live saltmarsh vegetation cover three months after spill	Near total vegetative recovery 4 years after the spill.
1978. Super-tanker, Amoco Cadiz spill, Brittany, France in which 200,000 gallons of crude oil was spilled.	Saltmarsh vegetation heavily affected. Rapid erosion after surface oiled sediment removal up to 50 cm; 12 years later, vegetation area was reduced by 22%–38%	Plant recovery by invasion from annuals and rhizome spreading of perennials in 8 years
Spill of 184,900 gallons of No. 2 fuel from the Barge Florida, West Falmouth, Massachusetts September 1969	Four decades after the spill, stem density and biomass of S. *alterniflora* still reduced in oiled areas; unconsolidated sediments, increased topographical variation, and, ultimately, loss of salt marsh habitat	Only 100 of the original 595,000 kg of spilled oil still in salt marsh sediment 40 years later; effects on large-scale ecosystem functions were still evident

Vulnerability scores. Salt marshes

Based on these ecological and impact characteristics, saltmarshes have been allocated the vulnerability score 4 for all seasons for both surface oil spill and dispersed spill.

4.7 Underwater sandbanks

4.7.1 Location of underwater sandbanks

Figure 4-8 shows the location of underwater sandbanks on depths at or above 20 m and depths below 20 m in the BA area.

4.7.2 Ecological characteristics and significance. Underwater sandbanks

Underwater sandbanks are elevated, elongated, rounded or irregular topographic features, permanently submerged and predominantly surrounded by deeper water. They consist mainly of sandy sediments, but larger grain sizes, including boulders and cobbles, or smaller grain sizes including mud may also be present on a sandbank. Banks where sandy sediments occur in a layer over hard substrata are classed as sandbanks if the associated biota are dependent on the sand, rather than on the underlying hard substrata (European Commission (2007).

Characteristic Vegetation

Many sandbanks are devoid of vegetation. Seagrass may, however, be encountered on sandbanks on shallow water (European Commission 2007).

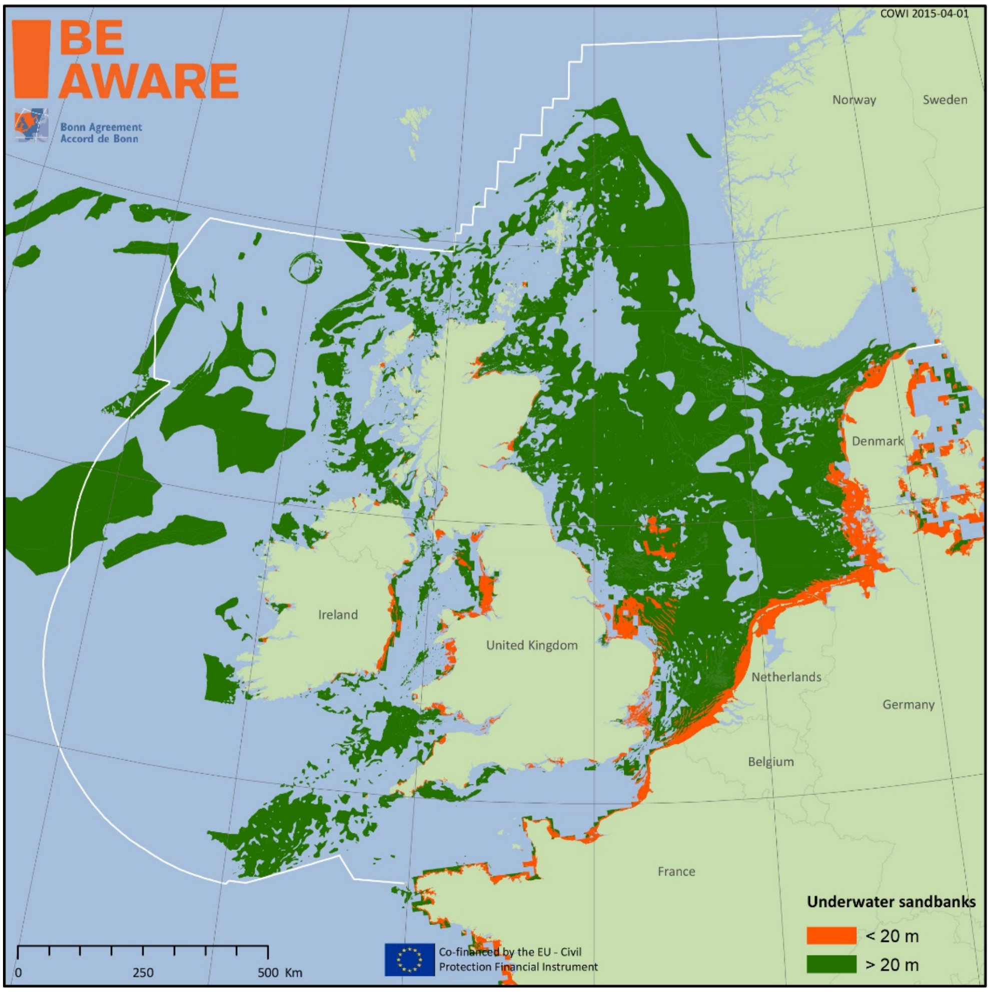

Figure 4-8 Location of underwater sandbanks.

Characteristic Fauna

Invertebrate and demersal fish communities of sandy sublittoral including (European Commission (2007):

- Invertebrate fauna: Polychaete worms, crustacean, anthozoans, burrowing bivalves and echinoderms
- Demersal fish such as sandeels (*Ammodytes* sp.), gobies (*Pomatoschistus* spp), lesser weever (*Echiichtys vipera*), plaice (*Pleuronectes platessa*) and dab (*Limanda limanda*).

EUNIS and other classification

The habitat underwater sandbanks correspond to the following nominations:

- EUNIS classification: A5.2 *Sublittoral sand*
- EU Habitats Directive Annex I habitat type: 1110 *Sandbanks which are slightly covered by sea water all the time*

4.7.3 Vulnerability. Underwater sandbanks

Fate and impacts of oil spill

Benthic fauna organisms are generally very sensitive to oil spill and elevated concentrations of toxic oil components in the water. There are numerous examples of severe impacts on benthic fauna following oil spills. However, impacts have only been observed on shallow water, especially on tidal flats along the coasts where oil components mixed with suspended solids have settled on the seabed or toxic concentrations of oil components have reached the seabed.

In general, benthic fauna has a high recovery potential. Recolonisation by most species is quite rapid but the recovery of certain sensitive species may be prolonged (such as species of crustaceans and mussels) (see section 4.5.3).

Vulnerability scores. Underwater sand banks

Underwater sandbanks under 20m depth

Based on these ecological features and impact characteristics, underwater sandbanks on shallow water (<20m) have been allocated the following vulnerability scores:

- Score surface oil spill: Spring: 3, Summer: 3, Autumn: 2, Winter: 2
- Score dispersed oil: Spring: 3, Summer: 3, Autumn: 3, Winter: 3

The lower score during autumn and winter reflects the lower biological productivity compared to spring and summer. The ranking score for dispersed oil is similar for the whole season as a reflection of a higher bioavailability of the dispersed oil.

Underwater sandbanks over 20m depth

Underwater sandbanks on deeper waters (more than 20 m depth) has been allocated score 1 for all seasons for surface oil spills, because there is only a small risk that oil spilled at the surface will reach the seabed and affect the organisms. In terms of dispersed oil, the vulnerability score has been raised to 2 reflecting the higher risk of oil reaching the seabed.

4.8 Biogenic reefs

4.8.1 Location of biogenic reefs

Figure 4-9 shows the location of registered biogenic reefs in the BA area.

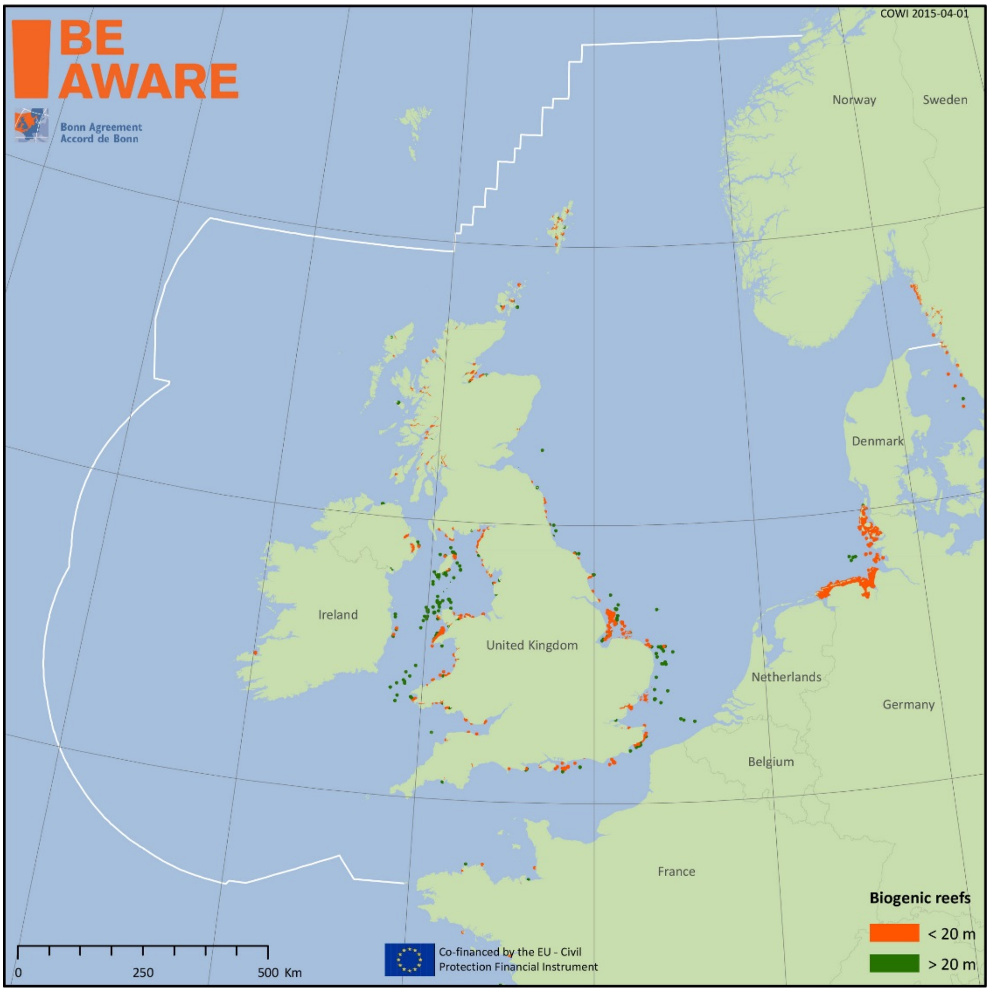

Figure 4-9 **Location of biogenic reefs on waters ≤ 20 m and > 20 m.**

4.8.2 Ecological characteristics and significance. Biogenic reefs

Biogenic reefs are those that are created by the animals themselves. The following types of biogenic reefs are encountered in European Waters:

- Beds of the common mussel (*Mytilus edulis*)
- Beds of the horse mussel (*Modiolus modiolus*);
- Colonies of tube-forming worms *Sabellaria alveolata*
- Colonies of tube-forming worms *Serpula vermicularis* and
- The deep-water, colonial, bank-forming coral *Lophelia pertusa*.

The latter type is described in section 4.20. The others are described below.

Common mussel beds

This habitat includes intertidal and subtidal beds of the common mussel *Mytilus edulis*. Beds of common mussel play an important part in a healthy functioning marine ecosystem, having a role in coastal sediment dynamics, acting as a food source for over-wintering waders, and providing an enhanced area of biodiversity in an otherwise sediment-dominated environment.

Horse mussel beds

The horse mussel *Modiolus modiolus* forms dense beds at depths of 5-70 m in fully saline, often moderately tide-swept areas. Although it is a widespread and common species, true beds forming a distinctive biotope are much more limited. *Modiolus modiolus* is a long-lived species and individuals within beds are frequently 25 years old or more. Juvenile *M. modiolus* are heavily preyed upon, especially by crabs and starfish, until they are about 3-6 years old, but predation is low thereafter. Recruitment is slow and may be very sporadic; there may be poor recruitment over a number of years in some populations. Beds of *M. modiolus* have rich associated faunas, sometimes with hundreds of species occurring on dense beds.

Sabellaria alveolata reefs

Sabellaria alveolata reefs are formed by the honeycomb worm *S. alveolata*, a polychaete, which constructs tubes in tightly packed masses with a distinctive honeycomb-like appearance. These reefs can be up to 30 or even 50 cm thick and take the form of hummocks, sheets or more massive formations. Reefs are mainly found on the bottom third of the shore, but can reach mean high water of neap tides and extend into the shallow sub-tidal water in places. Individual worms have a lifespan of typically three to five years, and possibly up to nine years, but reefs themselves may last longer because of further settlement of worms onto existing colonies.

Sabellaria spinulosa reefs

Sabellaria spinulosa reefs comprise dense sub-tidal aggregations of this small, tube-building polychaete worm. *Sabellaria spinulosa* can act to stabilise cobble, pebble and gravel habitats, providing a consolidated habitat for epibenthic species. They are solid (albeit fragile) massive structures at least several centimetres thick, raised above the surrounding seabed, and persisting for many years. As such, they provide a biogenic habitat that allows many other associated species to become established. However, in most parts of its geographical range *S. spinulosa* does not form reefs, but is solitary or in small groups encrusting pebbles, shell, kelp holdfasts and bedrock. It is often cryptic and easily overlooked in these habitats.

EUNIS Classification

The habitat “Biogenic Reefs” includes the following EUNIS habitats:

- A2.71 *Littoral Sabellaria reefs*
- A4.22 *Sabellaria reefs on circalitttoral rock*
- A561 *Subittoral polychaet worm reefs on sediment*
- A2.721 *Mytilus edulis beds on littoral sediments*
- A5.62 *Sublittoral mussel beds on sediment*

4.8.3 Vulnerability. Biogenic reefs

Fate and impact of oil on biogenic reefs

Biogenic reef fauna are generally very sensitive to oil spill and elevated concentrations of toxic oil components in the water. There are numerous examples of severe impacts on benthic fauna following oil spills. However, impacts have only been observed on shallow water along the coasts where oil or toxic concentrations of oil components may reach the seabed. For biogenic reefs on deeper waters, there is only a small risk that oil spilled at the surface will reach the seabed and affect the organisms, unless the oil is dispersed by the use of dispersants.

Biogenic reef organisms may be affected by oil due to:

- Smothering and toxic effects of oil components
- Ingesting of oil components filtered from the water and accumulated in the tissues (*Mytilus, Modiolus* and *Sabellaria* are filter feeders).

Table 4-9 shows examples of observed impacts of oil spills on biogenic reefs and recovery time for affected biogenic reefs.

Table 4-9 Selected references on field surveys on effects on biogenic reefs following oil spills.

Spill	Observed impacts	Reference
2002. Oil spill from the shipwrecked tanker "Prestige" on the northwest coast of Spain. 64,000 tonnes of oil were spilled	Two years after the spill severe impacts on lysosomes, tissues of digestive glands, health and immune system of the mussel *Mytilus galloprovincialis* were observed.	Basque Research (2009)
1999. Oil spill from the grounding of the tanker "Erika" on the Brittany coast of France	Measurements in mussels (*Mytilus edulis*) of the metabolism of organic contaminants using biomarkers showed that mussels were affected by the oil spill during the first year after the event	Bocquenè et al. 2004
1989 "Exxon Valdez" oil spill in Prince William Sound Alaska. 35,360 tonnes of oil spilled	Mussels (*Mytilus trossulus*) in a heavily oiled location in Prince William Sound in 1989 showed metabolic stress due to PAH exposure 11 years after the spill	Blackburn et al. 2014
1978. Super-tanker, Amoco Cadiz spill, Brittany, France in which 200,000 gallons of crude oil was spilled.	Mass mortality of mussels (*Mytilus edulis*) observed. Mussels continued to wash ashore for several weeks following the spill	Blackburn et al. 2014

Vulnerability scores. Biogenic reefs

Vulnerability scores. Biogenic reefs (< 20m)

Based on these ecological and impact characteristics, biogenic reefs on shallow water (< 20 m) have been allocated the vulnerability score 4 for both surface oil spills and for dispersed oil during all seasons.

Vulnerability scores. Biogenic reefs (> 20m)

Biogenic reefs on deeper waters have been allocated the following vulnerability scores:

- Score surface oil spill: Spring: 2, Summer: 2, Autumn: 2, Winter: 2
- Score dispersed oil: Spring: 4, Summer: 4, Autumn: 4, Winter: 4

The reason for allocating low scores for surface oil spills is the small risk that oil spilled at the surface will reach the seabed and affect the organisms. In case of dispersed oil, there is a higher risk of the oil reaching the seabed, therefore the higher vulnerability score.

4.9 Maerl beds

4.9.1 Location of maerl beds

Maerl beds are reported from Norway, France, UK (especially western Scotland) and Ireland (Figure 4 10).

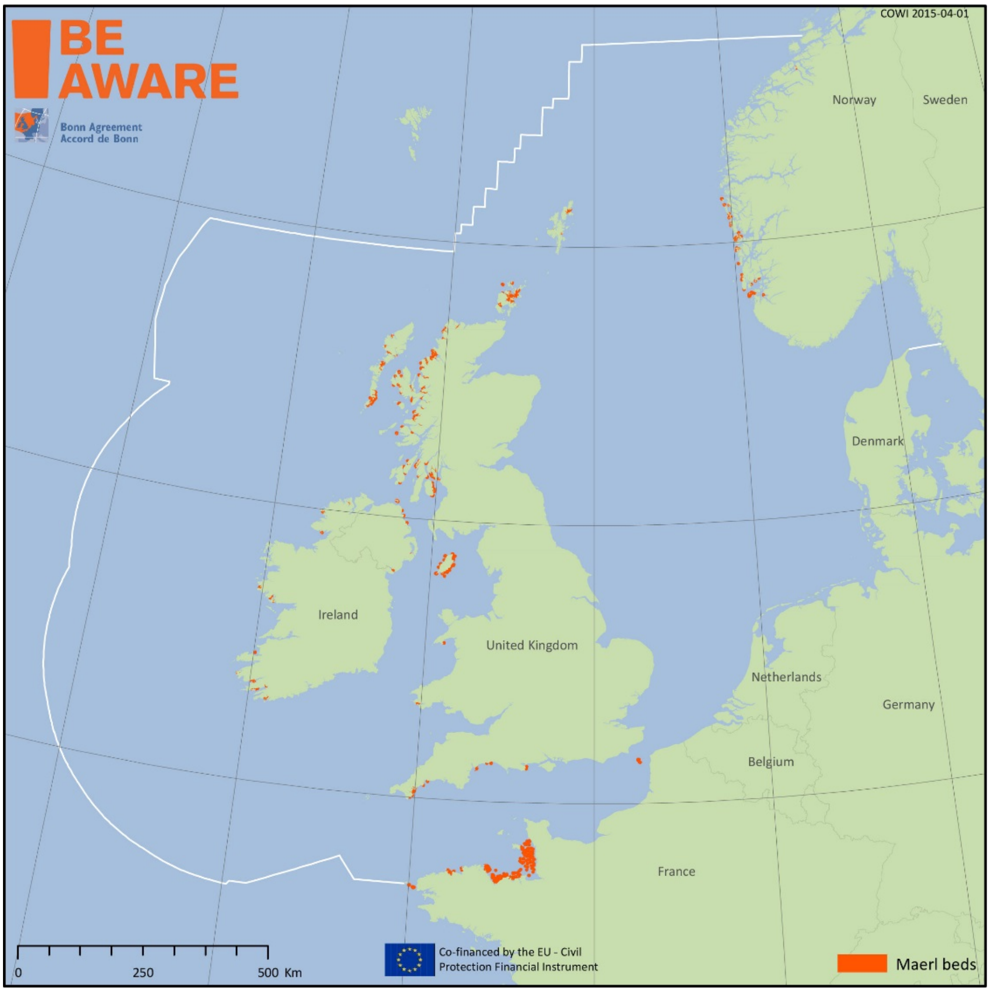

Figure 4-10 Location of maerl beds.

4.9.2 Ecological characteristics and significance. Maerl beds

Maerl beds are loose lying sub-tidal beds of nodular coralline red algae that produce a branched skeleton of calcium carbonate. The underlying structure comprises the skeletal remains of dead coralline algae, with a pink crust of living algae occupying the uppermost layer.

Characteristic flora

In the BA area, maerl is composed of the following three species of coralline red algae *Lithothamnion corallioides*, *L. glaciale* and *Phymatolithon calcareum* (Steneck 1986, Blake and Maggs 2003, Irvine et al 1994).

Due to very slow growth (approximately 1 mm per year), European maerl is ecologically fragile. (Wilson et al 2004).

Live maerl beds occur in the photic zone and can be found in water as deep as 40 m, but is most commonly encountered from 20 m depth to the low tide mark. Maerl is not encountered in the intertidal zone, as it is very sensitive to desiccation (Wilson et al 2004).

The distribution of maerl is dependent on water movement, light and salinity. Maerl favours sites with rapid flow such as tidal narrows, straits or sounds, or areas with sufficient wave action to prevent it from being smothered with sediment (Wilson et al. 2004).

Characteristic fauna

Maerl beds support high biodiversity of associated invertebrate and algal species, and are subject to European and UK conservation legislation (Steller et al 2003 and Wilson et al. 2004). Maerl beds are important nursery areas for the juvenile stages of commercial species such as juvenile cod (*Gadus morhua*), saithe (*Pollachius virens*), pollack (*Pollachius pollachius*) (Kamenos et al. 2004 a) and juvenile scallops (*Aequipecten opercularis)* (Kamenos et al. 2004 b).

Maerl contain $CaCO_3$ and $MgCO_3$. It has therefore traditionally been dredged for and crushed to a powder that has been used as a soil conditioner, an additive in animal feed in water filtration and in cosmetic products (Thomas 2002).

Maerl is considered to be of significant conservation importance due to its rarity and valuable role as a highly bio-diverse habitat.

EUNIS classification

The habitat “Maerl beds” correspond to the EUNIS habitat A5.51 *Maerl beds.*

4.9.3 Vulnerability. Maerl beds

Fate of and Impact of oil on maerl beds

Specific studies on the impacts of oil components on maerl beds have not been carried out. However, available general information on the vulnerability of maerl beds of various human activities and information on the toxicity of oil to red algae would suggest that maerl beds are highly vulnerable to oil spill, i.e.:

- Maerl beds are particularly sensitive to low oxygen concentrations, hydrogen sulphide and smothering which would prevent or hamper photosynthesis (Wilson et al 2004). If a maerl bed is smothered in spilled oil it is expected that mass mortality of live species will occur.
- O`Brien and Dixon (1976) suggested that red algae were the most sensitive group of algae to oil or dispersant contamination, possibly due to the susceptibility of phycoerythrins to destruction.
- Laboratory studies of the effects of oil and dispersants on several red algal species concluded that they were all sensitive to oil/dispersant mixtures, with little difference between adults, sporelings, diploid or haploid life stages (Holt et al 1995)
- Maerl beds are most commonly encountered from 20 m depth to the low tide mark, where toxic concentrations of oil may be encountered beneath oil slicks
- Maerl is ecologically fragile due to very slow growth and poor recovery potential. Partial recovery of an affected maerl bed is likely within 10 years and full recovery may take 25 years (OSPAR Commission 2010b)
- Maerl beds are considered to be of significant conservation importance due to their rarity and valuable role as a highly bio-diverse habitat. Maerl beds are important nursery areas for the juvenile stages of commercial fish species

Vulnerability scores. Maerl beds

Based on these ecological and impacts characteristics, maerl beds have been allocated the following vulnerability scores:

- Score surface oil spill: Spring: 4, Summer: 4, Autumn: 3, Winter: 3
- Score dispersed oil: Spring: 4, Summer: 4, Autumn: 4, Winter: 4

The scores of 3 in autumn and winter for surface oil spills reflects an anticipated higher wave energy exposure.

4.10 Seagrass beds

4.10.1Location of seagrass beds

Figure 4-11 shows known locations of seagrass beds, i.e. areas where the coverage of seagrass on the seabed is larger than 5 %

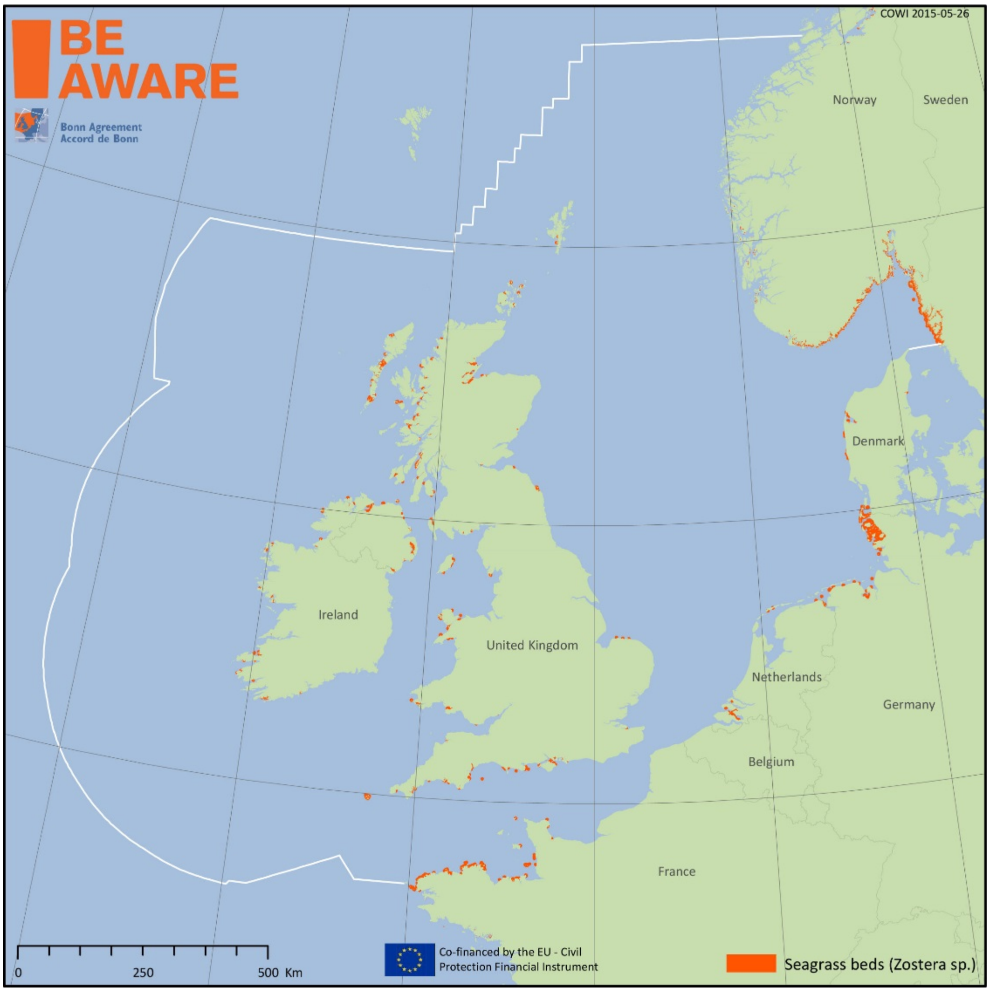

Figure 4-11 **Location of seagrass beds (> 5 % coverage).**

4.10.2Ecological characteristics and significance. Seagrass beds

Seagrass is found on sands and muds in intertidal and shallow subtidal areas sheltered from wave action. It is therefore typically found in estuaries, inlets, bays, lagoons and sheltered channels.

Where conditions are favourable, seagrass may cover extensive areas, forming seagrass beds. According to the OSPAR definition, plant density of seagrass on seagrass beds should cover at least 5% of the seabed. More typically, however, seagrass plant densities provide more than 30% cover.

Seagrass beds are very productive habitats with a high biodiversity (Barnes & Hughes, 1982) Seagrass beds have a rich associated fauna of benthic invertebrates and are important feeding, spawning and nursery grounds for fish. Seagrass is also food for some seabirds.

During the 1920s and mid-1930s a virulent fungus disease caused a mass die-back throughout western Europe and elsewhere causing seagrass to decline severely or to disappear completely in many locations. Today, seagrass populations have not recovered to the levels found prior to the outbreak of the disease. This has been attributed to the effects of increased load of nutrients from discharges of sewage and fertiliser runoff that may damage seagrass meadows by altering the metabolic balance of the plant and encouraging the growth of algae that blankets the beds (Den Hartog & Polderman, 1975; Jones et al., 2000; Davison and Hughes, 1998).

Characteristic vegetation

There are three species of native seagrass in the BA area: dwarf seagrass, narrow-leaved seagrass and common seagrass. Common seagrass is the most widespread of the three, with a distribution that extends from the Arctic down to Gibraltar. The three species are found at different shore levels or on different substrata, i.e.:

- Dwarf seagrass, *Zostera noltii* is found in the intertidal zone, highest on the shore, often adjacent to lower saltmarsh communities. It can however, also occur in the very shallow subtidal zone, on mud/sand mixtures of varying consistency.
- Narrow-leafed seagrass (*Zostera angustifolia*) on the mid to lower shore and
- Common seagrass (*Zostera marina*) is predominantly found in the sublittoral from low water to depths of several metres (typically about 4 m) (Gubbay, 1988).

In locations where seagrass beds are well developed, the leaves of the seagrass plants may be colonised by diatoms and epiphytic algae such as *Enteromorpha* spp, *Cladophora rectangularis*, *Rhodophysema georgii* and *Ceramium rubrum.*

Characteristic fauna

Live seagrass plants are a major source of food for wildfowl, particularly Brent goose and widgeon but also for mute and whooper swans that congregate in areas where seagrass is abundant.

However, the bulk of the seagrass production (95 %) is thought to be consumed in the ecosystem in the form of organic matter from dead plant material (Barnes & Hughes, 1982). The organic matter is utilised by a rich fauna of benthic infauna species. The species composition of the infauna is generally similar to species occurring in shallow areas in a variety of substrata (e.g. amphipods, polychaete worms, bivalves and echinoderms).

As well as an important source of organic matter, seagrass beds may also provide an important nursery habitat for juvenile fish (ICES, 2003). Adult fish frequently seen in seagrass beds include pollack, two-spotted goby, various species of wrasse and pipefish.

EUNIS classification

Seagrass meadows include the following EUNIS habitats:

- A2.61 *Seagrass beds on littoral sediments*
- A5.53 *Sublittoral seagrass beds*

4.10.3Vulnerability. Seagrass beds

Fate of oil

Seagrass on deeper waters may not be exposed to oil as the oil generally floats in the surface. However, seagrass on shallow water is highly at risk of being affected by oil components in case an oil slick reaches the area. Seagrass may be exposed to oil in the following ways:

- Direct oil contact is possible when surface oil is deposited on tidal seagrass that live near the surface when the water level drops at low tide;
- Oil components can dissolve in water especially in case of the spill of a light refined product which exposes seagrass on shallow water to potentially toxic compounds;
- Rough seas can mix lighter oil products into the water column (like shaking up a bottle of salad dressing), where they can drift down to seagrass beds;
- As heavy oil weathers or is mixed with sand or sediment, it can become dense enough to sink below the ocean surface and smother seagrass below and
- The use of chemical oil dispersants will increase the dispersion of the oil into the water column, thus increasing the potential for contact with seagrass.

Seagrass favours areas sheltered from wave action, so spilled oil may persist for quite a while in areas with seagrass.

Impact of oil/sensitivity

Oil spills may affect seagrass beds either by direct smothering or by toxic effects of the water-soluble fraction of oil. Petroleum products can damage seagrass ecosystems in a variety of ways, including (Wilson 2010, Runcie et al 2004, Anon 2010, Howard et al 1989):

- Direct mortality of organisms due to smothering leading to reduced growth rates, blackened leaves and mortality,
- Direct mortality due to asphyxiation or poisoning;
- Photosynthetic stress;
- Indirect mortality due to the death of food sources or the destruction or removal of habitat;
- Destruction of juveniles using grass beds as a nursery ground and
- Incorporation of sub-lethal amounts of petroleum fractions into body tissues, potentially lowering tolerance to other stresses.

The use of dispersants may increase the exposure of submerged seagrasses to oil as dispersed oil enters the water column and it has been demonstrated that the impact of dispersed oil on photosynthesis of seagrasses is more severe than undispersed oil (Wilson 2010).

Adverse impacts on seagrass have been observed following oil spills, including the Amoco Cadis spill in 1978 and the Exxon Valdez oil spill in 1989

- Direct effects on seagrass (*Zostera marina*) were observed locally, following the Amoco Cadiz oil spill in 1978. Many plants had black "burnt " leaves. This was however a temporary impact. The benthic invertebrate fauna associated with seagrass beds was severely affected. A sharp decrease in numbers of individuals and species occurred. Recovery was relatively fast except for Amphipoda (Jacobs 1980).
- The Exxon Valdez oil spill in 1989 caused seagrass leafs to be bleached white and ultimately killed (Juday and Foster 1990). Another study of this spill noted a decrease in the density of leaves and flowering shoots of seagrass beds

Vulnerability scores. Seagrass beds

Based on these ecological and impact characteristics, seagrass beds have been allocated the vulnerability score 4 for both surface oil spills and for dispersed oil during all seasons.

4.11 Estuaries

4.11.1Location of estuaries

Figure 4-12 shows the location of estuaries in the BA area.

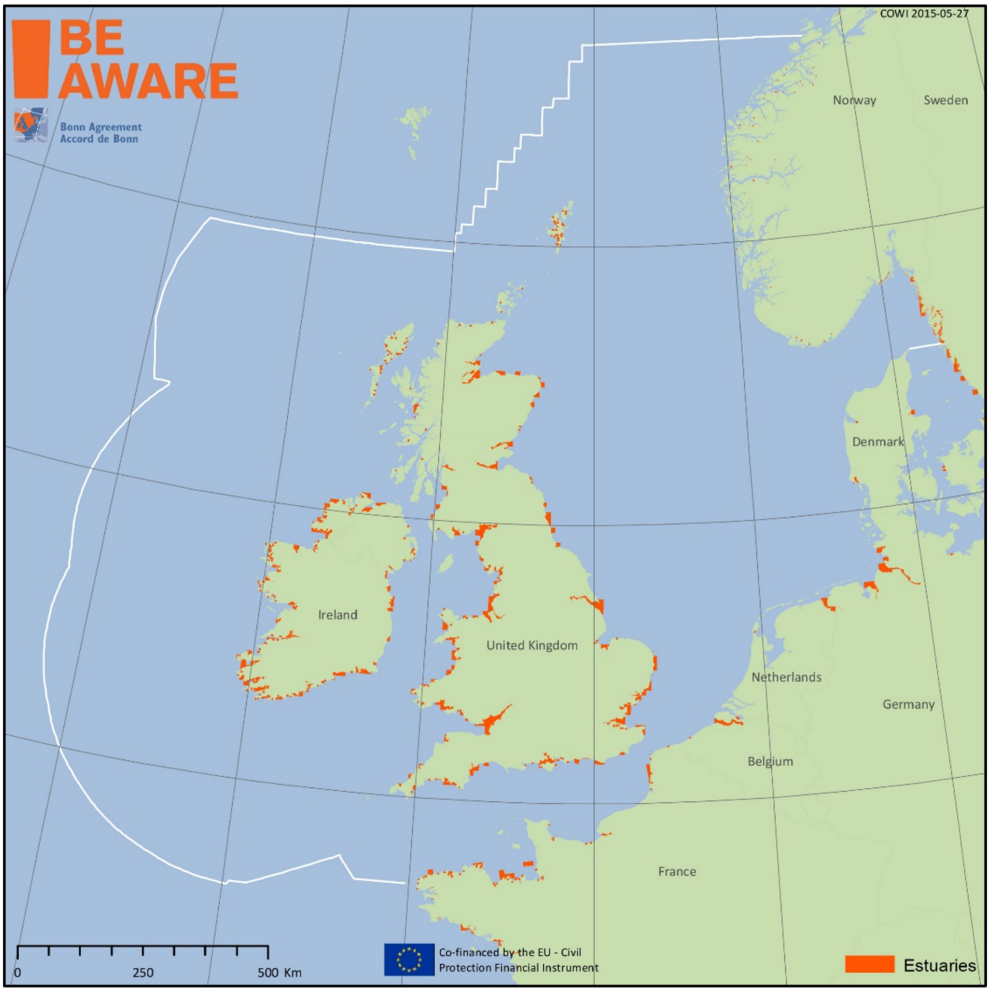

Figure 4-12 Location of estuaries.

4.11.2Ecological characteristics and significance. Estuaries

Estuaries are downstream parts of a river valley, subject to the tide and extending from the limit of brackish waters. River estuaries are coastal inlets where, unlike 'large shallow inlets and bays' there is generally a substantial freshwater influence. The mixing of freshwater and seawater and the reduced current flows in the shelter of the estuary lead to deposition of fine sediments, often forming extensive intertidal sand and mud flats. In estuaries where the tidal currents are faster than flood tides, most sediments deposit to form a delta at the mouth of the estuary. Baltic river mouths, considered as an estuary subtype, have brackish water and no tide, with large wetland vegetation (helophytic) and luxurious aquatic vegetation in shallow water areas (European Commission 2007).

Estuaries typically include some of the vulnerable habitats described above, especially, tidal sand and mudflats and saltmarshes as well as seagrass beds and biogenic reefs.

Estuaries are highly productive and have a high biodiversity. Characteristic vegetation and fauna include the following:

Characteristic vegetation

Benthic algal communities, Zostera beds e.g. *Zostera noltii* or vegetation of brackish water origin: *Ruppia maritima*; *Spartina maritima* (Spartinetea); *Sarcocornia perennis*.

Characteristic Fauna

Invertebrate benthic communities. Estuaries are important feeding areas for many birds and spawning and nursery areas for many species of fish.

EU classification

Estuaries correspond to the EU Habitats directive Annex I habitat: 1130 *Estuaries*

4.11.3Vulnerability. Estuaries

Fate and impacts of oil in estuaries

If oil enters into estuaries, natural removal rates are very slow because there is little wave action to remove the oil. Toxic concentrations of oil may be encountered on the shallow water. In addition, there are often tidal flats and oil components tend to adhere to the flat, preventing removal by tides. Therefore, oil may persist for years on the flats. Flora and fauna in estuaries are generally very sensitive to oil spills. Fate and impacts of oil in the habitats typically encountered in estuaries are described in more detail in the sections 4.5.3 (tidal sand and mudflats), 4.6.3. (salt marshes), 4.8.3. biogenic reefs, 4.10.3 (seagrass beds) and 5.1.3 (birds).

Vulnerability scores. Estuaries

Based on these ecological and impact characteristics, estuaries have been allocated the vulnerability score 4 for both surface oil spills and for dispersed oil during all seasons.

4.12 Coastal lagoons

4.12.1Location of coastal lagoons

The location of coastal lagoons in the BA area is shown in Figure 4-13.

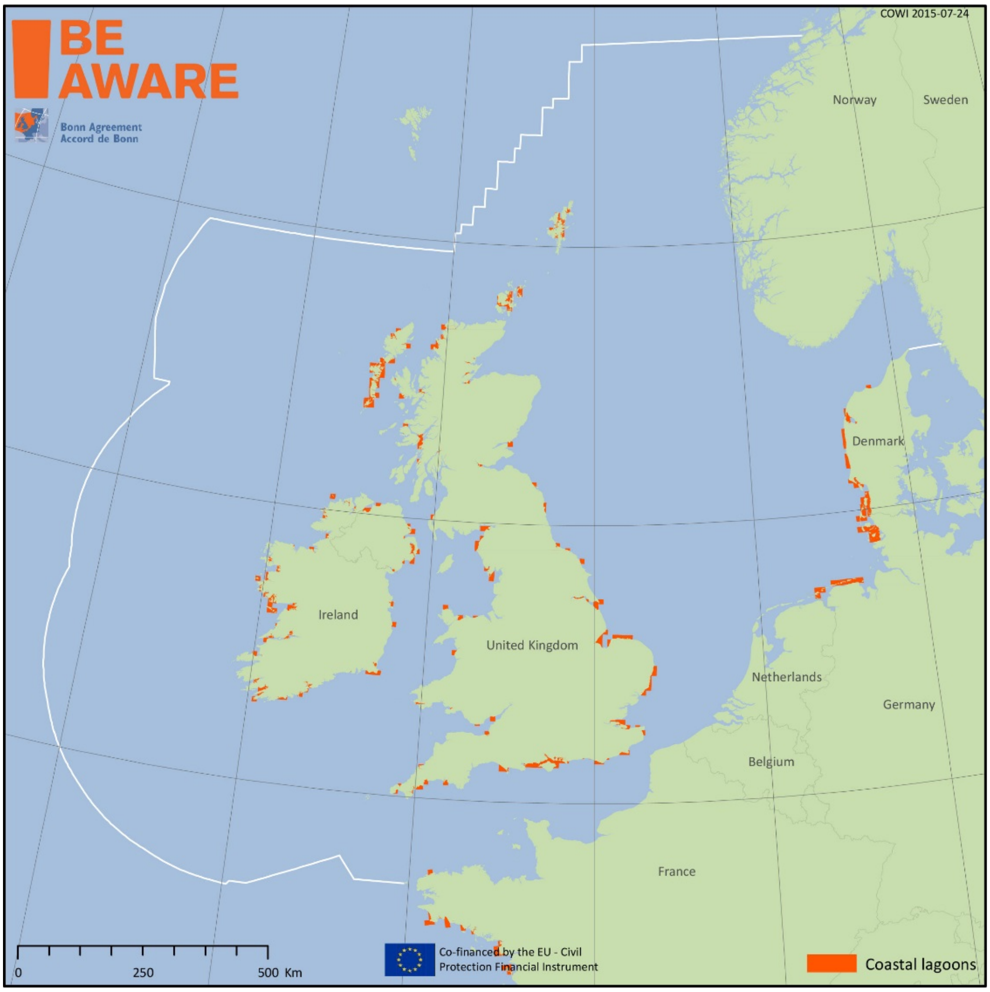

Figure 4-13 Location of coastal lagoons.

4.12.2Characteristics and significance. Coastal lagoons

Lagoons are expanses of shallow coastal salt water, of varying salinity and water volume, wholly or partially separated from the sea by sand banks or shingle, or, less frequently, by rocks. Salinity may vary from brackish water to hypersalinity depending on rain, evaporation and through the addition of fresh seawater from storms, temporary flooding of the sea in winter or tidal exchange (European Commission 2007).

Characteristic Vegetation

Coastal lagoons have a high biodiversity. Characteristic species include the following: *Callitriche* spp., *Chara canescens, C. baltica, C. connivens, Eleocharis parvula, Lamprothamnion papulosum, Potamogeton pectinatus, Ranunculus baudotii, Ruppia maritima, Tolypella n. nidifica*. (European Commission 2007).

Characteristic Fauna

Invertebrate benthic communities. Coastal lagoons are spawning and nursery areas for fish and staging areas for birds during migration and moulting.

EU Classification

This habitat corresponds to the EU Habitats Directive Annex I habitat type 1150 *Coastal lagoons*.

4.12.3 Vulnerability. Coastal Lagoons

Fate and impact of oil in coastal lagoons

The fate of oil in coastal lagoons is similar to estuaries and they house similar organisms (see section 4.11.3).

Vulnerability scores. Coastal Lagoons

Based on these considerations, coastal lagoons have been allocated the vulnerability score 4 for both surface oil spills and for dispersed oil during all seasons.

4.13 Large shallow inlets and bays

4.13.1 Location of large shallow inlets and bays

Figure 4-14 shows the location of large shallow inlets and bays. The Norwegian Fjords are deep water bays so are not included in the analysis here, but their coastlines are covered under rocky shores and reefs .

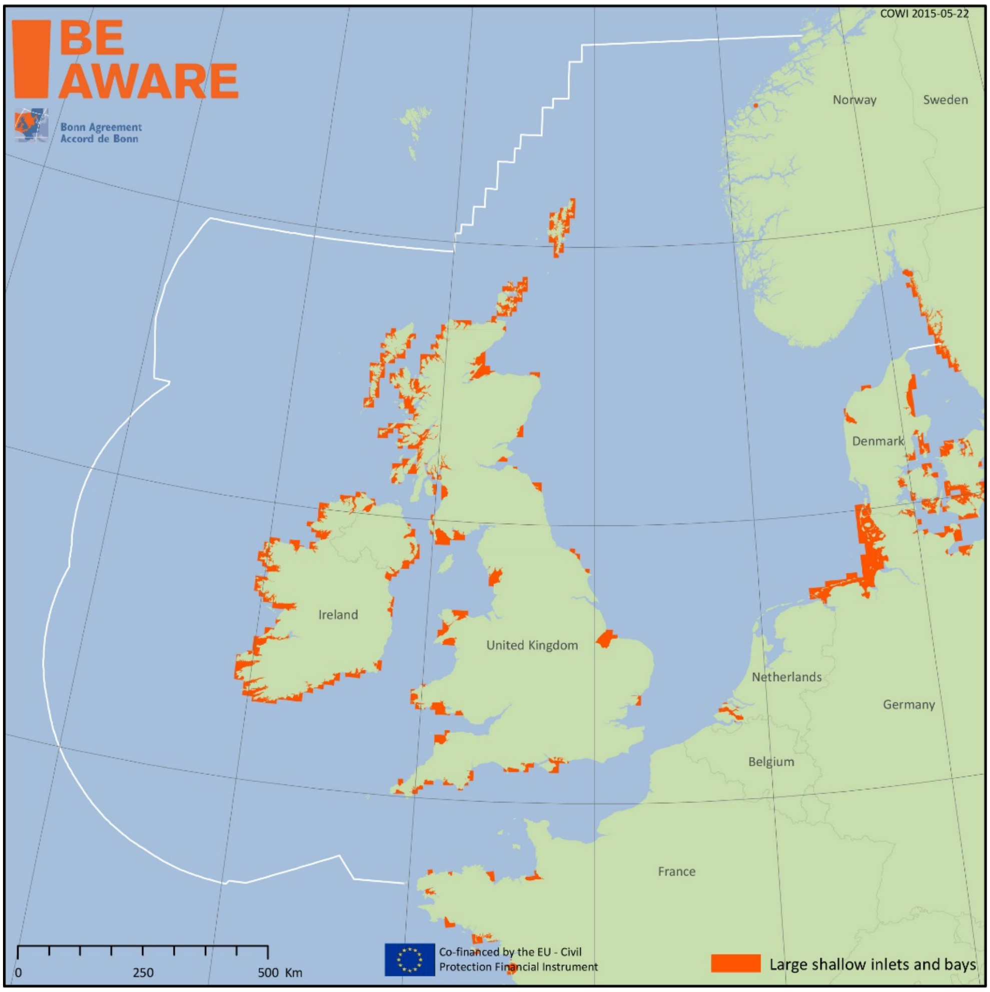

Figure 4-14 Locations of large shallow inlets and bays.

4.13.2 Ecological characteristics and significance. Large shallow inlets and bays

Shallow inlets and bays are large indentations of the coast where, in contrast to estuaries, the influence of freshwater is generally limited. These shallow indentations are generally sheltered from wave action and contain a great diversity of sediments and substrates with a well-developed zonation of benthic communities. These communities have generally a high biodiversity (European Commission 2007).

Large shallow inlets and bays typically include some of the habitats described above, i.e. sandy beaches, tidal sand and mudflats, underwater sandbanks on shallow water, saltmarshes as well as seagrass beds and biogenic reefs.

Characteristic vegetation and fauna

Large shallow inlets and bays have vegetation and benthic invertebrate communities as described for the different habitats.

Shallow inlets and bays are also nursery areas for fish and staging areas for birds during migration and moulting.

EU Classification

The habitat type corresponds to the EU Habitats Directive Annex I habitat type: 1160 *Large shallow inlets and bays*.

4.13.3Vulnerability. Large shallow inlets and bays

Fate and impacts of oil

The fate of oil in shallow inlets and bays is similar to estuaries and coastal lagoons and they more or less house the same type of organisms, although estuaries may contain species more adapted to salinity fluctuations compared to shallow inlets and bays. In addition, water exchange and wave action that may remove oil is somewhat larger in large shallow inlets and bays, compared to estuaries and coastal lagoons that are more sheltered. Consequently, the persistence of oil in large shallow inlets and bays is shorter than in estuaries and lagoons.

The vegetation and benthic fauna encountered in shallow inlets and bays are vulnerable to oil spills. So too are the bird areas and fish spawning and nursery areas encountered in shallow inlets and bays.

Fate and impacts of oil in the habitats typically encountered in estuaries are described in more detail in the sections 4.5.3 (tidal sand and mudflats), 4.6.3. (salt marshes), 4.8.3. biogenic reefs, 4.10.3 (seagrass beds) and 5.1.3 (birds).

Vulnerability scores. Large shallow inlets and bays

Based on these ecological and impact characteristics, large shallow inlets and bays have been allocated the vulnerability score 3 for both surface oil spills and for dispersed oil during all seasons.

4.14 Open water column

Figure 4 15 shows the distribution of open waters on water depths of more than 20 metres and less than 20 metres.

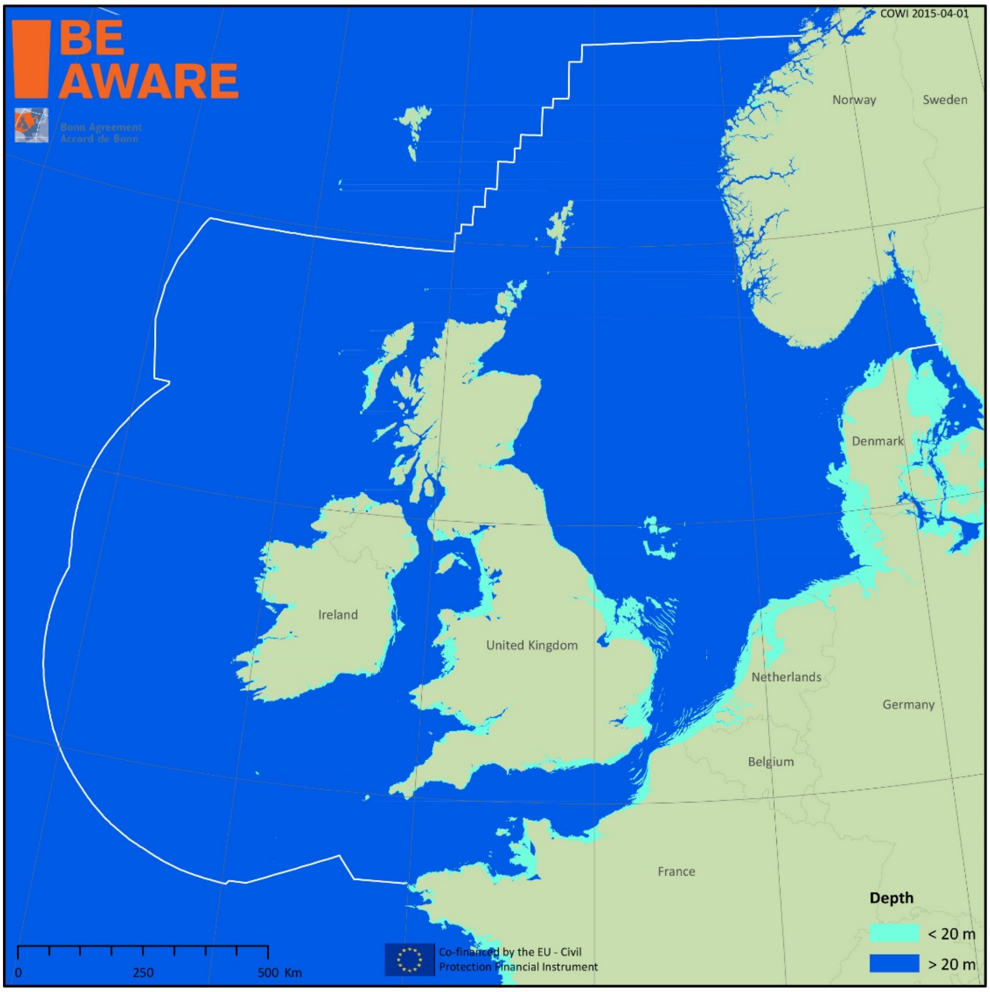

Figure 4-15 Location of open water column more than and less than 20 m depth.

4.14.1Ecological characteristics and significance. Open water column

Plankton, pelagic fish species and seabirds dominate the fauna and flora in the open water column. Plankton organisms are very important elements of the marine ecosystems. Plankton includes phytoplankton (pelagic microscopic algae) and zooplankton (pelagic microscopic animals) drifting passively with currents.

The primary production of phytoplankton forms the basis for most of the secondary production in the North Sea and adjacent waters. Diatoms and dinoflagellates dominate the phytoplankton in these waters.

Zooplankton include both organisms that stay planktonic during the entire life cycle (holoplankton) and organisms that are only planktonic in the earliest life stages (meroplankton) such as larvae of fish, sea urchins, starfish, mussels, bristle worms, shrimps, crabs and lobsters. Copepods dominate the zooplankton in the North Sea. Copepods are food for fish and other organisms, including larvae, juveniles and mature individuals of many commercially important fish species such as herring and sprat.

Some plankton organisms, such as copepods, undertake diurnal vertical migration. During daylight, they descend to deeper waters and during the night, they return to the upper water layers. Predators of copepods such as herring, typically also follow this migration pattern.

The vulnerability ranking of open waters does not include fish eggs, fish larvae and seabirds. They are dealt with separately in chapters 5.2 and 5.1.

EUNIS classification

Open water corresponds to the EUNIS habitat: A7. *Pelagic water column.*

4.14.2Vulnerability open water column

Fate of oil in open water

After an oil spill in open water, the oil plume is subject to complex, interrelated physicochemical processes including spreading, drift, evaporation, dissolution, dispersion, emulsification, sedimentation, biodegradation and photo-oxidation, all of which ultimately cause degradation and removal of oil components from the water column (see Appendix A for a detailed description). Oil components that have not evaporated, degraded or sunk during dispersal after the spill will eventually end up on the shore where they will be further degraded, removed and transformed by natural processes.

Impact of oil in open water

Laboratory studies have revealed that plankton organisms are sensitive to exposure to oil components. Both acute toxic and sub-lethal effects of certain oil components have been demonstrated in the laboratory (Falk Petersen et al.1982, Kühnholt 1977). Some field studies have also demonstrated short term impacts on plankton following an oil spill but the effects appeared to be only very short lived and localised (Khalaf 2006, Anon 1985). Most field studies carried out in connection with oil spills have in fact failed to demonstrate any impacts on plankton.

Table 4-10 shows some examples.

The fact that long-term effects have not been observed on plankton populations despite the toxicity of oil is probably partly due to the enormous regeneration capacity of plankton and the possibility of transport by the current of plankton into an affected area from adjacent unaffected areas, both of which counteract short-term reductions in numbers caused by the oil. Another factor may be that the oil and its soluble components (which are the most toxic components), rapidly evaporate or are diluted to non- toxic concentrations downstream of the spill (Kennington & Rowlands 2004 Batten et al.1998Neff and Stubbefield 1995; Anon 1985).

Table 4-10 Selected references from field surveys following oil spills where effects on plankton were not observed.

Spill	Reported effect	Reference
2002. Oil spill from the shipwrecked tanker "*Prestige*" on the northwest coast of Spain. 64,000 tonnes were spilled	Studies of chlorophyll, primary production, zooplankton biomass and species composition of phyto- and zooplankton were carried out. Impacts on plankton were not observed	Varelaa et al 2006
1996 "*Sea Empress*" oil spill in the southern Irish Sea 72,000 tonnes of oil were spilled	Field studies carried out in connection with the oil spill failed to demonstrate any impact on phyto-and zooplankton in the area	Kennington & Rowlands 2004.
1989 "*Exxon Valdez*" oil spill in Prince William Sound Alaska. 35,360 tonnes of oil spilled	Following the spill, water samples were collected analysed for PAH and toxicity tested. Traces of petroleum hydrocarbons present shortly after the spill were well below effect concentrations for plankton.	Neff and Stubbefield 1995
1977. "*Thesis*", Baltic Sea Sweden; spill of 1,000 tonnes medium fuel	Observations on phytoplankton biomass and primary productivity carried out	Anon 1985

oil	following the oil spill revealed no differences between contaminated areas and areas that were not contaminated

There is no evidence that even major oil spills such as the Torrey Canyon disaster have caused massive kills of fish in the open sea. One of the few cases where spilled oil has been shown to kill adult fish is the Amoco Cadiz oil spill in March 1978 on the Brittany coast. Rough seas dispersed the oil in the sub-littoral zone and dead fish were seen some 10 km around the wreck. Virtually all of the fish killed belonged to inshore species (Anon 1985).

The reason that adult pelagic fish are apparently not affected by oil spills is probably that concentrations of oil components, which are toxic to adult pelagic fish, are not normally encountered in the water column beneath the oil slick. In addition, adults are highly mobile and are capable of actively avoiding oil-impacted areas.

4.14.3Vulnerability scores.

Open water column (< 20 m)

Based on these ecological and impact characteristics open waters on depths less than 20 m have been allocated the following vulnerability scores:

- Score surface oil spill: Spring: 2, Summer: 2, Autumn: 1, Winter: 1
- Score dispersed oil: Spring: 2, Summer: 2, Autumn: 2, Winter: 2

The difference in scores between spring/summer and autumn/winter for surface oil spill reflects the seasonal differences in productivity of open waters.

Deep sea water column (> 20 m)

Waters on depths of more than 20 m have been allocated the following vulnerability scores:

- Score surface oil spill: Spring: 1, Summer: 1, Autumn: 1, Winter: 1
- Score dispersed oil: Spring: 2, Summer: 2, Autumn: 2, Winter: 2

The deep-sea water column is not vulnerable to surface oil spills, as oil will not reach the deep sea. This cannot be stated for dispersed oil in deep water, which consequently has been ranked as a little more vulnerable.

4.15 Deeper sea floor (> 20m)

The location of deeper sea floor areas in the BA area is shown in Figure 4-15.

4.15.1Ecological characteristics and significance. Deeper sea floor

Deeper seafloor on depths larger than 20 m houses a wide variety of different seabed habitats, including the following that are described and assessed elsewhere in this report:

- Underwater sandbanks on waters deeper than 20 m (described in chapter 4.7)
- Biogenic reefs on waters deeper than 20 m (chapter 4.8)
- Seamounts (chapter 4.16)
- Coral gardens and sponge aggregations (chapter 4.17)
- Carbonate mounds (chapter 4.18)
- Lophelia pertusa reefs (chapter 4.19)

- Seapen and burrowing megafauna (chapter 4.20)

In addition to these habitats, deep sea floor includes the following EUNIS habitats:

- A6.1 *Deep sea rock and artificial hard substrata*
- A6.2. *Deep-sea mixed substrata*
- A6.3. *Deep-sea-sand*
- A6.4. *Deep-Sea muddy sand*
- A6.5 *Deep-sea mud*
- A6.7 *Raised features of the deep sea bed*
- A6.8 *Deep sea trenches and canyons, channels slope failures and slumps on the continental slope*
- A6.9 *Vents, seeps, hypoxic and anoxic habitats of the deep sea*

4.15.2Vulnerability. Deeper sea floor (>20m)

Deep-sea floor is not vulnerable to surface oil spills as oil will not reach the deep sea. In case of dispersed oil there may be a slightly bigger risk that oil will reach the seabed. Therefore, the deeper sea floor has been allocated the following vulnerability scores:

- Score surface oil spill: Spring: 1, Summer: 1, Autumn: 1, Winter: 1
- Score dispersed oil: Spring: 2, Summer: 2, Autumn: 2, Winter: 2

4.16 Seamounts

4.16.1Location of seamounts

In the BA area, seamounts have been observed in three areas north-west of Scotland (Figure 4-16).

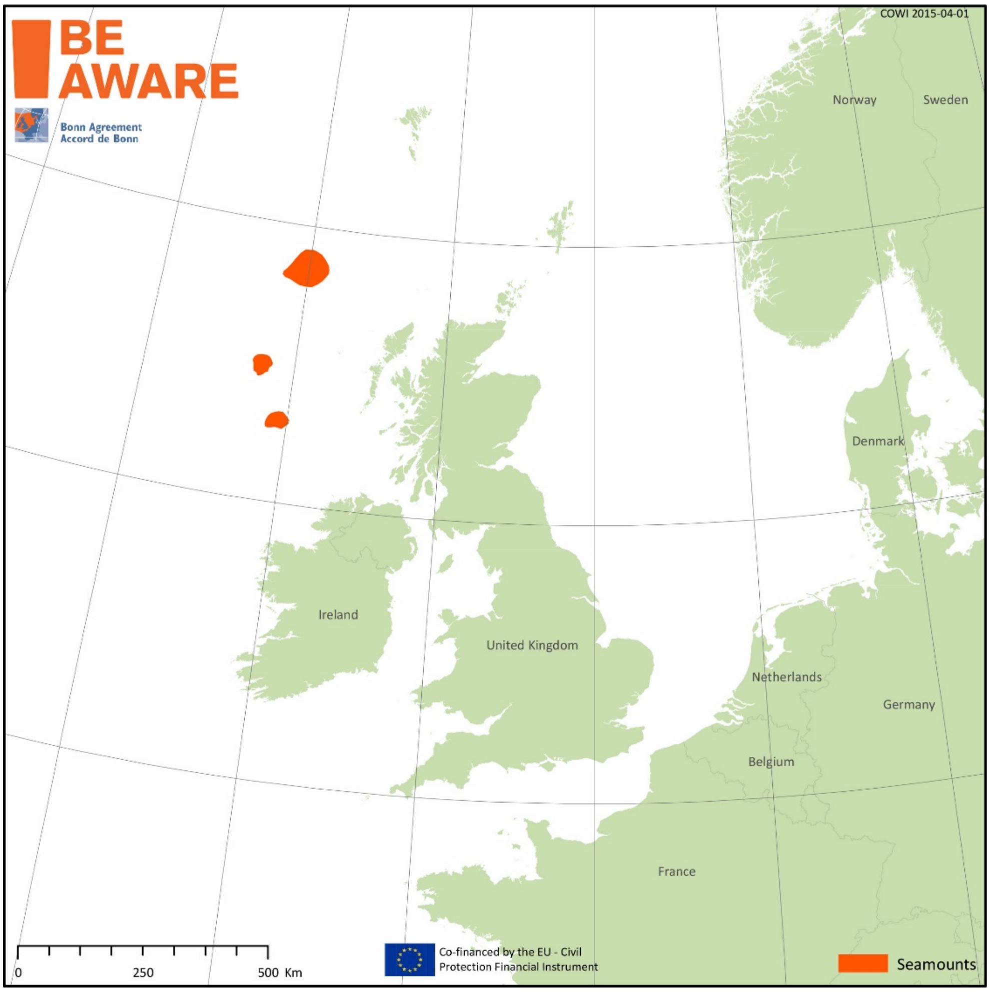

Figure 4-16 Location of seamounts.

4.16.2 Ecological characteristics and significance. Seamounts

Seamounts are of volcanic origin. They are undersea mountains, with a crest that rises more than 1,000 metres above the surrounding sea floor (Rogers, 1994). The majority of seamounts occur along the Mid- Atlantic ridge between Iceland and the Hayes fracture zone (Gubbay, 2002).

Seamounts affect the surrounding water circulation markedly and causes the formation of trapped waves, jets, eddies and closed circulations, which provide ideal conditions for suspension feeders. Suspension feeders that are encountered on seamounts include corals, sponges, hydroids and ascidians. Concentrations of commercially important fish species, such as deep sea perch (*Hoplostethus atlanticus*), aggregate around seamounts and live in close association with the benthic communities (Rogers, 1994, 2002). The deep sea perch is notable for its extraordinary lifespan of up to 150 years. It is important to commercial deep-trawl fisheries.

EUNIS classification

This habitat corresponds to the EUNIS classification: A6.72 *Seamounts, knolls and banks.*

4.16.3Vulnerability. Seamounts

Fate and impact of oil on seamounts

Seamounts are not vulnerable to surface oil spills. As the seamounts are encountered in very deep waters, there is an insignificant risk that harmful oil components will reach and affect seamounts. There may be a slightly higher risk that dispersed oil will reach a seamount.

Vulnerability scores. Seamounts

Seamounts have therefore been allocated vulnerability score 1 for surface oil spill for all seasons and score 2 for dispersed oil for all seasons.

4.17 Coral gardens and sponge aggregations

4.17.1Location of coral gardens and sponge aggregations

The location of coral gardens and sponge aggregations in the BA area is shown in Figure 4-17.

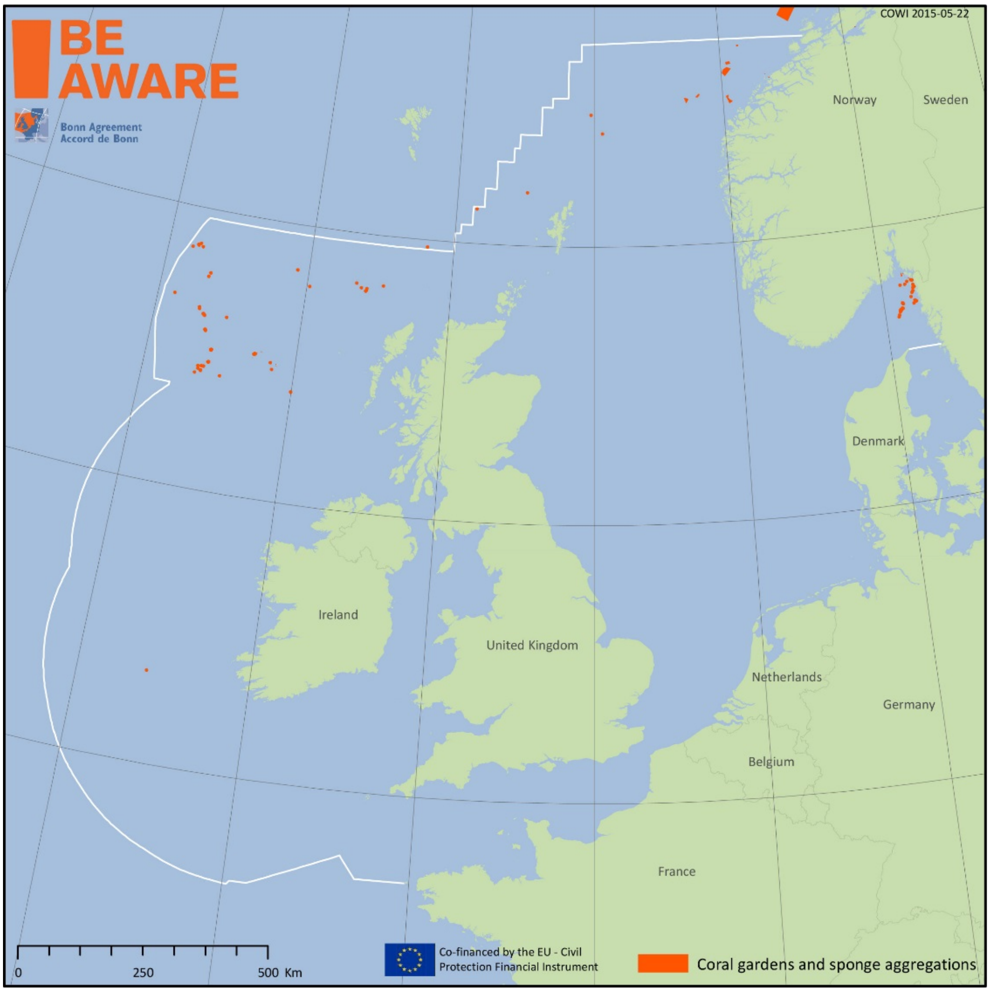

Figure 4-17 Location of coral gardens and sponge aggregations.

4.17.2Ecological characteristics and significance. Coral gardens and sponge aggregations

Coral gardens

A coral garden is a relatively dense aggregation of coral species. The biological diversity is typically high. The habitat can also include relatively large numbers of sponge species. Other commonly associated fauna include basket stars (*Gorgonocephalus*), brittle stars, crinoids, molluscs, crustaceans and deep-water fish (OSPAR Commission 2010b).

Coral gardens can occur on a wide range of soft and hard seabed substrata. They can be found as shallow as 30 m depth (in Norwegian fjords) and down to several thousand metres on open ocean seamounts.

Deep-sea Sponge Communities

Deep-sea sponge aggregations mainly include species from the two classes of sponge: Glass sponges (*Hexactinellida*) and *Demospongia*. Glass sponges tend to be the dominant group of sponges in the deep sea.

The sponges provide shelter to small epifauna, within their oscula and canal system, and an elevated perch, e.g. for brittle stars. Deep-sea sponges have similar habitat preferences to cold-water corals, and hence are often found at the same location. The deep-sea sponge communities occur in water depths of 250-1300 m (OSPAR 2008).

EUNIS classification

The coral garden habitat occurs within each of the following deep seabed EUNIS types:

- A6.1 *Deep-sea rock and artificial hard substrata*
- A6.2 *Deep-sea mixed substrata*
- A6.3 *Deep-sea sand*
- A6.4 *Deep-sea muddy sand*
- A6.5 *Deep-sea mud*
- A6.7 *Raised features of the deep-sea bed*
- A6.8. *Deep-sea trenches and canyons, channels, slope failures and slumps on the continental slope*
- A6.9 *Vents, seeps, hypoxic and anoxic habitats of the deep sea*

Deep sea sponge aggregations correspond to the EUNIS type A6.62: *Deep-sea sponge aggregations.*

4.17.3Vulnerability. Coral gardens and sponge aggregations

Fate and impact of oil on coral gardens and sponge aggregations

Sponge aggregations and most coral gardens are encountered on deep water, however in certain areas coral gardens can be shallower water (around 30 m). In general, the risk that harmful oil components will reach and affect these habitats is small. There is a higher risk that dispersed oil will reach coral gardens and sponge aggregations than an undispersed spill

Vulnerability scores. Coral gardens and sponge aggregations

Coral gardens and sponge aggregations have been allocated vulnerability score 2 for surface oil spill for all seasons and score 3 for dispersed oil for all seasons.

Although coral gardens and sponge aggregations are not particularly vulnerable to oil spills due to their deep location, they have been allocated a relatively high score, particularly for dispersed oil due to their high biodiversity and slow-growing characteristics.

4.18 Carbonate mounds

4.18.1Location of carbonate mounds

Carbonate mounds are found on deep waters to the west and north of Ireland (Figure 4-18).

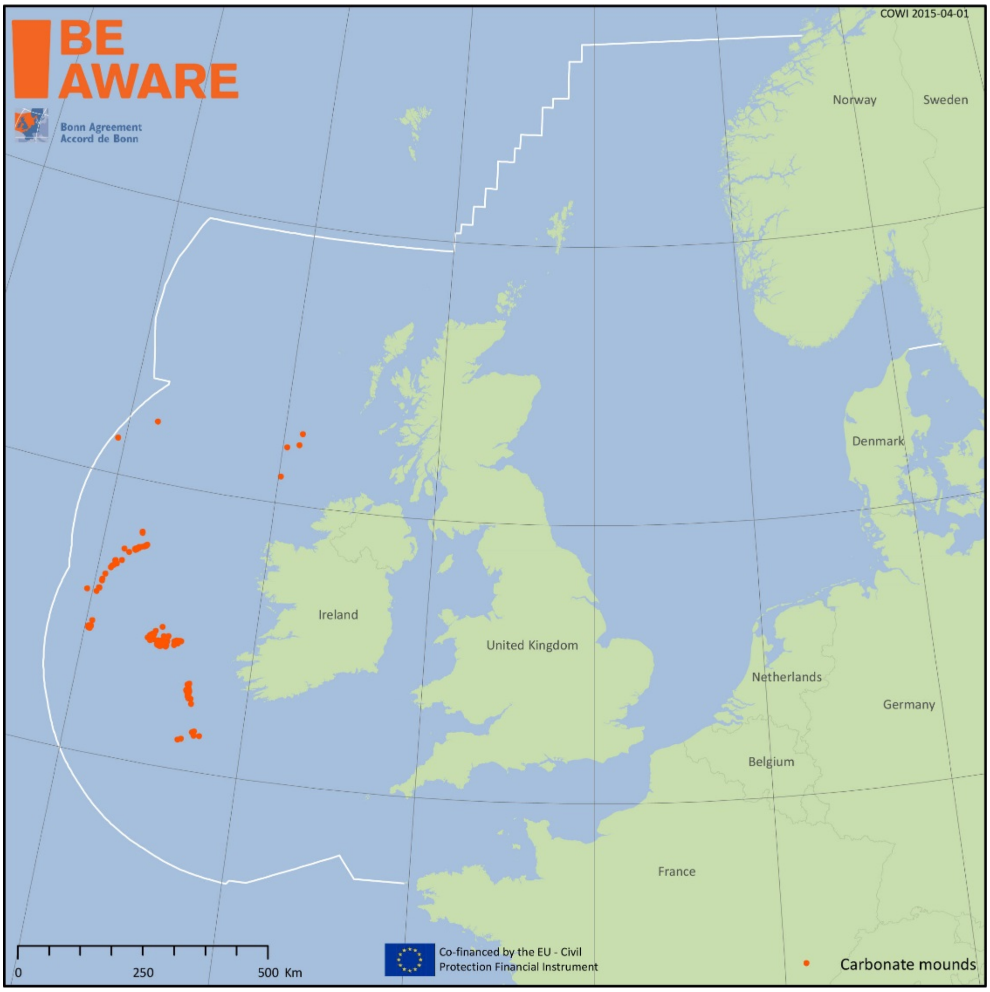

Figure 4-18 Location of carbonate mounds.

4.18.2Ecological characteristics and significance. Carbonate mounds

Carbonate mounds are very steep-sided mounds of variety of shapes. They may be up to 350 m high and 2 km wide at their base. They occur in water depths of 500-1100 m (OSPAR 2008).

Characteristic fauna of carbonate mounds include the coral species Lophelia pertusa and *Madrepora oculata* as well as echiuran worms. Other species that may be encountered include; large eunicid worms and sipunculids, *Ophiactis balli* (ophiuroid), *Astarte* sp. (bivalve), ceriantid anemones and caridean shrimps (OSPAR 2008).

EUNIS Classification

This Habitat correspond to the EUNIS habitat: A6.75 *Carbonate mounds*.

4.18.3Vulnerability. Carbonate mounds

Fate and impacts of oil

Carbonate mounds are encountered in deep water, so the risk that harmful oil components will reach and affect carbonate mounds is small. There is a higher risk that dispersed oil will reach carbonate mounds than an undispersed spill.

Vulnerability ranking. Carbonate mounds

Carbonate mounds have been allocated vulnerability score 2 for surface oil spill for all seasons and score 3 for dispersed oil for all seasons.

Although carbonate mounds are not particularly vulnerable to oil spills due to their deep location, they have been allocated a rather high score, particularly for dispersed oil due to their high biodiversity and slow-growing characteristics.

4.19 Lophelia pertusa reefs

4.19.1Location of Lophelia pertusa reefs

Known locations of Lophelia pertusa reefs in the BA area is shown in Figure 4-19.

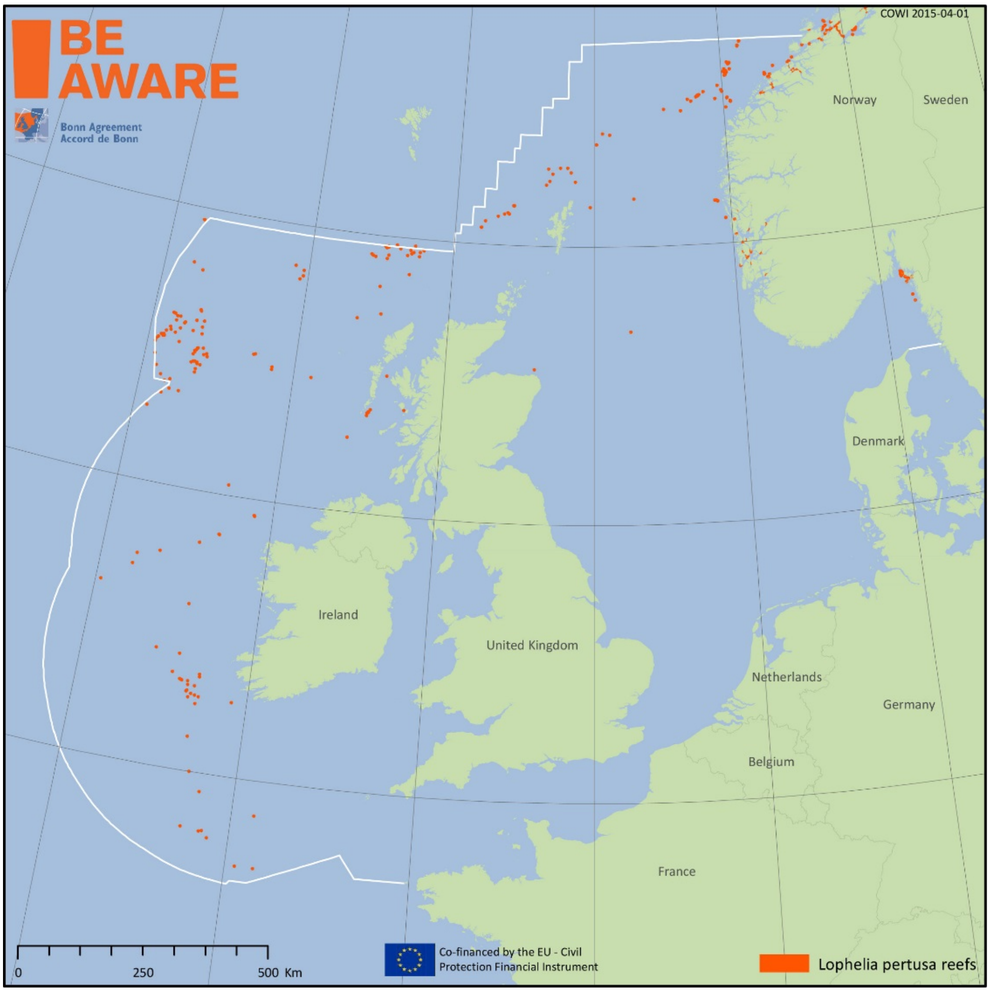

Figure 4-19 Location of *Lophelia pertusa* reefs.

4.19.2Ecological characteristics and significance. Lophelia pertusa reefs

Lophelia pertusa is a reef building, deep-water coral, which grows in the deep waters throughout the North Atlantic Ocean. It is unusual for its lack of symbiotic algae, which live inside most tropical reef building corals. Therefore the coral do not require light and can live on deep water with very little or no sunlight between 80 metres to more than 3,000 metres depth. It is most commonly encountered on the continental slope at depths of 200 – > 2,000 metres (Hall – Spencer & Stehfest 2009).

The extent of *Lophelia pertusa* reefs varies. The largest recorded reef in the North East Atlantic is 105 km². This reef is located at a depth of 300-400 m off the Lofoten Islands (Marine Research Norway 2002).

The growth of *Lophelia pertusa* is extremely slow. The growth rate is thought to be about 6 mm per year implying that normal sized colonies of about 1.5 m high are about 250 years old (Hall – Spencer & Stehfest 2009).

The biodiversity of these reefs is high and can be three times as high as the surrounding soft sediment (Hall – Spencer & Stehfest 2009). Lophelia beds create a specialised habitat favoured by some species of deep-water fish. Although functional relationships have not been demonstrated so far, the reefs are presumed to be breeding grounds for commercial species such as redfish (Sebastes spp) and feeding ground for demersal fish such as monkfish, cod, ling, saithe and tusk (Husebo et al 2002, Costello et al 2005). The invertebrate community consists of brittle stars, molluscs, amphipods and crabs.

The OSPAR Commission for the protection of the marine environment of the North-East Atlantic have recognised Lophelia pertusa reefs as a threatened habitat in need of protection (OSPAR 2010).

EUNIS classification

This habitat corresponds to the following EUNIS habitats:

- A5.631 *Circalittoral (Lophelia pertusa) reefs*
- A6.611. *Deep sea (Lophelia pertusa) reefs*

4.19.3Vulnerability. Lophelia pertusa reefs

Fate and impact of oil

Lophelia pertusa reefs are encountered on deep water, so the risk that harmful oil components will reach and affect such reefs is not very likely. There is a higher risk that dispersed oil will reach Lophelia pertusa reefs than an undispersed spill.

Vulnerability ranking. Lophelia pertusa reefs

Lophelia pertusa reefs have been allocated vulnerability score 2 for surface oil spills for all seasons and score 3 for dispersed oil for all seasons.

Although *Lophelia pertusa* reefs are not particularly vulnerable to oil spills due to their deep location, they have been allocated a relatively high score, particularly for dispersed oil due to their high biodiversity and slow-growing characteristics.

4.20 Sea-pen and burrowing megafauna

4.20.1Location of sea pen and burrowing megafauna

Figure 4-20 shows known locations of sea pen and burrowing megafauna habitats in the Bonn Agreement area.

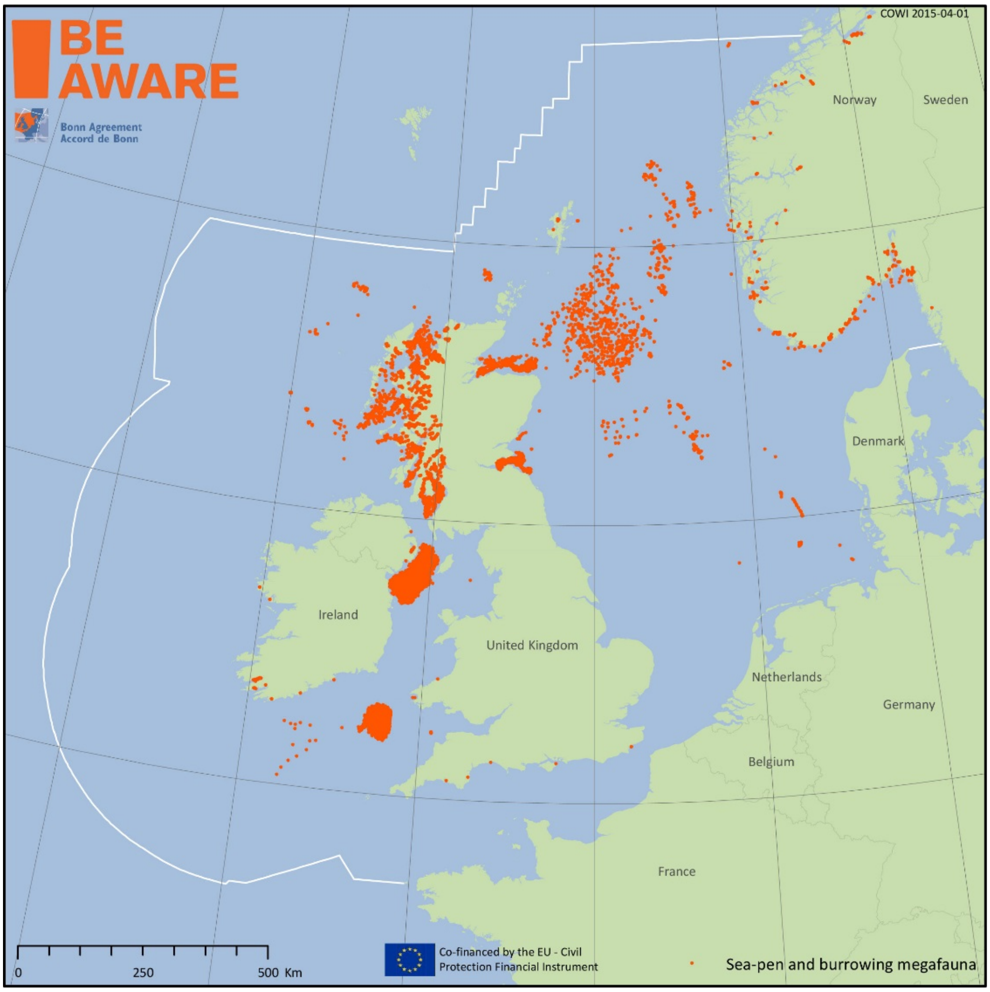

Figure 4-20 Location of sea pen and burrowing megafauna.

4.20.2Ecological characteristics and significance. Sea pen and burrowing megafauna

This habitat occurs in areas of fine mud that is heavily bioturbated by burrowing megafauna at water depths ranging from 15-200 m or more. Burrows and mounds may form a prominent feature on the sediment surface with conspicuous populations of seapens, typically *Virgularia mirabilis* and *Pennatula phosphorea*. In the deeper fiords or lochs, which are protected by an entrance sill, the tall seapen *Funiculia quadrangularis* may also be present. These soft mud habitats occur extensively throughout the more sheltered basins of sea-lochs and voes and are present in quite shallow depths probably because they are very sheltered from wave action. The habitat also occurs in deep offshore waters in the North Sea with high densities of Nephrops norvegicus present (OSPAR 2008).

EUNIS classification

This habitat include the following EUNIS habitats:

- A5.361 *Seapens and burrowing megafauna in circalittoral fine mud*
- A5.362 *Burrowing megafauna and Maxmuelleris lankestri in circalittoral mud*

4.20.3Vulnerability. Sea-pen and burrowing megafauna

Fate and impacts of oil

This biotope occurs in areas of fine mud that is heavily bioturbated by burrowing megafauna at water depths ranging from 15-200 m or more. Impacts on this habitat in shallower waters cannot be excluded, but are not very likely. The risk that habitats on deeper waters will be affected is insignificant as it is not very likely that spilled oil on the surface will reach the seabed. There is a slightly higher risk that dispersed oil will reach the habitat than an undispersed spill.

Vulnerability scores. Sea-pen and burrowing megafauna

Sea-pen and burrowing megafauna habitats have been allocated vulnerability score 2 for surface oil spill for all seasons and score 3 for dispersed oil for all seasons.

Although sea-pen and burrowing megafauna are not particularly vulnerable to oil spills due to their deep location, they have been allocated a relatively high score, particularly for dispersed oil because it is a threatened/declining habitat (OSPAR 2008).

5. VULNERABILITY ANALYSIS OF SPECIES

5.1 Birds

5.1.1 Ecological characteristics and significance.

Due to its high biological production providing excellent feeding conditions, the North Sea is a very important area for seabirds and coastal birds. More than 10 million birds make use of the North Sea for breeding, feeding, or migratory stopovers every year and important breeding colonies fringe the coastlines. (Skov et al. 1995).

Seabirds

Seabirds include those species of bird that depend wholly or mainly on the marine environment for their survival. They spend most of their lives at sea, exploiting its surface and the water column to varying depths for food. Most of these species come ashore only to breed. Many of the seabird species are encountered in internationally important numbers including:

- Internationally important breeding populations of auks, gannets, and cormorants.
- Internationally important pathways for numerous species of migratory seabirds.
- Internationally important wintering areas of auks, divers and sea duck

Coastal birds

Costal birds are birds commonly found along sandy or rocky shorelines, mudflats, and shallow waters, mainly including gulls, terns, waders, ducks, geese and swans.

5.1.2 Location of breeding, wintering and staging areas for sea- and coastal birds

The location of important breeding, wintering and staging areas for sea-and coastal birds is shown in Figure 5-1, Figure 5-2 and Figure 5-3, respectively.

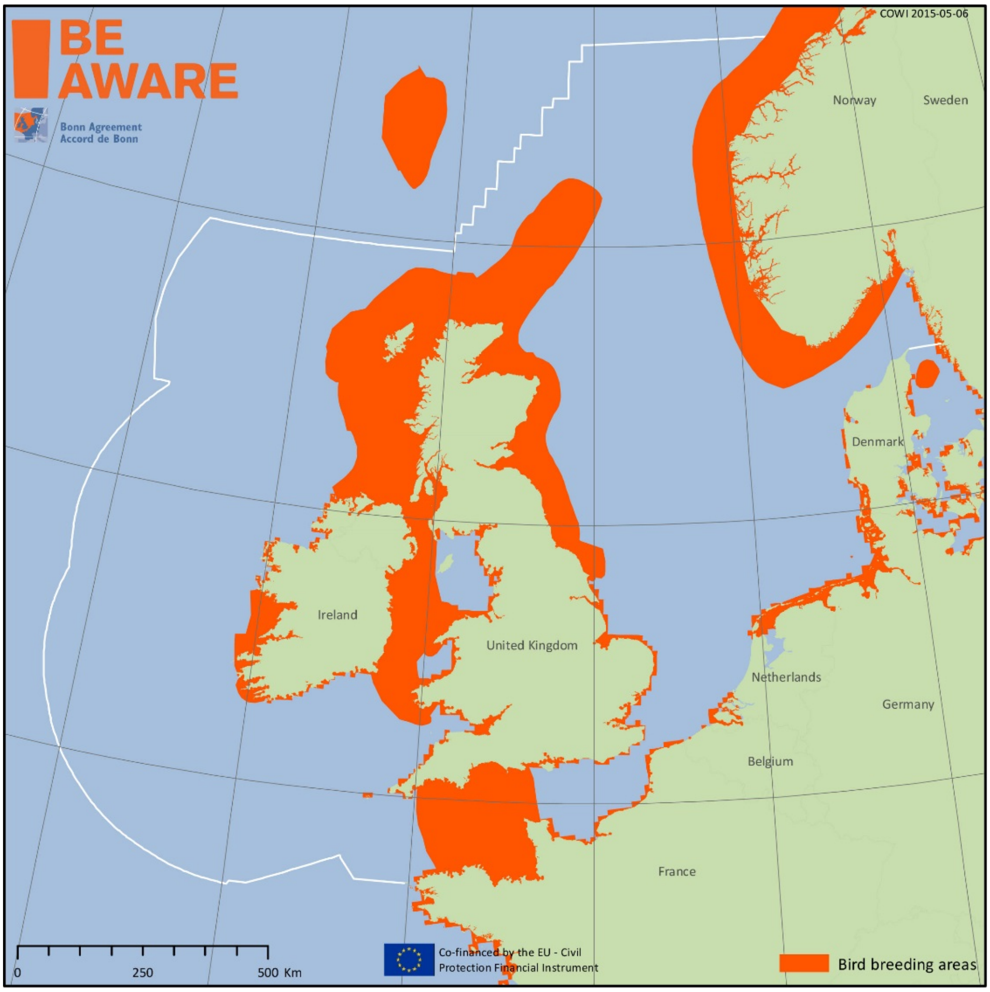

Figure 5-1 **Important breeding areas for sea and coastal birds in the BA area. Offshore foraging areas for breeding birds are included.**

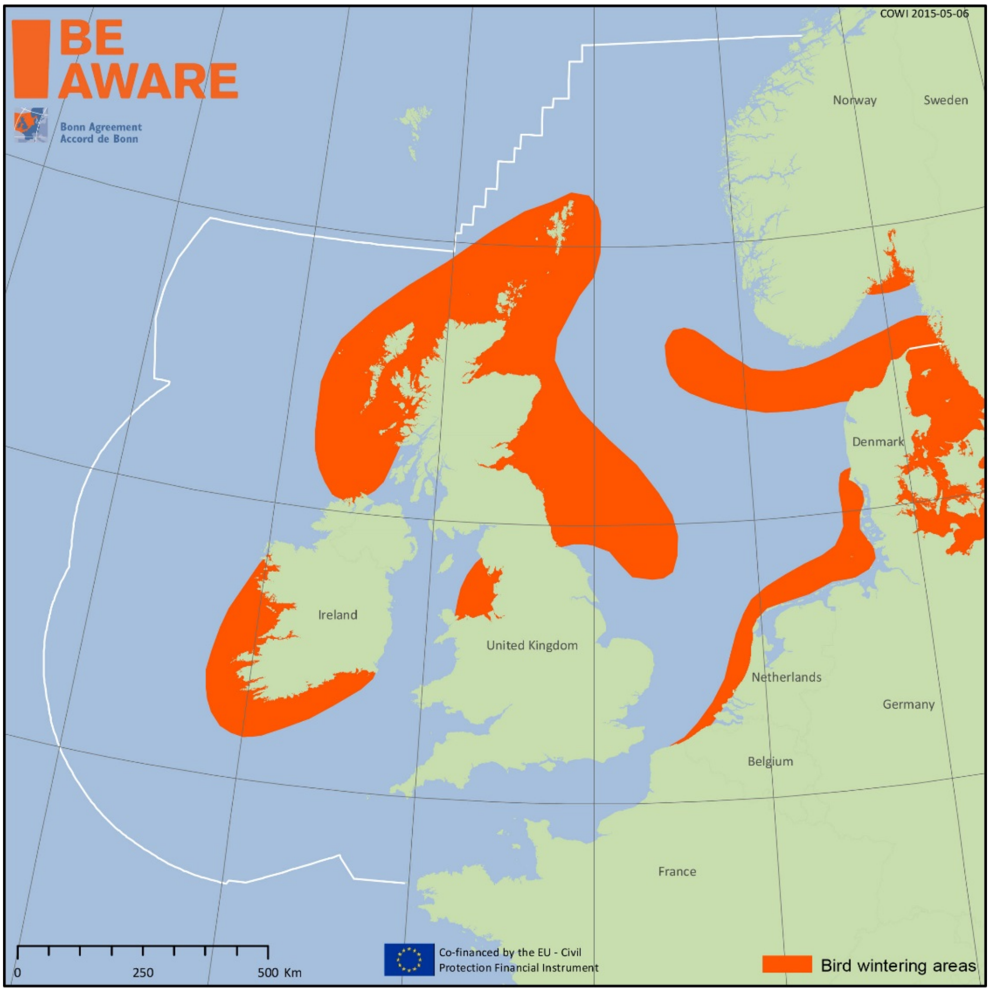

Figure 5-2 Important wintering areas for migrating sea and coastal birds in the BA area.

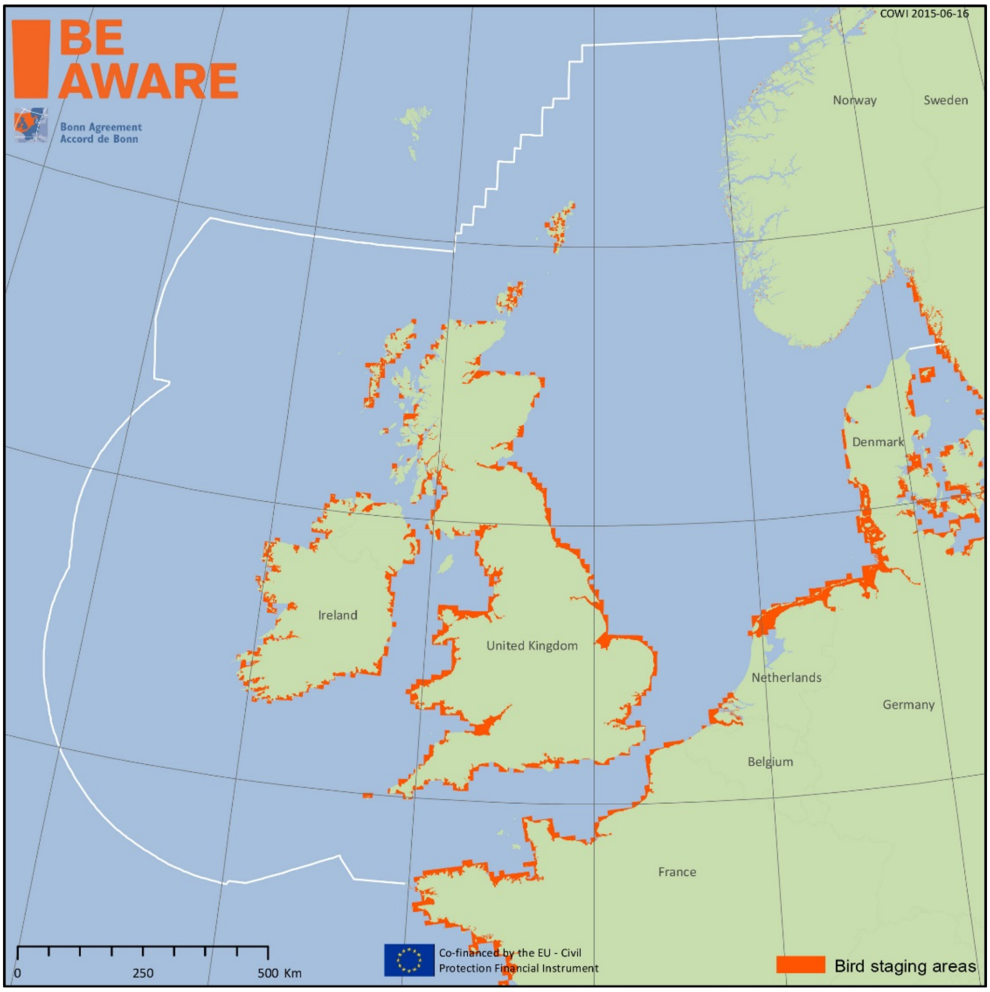

Figure 5-3 **Important staging areas for migrating sea and coastal birds in the BA area.**

5.1.3 Vulnerability. Birds

Impacts of oil/sensitivity

Seabirds are perhaps the most conspicuous victims of oil spills at sea. Harmful effects of oils are well documented and severe bird mortality often occurs if spilled oil enters areas where seabirds are concentrated. Some examples are presented in Table 5-1.

The reason for seabirds being easily harmed by floating oil is the fact that, if oil sticks to the plumage, feathers may collapse destroying the insulating properties of the plumage. The plumage of seabirds is water-repellent but oil absorbent. When the feathers get in contact with oil, the natural water-repellent effect ceases and water penetrates the normally insulating cover of the plumage. Birds that are smothered in oil may therefore die from exposure/hypothermia. Even very small stains of oil on the plumage may be lethal, especially during the winter. Oiled feathers may also severely hamper the ability of birds to fly. Increased weight or lack of air trapped in the feathers due to oiled feathers may also cause seabirds to lose buoyancy, sink and drown (Neff and Anderson 1981, Walraven1992, Leighton 1995. IBRRC 1985, Jessop et al 1993).

Table 5-1 **Selected references from field surveys where the effects on seabirds were observed following oil spills.**

Spill	Reported effect	Reference
2002. Oil spill from the shipwrecked tanker "*Prestige*" on the northwest	It was estimated that 250,000-300,000 birds were killed. Most of the casualties were alcidae (with common guillemot accounting for half of the	Garcia 2003

coast of Spain. 64,000 tonnes were spilled	victims, Atlantic puffins and razorbills), gannets, shags and various species of gulls	
1989 "*Exxon Valdez*" oil spill in Prince William Sound Alaska. 35,360 tonnes of oil spilled	An estimated 250,000 seabirds were killed. Some claim that the death toll was as high as 550,000-735,000 birds. Most of the casualties were Common murres. Other species were Loon, Oystercatcher, Pigeon guillemot, Cormorant, Scoter, Barrows goldeneye, Merganser, Harlequin duck, Marbled murrelet. In 2002, the following bird species showed little or no clear improvement since spill injuries occurred: Common loon, Cormorants (3 species), Harlequin duck and Pigeon guillemot.	Peterson et al 2003 Exxon Valdez Oil Spill Trustee Council (1994)
1978 "*Amoco Cadiz*" oil spill. 200,000 tonnes of oil spilled	An estimated 20,000 were killed including Puffin, Razorbill, Guillemots and Gavia spp.	Jonesa et al 1978 Burger 1993
1967.The "*Torrey Canyon*" tanker accident. 120,000 tonnes of oil spilled	The death toll of birds was estimated at 30,000 birds	Burger 1993

All groups of birds can be affected, but birds that spend a large part of their time on the sea surface, such as auks, ducks, cormorants and divers are mainly at risk of being smothered in oil. Table 5-2 gives an overview of the vulnerability to oils spill of different groups of seabirds.

Shorebirds and waterfowl are often concentrated on tidal flats and are very vulnerable to oil spills. Apart from the impacts on plumage described for the offshore birds waterfowl and shorebirds, they may be affected from the ingestion of oil during preening, ingestion of oiled prey, inhalation of oil fumes or absorption of oil through skin or eggs and indirect effects resulting from destruction of bird habitats or food resources. The toxic effects of inhalation of fumes /ingestion of oil may include (Walraven 1992):

- The destruction of red blood cells, which are important for the immune response
- Alterations of liver metabolism
- Adrenal tissue damage
- Pneumonia
- Intestinal damage
- Reduced reproduction ability
- Reduction in the number of eggs laid
- Decreased fertility of eggs
- Decreased shell thickness
- Disruption of the normal breeding and incubating behaviours

Oil may also cause such toxic effects on seabirds, but the mechanical effects on the plume are probably more significant for seabirds.

Table 5-2 Overview of the vulnerability to oil spill of different groups of seabirds

Vulnerability to oil	Birds group	Comment
High vulnerability	Auks, divers, grebes, diving ducks, swans	These birds spend most of their time on the water, swimming, feeding and resting. The risk of contact with oil slicks is high and the birds do not avoid oiled areas.

		Direct mortality from oil slicks can be very high.
Medium vulnerability	Fulmars, gannets, cormorants, kittiwakes	These birds do not spend much time on the sea surface. Risk of direct mortality due to oil is therefore smaller. Effects on reproduction from oiling and ingestion of oil has occurred
Low vulnerability	Seagull, terns , geese, ducks	These groups of birds only stay on the sea surface for a very short period or are only using the seas as an alternative feeding area.

Vulnerability scores. Breeding areas for sea and shore birds

The open waters and tidal flats off breeding areas are important feeding areas for breeding birds and large numbers of birds are concentrated here. Oil spills in such areas may therefore cause massive kills of birds, whereas dispersed oil may have a lesser impact.

Breeding areas for sea and shore birds have been allocated the following scores for undispersed oil spills:

- Score 4 for spring and summer when breeding is at its peak;
- Score 3 and score 2 for autumn and winter, respectively as oil spills during the seasons may persist and affect birds during the breeding season.

Effects of dispersed oil on birds are much less severe compared to surface oil spills. There are no major effects on the plumage, although increased dietary uptake of oil may occur. The scores for dispersed oil show the same seasonal pattern as for surface oil, but lowered by one unit i.e.:

- Score 3 for spring and summer;
- Score 2 and score 1 for autumn and winter

Vulnerability scores. Wintering areas for sea and shore birds

Wintering birds at sea spend most of the time on the sea-surface and are therefore particularly vulnerable. Wintering areas for birds have been allocated score 4 during winter. Sensitivity of wintering areas for birds to surface oil spills that are not dispersed have been allocated score 4 during winter. For spring, the score is lowered to score 3 because there may still be some "wintering" birds in the areas. During summer, there are very few and the score is set to 1. During autumn some individuals have started to arrive, and autumn has been allocated the score 3

Effects of dispersed oil on birds are much less severe compared to surface oil spills. There are no major effects on the plumage, although increased dietary uptake of oil may occur. The scores for dispersed oil follow the same seasonal pattern as surface oil, but has been decreased as follows: Winter: 2, spring, summer and autumn: 1

Vulnerability scores. Staging areas for migrating birds

The majority of birds in staging areas for migrating birds are shorebirds and waterfowl that are often concentrated on tidal flats and are very vulnerable to oil spills. Staging areas for migrating birds have been allocated the score 4 in spring and autumn when the peak numbers are encountered. For winter and summer, the score has been lowered to 2.

Effects of dispersed oil on birds are much less severe compared to surface oil spills. The scores for dispersed oil follow the same seasonal pattern as surface oil, but has been decreased as follows: Spring: 2, Summer: 1, Autumn: 2, Winter: 1.

5.2 Spawning areas for fish

5.2.1 Location and characteristics of spawning areas for fish

The North Sea is one of the world's most important fishing grounds. Over 230 fish species are known to inhabit the North Sea, but only some 10 species are of significant commercial importance. The analysis of oil spill vulnerability of spawning grounds for fish are concentrated on the spawning ground for these species.

The fish can be divided into demersal spawners, i.e. fish that deposit their eggs on the seabed (often on vegetation, gravel or hard substrates), and pelagic spawners that shed their eggs in the water column.

Herring and sandeel are demersal spawners. Herring, which is a commercially very important species, deposits its sticky eggs primarily on gravel, stones, broken mussel shells and/or flat rock on shallow water. Sandeel, which is an important part of the foodweb and an industrially fished species, deposits its eggs on sandy bottom on deeper waters. This species has not been included in the analysis because it is not very likely that an oil spill will affect the sandeels' eggs due to the depth at which they are deposited.

The remaining species (9) that are included in the analysis are pelagic spawners.

Demersal spawners (Herring)

There are several stocks of herring in the BA area that differ in terms of spawning season:

- The Norwegian spring spawning stock, which spawns along the Norwegian west coast in February to March;
- The Buchan/Shetland herring, spawning off the Scottish north and east coast and the coast around the Shetlands during August and September;
- The Banks herring spawning off the English east coast from August until October;
- The West of Scotland autumn spawning herring that spawn to the west and north of the outer Hebrides and off Cape Wrath from late August to October;
- The Irish autumn/winter spawning herring that spawns during the period September to February and
- The Down herring spawning in the English channel from November until January

Figure 5-4 shows the location of known spawning grounds for herring and the spawning season for the different stocks.

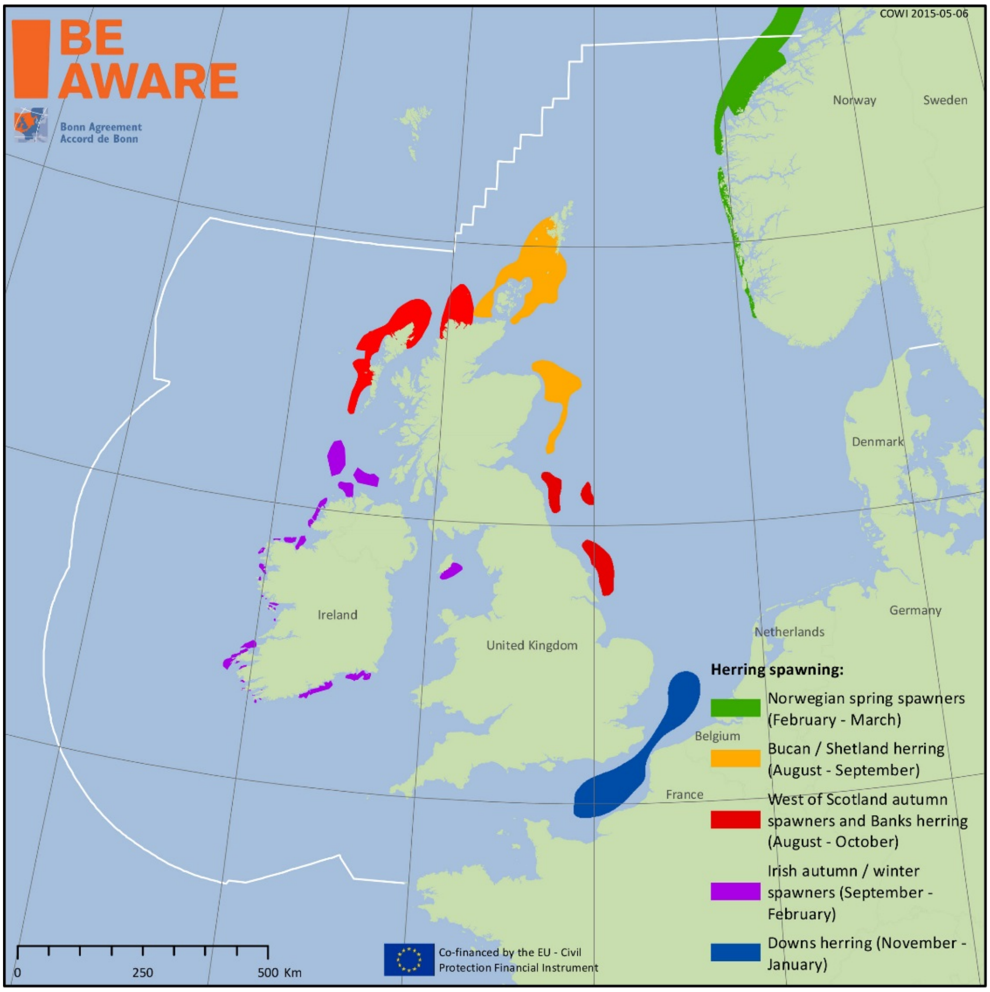

Figure 5-4 **Spawning grounds for herring in the BA area.**

Pelagic spawners

The pelagic spawning species differ markedly with regard to spawning period. Separate maps of the location of spawning grounds for the four seasons have therefore been prepared.

Spawning areas for pelagic spring spawners

Figure 5-5 show spawning areas for fish with pelagic eggs spawning in spring in the BA area. The following species spawn during this period:

- **Haddock**: Spawning takes place in the Norwegian Sea along the coast of Norway, in areas in the northern part of the North Sea and north-west of Scotland;
- **Blue whiting**: Spawning takes place west of the British Isles;
- **Norway pout**: Spawning takes place in the Norwegian Sea along the coast of Norway, in areas in the northern part of the North Sea and in the Irish Sea;
- **Saithe**: Spawning takes place in the Norwegian Sea along the coast of Norway, north and east of the Shetland Islands and north-west of Scotland;
- **Cod**: During spring spawning takes place in the Norwegian Sea along the coast of Norway, in areas in the northern part of the North Sea and north-west of Scotland;

- **Whiting**: Spawning takes place in areas in the southern part of the North Sea, the English Channel and the northern part of the Irish Sea during spring;
- **Western mackerel**: Spawns north and west of the British Isles and west of Brittany;
- **Horse mackerel**: Spawns in the southern part of the north sea and south-west of the British Isles and Brittany and
- **Sprat**: Spawns in waters around the British isles, in the central and southern part of the North Sea, in Skagerrak and in Kattegat

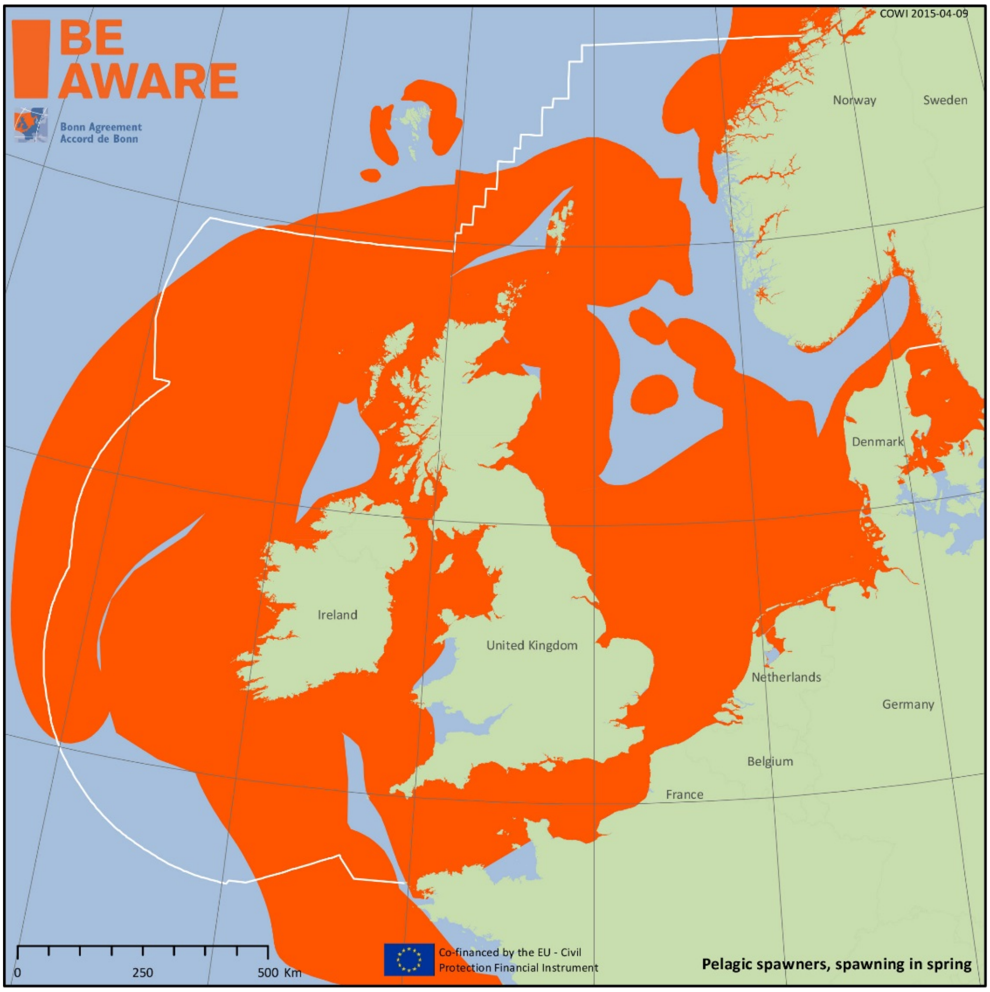

Figure 5-5 Spawning areas for fish with pelagic eggs spawning in spring in the BA area.

Spawning areas for pelagic summer spawners

Figure 5-6 shows the location of spawning areas for fish with pelagic eggs spawning in spring in the BA area. The following species spawn during this period:

- **Whiting**: During summer spawning takes place in areas in the southern part of the North Sea, the English Channel and the northern part of the Irish Sea;
- **North Sea mackerel**: Spawns in most of the North Sea;
- **Horse mackerel**: Spawns in the southern part of the north sea and south-west of the British Isles and Brittany and

- **Sprat**: Spawns in waters around the British Isles, in the central and southern part of the North Sea, in Skagerrak and in Kattegat.

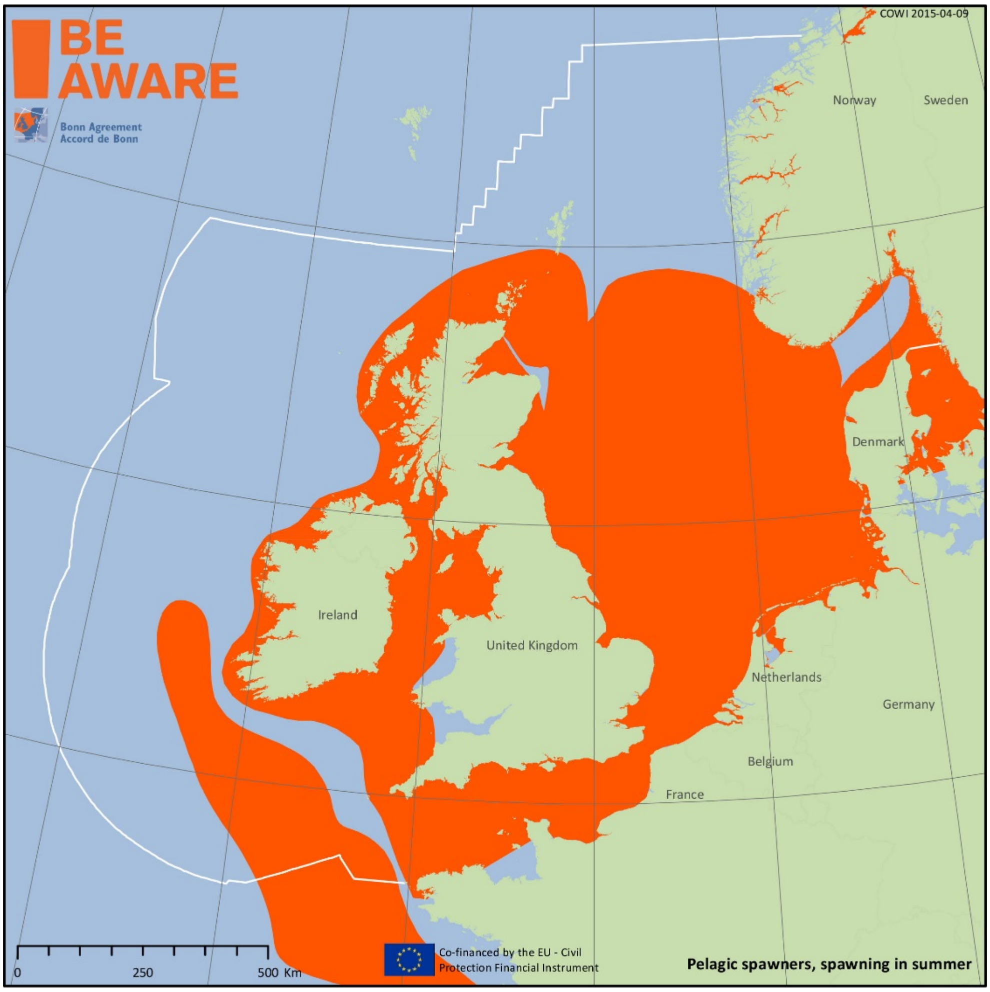

Figure 5-6 Spawning areas for fish with pelagic eggs spawning in summer in the BA area.

Spawning areas for pelagic autumn spawners

Figure 5-7 shows the location of spawning areas for fish with pelagic eggs spawning in autumn in the BA area. Only whiting in the northern part of the area spawn during autumn.

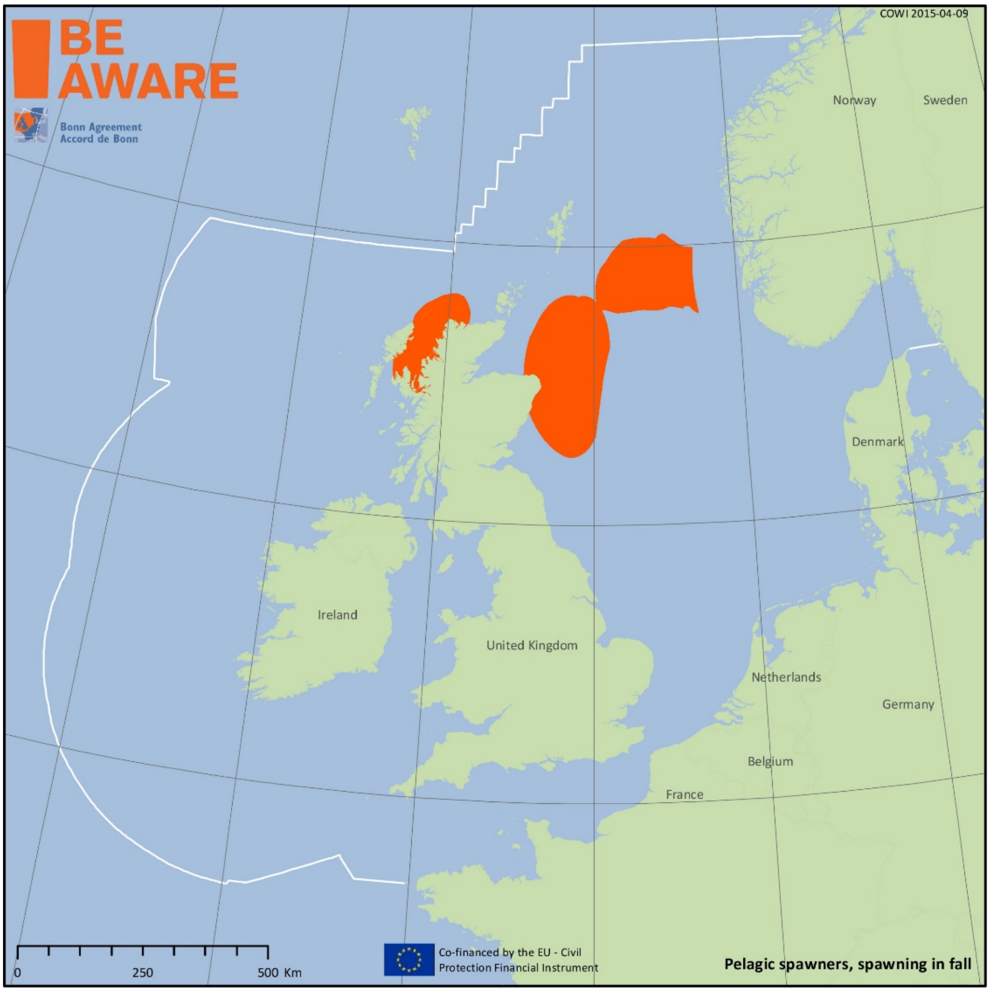

Figure 5-7 **Spawning areas for fish with pelagic eggs spawning in autumn in the BA area (i.e. whiting).**

Spawning areas for pelagic winter spawners

Figure 5-8 shows the location of spawning areas for fish with pelagic eggs that are spawning in winter in the BA area. The following species spawn during this period:

- **Whiting**: During winter, spawning takes place in areas in the southern part of the North Sea, the English Channel and the northern part of the Irish Sea;
- **Saithe**: Spawning takes place in the Norwegian Sea along the coast of Norway, north and east of the Shetland Islands and north-west of Scotland;
- **Cod**: During winter spawning takes place in the Norwegian Sea along the coast of Norway, in areas in the northern part of the North Sea and north-west of Scotland;
- **Western mackerel**: Spawns north and west of the British Isles and west of Brittany and
- **Plaice**: Spawns in the central and southern part of the North Sea, the English channel and the Irish sea.

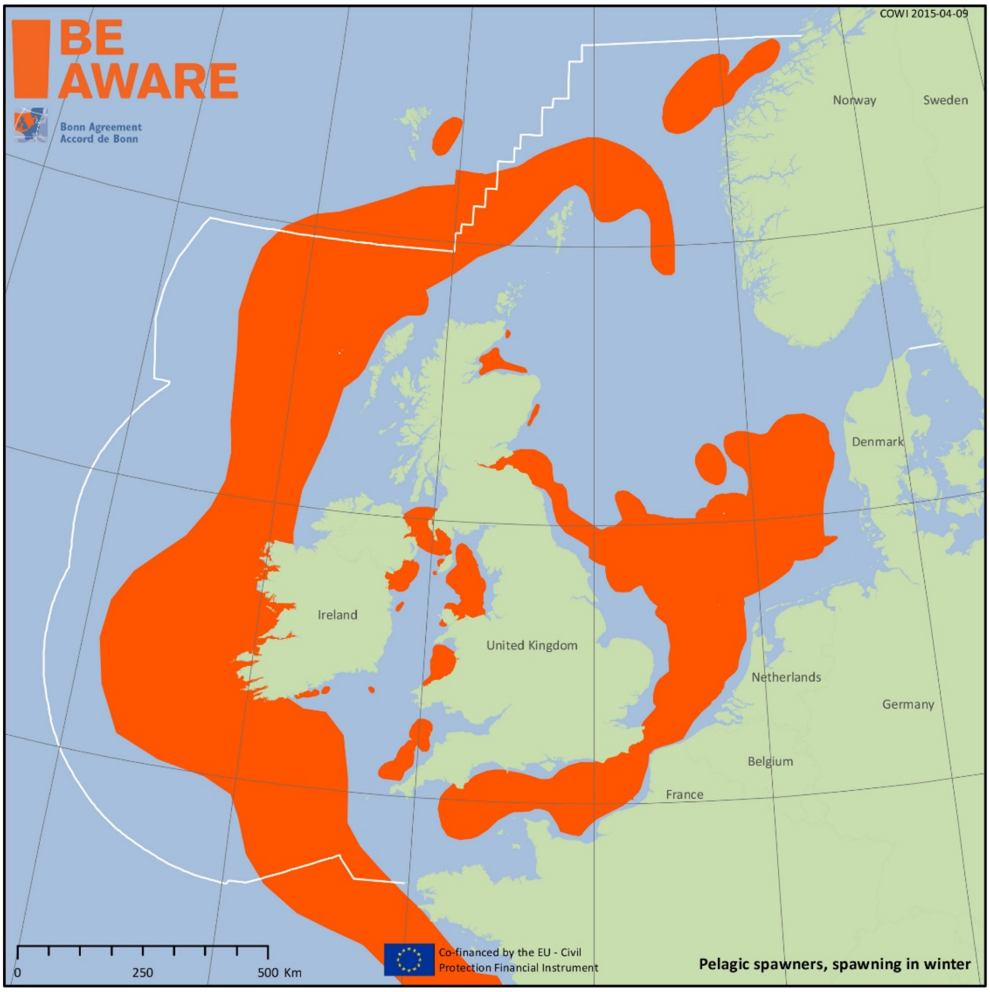

Figure 5-8 **Spawning areas for fish with pelagic eggs spawning in winter in the BA area.**

5.2.2 Vulnerability. Spawning areas for fish

Impacts of oil/sensitivity

Fish eggs and larvae are quite sensitive to oil, as demonstrated in numerous laboratory toxicity tests (Falk-Petersen & Kjørsvik 1987, Serigstad & Adoff 1985, Tilseth, Solberg & Westrheim 1984, Kühnhold 1977).

However, in several studies effects on pelagic fish eggs and larvae were not observed in the field following oil spills (Table 5-3). One reason for this may be that toxic concentrations of oil components are generally confined to the uppermost parts of the water column immediately beneath an oil slick and that fish eggs and larvae are encountered below the toxic water layers.

Other studies have demonstrated massive kills of fish eggs and larvae near oil spills without causing any significant effect on fish populations in the open sea (Table 5-4). The lack of effects on numbers in subsequent adult populations following massive kills of eggs and larvae is probably because most fish species produce vast numbers of eggs and larvae and because most species have extensive spawning grounds (IPIECA 2000a).

There is no evidence to date that even very large oil spill has affected stocks of species with pelagic eggs even in cases where massive kills of eggs and larvae were observed. The lack of effects on numbers in subsequent adult populations following massive kills of eggs and larvae is probably because the fish produce extremely large numbers of eggs and larvae and because most species have extensive spawning grounds (IPIECA 2000a).

Table 5-3 Selected references on field surveys where effects on fish eggs and larvae following oil spills were not observed.

Spill	Reported effect	Reference
1983: "*Castillo de Bellver*", South Africa; 160,000–190,000 tonnes crude oil	Occurrence and abundance of fish eggs and larvae normal. Spill occurred prior to main fish spawning season.	IPIECA 2000c
1979: "*Betelgeuse*", Bantry Bay, Ireland; Arabian light crude oil—explosion then leakage for 18 months.	Whiting and sprat spawned normally in spring. No serious adverse effects on eggs and larvae of commercial species detected	IPIECA 2000c
1977: "*Thesis*", Baltic, Sweden; 1,000 tonnes medium fuel oil	Herring moved normally through oiled areas during the month after the spill. Contamination not detected in their tissues. Some effects on spawning were recorded the following spring but these may have resulted from causes other than the spill	IPIECA 2000c

Table 5-4 Selected references on field surveys where effects on fish eggs and larvae were observed following oil spills.

Spill	Reported effect	Reference
1993: "*Braer*", Shetland; 84,700 tonnes oil	Larvae of sandeels where exposed to petroleum hydrocarbons over a wide area to the south of Shetland. The exposure was confirmed by high levels of 7-ethoxyresorufin O-deethylase activity in the larvae. However, the spill did not appear to have a major impact on the survival and settlement or on the growth and sexual maturation of the 1993 year-class of sandeels in the following year.	Wright et al 1997
1989 "*Exxon Valdez*" oil spill in Prince William Sound Alaska. 35,360 tonnes of oil spilled	Pink salmon (*Onchorhyncos gorbuscha*) which spawn demersal eggs in the intertidal reaches of numerous small streams were affected severely by the spill. The eggs in oiled streams had elevated mortality for at least four years after the spill due to toxic concentration of oil components such as PAH. Pacific herring (*Clupea pallasi)* spawn their demersal eggs along hundreds of kilometres of shoreline in the Prince William sound. The spill occurred a few weeks before herring spawned. It was estimated that 40-50% of the spawned eggs were exposed to oil causing premature hatching, low larval weights, reduced growth, morphological abnormalities and mortality. It was estimated that the larval production of the 1989 year class was significantly reduced. It was estimated that oiled areas produced only 17 million viable pelagic larvae compared to 12 billion from un-oiled areas	Peterson et al 2003. Brown and Carls 1998
1989. Spill from oil tanker "*World Prodigy*" off Newport Rhode Island USA. More than a quarter of a million gallons of fuel oil was spilled	The oil spread over 120 square miles and poisoned eggs and larvae of fish and shellfish at the surface	NOAA 1996
1976: "*Argo Merchant*",Massachusetts,	Biological studies were carried out during this spill. A high proportion of cod eggs (20%), pollack eggs	IPIECA 2000a, Longwell 1977,

USA; 25,000 tonnes No. 6 fuel oil.	(46%) and larvae caught in the area were found dead or moribund. Furthermore, abnormalities in development were observed. Fish stocks studied 1975–77 showed no major impacts.	1978
1967. The "*Torrey Canyon*" tanker accident.	The oil spill caused massive kill of pilchard eggs but there was no detectable effect on the pilchard population in subsequent years.	Kronberg 1981

Long-term studies following the Exxon Valdez accident in 1989 has indicated that stocks of fish species that spawn demersal eggs on shallow water in enclosed waters along the coast, may in fact have been affected because of mass kill of eggs and larvae and that recovery of the stock may take a long time. Thorough and long-lasting investigations of impacts on fish were carried out following the Exxon Valdez oil spill.

Pacific herring (*Clupea pallasi*) spawn their demersal eggs along hundreds of kilometres of shoreline in Prince William Sound. The spill occurred a few weeks before herring spawned and the 1989-year class was significantly affected in terms of significantly reduced larval production so that this year class became one of the smallest cohorts of spawning adults ever recorded (see Table 5-4). In 1993, the Prince William Sound herring stock collapsed and had not recovered twenty years after the oil spill (Exxon Valdez Oil Spill Trustee Council 2009).

The mechanism and causes of the collapse is still debated and it has not been possible to establish a definitive link between the collapse and the effects of the oil spill. A preliminary study in 1992 suggested a possible long-term effect of the oil spill on reproductive success, but a study in 1995 found no evidence of long-term, oil-related reproductive impairment (Brown and Carls 1998, Peterson et al. 2003).

As herring return to the same spawning grounds year after year, (Oulasvirta & Lehtonen 1988) loss of sites that are critical for spawning due to oil pollution may have a long-term effect on herring population size.

Vulnerability scores. Spawning areas for fish

Pelagic spawners

Based on the observed impacts described above and the spawning period for different species, the following vulnerability scores have been allocated to spawning areas for pelagic spawners in situations where dispersants are not used:

- Spawning areas for fish with pelagic eggs spawning during spring have been allocated score 2 for spring, score 1 for summer and score 0 for autumn and winter;
- Spawning areas for fish with pelagic eggs spawning during summer have been allocated score 1 for spring, score 2 for summer, score 1 for autumn and score 0 for winter;
- Spawning areas for fish with pelagic eggs spawning during autumn have been allocated score 0 for spring, score 1 for summer, score 2 for autumn and score 0 for winter;
- Spawning areas for fish with pelagic eggs spawning during winter have been allocated score 1 for spring, score 0 for summer, score 0 for autumn and score 2 for winter

For situations where dispersants are used, the scores have been increased a little due to the increased risk of exposure to oil components. The following scores have been allocated:

- Spawning areas for fish with pelagic eggs spawning during spring: score 3 for spring, score 2 for summer and score 0 for autumn and winter;

- Spawning areas for fish with pelagic eggs spawning during summer have been allocated score 2 for spring, score 3 for summer, score 2 for autumn and score 0 for winter;
- Spawning areas for fish with pelagic eggs spawning during autumn have been allocated score 0 for spring, score 2 for summer, score 3 for autumn and score 0 for winter;
- Spawning areas for fish with pelagic eggs spawning during winter have been allocated score 2 for spring, score 0 for summer, score 0 for autumn and score 3 for winter

Herring (demersal spawners)

Spawning areas on shallow water for herring have been allocated score 4 during the spawning season. For the non-spawning season, the score has been lowered to score 3 because on the one hand it is outside the spawning season and on the other, persisting oil spilled during the spawning season may still affect spawning outside the spawning season due to destruction of spawning substrate. The different herrings stocks have been allocated the following scores:

- The Norwegian spring spawning stock: Score 4 during spring, score 3 during summer and autumn and score 4 during winter for both the undispersed and dispersed oil spill
- The Buchan/Shetland herring: Score 3 during spring, score 4 during summer and score 3 during autumn and winter for both the undispersed and dispersed oil spill
- The Banks herring and the West of Scotland autumn spawning herring: Score 3 during spring, score 4 during summer and autumn and score3 during winter for both the undispersed and dispersed oil spill
- The Irish autumn/winter spawning herring. Score 3 during spring, score 3 during summer and score 4 during autumn and winter for both the undispersed and dispersed oil spill
- The Down herring Score 3 during spring, score 3 during summer and score 4 during autumn and winter for both the undispersed and dispersed oil spill.

6. VULNERABILITY ANALYSIS OF MARINE PROTECTED AREAS

6.1 Coastal and marine protected areas

Coastal and marine protected areas include:

- Natura 2000 areas and Norwegian national plan for protection of marine areas
- RAMSAR Convention areas
- OSPAR Marine Protected Areas
- World heritage sites

6.1.1 Location of coastal and marine protected areas

Natura 2000 areas and Norwegian national plan for protection of marine areas

Natura 2000 is a network of nature protection areas in the territory of the European Union. It is made up of Special Areas of Conservation (SACs) and Special Protection Areas (SPAs). The Norwegian national plan for protection of marine areas is the equivalent of Natura 2000.

Special areas of conservation (SAC)

A Special Area of Conservation (SAC) is defined in the European Union's Habitats Directive (92/43/EEC), also known as the Directive on the Conservation of Natural Habitats and of Wild Fauna and Flora. They are to protect habitats and species listed in annex I and II of the directive, which are considered to be of European interest following criteria given in the directive. The areas must be chosen from the Sites of Community Importance by the Member States, and designated as SAC by an act assuring the conservation measures of the natural habitat.

Special protection area (SPA)

A special protection area (SPA) is a designation under the European Union Directive on the Conservation of Wild Birds.

Under the Directive, Member States of the European Union (EU) have a duty to safeguard the habitats of migratory birds and certain particularly threatened birds.

The locations of marine and coastal Natura 2000 sites and the Norwegian equivalent in the BA area is shown in Figure 6-1.

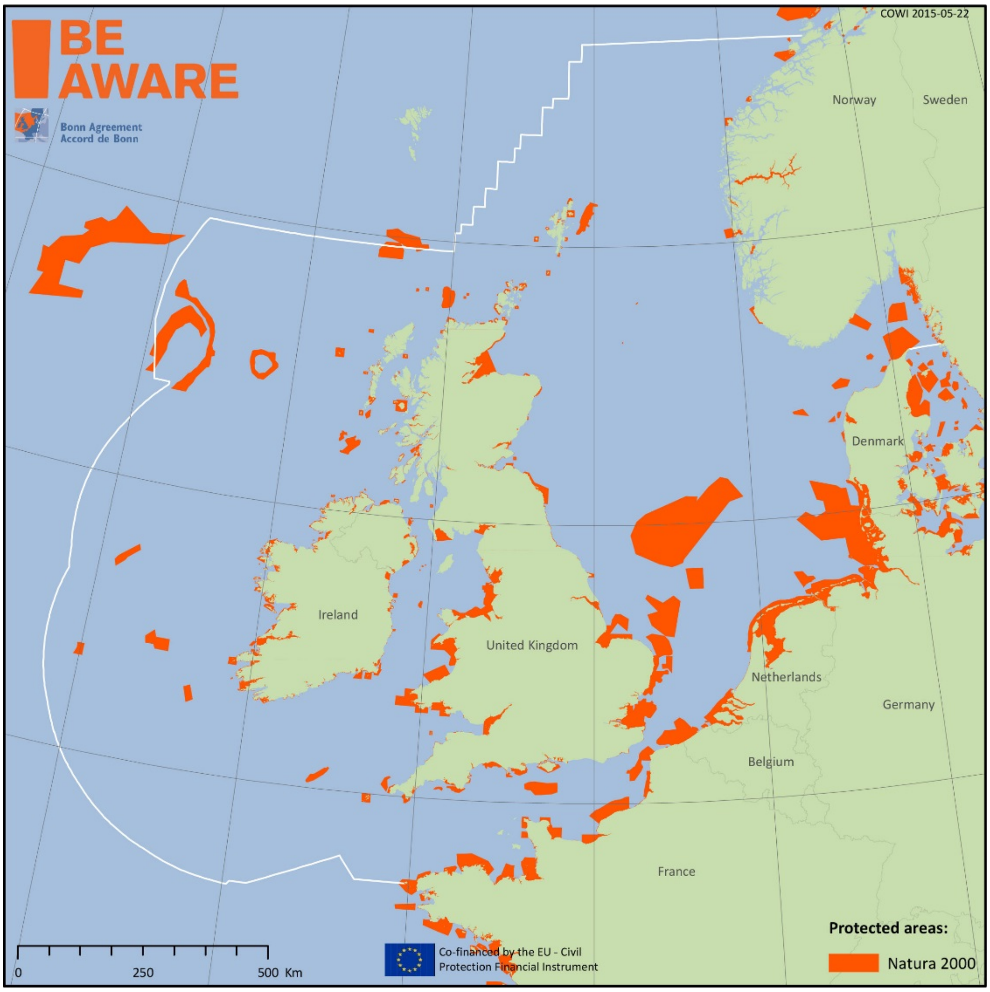

Figure 6-1 **Location of marine and coastal Natura 2000 areas and Norwegian national plan for protection of marine areas.**

RAMSAR Convention areas

The Ramsar Convention (formally, the Convention on Wetlands of International Importance, especially as Waterfowl Habitat) is an international treaty for the conservation and sustainable utilisation of wetlands, recognizing the fundamental ecological functions of wetlands and their economic, cultural, scientific, and recreational value. It is named after the city of Ramsar in Iran, where the Convention was signed in 1971. Figure 6-2 show the location of RAMSAR sites in the BA area.

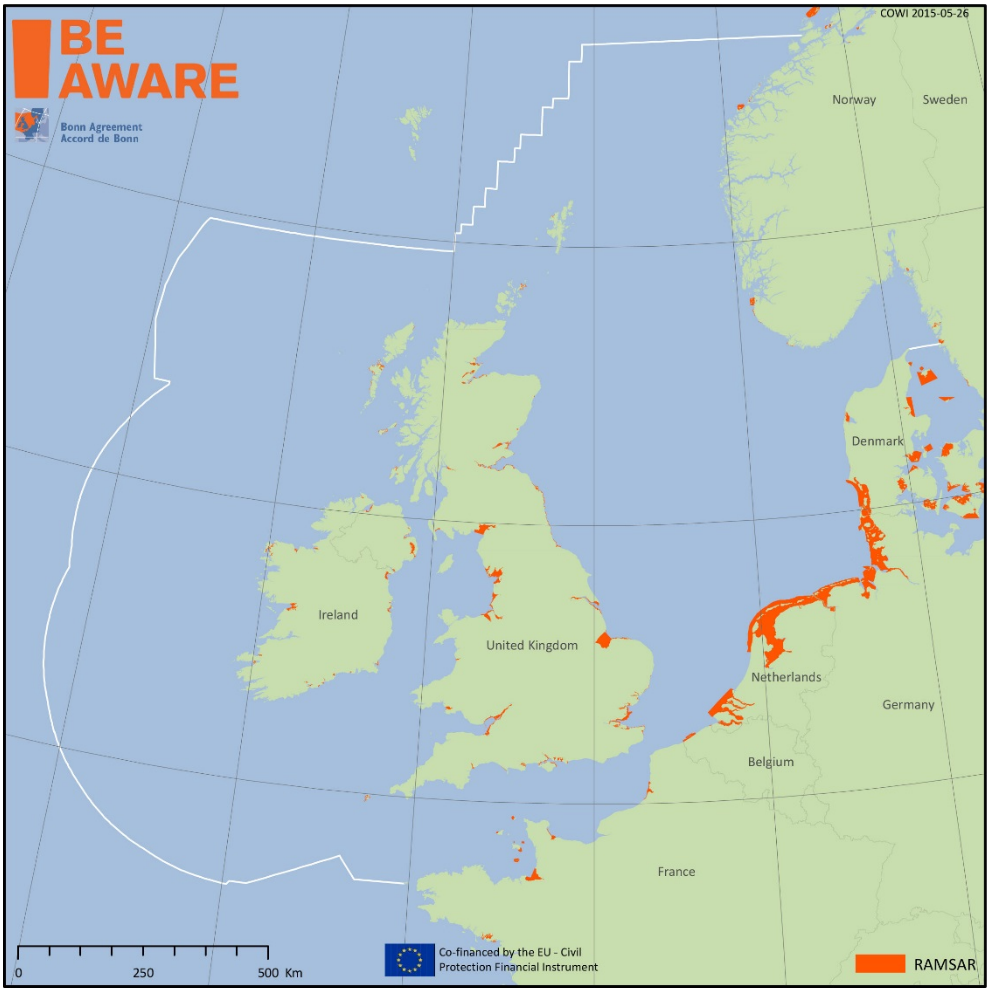

Figure 6-2 **Location of Ramsar sites.**

OSPAR Marine Protected Areas

The Convention for the Protection of the Marine Environment of the North-East Atlantic or OSPAR Convention is the current legislative instrument regulating international cooperation on environmental protection in the North-East Atlantic. The OSPAR Commission manages the work carried out under the convention.

OSPAR has established a network of Marine Protected Areas (MPA). Since 2005, all contracting parties to OSPAR bordering the North-East Atlantic have nominated sites to the OSPAR MPA network. The aims of the MPAs are:

- To protect, conserve and restore species, habitats and ecological processes which have been adversely affected by human activities;
- To prevent degradation of, and damage to, species, habitats and ecological processes, following the precautionary principle;
- To protect and conserve areas that best represent the range of species, habitats and ecological processes in the maritime area.

Figure 6-3 shows the location of OSPAR Marine Protected Areas.

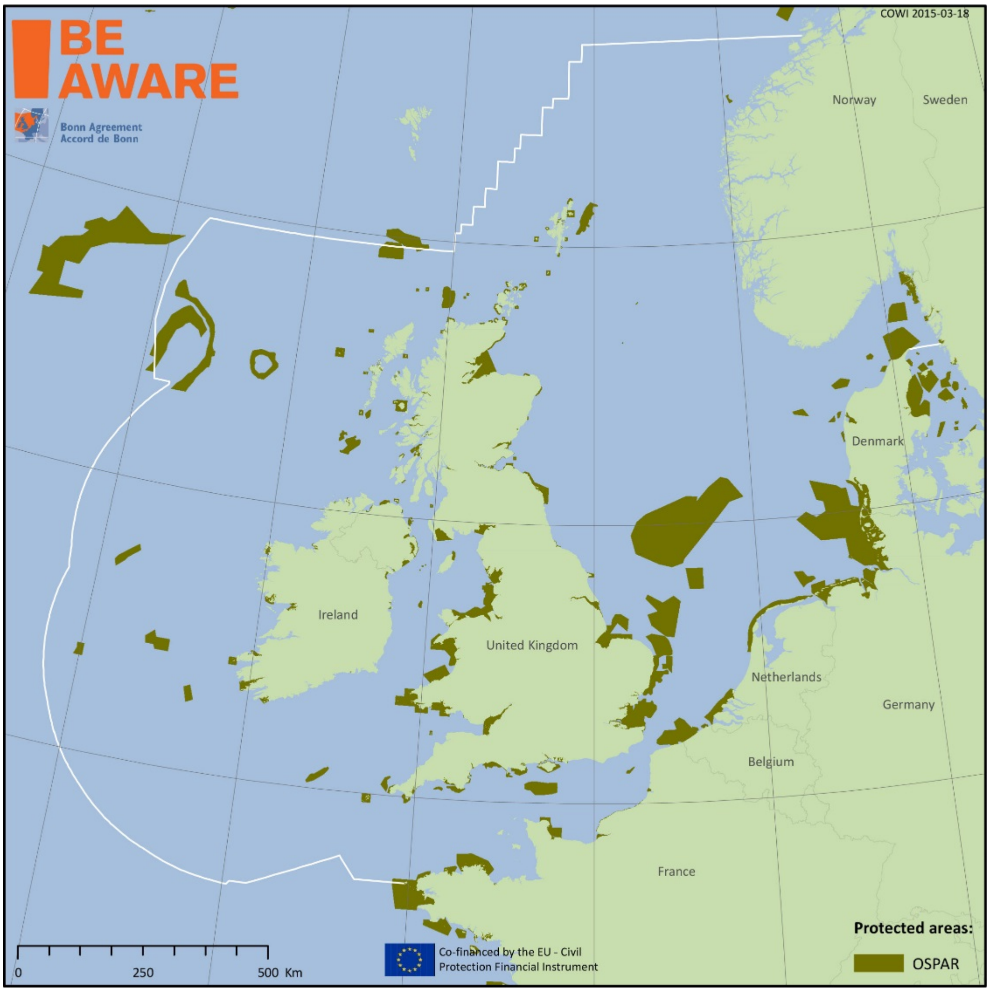

Figure 6-3 Location of OSPAR Marine Protected Areas.

World Heritage Sites

A World Heritage Site is a place that is listed by the United Nations Educational, Scientific and Cultural Organization (UNESCO) as being of special cultural or physical significance. To be included on the World Heritage List, sites must be of outstanding universal value and meet at least one out of the following ten selection criteria:

- To represent a masterpiece of human creative genius;
- To exhibit an important interchange of human values, over a span of time or within a cultural area of the world, on developments in architecture or technology, monumental arts, town-planning or landscape design;
- To bear a unique or at least exceptional testimony to a cultural tradition or to a civilization which is living or has disappeared;
- To be an outstanding example of a type of building, architectural or technological ensemble or landscape which illustrates (a) significant stage(s) in human history;
- To be an outstanding example of a traditional human settlement, land-use, or sea-use which is representative of a culture (or cultures), or human interaction with the environment especially when it has become vulnerable under the impact of irreversible change;

- To be directly or tangibly associated with events or living traditions, with ideas, or with beliefs, with artistic and literary works of outstanding universal significance;
- To contain superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance;
- To be outstanding examples representing major stages of earth's history, including the record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic features;
- To be outstanding examples representing significant on-going ecological and biological processes in the evolution and development of terrestrial, fresh water, coastal and marine ecosystems and communities of plants and animals;
- To contain the most important and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species of outstanding universal value from the point of view of science or conservation.

The location of World Heritage Sites in the BA area is shown in Figure 6-4.

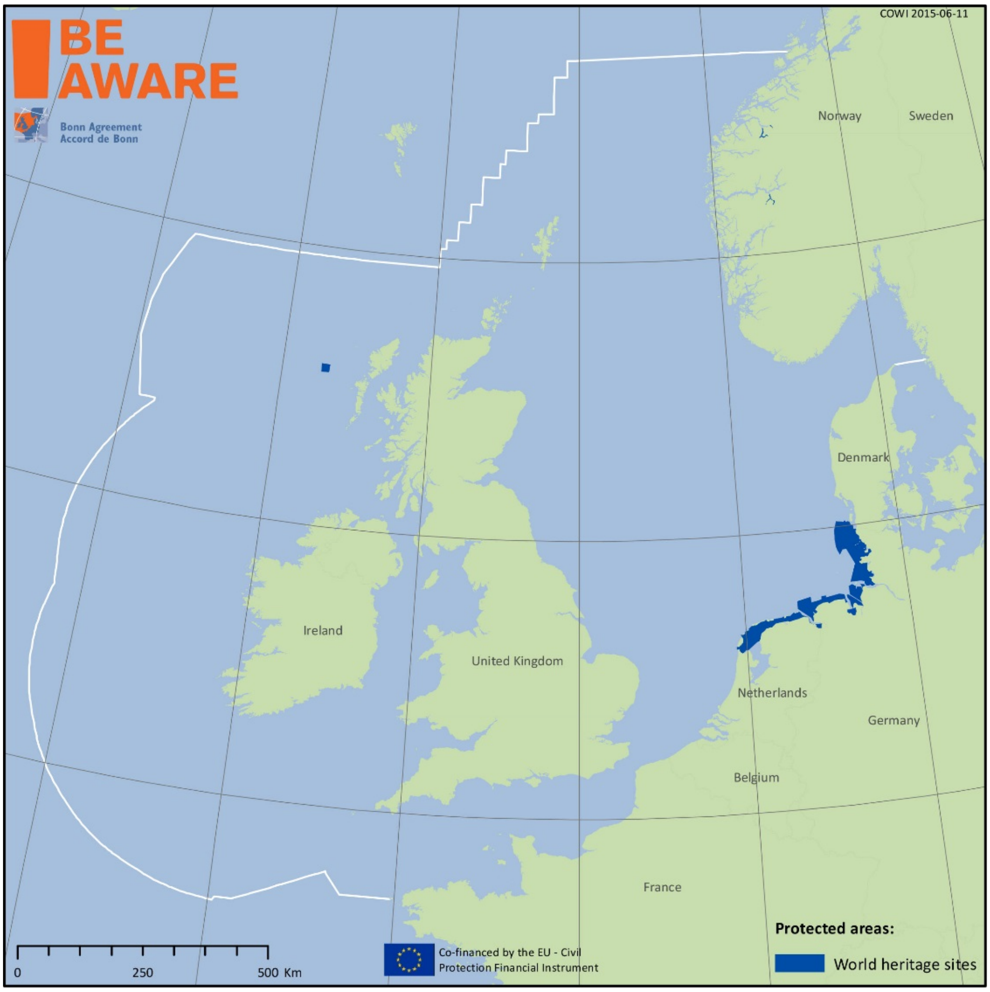

Figure 6-4 Location of World Heritage Sites in the BA area.

6.1.2 Vulnerability scores

The above categorised protected areas house some of the sensitive species and habitats described earlier in this document. As these areas have already been selected for protection, they have been allocated and extra vulnerability score i.e. score 4 for all seasons for both surface oil spills and dispersed oil.

7. VULNERABILITY ANALYSIS OF SOCIOECONOMIC FEATURES

7.1 Fisheries

7.1.1 Location of fishing areas in the BA area

The North Sea and adjacent waters is one of the world's most important fishing grounds.

Figure 7-1 shows the location of higher intensity fishing areas in the Bonn Agreement area. The figure shows the fishing effort based on information from two different sources: ICES analysis of fishing effort (based on VMS) of vessels using dredges, beam trawl, otter trawl or demersal seiners during the period 2006-2012 and a Norwegian plot based on AIS data.

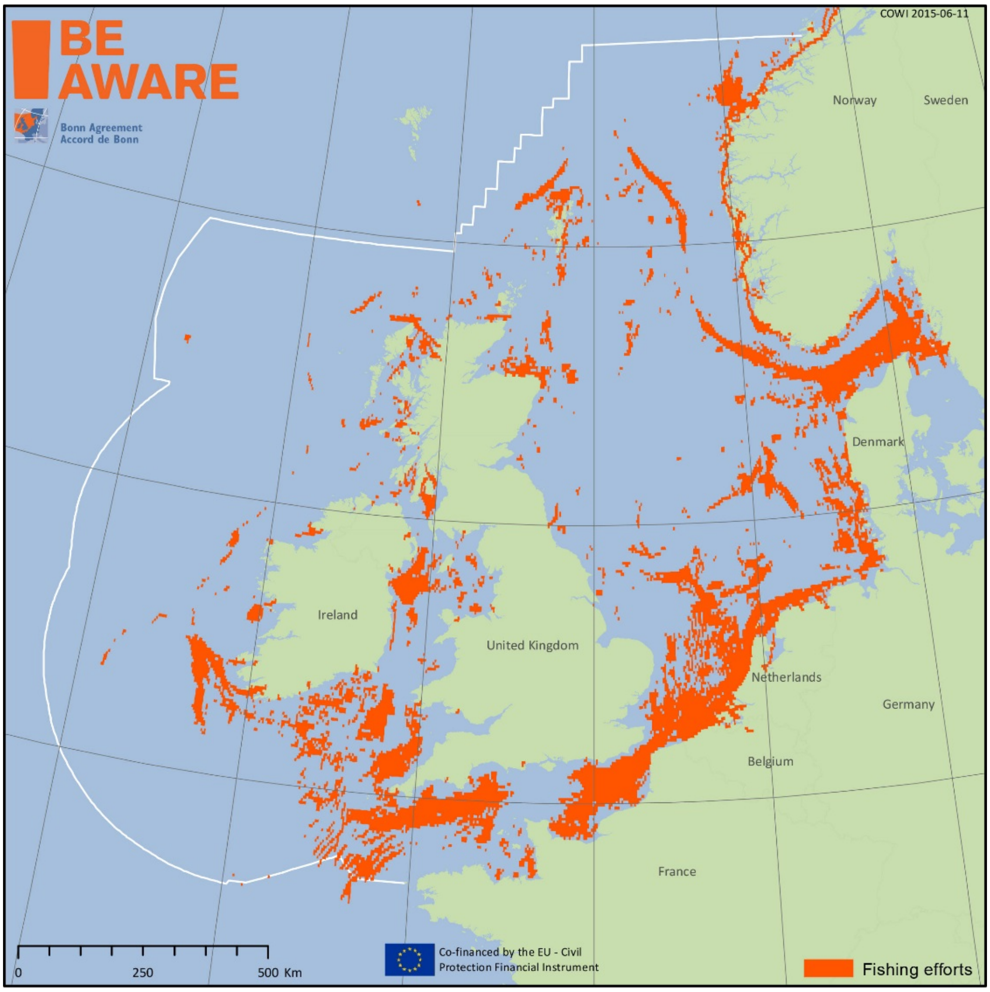

Figure 7-1 **Location of important fishing grounds (fishing effort).**

It appears that the fishery effort is concentrated in the following areas:

- East, North and Northeast of Scotland and around the Shetland Islands

- Along the Norwegian coast, along the edge of the Norwegian trench and the Skagerrak
- The western part of the central North Sea (mainly along the Danish west coast)
- The southern North Sea and the eastern part of the English Channel
- The western part of the English Channel and the Celtic Sea
- The Irish Sea and
- The waters west of Scotland and Ireland.

7.1.2 Characteristics of fisheries in the BA area

A wide variety of different fisheries exists in the BA area. Table 7-1 and Table 7-2 outline the most important fisheries in the different parts of the BA area.

Table 7-1 Overview of the main fisheries in the different parts of the BA area. Data from ICES 2015, Anon 2015, Centenera 2014, Semrau and Ortega Gras 2013.

Area	Main Fisheries in the area
Northern North Sea and Skagerrak	• Mixed demersal fishery by otter trawl or seine vessels that targets cod, haddock and whiting and with saithe as a by-catch to the east, north and northeast of Scotland and around the Shetland Islands primarily by UK vessels • Deep-water trawl fishery targeting saithe along the edge of the Northern Shelf and the Norwegian deep primarily by vessels from Norway, Germany and France • Fishery with trawls, Danish seines and gill nets for round-fish species such as cod and haddock, and various flatfish such as plaice, sole and turbot by Danish vessels • Fishery for Norwegian lobster, using otter trawls with by- catch of cod, haddock and whiting in the north-eastern part of the North Sea. This fishery is mainly carried out by vessels from the UK • Fishery for Norwegian lobster along the edge of Norwegian Deep in the northeastern North Sea and in Skagerrak. Fished with otter trawls. Bycatch of cod, haddock and whiting by Denmark and Norway • Trawl fishery for Northern shrimp in the Skagerrak and Norwegian deep using either single or double trawls. This fishery is carried out by vessels from Norway, Denmark and Sweden. • Fishery for mackerel by pelagic trawlers or purse seiners primarily by UK, Norwegian and Danish vessels • Fishing for Herring (Norwegian spring spawning stock). This fishery is mainly conducted with purse seine and pelagic trawls and it follows the migration of the stock as it moves from the wintering and spawning grounds along the Norwegian coast to the offshore summer grounds. This fishery is carried out by Norway in the BA area and by Iceland outside the BA area. • Fishing for Herring in the Skagerrak (Baltic spring-spawning stock). Targeted by trawlers from Denmark and Sweden • Fishing for Herring (North Sea autumn spawning stock). Mainly caught by trawlers and purse-seiners in the late spring and summer in the central and northern North Sea. Fishing for autumn spawning herring is mainly carried out by Norway, Denmark and the Netherlands. • Trawling for sandeel in Skagerrak and the northern North Sea. Fishing is carried out by Danish and Norwegian trawlers using small meshed demersal trawl in industrial fisheries (i.e. for fishmeal) • Industrial fisheries for Norwegian pout for fishmeal with small meshed trawl gear by Denmark and Norway • Danish industrial fisheries for sprat, for fish oil and fish meal using small meshed trawls in the Skagerrak
Central and southern North Sea (continued next page)	• Mixed flatfish fishery for plaice and sole by beam trawlers in the southern and southeastern North Sea. By-catch of brill, turbot, lemon sole and dab. Most trawling activity is concentrated in the Southern Bight of the North Sea, particularly along the Continental coast from Denmark to the Straits of Dover. Mainly vessels from the Netherlands, UK and Belgium participate in this fishery • Mixed demersal fishery by otter trawl and seine vessels that targets cod, haddock

	and whiting near the Dogger Bank and Silver pit by UK vessels • Fishery for Norwegian lobster, using otter trawls with by- catch of cod, haddock and whiting. Fishing is mainly carried out by vessels from the UK, Denmark and the Netherlands • Fishing for Herring (North Sea autumn spawning stock). Mainly caught by trawlers and purse-seiners in the southern North Sea eastern English Channel. Fishing for autumn spawning herring is mainly carried out by Norway, Denmark and the Netherlands • Industrial fishery for sandeel on the Dogger Bank area and in the southeastern North Sea by trawlers using small meshed demersal trawl in industrial fisheries (i.e. for fishmeal). The fishery is mainly carried out by Danish and Norwegian vessels

Table 7-2 Overview of the main fisheries in the different parts of the BA area. Data from ICES 2015, Anon 2015, Centenera 2014, Semrau and Ortega Gras 2013.

Area	Main Fisheries in the area
Central and southern North Sea (continued)	• Danish industrial fisheries for sprat for fish oil and fish meal using small meshed trawls
Eastern English channel	• Mixed flatfish fisheries targeting sole and plaice using beam-trawls, otter trawls or gill/trammel nets. Mainly vessels from France, UK and Belgium participate in these fisheries. • Herring fishery in the autumn and winter mainly by Dutch trawlers • Horse mackerel fishery using pelagic trawls by Dutch, German and UK vessels • Sprat fishery by mid-water trawl by UK vessels
Western English channel	• Mixed flatfish fisheries mainly targeting sole and plaice using beam trawls, otter trawl and gill nets with by catch of brill, lemon sole, monkfish, pollack, and cuttlefish. Mainly vessels from UK and France participate in this fishery • Sprat fishery by mid-water trawl by UK vessels
Celtic Sea	• Fishery for Norwegian lobster using twin or single trawls with by-catch of whiting, monkfish, cod, hake and megrim. This fishery is mainly carried out by vessels from Ireland, but vessels from France, UK and Spain also participate; • Trawl fishery targeting mixed round fish primarily by the use of otter trawl. Main species caught in this fishery include cod, haddock, pollack and whiting. Primarily France, Ireland and the UK participate in this fishery; • Trawl fishery for plaice and sole using beam- or otter trawls, with a by-catch of species such as cod, rays, brill, turbot and monkfish. Mainly France, Belgium and the UK participate in this fishery; • Trawl fishery for hake and monkfish primarily by Spanish and French vessels • Trawl fishery for herring, sprat mackerel and horse mackerel primarily using pelagic trawl. Mainly vessels from Ireland and UK participate in this fishery • Purse-seine fisheries for sardines in mixed fisheries that also target anchovy , mackerel and horse mackerel by France and Spain
Irish Sea	• Norwegian lobster fishery by a mixture of single and twin-rigged otter trawls and with by-catch of whiting, haddock, plaice and cod. Mainly Ireland and UK participate in this fishery • Mixed demersal trawl fisheries for round fish (mainly cod and haddock), using mid-water trawls and otter trawls or seine nets. Ireland and UK. This fishery is mainly carried out by vessels from Ireland and UK • Beam trawl fishery for plaice and sole, mainly carried out by vessels from the UK, Belgium and Ireland • Herring fishery by pelagic trawls in autumn and winter which is mainly carried out by UK vessels
West of Ireland and Scotland	• Trawling for Norwegian lobster west of Ireland with a by-catch of hake, megrim , haddock and monkfish by vessels from Ireland • Purse-seine fisheries for sardines in mixed fisheries that also target anchovy , mackerel and horse mackerel west of Ireland by France and Spain • Mixed demersal fishing by trawling for cod, haddock and Norway lobster and whiting west of Scotland with a by-catch of monkfish, megrim and whiting. Mainly vessels from UK, Ireland and Norway participate in this fishery • Trawling for Norwegian lobster west of Scotland with a by catch of haddock and

	whiting by UK (Scotland) • Fishing for monkfish west of Scotland mainly by vessels from UK, Ireland and France • Fishing for herring west of Ireland and Scotland. Fished using pelagic trawls by Ireland, UK and Germany • Fishery for mackerel by pelagic trawlers or purse seiners primarily by UK , Irish and Norwegian vessels

7.2 Vulnerability. Fisheries

Impacts of oil on fisheries

An oil spill may affect fisheries as follows:

- Fishing gear may be contaminated by oil. The risk of contamination is largest for flotation gear, such as drift nets and seines and fixed traps extending above the sea surface. Bottom trawls, lines, dredges and gill nets are usually well protected, provided they are not lifted through an oily sea surface, or affected by sunken oil. However, bottom gear may sometimes be affected by dispersed or sunken oil.
- The catch may become contaminated which in turn may result in the tainting (objectionable oil-derived taste) of fish. In some cases there may be a loss of sales because clean fish are presumed to be tainted if they come from a spill area and fishing may be banned for a short time in the region of an oil spill in order to maintain market confidence
- Halting of fishing until the gear is cleaned.

Such impacts will be of short duration and in most cases, it will be possible to move to other fishing grounds free of oil slicks. However, it is noted that coastal fisheries do not have the same range and mobility as offshore fisheries.

Most fisheries in the BA area are carried out by the use of bottom gear that is less vulnerable to spills compared to floating gear. Financial compensation may be available to some extent.

Vulnerability scores

Based on these considerations offshore fisheries and coastal fisheries have been allocated score 2 and score 3, respectively for all seasons and for both surface oil spills and dispersed oil.

7.3 Aquaculture

7.3.1 Location of aquaculture facilities

Aquaculture is an increasingly important industry in the BA area involving the farming or culture of fish, shellfish and seaweed.

Fish farms are mainly located in the Norwegian Fjords, the west coast of Scotland, the Hebrides, the Orkneys and the Shetlands (Figure 7-2).

Shellfish farms are encountered in Ireland, the west coast of Scotland, the Hebrides, the Shetlands, Norway and the German Wadden Sea (Figure 7-3).

Cultivation of seaweed takes place in a few sites in Norway and Ireland (Figure 7-4).

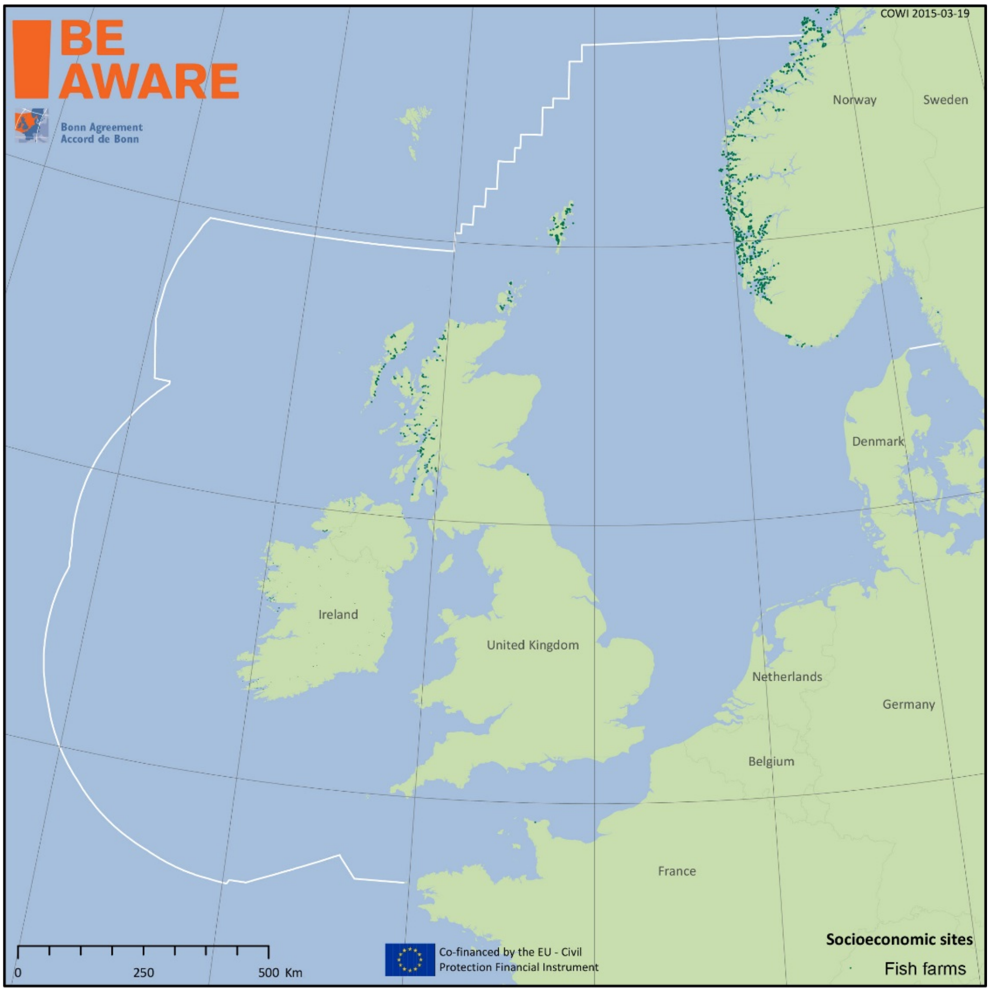

Figure 7-2 Location of fish farms.

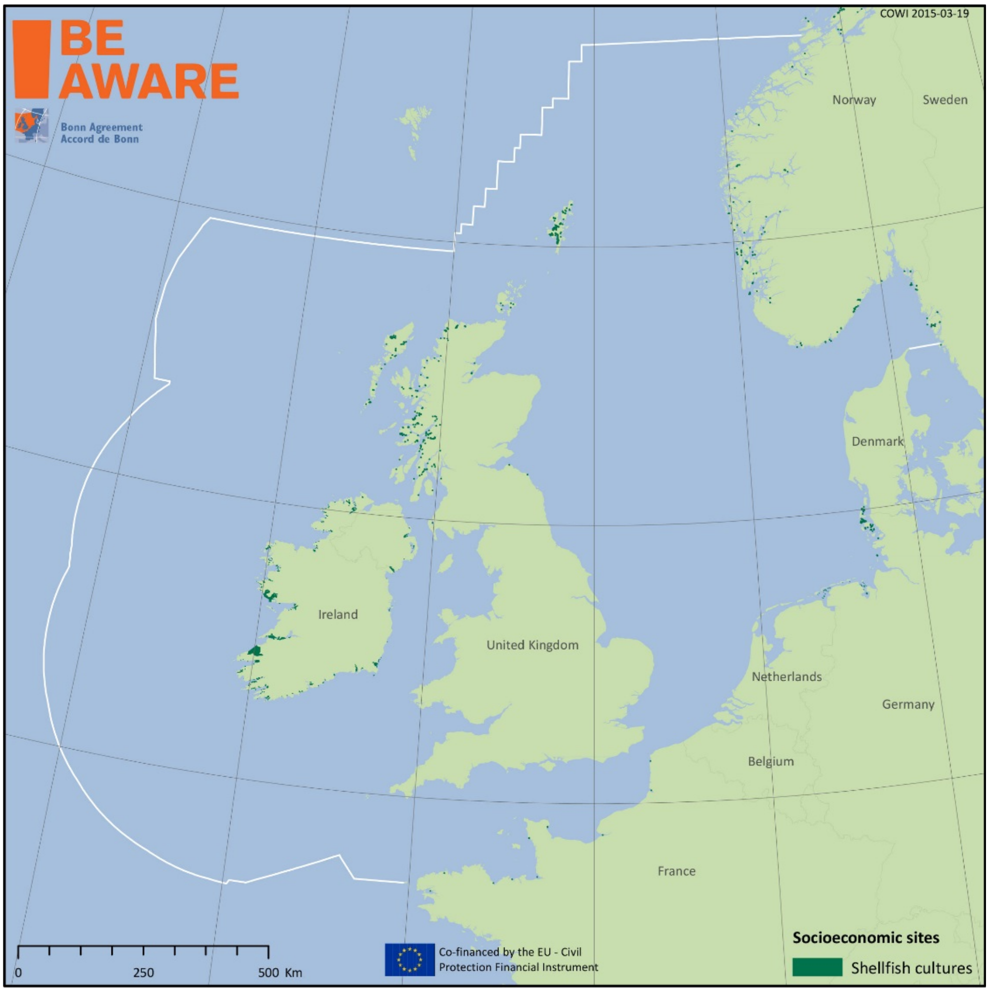

Figure 7-3 Location of shellfish farms.

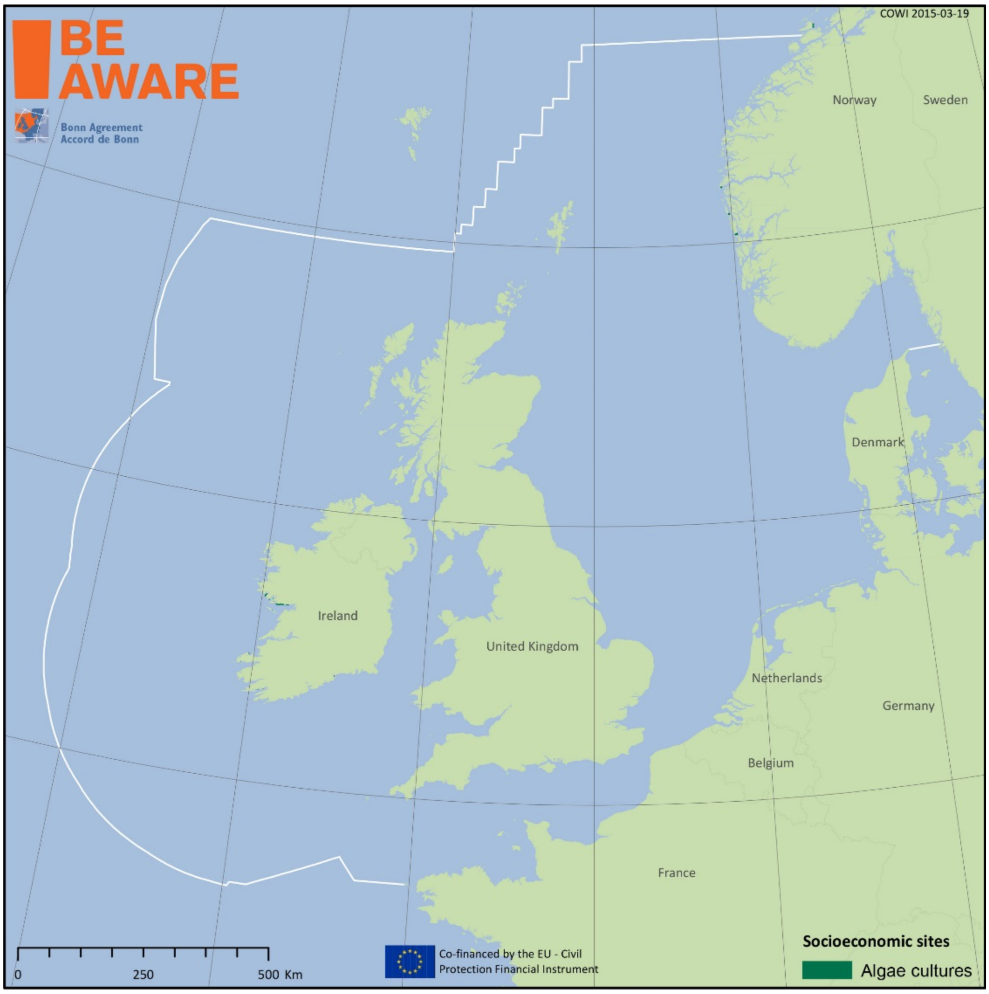

Figure 7-4 Location of algae cultures.

7.3.2 Characteristics and significance of aquaculture in the BA area

Fish farms

Farming of Atlantic salmon is by far the most important fish farming activity in Norway, Scotland, the Hebrides, the Orkneys and the Shetlands. In Norway farming of salmon accounts for more than 80 percent of the total Norwegian aquaculture production and farmed salmon is now one of the main export commodities from Norway. Rainbow trout is also important in these areas. Salmon and rainbow trout are anadromous species, having both a freshwater and saltwater phase to their life cycle. Hatching and smolt production takes place in onshore freshwater tanks, while intensive on growing to market size takes place offshore in marine cages (FAO 2011, Anon 2015)

Farming of cod and halibut are in the process of becoming commercialised in Norway. Hatching of these species takes place in onshore tanks by pumping seawater ashore. Further growth is then carried out in much the same way as for salmon and rainbow trout.

Shellfish farms

The following shellfish species are farmed: blue mussels, pacific oysters, native oysters, clams and scallops. Blue mussels and oysters are the most important species.

Blue mussels are cultivated using the following two techniques:

- On-bottom culture: On-bottom culture is based on the principle of transferring mussel seed (spat) from areas where they have settled naturally to areas where they can be placed in lower densities to increase growth rates, facilitate harvest, and control predation;
- Rope culture: In this method, long-lines are suspended by a series of small anchored floats and ropes or "socks" of mussels are then suspended vertically from the line. Mussel larvae are collected using collector lines suspended in the water. The mechanism is as follows: spawning mussel larvae are pelagic after which juveniles (spat) settle on the seabed or other substrates including collector lines. After a certain period of growth, the juvenile mussels are transferred to "socks" which are long mesh tubes. The mussels are roughly sorted into similar sizes before being placed in the socks. This helps maintain uniform shell sizes. The mussels will then gradually move to the outside of the sock. Mussels cultivated this way are generally free of sand, grow relatively fast and obtain large uniform size.

Pacific oysters are cultivated on trestles. Juveniles are usually bought from special hatcheries.

Algae cultures

Seaweed farming is not very well developed in Europe. Seaweed farming is carried out on an experimental basis in Norway and Ireland.

In Norway harvesting of naturally growing kelp species *Laminaria hyperborea* and *Ascophyllum nodosum* is an established industry. *L. hyperborea* is processed to alginates used in pharma- and nutraceutical products. *A. nodosum* is processed to seaweed meal for agricultural, nutraceutical and cosmetic products (Skjermo 2012, Meland & Rebours 2011). *L. hyperborea* and *A. nodosum* are now experimentally grown on suspended ropes.

In Ireland, harvesting of natural growing seaweed is also an established industry and harvest occurs along the coasts of Donegal, Sligo, Mayo, Galway, Kerry and Cork. Aquaculture of seaweed is however, still largely experimental in Ireland and has not contributed significantly to domestic production of algae, experimental cultivation of *Asparagopsis armata, Alaria esculenta, Palmaria palmata, Laminaria digitata* and *Porphyra* has been achieved over the last 20 years (Netalgae 2011).

7.3.3 Vulnerability. Aquaculture

Impacts of oil spills on aquaculture

Aquaculture facilities are very vulnerable to oil spills that may result in severe economic losses. Possible impacts include:

- Mass mortality of fish, shellfish or algae that are coated and smothered by oil or exposed directly to toxic components in the oil. Shellfish, algae and cultivated fish kept in cages or tanks cannot avoid exposure to oil contaminants in the water so mortality may be worsened. Shoreline cultivation facilities such as trestles used for the cultivation of oysters are especially vulnerable. They are usually located in the middle or lower shore where oil often strands.
- Severe oil tainting of fish, shellfish or algae by acquiring oil-derived substances in the tissues, which impart unpleasant odours and flavours rendering the polluted specimens unfit for sale. Tainting can result from very low concentrations of oil since caged fish and immobile shellfish cannot swim away. Oil tainting of fish have been reported frequently in connection with oil spills such as the Juliana, the Torrey Canyon, the Ekofisk blow-out, the Amoco Cadiz and the Braer oil spill (Whittle et al. 1997).

- Worsening of existing stress effects in aquaculture facilities due to the presence of oil pollutants. Oil components may significantly add to the stresses already imposed by keeping animals in artificial conditions. If, for example, the stocking density or the water temperature in a fish farm is unusually high, there is a greater risk that mortality, disease or growth retardation will occur because of oil contamination.
- Impacts on normal production and loss of market confidence. Oil on the water and the application of temporary harvesting bans may prevent normal production, or a loss of market confidence may occur, leading to price reductions or outright rejection of seafood products by commercial buyers and consumers. In extreme cases, the mere hint of oil contamination can affect the marketing of high-value luxury seafood even if the produce is proven taint free after testing by trained sensory panels and contaminants are at background levels after exhaustive chemical analysis.

In case of an oil spill, affecting an aquaculture facility some compensation may be possible and it might be possible to move fish cages to other unaffected areas before a spill reaches the area.

Vulnerability scores. Aquaculture

Based on these considerations fish farms, shellfish cultures and algae cultures allocated score 3 for all seasons and for both surface oil spills and dispersed oil.

7.4 Coastal tourism

7.4.1 Characteristics and location of coastal tourism

Coastal tourism is important for the countries bordering the seas of the BA area and is a key economic sector for many countries. Tourists flock to the coastal areas to participate in the traditional tourist activities such as bathing, sunbathing and relaxation on the beach, boating, angling, diving, sightseeing etc. Tourists generate income to a wide variety of businesses such as hotels, campsites, caravan parks, summerhouse rentals, restaurants, bars, suppliers to hotels and restaurants, various shops and many other businesses whose livelihoods depend on tourism.

In this analysis, coastal tourism is described and analysed in terms of the following features:

- Magnitude of tourist activities indicated by number of overnight stays in coastal hotels
- Amenity beaches
- Recreational fishery areas
- Marinas
- Cruise liner stops

This section deals with overnight stays, amenity beaches and recreational fishery areas. Marinas and cruise liner stops are dealt with in chapter 7.5 together with ports as the type of impacts are similar.

Figure 7-5 show the magnitude of coastal tourist activities in the BA area indicated by numbers of annual overnight stays in coastal hotels of more than 20,000. It should be mentioned that tourist activities in Norway and Denmark will be underestimated using this method as the tourists here mainly stay in summer houses, camping sites and in pleasure crafts etc. of which available, reliable data are lacking.

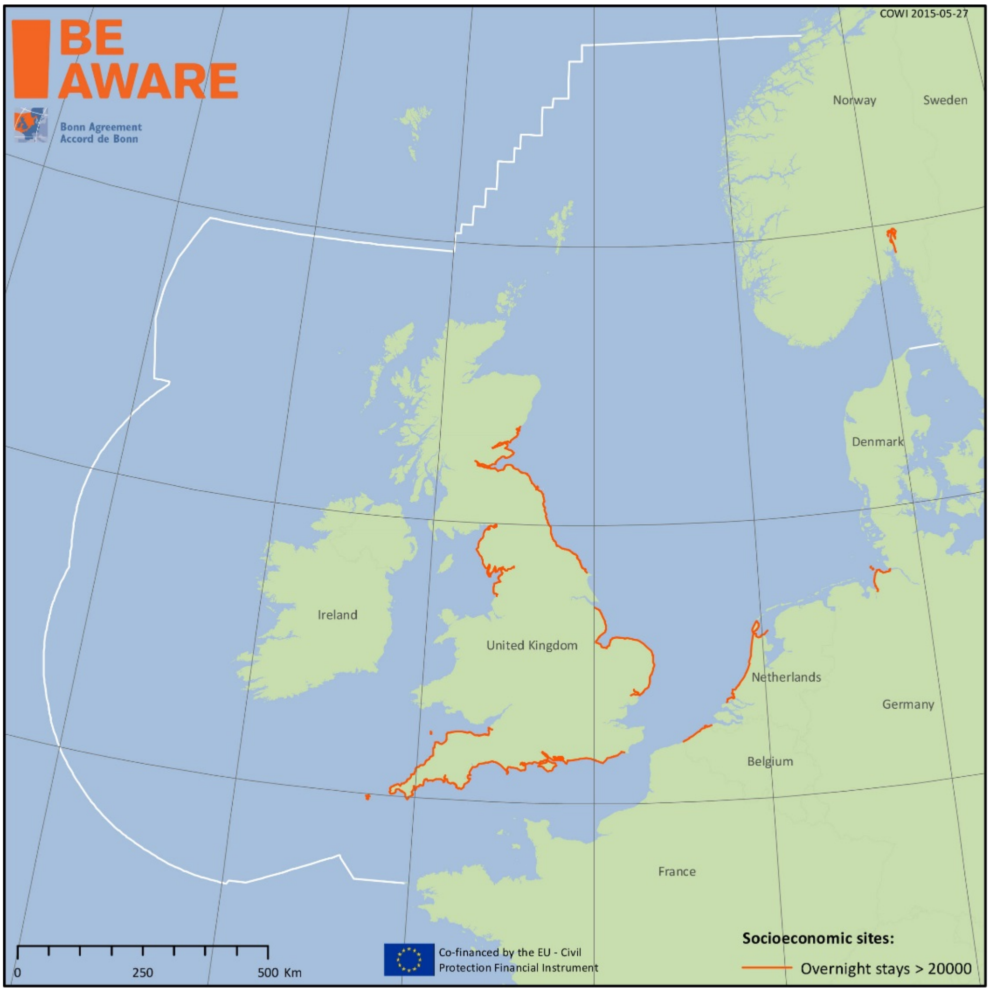

Figure 7-5 Overnight stays in coastal hotels. The figure shows areas with more than 20 000 annual overnight stays.

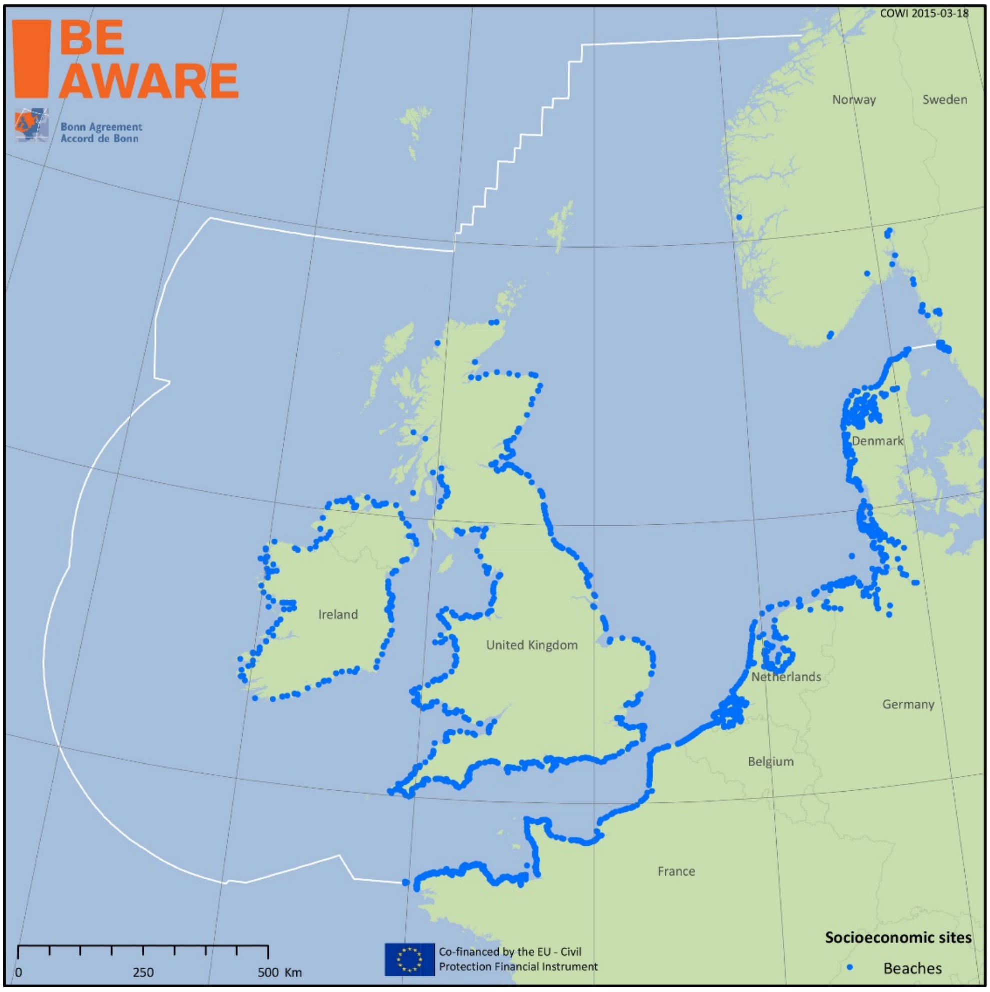

Figure 7-6 **Location of amenity beaches.**

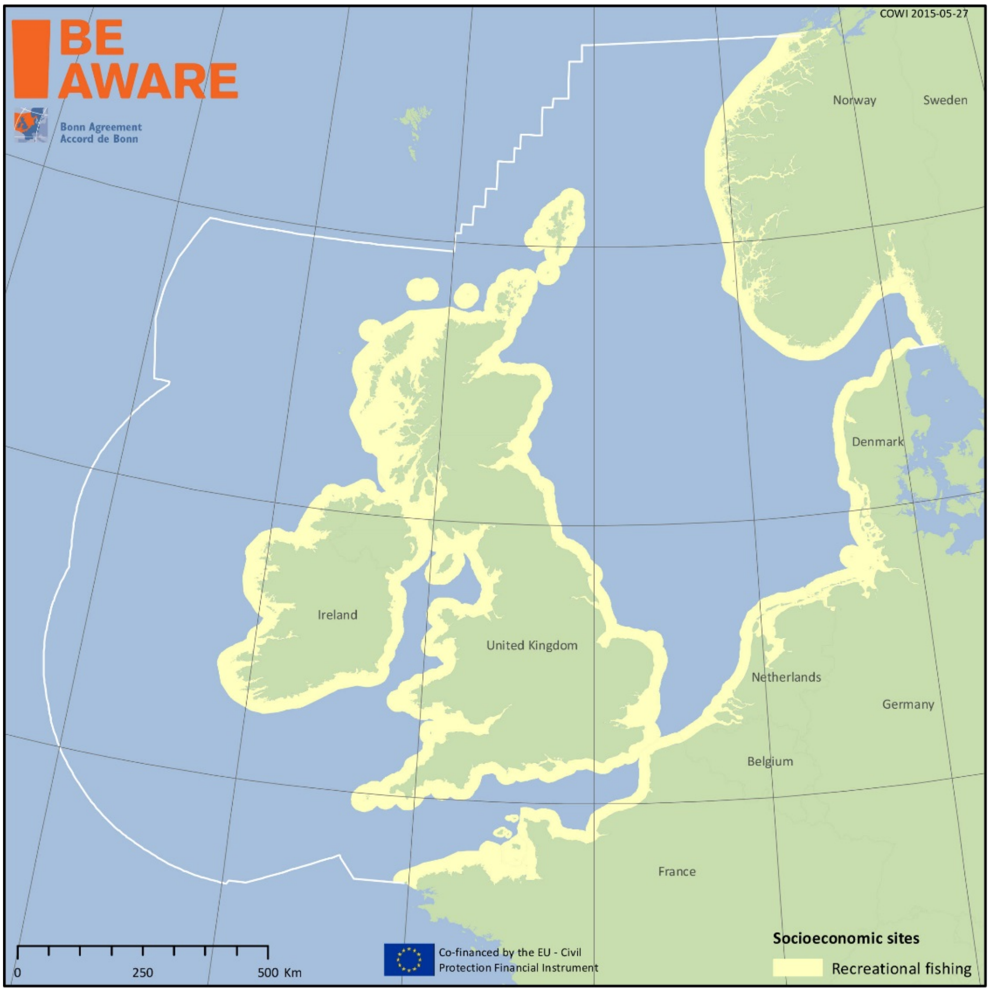

Figure 7-7 **Location of recreational fishing areas.**

7.4.2 Vulnerability. Coastal tourism

Impacts of oil spills on coastal tourism

The tourist industry may be severely affected by an oil spill with the most serious consequences just before and during the tourist season.

Oil contamination of recreational beaches and waters off these beaches will deleteriously affect typical tourist activities such as, sun-bathing and relaxation on the beach, boating, angling, diving, sightseeing etc. Affected beaches may have to be closed during clean up. On beaches that remain open the oil and the presence of clean-up personnel and machinery may disturb tourists.

Hotel and restaurant owners and others who gain their livelihood from the coastal tourist trade can suffer economic losses due to these impacts of oil spill. Holidaymakers may cancel bookings of accommodation in the affected area and rumours of oil spill affecting the coast might prevent bookings or entail cancelling of bookings even in areas along the coast not directly affected by oil. Retail and restaurant establishments that cater to the tourism industry as well as transportation, guides, activities and recreational fisheries are also exposed to losses in sales and wages.

In surveys after Exxon Valdez, 59% of tourism businesses in the spill area reported spill-related cancellations, and visitor spending decreased 35% from pre-spill levels in Southwest Alaska (Chang et al 2014).

Typical bathing beaches are easy to clean because they are often composed of fine grained sand and because good access roads to the beaches are available and the physical disturbance to coastal areas affected by oil spill is usually comparatively short-lived. Once the shorelines are cleaned, normal trade can resume. However, the duration of interruption of business can be prolonged, even after a clean up has taken place because negative media attention and public perception of a coastal tourist area that has been affected by an oil spill has damaged the image of the areas.

Amenity beaches and other coastal tourist assets represent the highest value in the tourist season, which culminates in summer, but also with some activity in spring and autumn. There is some recreational use of beaches in winter. Information on economic compensation for oil spill damage to the coastal tourist trade is not readily available.

Application of dispersants before the oil reaches the shoreline will reduce the impacts of oil spills on coastal tourism.

Vulnerability scores. Coastal tourism

Based on these considerations the following vulnerability scores have been allocated to tourist activities, amenity beaches and recreational fishing areas:

- For tourist activities, measured as number of overnight stays:
    - Score surface oil spill: Spring: 2, Summer: 3, Autumn: 3, Winter: 2
    - Score dispersed oil: Spring: 1, Summer: 2, Autumn: 1, Winter: 1
- For amenity beaches:
    - Score surface oil spill: Spring: 3, Summer: 4, Autumn: 3, Winter: 2
    - Score dispersed oil: Spring: 2, Summer: 3, Autumn: 2, Winter: 1
- For recreational fishing areas:
    - Score surface oil spill: Spring: 3, Summer: 4, Autumn: 3, Winter: 2
    - Score dispersed oil: Spring: 3, Summer: 3, Autumn: 2, Winter: 2

7.5 Ports, marinas and cruise liner stops

7.5.1 Locations of ports, marinas and cruise liner stops

Figure 7-8, Figure 7-9 and Figure 7-10 show the location of ports, coastal marinas and cruise liner stops in the BA area.

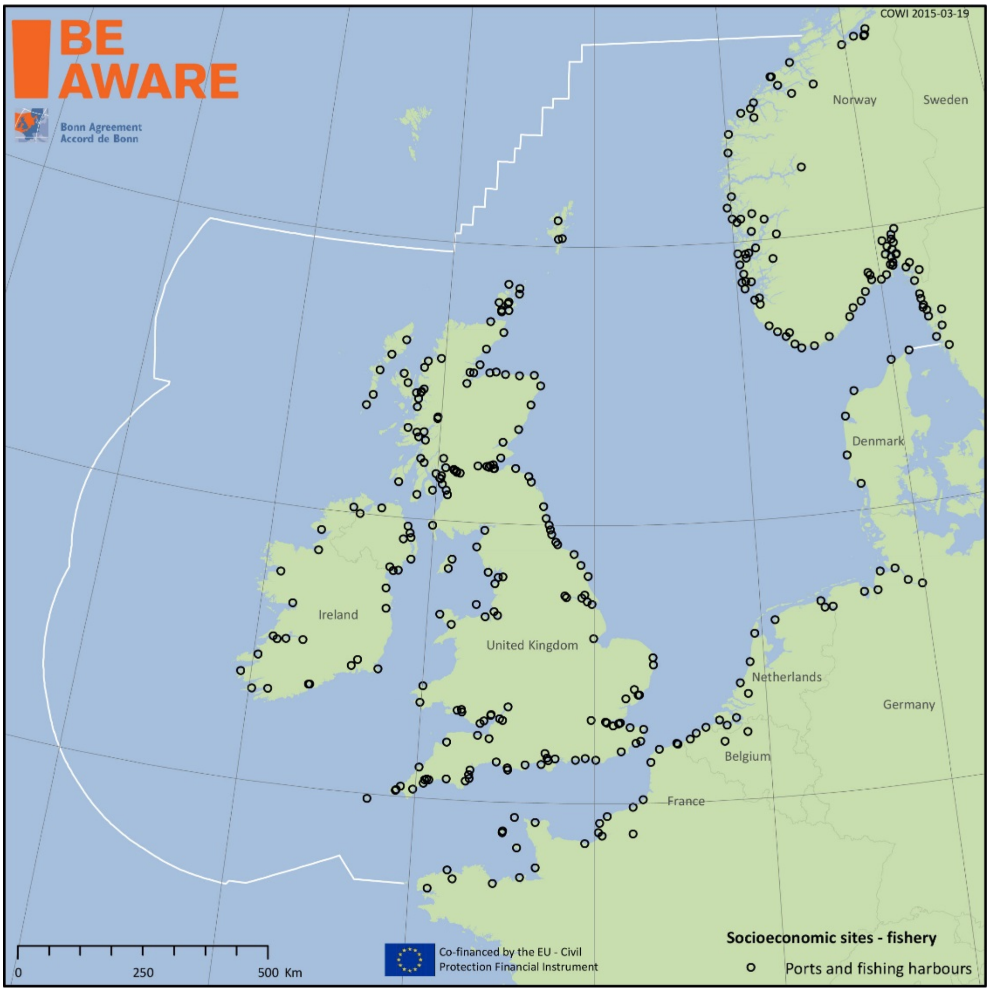

Figure 7-8 **Location of ports.**

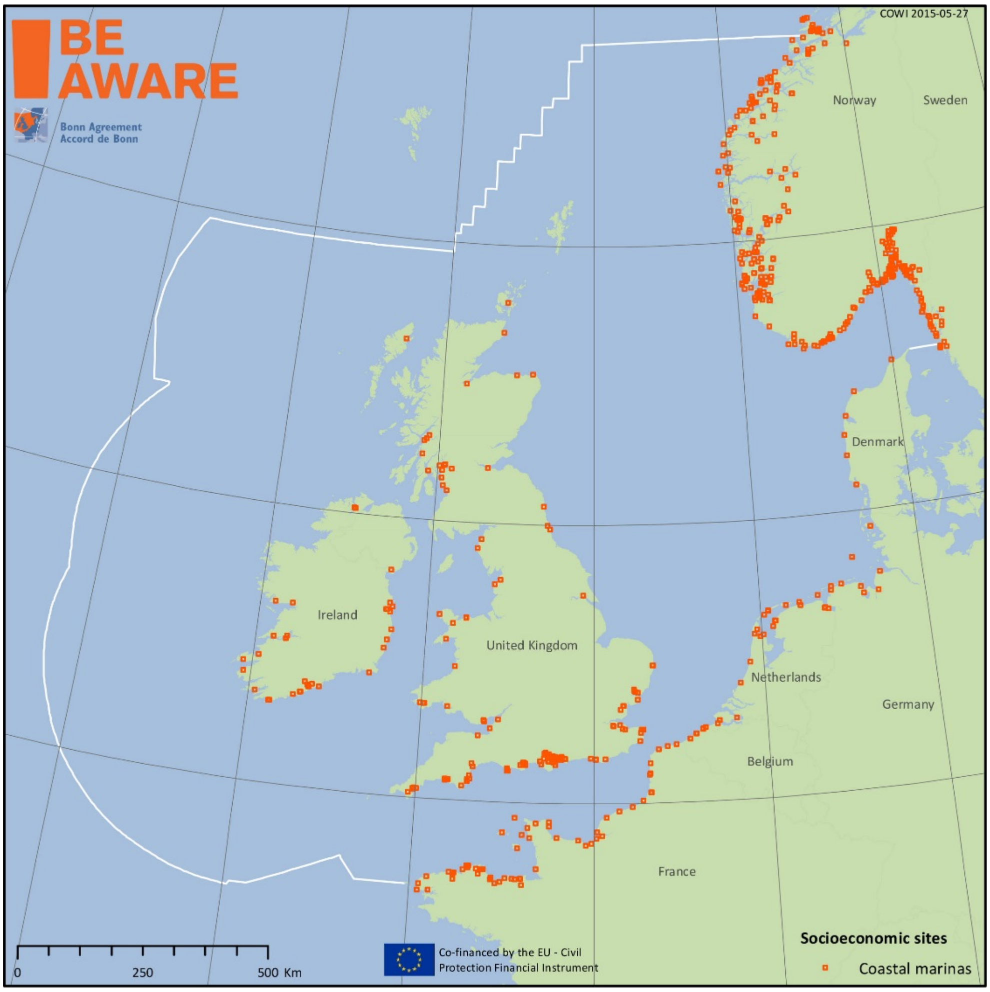

Figure 7-9 **Location of coastal marinas.**

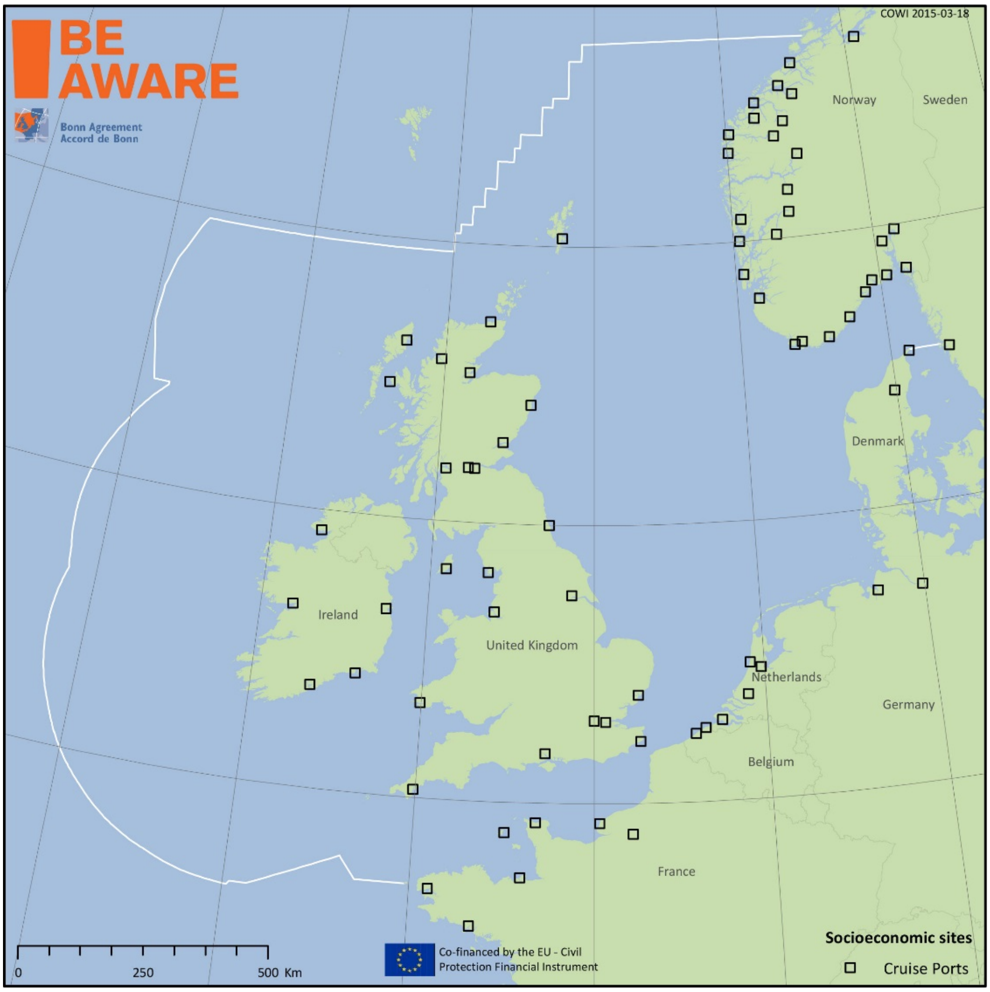

Figure 7-10 Location of cruise liner stops.

7.5.2 Vulnerability. Ports, marinas and cruise liner stops

Impacts of oil spills on ports, marinas and cruise liner stops

Oil spills in or near ports, marinas and cruise liner stops' harbour areas will hamper normal ship traffic and calls. The vessels can be oiled in the waterline and oil in the water intakes for cooling the engine might create operational problems for the vessels. Mooring lines and berths may also be oiled. In addition, breakwaters that are usually made of rock or concrete tetrapod armour may be difficult to clean as the oil may penetrate deep into the structure. This oil may become a secondary source of oil pollution. Risk of ignition of the floating oil (if easily flammable oil is spilled) might prevent sailing, loading and unloading operations. Furthermore, deployed oil spill combat equipment (e.g. booms) might also hamper usual shipping operations.

The consequences for the ports, marinas and cruise liner stops of oil spills are economic losses and claims from ship owners and firms relying on harbour operations. The impact might also cause temporary unemployment for workers at the harbour.

On the other hand, prevention of oil entering the port or marina may be easily prevented by placing booms across the narrow entrances of ports, harbours and marinas. The sheltered nature of the port and harbour basins allow for a rapid and effective response, implying that the length of interruption will be short

Ports are vulnerable all the year round, whereas marinas are least vulnerable outside the holiday season. The traffic at cruise liner stops is highest during May-September.

Vulnerability scores

Based on these considerations the following vulnerability scores have been allocated to ports, marinas and cruise liner stops:

- For ports:
    - Score surface oil spill: Spring: 2, Summer: 2, Autumn: 2, Winter: 2
    - Score dispersed oil: Spring: 1, Summer: 1, Autumn: 1, Winter: 1
- For marinas:
    - Score surface oil spill: Spring: 2, Summer: 3, Autumn: 3, Winter: 1
    - Score dispersed oil: Spring: 1, Summer: 1, Autumn: 1, Winter: 1
- For cruise liner stops:
    - Score surface oil spill: Spring: 1, Summer: 2, Autumn: 1, Winter: 1
    - Score dispersed oil: Spring: 1, Summer: 1, Autumn: 1, Winter: 1

7.6 Other

7.6.1 Heritage sites

Location and characteristics of heritage sites

Figure 7-11 show the location of heritage sites in the BA area.

Heritage sites include cultural buildings, artefacts and nature sites.

An example of a cultural site is Mont Saint-Michel in Normandy France, which is an Island on a tidal flat, housing 61 historic monuments including a monastery and a church, which was first established in 708.

Examples of natural heritage sites are the Cliffs of Dover in southern England and the Wadden Sea.

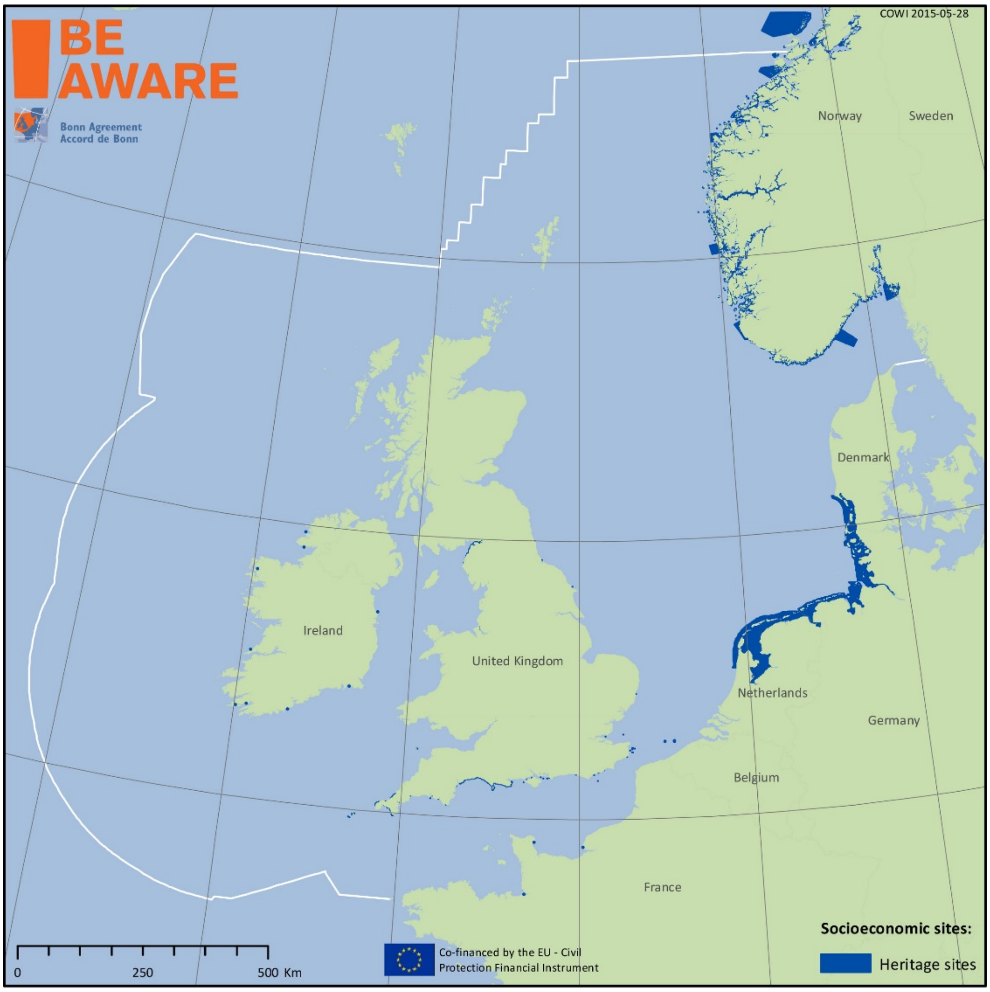

Figure 7-11 **Location of heritage sites.**

Impacts of oil spills on heritage sites

In most cases, oil spill in the sea facing a cultural site or a historical monument will not have a direct impact on the buildings or sites but the perception of the historical monument to the visitors will be negatively affected during oil spill events. However, some artefacts such as historical quays or berths could be affected through direct contact with oil and be damaged. Oil spills at natural sites may cause severe impacts. Heritage sites and their socio-economic value are therefore estimated to be very sensitive to oil spills. Application of dispersants before the oil reaches a heritage site will significantly reduce the risk of severe impacts.

Vulnerability scores. Heritage sites

Based on the above considerations the following scores have been allocated to heritage sites:

- Score surface oil spill: Spring: 4, Summer: 4, Autumn: 4, Winter: 4
- Score dispersed oil: Spring: 2, Summer: 2, Autumn: 2, Winter: 2

7.6.2 Densely populated towns and communities

Location and characteristics of densely populated towns and communities

The location of large densely populated towns and communities in the BA area is shown in Figure 7-12.

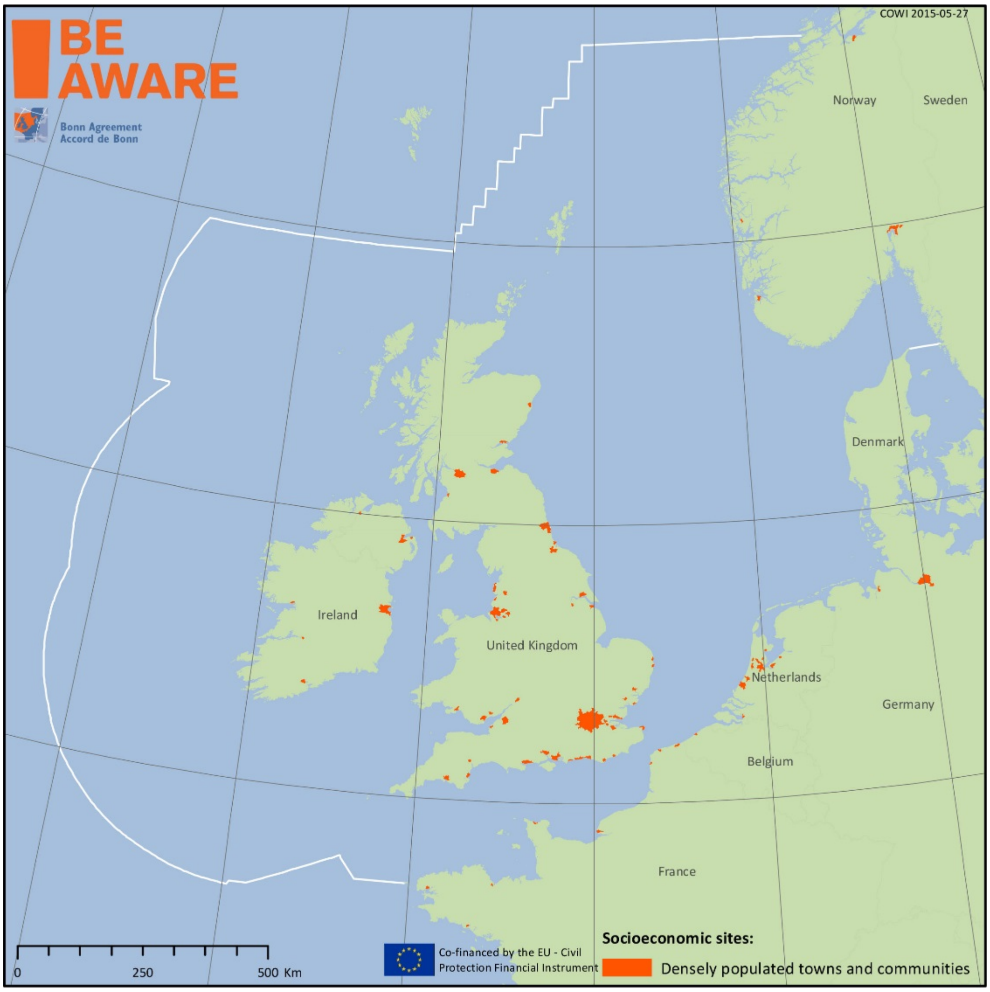

Figure 7-12 **Location of densely populated coastal towns and communities in the BA area.**

Impacts of oil spills on densely populated towns and communities

A major spill of volatile crude oil close to a centre of populations is likely to raise health concerns and complaints of breathing difficulties headache and nausea. In extreme cases, the oil may represent a fire hazard and necessitate the evacuation of such communities. In addition, the smell of oil can be very unpleasant and presents a severe nuisance to people living close to the affected coastline (ITOPF 2007).

A health study carried out after the Braer oil spill off the coast of Scotland in 1993 showed that residents living within 4.5 km of the wreck site experienced a higher incidence of irritated throats and eyes compared to non-exposed residents living farther away. Most symptoms (97%) however, resolved within a week. Similarly, a range of acute symptoms after the Sea Empress accident in Wales in 1996 was observed. The authors observed a statistically significant increase in the prevalence of headaches, nausea, sore eyes, sore throat, cough, itchy skin, rashes, shortness of breath, and general weakness among the exposed (Eyebosh 2014).

Such impacts are of short duration and, as the Braer study showed, disappear within a week. This is probably because the volatile components that cause these symptoms, usually evaporate within a week (see Appendix A).

It has been speculated that oil spills may negatively affect the mental health and the social relationships between people and their confidence in social institutions. However, a study of the

Galician coast affected by the Prestige spill found no significant impact on these factors because of the strong support of social groups and appropriate levels of interim financial aid (Cheng et al 2014).

Vulnerability scores. Densely populated towns and communities

Based on the above considerations the following vulnerability scores have been allocated to densely populated towns and communities:

- Score surface oil spill: Spring: 2, Summer: 2, Autumn: 2, Winter: 2
- Score dispersed oil: Spring: 1, Summer: 2, Autumn: 1, Winter: 1

7.6.3 Mineral extraction sites

Location and characteristics of mineral extraction sites

Marine mineral deposits are extracted from the seabed in the BA area, mainly in the southern part of the North Sea (Figure 7-13). The principal material is sand and gravel for the construction industry (especially concrete sand and mortar sand) or sand for beach nourishment. The Netherlands is the largest marine sand extractor followed by the UK. In some countries (for example France and Ireland), non-aggregate marine mineral resources such as maerl or shelly sands are also extracted (Lauwaert et al. 2009, Phua et al 2004).

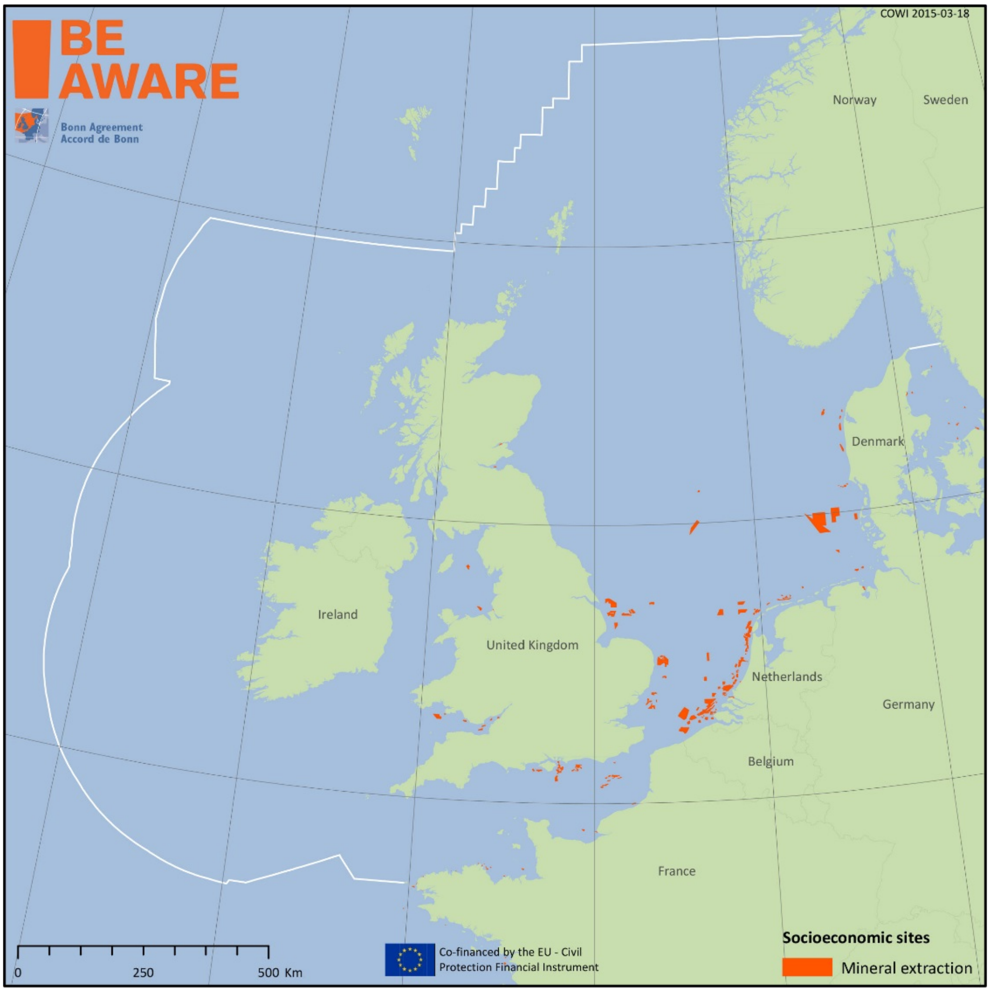

Figure 7-13 Location of mineral extraction sites.

Impacts of oil on mineral extraction sites and vulnerability scores

If an oil slick passes a mineral extraction site, the risk that the oil will contaminate the material on the seabed is small. Vessels that are extracting the materials may be smeared in oil, if the slick is not discovered on board and the vessel fails to avoid the slick. The duration of risk of impact is short and will only last during the period the oil slick passes the area.
Mineral extraction sites have therefore been allocated the score 1 for all seasons and for both a surface oil spill and for dispersed oil: Spring: 1, Summer: 1, Autumn: 1, Winter: 1.

7.6.4 Offshore wind farms

Location of offshore wind farms

Figure 7-14 shows the location of offshore windfarms in the BA area.

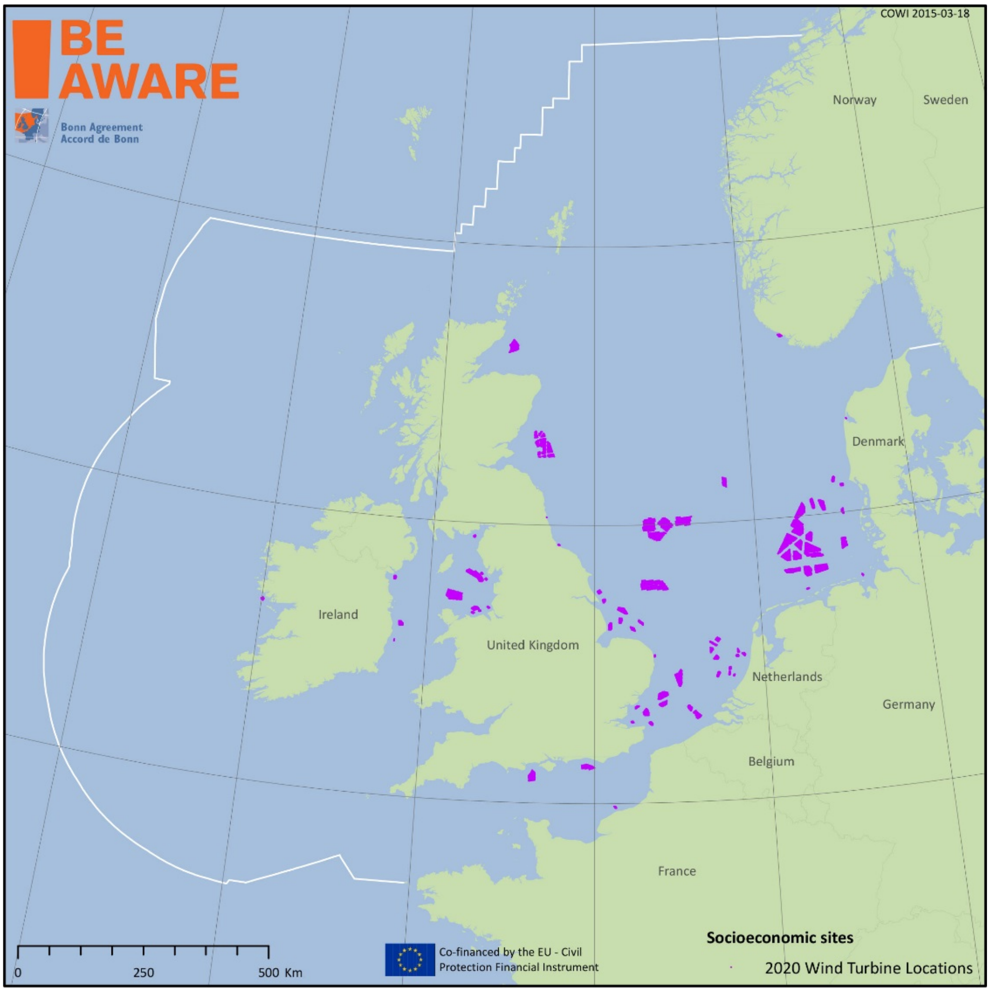

Figure 7-14 Location of offshore windfarms.

Impacts of oil spills on offshore windfarms

If an oil slick hits an offshore wind, oil pollution will generally be limited to a narrow of band of oil on the leg of the turbine in the transition area between air and water.

Offshore windfarm sites have therefore been allocated the score 1 for all seasons and for both a surface oil spill and for dispersed oil.

7.6.5 Water intakes

Location and characteristics of water intakes

Numerous industries rely on the ability to draw clean seawater from the sea. For instance, seawater is used for:

- Cooling water for thermal or nuclear power plants
- Process water in seafood processing plants
- Water for aquariums or onshore aquaculture facilities

Figure 7-15 shows the location of major water inlets in the BA area.

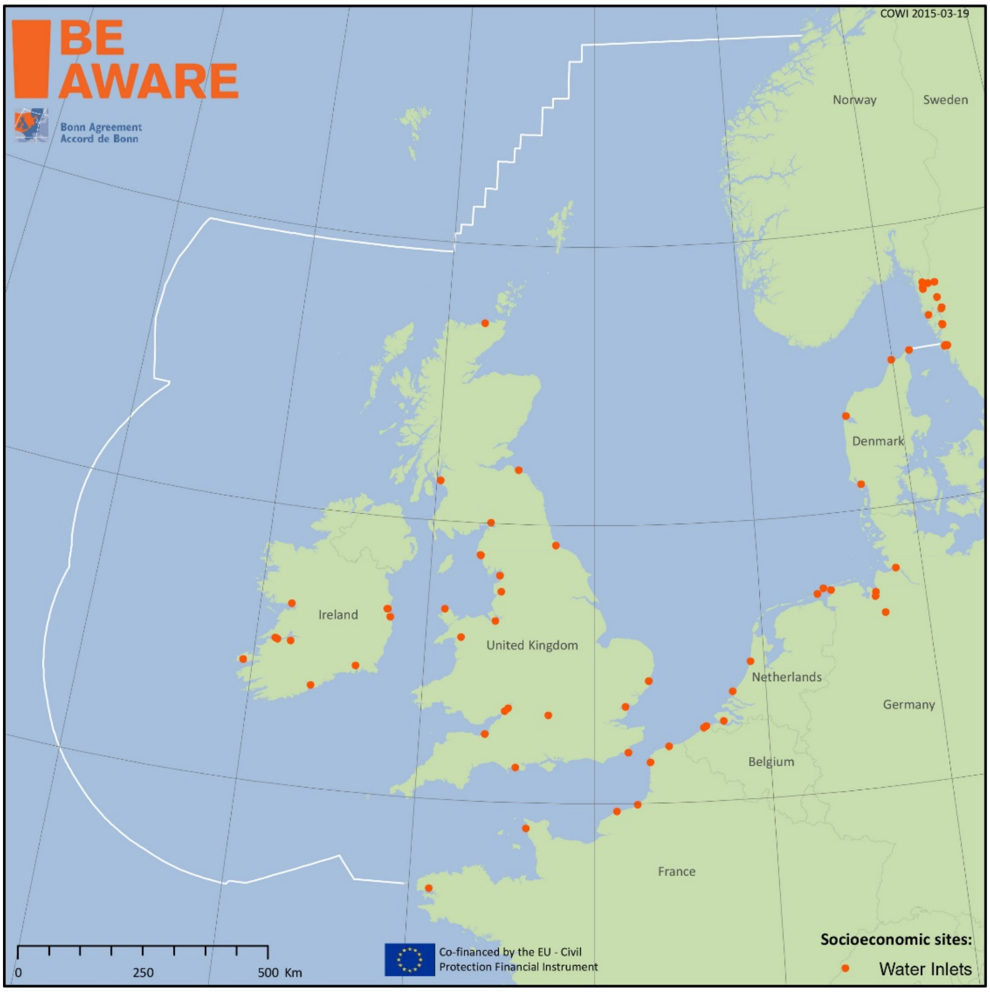

Figure 7-15 Location of water inlets.

Impacts of oil spills on water intakes

Oil contamination in the water intakes could cause severe economic effects. If oil is taken into the water circulation system of the facilities, which are vital for normal operations, machinery or products could be destroyed. Temporary closure of the intake as a precaution against damage might affect the entire operation of the plant and thus vital economic interests. The consequences of temporary closure of an electric power plant, for instance, are likely to be far-reaching, as electricity is vital for a local community and industry and it may become necessary to buy electricity from other producers to maintain supplies (ITOPF 2007).

Vulnerability scores. Water intake

Water intakes have therefore been allocated the score 3 for all seasons and for both a surface oil spill and for dispersed oil.

8. RANKING MATRICES

This chapter sums up the outcome of the ranking exercise for habitats, species, protected areas and socioeconomic features.

8.1 Ranking matrices. Habitats

Table 8-1 and Table 8-2 outline the vulnerability scores for habitats for surface oil spills and dispersed oil, respectively.

Table 8-1 Habitats. Ranking matrix for surface oil spills.

Habitats	**Ranking scores surface oil spill**			
	Spring	Summer	Autumn	Winter
Shoreline habitats				
Exposed rocky shores and reefs (< 20m)	3	3	2	2
Exposed rocky shores and reefs (>20 m)	1	1	1	1
Sheltered rocky shores and reefs (<20m)	4	4	3	3
Sheltered rocky shores and reefs (>20m)	2	2	2	2
Littoral chalk communities	4	4	3	3
Sandy beaches	2	2	1	1
Shingle beaches	3	3	3	3
Tidal sand and mud flats	4	4	4	4
Salt marshes	4	4	4	4
Underwater sandbanks (<20m)	3	3	2	2
Underwater sandbanks (>20m)	1	1	1	1
Biogenic reefs (<20m)	4	4	4	4
Biogenic reefs (>20m)	2	2	2	2
Maerl beds	4	4	3	3
Seagrass beds (*Zostera* sp coverage >5 %)	4	4	4	4
Estuaries	4	4	4	4
Coastal lagoons	4	4	4	4
Large shallow inlets and bays	3	3	3	3
Open sea Habitats				
Open water column (< 20m)	2	2	1	1
Open water column (>20m)	1	1	1	1
Deeper sea floor (> 20 m)	1	1	1	1
Seamounts	1	1	1	1
Coral gardens and sponge aggregations	2	2	2	2
Carbonate mounds	2	2	2	2
Lophelia pertusa reefs	2	2	2	2
Sea-pens and burrowing megafauna	2	2	2	2

Table 8-2 Habitats. Ranking matrix for chemical dispersed oil spills.

Habitats	**Ranking scores chemical dispersed oil**			
	Spring	Summer	Autumn	Winter
Shoreline habitats				
Exposed rocky shores and reefs (< 20m)	3	3	2	2
Exposed rocky shores and reefs (>20 m)	2	2	2	2
Sheltered rocky shores and reefs (<20m)	4	4	3	3
Sheltered rocky shores and reefs (>20m)	4	4	4	4
Littoral chalk communities	4	4	3	3
Sandy beaches	2	2	1	1
Shingle beaches	3	3	3	3

Tidal sand and mud flats	4	4	4	4
Salt marshes	4	4	4	4
Underwater sandbanks (<20m)	3	3	3	3
Underwater sandbanks (>20m)	2	2	2	2
Biogenic reefs (<20m)	4	4	4	4
Biogenic reefs (>20m)	4	4	4	4
Maerl beds	4	4	4	4
Seagrass beds (Zostera sp. coverage >5 %)	4	4	4	4
Estuaries	4	4	4	4
Coastal lagoons	4	4	4	4
Large shallow inlets and bays	3	3	3	3
Open sea Habitats				
Open water column (< 20m)	2	2	2	2
Open water column (>20m)	2	2	2	2
Deeper sea floor (> 20 m)	2	2	2	2
Seamounts	2	2	2	2
Coral gardens and sponge aggregations	3	3	3	3
Carbonate mounds	3	3	3	3
Lophelia pertusa reefs	3	3	3	3
Sea-pens and burrowing megafauna	3	3	3	3

8.2 Ranking matrices. Species

Table 8-3 and Table 8-4 outline the vulnerability scores for species for surface oil spills and dispersed oil, respectively.

Table 8-3 Species features. Ranking matrix for surface oil spills.

Species features	**Ranking scores surface oil spill**			
	Spring	Summer	Autumn	Winter
Fish				
Spring spawners with pelagic eggs	2	1	0	0
Summer spawners with pelagic eggs	1	2	1	0
Autumn spawners with pelagic eggs	0	1	2	0
Winter spawners with pelagic eggs	1	0	0	2
Norwegian spring spawning herring (Feb-Mar)	4	3	3	4
Bucan/Shetland herring spawning (Aug-Sept)	3	4	4	3
Banks and West of Scotland herring spawning (Aug-Oct)	3	4	4	3
Irish autumn/winter spawning herring (Sept-Feb)	3	3	4	4
Downs herring (Nov-Jan)	3	3	4	4
Birds				
Wintering areas for birds	3	1	3	4
Staging areas for birds	4	2	4	2
Breeding areas for birds	4	4	3	1

Table 8-4 Species features. Ranking matrix for dispersed oil spills.

Species features	**Ranking scores surface oil spill**			
	Spring	Summer	Autumn	Winter
Fish				
Spring spawners with pelagic eggs	3	2	0	0
Summer spawners with pelagic eggs	2	3	2	0
Autumn spawners with pelagic eggs	0	2	3	0
Winter spawners with pelagic eggs	2	0	0	3
Norwegian spring spawning herring (Feb-Mar)	4	3	3	4
Bucan/Shetland herring spawning (Aug-Sept)	3	4	4	3
Banks and West of Scotland herring spawning (Aug-Oct)	3	4	4	3
Irish autumn/winter spawning herring (Sept-Feb)	3	3	4	4
Downs herring (Nov-Jan)	3	3	4	4

Birds				
Wintering areas for birds	1	1	1	2
Staging areas for birds	2	1	2	1
Breeding areas for birds	3	3	2	1

8.3 Ranking matrices. Protected areas

Table 8-5 and Table 8-6 outline the vulnerability scores for protected areas for surface oil spills and dispersed oil, respectively.

Table 8-5 Protected areas. Ranking matrix for surface oil spills

Habitats	Ranking scores surface oil spill			
	Spring	Summer	Autumn	Winter
Ramsar areas	4	4	4	4
Nature 200 areas	4	4	4	4
National protected areas	4	4	4	4
World heritage areas	4	4	4	4

Table 8-6 Protected Areas. Ranking matrix for chemical dispersed oil spills.

Habitats	Ranking scores surface oil spill			
	Spring	Summer	Autumn	Winter
Ramsar areas	4	4	4	4
Nature 200 areas	4	4	4	4
National protected areas	4	4	4	4
World heritage areas	4	4	4	4

8.4 Ranking matrices Socioeconomic features

Table 8-7 and Table 8-8 outline the vulnerability scores for socioeconomic features for surface oil spills and dispersed oil, respectively.

Table 8-7 Socioeconomic features. Ranking matrix for surface oil spills.

Socioeconomic feature	Ranking scores surface oil spill			
	Spring	Summer	Autumn	Winter
Offshore fisheries	2	2	2	2
Coastal fisheries	3	3	3	3
Fish farms	3	3	3	3
Shellfish cultures	3	3	3	3
Algae cultures	3	3	3	3
Amenity beaches	3	4	3	2
Marinas	2	3	3	1
Overnight stays coastal tourist hotels	2	3	3	2
Densely populated towns and communities	2	2	2	2
Main recreational fishing locations	3	4	3	2
Cruiser liner stops	1	2	1	1
Heritage sites	4	4	4	4
Ports	2	2	2	2
Mineral extraction sites	1	1	1	1
Offshore windfarms	1	1	1	1
Water intakes	3	3	3	3

Table 8-8 Socioeconomic features. Ranking matrix for chemical dispersed oil spills.

Socioeconomic feature	Ranking scores chemical dispersed oil			
	Spring	Summer	Autumn	Winter
Offshore fisheries	2	2	2	2
Coastal fisheries	3	3	3	3
Fish farms	3	3	3	3
Shellfish cultures	3	3	3	3
Algae cultures	3	3	3	3
Amenity beaches	2	3	2	1
Marinas	1	1	1	1
Overnight stays coastal tourist hotels	1	2	1	1
Densely populated towns and communities	1	1	1	1
Main recreational fishing locations	3	3	2	2
Cruiser liner stops	1	1	1	1
Heritage sites	2	2	2	2
Ports	1	1	1	1
Mineral extraction sites	1	1	1	1
Offshore windfarms	1	1	1	1
Water intakes	3	3	3	3

9. VULNERABILITY MAPS

Vulnerability maps are the final product of the sensitivity and vulnerability mapping process. The integrated vulnerability maps are included in the next step of the overall project process, where they are integrated with impact data to estimate damage.

In this section, the vulnerability maps are presented. Detailed interpretations of the maps have not been done, as it was not within the scope of the analytical process. In general, the results are consequences of the integrated sensitivity ranking of all the features as they have been discussed in the previous chapters.

First, the separate environmental and socioeconomic vulnerability maps for each season are shown for the four feature groups: habitats, species, protected areas and socioeconomic features.

The final integrated total vulnerability maps were then prepared from a combination of the four series of seasonal vulnerability maps based on the use of a weighting ratio.

9.1 Vulnerability maps. Habitats

9.1.1 Undispersed oil spills

Figure 9-1 shows the maps of seasonal vulnerability of habitats to undispersed oil spills. It is evident that:

- Coastal habitats are generally more vulnerable than offshore habitats.
- The most vulnerable areas are (in no prioritised order):
    - The Danish, German and Dutch Wadden Sea coasts
    - The mouth of the Rhine
    - The Normandy coast
    - The continental peninsula coast of Brittany
    - Areas along the Belgian coasts

  - Most of the UK and Irish coasts
  - The unexposed parts of the Norwegian and Swedish coast and fjords
- Spring and summer are the seasons with the most vulnerable areas

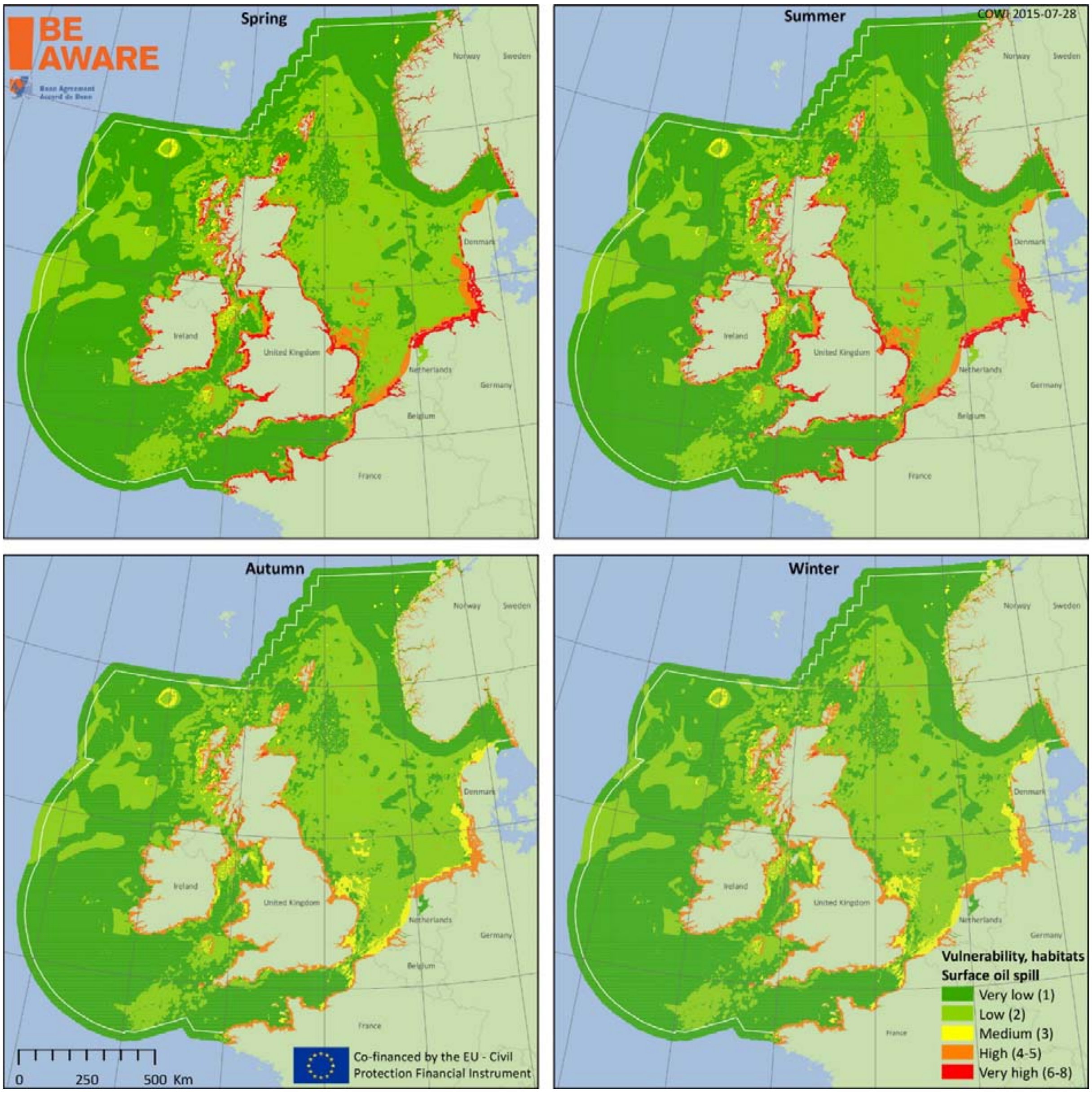

Figure 9-1 **Seasonal vulnerability of habitats to undispersed oil spill.**

9.1.2 Dispersed oil spills

The seasonal habitat vulnerability maps for dispersed oil spills are distinctly different from the maps of the undispersed oil spills (Figure 9-2). The most marked differences are:

- The vulnerability of offshore habitats increases markedly in the North Sea, the Celtic Sea, the Irish Sea and in the waters west of Ireland and Scotland
- The vulnerability of coastal habitats remains very high during autumn and winter in contrast to the undispersed scenarios.

The differences are probably due to the use of dispersants transfer oil components to the water column, where sensitive ecological features are present, also during autumn and winter.

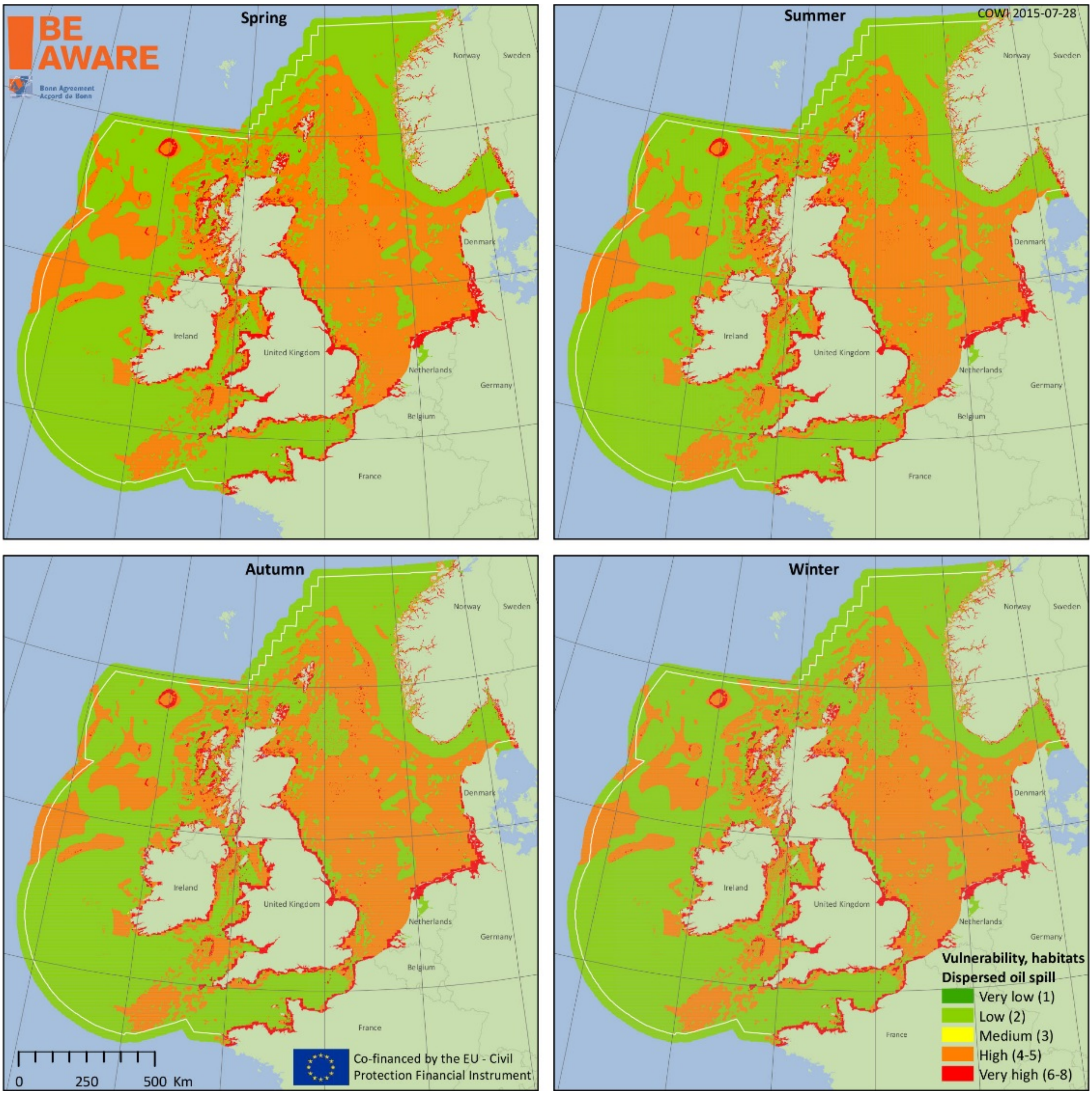

Figure 9-2 **Seasonal vulnerability of habitats to <u>dispersed</u> oil spill.**

9.2 Vulnerability maps. Species

9.2.1 Undispersed oil spills

Figure 9-3 shows the maps of seasonal vulnerability of species to undispersed oil spills. It can be seen that:

- Spring season is where the most vulnerable coastal areas are found of Scotland, the northern coasts of England, the coasts of Ireland and the Danish, German and Dutch Wadden Sea coasts. This is the time of year, when birds are breeding, especially cliffs, and tidal flats are full of staging birds.
- During summer and autumn there are also quite vulnerable areas especially on the coasts of Scotland (birds)
- Winter is where the least vulnerable areas are found.

9.2.2 Dispersed oil spills

In terms of dispersed oil, the seasonal pattern is much like the undispersed scenarios, but the vulnerabilities decreased along the coasts (Figure 9-4). This is mainly because dispersion of oil will reduce the impacts on birds.

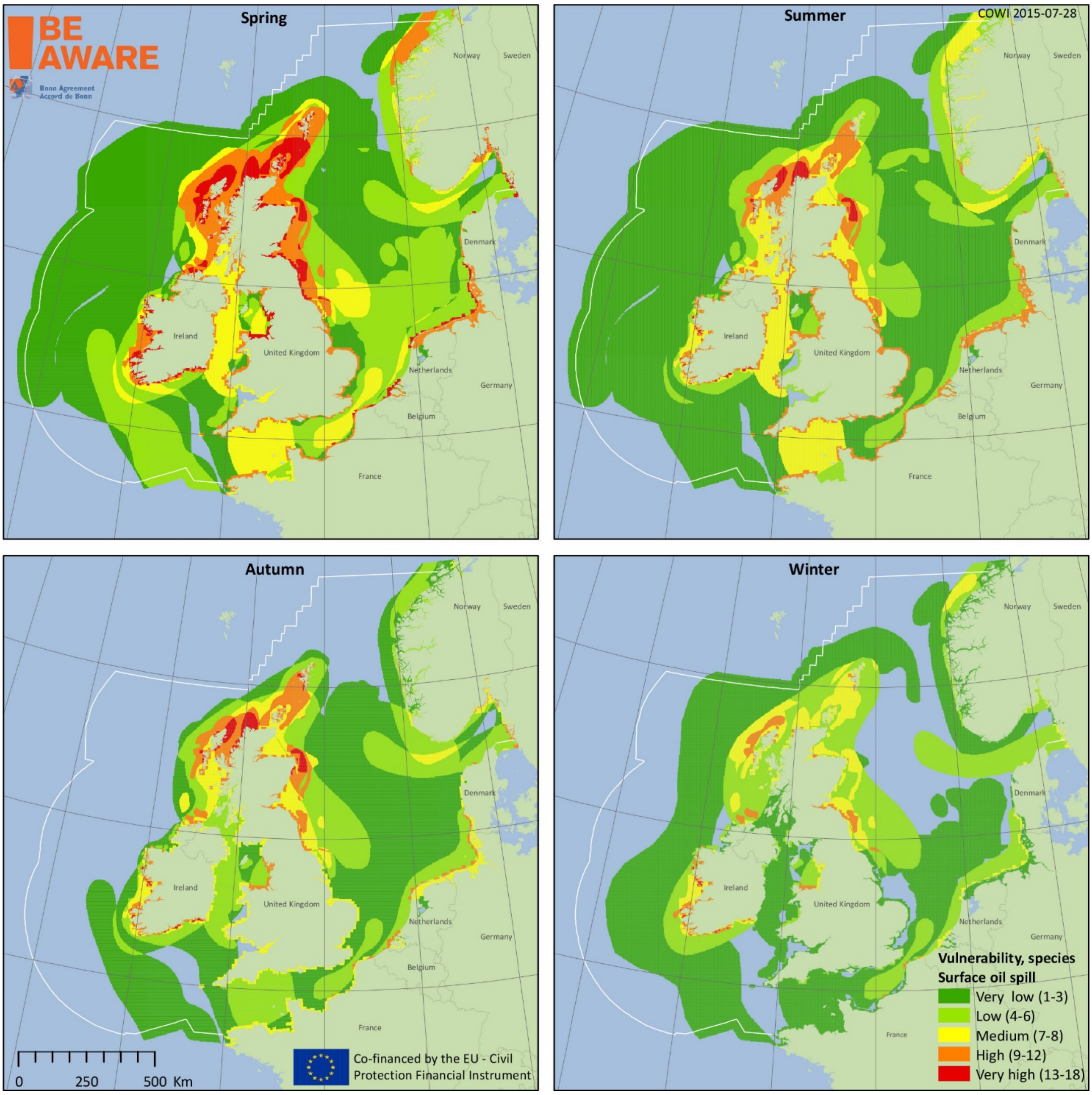

Figure 9-3 Seasonal vulnerability of species to undispersed oil spill.

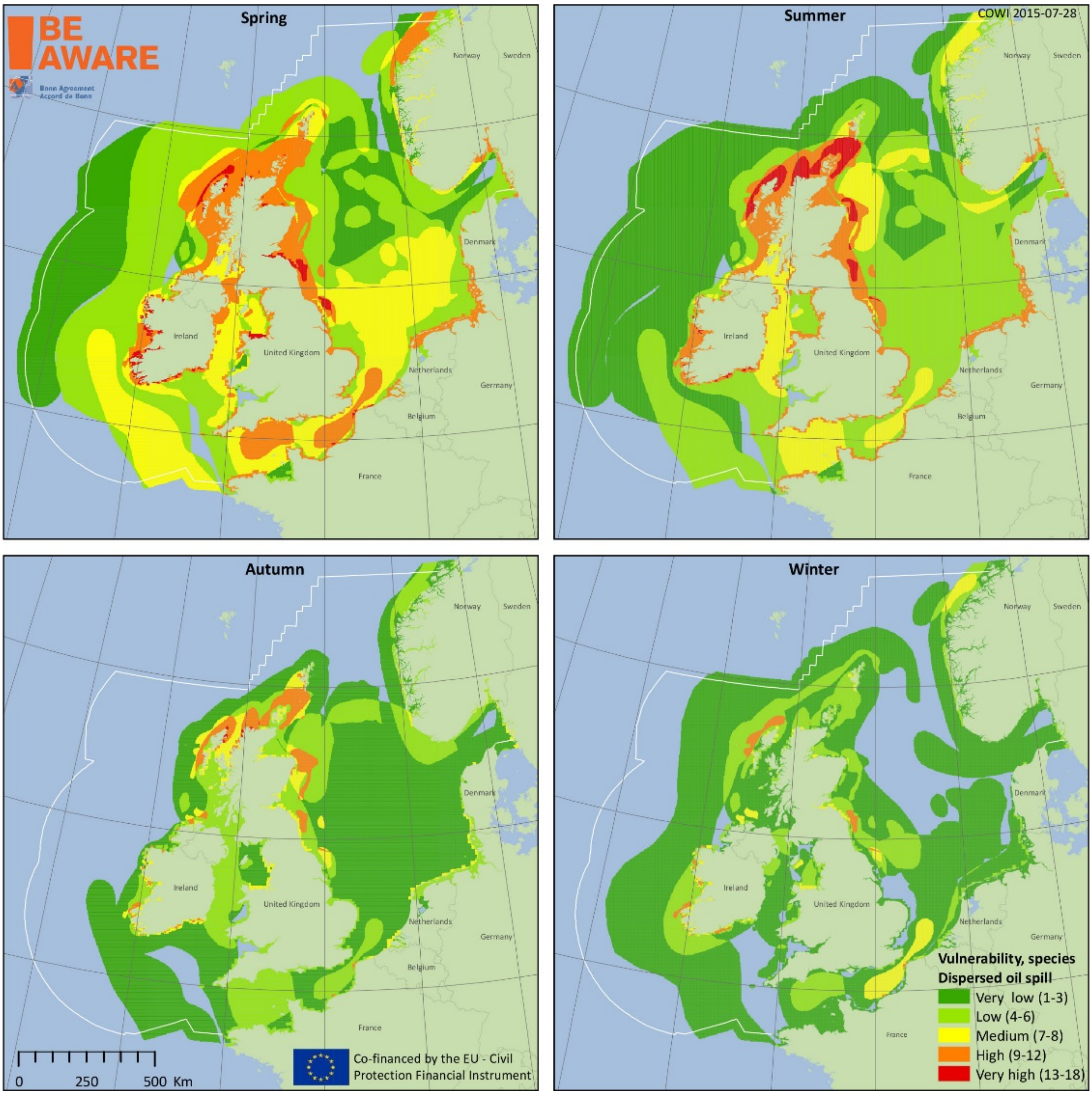

Figure 9-4 **Seasonal vulnerability of species to dispersed oil spill.**

9.3 Vulnerability maps. Socio-economy

9.3.1 Undispersed oil spills

Figure 9-5 shows the maps of seasonal vulnerability of socioeconomic features to undispersed oil spills. It is seen that the Danish, German and Dutch Wadden Sea areas and the Norwegian fiords are the most vulnerable areas and that winter is the least vulnerable season.

9.3.2 Dispersed oil spills

From Figure 9-6 it is seen that the general effect from dispersion of oil is a reduction of impacts, especially in the Danish, German and Dutch Wadden Sea areas and the Norwegian fiords. However, mapping on a regional scale reduces resolution of the data and several vulnerable resources like fish in the fish farms and shellfish in the shellfish farms and the revenue they represent, may not experience reductions in impact but this cannot clearly be seen on regional maps.

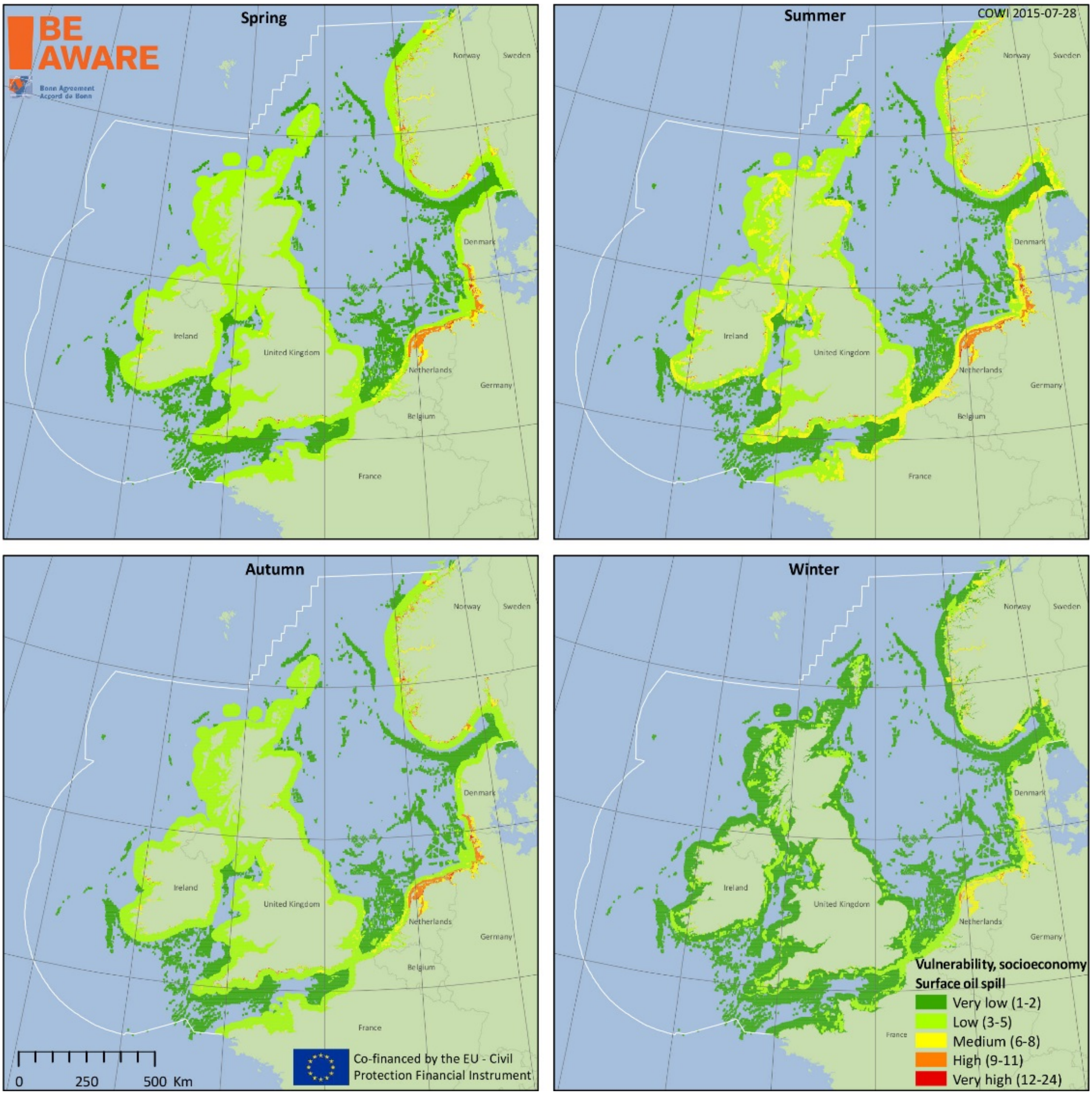

Figure 9-5 **Seasonal vulnerability of socioeconomic features to undispersed oil spill.**

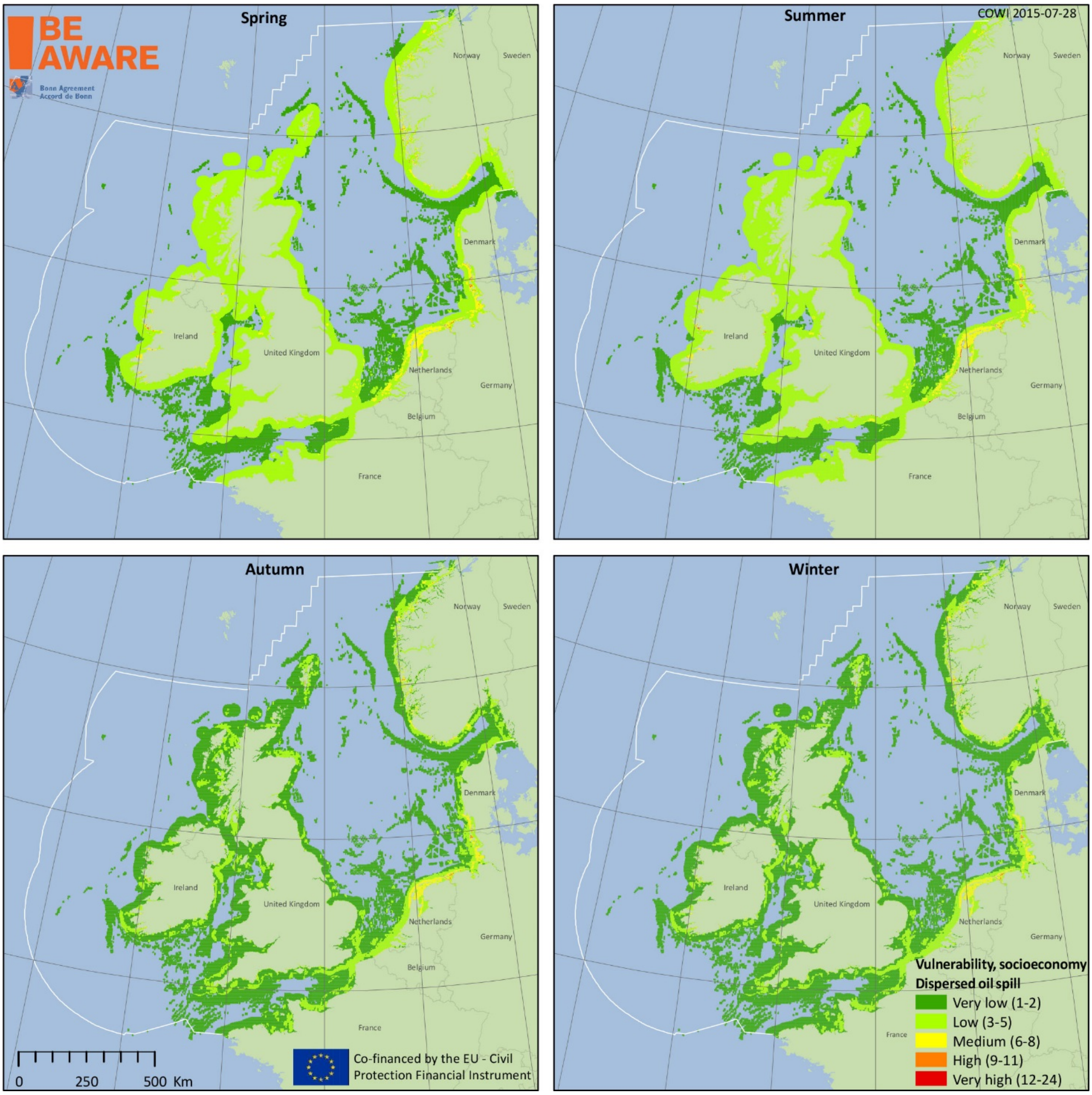

Figure 9-6 **Seasonal vulnerability of socioeconomic features to dispersed oil spill.**

9.4 Vulnerability map. Protected areas

Figure 9-7 shows the vulnerability of protected areas. The vulnerability for each protected area is very high during all seasons for both undispersed and dispersed oil spills. The difference in vulnerability score reflects the number of protected areas at the different sites.

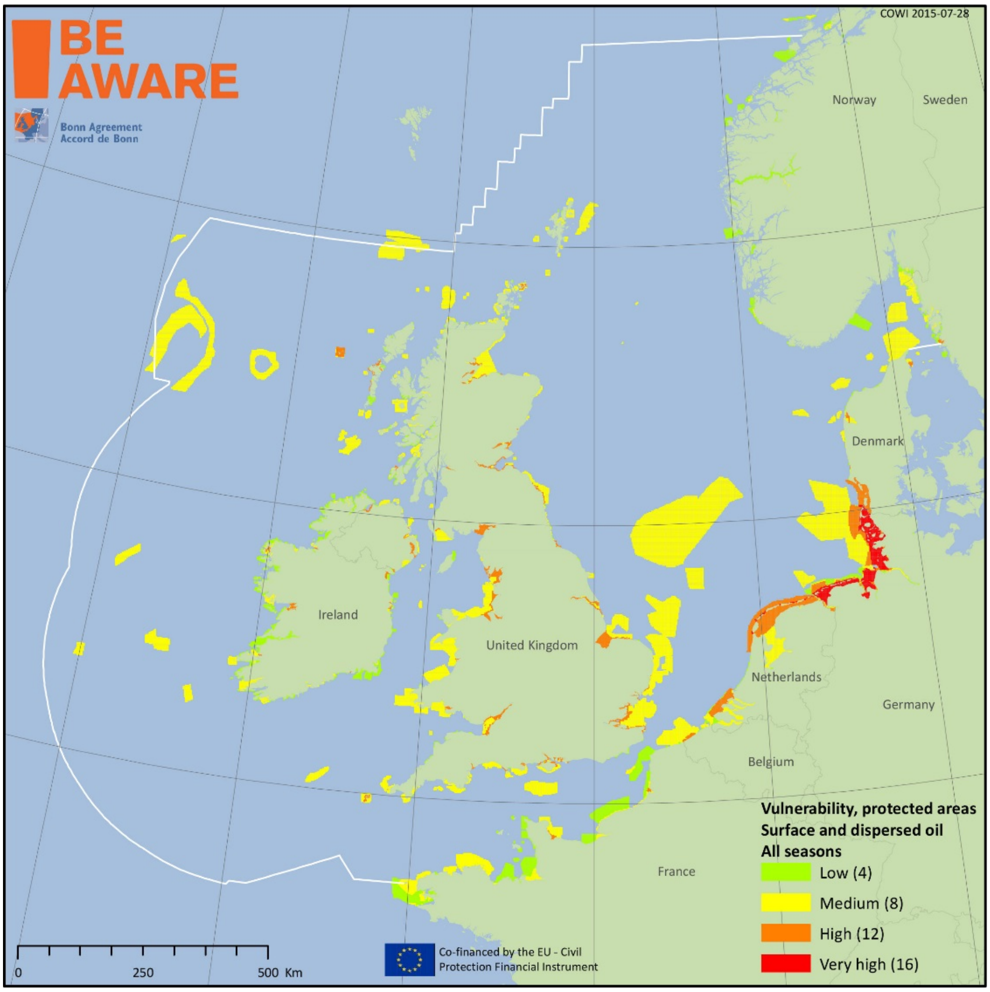

Figure 9-7 **Vulnerability of protected areas to both undispersed and dispersed oil spill.**

9.5 Combined vulnerability maps

This section presents the integrated combined vulnerability maps based on the for four different weighting scenarios using the different weighting ratios of habitat, species and protected areas and socioeconomic features.

Several weighting ratios between the four feature groups were discussed among the project partners during the environmental sensitivity workshop. It was decided to use the four options shown in Table 9-1.

Table 9-1 **Proposed weighting ratios of feature groups.**

Groups	Weighting ratios (%)			
	1	2	3	4
1 Habitats	25	35	15	50
2 Species	25	25	15	10
3 Protected areas	25	30	20	15
4 Socio-economy	25	10	50	25

The first weighting scenario uses equal weight per feature group (25% each). The rationale behind this weighting scenario is that all features are considered equally important.

Weighting scenario 2 is characterised by relatively lower weight on socio-economic features.

Weighting scenarios 3 is characterised by relatively higher weight on socio-economic features.

Weighting scenario 4 characterised by relatively higher weight on habitat features.

Maps of combined vulnerability are prepared using each of the four ratios to assess variations in sensitivity distribution due to weighting.

9.5.1 Combined vulnerability maps. Scenario 1

Figure 9-8 and Figure 9-9 show the combined vulnerability maps for scenario 1 for undispersed and dispersed oil spills, respectively. In scenario 1, the following weightings were applied:

- Habitats: 25%
- Species: 25 %
- Protected areas: 25 %
- Socio-economy: 25 %

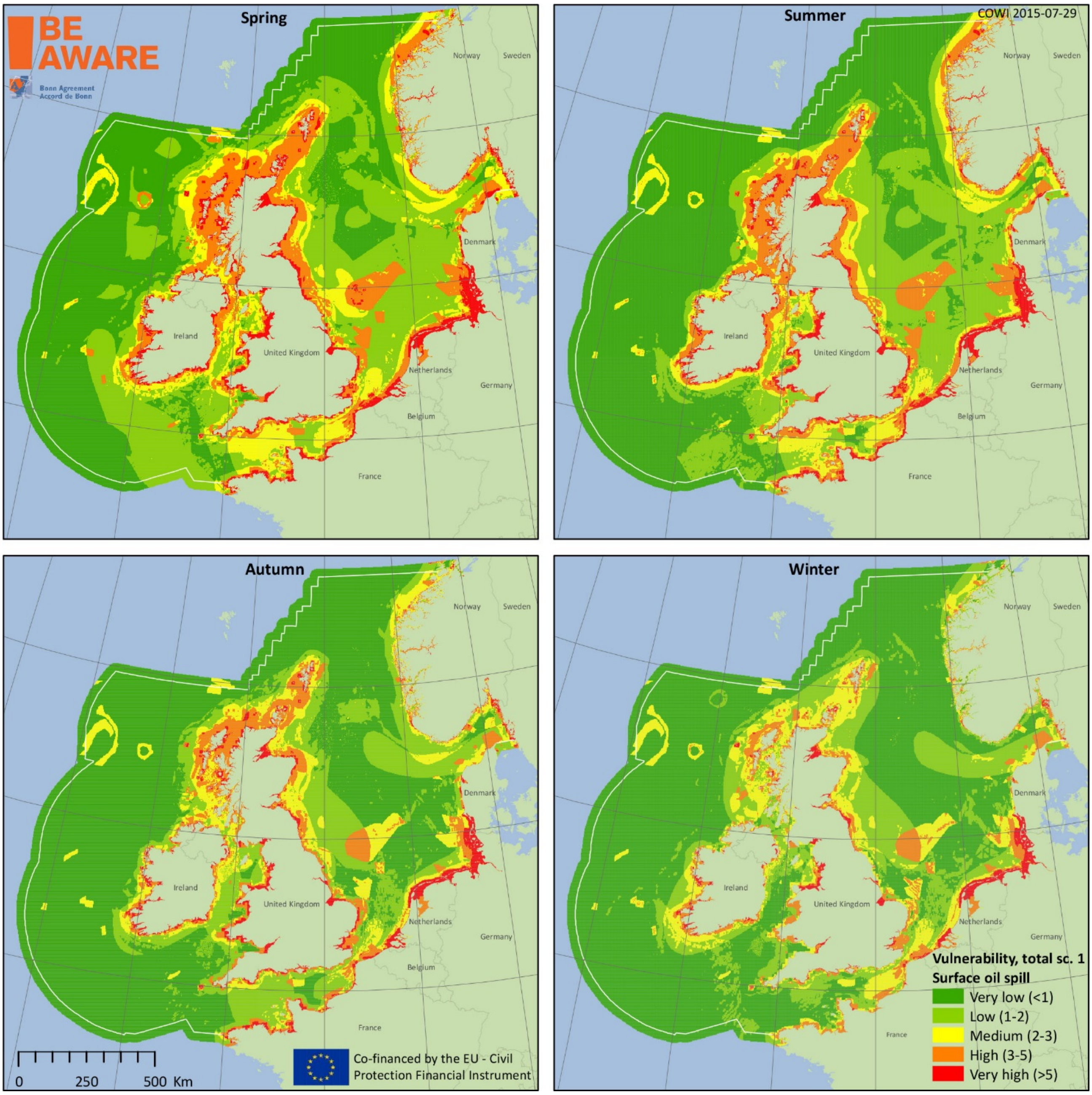

Figure 9-8 **Weighting scenario 1. Combined seasonal vulnerability to undispersed oil spill.**

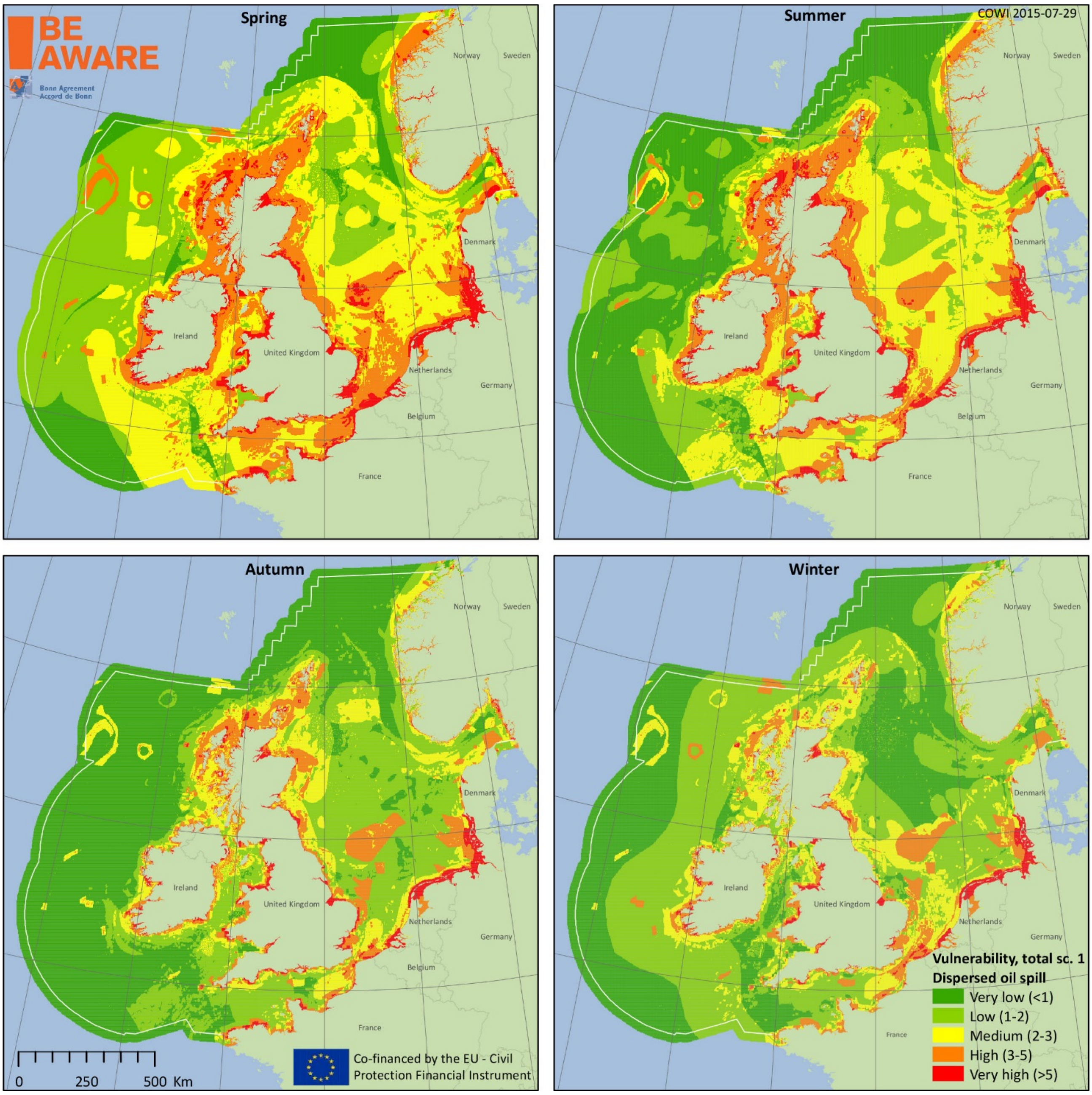

Figure 9-9 **Weighting scenario 1. Combined seasonal vulnerability to <u>dispersed</u> oil spill.**

9.5.2 Combined vulnerability maps. Scenario 2

Figure 9-10 and Figure 9-11 show the combined vulnerability maps for scenario 2 for undispersed and dispersed oil spills, respectively. In scenario 2 the following weightings were applied:

- Habitats: 35%
- Species: 25 %
- Protected areas: 30 %
- Socio-economy: 10 %

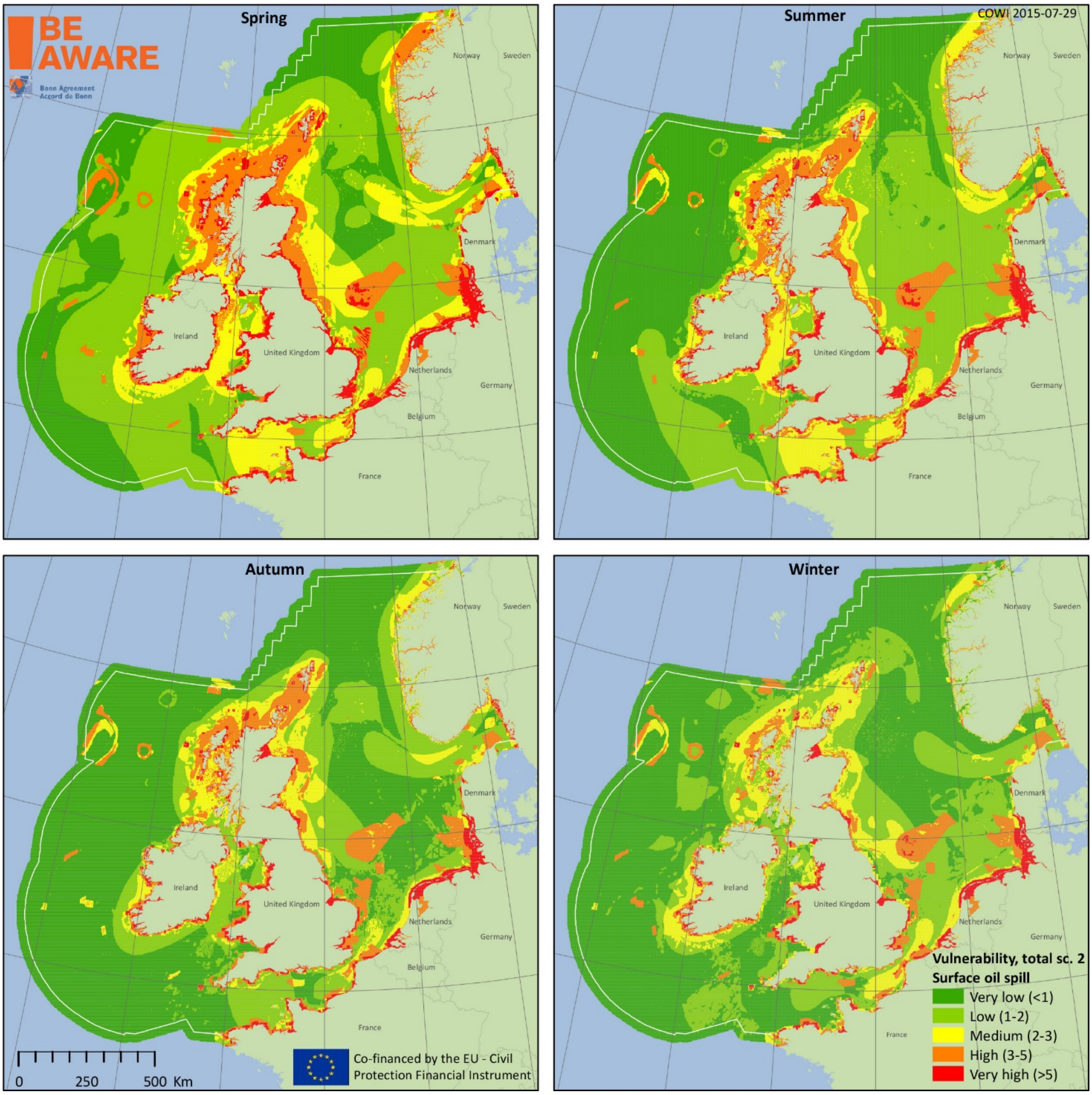

Figure 9-10 Weighting scenario 2. Combined seasonal vulnerability to <u>undispersed</u> oil spill.

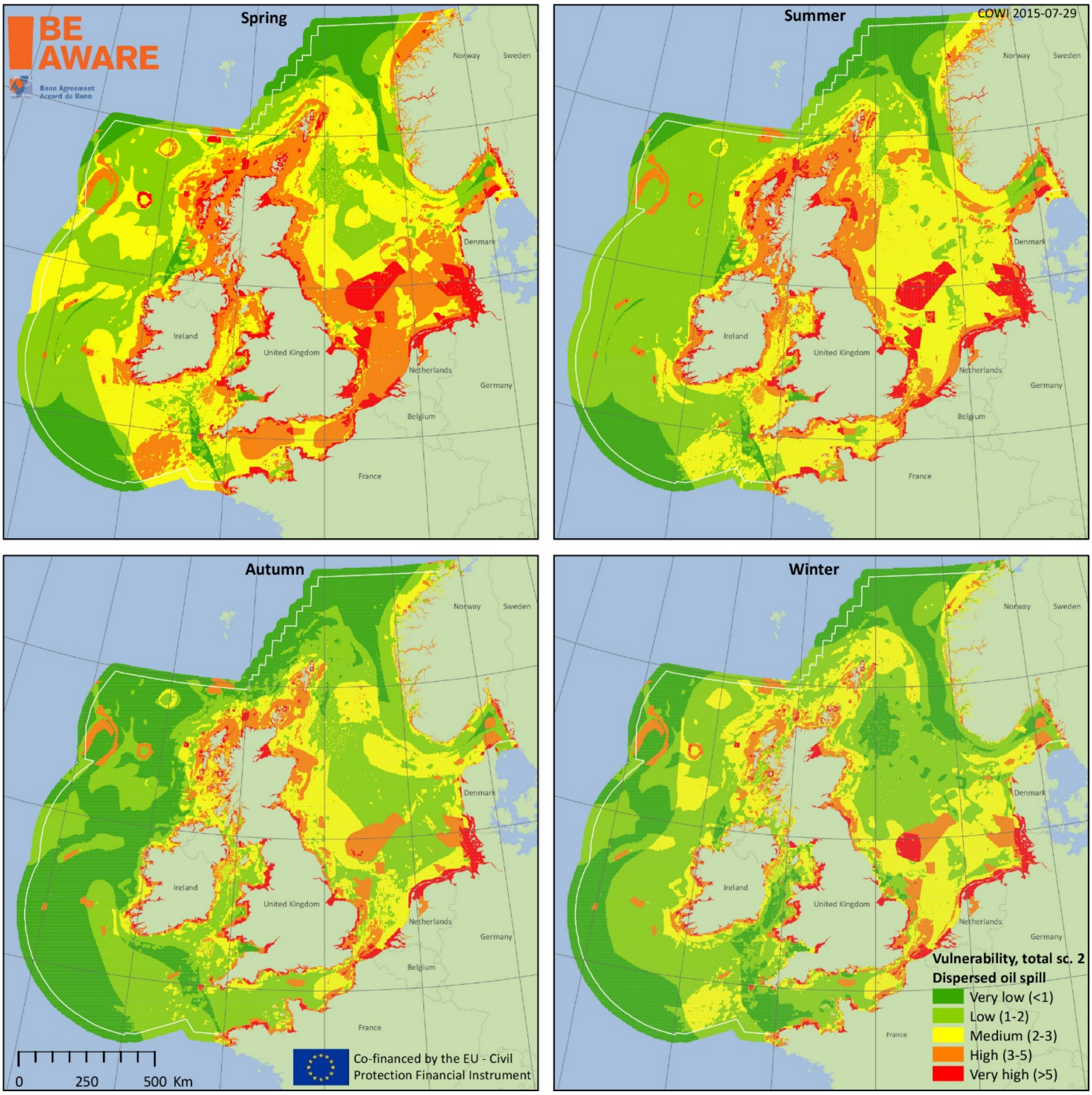

Figure 9-11 **Weighting scenario 2. Combined seasonal vulnerability to dispersed oil spill.**

9.5.3 Combined vulnerability maps. Scenario 3

Figure 9-12 and Figure 9-13 show the combined vulnerability maps for scenario 3 for undispersed and dispersed oil spills, respectively. In scenario 3 the following weightings were applied:

- Habitats: 15%
- Species: 15 %
- Protected areas: 20 %
- Socio-economy: 50 %

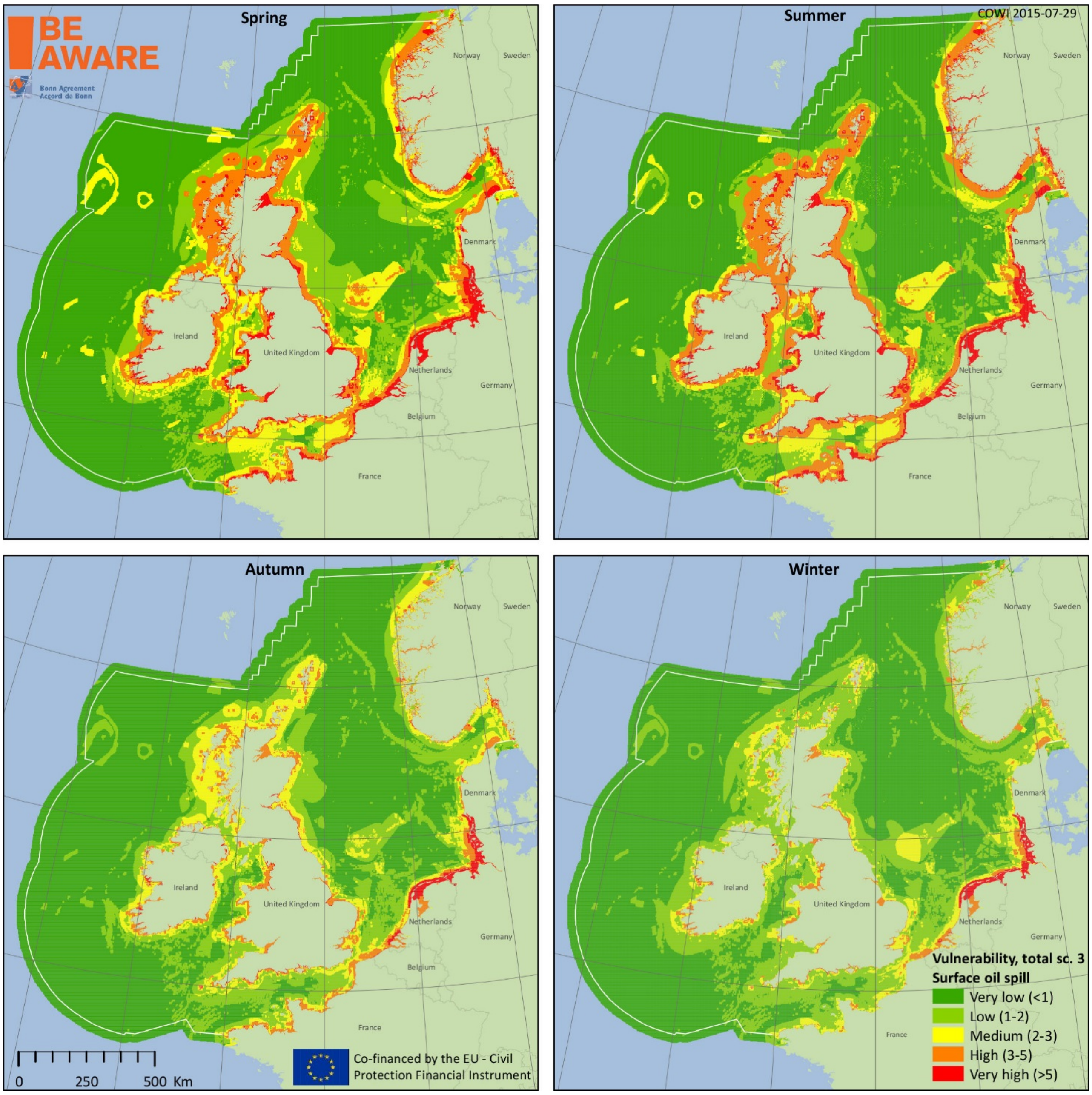

Figure 9-12 **Weighting scenario 3. Combined seasonal vulnerability to <u>undispersed</u> oil spill.**

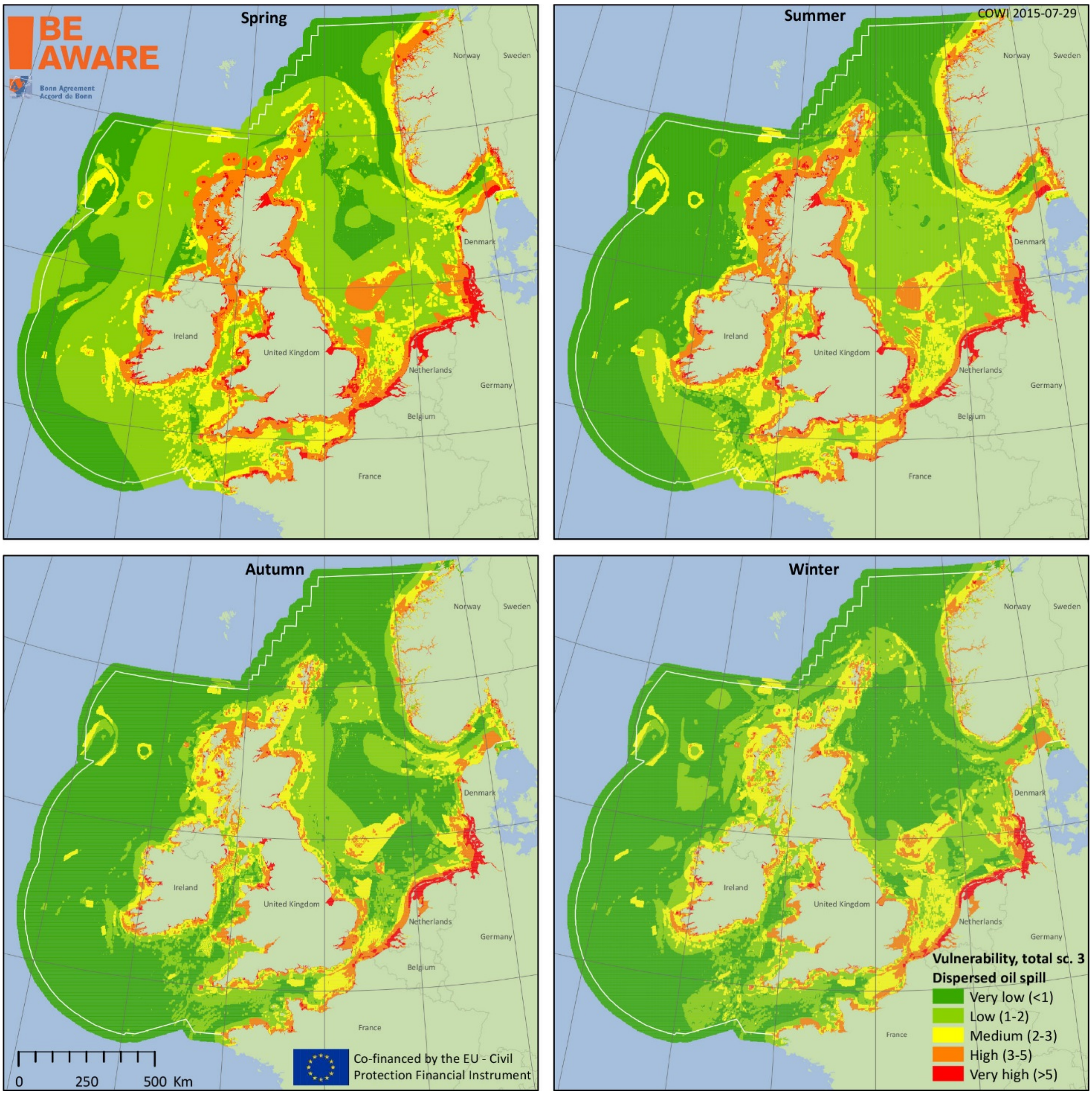

Figure 9-13 **Weighting scenario 3. Combined seasonal vulnerability to dispersed oil spill.**

9.5.4 Combined vulnerability maps. Scenario 4

Figure 9-14 and Figure 9-15 show the combined vulnerability maps for scenario 4 for undispersed and dispersed oil spills, respectively. In scenario 4 the following weightings were applied:

- Habitats: 50%
- Species: 10 %
- Protected areas: 15 %
- Socio-economy: 25 %

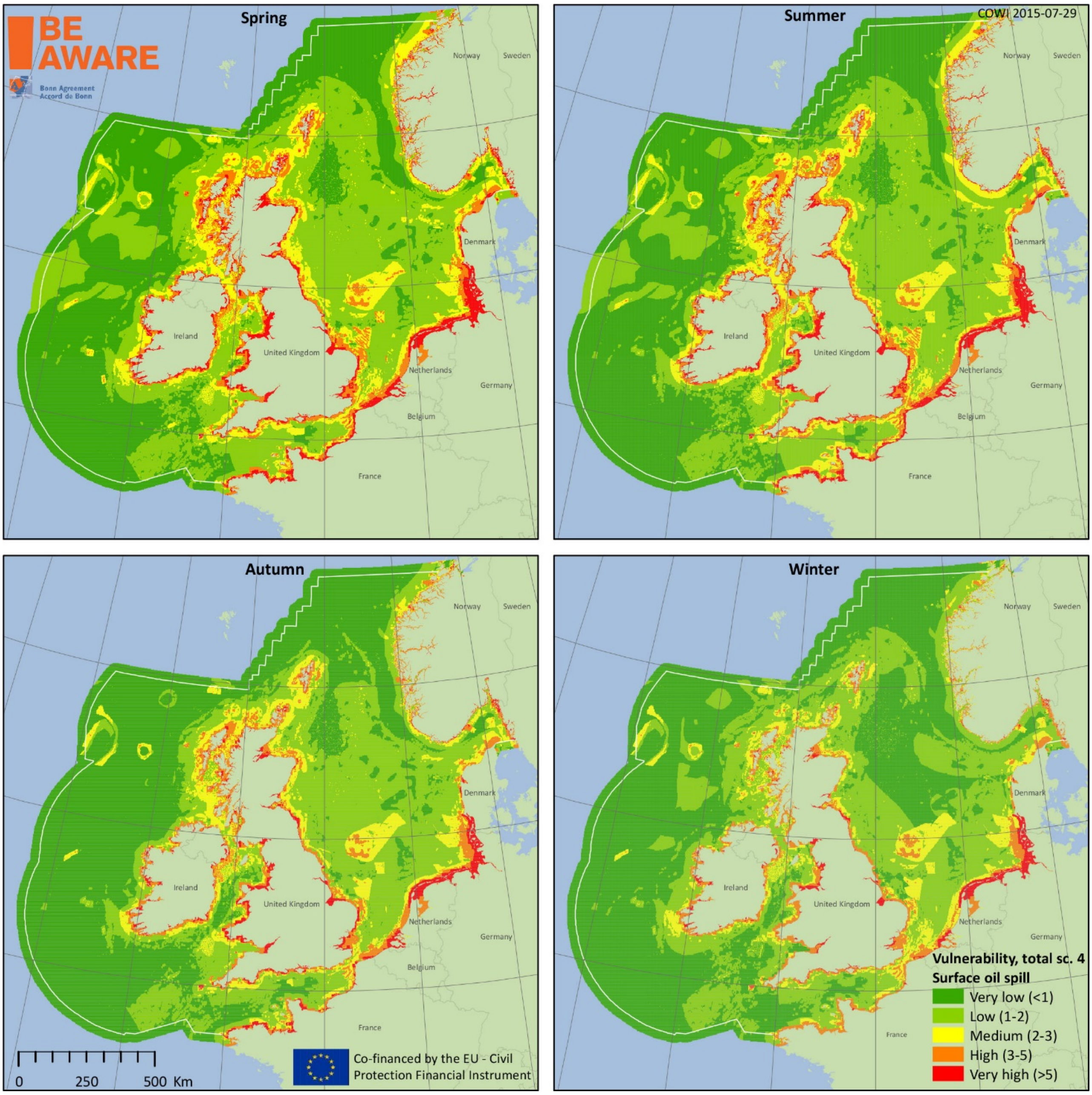

Figure 9-14 **Weighting scenario 4. Combined seasonal vulnerability to undispersed oil spill.**

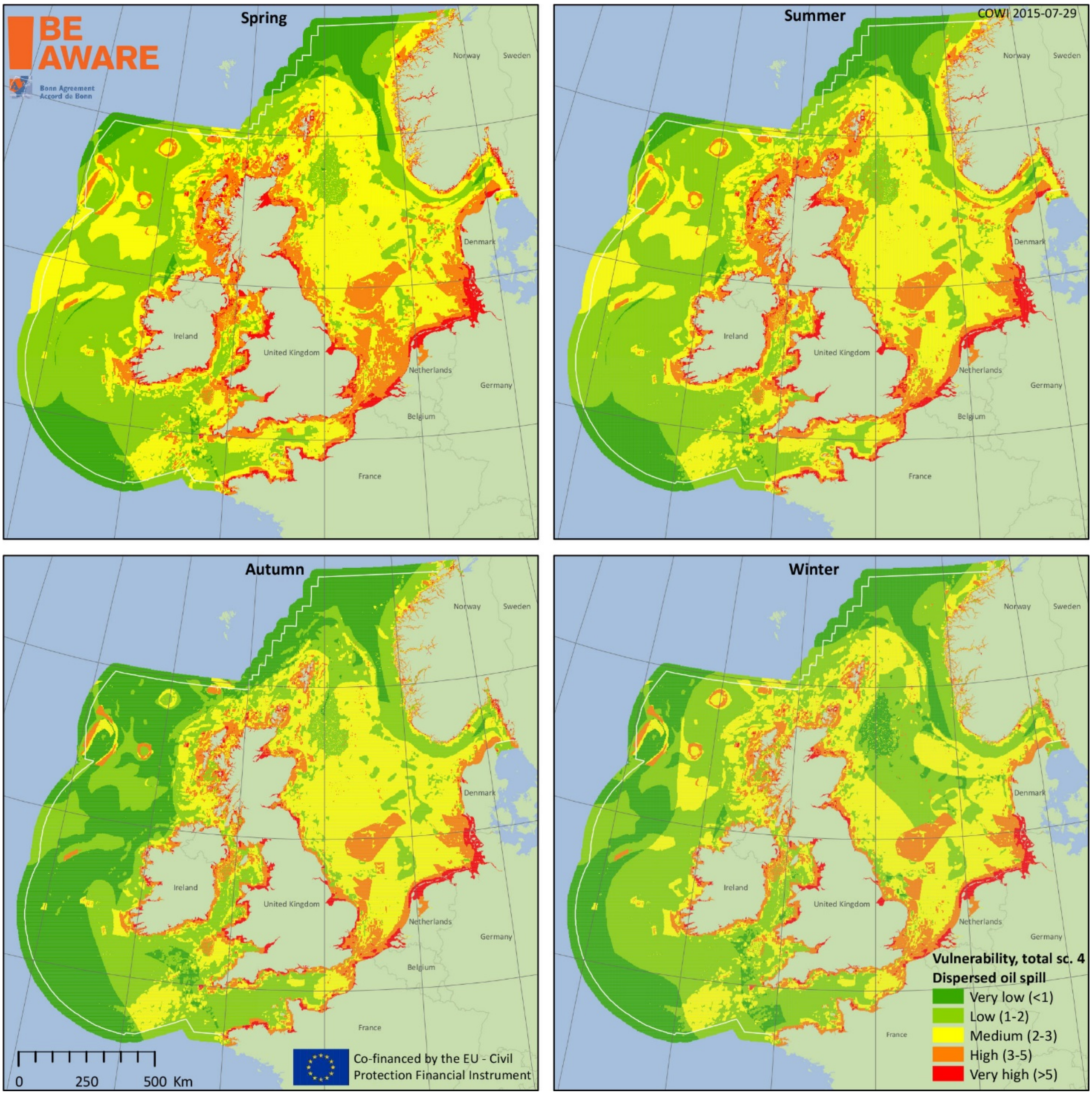

Figure 9-15 **Weighting scenario 4. Combined seasonal vulnerability to dispersed oil spill.**

9.5.5 Maps selected for risk assessment

The vulnerability maps from Scenario 1 were selected for the risk assessment. The major reason for choosing this particular ratio combination was that:

- All feature groups in principle are important
- It was not possible for the group of Contracting Partners nor their respective external experts to provide a quantitative and objective argumentation as to why the concept of equality between the groups of feature should not be used.
- Differences of major consequence where not found between the maps of the different ratio combinations. Therefore, areas with high vulnerability for one specific combination also had high vulnerability for the three other combinations; and visa-versa, areas with particularly low sensitivity for one combination had low vulnerabilities in the maps for the

three other combinations. In other words: "the highs are always the highs and the lows are always the lows". The relative vulnerabilities in the four different cases are found to be approximately uniform.

9.5.6 Combined vulnerability maps.

Figures 9-8 and 9-9 show the combined vulnerability maps for undispersed and dispersed oil spills, respectively.

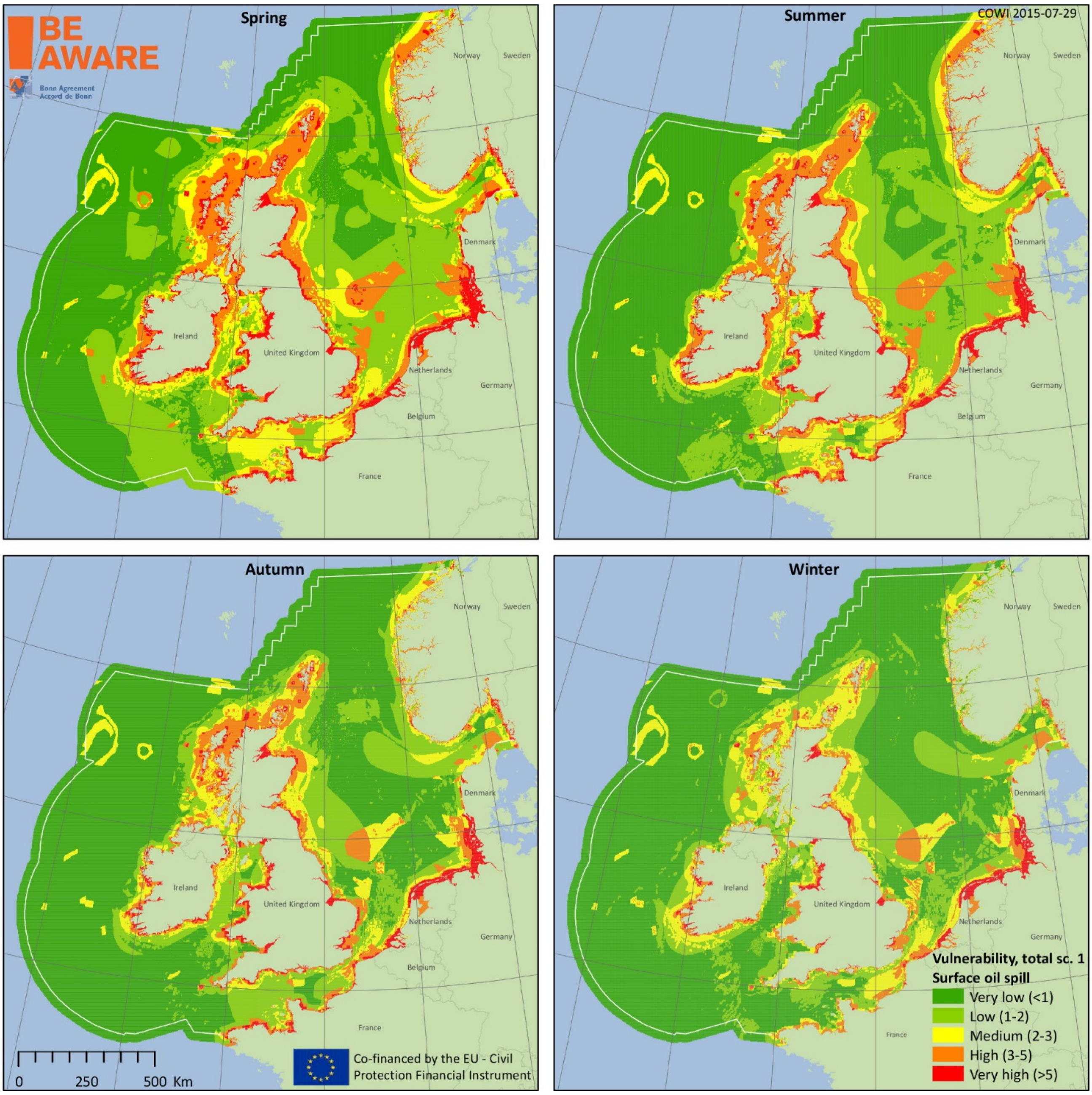

Figure - Combined seasonal vulnerability to undispersed oil spill.

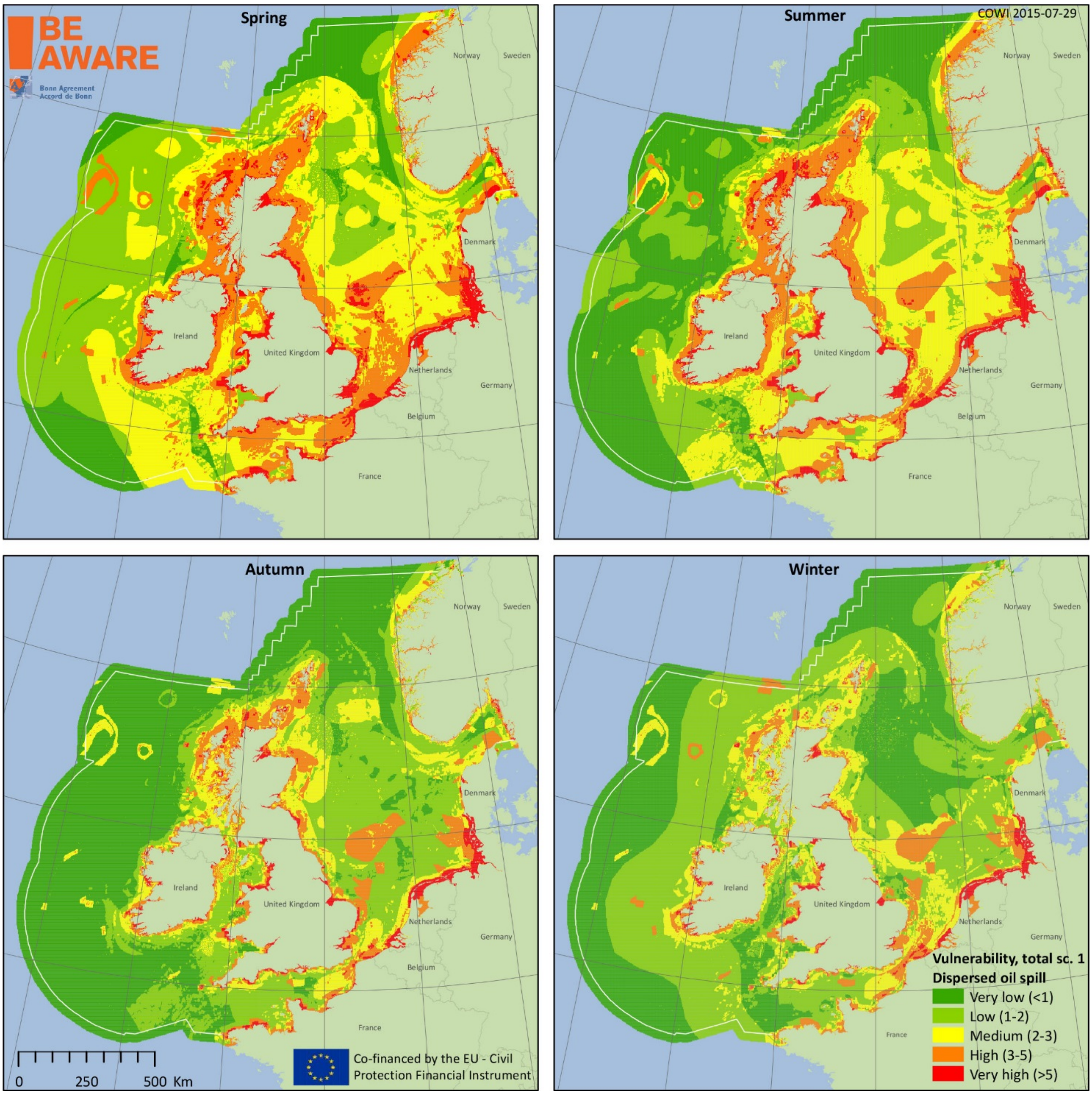

Figure - Combined seasonal vulnerability to dispersed oil spill.

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1. APPENDIX A.

General description of fate of oil in the marine environment and impact of oil on marine organisms.

1.1 Introduction

In this project, the ranking of vulnerability to oil spills of habitats and marine organisms was based on knowledge of the physical and biological character of the different habitats and organisms in terms of vulnerability to oil spill, i.e.

- The fate of oil i.e. the removal and degradation of oil in particular habitats/ environments and
- Potential impacts of oil on organisms and habitats and their recovery
- Effects of dispersants on fate and impacts of oil

This appendix outlines these aspects.

1.2 Fate of oil

The fate of spilled oil in terms of the rate of natural, chemical and physical degradation and removal varies considerably in different types of habitats and is of fundamental significance when classifying the vulnerability of habitats.

1.2.1 Fate of spilled oil in open water

After an oil spill in open water, the oil plume is subject to complex, interrelated physicochemical processes including spreading, evaporation, dispersion, dissolution, emulsification, sedimentation, oxidation and biodegradation all of which ultimately cause degradation and removal of oil components from the water column (Table 1.21 and Figure 1-1).

The processes of spreading, evaporation, dispersion, emulsification and dissolution are most important during the early stages of a spill whilst oxidation, sedimentation and biodegradation are more important later on and determine the ultimate fate of the oil (Figure 2).

Rate and scale of the different processes are dependent on:

- The physical and chemical characteristics of the oil;
- Temperature, wind and currents and
- Whether the oil is spilled beneath or on the surface of the water.

Table 1.21 Processes that affect oil spills at sea.

Spreading
On the sea surface the oil will initially be distributed as a very thin layer over a relatively large area as a single slick due to the weight of the oil. The slick will quickly be spread by wind and currents in narrow bands parallel to the wind and current direction and will cover extensive areas of the sea surface. The oil slick may be broken up into several separate oil slicks because of winds, wave action and water turbulence.
Evaporation
The volatile components of the oil will evaporate to the atmosphere within a short period of time. The rate of evaporation is dependent on temperature, atmospheric pressure and the surface area of the oil film, the rate increasing with increasing temperature, decreasing atmospheric pressure and increasing surface area.
Dispersion

Waves and turbulence can break all or part of the oil slick into fragments and droplets of varying size that will be mixed into the upper layers of the water column. Some of the smaller droplets will remain suspended in the water column while the larger ones will tend to rise back to the surface, where they may either coalesce with other droplets to reform a slick or spread out to form a very thin film.
Dissolution
The lighter water soluble components of the oil, such as light aromatic hydrocarbons compounds like benzene and toluene, may dissolve into the surrounding water but most of these components will evaporate
Emulsification
Due to wave action sea water droplets may become suspended in the oil, forming water-in oil emulsions (often called chocolate mousse), which is usually very viscous and quite persistent.
Oxidation
Hydrocarbons can react chemically with oxygen forming either soluble compounds or persistent tar balls with a solid outer crust surrounding a softer, less weathered interior. Such tar balls are often found on shorelines
Sedimentation
Some heavy refined products or dispersed oil that mix with suspended solids have a higher density than seawater and may sink to the bottom. This process mainly takes place on shallow waters that are often laden with suspended solids providing favourable conditions for sedimentation.
Biodegradation
Seawater contains a range of microorganisms that can degrade oil components into water soluble compounds and eventually into carbon dioxide and water. However, some compounds in oil are very resistant to attack and may not degrade.

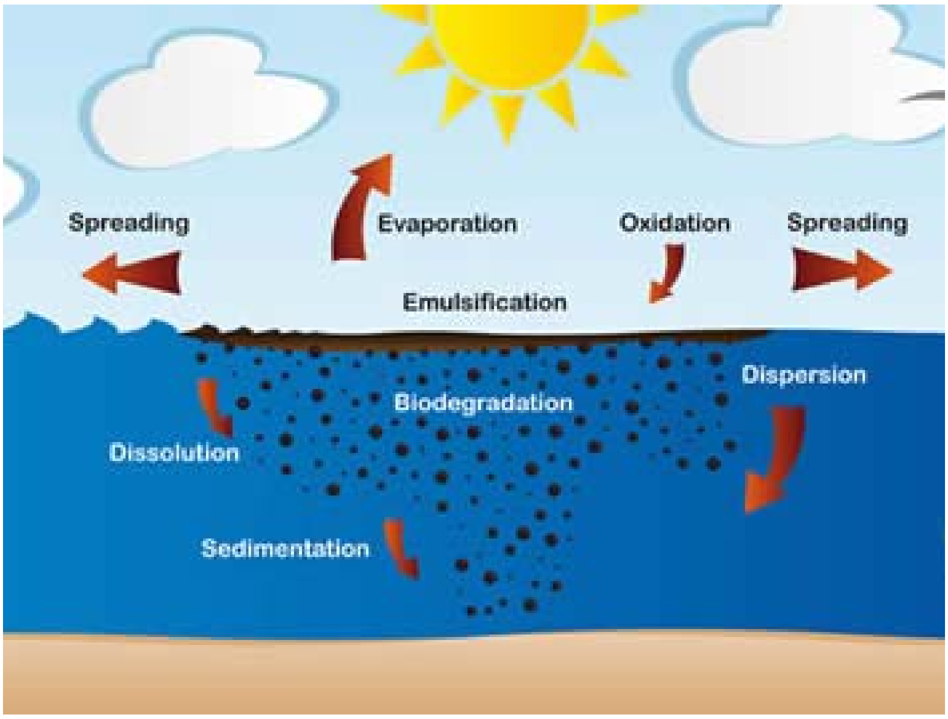

Figure 1-1.2 Processes affecting oil spilled at the surface (Source: ITOPF 2002[1]).

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[1] ITOPF (2002). Fate of Marine Oil Spills. Technical Information paper No. 2 2002.

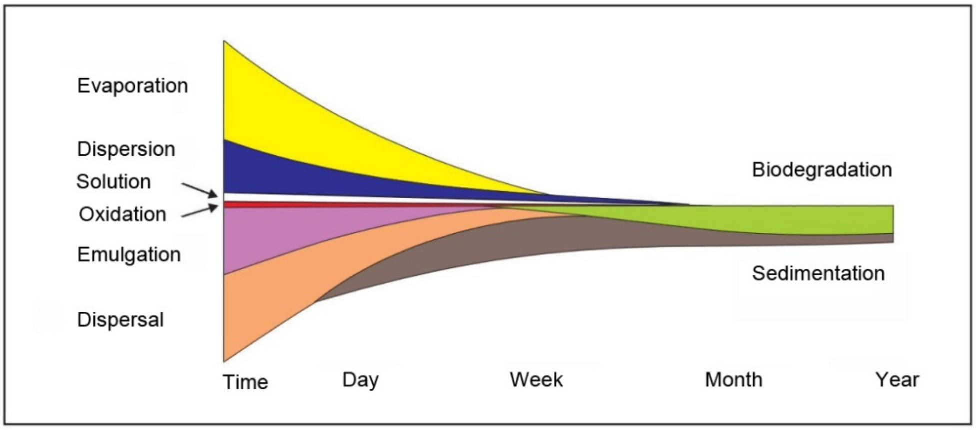

Figure 1.2. **Overview of the relative significance of the different physical and chemical processes that affect spilled oil at sea as a function of time (after ITOPF 2002).**

1.2.2 Fate of oil on the coast

Shorelines, more than any other part of the coastal environment, are exposed to the effects of floating oil. Oil stranded on beaches often gives rise to concern because it may affect a number of ecological and social conditions. Furthermore, the cleaning of oiled beaches may be costly. The vulnerability of shorelines differs considerably with respect to how easy they are to clean up after an oil spill.

In general, environmental impacts of oil spill are most severe if the slick of petroleum hydrocarbons reaches shallow coastal waters and the shore or if the slick passes concentrations of seabirds, which are particularly sensitive to oil spills.

Oil components that have not evaporated, degraded or sunk, during dispersal after the spill will eventually end up on the shore, where they will be further degraded, removed and transformed by natural processes.

The rate of removal and degradation differs significantly by the type of beach. The most important factors affecting the fate of oil stranded on beaches are:

- Relative exposure to wave and tidal energy
- Shoreline slope and
- Substrate type

Table 1.3 outlines the effects of these factors on the fate of oil stranded on beaches.

Table 1.2 **Factors affecting the fate of oil stranded on beaches.**

Effects of Wave and Tidal energy on the fate of oil on beaches
The persistence and natural removal of stranded oil depends much on the expo-sure to waves and tide, i.e.: • Exposure to high wave/tidal energy means rapid removal from the shoreline, usually within days to weeks • Exposure to medium wave/tidal energy means that stranded oil will be removed when the next high-energy event occurs, which could be days to months after spill • Exposure to low wave/tidal energy implies a slow natural removal usually within years
Effects of shoreline slope on the fate of oil on beaches
Shoreline slope is a measure of the steepness of the intertidal zone between maximum high and low tides. It can be characterized as steep (greater than 30 degrees), moderate (between 30 and 5 degrees), or flat (less than 5 degrees). In exposed areas shoreline slopes affect wave reflection and breaking, i.e.: • Steep intertidal areas are subject to abrupt wave run-up and breaking and even reflection enhancing natural clean-up of the shoreline • Flat intertidal areas promote dissipation of wave energy further off-shore, allowing the oil to persist longer in the intertidal zone

Effects of substrate type on the fate of oil on beaches

The type of substrate on the shoreline is significantly affect the fate of stranded oil. The possibility and extent of penetration and burial of oil in the substrate, which in turn affects the natural removal of oil depends on whether the substrate is rock or sediments (mud, fine-medium grained sand, coarse grained sand, granule, pebble, cobble or boulder).

In unconsolidated sediments there is the potential for penetration and/or burial of stranded oil. Penetration and burial increase the persistence of oil because removal by wave action and tidal currents are prevented or hampered and because the natural degradation processes are retarded. Penetration and burial may lead to potential long-term biological impacts and may make clean-up much more difficult and intrusive.

Penetration occurs when oil stranded on the surface sinks into permeable sediments; the depth of penetration is controlled by the grain size of the substrate, as well as the sorting (range of grain sizes in the sediments). Deepest penetration is expected for coarse sediments (gravel) that are uniform in grain size (well-sorted). On gravel beaches, heavy oil accumulations can penetrate up to one metre. If the sediments are poorly sorted, such as on mixed-sand-and gravel beaches, oil usually penetrates less than 50 cm. Sand beaches are also differentiated into grain-size categories (fine- to medium grained versus coarse grained) that differ by permeability and thus potential depths of penetration.
Muddy sediments have the lowest permeability and also tend to be water saturated, so oil penetration is very limited.
Burial occurs when clean sediments are deposited on top of oil layers. The rate of burial can vary widely and can be as short as six hours (one-half of a tidal cycle) after the initial stranding of oil. The most rapid burial usually occurs on coarse-grained sand beaches, because they have the highest mobility under normal conditions
Penetration or burial does not take place on rock.

Furthermore, cleaning of oiled beaches may be costly. The vulnerability of shorelines differs considerably depending on the type of habitat with respect to how easy they are to clean up after an oil spill. Certain beach types may induce impacts on adjacent habitats or human use features if oil stranded on them and other beaches could be severely impacted during clean-up.

Based on the fate of oil on different types of shores, the ease of clean-up and risk of affecting adjacent habitats, the vulnerability of different coastal habitats can be ranked as follows (with increasing vulnerability) (IPIECA, 1996[2]):

- 1) Exposed headlands and wave-cut rocky platforms
- 2) Fine grained sandy beaches
- 3) Beaches of mixed sand and coarser sediments (gravel, pebbles and boulders)
- 4) Beaches of a range of gravel, pebbles and boulders
- 5) Sheltered rocky shores
- 6) Sheltered tidal flats
- 7) Saltmarshes

1.3 Effects of undispersed oil on organisms and populations

In the assessment of the impacts of oil on different habitats and organisms, two important factors have been taken into consideration:

- Effects of oil on the organisms
- Population and life cycle considerations for species encountered in the particular habitat

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[2] IPIECA 1996. Sensitivity mapping for oil spill response. IMO/IPIECA Report Series Volume eight.

The assessments of impacts on different organisms have been based on a literature survey of observed impacts of oil spills in the marine environment.

1.3.1 Effects on organisms

Marine organisms may be affected by oil in several ways:

- As a result of physical contamination (smothering)
- By toxic effects of chemical components and
- By accumulation of substances leading to physiological effects or tainting of meat

Physical smothering by the persistent residues of spilled oils and water-in-oil emulsions is the main threat to marine organisms and habitats. The animals and plants most at risk after an oil spill are those that might be exposed to oil slicks on the sea surface or on the beach such as seabirds, marine mammals, organisms on shorelines and fish and shellfish in aquaculture facilities.

The most toxic components in oil are the volatile components, which are lost rapidly through evaporation when oil is spilt. Therefore, large-scale mortalities of marine organisms due to lethal concentrations of toxic components are relatively rare, localised and short-lived.

Sub-lethal effects that impair the ability of individual marine organisms to reproduce, grow, feed or perform other functions can be caused by prolonged exposure to a concentration of oil or oil components far lower than what will cause death.

Sedentary animals in shallow waters such as oysters, mussels and clams that routinely filter large volumes of sea-water to extract food are especially likely to accumulate oil components. Whilst these components may not cause any immediate harm, their presence may cause such animals to be unpalatable for human consumption, due to the presence of an oily taste or smell. This is a temporary problem since the components causing the taint are lost when normal conditions are restored.

1.3.2 Population and life cycle considerations

The ability of plants and animals to survive and recover from contamination by oil varies significantly. Populations of organisms are most at risk from oil spills when:

- Large numbers of individuals are concentrated in a relatively small area;
- Marine or aquatic species come ashore during special life stages or activities, such as nesting, birthing, resting, or moulting;
- Early life stages or important reproductive activities occur in sheltered, near shore environments where oil tends to accumulate;
- Limited suitable habitats exists within an area for specific life stages or along critical migratory routes;
- Specific areas are known to be vital sources for seed or propagation;
- A species is threatened, endangered, or rare; or
- A significant percentage of the population is likely to be exposed to oil

All these factors have been included in the assessments of the vulnerability of the selected habitats and organisms.

1.4 Effects of dispersants on fate and impacts of oil

Dispersants may be applied to oil slicks in order to prevent or reduce the risk of exposure of oil to organisms encountered on the sea-surface such as seabirds or sensitive coastal habitats.

The dispersants break oil into small droplets, which subsequently disperse in the water column and where they may be more readily biodegraded.

However, while submerging the oil with dispersant may lessen exposure to marine life on the surface, dispersion increases exposure for animals dwelling underwater. Such organisms may be harmed both due to toxicity of dispersed oil and by the dispersant itself (US EPA 2014[3]).

During the Deepwater Horizon oil spill the dispersant Corexit was used in an attempt to reduce the amount of surface oil and mitigate the damage to coastal habitats. In 2012, a study carried out by the Georgia Institute of Technology found that mixing oil with Corexit dispersant increased the toxicity. The study showed that Corexit made the oil up to 52 times more toxic than oil alone and that the dispersant's emulsifying effect makes oil droplets more bio-available to plankton (Martineza et al. 2013[4]).

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[3] US EPA (2014). Dispersants EPA.gov (http://www.epa.gov/bpspill/dispersants html).

[4] Martíneza R.R., T.W Snellb and T. L. Shearer (2013). Synergistic toxicity of Macondo crude oil and dispersant Corexit 9500A® to the Brachionus plicatilis species complex (Rotifera) Environmental Pollution. Volume 173, February 2013, Pages 5–10.