DET NORSKE VERITAS

Technical Report

Navigational Risk Assessment Vesterhav Syd Offshore Wind Farm

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MANAGING RISK

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Summary:

This technical report covers the navigational risk assessment for the Vesterhav Syd Offshore Wind Farm.

A HAZID has been performed and it has been identified that the critical hazards associated with establishing the Vesterhav Syd Offshore Wind farm are ship-wind turbine collision and ship-ship collisions caused by the presence of the wind farm.
A frequency analysis has been performed to evaluate the frequency of ship-wind turbine collisions. The combined return period for ship-wind turbine collision has been estimated to between 62 and 94 years. This is judged to be an acceptable risk and the Danish Maritime Authority agrees on this conclusion. It is not expected that the establishment of the Vesterhav Syd Offshore Wind Farm will cause an increase in the number of ship-ship collisions or groundings.

The Vesterhav Syd Offshore Wind Farm is therefore found to have *minor negative impact* on the navigational safety in the operational phase. The impact has not been evaluated for the installation and decommissioning phase as this is normally part of the appointed contractor's scope of work.

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1 SUMMARY

1.1 English version

Vesterhav Syd Offshore Wind Farm is one of the six sites in Denmark that are subject to pre-investigations prior to the development and production of a total of 450 MW wind power. The Vesterhav Syd Offshore Wind Farm will comprise establishment of a near-shore wind farm, inter-array and export cables as well as cable landfall facilities and substation for connection to the power grid on land. The entire installation phase is assumed to last for a period of approximately 3½ years, from mid 2016 to the end of 2019. The offshore wind farm is expected to be in commission by 2020 and has an anticipated operational time of 25-30 years.
With injunction from the Danish Energy Agency dated January 29th 2013 Energinet.dk is designated to manage and contract the preparation of technical reports as well as environmental impact assessment (EIA) reports. As part of the total EIA for the Vesterhav Syd Offshore Wind Farm project a navigational risk assessment shall be carried out. The scope of present report is to assess the navigational risk associated with establishment of the Vesterhav Syd Offshore Wind Farm.

The overall approach for this navigational risk assessment follows IMOs (international Maritime Organization) guidelines for evaluation of navigational safety assessment. A stepwise approach is adopted meaning that results are presented after each step and it is evaluated together with the Danish Maritime Authority (Søfartsstyrelsen) whether a next step needs to be executed.

Step 1: A frequency analysis based on ship traffic and proposed offshore wind farm layout is executed and results are presented to the Danish Maritime Authority.

Step 2: If the Danish Maritime Authority do not find it possible to conclude from the results of the frequency analysis that the navigational risk is acceptable, a consequence analysis must be completed and combined with the frequency results. The navigational risk assessment will then be updated with the resulting risk derived by combining the frequency and the consequence analyses.

Step 3: If the Danish Maritime Authority cannot approve the estimated risk, possible risk reducing measures have to be identified, analysed and adopted if considered feasible. Such risk reduction must be continued until the risk reaches an acceptable level. Otherwise, it must be concluded that the project is not feasible according to a defined acceptable ship collision risk.

For the present Vesterhav Syd Offshore Wind Farm it is found that Step 1 is sufficient for the risk assessment. This implies that only a frequency analysis is carried out for the present study.
The ship traffic around the proposed area for the Vesterhav Syd Offshore Wind Farm is established based on available AIS data and used as the basis for the navigational risk assessment. The ship traffic in the closest proximity of the Vesterhav Syd Offshore Wind Farm is constituted by the vessels approaching and leaving Hvide Sande Havn. These are observed to be vessels of smaller size (typically less than 5.000 dwt (dead weight tonnage)) like e.g. fishing vessels. Leisure traffic will also be concentrated around Hvide Sande Havn but this traffic is known to be moderate. The largest part of the ship traffic, which also includes the large size vessels such as e.g. tankers, mainly follow north-south going routes that are located far from shore and hence also relatively far from the Vesterhav Syd Offshore Wind Farm.

The HAZID report concludes that the hazards related to navigational risk are all related to the risk of ships colliding with a turbine or ship-ship collision due to the presence of the Offshore Wind Farm. The frequency analysis was performed to estimate the frequency of ship-wind turbine collision for a case where the Vesterhav Syd Offshore Wind Farm is established. A wind farm layout consisting of 66 turbines of 3-MW (200 MW total) has been used as the worst case scenario (scenario that is expected to produce the largest navigational risk) for this evaluation. Since Vesterhav Syd Offshore Wind Farm is located close to Hvide Sande Harbour it is assumed that some of the ship traffic will choose to go through the offshore wind farm after it is established.

The frequency analysis is first performed for a scenario where the entire ship traffic, currently observed in the wind farm area, is assumed to maintain their routes and thus go through the offshore wind farm after it is established. This is a very conservative assumption since it entails that large ship types such as e.g. tankers will go through the offshore wind farm. Such ship types will however not intentionally go through an offshore wind farm. This gives a return period for ship-wind turbine collisions of 34 years for powered collisions (i.e., typical human error), and 341 years for drifting collisions (i.e., typical technical errors). The combined return period for powered and drifting collision is thus estimated to 31 years for this very conservative scenario. When only the smaller vessels (<1000 dwt) are assumed to continue passing through the offshore wind farm the combined return period of collisions increases to 62 years, and when no traffic is assumed to intentionally pass through the offshore wind farm the combined return period increases further to 94 years. The largest contribution to the collision frequency is from vessels that carry out dredging activities within the contours of the offshore wind farm. The estimated collision frequency from this is considered to constitute a conservative estimate. Reducing this contribution will increase the total estimated collision return periods of 62 - 94 years significantly.

The risk of ship-ship collision and grounding around the offshore wind farm area is found to be very low under existing conditions. The change in ship-ship collision risk due to increased traffic density and the increase of grounding incidents is evaluated to be insignificant since none of the ship routes with heavy traffic are affected by the presence of the Offshore Wind Farm.

Based on these evaluations it is judged not to be necessary to perform a consequence analysis (Step 2) and, hence, neither to perform a detailed evaluation of risk reducing measures (Step 3). The conclusions from the frequency analysis (Step 1) indicate that the occurrence of ship-turbine collisions will be low and hence the increase in navigational risk due to establishment of the Vesterhav Syd Offshore Wind Farm is acceptable. This conclusion has also been accepted by the Danish Maritime Authority.

For the operational phase the impact from the Vesterhav Syd Offshore Wind Farm on the Navigational risk is therefore judged to be *minor negative impact* for both ship-wind turbine collision, ship-ship collision and grounding incident according to the severity definitions given in Appendix 3.

The impact on the navigational risk during the installation and decommissioning phases has not been evaluated since there are still too many unknown parameters to complete this analysis. The risk assessment for the installation and decommissioning would normally be part of the scope of work for the appointed contractor.

1.2 Dansk version

Vesterhav Syd Havmøllepark er en af seks lokaliteter i Danmark, som indgår i forundersøgelser forud for udvikling og opstilling af 450 MW vindkraft. Vesterhav Syd Havmøllepark omfatter etableringen af en kystnær havmøllepark, inter-array og eksport kabler såvel som faciliteter til iland føring samt substation for forbindelse til el nettet på land. Den samlede installationsfase anslås til at ville vare omkring 3½ år fra midten af 2016 til udgangen af 2019. Havmølleparken forventes at være i drift i 2020 med en forventet levetid på 25-30 år.
Ifølge et påbud fra Energistyrelsen fra 29. januar 2013 er Energinet.dk udpeget til at administrere og kontrahere forberedelsen af tekniske rapporter samt miljøvurderingsrapporter (VVM). Den samlede miljøvurdering for Vesterhav Syd Havmøllepark projektet indbefatter udarbejdelsen af en sejladsrisikovurdering. Formålet med nærværende rapport er således at vurdere den risiko for skibstrafikken der kunne opstå ved etablering af Vesterhav Syd Havmøllepark.

Denne sejladsrisikovurdering følger IMOs (International Maritime Organization) retningslinjer hvad angår vurdering af sejladssikkerhed. Der benyttes en trinvis tilgang, således at resultaterne udarbejdes, vurderes og præsenteres trin for trin. Efter hvert trin vurderes det i samarbejde med Søfartsstyrelsen, om grundlaget er tilstrækkeligt til at kunne træffe en endelig konklusion eller om det næste trin skal igangsættes.

Trin 1: Der udarbejdes en frekvensanalyse baseret på skibstrafikken i forhold til den kommende vindfarms foreslåede placering. Resultaterne forelægges for Søfartsstyrelsen.

Trin 2: Såfremt Søfartsstyrelsen ikke er i stand til, på baggrund af resultaterne af frekvensanalysen, at konkludere at de sejladsmæssige risici er acceptable, skal der udarbejdes en konsekvensanalyse, som i kombination med frekvensanalysen giver et mere konkret billede af risikoen.

Trin 3: Såfremt Søfartsstyrelsen ikke kan godkende det udarbejdede anslåede risikobillede, skal der foretages en identifikation af mulige risikoreducerende tiltag. Effekten af de foreslåede tiltag skal vurderes kvantitativt og de tiltag, der vurderes dels at have en tilstrækkelig betydelig effekt og samtidig vurderes at være realistisk gennemførlige, skal indarbejdes i projektet. Denne risikoreduktion fortsættes, indtil den samlede risiko når et acceptabelt niveau. Konklusionen kan også blive, at projektet ikke er realiserbart, såfremt der skal implementeres uforholdsmæssigt mange risikoreducerende tiltag for at opnå et acceptabelt risikoniveau for sejladssikkerheden.

For Vesterhav Syd Havmøllepark viste det sig, at trin 1 var tilstrækkeligt. Således blev der kun udarbejdet en frekvensanalyse.
Skibstrafikken omkring Vesterhav Syd Havmøllepark er blevet fastlagt på basis af AIS data, og denne trafikbeskrivelse har dannet grundlag for risikovurdering af sejladssikkerheden.
Skibstrafikken tæt på Vesterhav Syd Havmøllepark udgøres af skibe der ankommer og forlader Hvide Sande Havn. Dette er observeret at være fartøjer af mindre størrelse (typisk mindre en 5.000 dwt (dead weight tonnage)) som f.eks. fiskefartøjer. Lystsejlere vil også være koncentreret omkring Hvide Sande Havn men denne trafik vides at være moderat. Den største del af skibstrafikken, som også inkluderer fartøjer af stor størrelse som f.eks. tank skibe, følger hovedsageligt nord-syd gående ruter placeret langt fra kysten og derved også relativt langt fra Vesterhav Syd Havmøllepark.

En HAZID konkluderede, at risici relateret til sejladssikkerhed alle var knyttet til risikoen for kollisioner mellem skib og havmølle eller skib-skib kollisioner forårsaget af havmølleparkens tilstedeværelse. Frekvensanalysen havde til formål at estimere frekvensen for kollisioner mellem skibe og havmøllerne i Vesterhav Syd Havmøllepark. For at indarbejde det værst tænkelige scenarie i analysen benyttedes et layout bestående af 66 3MW havmøller (200 MW totalt). Da Vesterhav Syd Havmøllepark er placeret tæt på Hvide Sande Havn antages det at noget skibstrafik vil passere gennem havmølleparken.

Frekvensanalysen blev først udført for et scenarie hvor al eksisterende skibstrafik i havmølleparkens område antages at bibeholde deres ruter og derved passere gennem havmølleparken efter denne er etableret. Dette er en meget konservativ antagelse idet det medfører at store skibstyper så som tankskibe vil passere gennem havmølleparken. Sådanne skibstyper vil normalt ikke tilsigte at passere gennem en havmøllepark. Dette giver en kollisionsfrekvens mellem skib og havmølle på 34 år for direkte påsejling (dvs. typisk menneskelig fejl) og 341 år for drivende skibe (dvs. typisk teknisk fejl). Den kombinerede frekvens for direkte påsejling og drivende skib er 31 år for dette eget konservative tilfælde. Når kun mindre skibe (<1000 dwt) antages at passere igennem havmølleparken stiger den kombinerede returperiode til 62 år, og når ingen skibstrafik antages at passere igennem havmølleparken stiger den kombinerede retur-periode yderligere til 94 år. Det største bidrag kommer fra råstofindvinding som foregår tæt ved havmølleparken. Den estimerede kollisions frekvens fra dette betragtes som værende et konservativt estimat. En reduktion af dette bidrag vil forøge den totale estimerede kollisions retur periode på 62 – 94 år betydeligt.
Risikoen for skib-skib kollision samt grundstødning omkring havmølleparkens område er fundet værende meget lav for de nuværende forhold. Ændringen i risiko for skib-skib kollision og forøgelse af grundstødninger pga. Vesterhav Syd Havmøllepark er vurderet til at være marginal.

På baggrund af disse konklusioner vurderes det ikke at være nødvendigt at foretage en konsekvens analyse (trin 2) eller en detaljeret evaluering af risikoreducerende tiltag (trin 3). Konklusionerne fra frekvensanalysen (trin 1) har godtgjort, at risiko relateret til sejladssikkerhed ved etableringen af Vesterhav Syd Havmøllepark er acceptabel. Denne konklusion er blevet accepteret af Søfartsstyrelsen.
Med udgangspunkt i ovenstående resultater og vurderinger klassificeres Vesterhav Syd Havmøllepark at have en *mindre negativ påvirkning* (minor negative impact) på sejladssikkerheden i henhold til definitionerne i Appendix 3.
Påvirkningen af sejladssikkerheden for installation og nedlukning faserne er ikke evalueret da for mange faktorer er ukendte for disse faser. Risikovurdering og risikostyring for disse faser vil normalt være en del af den valgte entreprenørs arbejde.

2 INTRODUCTION

On March 22nd 2012 a broad political majority of the Danish Parliament agreed on the energy policy for the period 2012-2020. Establishment of 450 MW near-shore wind farms will ensure fulfilment of part of the agreement and conversion to a green energy supply in Denmark by 2020. On November 28th 2012 the Danish government pointed out six sites around Denmark, which are subject to pre-investigations prior to the development and production of a total of 450 MW wind power, including submarine cables and cable landfall. The selected sites are Bornholm, Smålandsfarvandet, Sejerø Bugt, Sæby, Vesterhav Syd and Vesterhav Nord. The Danish Energy

Agency is responsible for the procurement of the 450 MW wind power for the six nearshore wind farm areas.

With injunction from the Danish Energy Agency dated January 29th 2013 Energinet.dk is designated to manage and contract the preparation of technical reports, appropriate assessment as well as environmental impact assessment (EIA) reports, including appurtenant plan documents and an environmental statement for the selected six sites. The work will include assessments of the structures and the installation of these, both at sea and on land.
The present report deals with Vesterhav Syd Offshore Wind Farm and the associated navigational risk assessment.

2.1 Objectives

The objective of the present navigational risk assessment is to evaluate how and to what extend the ship traffic in the area will be influenced by the Vesterhav Syd Offshore Wind Farm and to identify and estimate any associated increase in the navigational risk in the region near the wind farm.

3 PROJECT DESCRIPTION

Vesterhav Syd Offshore Wind Farm comprises the establishment of a nearshore wind farm, inter-array and export cables as well as cable landfall facilities includ-ing cable termination station (and additional substations) for connection to the power grid on land.

The entire installation phase is assumed to last for a time period of approx. 3½ years, from mid 2016 to the end of 2019. The offshore wind farm is expected to be in commission by 2020 with an expected operation time of 25-30 years.
The entire survey area is shown in Figure 1. A nautical chart of the area around the survey area is included in Appendix 4.

Figure 1. Survey area of the wind farm Vesterhav Syd Offshore Wind Farm.

3.1 Installations offshore

Vesterhav Syd Offshore Wind Farm will be located within an approx. 60 km^2 survey area, which covers an area, situated 4 – 10 km off the coast northwest of Hvide Sande. Water depths in the area vary between 15 and 25 m. The offshore wind farm will possibly be established with a maximum capacity of 200 MW and will possibly take up an area of 44 km^2 within the survey area.

Facts about the project offshore

Capacity
Max. 200 MW

Turbine sizes
The size of the turbines may vary between 3 and 10 MW. Impact assessments are applied to the turbine size that is most critical regarding individual environmental factors.

Turbine capacity	Rotor diameter	Total height	Hub height	Max. number
3 MW	112 m	137 m	81 m	66 stk.
10 MW	190 m	220 m	125 m	20 stk.

The export cables from the wind farm to the mainland may be installed in two 500 m broad corridors, running from the northern part of the wind farm to the coast near Klegod and Tyvmose, both sites located north of Hvide Sande.
A description of the project and construction methods for the installations off-shore is presented in a separate report (Energinet.dk, 2015).

3.2 Wind farm layout

The possible positions for the 3 MW and 10 MW turbines within the offshore wind farm area are presented in Figure 2. It is noted that no offshore substation will be installed.

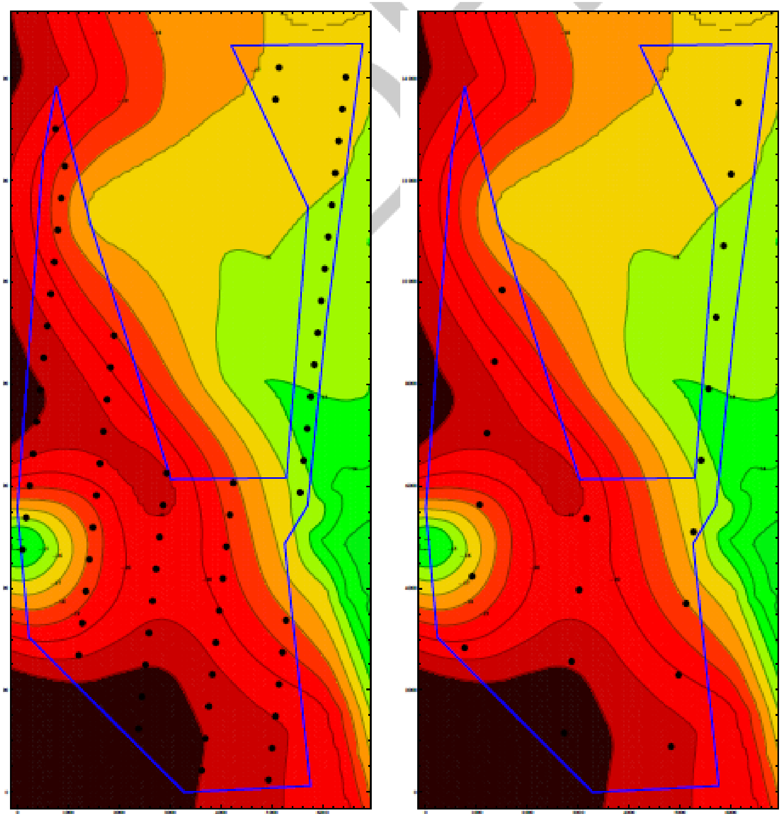

Figure 2. Possible positions for 3 MW turbines (left) and 10 MW turbines (right). Taken from report (DTU, February 2014).

4 BACKGROUND

The navigational risk assessment presented in the present report is part of the total EIA for the Vesterhav Syd Offshore Wind Farm project.
The overall approach for this navigational risk assessment follows IMOs (international Maritime Organization) guidelines for evaluation of navigational safety assessment. A stepwise approach is adopted meaning that results are presented after each step and evaluated together with the Danish Maritime Authority (Søfartsstyrelsen) whether next step needs to be executed.

Step 1: A frequency analysis based on ship traffic and proposed offshore wind farm layout is executed and results are presented to the Danish Maritime Authority.

Step 2: If the Danish Maritime Authority does not find it possible to conclude from the results of the frequency analysis that the navigational risks will be acceptable, a consequence analysis must be executed and combined with the frequency results. The navigational risk assessment will then be updated with the resulting risk derived by combining the frequency and the consequence analyses.

Step 3: If the Danish Maritime Authority cannot approve the estimated risk, possible risk reducing measures have to be identified, analyzed and adopted if considered feasible. This risk reduction process must continue until the risk reaches an acceptable level. Otherwise it has to be concluded that the project will not be feasible when required to be associated with an acceptable ship collision risk.

The basis for the evaluation covered in Step 1 (The frequency analysis) is described in the following subsections. The objective of Step 1 is to estimate the frequency of ship collisions with the wind turbines and this is performed based on a worst case layout of the offshore wind farm. The results are initially used to assess if the risk associated with collisions can be concluded acceptable without quantifying the consequences of these collisions. This would be the case if the frequencies are so low that the associated risks would be acceptable even with the most conservative assessment of the consequences. If this is not the case Step 2 (The consequence analysis) has to be carried out.

4.1 Method

The following describes the method for performing Step 1, - the frequency analysis.
The frequency analysis is based on acknowledged mathematical models typically used for such analyses and with input based on historical (statistical) data. The applied calculation tool MARCS is described in Appendix 2.
A description of the ship traffic constitutes the central input for a navigational risk assessment. Automatic Identification System (AIS) data provides a detailed geographic and temporal description of the ship traffic in a region and has been used as the primary data basis. Because the predominant part of the ship traffic is following routes – which can be more or less well defined – the modelling of the ship traffic and the associated models of the risk of collisions and groundings usually adopts a route based description of the traffic. Besides giving an intuitive and simple modelling the route based description also makes it easy to implement anticipated changes to the ship traffic pattern due to changing conditions such as the installation of an offshore wind farm.

Installation of an offshore wind farm will introduce obstacles that the ship traffic has to avoid. If not successful in doing this a collision to a wind turbine will be the result. However, the deviations required of the ship traffic to avoid the wind turbines may also increase the potential for ship-ship collisions. A navigational risk analysis shall therefore cover the following three risk contributions:

- Ship-turbine collision risk for powered vessels (i.e., typically human error).
- Ship-turbine collision risk for drifting vessels (e.g., vessel with technical error).
- Changes in ship-ship collision risk due to increased traffic density around the offshore wind farm area.

The frequency analysis shall determine how often the three scenarios are expected to occur when the offshore wind farm has been introduced and based on this it can initially be judged if the risk associated with such collisions is readily acceptable. If not, the likely consequences of the collisions have to be determined to establish the fully detailed risk picture.

4.2 Worst case - assumptions

As described in section 3.1 either 3 MW or 10 MW turbines are to be installed and the maximum total capacity is 200 MW. Since the final layout of the turbines in the offshore wind farm is not known at present, the navigational risk assessment is performed such that it will represent a worst case for all possible turbine layouts i.e. both with regards to turbine size and location of the turbines within the offshore wind farm area.

During the HAZID all possible turbine positions were considered in the process of identifying hazards. The identified hazards given in the HAZID report (DNV, 2014-08-18) will all be relevant regardless of the chosen final turbine layout, but the magnitude of each of the individual risks might differ depending on the exact turbine layout. The hazards identified in the HAZID and the conclusions made thus regarding are therefore considered to remain valid for all possible turbine layouts.

The collision frequency analysis is based on a layout of wind turbines that, in the context of navigational risk, is considered as the worst case scenario. The chosen worst case scenario is 66 3-MW turbines since this will result in the highest risk of collision. It is noted that a layout with 20 10-MW turbines would take up approximately the same area, but the lower number of turbines would present fewer obstacles to the ship traffic which would lead to a reduced potential of ship collisions. The 66 3-MW turbines are in the worst case scenario distributed over the entire offshore wind farm area since this represents the case where the existing ship traffic will be disturbed the most. The resulting worst case layout of turbines is shown in Figure 3 below. The exact positions of the turbines constituting the worst case layout are listed in Appendix 1.

Since the HAZID has identified hazards based on all possible turbine sizes and locations, and the frequency analysis is performed based on the worst case turbine layout, the total navigational risk assessment in this report is considered to provide a conservative risk estimate for all possible turbine layouts.

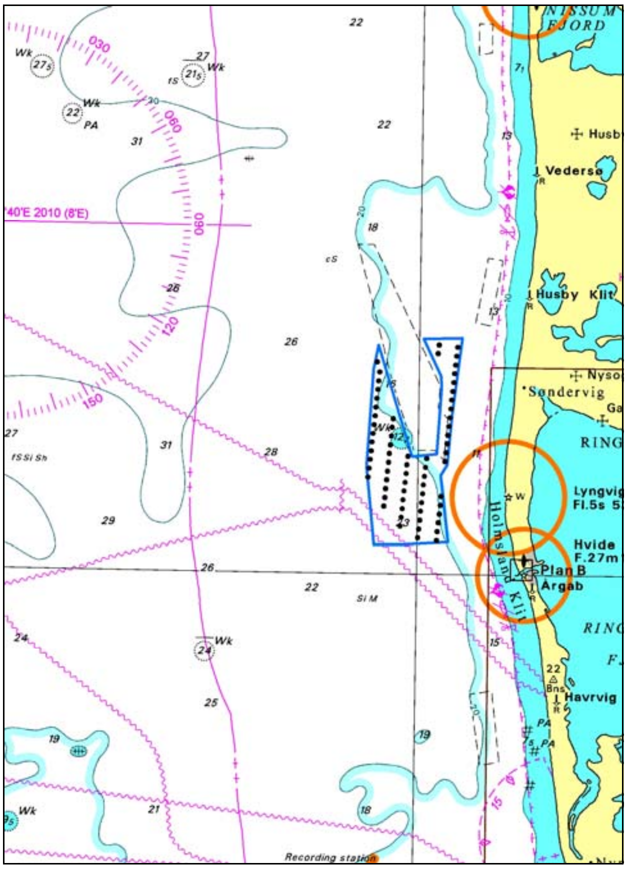

Figure 3. Worst case scenario for 200 MW total capacity. Note that it is the same positions as shown on the left picture in Figure 2.

4.3 0-alternative

The 0-alternative represents the case where the offshore wind farm is not established and is meant as a base for comparison in order to assess the impact the offshore wind farm will have on the navigational risk. According to the HAZID report (DNV, 2014-08-18) the main concern regarding navigational risk is ship-turbine and ship-ship collisions. Hence the conditions for these two collision scenarios in the 0-alternative are outlined in the following.

For ship-turbine collision the risk of collision will be “zero” if the offshore wind farm is not established and the results from the frequency analysis can therefore be interpreted as a direct consequence of establishing the offshore wind farm.

For ship-ship collision and grounding of ships the risk under current conditions is investigated based on (COWI, Juni 2002) which has collected the number of collisions and grounding incidents in the period from 1997 to 2001, both years inclusive. In the entire North Sea region a total of 3 collisions and 11 grounding incidents are reported. It is observed that 2 of the 3 collisions have occurred far from shore while 1 has occurred at Grådyb (far from the offshore wind farm area). The grounding incidents are concentrated within Grådyb, Nissum Bredning and Nissum Fjord, i.e. typically associated with approaching a harbor. The area around the offshore wind farm is hence evaluated as being a low risk area with regards to ship-ship collision under the existing conditions.

5 EXISTING CONDITIONS

In the context of navigational risk the relevant existing conditions are constituted by the ship traffic in the area. The existing ship traffic in the vicinity of the offshore wind farm area is shown in Figure 4. The figure is based on AIS data collected in the period from September 2013 to December 2013 and hence represents the existing conditions undisturbed by the presence of an offshore wind farm. It is seen that relative to the total traffic only a small amount of traffic passes through the offshore wind farm area. The collection of ship traffic data and subsequent modifications in order to use it for the frequency analysis is described in the following subsections.

5.1 Ship traffic based on AIS data

This subsection describes the ship traffic used as input for the frequency analysis. The ship traffic is determined from regional AIS data collected for four months – September, October, November and December in 2013. These four months cover 122 days or 33% of a year, and are considered to be broadly representative of the annual ship traffic that can be expected in the area. To limit the volume of data to be handled in the analysis, the AIS data have been limited to an area surrounding the proposed offshore wind farm site – see Figure 4 – with the following limits (in geographic coordinates):

West: 06° 50’ 00’’	East: 08° 20’ 00’’
South: 55° 30’ 00’’	North: 57° 01’ 00’’

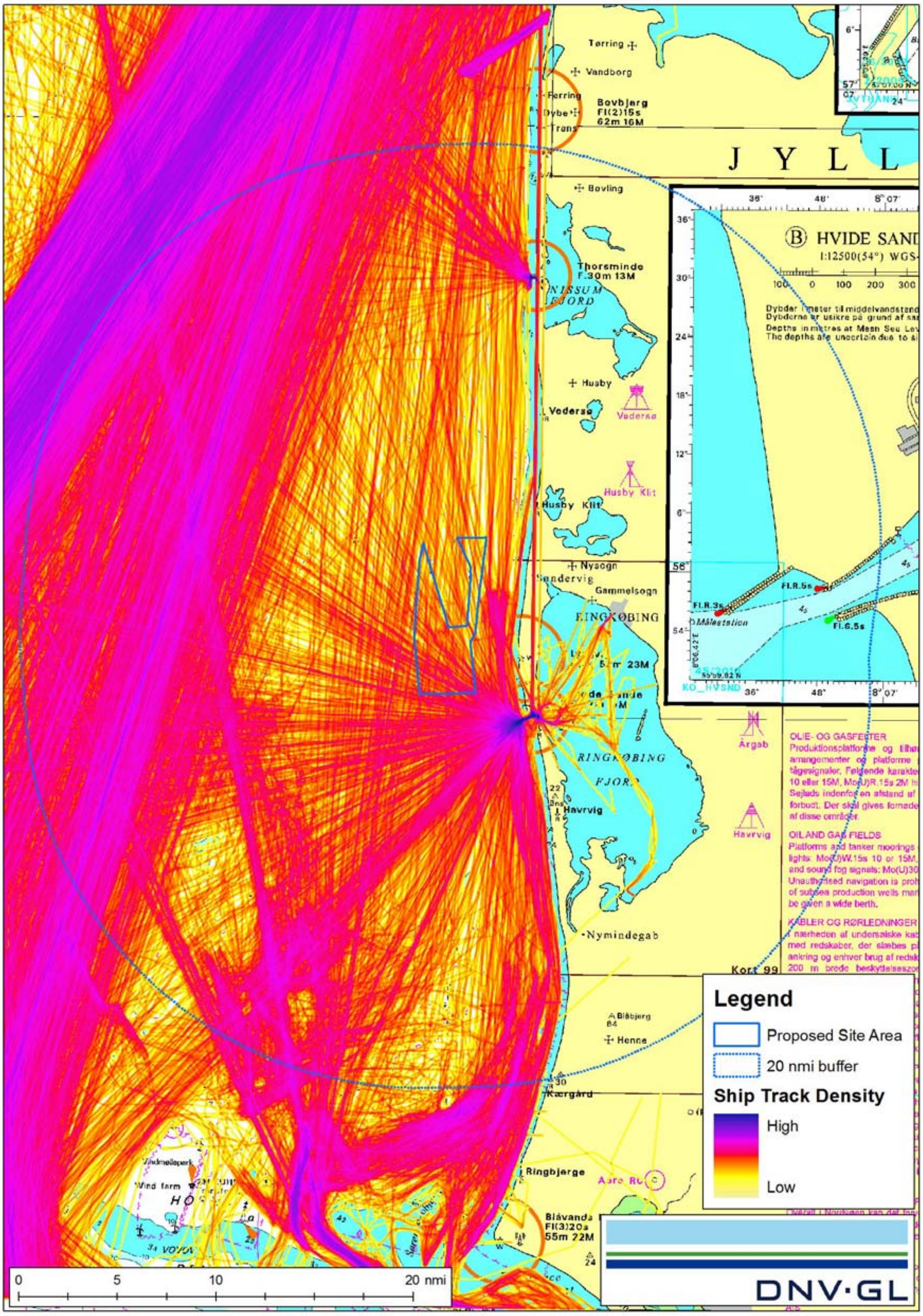

Figure 4. Ship traffic density based on the received AIS data.
Note that the shown 20 nmi buffer zone defines the area where the ship traffic is considered to be of interest with regards to a navigational risk assessment.

5.1.1 Analysis of AIS data

The AIS consists basically of successive position reports from each individual vessel that are within the selected geographic area. The first step in the analysis is to separate the position reports for each vessel, arrange them chronologically and combine them in sequence to form tracks that describe their passage within the area. These tracks form the basis for the subsequent analyses. The first result of the analysis is the density of tracks that is shown in Figure 4.

In the traffic modelling these corridors are approximated by poly-linear centre-lines – the route – and a probabilistic description of the traffic distribution trans-verse to this ideal centreline. Based on successive definition of routes and association of the AIS tracks to these routes, a set of 12 routes have been found necessary and relevant in order to model the ship traffic considered in the present study which is of particular concern to the proposed Vesterhav Syd Offshore Wind Farm. The association of the observed ship traffic with the defined routes is done in terms of the crossing lines. The crossing lines associated with each route are listed in Table 1, and shown in Figure 5. Hence, a track that passes the crossing lines in the sequence shown – or in reverse sequence – will be associated with the route. As an example, the tracks that pass both crossing lines 1 and 3 will be associated with route 1, and tracks that cross lines 8 and 10 in sequence – or in the reverse sequence – will be associated with route 7.

In addition to the 12 routes derived from AIS data, discussions with Danish Local Authority (Kystdirektoratet) led to the inclusion of a route representing dredging activities (sand extraction), in the vicinity of the northern area of the site. This route has been assumed to leave from Thorsminde and has been given rute number 13.

Route No	Description	One way[1]	Crossing lines
1	Ringkøbing fjord – north-west direction	No	1 and 3
2	Ringkøbing fjord – west direction	No	1 and 4
3	Ringkøbing fjord – south-west direction	No	1 and 5
4	Ringkøbing fjord – south direction	No	1 and 6
5	Ringkøbing fjord – north direction	No	2 and 7
6	North-south going traffic around 5 nmi from shore	No	8 and 9
7	East of Horns rev – north direction	No	8 and 10
8	East of Horns rev – north-west direction	No	8 and 13
9	North-south going traffic around 25 nmi from shore	No	11 and 12
10	North-south going traffic around 15 nmi from shore	No	11 and 13
11	Nissum fjord – north-west direction	No	14 and 15
12	Ringkøbing fjord – north direction	No	2 and 9
13[2]	*Nissum fjord – north part of offshore wind farm area (dredging)*	*No*	*n/a*

Notes:
1. *"One-way" indicates whether traffic on the route is modelled as being in one direction only.*
2. *This route is not based on compiled AIS ship traffic. It has been manually added following discussion with local authorities regarding dredging activities in the area.*

Table 1 Routes used in the ship traffic modelling.

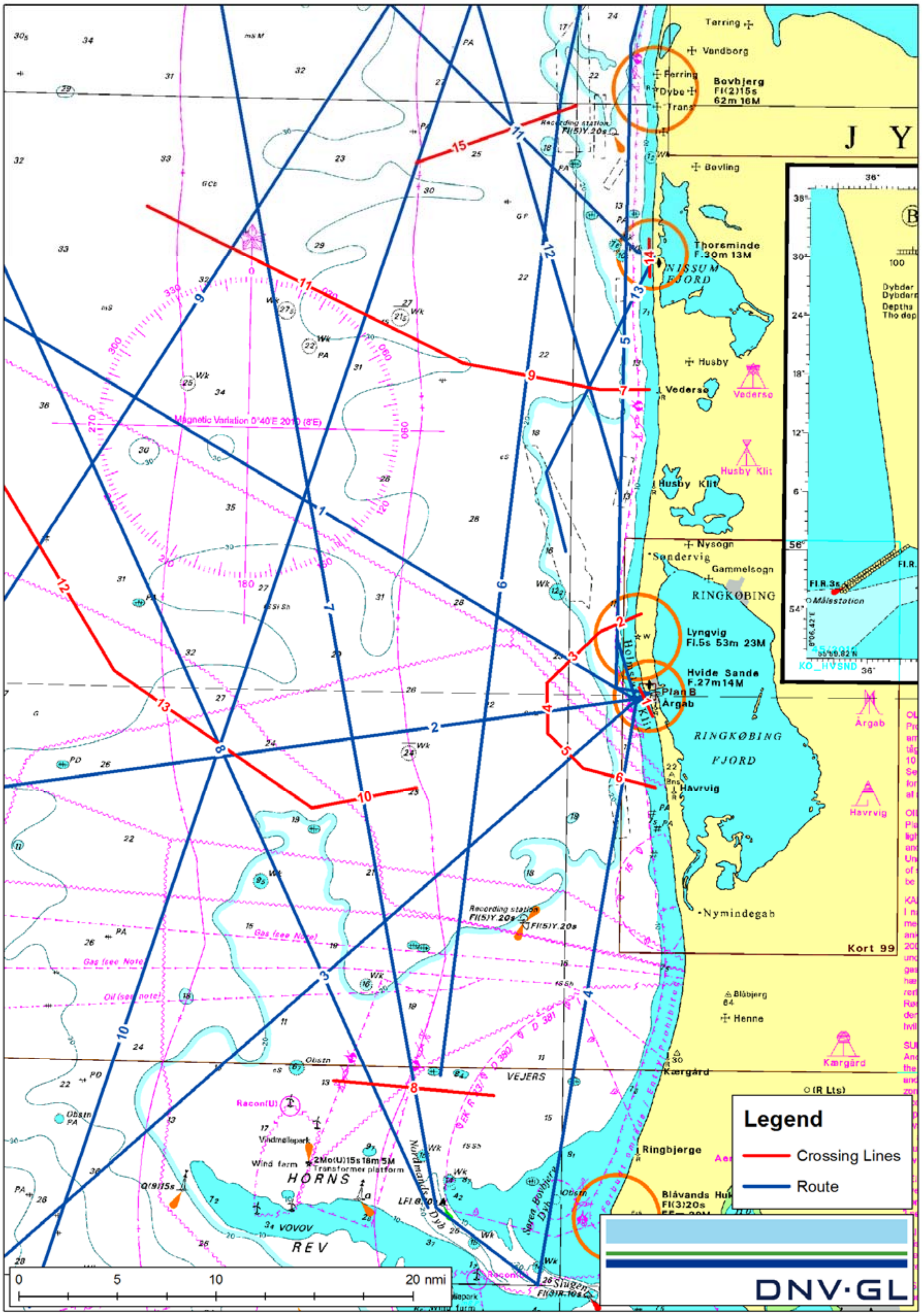

Figure 5 Ship traffic routes and associated crossing lines

A systematic graphic overview of the AIS-tracks, that have been associated with each of the routes described in Table 1 is provided in Appendix 5. Based on the passage of the associated tracks, it is evident that the ship traffic on the routes passing through the site, or in close proximity, will be forced to adapt to the presence of the proposed Vesterhav Syd Offshore Wind Farm. Also, it is noted that the routes, with the exception of route 13, have been selected to represent the traffic pattern observed in the AIS data period. It is noted that route 1 and 12 are passing directly through the proposed Vesterhav Syd Offshore Wind Farm area. Hence, when using the routes to define the traffic pattern after the offshore wind farm has been established, it is necessary to consider relocating these routes – see end of section 5.1.3 – to represent the reaction of the ship traffic on the presence of the wind farm: to stay outside the wind farm and at a reasonable distance

The number of passages associated with each route is listed in detail in Appendix 6. The association of tracks does not capture all the tracks in the AIS database and the ship traffic activity that has not been associated with a route will therefore not be explicitly represented in the ship traffic model. To get an impression of the extent and nature of these neglected tracks a graphic comparison is made in Figure 6 that shows the traffic density of: all AIS tracks, the routed tracks and the remaining un-routed tracks.
It is noticed that the routed tracks are capturing most of the essential features of the total traffic density. Also, the density of the remaining, un-routed tracks is mostly a uniform smear of activity, which is not suitable for representation in a route based traffic model. Inspection of the neglected tracks reveals that a large fraction of these are made by not identified vessels. This can either be because the AIS information in the vessels AIS transponder is incorrect or because the vessels are not found in the established ship registers (e.g., Lloyds Register). The latter would be the case for e.g., SAR vessels, pilot vessels and inspection vessel. Based on those vessels that have been identified, it is generally found that the un-routed tracks are associated with smaller ships and the size distribution of these vessels is much more focussed on the small ship sizes than by the routed traffic.

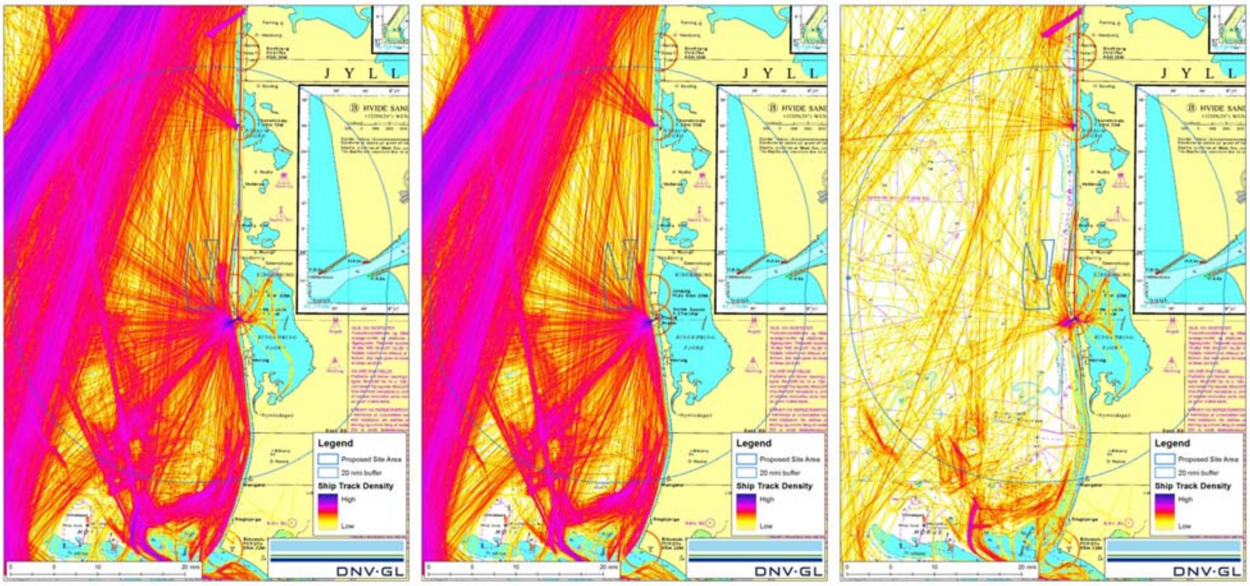

Figure 6. Ship traffic density comparison: All identified tracks (left), tracks associated with a route (middle) and neglected tracks (right).

The traffic model is solely based on the routed tracks. The part of the AIS tracks that have not been associated with a route in the traffic model represents ship activity – movements – in the area, and in order not to lose this activity and the associated risk contributions, the route modelled traffic is increased such that the mileage (number of miles traversed) in the routed traffic model is equal to the mileage in the original AIS data. It is found that the mileage of the un-routed traffic represents 6% of the mileage in the original AIS data, so the modelled traffic – the count of movements on each route – is factored uniformly by 1.06.

The size of the ships in the non-routed tracks is generally of smaller tonnage than the ship sizes associated with the routed tracks. So the above suggested scalar adjustment will have the conservative element that un-routed mileage made typically by smaller vessels is represented by mileage by larger vessels.

The AIS data covers 122 days out of the 365 days of at full year, and is considered to provide a reasonable approximation of the annual traffic. By inspection of the data for the 122 days – see Figure 7 – it can be seen that within the entire period all days are represented by an acceptable amount of data. Hence, no adjustment for downtime of the data collection system needs to be made.

The approach is found acceptable as information about dredging activities is gained from the Danish Coastal Authority. The data used include a conservative outlook to 2018 as the activity is expected to increase.

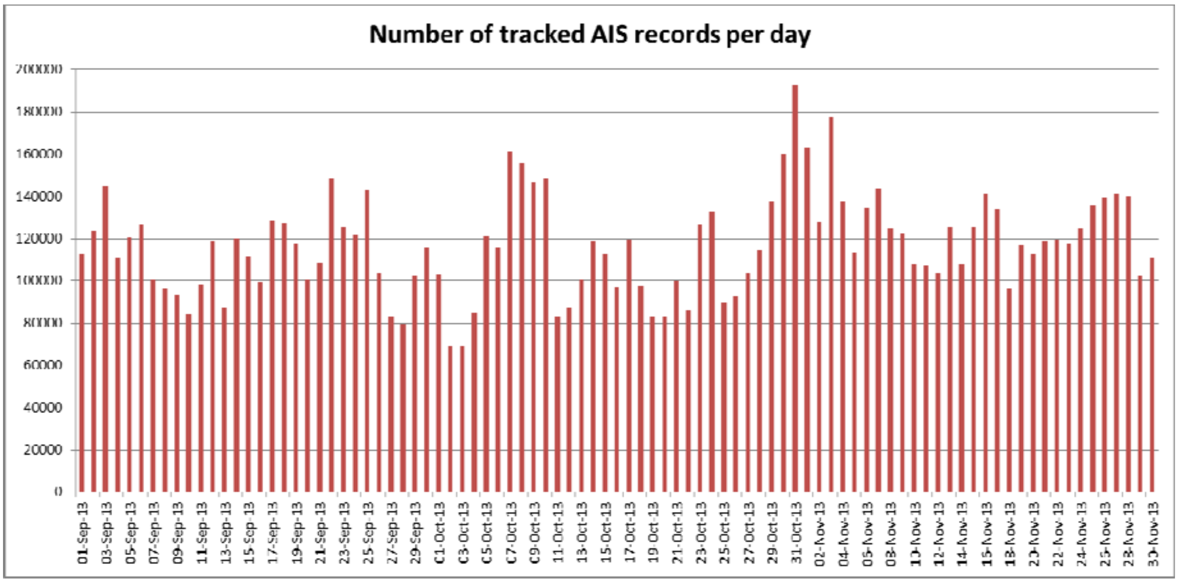

Figure 7. Variation in number of AIS records per day for the survey period.

Concluding that all days in the period appear to have full AIS data representation, and assuming that the data period is representative for the traffic pattern and volume for a full year, the annual traffic on routes 1 to 12 – including the correction for non-routed traffic – is obtained by multiplying the observed number of route passages by the factor:

$$Global\ traffic\ scaling\ \ factor = 1.06 * \frac{365.25\ days}{122\ days} = 3.17$$

The resulting annual traffic for the 13 routes is shown in Appendix 6.

5.1.2 Resulting route traffic

Ship Classification

The routed traffic resides in the database as explicit passages made by distinct vessels with specific characteristics extracted from Lloyds Register and supplemented by publicly available sources. The subsequent modelling of the risk to the offshore wind farm requires that the ship traffic is described in accordance with a relatively general classification system – i.e., based on the type and size categories of the specific ships.

The utilized type classification information from Lloyds Register refers to more than a hundred different vessel types which for the present analysis are reduced to the 5 general vessel types listed in Table 2. The motivation for selecting these ship types is based on the need to differentiate on the possible consequences of an accident (type and size of release of cargo or bunker oil) and on the differences in velocity and failure frequency. The ship type “Tanker” have the potential of an oil cargo release. The vessels in the groups “Ferry” and “RO-RO” normally travel faster and generally have higher engine reliability as they are equipped with more than one set of propulsion machinery. The group “Other” is a large residual group of merchant ships that includes bulk carriers, container ships, general cargo ships etc.

The classification on vessel size is based on DWT (dead weight tonnage) which is the weight of cargo, fuels, water, stores and crew that the ship can carry when fully loaded. The DWT size classes listed in Table 2 is by experience found to provide a sufficiently detailed and appropriately balanced representation of the size distribution for the present risk analysis.

No.	Ship types
1	Tanker
2	Other
3	Ferry
4	RO-RO
5	Fishing

Ship Size Classes
0 - 1,000 DWT
1,000 - 3,000 DWT
3,000 - 5,000 DWT
5,000 - 10,000 DWT
10,000 - 20,000 DWT
20,000 - 40,000 DWT
40,000 - 80,000 DWT
> 80,000 DWT

Table 2. Ship types and size groups used in the analysis.

The basic geometric and tonnage characteristics (DWT, GRT, length and breadth) for the defined ship classes are given in Table 3 through Table 5.

Tankers				
Ship class DWT	DWT	GRT	L [m]	B [m]
0 – 1.000	800	560	53	9
1.000 – 3.000	2,400	1,680	77	13
3.000 – 5.000	4,000	2,800	91	15
5.000 – 10.000	8,000	5,600	115	19
10.000 – 20.000	16,000	11,200	145	24
20.000 – 40.000	32,000	22,400	183	30
40.000 – 80.000	64,000	44,800	230	38
> 80.000	96,000	67,200	263	44

Table 3. Tonnage and geometric characteristics for Tankers

Other ships (including fishing vessels)				
Ship class DWT	DWT	GRT	L [m]	B [m]
0 – 1.000	800	560	53	9
1.000 – 3.000	2,400	1,680	77	13
3.000 – 5.000	4,000	2,800	91	15
5.000 – 10.000	8,000	5,600	115	19
10.000 – 20.000	16,000	11,200	145	24
20.000 – 40.000	32,000	22,400	183	30
40.000 – 80.000	64,000	44,800	230	38
>80.000	96,000	67,200	263	44

Table 4. Tonnage and geometric characteristics for Other ships.

Ferries and RO-RO				
Ship class DWT	DWT	GRT	L [m]	B [m]
0 – 1.000	800	4,000	103	17
1.000 – 3.000	2,400	12,000	148	25
3.000 – 5.000	4,000	20,000	176	29
5.000 – 10.000	8,000	40,000	222	37
10.000 – 20.000	16,000	80,000	279	47
20.000 – 40.000	32,000	160,000	351	59
40.000 – 80.000	64,000	320,000	443	74
>80.000	96,000	480,000	507	84

Table 5. Tonnage and geometric characteristics for ferries and RO-RO vessels.

Modelling of traffic distribution across routes

The ship traffic as identified through the AIS data has been associated with ideal – or generic – routes described in terms of the ideal centrelines. In order to calculate the risk of collisions to the offshore wind farm structures it is required that the deviation of the ship traffic from these ideal centrelines is described by a probabilistic model. In some cases the description of the deviations can be extracted from the observed deviations – i.e., via the spreading of the observed traffic density. But, for some routes, the establishment of the proposed offshore wind farm will impose changes to the navigational pattern to ensure a safe passing distance to the offshore wind farm structures. In these cases the spread and distribution type of the traffic has to be assumed on the basis of the presently observed spread combined with the proximity and restriction that the offshore wind farm structures is considered to constitute to the ship traffic.

The transverse distribution is composed of a normal (Gaussian) distribution and a uniform distribution. The normal component is described by the associated standard deviation σ and the uniform distribution is described by its extent and the relative weight that this component is

given. Hence, three parameters shall be specified for each route. These parameters can be varied along the route and, for those for which it has been the case, the range of value used on the different sections of the route are listed in Table 6. Typically the traffic spread is largest in open sea, and decreases towards harbours. This table also indicates whether the parameters are based on observation or whether they have been assumed, because the traffic on the route has to adapt to the future presence of the offshore wind farm.
The standard deviation σ fully controls the compound distribution function since the width of the uniform part is set to 6·σ and the relative fraction of the uniform distribution is fixed to 2%. These limitations or restrictions on the parameter choice have been introduced to ensure compatibility in the results produced across different risk calculation computer models (MARCS, SAMSON, COLFREQ).

Route No	Estimation basis	Standard deviation σ of Gaussian part [nm]	Width of uniform part(= 6·σ) [nm]	Relative fraction of Uniform part
1	Observation	0.250 - 5.000	1.5 - 30.00	2 %
2	Observation	0.250 - 2.500	1.5 - 15.00	2 %
3	Assumption	0.250 - 2.500	1.5 - 15.00	2 %
4	Observation	0.250 - 5.000	1.5 - 30.00	2 %
5	Observation	0.250	1.5	2 %
6	Observation	0.250 - 1.000	1.5 - 6.00	2 %
7	Observation	0.250	1.5	2 %
8	Observation	0.250 - 1.000	1.5 - 6.00	2 %
9	Observation	2.000	12.0	2 %
10	Observation	2.000	12.0	2 %
11	Observation	0.250 - 2.500	1.5 - 15.00	2 %
12	Assumption	0.250	1.5	2 %
13	Assumption	0.250	1.5	2 %

Table 6. Transverse distribution parameters used on the defined routes.

5.1.3 Revised routes for future ship traffic due to wind farm

The presence of the offshore wind farm under investigation will require that some of the ship traffic has to relocate to avoid passing through the offshore wind farm. The routes used to model these components of the ship traffic in the risk analysis must be adjusted accordingly based on the assumed future behaviour of this traffic – i.e., how far the traffic will tend to relocate.
Route 12 has low annual traffic and is assumed to adapt to the offshore wind farm and hence go around. For route 1 however, since a large part of the traffic is constituted by fishing vessels it is conservatively assumed that this traffic will continue to use this route and hence pass through the offshore wind farm. Route 1 has therefore not been relocated which is considered to be extremely conservative for analysis purposes, because ship types such as e.g. tankers are included in this route as well.

The proposed revisions to route 12 along with the remaining routes are shown in Figure 8 and are the ones used in the frequency analysis.

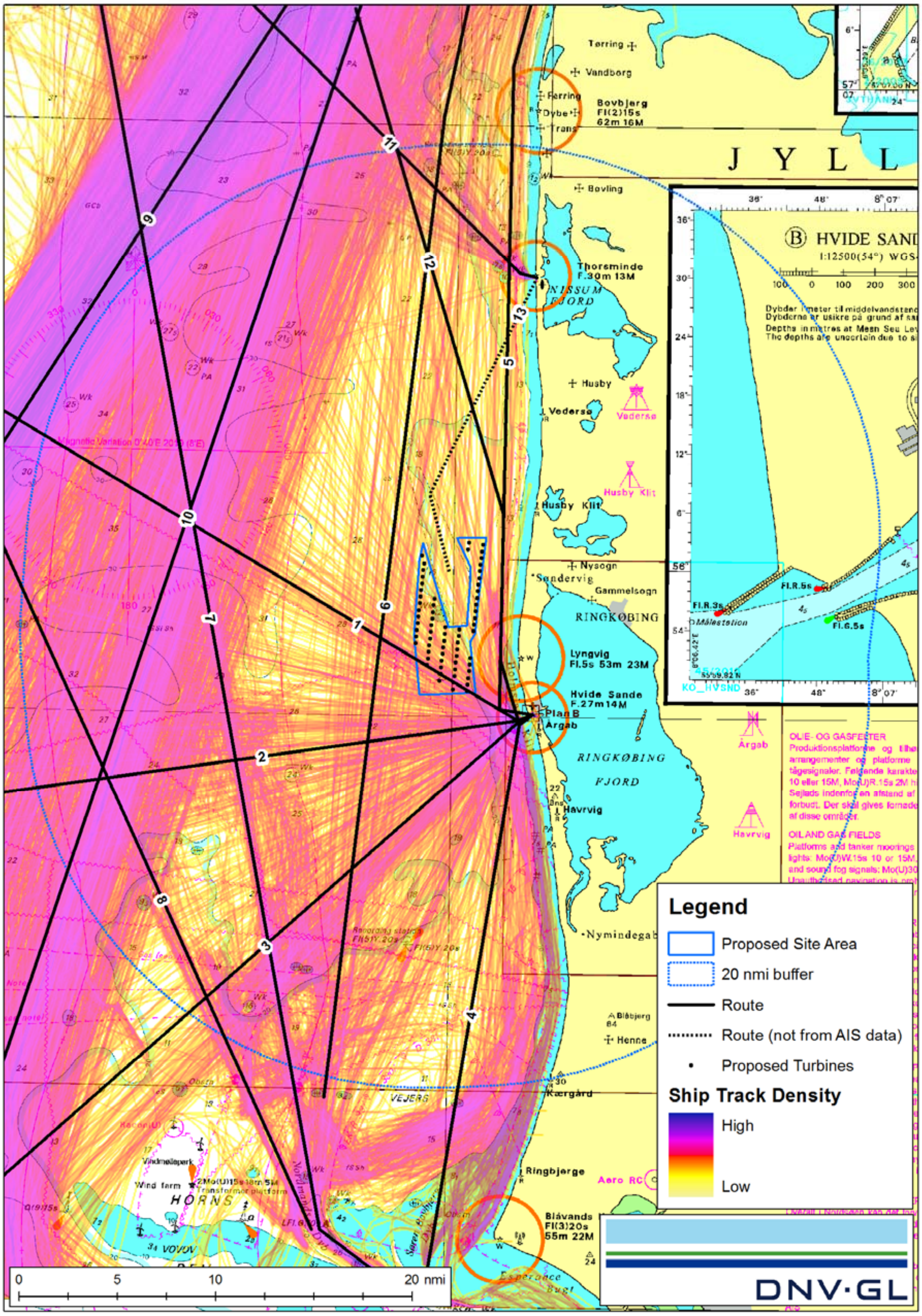

Figure 8. Ship traffic routes used in frequency analysis.

The waypoints for the 13 routes, including the proposed revisions to route 12, are listed, below, in Table 7.

Route ID	Point	Longitude [°]	Latitude [°]	Route ID	Point	Longitude [°]	Latitude [°]
1	1	8.1222	56.0024	7	1	7.3955	56.7358
1	2	8.0993	55.9974	7	2	7.8140	55.5642
1	3	6.8258	56.4054	7	3	7.9669	55.5002
2	1	8.1222	56.0024	8	1	7.8016	55.5641
2	2	8.0993	55.9974	8	2	6.8349	56.6896
2	3	6.8148	55.8804	9	1	6.7885	55.7400
3	1	8.1222	56.0024	9	2	8.2262	57.0340
3	2	8.1007	55.9960	10	1	7.2107	55.4729
3	3	7.1411	55.4992	10	2	8.0980	57.0311
4	1	8.1222	56.0024	11	1	8.1206	56.3724
4	2	8.1020	55.9938	11	2	8.0940	56.3756
4	3	7.9669	55.5002	11	3	6.8698	57.0251
5	1	8.1222	56.0024	12	1	8.1222	56.0024
5	2	8.1006	55.9971	12	2	8.0720	56.0070
5	3	8.0718	56.0484	12	3	8.0740	56.1710
5	4	8.0809	56.5504	12	4	7.8373	56.5976
5	5	8.2174	56.8381	13	1	8.1206	56.3724
5	6	8.3362	56.9805	13	2	7.9618	56.1881
6	1	7.8167	55.6763	13	3	7.9930	56.1220
6	2	7.9756	56.5075				
6	3	8.0663	56.7567				
6	4	8.3097	57.0258				

Table 7. Way-points for the 13 shipping routes used in the analysis.

5.2 Leisure traffic

The leisure vessels will usually travel in patterns that are more irregular than that of the merchant ship traffic. These travelling patterns are not well described in the route structure that is used for the merchant traffic, and a different more diffuse modelling of this ship traffic would be required for use in a frequency analysis. However, the leisure vessels are limited in size and their activity is known to be moderate in the region. Due to this the leisure traffic will not constitute a significant risk neither to the turbines nor to the environment as a consequence of accidental interaction with the turbines. The turbines will likewise not constitute an appreciable risk to the leisure traffic. Data collection, analysis and modelling of this specific ship traffic have therefore not been made for the present study.

5.3 Fishing traffic

The fishing vessels will usually travel in patterns that are more irregular than that of the merchant ship traffic. However, due to significant fishing activity within the area of interest, the ship routing was defined so that a large portion of the fishing vessels could be included in the AIS based traffic modelling described in section 5.1. The fishing vessels are hence considered to be accounted for in the frequency analysis.

6 IMPACT ASSESSMENT DURING INSTALLATION PHASE

The present report focusses on the operation phase. Key parameters necessary for performing a thorough risk assessment of the installation phase (installation technique, type of installation vessels and transport route of components from onshore fabrication facility to the offshore site etc) will be chosen by the contractor. Hence the risk assessment for the installation phase cannot be carried out before the necessary decisions have been taken by the appointed contractor. The risk assessment would normally be part of the scope of work for the appointed contractor.
Furthermore the choice of foundation type for the turbines and the amount of turbines to be installed (66 3-MW or 20 10-MW) will also influence the duration of the installation and hence also the risk assessment.
It is assumed that a "safety zone" will be laid out during the installation work in order to protect the installation vessels, the personnel and the installed assets from collision with incoming vessels.

6.1 Hazard identification

In the HAZID report (DNV, 2014-08-18) two hazards for the installation phase are identified and evaluated to be in the high risk range. These hazards are related to the risk that installation vessels will collide with each other or with the normal ships or dredging vessels in the area. It is suggested to mitigate this risk by establishing and enforcing a working zone / safety zone and implementing traffic coordination. In the HAZID report it is evaluated that implementation of these mitigation meassures will bring the risk down to medium risk range (ALARP). However, for the same reasons as given above in section 6, an exact evaluation of the effect of these mitigation meassures has not been performed in present report.

6.2 Total impact

Not evaluated, see section 6 above.

7 IMPACT ASSESSMENT DURING OPERATION

This section evaluates the risks associated with the operation phase.

7.1 Hazard identification

In the HAZID report (DNV, 2014-08-18) hazards for the operation phase have been identified. The majority of identified hazards relate to the risk that ships in the area will collide with a turbine and these were all evaluated to be low risk.
Also the risk of two ships colliding with each other was identified due to the potentially increased traffic density caused by the Offshore Wind Farm. However, any change in ship traffic density due to the offshore wind farm would mostly be governed by the vessels own preference for safety distance – to the wind turbines, to the shore and to other ships. And the same cautiosness is controlling the navigational pattern and density now, without the offshore wind farm. So any risk increase for ship-ship collision that could be caused by the Vesterhav Syd Offshore Wind Farm has been assessed to be low.

A single high risk hazard is identified in (DNV, 2014-08-18). This hazard is for a situation where a fishing vessel on the east side of the offshore wind farm unintended hits an export cable with its fishing gear. Even though this situation probably would result in damage on the export cable, it is however not expected to constitute any risk to the ship traffic and this hazard is hence not considered furter in present report. Also it should be noted that cables on the seabed normally are protected by a restriction zone where fishing gear dragged along the seabed, such as e.g. bottom trawling, is not allowed and hence the risk will only be high if dispensation is given to this kind of fishing over the cables.
In the HAZID report is also stated some remarks given by the Admiral Danish Fleet (Søværnets Operative Kommando) related to Search and Rescue (SAR). These are not related to the identified hazards for navigational risk, but can have some complications for SAR operations.

Even though all hazards (exept for damaging export cables) are evaluated to be low risk, it is still obvious from the HAZID report that the main concern with regards to navigiational risk is ship-turbine collision.

The following four actions are defined in Appendix A of the HAZID report.
HAZID ID 1.5 concerns an evaluation from the Admiral Danish Fleet (Søværnets Operative Kommando) related to Search and Rescue (SAR). The Admiral Danish Fleet has provided the following remarks regarding SAR in and around the Vesterhav Syd Offshore Wind Farm:

- It is expected that the distance from sea surface to the tip of the wind turbine blades is enough to allow SAR vessels to pass under, and that a control center can be contacted in order to shut down the turbines.
- The coastal radars at Thyborøn and Oksbøl will possibly be able to “see” the turbines. The distance to the Vesterhav Syd Offshore Wind Farm from these two radar sites however means that a disturbance of the radarpictures not will be likely to occur.
- Flyvertaktisk Kommando (FTK) and Helicopter Wing Karup (HW) have no interest in flying low level over the water and hence the offshore wind farm is not expected to cause any problems in that regard. It is however mentioned that use of NVG compatible lights could be problematic.

It is observed that none of these remarks are related to the identified hazards for navigational risk, but can have some complications for SAR operations. They are hence not considered furter in this navigational risk assessment.
HAZID ID 1.6 concerns that Kystdirektoratet is to provide current and expected future dredging activities. DNV GL has, based on discussions with Kystdirektoratet, established a traffic model to be used in the frequency analysis (route 13) and hence the navigational risk assessment, refer to section 5.1.1 in present report.
HAZID ID 1.8 concerns evaluation of fishing activity to be performed by BioApp/Krog Consult. The report from BioApp/Krog Consult has been provided to DNV GL but the report does not contain any data relevant for describing the fishing traffic. Anyhow a large part of the fishing traffic turned out to be covered by the AIS traffic data obtained by DNV GL, and the fishing traffic is hence considered included in the frequency analysis and hence the navigational risk assessment.
HAZID ID 1.10 concerns investigation of the number of leisure vessels using the harbours nearby. It has not been possible to obtain specific data on number of leisure vessels leaving, approaching or passing by Hvide Sande Havn. Anyhow, as described in section 5.2 the activity of the leisure traffic is known to be moderate in the region and the increase in navigational risk for

the leisure traffic will therefore be insignificant. It is therefore deemed acceptable to perform the evaluation based on the general knowledge of the leisure traffic activity in lieu of specific data.

7.2 Collision frequency

In order to evaluate the risk of ship-turbine collision a frequency analysis is performed in section 7.2.1. The possibility of an increase in ship-ship collision incidents is discussed in section 7.2.2.

7.2.1 Ship-turbine collision

The ship-turbine collision frequencies are calculated for the two scenarios below.

- Collision from powered vessel
- Collision from drifting vessel

The frequency results are derived based on the worst case scenario defined in section 4.2 which consist of 66 3-MW turbines and is evaluated to constitute the largest risk of ship collision. The ship routes and traffic are as defined in section 5.1.3 and reflects the presence of the Vesterhav Syd Offshore Wind Farm. It is noted that the calculated collision frequencies cover all cases of collision, i.e., both minor collisions as well as severe collisions where repair of ship is needed before the ship can continue its planned journey.
The accumulated results for the entire offshore wind farm are presented in Table 8. It shows the frequency and return period for the two above mentioned scenarios (powered/drifting) as well as the combined sum for the two. The results are calculated without any risk reducing measures implemented.

Considered traffic	Powered vessel	Drifting vessel	Sum
All routes & all vessel types cumulated	$2.9{\cdot}10^{-2}$ (34)	$2.9{\cdot}10^{-3}$ (341)	$6.5{\cdot}10^{-2}$ (31)

Table 8. Collision frequency and associated return period in years indicated in brackets.

From Table 8 it is seen that the total return period for collisions is estimated to 31 years without any particular risk reducing measures implemented. The collision frequency is dominated by the contribution from powered collisions since the contribution from drifting collisions is very small. The results are detailed further in the following figures.
The cumulative collision frequencies for powered and drifting vessels distributed on ship routes are shown on Figure 9 and Figure 10 respectively.

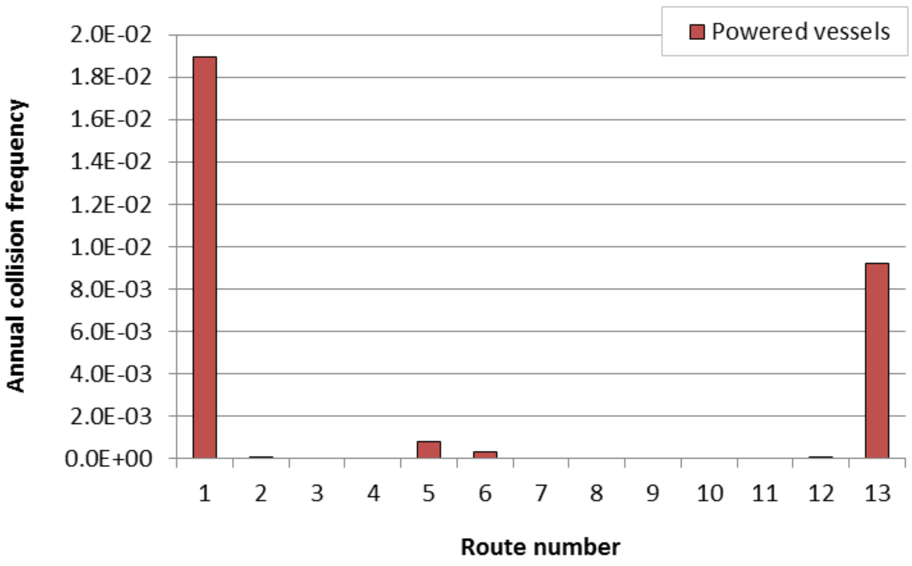

Figure 9. Collision frequency for powered vessels distributed on ship routes.

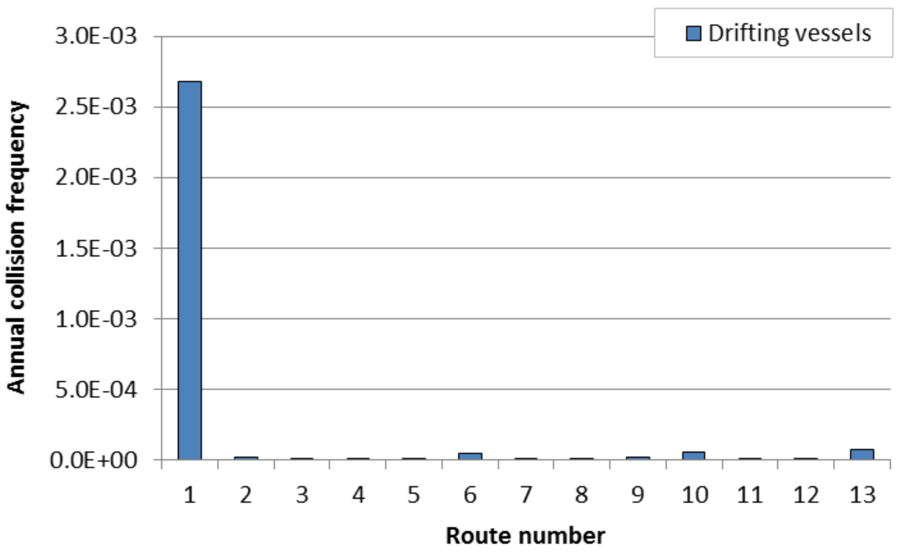

Figure 10. Collision frequency for drifting vessels distributed on ship routes.

When inspecting Figure 9 and Figure 10 it is seen that the primary contributor to the high collision frequency is route 1, and to some extent also route 13. Route 1 is very conservatively assumed to be passing through the offshore wind farm which unavoidably results in high collision frequencies. A more reasonable assumption could be to relocate route 1 so it follows route 2 from the harbor and west-going until it has passed the south side of the offshore wind farm, and then turn to north-west going direction. This is believed to reduce the collision frequency significantly. The argument for this is that the annual traffic on route 1 and 2 practically are identical, see Appendix 6, and hence the calculated collision frequencies seen on Figure 9 and Figure 10 for these two routes are a direct indication of the effect of the location of the routes relative to the offshore wind farm. A rough estimation is made in order to assess the collision frequency in case route 1 would go south of the offshore wind farm. However, in order to keep some conservatism it is assumed that that vessels on route 1 less than 1000 DWT still will pass through the offshore wind farm, this is about 25% of the total traffic on route 1. Also a case where the entire ship traffic on route 1 goes south of the offshore wind farm is estimated. The resulting collision frequencies for both cases are shown in Table 9. It is noted that these results are based on a weighting of the above presented collision frequencies.

Considered traffic	Powered vessel	Drifting vessel	Sum
All routes & all vessel types cumulated. 75% of traffic from route 1 follows route 2, 25% goes through OWF.	$1.5 \cdot 10^{-2}$ (66)	$9.4 \cdot 10^{-4}$ (1063)	$1.6 \cdot 10^{-2}$ (62)
All routes & all vessel types cumulated. 100% of traffic from route 1 follows route 2, 0% goes through OWF.	$1.0 \cdot 10^{-2}$ (96)	$2.9 \cdot 10^{-4}$ (3514)	$1.1 \cdot 10^{-2}$ (94)

Table 9. Evaluated collision frequency for the case with route 1 modified. Note that OWF is an abbreviation for Offshore Wind Farm.

By comparing Table 8 and Table 9 the effect of assuming route 1 to be relocated is obviously beneficial and decreases the collision frequency significantly in both cases. Since the ship traffic in reality most probably will go south of the offshore wind farm instead of going through it, the collision frequencies in Table 9 are considered to give a more correct picture of the collision risk compared to Table 8. In that case, the largest risk of collision will then be posed by route 13 which only covers dredging activities. Since the vessels carrying out these activities quickly will become used to working within the offshore wind farm area it is also expected that the collision frequency for route 13 is overestimated by the result presented in Figure 9. Consequently the resulting collision frequencies in Table 8 and Table 9 can also be expected to be lower.
Finally it is again highlighted that the frequency analysis is performed without assuming any risk reducing measures and thus implementation of such could possibly reduce the collision risk even further if needed.

7.2.2 Ship-ship collision and grounding

In section 4.3 the risk of ship-ship collision around the area of the Vesterhav Syd Offshore Wind Farm under existing conditions is found to be very low based on the report (COWI, Juni 2002) which reports actual collision and grounding incidents.
A calculation of ship-ship collision frequency with an established offshore wind farm has not been performed since it is evaluated that a change in risk of ship-ship collisions due to the presence of the Vesterhav Syd Offshore Wind Farm will be marginal. For the worst case turbine layout only the ship traffic on route 12 has been moved to the east in order to get around the offshore wind farm and will as a result follow a part of route 5 along the coast line. The increase in traffic density due to the coincidence of route 12 with route 5 is deemed insignificant since route 12 only has very few passages per year. In case route 1 would go south of the offshore wind farm instead of going through it, this would still be clear of the other defined main routes in the vicinity (e.g. route 2) and hence the increase in traffic density is evaluated to be small and not increase the risk of ship-ship collision significantly.
The frequency of grounding incidents are also evaluated to be unchanged since only route 1 and 12 will be slightly affected in the worst case as explained above.

7.3 Total impact

The total impact for the operational phase is assessed according to the Energinet.dk definitions in Appendix 3. From the hazard identification process, refer section 7.1, it is determined that the

main risk is posed by ship-turbine collision. The risk of ship-ship collision is evaluated to be less critical.
This risk is evaluated by performing a frequency analysis which yielded a return period of 31 years for the very conservative scenario where all ship traffic on route 1 was assumed to go through the offshore wind farm. When only the smaller vessels (<1000 dwt) were assumed to continue passing through the offshore wind farm the return period of collisions increased to 62 years, and when no traffic was assumed to intentionally pass through the offshore wind farm the return period increased further to 94 years. The largest contribution to the collision frequency is from vessels that carry out dredging activities within the contours of the offshore wind farm and the estimated collision frequency from this is considered to constitute a conservative estimate. Reducing this contribution will increase the total estimated collision return periods of 62 - 94 years significantly, and hence the actual risk of ship-turbine collision is deemed to be low.
The increase in ship-ship collision and grounding incidents due to the presence of the Vesterhav Syd Offshore Wind Farm is deemed to be insignificant.

Based on these evaluations it was not deemed necessary to perform a consequence analysis or to perform a detailed evaluation of risk reducing measures. The conclusions from the frequency analysis alone indicate that the occurrence of ship-turbine collisions will be low and hence the increase in navigational risk due to establishment of the Vesterhav Syd Offshore Wind Farm is acceptable. This conclusion has also been accepted by the Danish Maritime Authority (Søfartsstyrelsen).

The Vesterhav Syd Offshore Wind Farm is therefore evaluated to cause “Low disruption” of the ship traffic and have “Minor negative impact” in the operational phase with regards to navigational risk (according to the Energinet.dk definitions given in Appendix 3). This is reflected in Table 10 below.

Topic	Phase	Disruption	Impact	Comments
Ship-turbine collision	Operation	Low	Minor negative impact	-
Ship-ship collision and grounding	Operation	Low	Minor negative impact	-

Table 10 Impact assessment for operation phase

8 IMPACT ASSESSMENT DURING DECOMMISSION

Risk of collision during the decommissioning phase has not been evaluated in present report. This should be the responsibility of the appointed contractor taking care of the decommissioning and should not be evaluated in detail before the offshore wind farm is close to the end of the defined service life, which according to section 3 is expected to be in 2045-2050.
Furthermore the foundation type for the wind turbines and eventual technological improvements within the field of decommissioning are currently not known and hence a detailed evaluation is not deemed relevant at this point.

8.1 Hazard identification

The decommissioning phase was not covered in the HAZID, see report (DNV, 2014-08-18).

8.2 Total impact

Not evaluated, see section 8 above.

9 CUMULATIVE EFFECTS

An increased navigational risk due to cumulative effects in the area has been assessed. The Vesterhav Syd Offshore Wind Farm will be located relatively close to the planned Horns Rev 3 offshore wind farm. However, since there is a reef on the Horns Rev 3 site the ship traffic is already avoiding this area and is hence not expected to change drastically due to establishment of Horns Rev 3. The Vesterhav Syd Offshore Wind Farm is also relatively close to the Vesterhav Nord Offshore Wind Farm. If the Vesterhav Nord Offshore Wind Farm is established the ship traffic coming from north will probably react by keeping a larger distance to shore which entails that the ship traffic probably will have the tendency to stay further from shore when passing the Vesterhav Syd Offshore Wind Farm, so this will actually have a positive effect on the navigational risk.
There is hence currently not known to be any cumulative effects that would affect the navigational risk near the Vesterhav Syd Offshore Wind Farm in a negative way.

10 MITIGATION MEASURES

It is not found necessary to implement mitigation measures in addition to the usual precautions that by default are required for offshore installations, refer to conclusion in section 7.3. These default requirements include that; turbine foundations must be painted yellow, turbine foundations must have identification signs that are illuminated, and the offshore wind farm must have light marking. These measures have already been taken into account in the risk assessment since the risk calculation models have been calibrated against observed collisions and these have happened under usual conditions and thus under the precautions normally required. Additional mitigation measures are as previously stated not included in the risk assessment.

11 MONITORING

Access to the waters within the offshore wind farm area is not restricted and hence there will not as such be monitoring of approaching ship traffic.

12 POTENTIAL INSUFICIENT INFORMATION OR KNOWLEDGE OF IMPORTANCE REGARDING THE ASSESSMENTS

All input information necessary to perform the frequency analysis is well de-scribed and hence the analysis output is not compromised due to insufficient or lacking information. Only input worth mentioning in this regard is that ship traffic is based on AIS data not covering a full calendar year. However, the adjustment of the ship traffic described in section 5.1 is considered to fully mitigate this and hence yield results that are on the safe side.

13 CONCLUSION (CONCLUSION OF THE TOTAL IMPACT)

The impact of the Vesterhav Syd Offshore Wind Farm on the navigational risk is evaluated based on hazards identified in a HAZID and a subsequent calculation of collision frequencies. The risk assessment is performed on this basis.

In the HAZID report (DNV, 2014-08-18) the majority of identified hazards for the operation phase relate to the risk that ships in the area will collide with a turbine. Also the risk of two ships colliding with each other was identified.
In the context of the HAZID it is also noted that the Admiral Danish Fleet usually expects that a control center can be contacted in order to shut down the turbines, in case this shoud be necessay.

A frequency analysis is performed to evaluate the likelihood of ship-turbine collision. An offshore wind farm layout consisting of 66 turbines of 3 MW distributed over the entire offshore wind farm area is used as worst-case scenario for the assessment. The ship traffic is established based on AIS data and routes have been adjusted where necessary to reflect the reaction of the ship traffic to the presence of the offshore wind farm.

The frequency analysis is first performed for a very conservative scenario where the entire ship traffic, currently observed within the wind farm area, is assumed to maintain their routes and thus go through the offshore wind farm. This gives a return frequency for ship-wind turbine collisions of 34 years for powered collisions (i.e., typical human error), and 341 years for drifting collisions (i.e., typical technical errors). The combined frequency for powered and drifting collision is thus estimated to 31 years for this very conservative scenario. When only the smaller vessels (<1000 dwt) are assumed to continue passing through the offshore wind farm the return period of collisions increases to 62 years, and when no traffic is assumed to intentionally pass through the offshore wind farm the return period increases further to 94 years. The largest contribution to the collision frequency is from vessels that carry out dredging activities within the contours of the offshore wind farm. The estimated collision frequency from this is considered to constitute a conservative estimate. Reducing this contribution will increase the total estimated collision return periods of 62 - 94 years significantly.
A change in ship-ship collision risk due to the presence of the offshore wind farm is evaluated to be marginal as only a very little amount of the total traffic need to adjust their routes.

Based on these evaluations it was not deemed necessary to perform a consequence analysis (Step 2) or to perform a detailed evaluation of risk reducing measures (Step 3). The conclusions from the frequency analysis alone (Step 1) indicate that the occurrence of ship-turbine collisions will be low and hence the increase in navigational risk due to establishment of the Vesterhav Syd Offshore Wind Farm is acceptable. This conclusion has also been accepted by the Danish Maritime Authority (Søfartsstyrelsen).

For the operation phase the Vesterhav Syd Offshore Wind Farm is therefore evaluated to cause “Low disruption” of the ship traffic and have “Minor negative impact” for both ship-turbine and ship-ship collision according to the definitions given in Appendix 3.

The impact on the navigational risk during the installation and decommissioning phases has not been evaluated since too many parameters are unknown. The risk assessment for the installation and decommissioning would normally be part of the scope of work for the appointed contractor.

Evaluation of total impact on the navigational risk for all phases (installation, operation and decommissioning) is listed in Table 11 below.

Topic	Phase	Disruption	Impact	Comments
Ship-turbine collision	Construction	N/A	N/A	Evaluation not possible on current basis.
	Operation	Low	Minor negative impact	-
	Decommission	N/A	N/A	Evaluation not possible on current basis.
Ship-ship collision and grounding	Construction	N/A	N/A	Evaluation not possible on current basis.
	Operation	Low	Minor negative impact	-
	Decommission	N/A	N/A	Evaluation not possible on current basis.

Table 11 Impact assessment for navigational risk

14 REFERENCES

COWI. (Juni 2002). *Risikovurdering af sejladssikkerheden i de danske farvande.*

DNV. (2014-08-18). *Technical Report - Hazard Identifikation og Kvalitativ Risiko Evaluering af Sejladssikkerheden for Vesterhav Syd Havmøllepark Projekt, Report no: PD-644204-18PYFR2-1, Rev. no: 1.*

DTU. (February 2014). *Wind farm layouts for Vesterhav Syd.*

Energinet.dk (2015). Technical Project Description for Offshore Wind Farms (200MW) Offshore Wind Farms at Vesterhav Nord, Vesterhav Syd, Sæby, Sejerø Bugt, Smålandsfarvandet and Bornholm. Appendix 1: Vesterhav Syd Offshore Wind Farm – Technical description, Offshore, Energinet.dk, 2015.

APPENDIX
1
COORDINATES FOR TURBINE POSITIONS IN WORST CASE SCENARIO

Worst case scenario for Vesterhav Syd Offshore Wind Farm.

Turbine ID	Longitude	Lattitude
Vs-A5	7.954862	56.129197
Vs-A6	7.953905	56.123564
Vs-A7	7.952948	56.117922
Vs-A8	7.951975	56.112289
Vs-A9	7.951019	56.106656
Vs-A10	7.950063	56.101023
Vs-B10	7.971196	56.099494
Vs-D3	7.951724	56.135730
Vs-A11	7.949107	56.095390
Vs-A12	7.948151	56.089748
Vs-A13	7.947196	56.084115
Vs-A14	7.946241	56.078482
Vs-A15	7.945286	56.072849
Vs-A16	7.944316	56.067216
Vs-A17	7.943362	56.061574
Vs-B11	7.970238	56.093852
Vs-B12	7.969279	56.088219
Vs-B13	7.968321	56.082586
Vs-B14	7.967363	56.076954
Vs-B15	7.966405	56.071321
Vs-B16	7.965431	56.065679
Vs-B17	7.964474	56.060046
Vs-B18	7.963517	56.054413
Vs-C14	7.988482	56.075421
Vs-C15	7.987521	56.069788
Vs-C16	7.986561	56.064147
Vs-C17	7.985585	56.058514
Vs-C18	7.984625	56.052881
Vs-B19	7.962560	56.048780
Vs-B20	7.961604	56.043147
Vs-C19	7.983665	56.047248
Vs-C20	7.982705	56.041616
Vs-C21	7.981746	56.035974

Turbine ID	Longitude	Lattitude
Vs-C22	7.980787	56.030341
Vs-D1	8.022188	56.147126
Vs-E1	8.043344	56.145584
Vs-D2	8.021204	56.141493
Vs-E2	8.042374	56.139952
Vs-E3	8.041387	56.134319
Vs-E4	8.040418	56.128678
Vs-E5	8.039448	56.123046
Vs-E6	8.038478	56.117414
Vs-E7	8.037509	56.111781
Vs-E8	8.036540	56.106149
Vs-E9	8.035572	56.100508
Vs-D14	8.009601	56.073885
Vs-D15	8.008637	56.068244
Vs-D16	8.007673	56.062611
Vs-D17	8.006694	56.056978
Vs-E10	8.034588	56.094875
Vs-E11	8.033620	56.089243
Vs-E12	8.032652	56.083610
Vs-E13	8.031684	56.077978
Vs-E14	8.030717	56.072337
Vs-D18	8.005731	56.051346
Vs-D19	8.004768	56.045713
Vs-D20	8.003805	56.040072
Vs-D21	8.002843	56.034439
Vs-D22	8.001881	56.028806
Vs-D23	8.000919	56.023174
Vs-E18	8.026835	56.049807
Vs-E19	8.025869	56.044174
Vs-E20	8.024904	56.038533
Vs-E21	8.023938	56.032900
Vs-E22	8.022973	56.027268
Vs-E23	8.022009	56.021635

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APPENDIX
2
DESCRIPTION OF THE CALCULATION TOOL MARCS

14.1 Overview

The Marine Accident Risk Calculation System (MARCS) was developed by DNV to support our marine risk management consultancy business. The MARCS model provides a general framework for the performance of marine risk calculations. A block diagram of the model is shown in *Figure 14-1*.

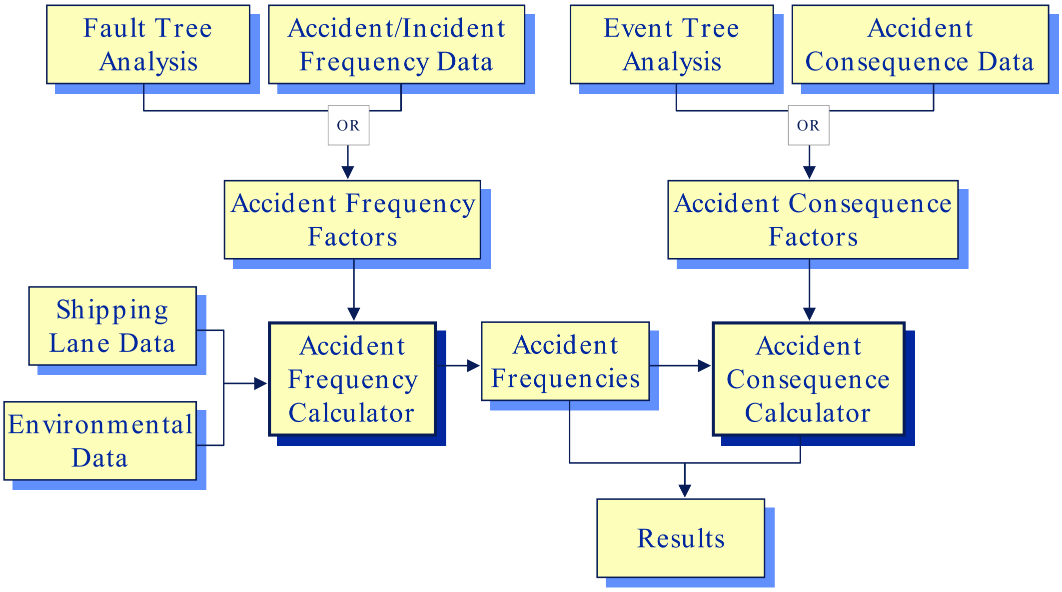

Figure 14-1: Block Diagram of MARCS

The MARCS model classifies data into 4 main types:

- Shipping lane data describes the movements of different marine traffic types within the study area;
- Environment data describes the conditions within the calculation area, including the location of geographical features (land, offshore structures etc) and meteorological data (visibility, wind rose, currents and sea state);
- Internal operational data describes operational procedures and equipment installed onboard ship – such data can affect both accident frequency and accident consequence factors;
- External operational data describes factors external to the ship that can affect ship safety, such as VTMS (Vessel Traffic Management Systems), TSS (Traffic Separation Schemes), and the location and performance of emergency tugs – such data can affect both accident frequency and accident consequence factors.

As indicated in *Figure 14-1*, accident frequency and consequence factors can be derived in two ways. If a coarse assessment of accident risk is required, the factors may be taken from worldwide historical accident data. Alternatively, if a more detailed study is required, these factors may be derived from generic fault trees or event trees which have been modified to take account of specific local factors.

14.2 Critical Situations

MARCS calculates the accident risk in stages. It first calculates the location dependent frequency of critical situations (the number of situations which could result in an accident –"potential accidents" – at a location per year; a location is defined as a small part of the study area, in this case about 1/8 nautical mile square, but depending on the chosen calculation resolution). The definition of a critical situation varies with the accident mode. MARCS then assesses the location dependent frequency of serious accidents for each accident mode via "probability of an accident given a critical situation" parameters. A "serious accident" is defined by Lloyds as any accident where repairs must be made before the ship can continue to trade. Finally, the location dependent accident consequence, and hence risk, is assessed.

14.3 Data used by MARCS

14.3.1 Traffic Image Data

The marine traffic image data used by MARCS is a representation of the actual flows of traffic within the calculation area. Marine traffic data is represented using lane data structures. Different traffic types are divided into separate marine databases in order to facilitate data verification and the computation of different types of risk (for example, crude oil spill risk versus human safety).

A typical traffic lane is shown in *Figure 14-2*. The following data items are defined for all lanes:

1. The lane number (a unique identifier used as a label for the lane);
2. The lane width distribution function (Gaussian, truncated Gaussian or uniform);
3. The lane directionality (one-way or two-way);
4. The annual frequency of ship movements along the lane;
5. A list of waypoints, and an associated lane width parameter at each waypoint;
6. The vessel size distribution on the lane.

Additional data may be attached to the lane, such as: the hull type distribution (single hull, double hull, etc) for tankers; the loading type (full loading, hydrostatic loading) for tankers; ship type etc.

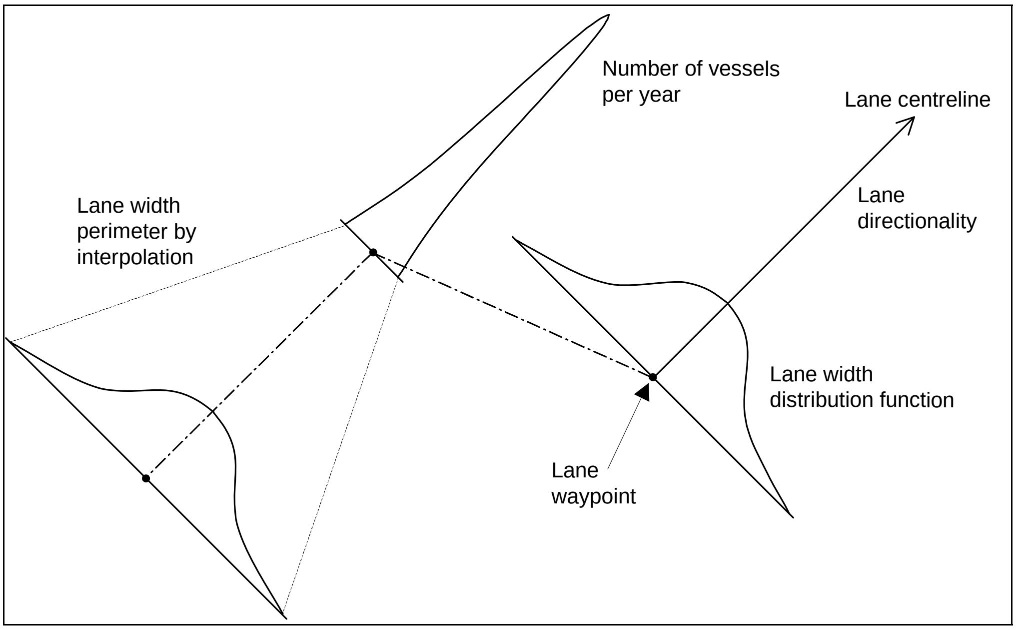

Figure 14-2: Shipping Lane representation used in MARCS

Detailed surveys of marine traffic in UK waters in the mid 1980s (e.g. HMSO, 1985, ref /C/) concluded that commercial shipping follows fairly well defined shipping lanes, as opposed to mainly random tracks of individual ships. Further detailed analysis of the lanes showed that the lateral distribution across the lane width was approximately Gaussian, or truncated Gaussian plus a small part uniform distributed for traffic arriving in coastal waters from long haul voyages (e.g. from the US or Canada). The transverse ship distribution is also investigated in Øresund where the analysis is based on registrations carried out by VTS Drogden, ref. /F/.

The shipping lane distributions used in MARCS are shown in Figure 14-3.

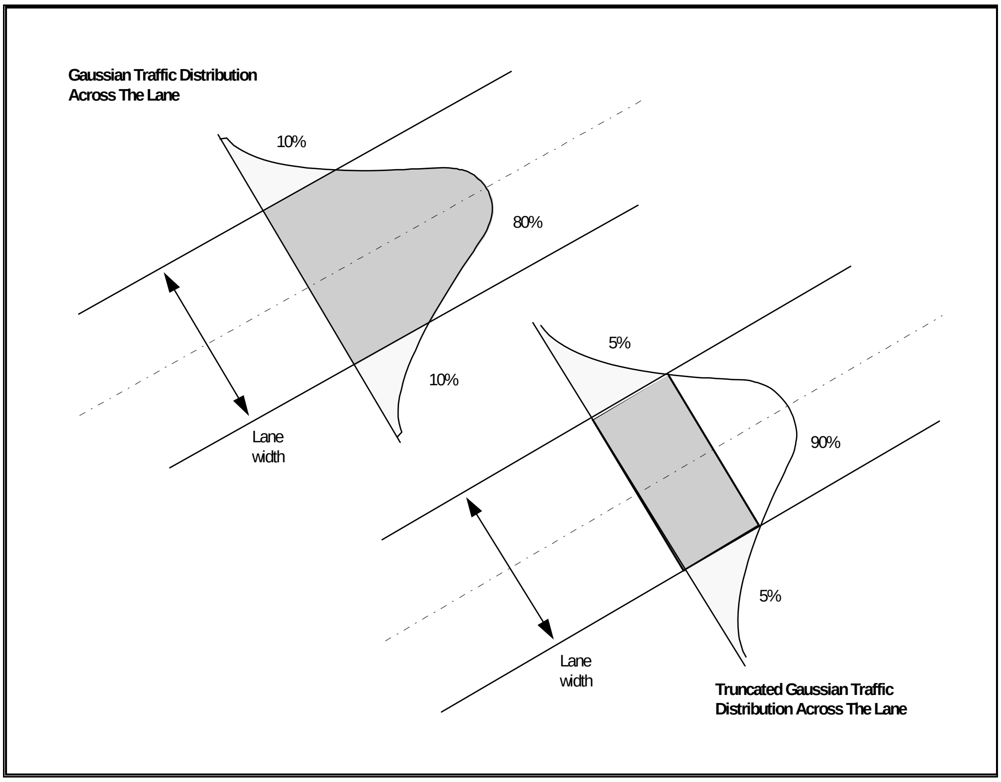

Figure 14-3: Shipping Lane Width Distribution Functions used in MARCS

The marine traffic description used by MARCS is completed by the definition of four additional parameters for each type of traffic:

- Average vessel speed (generally 8 to 18 knots);
- Speed fraction applied to faster and slower than average vessels (generally plus/minus 20%);
- Fraction of vessels travelling faster and slower than the average speed (generally plus/minus 20%);
- Fraction of vessels that exhibit "rogue" behaviour (generally set to 0%, though historical accident data in many geographical areas shows a small proportion of (usually) smaller vessels undergo accidents through lack of watch keeping (bridge personal absent or incapacitated)).

A rogue vessel is defined as one that fails to adhere (fully or partially) to the Collision Avoidance Rules (Cockcroft, 1982, ref. /A/). Such vessels are assumed to represent an enhanced collision hazard. These four parameters can be specified as a function of location within the study area for each traffic type.

The marine traffic image is made up by the superposition of the defined traffic for each contributing traffic type.

14.3.2 Internal Operational Data

Internal operational data is represented within MARCS using either worldwide data or frequency factors obtained from fault tree analysis or location specific survey data. Fault tree parameters take into consideration factors such as crew watch-keeping competence and internal vigilance (where a second crew member, or a monitoring device, checks that the navigating officer is not incapacitated by, for example, a heart attack). Examples of internal operational data include:

- The probability of a collision given an encounter;
- The probability of a powered grounding given a ship's course is close to the shoreline;
- The frequency (per hour at risk) of fires or explosions.

Internal operational data may be defined for different traffic types and/or the same traffic type on a location specific basis.

14.3.3 External Operational Data

External operational data generally represents controls external to the traffic image, which affect marine risk. In MARCS it relates mainly to the location of VTS zones (which influence the collision and powered grounding frequencies by external vigilance, where external vigilance means that an observer external to the ship may alert the ship to prevent an accident) and the presence and performance of emergency towing vessels (tugs) which can save a ship from drift grounding.

14.3.4 Environment Data

The environment data describes the location of geographical features (land, offshore structures etc.) and meteorological data (visibility, wind rose, sea currents and sea state).

Poor visibility arises when fog, snow, rain or other phenomena restricts visibility to less than 2 nautical miles. It should be noted that night-time is categorized as good visibility unless fog, for example, is present.

Wind rose data is defined within 8 compass points (north, north-east, east etc.) in 4 wind speed categories denoted: calm (0 – 20 knots); fresh (20 to 30 knots); gale (30 to 45 knots); and storm (greater than 45 knots). Sea state (wave height) within MARCS is inferred from the wind speed and the nature of the sea area (classified as sheltered, semi-sheltered or open water).

Sea currents are represented as maximum speeds in a defined direction within an area.

14.4 Description of Accident Frequency Models

The section describes how MARCS uses the input data (traffic image, internal operational data, external operational data and environment data) to calculate the frequency of serious accidents in the study area.

14.4.1 The ship – ship Collision Model

The collision model calculates the frequency of serious inter-ship powered collisions at a given geographical location in two stages. The model first estimates the frequency of encounters (critical situations for collision - when two vessels pass within 0.5 nautical miles of each other) from the traffic image data using a pair-wise summation technique, assuming no collision avoiding actions are taken. This enables the calculation of either total encounter frequencies, or encounter frequencies involving specific vessel types.

The model then applies a probability of a collision for each encounter, obtained from fault tree analysis, to give the collision frequency. The collision probability value depends on a number of factors including, for example, the visibility or the presence of a pilot. *Figure 14-4* shows a graphical representation of the way in which the collision model operates.

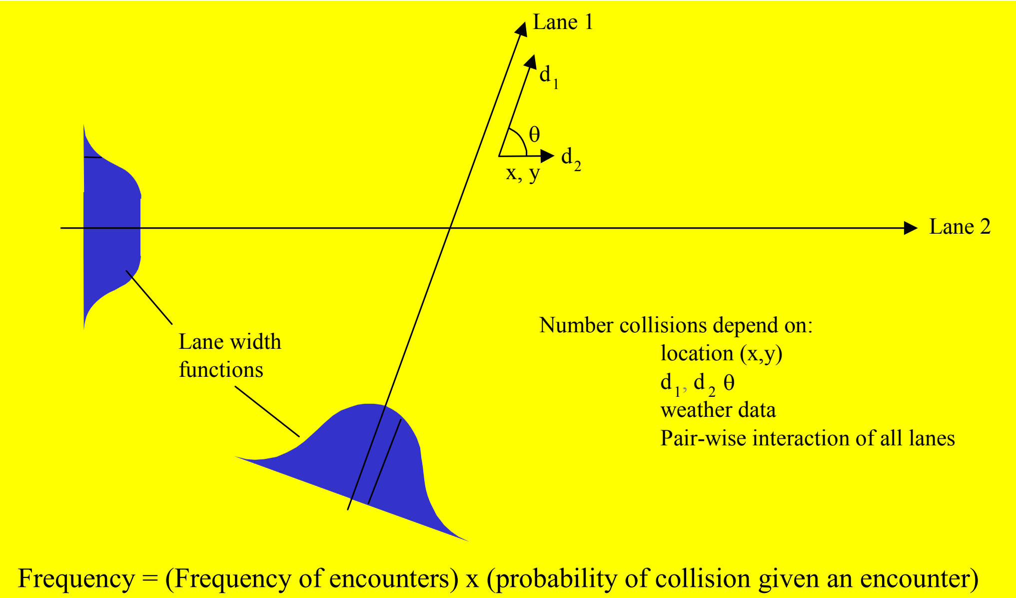

Figure 14-4: Graphical representation of the collision model

In Figure 14-4, d_1 refers to the density of traffic associated with lane 1 at the location x, y. The frequency of encounters at location x, y through the interaction of lanes 1 and 2 is proportional to the product of d_1, d_2 and the relative velocity between the lane densities.

14.4.2 The Powered Grounding Model

The powered grounding frequency model calculates the frequency of serious powered grounding accidents in two stages. The model first calculates the frequency of critical situations (sometimes called “dangerous courses” for powered grounding accidents). A critical situation is defined as a planned course change point (waypoint) located such that failure to make the course change would result in grounding within 20 minutes navigation from the planned course change point if the course change is not made successfully.

The frequency of serious powered groundings is calculated as the frequency of critical course changes multiplied by the probability of failure to make the course change correctly. *Figure 14-5* shows a graphical representation of the way in which the powered grounding model operates.

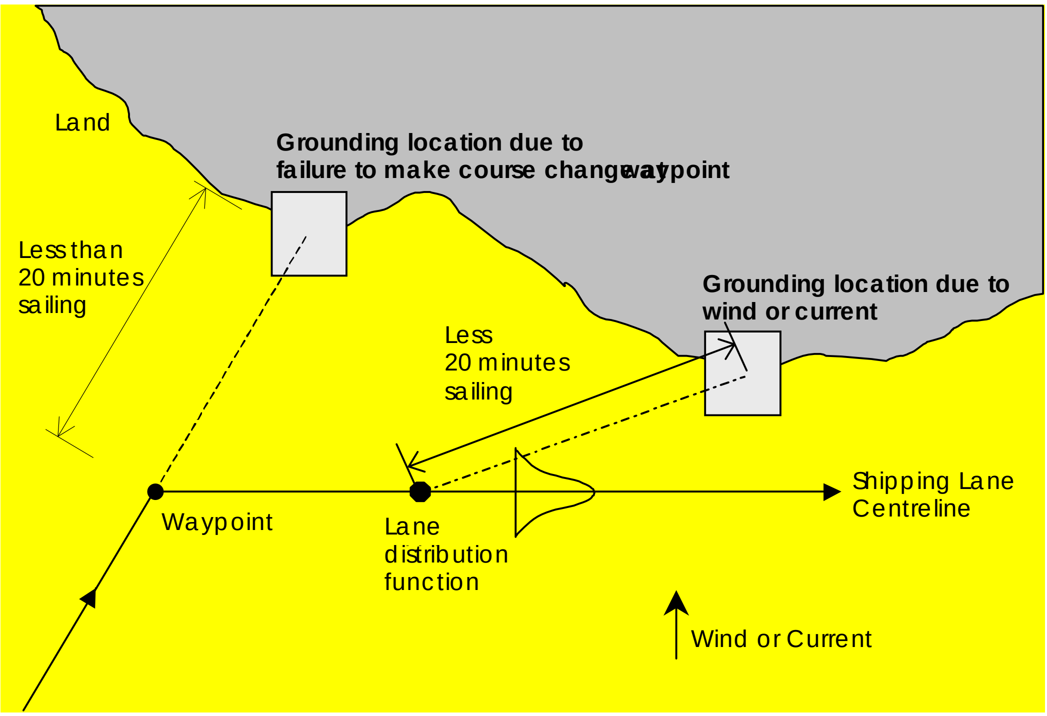

Figure 14-5: Graphical representation of the powered grounding model

The powered grounding parameters are derived from the fault tree analysis of powered grounding. The powered grounding fault tree contains 2 main branches:

- Powered grounding through failure to make a course change whilst on a dangerous course. A dangerous course is defined as one that would ground the vessel within 20 minutes if the course change were not made.
- Powered grounding caused by crew inattention and wind or current from the side when the ship lane runs parallel to a shore within 20 minutes sailing (the frequency of this hazard mode is not assessed in this project).

Both these branches are illustrated in *Figure 14-5*. The powered grounding frequency model takes account of internal and external vigilance, visibility and the presence of navigational aids (radar) in deducing failure parameters.

14.4.3 The Drift Grounding Model

The drift grounding frequency model consists of two main elements as follows: first, the shipping activities image is combined with the ship breakdown frequency factor to generate the location and frequency of vessel breakdowns; second, the recovery of control of drifting ships can be regained by one of 3 mechanisms: a) repair, b) emergency tow assistance, or c) anchoring. Those drifting ships that are not saved by one of these three mechanisms (and do not drift out into the open sea) contribute to the serious drift grounding accident frequency results.

The number and size distribution of ships which start to drift is determined from the ship breakdown frequency, the annual number of transits along the lane and the size distribution of vessels using the lane. The proportion of drifting vessels which are saved (fail to ground) is determined from the vessel recovery models. The drift grounding frequency model is illustrated in Figure 14-6.

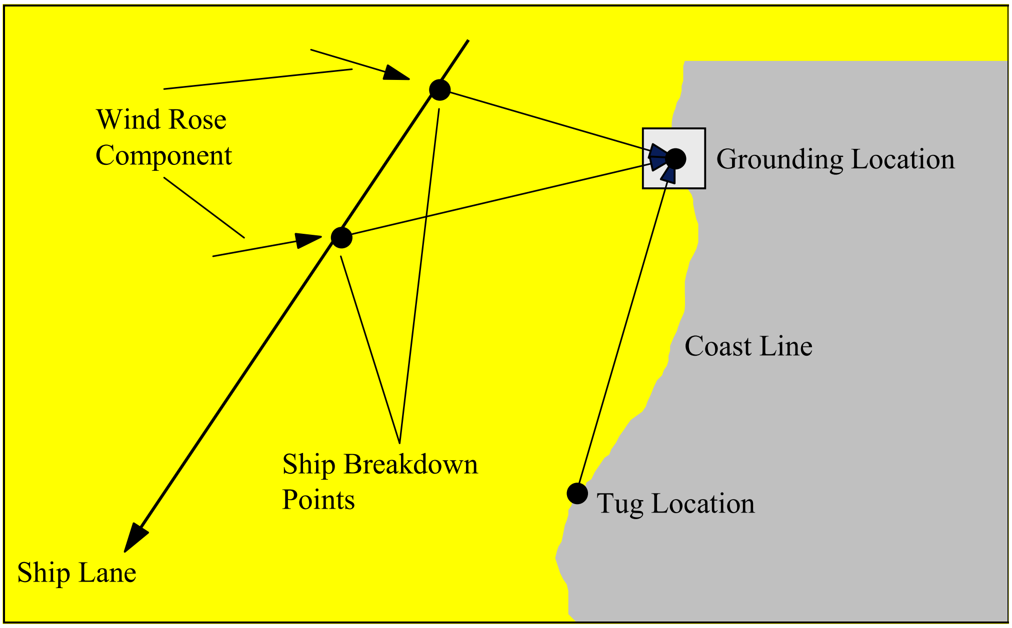

Figure 14-6: Graphical representation of the drift grounding model

Implicit in Figure 14-6 is the importance of the time taken for the ship to drift aground. When this time is large (because the distance to the shore is large and/or because the drift velocity is small) then the probability that the ship will recover control before grounding (via repair or tug assistance) will be increased.

14.5 Repair Recovery Model

Vessels which start to drift may recover control by effecting repairs. For a given vessel breakdown location, grounding location and drift speed there is a characteristic drift time to the grounding point. The proportion of drifting vessels which have recovered control by self-repair is determined from this characteristic drift time and the distribution of repair times.

The graph given in *Figure 14-7* is the values agreed in the risk harmonization group under BSH.

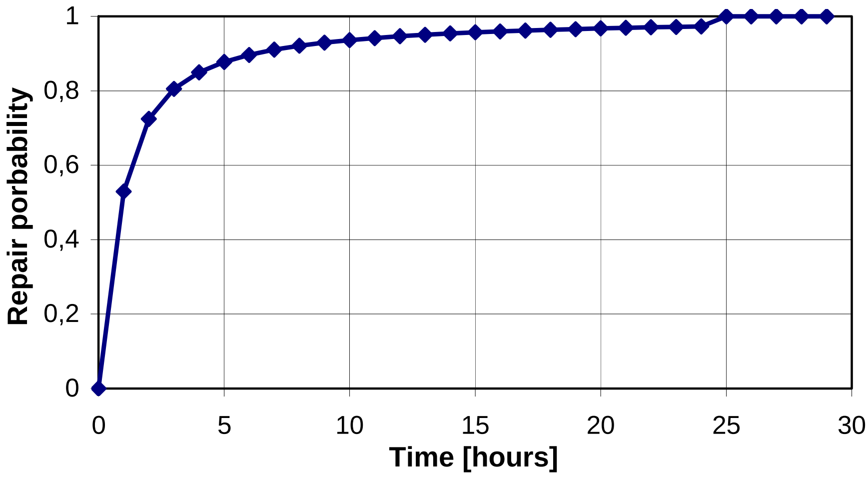

Figure 14-7: Graphical representation of the self-repair save mechanism

14.6 Recovery of Control by Emergency Tow

Drifting vessels may be brought under control (saved from grounding or collision) by being taken in tow by an appropriate tug. It should be noted that the tug save model assumes a save is made when the ship is prevented from drifting further towards the shoreline by the attachment of a suitable tug. In practice, two or more tugs would be required to complete the ship save, by towing the vessel to a safe location, but this aspect of the save is not modelled in MARCS.

Two types of tug can be represented within MARCS. Close escort tugs move with ships through their transit, thus their time to reach a drifting ship is always small. Pre-positioned tugs are located at strategic points around the study area. The model works by calculating for each tug:

- If the tug can reach the drifting vessel in time to prevent it grounding. This time consists of the time to reach the ship (almost zero when close escorting) and the time to connect and take control of the ship (which is a function of sea state);
- If the tug can reach the ship before it grounds, then the adequacy of the tug with regard to control of the ship is evaluated. (The presence of several tugs of differing power is assumed to be represented by the presence of one tug of the largest power. This is because only one tug is usually used to exert the main “saving” pull. Other tugs present are used to control the heading of the disabled ship, and to bring the ship to a safe location.)
- When several tugs of various capabilities can reach the drifting ship in time, then the tug with the best performance is assumed to be connected to the ship and takes control of the largest proportion of the drifting vessels.

The tug model contains parameters to take explicit account of:

- The availability of the tug (some tugs have other duties);
- The tugs response time (delay before assistance is summoned);
- The tug speed (as a function of sea state);
- The time to connect a line and exert a controlling influence on the ship (as a function of sea state);
- The performance of the tug (identified as the maximum control tonnage for the tug) as a function of wind speed and location (since the wind speed and the fetch control the sea state).

Tug performance parameters can take account of ship wind and wave resistance, tug wind and wave resistance and tug length and propulsion arrangement (open versus nozzle) which influences the propulsion efficiency.

14.7 Recovery of Control by Anchoring

The anchor save model is derived with reference to the following reasoning:

1. Anchoring is only possible if there is a sufficient length of suitable water to prevent the ship running aground. Suitable water is defined as a depth of between 30 fathoms (about 60m - maximum for deployment of anchor) and 10 fathoms (about 20m - minimum for ship to avoid grounding). Sufficient length is calculated as 100m for anchor to take firm hold of the seabed + 300m to stop ship + 300m for length of ship + 100m for clearance = 800m, or 0.5 nautical miles (to be slightly conservative).
2. If such a track exists, then the probability that the anchor holds is calculated as a function of the wind speed and the sea bottom type (soft sea beds consist predominantly of sands, silts and muds). If the anchor hold, then an anchor save is made.

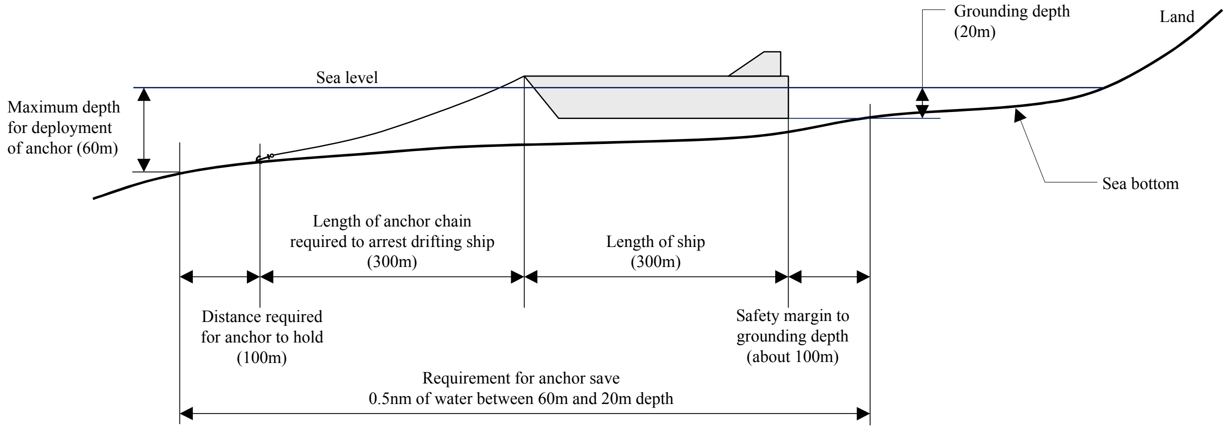

Figure 14-8: Graphical representation of the Anchor save mechanism

The anchor save model is conservative in that it under-predicts the effectiveness of this save mechanism for average and smaller ships.

14.8 Description of Accident Consequence Models

Marine transport risks are estimated by combining the frequencies of serious accidents with the accident consequences, given a serious accident. Marine accident consequences are typically expressed in terms of cargo spilled, lives lost or financial loss.

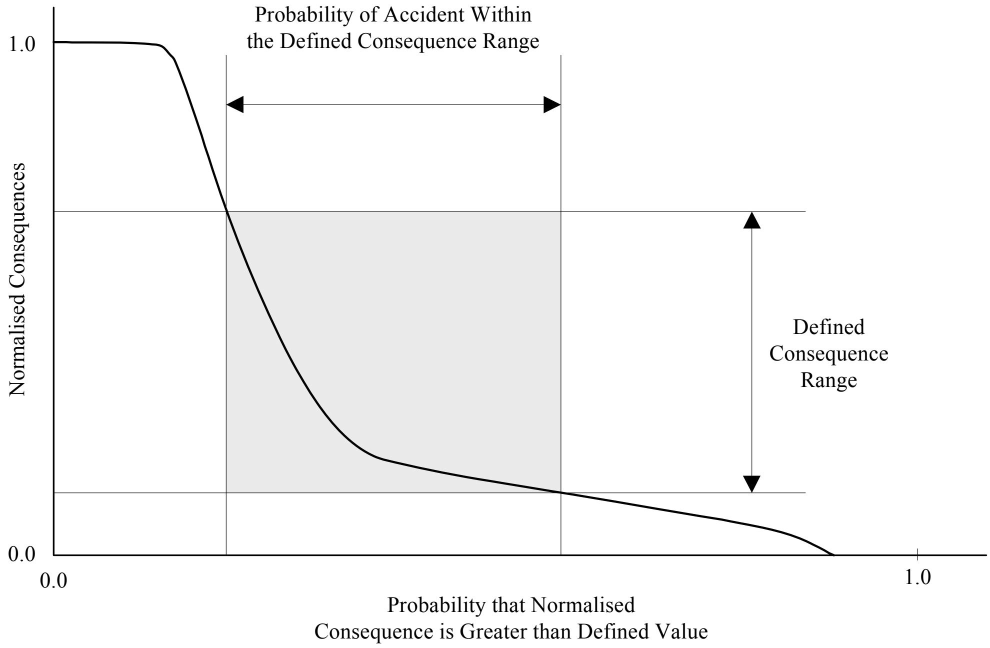

Figure 14-9: Generic Accident Consequence versus Probability Curve

Previous projects performed by DNV have developed crude oil outflow models for different accident types (collision, fire/explosion etc.) and different hull configurations (single hull, double hull etc.). These models (normalized cumulative probability distributions) take the generic form shown in *Figure 14-9*. The curve shows the normalized consequence (in terms of, for example, cargo mass outflow into the environment) versus the probability that the consequence is greater than this value. Thus the normalized consequence of 1.0 (equal to total loss of all cargo carried) occurs for relatively low probabilities, whereas the probability that the normalized consequence is greater than a small fraction of the cargo carried generally approaches 1.0 for single hulled ships.

14.9 Marine Accident Risk Acceptance Criteria, Targets and Benchmarks

In general, responsible operators define their objective as zero accidents. However a risk assessment that estimates zero risk from an operation is not credible. The objective of risk management is, therefore, to ensure that estimated risk levels for an operation are acceptable (by comparison to risk acceptance criteria or through cost-benefit analysis). Where risks are not acceptable, additional risk reduction measures are introduced to reduce the risks to acceptable levels.

Marine accidents result in losses/impacts in 3 main areas:

- Human fatalities;
- Environmental impacts due to cargo or fuel oil release;
- Financial impacts.

It would be convenient if established criteria existed to judge the acceptability of the risks posed by a specific operation or trade. However, at the present time there are no established, generally accepted criteria which can be used to judge if calculated marine risk levels are acceptable. This statement is especially true for accidents involving the release of cargo into the marine environment.

In order to address this lack of criteria, risk analysts within DNV have proposed risk acceptance criteria for application in the marine industry. It is important to emphasise that, at this stage, the criteria quoted below are neither official DNV criteria nor are they recognised by regulatory bodies. Individual human fatality criteria are given in Table 14.1.

Risk Acceptance Criteria	Value
Maximum tolerable risk for crew members	1 fatality per thousand at risk per year
Maximum tolerable risk for ship passengers	1 fatality per ten thousand at risk per year
Maximum tolerable risk for public ashore	1 fatality per ten thousand at risk per year

Table 14-1: Proposed Individual Human Fatality Risk Acceptance Criteria for the Shipping Industry (Spouge, 1997, ref. /E/; DNV 1999, ref /B/)

The criteria shown in *Table 14-1* are closely related to the HSE individual risk criteria (HSE 99, ref. /D/), which in turn are based upon observed fatality rates in a number of industries in the UK.

Table 14-2 shows total loss and oil spill targets proposed by DNV for the shipping industry. It should be noted that DNV do not consider it is essential to meet these targets, but if they are not met it may indicate that cost-effective risk reduction measures may be available.

Risk Targets	**Value**
Target total ship loss frequency	2 losses per thousand ship-years
Target cargo spill risk	20 tonnes per million tonnes transported
Target bunker oil spill risk	20 tonnes per million tonnes consumed

Table 14-2: Proposed Total Loss, Cargo Spill and Bunker Spill Targets for the Shipping Industry (DNV, 1999, ref. /B/)

The targets shown in *Table 14-2* are based on an analysis of the worldwide shipping fleet and accident data between 1981 and 1997. They may be seen as desirable "stretch targets" based on observed accident statistics, which show an average of 70 tonnes of cargo split per million tonnes transported. There are significant uncertainties in both the cargo/bunker pollution statistics and total cargo transportation tonnage. The pollution targets shown in *Table 14-2* should, therefore, be regarded as preliminary at this stage.

The risk targets shown in *Table 14-2* are derived from marine accident data, which is sometimes under-reported. Marine risk assessment uses conservative accident models, which tend to over-predict risk levels. Thus comparison of the risk targets shown in *Table 14-2* with risk assessment results can give mis-leading results. For this reason, DNV often compare calculated risk levels with "risk benchmarks" (risks calculated in other areas). This comparison of "like with like" is thought to provide a better interpretation of risk results.

14.10 Risk Analysis, Assessment and Management

The process of estimating the frequency of accidents and the range of potential accident consequences (using MARCS, other quantitative methods or qualitatively) is called risk analysis. When combined with the evaluation of the significance of risk results the process is called risk assessment. In general, risk assessment entails finding robust answers to questions such as:

- Are the risks acceptable?
- What can be done to reduce the risks further?
- Are risk reduction measures cost effective?

Clearly the answers to these questions are related. For example, higher risks may be acceptable if there are no more cost-effective risk reduction measures to be applied.

The acceptability of risks can be determined by reference to risk acceptance criteria (such as those proposed in Section II.6 above), other risk targets or benchmarks, expert judgement or the ALARP (As Low As Reasonably Practicable) principle. Risk acceptance criteria are defined in some areas of risk assessment by regulators (mainly human fatality risk). Such criteria are often derived by expert judgement assessment of suitable benchmarks. For example, the UK Health and Safety Executive have set a maximum tolerable individual human fatality risk criteria for workers of less than 10^{-3} fatalities per year. This criterion is similar to fatality frequencies observed in the more dangerous UK industries, such as construction and mining.

When regulators have not set specific risk acceptance criteria, as is generally the case for risks to the environment, the acceptability of risks can be argued on the basis that other operations (benchmarks) with comparable or higher risks are accepted by regulators on behalf of society. Alternatively, or in addition, a thorough assessment of alternative risk reduction measures on risk levels could be used to argue a risk level is ALARP and hence acceptable. Such an analysis may be supported by a formal (quantitative) cost benefit analysis, which may show that implementing further risk reduction measures is disproportionately expensive compared with the risk reduction achieved.

Risk management is the process of using risk analysis, risk assessment and other inputs to maintain risk levels within bounds which are acceptable to the operator and their stakeholders.

14.11 References

/A/ Cockcroft, 1988: “A guide to the collision avoidance rules”, Cockcroft, A N and Lameijar J N F, Stanford Maritime, 1982.

/B/ DNV, 1999: “Acceptance Criteria for Formal Safety Assessment Based Ship Rules DRAFT Revision 1”, internal DNV project c383184, April 1999.

/C/ HMSO, 1985: “Shipping routes in the area of the UK continental shelf: Offshore technology report”, OTH 85 213, HMSO, March 1985.

/D/ HSE 1999: “Reducing Risks, Protecting People”, UK Health and Safety Executive Consultation Document, HSE Books, 1999.

/E/ Spouge, 1997: “Risk Criteria for use in Ship Safety Assessment”, Marine Risk Assessment conference organised by Institute of Marine Engineers, May 1997, ISBN 0-907206-85-9.

/F/ The Øresund Link, Transverse Distribution of Shipping activities in the Realigned Drogden Channel, Øresundskonsortiet, May 2000.

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APPENDIX
3
ENERGINET.DK DEFINITIONS OF MAGNITUDE OF IMPACT

Definitions of "magnitude of impact" as provided by Energinet.dk.

Magnitude of impact	**The following effects are dominant.**
Neutral/ no impact	No impact compared to status quo.
Negligible negative impact	Small impacts, that are local restricted, uncomplicated, short-term persistent or without long-term effects and without any reversable effects.
Minor negative impact	Impacts of some extent and complexity, a certain degree of persistence beside the short-term effects, and with some probability to occur, but most likely without irreversible effects.
Moderate negative impact	Impacts with either a relatively large extend or long-term effects (e.g., lasting for the entire life span of the wind farm), occures occasionally or with a relatively high probability, and which may cause local irreversible effects, e.g., preservation worthy elements (nature, culture, ect.). Impacts, that may cause mitigation measurements. In this case, mitigation measurements have to be integrated in the report and a new impact assessment including the recommended mitigation measurements has to be applied.
Major negative impact	Impacts with a large extend and/or long-term effects, frequently occuring and with a high probability, and with the possibility of causing significant irreversible impacts. Impacts are classified as serious, thus changes of the project or the application of mitigation measurements should be considered in order to minimize the impact amplitude. In this case, a new impact assessment is conducted, including the recommended mitigation measurements.
Positive impacts	Positive impacts on one or more of the above mentioned effects

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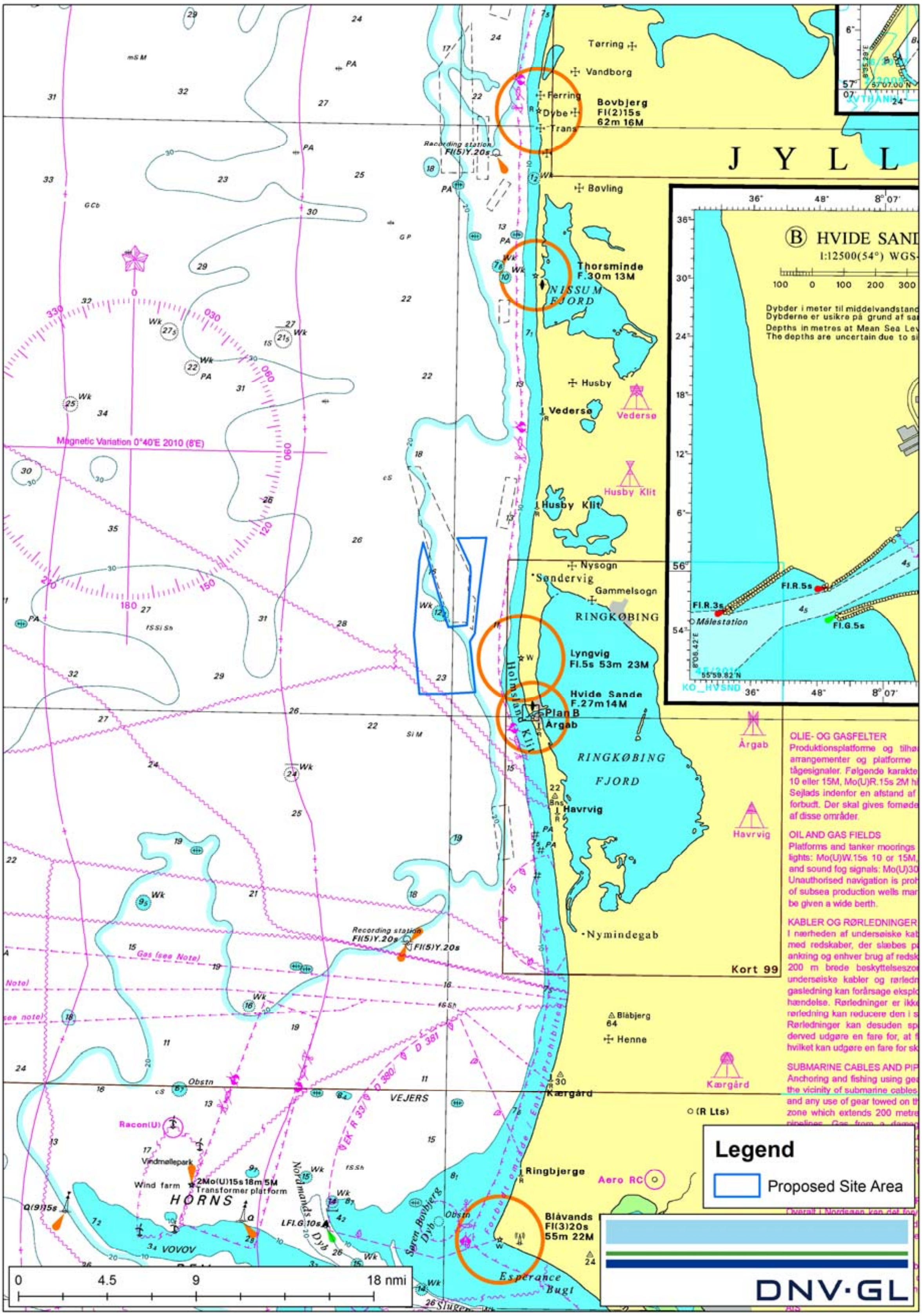
APPENDIX
4
NAUTICAL CHART


Tørring
Vandborg
Ferring
Dybe
Trans
Bovbjerg
Fl(2)15s
62m 16M
J Y L L
Bovling
Thorsminde
F.30m 13M
NISSUM
FJORD
Husby
Vedersø
Husby Klit
Nysogn
Søndervig
Gammelsogn
RINGKØBING
Lyngvig
Fl.5s 53m 23M
Hvide Sande
F.27m14M
Plan B
Årgab
Holmsland Klit
RINGKØBING
FJORD
Havrvig
Nymindegab
Kort 99
Blåbjerg
Henne
Kærgård
Ringbjerge
Aero RC
Blåvands
Fl(3)20s
55m 22M
Esperance
Bugt
HORNS
VOVOV
VEJERS
Wind farm
Transformer platform
Recording station
Fl(5)Y.20s
Magnetic Variation 0°40'E 2010 (8'E)
Gas (see Note)
Racon(U)
B HVIDE SANDE
1:12500(54°) WGS-
Dybder i meter til middelvandstand
Dybderne er usikre på grund af sa
Depths in metres at Mean Sea Le
The depths are uncertain due to s
Fl.R.5s
Fl.R.3s
Fl.G.5s
Målestation
OLIE- OG GASFELTER
OIL AND GAS FIELDS
KABLER OG RØRLEDNINGER
SUBMARINE CABLES AND PIP
Legend
Proposed Site Area
0
4.5
9
18 nmi
DNV·GL

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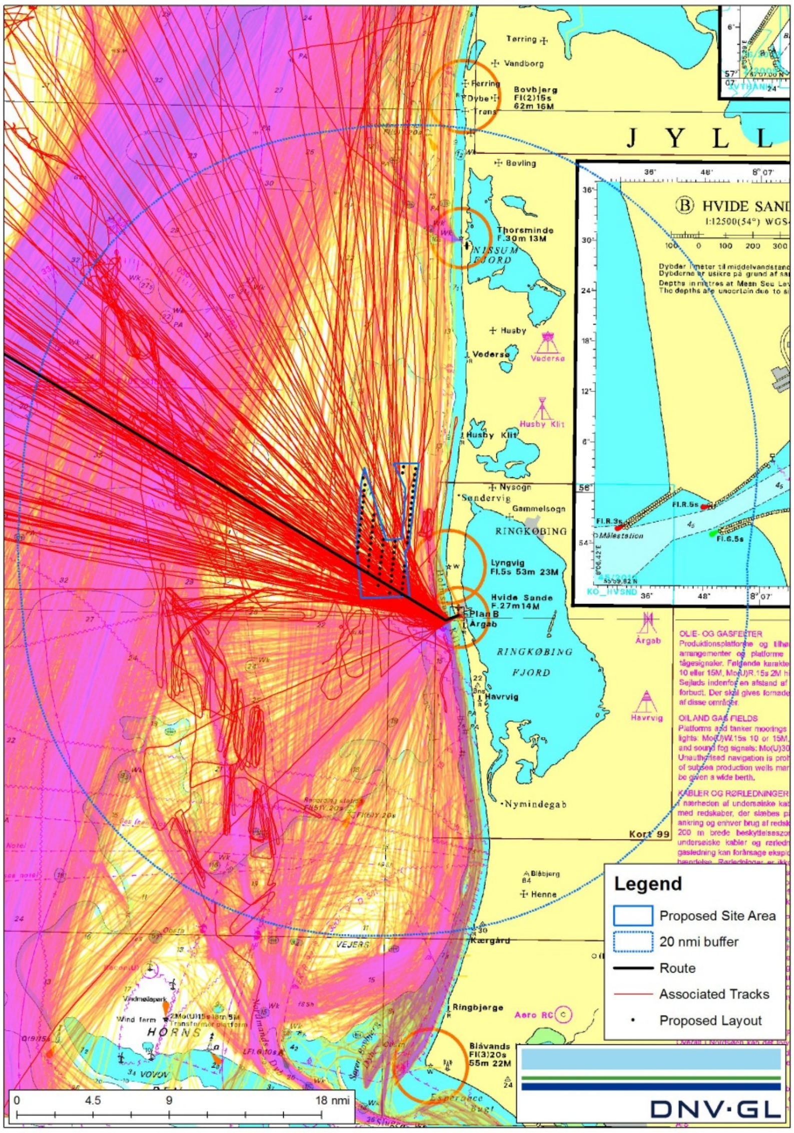
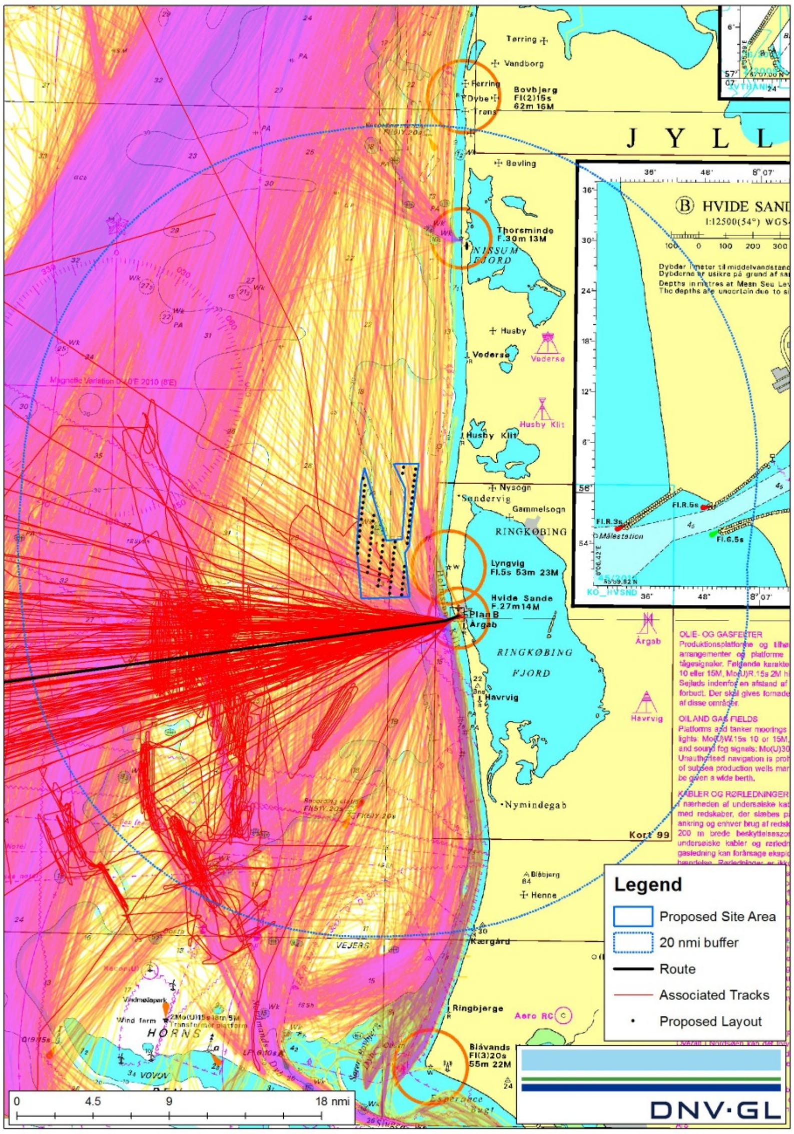
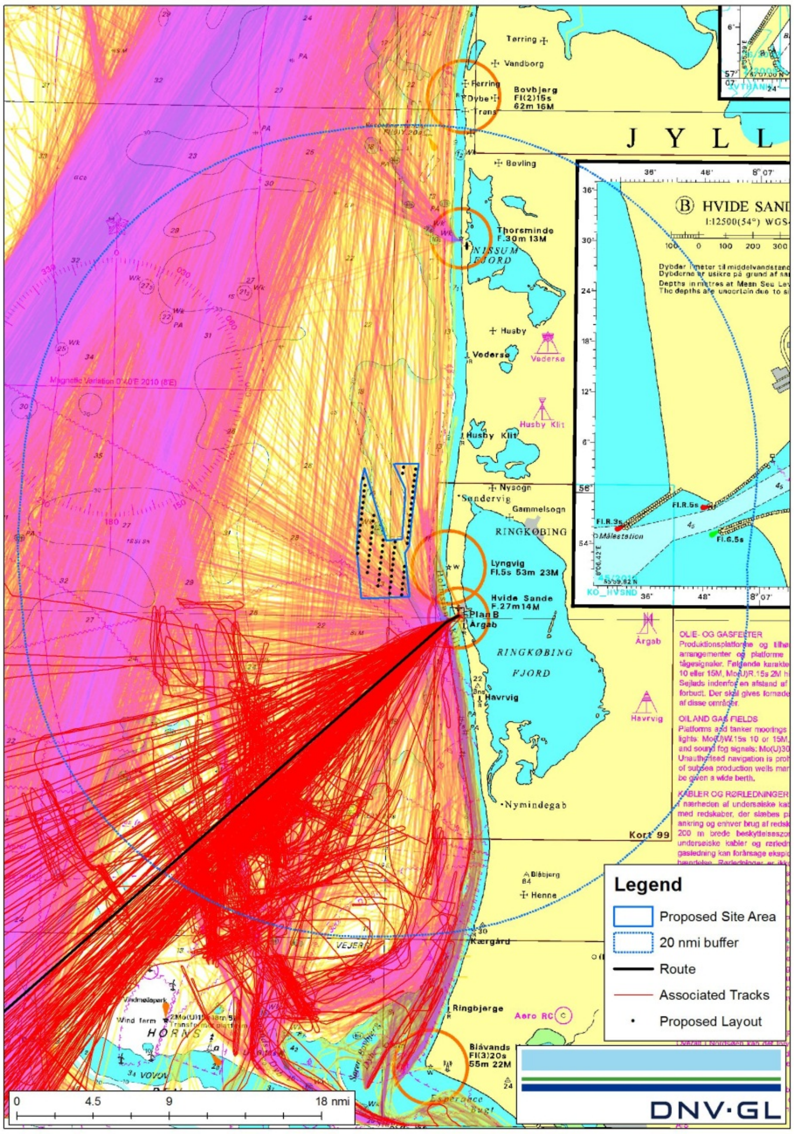
APPENDIX
5
SHIP TRAFFIC ROUTES - PLOTS



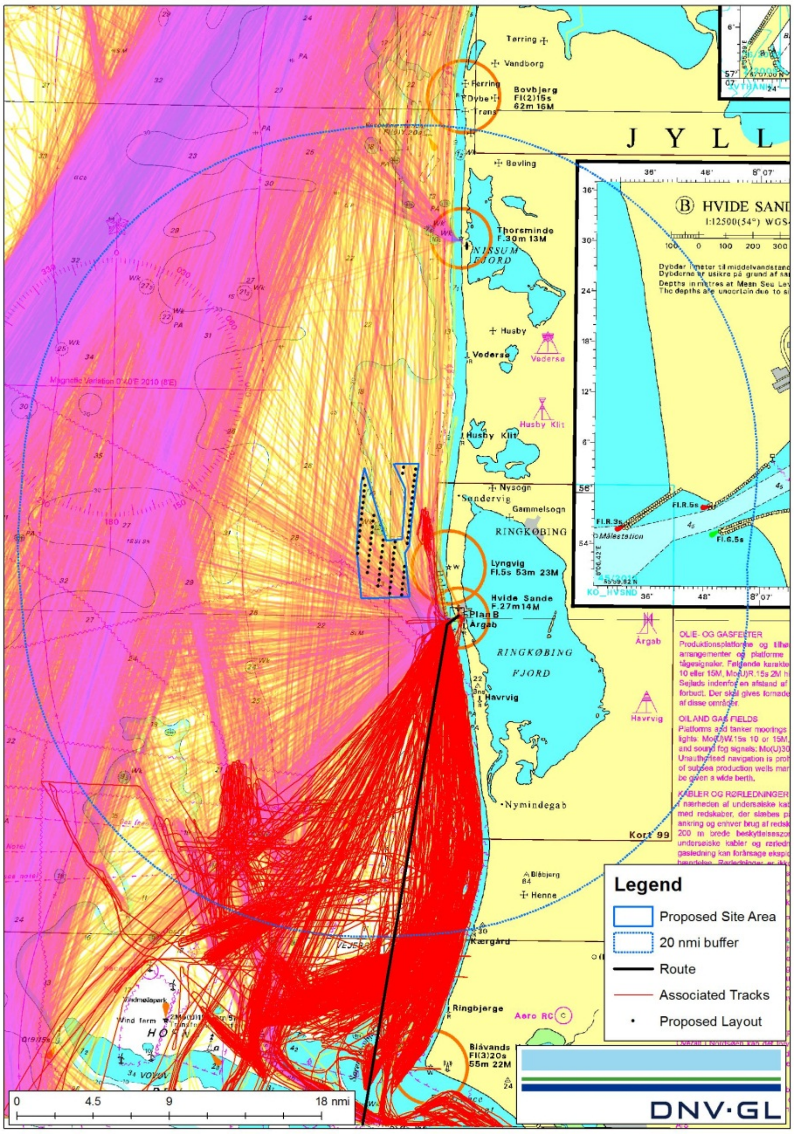
Ship traffic associated with Route 1



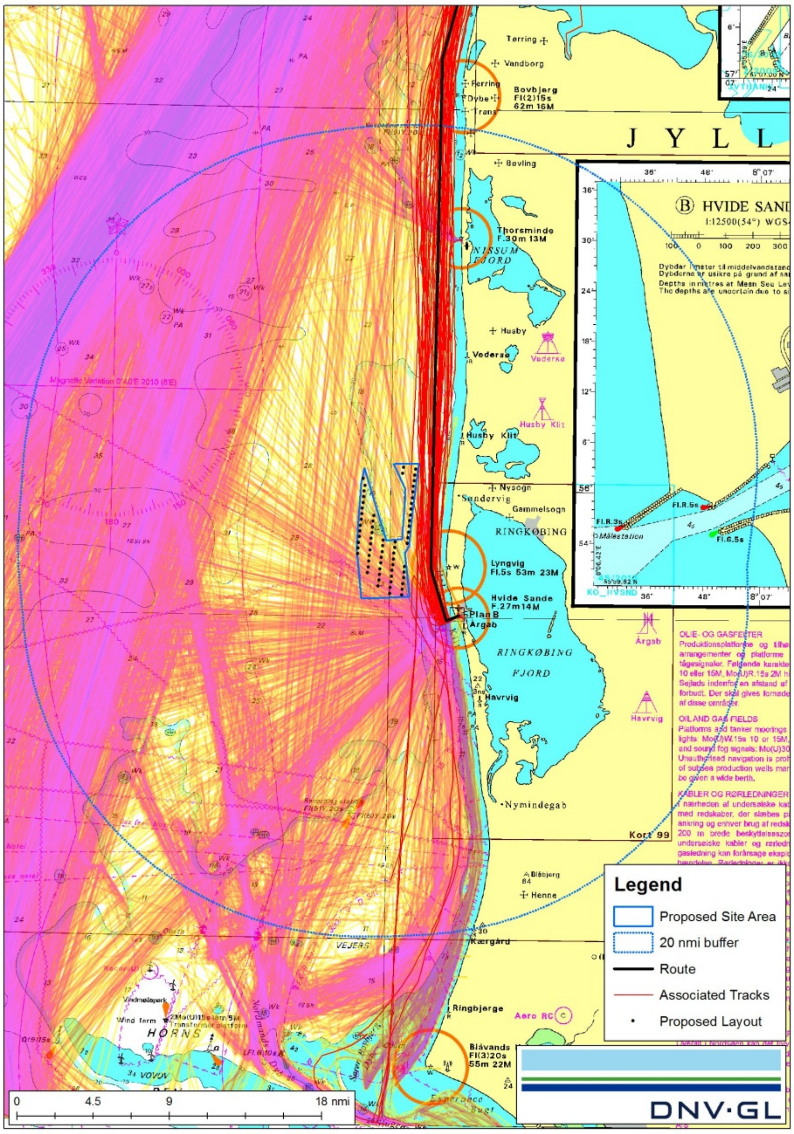
Ship traffic associated with Route 2



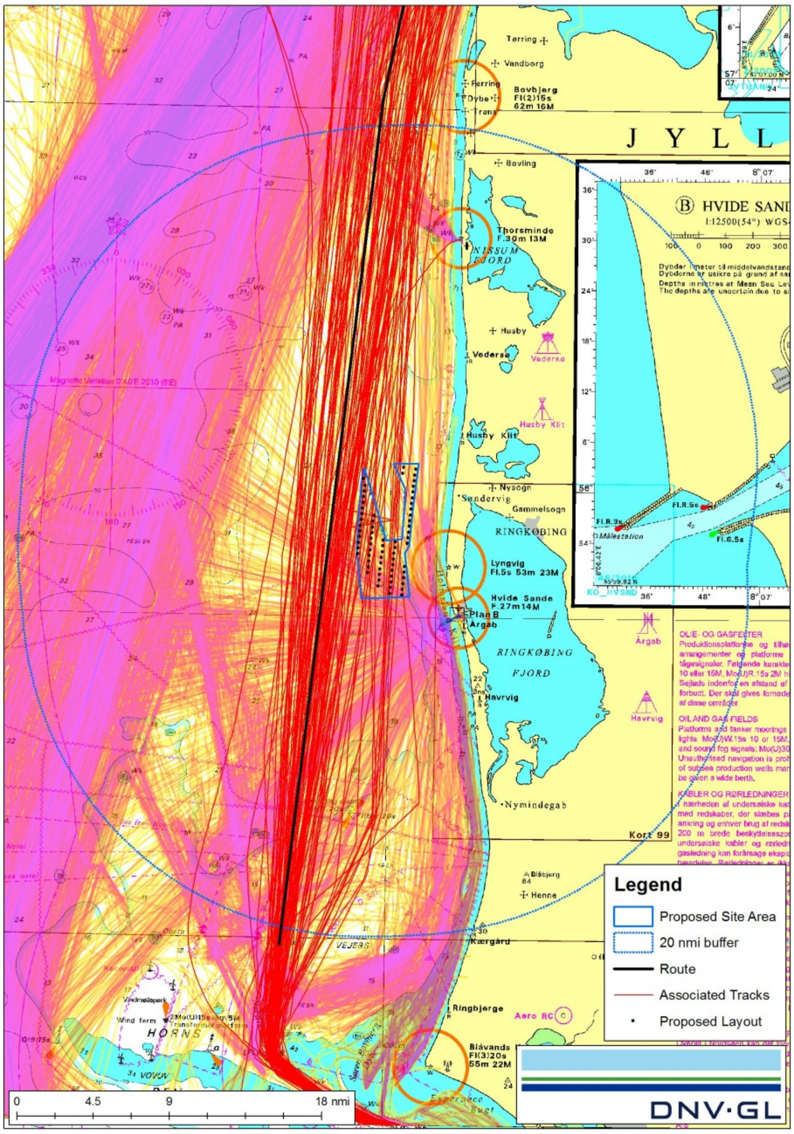
Ship traffic associated with Route 3



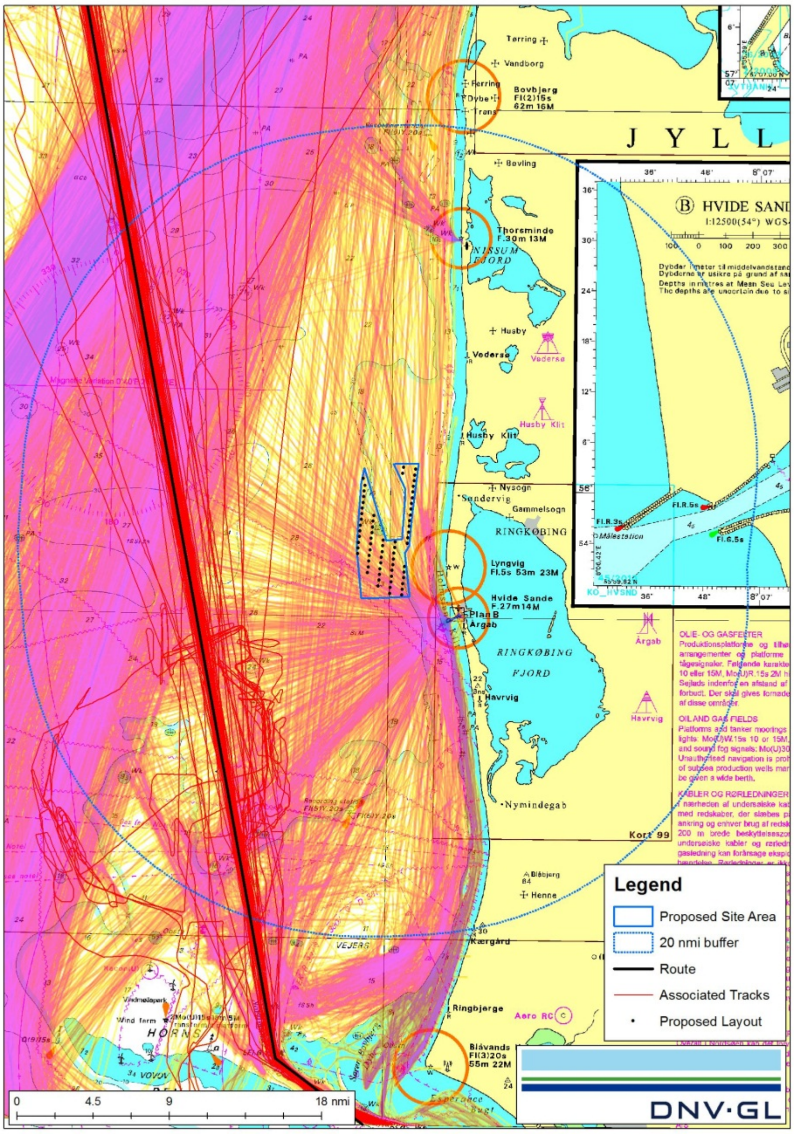
Ship traffic associated with Route 4



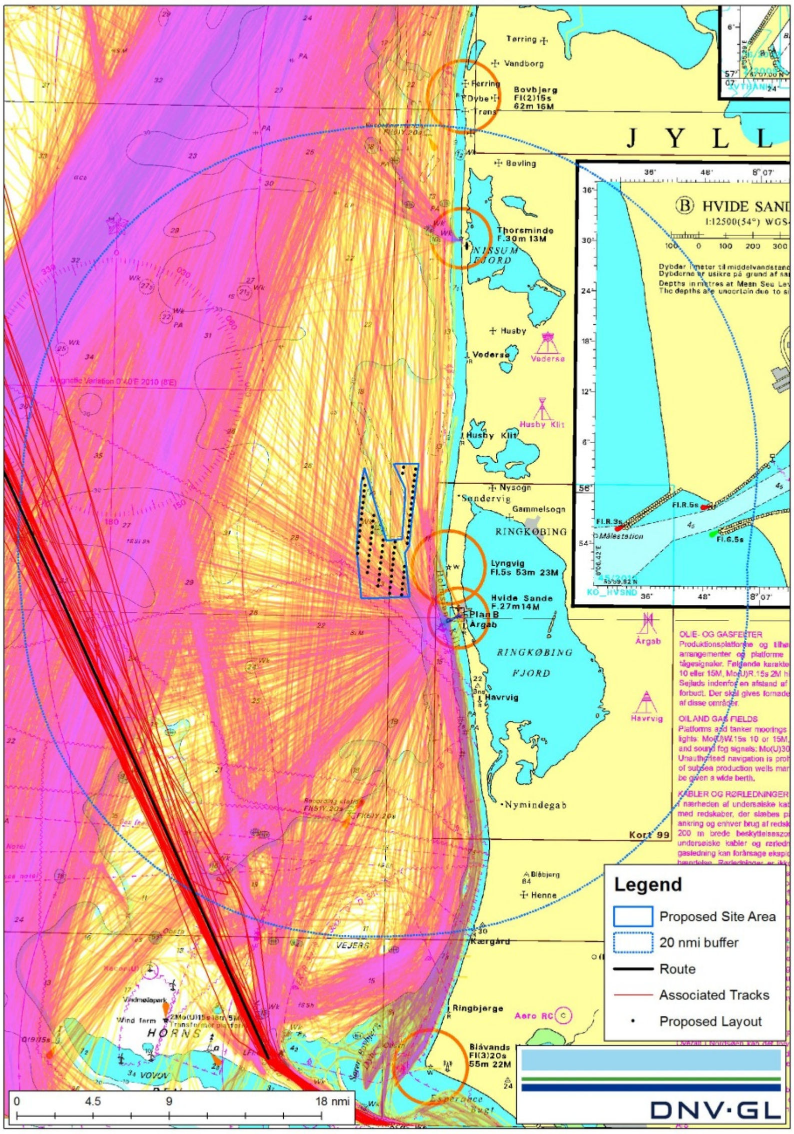
Ship traffic associated with Route 5



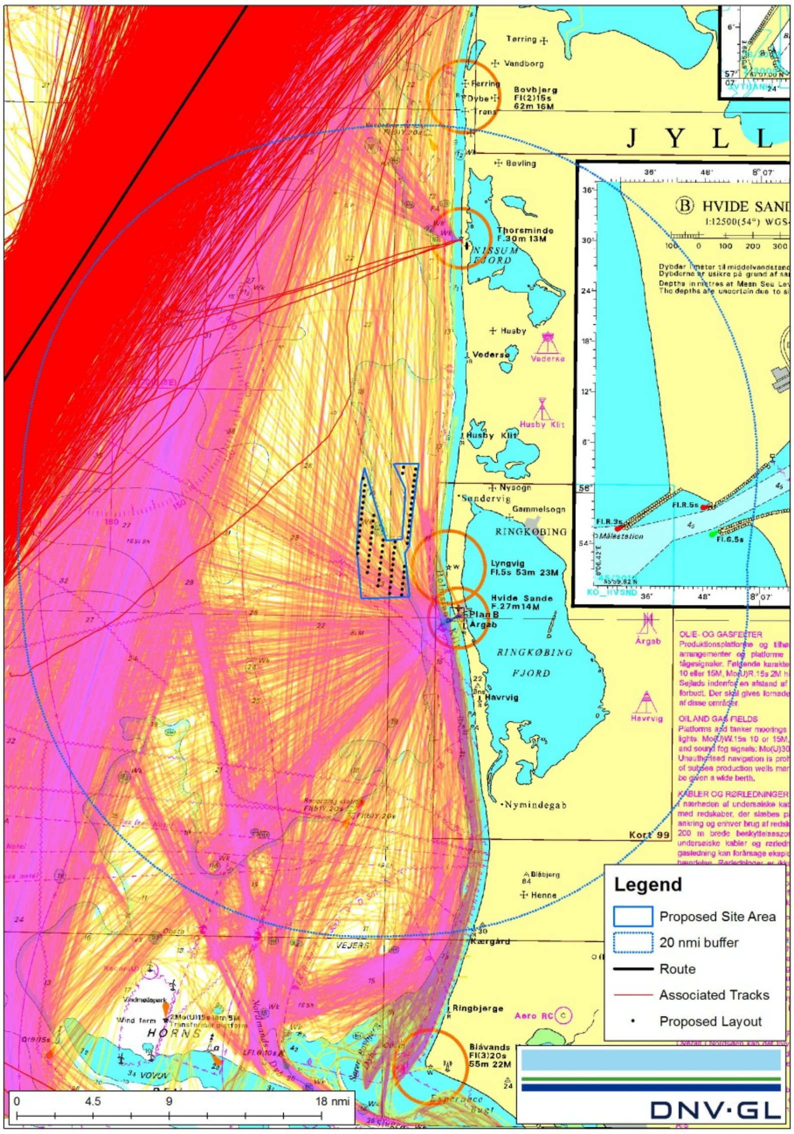
Ship traffic associated with Route 6



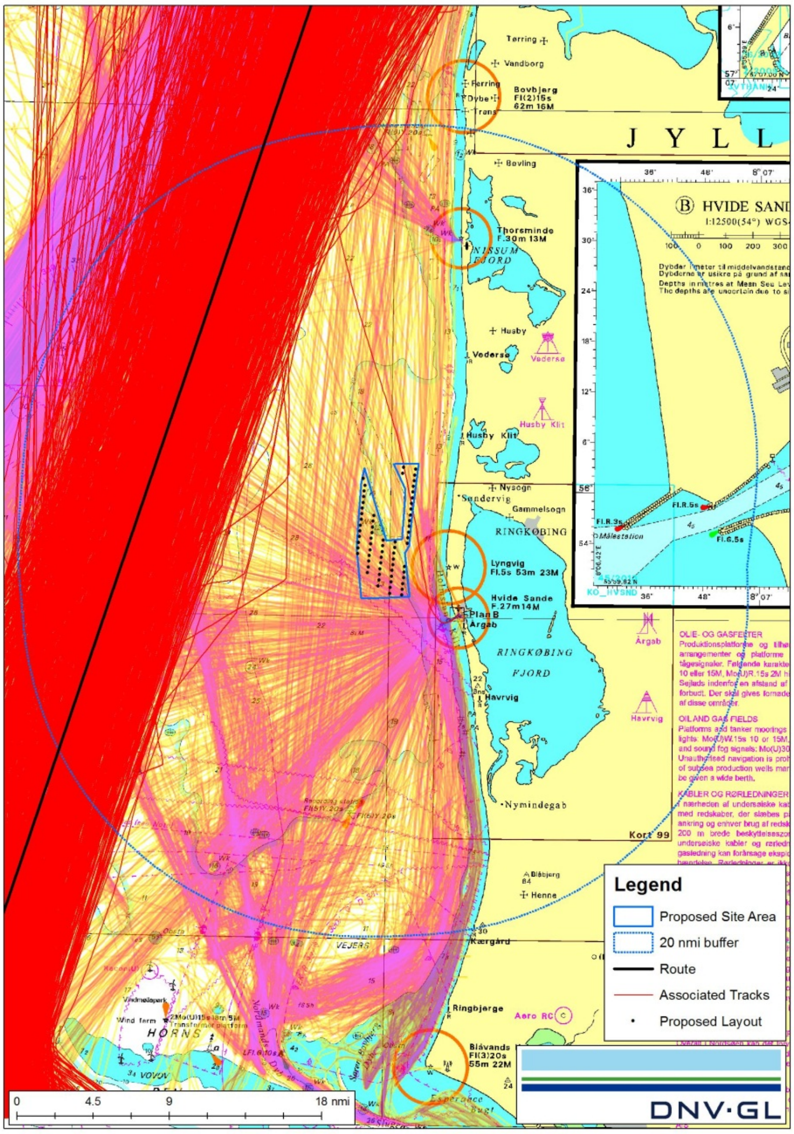
Ship traffic associated with Route 7



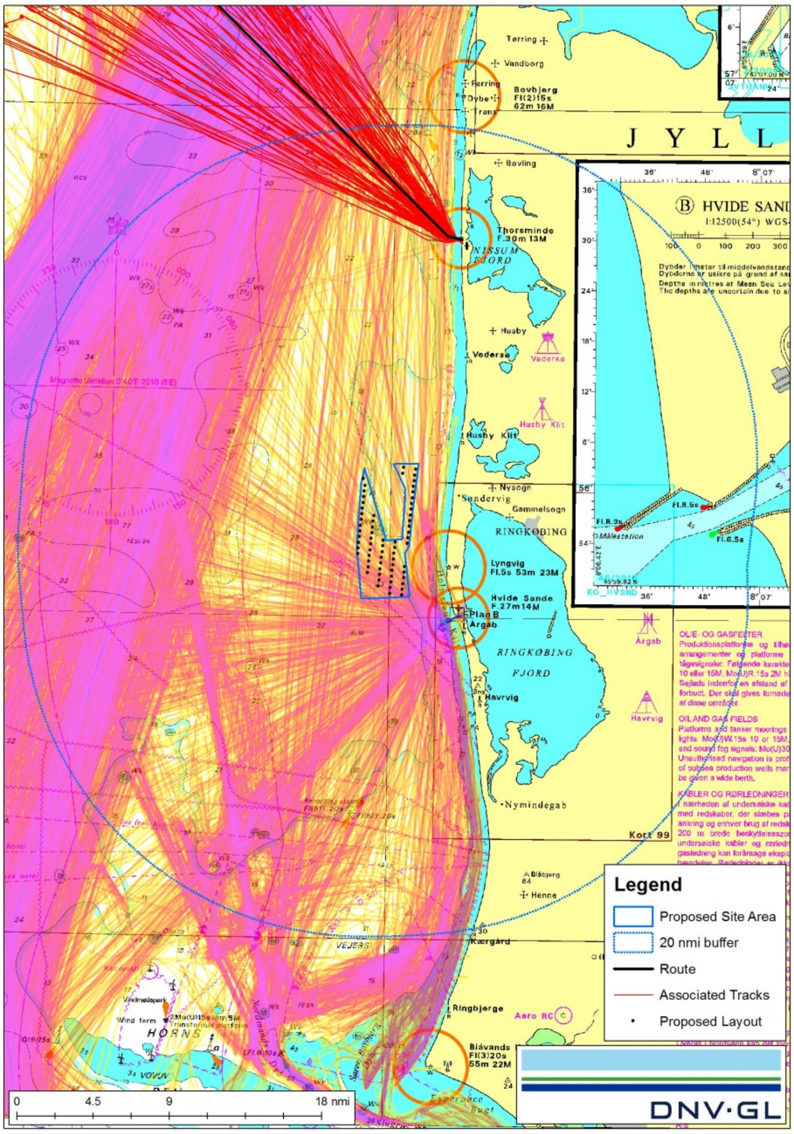
Ship traffic associated with Route 8



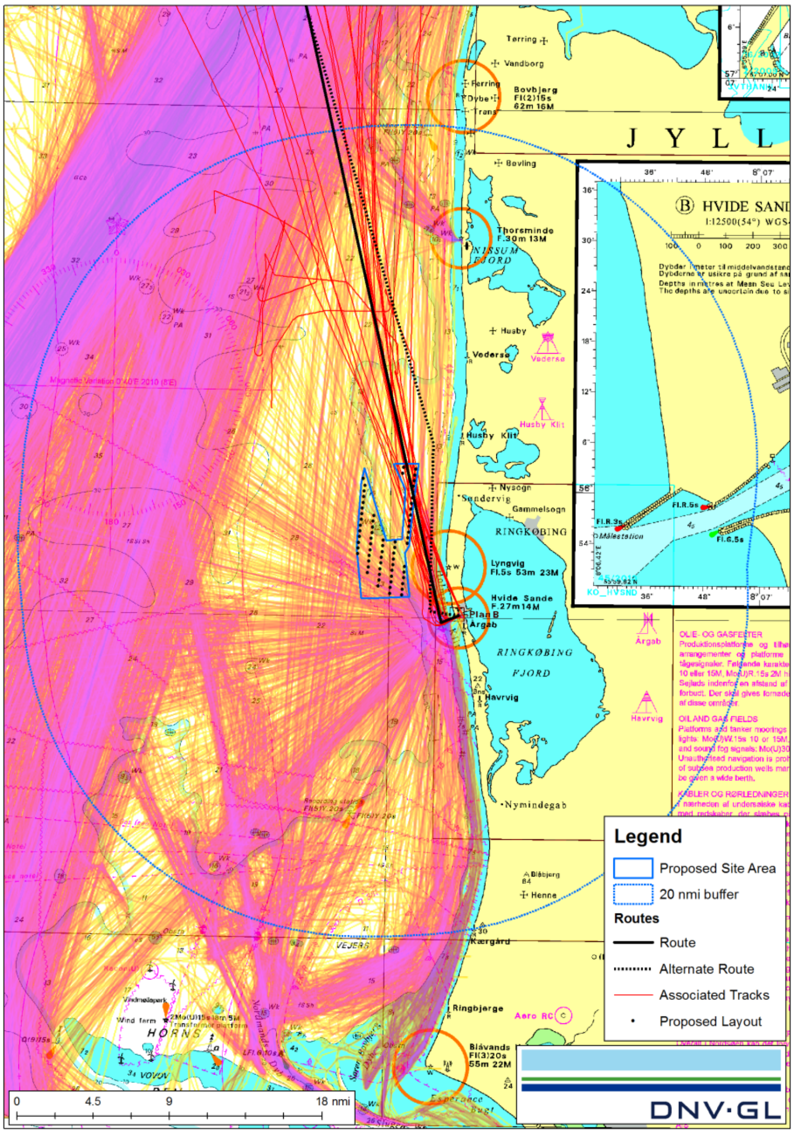
Ship traffic associated with Route 9



Ship traffic associated with Route 10



Ship traffic associated with Route 11



Ship traffic associated with Route 12

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APPENDIX
6
SHIP TRAFFIC ROUTES - DATA TABLES

Type	DWT								Total
	<1,000	1,000 - 3,000	3,000 - 5,000	5,000 - 10,000	10,000 - 20,000	20,000 - 40,000	40,000 - 80,000	>80,000	
1 Tanker		13	3						16
2 Other	113	12	24						149
3 Ferry									
4 RoRo									
5 Fishing	29	378							407
	142	403	28						572

Annual traffic associated with Route 1.

Type	DWT								Total
	<1,000	1,000 - 3,000	3,000 - 5,000	5,000 - 10,000	10,000 - 20,000	20,000 - 40,000	40,000 - 80,000	>80,000	
1 Tanker		3							3
2 Other	56	13	8						76
3 Ferry									
4 RoRo									
5 Fishing	31	398							429
	87	414	8						508

Annual traffic associated with Route 2.

Type	DWT								Total
	<1,000	1,000 - 3,000	3,000 - 5,000	5,000 - 10,000	10,000 - 20,000	20,000 - 40,000	40,000 - 80,000	>80,000	
1 Tanker		7	4						11
2 Other	26	13	26						65
3 Ferry									
4 RoRo									
5 Fishing	42	554							596
	68	574	30						672

Annual traffic associated with Route 3.

Type	DWT								Total
	<1,000	1,000 - 3,000	3,000 - 5,000	5,000 - 10,000	10,000 - 20,000	20,000 - 40,000	40,000 - 80,000	>80,000	
1 Tanker									
2 Other	130	6	17						152
3 Ferry				2			1		3
4 RoRo									
5 Fishing	46	598							644
	176	604	17	2			1		799

Annual traffic associated with Route 4.

Type	DWT								Total
	<1,000	1,000 - 3,000	3,000 - 5,000	5,000 - 10,000	10,000 - 20,000	20,000 - 40,000	40,000 - 80,000	>80,000	
1 Tanker									
2 Other	63								63
3 Ferry				6			2		8
4 RoRo									
5 Fishing	6	74							80
	66	69		6			2		143

Annual traffic associated with Route 5.

Type	DWT								Total
	<1,000	1,000 - 3,000	3,000 - 5,000	5,000 - 10,000	10,000 - 20,000	20,000 - 40,000	40,000 - 80,000	>80,000	
1 Tanker	3	10	13						25
2 Other	59	90	23	86					257
3 Ferry									
4 RoRo					6				6
5 Fishing	1	15							16
	63	114	35	86	6				305

Annual traffic associated with Route 6.

Type	DWT								Total
	<1,000	1,000 - 3,000	3,000 - 5,000	5,000 - 10,000	10,000 - 20,000	20,000 - 40,000	40,000 - 80,000	>80,000	
1 Tanker		3							3
2 Other	7	70	7	139					222
3 Ferry									
4 RoRo				19					19
5 Fishing	2	24							26
	9	97	7	158					270

Annual traffic associated with Route 7.

Type	DWT								Total
	<1,000	1,000 - 3,000	3,000 - 5,000	5,000 - 10,000	10,000 - 20,000	20,000 - 40,000	40,000 - 80,000	>80,000	
1 Tanker		3							3
2 Other		11	18						29
3 Ferry									
4 RoRo				143					143
5 Fishing		3							3
		17	18	143					178

Annual traffic associated with Route 8.

Type	DWT								Total
	<1,000	1,000 - 3,000	3,000 - 5,000	5,000 - 10,000	10,000 - 20,000	20,000 - 40,000	40,000 - 80,000	>80,000	
1 Tanker		95	283	330	226	273	76	105	1,388
2 Other	16	324	1,116	2,122	1,062	778	366	177	5,961
3 Ferry		3	6	13	6	6	16		51
4 RoRo	3	10	149	324	1,834	48			2,367
5 Fishing	16	177							194
	36	609	1,555	2,789	3,127	1,105	458	281	9,962

Annual traffic associated with Route 9.

Type	DWT								Total
	<1,000	1,000 - 3,000	3,000 - 5,000	5,000 - 10,000	10,000 - 20,000	20,000 - 40,000	40,000 - 80,000	>80,000	
1 Tanker		22	111	203	38	60		3	438
2 Other	65	300	421	610	679	362	49	13	2,498
3 Ferry		3	6	89			19		117
4 RoRo	6	44	470	292	89	25			927
5 Fishing	6	109							115
	78	479	1,008	1,194	806	447	68	16	4,094

Annual traffic associated with Route 10.

Type	DWT								Total
	<1,000	1,000 - 3,000	3,000 - 5,000	5,000 - 10,000	10,000 - 20,000	20,000 - 40,000	40,000 - 80,000	>80,000	
1 Tanker									
2 Other									
3 Ferry									
4 RoRo									
5 Fishing	23	294							317
	23	294							317

Annual traffic associated with Route 11.

Type	DWT								Total
	<1,000	1,000 - 3,000	3,000 - 5,000	5,000 - 10,000	10,000 - 20,000	20,000 - 40,000	40,000 - 80,000	>80,000	
1 Tanker									
2 Other	7	2	4	7	4	3	1		28
3 Ferry									
4 RoRo									
5 Fishing	2	38							40
	9	40	4	7	4	3	1		68

Annual traffic associated with Route 12.

Type	DWT								Total
	<1,000	1,000 - 3,000	3,000 - 5,000	5,000 - 10,000	10,000 - 20,000	20,000 - 40,000	40,000 - 80,000	>80,000	
1 Tanker 2 Other 3 Ferry 4 RoRo 5 Fishing	900	900							1,800
	900	900							1,800

Annual traffic associated with Route 13.

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