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Cover photograph: Installation of turbine foundations in the North Sea

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Drafted by		Royal HaskoningDHV (Beth Mackey)	
Checked by		Ben Orriss	
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Approved by		Angela Lowe	
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Forewind Approval		Julie Drew Murphy	
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Prepared by: Royal HaskoningDHV (Beth Mackey)	Checked by: Ben Orriss	
Approved by: Angela Lowe	Signature / Approval (Forewind)  Julie Drew-Murphy	Approval Date: 24 December 2013

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Contents

Table of Tables

Table of Figures

1. Introduction

1.1.1. Currently, there is no robust approach available to assess the potential impact of disturbance from pile driving noise on the future growth of the harbour porpoise population in the North Sea. The interim Population Consequences of Disturbance (PCoD) model, which is funded by the Offshore Renewables Joint Industry Programme (ORJIP), is being developed to provide methods to assess such impacts. However, this is not yet available to regulators or developers.

1.1.2. As such this paper provides the results of a Population Viability Analysis (PVA) modelling exercise to explore the potential impact of disturbance from pile driving during construction across the Dogger Bank Zone on the size and future growth of the North Sea harbour porpoise population. The North Sea harbour porpoise population is considered as the North Sea Management Unit (IAMMWG 2013). The most recent estimate of the population size 227,298 (95% confidence interval 176,360 – 292,948), which is based on data collected during the SCANS II survey in 2005.

1.1.3. The PVA considers disturbance during construction at each project (e.g. Dogger Bank Teesside A or Dogger Bank Teesside B etc.) and within each phase of the development (e.g. Dogger Bank Teesside A & B or Dogger Bank Creyke Beck A & B).

1.1.4. The PVA uses information presented in **Chapter 14 Marine Mammals** of the Environmental Statement (ES) for Dogger Bank Teesside A & B, as well as the submitted final Environmental Statement for Dogger Bank Creyke Beck A & B (Forewind 2013).

1.1.5. The results of this modelling exercise have been consulted on separately to the ES for Dogger Bank Teesside A & B and have therefore been included as an Appendix in support of the final application.

1.2. Quantitative impact assessment

1.2.1. The assessment of disturbance to harbour porpoise from pile driving is assessed within the ES **Chapter 14** for project specific impacts for Dogger Bank Teesside A & B, as well as a number of cumulative scenarios with other projects within the Dogger Bank Zone. The impact of pile driving at Dogger Bank Creyke Beck A & B is assessed in the Dogger Bank Creyke Beck A & B final ES (Forewind 2013).

1.2.2. The magnitude of the impacts of disturbance as detailed within each ES chapter is summarised in **Table 1**. The number of individuals that are likely to avoid, and may possibly avoid an area due to pile driving have been calculated from the areas within noise contours and from site specific densities, as detailed within each ES chapter.

1.2.3. In the relevant ES chapters impacts have been considered in relation to a single pile driving event and multiple piling events across the project area (Dogger

Bank Teesside A, Dogger Bank Teesside B, Dogger Bank Creyke Beck A or Dogger Bank Creyke Beck B) based on the ‘footprint approach’. This approach, as detailed within the ES **Chapter 14**, considers the potential area of disturbance based on pile driving around the perimeter of the project area, by joining the outer contours of disturbance ranges to make one continuous area.

1.2.4. However, in the PVA, a more realistic approach to displacement is considered which reflects the fact that pile driving cannot occur across the whole project area at one time, and that there will be a limit of two vessels pile driving within each project at any one time. Therefore, the number of individual harbour porpoise that may be displaced at any one time has been re-calculated for a number of combinations of projects pile driving within three different construction scenarios (see Section 2.2 and **Table 8**). It is these re-quantified impacts that are used within this PVA exercise.

1.2.5. The project specific impacts from Dogger Bank Teesside C and Dogger Bank Teesside D are yet to be assessed in isolation, therefore the worst case impacts of the other Dogger Bank Zone projects is used as a proxy for potential magnitude of effect.

Table 1: Results of the quantitative assessment summarised from ES Chapter 14 and Forewind (2013) showing the number of individuals each year which are likely to avoid, and number that may possibly avoid pile driving noise (percent of the reference population, North Sea Management Unit based on 2005 SCANS II estimate is given in brackets). The numbers are based on harbour porpoise densities [and potential harbour porpoise densities] from site specific survey data.

Scenario	Project (s)	Parameters	Impacted Number: Likely avoidance		Impacted Number: Possible avoidance	
			Project A	Project B	Project A	Project B
Single pile impact	Dogger Bank Teesside (A or B)	Max hammer energy of 3,000kJ Worst case location (maximum propagation ranges)	53 (0.02%) [59 (0.03%)]	53 (0.02%) [59 (0.03%)]	1,717 (0.76%) [1,920 (0.84%)]	1,820 (0.8%) [2,035 (0.9%)]
	Dogger Bank Creyke Beck (A or B)*		45 (0.02%) [51 (0.02%)]	54 (0.02%) [62 (0.03%)]	1,122 (0.48%) [1,288 (0.55%)]	1,982 (0.85%) [2,276 (0.98%)]
Multiple pile driving across a project (footprint approach)	Dogger Bank Teesside (A or B)	Max hammer energy of 3,000kJ	666 (0.29%) [745 (0.33%)]	687 (0.3%) [768 (0.34%)]	3,848 (1.7%) [4,302(1.9%)]	3,516 (1.55%) [3,931 (1.7%)]
	Dogger Bank Creyke Beck (A or B)*		583 (0.3%) [669 (0.33%)]	632 (0.27%) [726 (0.31%)]	2,716 (1.2%) [3,119 (1.3%)]	3,826 (1.65%) [4,394 (1.89%)]
	Dogger Bank Teesside (C or D)	Not modelled	Assumed to be equal to worst case of other projects (i.e. Dogger Bank Teesside A).			
Cumulative (within application phases)	Dogger Bank Teesside A and B (concurrent)		1,336 (0.59%) [1,494 (0.66%)]		5,679 (2.5%) [6,349 (2.79%)]	
	Dogger Bank Teesside A and B (sequential)		Impact would equate to either footprint impacts from Dogger Bank Teesside A for 5.5 years, sequential impact of Dogger Bank Teesside A and Dogger Bank Teesside B for 0.5 years, then footprint impact from Dogger Bank Teesside B for 5.5 years, or vice versa depending on which project was constructed first.			
	Dogger Bank Creyke Beck A and B (concurrent)		1,215 (0.52%) [1,395 (0.6%)]		6,542 (2.8%) [7,513 (3.23%)]	

Scenario	Project (s)	Parameters	Impacted Number: Likely avoidance		Impacted Number: Possible avoidance	
			Project A	Project B	Project A	Project B
	Dogger Bank Creyke Beck A and B (sequential)		Impact would equate to either footprint impacts from Creyke Beck A for 5.5 years, sequential impact of Dogger Bank Creyke Beck A and Dogger Bank Creyke Beck B for 0.5 years, then footprint impact from Dogger Bank Creyke Beck B for 5.5 years, or vice versa depending on which project was constructed first.			
	Dogger Bank Teesside (C or D) concurrent or sequential	Not modelled	Assumed to be equal to Dogger Bank Teesside A & B.			
Cumulative (between application phases)	Dogger Bank Creyke Beck A & B and Dogger Bank Teesside A & B (concurrent) *	Based on eight vessels across four projects 3,000kJ hammer.	346 (0.15%) [397 (0.17%)]		7,265 (3.1%) [8,344 (3.6%)]	
	Dogger Bank Teesside A & B and Dogger Bank Teesside C & D and Dogger Bank Creyke Beck A & B (concurrent)	Based on 12 vessels with maximum spacing.	602 (0.26%) [673 (0.3%)]		12,030 (5.29%) [13,449 (5.92%)]	

* Dogger Bank Creyke Beck impacts from Forewind (2013)

1.2.6. A number of assumptions have been made in the quantitative assessment within the ES chapters for Dogger Bank Teesside A and Dogger Bank Teesside B and Dogger Bank Creyke Beck A and Dogger Bank Creyke Beck B. Some of these assumptions have been taken forward into the PVA modelling, and some have been refined to provide more realistic, rather than absolute, worst case scenarios.

1.2.7. The assumptions from within the ES Chapters have not been repeated here, but any additional assumptions or refinements are detailed in **Table 2**. An indication of the likely effect on the conclusions of the impact assessment is also provided, including whether the assumption is likely to over or under-estimate effect of the impact. Further details on some of the assumptions are provided in subsequent sections of this report.

Table 2: Assumptions taken in the ES chapter, and in this Appendix which have been taken forward in the PVA modelling, and potential effect of these assumptions on the assessment of the impact

No	Assumption in ES	Approach in PVA	Likely effect on impacts taken forward to PVA
1	The footprint approach (assuming pile driving around the outside of the project areas) is used to assess impacts within a project (see Table 1). However, the maximum number of concurrent pile driving events within any project is two. Therefore, the area of possible disturbance in the 'footprint' will be greater than if only two piling events were happening concurrently. This approach will over-estimate the number of harbour porpoise impacted in a single year.	Areas of impact during multiple pile driving are based on the maximum of two vessels within each project area (see **Table 8**). The location of the vessels are based on firstly the piling location with the greatest propagation ranges for noise, and secondly a location furthest from the first location.	More-realistic but slight over-estimate
2	In the final ES, the impacts from a concurrent build at Dogger Bank Creyke Beck A and Dogger Bank Creyke Beck B (Forewind 2013) were not calculated by considering the overlapping footprint. They were calculated by summing the two individual project footprints. This means that there is no allowance for overlapping areas of disturbance, and therefore number of individuals impacted will be over-estimated.	The number of individuals impacted during multiple pile driving at Dogger Bank Creyke Beck A (two vessels) and Dogger Bank Creyke Beck B (two vessels) has been calculated for this Appendix using the approach set out in (1) above. The number impacted has not been presented in Forewind (2013) in this way (**Table 1** versus **Table 8**).	More-realistic but slight over-estimate
3	100% avoidance of the area is assumed within the 'possible avoidance' area. This will over estimate the number of individuals that could be displaced, as it is likely that individuals will respond along a dose response curve.	For this appendix the number of harbour porpoise displaced in total is based on the assumption that 100% of the animals within the 'likely' avoidance contour and 75% of the animals within the 'possible' avoidance contour do respond to the	More-realistic.

No	Assumption in ES	Approach in PVA	Likely effect on impacts taken forward to PVA
	Less than 100% of the individuals are likely to respond at greater ranges from the noise source (**Table 1**).	pile driving noise (**Table 8**).	
4	The impacts from single or multiple pile driving events within the Dogger Bank Teesside C and Dogger Bank Teesside D development phase have not been modelled explicitly.	Therefore, the impacts are assumed to be equal to the worst case of the other modelled projects. The greatest number of animals avoiding the area comes from the Dogger Bank Teesside A and Dogger Bank Teesside B assessment. The number displaced will depend on the densities and noise propagation characteristics of the site. Therefore, the impact could be over or understated. However, there is not likely to be a significant difference.	Unknown, but impact ranges from Dogger Bank Teesside C & D may be greater due to deeper water. Potentially a slight under-estimate.
5	The impacts from some combinations of projects being built concurrently which include scenarios with Dogger Bank Teesside C and/or Dogger Bank Teesside D have not been explicitly modelled. Therefore, the impacts have been assumed to be comparable to other developments across the same number of projects where modelling has been undertaken.	The number displaced will depend on the densities and noise propagation characteristics of the site. Therefore, the impact could be over or understated. However, there is not likely to be a significant difference.	Unknown.
6	Construction is considered to last up to the maximum of six years per project as a worst case.	It should be noted that each project may take only three years to construct. In addition within that construction time period there will be period of pile driving, followed by turbine installation (when there will be no pile driving).	Over-estimate, but see also more realistic scenario (3) which has been provided (see Section 2.2).
7	The worst case impact ranges are based on the 3,000kJ hammer. This will only be used to install monopoles.	The impact ranges for disturbance are also based on the 3,000kJ hammer energy. However, the maximum hammer energy will be lower, as will the range of disturbance impacts, if jacket foundations are used. A comparison has been done between the areas of impact from 12 concurrent pile driving vessels using a 2,300kJ hammer and a 3,000kJ hammer. It should be noted that the maximum ranges of disturbance are based on the maximum hammer energy for each scenario. These maximum hammer energies are only likely to be used for a small proportion of the piling duration, following a gentle	Over-estimate (see comparison in Section 4).

No	Assumption in ES	Approach in PVA	Likely effect on impacts taken forward to PVA
		ramp up though the installation of each pile.	
8	The assessment approach assumes that individuals are disturbed for 100% of the year in which pile driving occurs, regardless of the amount of time spent pile driving within that year. This is unlikely to be the case, as construction may start part way through a year, and there may be gaps in pile driving (due to weather or technical constraints) which allow animals to return to the area.	The same approach has been taken in this assessment.	Over-estimate
9	The number of individuals displaced is based on the site specific densities from the zone wide surveys (data collected from 2010-2012). The percentage of the population impacted is based on the SCANS II estimate of the North Sea Management Unit population (from 2005, IAMMWG 2013).	The model constructed here suggests that the population will have increased between 2005 and the survey period. Therefore, the number of individuals displaced has been calculated as a proportion of the predicted 2011 population size. However, the exact size of the population during the survey period is not known, and a number of assumptions in the model have been made in relation to life history and by-catch. It is possible that the outputs of the JCP will help refine the population estimates post 2005. If available these can be incorporated into the assessment.	Unknown, but likely to be more realistic.
10	The number of individuals displaced has been calculated using Zone specific densities for both harbour porpoise, and for harbour porpoise and potential harbour porpoise sightings combined. The latter approach can be considered a more precautionary approach to estimating harbour porpoise densities. However, it is likely that a large proportion of the unidentified sightings during the Zone surveys were harbour porpoise.	The PVA assumes that the impacts are based on the harbour porpoise and potential harbour porpoise combined density estimates.	May over-estimate.
11	The estimates of Zone specific density are based on sightings of marine mammals both above and below the water. However, all of the sightings have been corrected	The same approach has been applied in the PVA.	Over-estimate

No	Assumption in ES	Approach in PVA	Likely effect on impacts taken forward to PVA
	for availability at the surface. This approach has been take as an unknown number of sightings were below the surface, but it will lead to an over-estimate of absolute density,		
12	The percentage of the population displaced is calculated each year and remains the same as estimated for the first year of construction. The assessment does not take account of individual movement and any resultant change in the underlying densities which may occur between years during the construction programme.	The same assumption is applied.	Unknown
13	No assumption	The stage structure of the population is assumed to be stable pre impact. However, a lack of data to support a different stage structure means that stability is assumed.	Unknown.

2. Approach to Modelling

2.1. Model parameterisation

2.1.1. To investigate the impact of pile driving a simple stage structured population model has been constructed (Leslie 1966; Caswell 1989). The parameters of survival and fecundity are based on those used by the by-catch modelling in the SCANS-II final report (SCANS-II 2008; Winship 2009). Maximum age for harbour porpoise was set at 25, based on data presented in Lockyer (1995).

2.1.2. The model is a stage structured female only model, assuming simultaneous birth (birth pulse model). The parameters used in the model are shown in **Table 3**.

Table 3: Age and specific survival and fecundity probabilities

Stage class	Age class	Survival probability	Fecundity (No. females born per female)
1	0	0.81	0
2	1	0.83	0
3	2 to 4	0.87	0.165
4	5 to 25	0.88	0.325

2.1.3. The unperturbed (with no impacts) population growth trajectory was modelled for 100 years from a generic starting population of 1,000 porpoise. This allowed a stable distribution to be determined prior to conducting the assessment. This also allowed calculation of the proportion of individuals in each stage class, based on the life history data shown in **Table 3**.

2.1.4. Using the SCANS-II estimate of population size of 227,298 (IAMMWG 2013) the number of each individuals in each stage class in 2005 was calculated (assuming this stable distribution, **Table 4**). Although the population prior to 2005 will have been subject to a number of pressures (including by-catch) it is not possible to determine the likely stage structure in 2005, therefore a stable distribution was assumed.

Table 4: Number of individuals within each stage class in 2005 (assuming a stable distribution)

Stage	Females	Males
1	19,817	19,817
2	15,441	15,441
3	30,470	30,470
4	47,921	47,921
Total	**113,649**	**113,649**

2.1.5. The projection resulting from this unperturbed scenario (with a lambda of 1.04) modelling is representative of the predicted growth rate of the population when there are no impacts. This lambda value suggests a growth rate (approximately 3.96% per year). This is slightly higher than that predicted by Winship (2009) a lambda of 0.99 (0.95-1.03). This difference suggests that the model used here does suggest the population will grow in the absence of any external influence, whereas the Winship model suggests the population may be stable, or decline slightly. The differences are a function of the life history data used and the construction of the model. However, more robust data are needed to determine the true rate of change in this population.

2.1.6. In order to model the potential impact of disturbance from pile driving noise at a population level, consideration needs to take account of existing pressures on the population, namely by-catch. Winship (2009) suggested that by-catch decreased between 1987 and 2005 (the period over which Winship modelled population change), with 2005 representing the lowest estimated by-catch of 3,000 (1,800- 5,300). Post 2005 (the period modelled in this assessment) by-catch in UK waters is likely to have further reduced due to the implementation of management measures. However, by-catch across other parts of the North Sea is difficult to quantify (e.g. SMRU 2009; Bjøreg *et al*. 2013).

2.1.7. As such, in this assessment by-catch post 2005 has been set at the equivalent to the upper confidence limit of 5,300 in 2005. This equates to 2.45% of the North Sea population being removed each year due to by-catch. This is based on the SCANS II population estimate of 216,415 for the study area used in Winship (2009). This area is slightly smaller than the North Sea MU (IAMMWG 2013), but the proportion of the population that is by-caught is assumed to be comparable over the MU used in this PVA.

2.1.8. This impact of by-catch has been modelled to occur across all stage classes in direct proportion to their size (this is supported by Winship 2009), and the impact of by-catch is assumed to occur prior to any impact of disturbance from pile driving noise (i.e. pile driving impacts on the population are in addition to by-catch). It should be noted that by-catch may be more or less than this percentage in any given year, although there should be an overall decreasing trend due to management measures (e.g. SMRU 2009).

2.1.9. The PVA model was run for 25 years without by-catch (unperturbed) and with by-catch at 2.45% to show the potential population growth rate with and without this impact. The predicted population growth rate with by-catch is considered the baseline condition, and the impact of pile driving comes in addition to removal of individuals from the population due to by-catch.

2.1.10. The model is a simple birth pulse model, and assumes that the impact of pile driving occurs on the population at the time of the birth pulse census. At this single point in time reproduction is assumed to occur in the population, by-catch will remove 2.45% of this population (in a stable distribution across all stage classes), and then impact of disturbance from pile driving will occur.

2.2. Modelling scenarios

2.2.1. The biological consequences of disturbance from pile driving noise are not well understood, and there are no empirical data that link disturbance from pile driving noise to a reduction in fecundity or survival in any species of marine mammal. As such this assessment considered the impacts on individuals' fitness in the form of complete reproductive failure in any year (i.e. fecundity = 0) for any animal that disturbed is predicted to be disturbed by pile driving noise.

2.2.2. Three modelling scenarios have been considered which focus on the cumulative impacts from pile driving within the Dogger Bank Zone at Dogger Bank Creyke Beck A & B, Dogger Bank Teesside A & B and Dogger Bank Teesside C & D (**Table 5**, **Table 6** and **Table 7**).

2.2.3. The scenarios have been limited in this illustrative modelling exercise due to limited information on the exact timing of construction for each project. In Scenario 1 and 2 the worst case scenarios have been presented in terms of:

- The maximum duration of the construction programme (a sequential build), and;
- The maximum impacted area across years (a concurrent build).

2.2.4. Scenario 3 has been included to provide a more representative construction programme where each phase of the development is built sequentially as determined by the consent application timetable (i.e. Dogger Bank Creyke Beck A & B then Dogger Bank Teesside A & B then Dogger Bank Teesside C & D), but within phases projects are built concurrently (i.e. Dogger Bank Creyke Beck A & B are built at the same time). In this scenario construction is also assumed to last up to three years, with pile driving to install foundations only occurring in the first two years of the construction period only. The installation of the wind turbines is assumed to occur in the final year.

2.2.5. The timing of pile driving in all of the Scenario's considers the constraints within the final ES chapter for Dogger Bank Creyke Beck A & B (Forewind, 2013) and the ES for Dogger Bank Teesside A & B for commencement of construction post consent.

2.2.6. Due to the constraints of the planning process influencing the timings of construction at each of the offshore wind farms pile driving may start mid-year. Therefore, for the purpose of this PVA, any pile driving activity occurring in quarter 1 or quarter 2 of any given year is considered to impact the population. Pile driving starting in quarter 3 or 4 is assumed to impact the population in the subsequent year.

2.2.7. Based on the Scenario's, there are several combinations of pile driving that can occur across the Zone in different years (**Table 8**). The assessment assumes that within each project a maximum of two pile driving events will occur at any one time. One of the vessels will be located at the site where the greatest propagation ranges have been predicted, the other vessel will be located at the furthest location from the first vessel. Where pile driving can occur across projects, and across development phases at the same time the vessel locations will be chosen to reflect the greatest spread between vessels, and thus provide the minimum overlap, and therefore maximum impacted area.

2.2.8. The number of individuals predicted to be disturbed within any given year has been calculated based on the number of individuals which may be within the range of disturbance based on the densities of harbour porpoise and potential harbour porpoise combined (**Table 8**). It has been assumed that 100% of the individuals within the likely avoidance range (164dB re 1 μPa2.s threshold) will be disturbed, and 75% of the individuals within the possible avoidance range (145dB re 1 μPa2.s) are disturbed. The response of 75% of the animals at the lower threshold reflects the fact that at greater ranges, where a lower stimulus is received, some of the animals may not respond.

2.2.9. The number of animals predicted to be displaced during pile driving is based on Zone specific densities calculated from surveys between 2010 and 2012. Therefore, the percentage of the population predicted to be displaced has been calculated in relation to the predicted population size in 2011. The population size has been estimated using the PVA model which assumes by-catch as 2.45% per annum since the 2005 (SCANS II) survey.

Table 5 Timelines for Scenario 1 (sequential). Cells in green represent periods of time during which pile driving will occur

Year			Dogger Bank Creyke Beck projects		Dogger Bank Teesside projects (assume A & B six months behind Creyke Beck, and assume C & D six months behind TS A & B)			
			A	B	A	B	C	D
0	2015	Q1/2	Consented	Consented				
		Q3/4			Consented	Consented		
1	2016	Q1/2					Consented	Consented
		Q3/4	Start construction					
2	2017	Q1/2	End of year 1		Start construction			
		Q3/4			End of year 1		Start construction	
3	2018	Q1/2	End of year 2				End of year 1	
		Q3/4			End of year 2			
4	2019	Q1/2	End of year 3				End of year 2	
		Q3/4			End of year 3			
5	2020	Q1/2	End of year 4				End of year 3	
		Q3/4			End of year 4			
6	2021	Q1/2	End of year 5				End of year 4	
		Q3/4			End of year 5			
7	2022	Q1/2	End of year 6, finish construction	Start construction			End of year 5	
		Q3/4		End of year 1	End of year 6, finish construction	Start construction		
8	20	Q1/2				End of year 1	End of year 6, finish	Start construction

Year			Dogger Bank Creyke Beck projects		Dogger Bank Teesside projects (assume A & B six months behind Creyke Beck, and assume C & D six months behind TS A & B)			
			A	B	A	B	C	D
	23						construction	
		Q3/4		End of year 2				End of year 1
9	20 24	Q1/2				End of year 2		
		Q3/4		End of year 3				End of year 2
1 0	20 25	Q1/2				End of year 3		
		Q3/4		End of year 4				End of year 3
1 1	20 26	Q1/2				End of year 4		
		Q3/4		End of year 5				End of year 4
1 2	20 27	Q1/2				End of year 5		
		Q3/4		End of year 6, finish construction				End of year 5
1 3	20 28	Q1/2				End of year 6, finish construction		
		Q3/4						End of year 6, finish construction

Table 6 Timelines for Scenario 2 (concurrent). Cells in green represent periods of time during which pile driving will occur

Year			Dogger Bank Creyke Beck projects		Dogger Bank Teesside projects (assume A & B six months behind Creyke Beck, and assume C & D six months behind TS A & B)			
			A	B	A	B	C	D
0	2015	Q1/2	Consented	Consented				
		Q3/4			Consented	Consented		
1	2016	Q1/2					Consented	Consented
		Q3/4						
2	2017	Q1/2						
		Q3/4	Start construction	Start construction	Start construction	Start construction	Start construction	Start construction
3	2018	Q1/2	End of year 1	End of year 1	End of year 1	End of year 1	End of year 1	End of year 1
		Q3/4						
4	2019	Q1/2	End of year 2	End of year 2	End of year 2	End of year 2	End of year 2	End of year 2
		Q3/4						
5	2020	Q1/2	End of year 3	End of year 3	End of year 3	End of year 3	End of year 3	End of year 3
		Q3/4						
6	2021	Q1/2	End of year 4	End of year 4	End of year 4	End of year 4	End of year 4	End of year 4
		Q3/4						
7	2022	Q1/2	End of year 5	End of year 5	End of year 5	End of year 5	End of year 5	End of year 5
		Q3/4						
8	2023	Q1/2	End of year 6, finish construction	End of year 6, finish construction	End of year 6, finish construction	End of year 6, finish construction	End of year 6, finish construction	End of year 6, finish construction

Year			Dogger Bank Creyke Beck projects		Dogger Bank Teesside projects (assume A & B six months behind Creyke Beck, and assume C & D six months behind TS A & B)			
			A	B	A	B	C	D
		Q3/4						

Table 7 Timelines for Scenario 3 (realistic). Cells in green represent periods of time during which pile driving will occur

Year			Dogger Bank Creyke Beck projects		Dogger Bank Teesside projects (assume A & B six months behind Creyke Beck, and assume C & D one year behind TS A & B)			
			A	B	A	B	C	D
0	2015	Q1/2	Consented	Consented				
		Q3/4			Consented	Consented		
1	2016	Q1/2					Consented	Consented
		Q3/4	Start construction, pile driving.	Start construction, pile driving.				
2	2017	Q1/2	End of year 1	End of year 1	Start construction, pile driving.	Start construction, pile driving.		
		Q3/4			End of year 1	End of year 1	Start construction, pile driving.	Start construction, pile driving.
3	2018	Q1/2	End of year 2, finish pile driving.	End of year 2, finish pile driving.			End of year 1	End of year 1
		Q3/4			End of year 2, finish pile driving.	End of year 2, finish pile driving.		
4	2019	Q1/2	End of year 3, finish turbine installation.	End of year 3, finish turbine installation.			End of year 2, finish pile driving.	End of year 2, finish pile driving.
		Q3/4			End of year 3, finish turbine installation.	End of year 3, finish turbine installation.		
5	2020	Q1/2					End of year 3, finish turbine installation.	End of year 3, finish turbine installation.
		Q3/4						

Table 8 Construction combinations based on different combinations of projects pile driving within each year. Number of animals has been calculated using the average densities across the Zone for harbour porpoise and potential harbour porpoise combined (0.716 individuals per km^2).

Combination reference	Projects where pile driving is occurring at the same time (assume two vessels within each project are pile driving over the same time period)						Number of animals displaced			Percent of reference population displaced (based on 2011 predicted population size of 247,260)
	Dogger Bank Creyke Beck A	Dogger Bank Creyke Beck B	Dogger Bank Teesside A	Dogger Bank Teesside B	Dogger Bank Teesside C	Dogger Bank Teesside D	Likely (100% response within area)	Possibly (75% response within area)	Total	
A	Y	Y					222	3,382	3,604	1.46%
B	Y	Y	Y	Y			435	6,856	7,291	2.95%
C	Y	Y	Y	Y	Y	Y	673	9,582	10,255	4.15%
D			Y	Y	Y	Y	418	7,891	8,309	3.36%
E			Y	Y			206	3,671	3,876	1.57%
E1					Y	Y	Not modelled, assume to be the same as E.			
E2				Y		Y	Not modelled, assume to be the same as E.			
F	Y		Y				202	3,030	3,232	1.31%
D1	Y		Y		Y		Not modelled assumed to be the same as D.			
D2	Y	Y	Y		Y		Not modelled assumed to be the same as D.			
D3		Y		Y	Y	Y	Not modelled assumed to be the same as D.			
D4		Y		Y		Y	Not modelled assumed to be the same as D.			

3. Results

3.1.1. The predicted population growth rates between 2005 and 2045 are shown in **Figure 1** if there was no by-catch, and if by-catch remains at 2.45% during this period and there was no pile driving in the Dogger Bank Zone. The results of the modelling exercise for Scenarios 1, 2 and 3 which consider a 100% reduction in fecundity are also shown in **Figure 1**.

3.1.2. As can be seen from **Figure 2**, the rate of unperturbed population growth is substantially decreased due to by-catch, although it continues to grow at approximately 1.4% (as opposed to 3.96%) per annum. With the addition of impacts from pile driving the population also continues to grow in each of the Scenarios during the impact phases.

3.1.3. The lowest growth rates are observed during the period of concurrent piling across all of the projects (within Scenario 2 and 3), where the numbers displaced are greatest. However, population recovery is quicker when pile driving occurs over a shortened time period due to concurrent piling. As such, in the longer-term the deviation between the by-catch only population size and the impacted Scenarios is greater for Scenario 1, when sequential pile driving occurs. In Scenario 1, the predicted population size post impact remains approximately 3.8% lower than it would be with no pile driving, in Scenario 2 the population size remains approximately 2.6% lower than it would be with no pile driving, and in the more realistic Scenario 3, the population size is approximately 0.9% lower than it is predicted to be with no pile driving.

3.1.4. As stated previously, Scenario 1 and 2 represent precautionary examples of the duration of the construction programme. In the more realistic scenario there is only a small deviation from the by-catch only scenario.

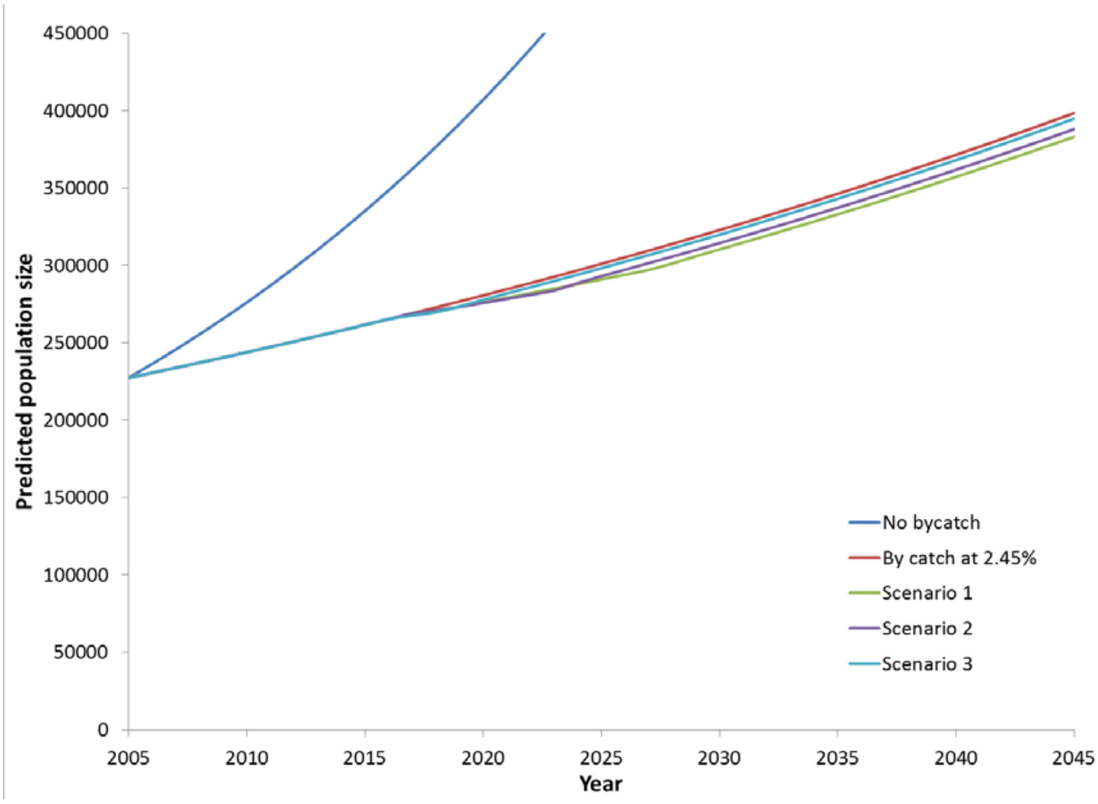

Figure 1 Results of PVA modelling

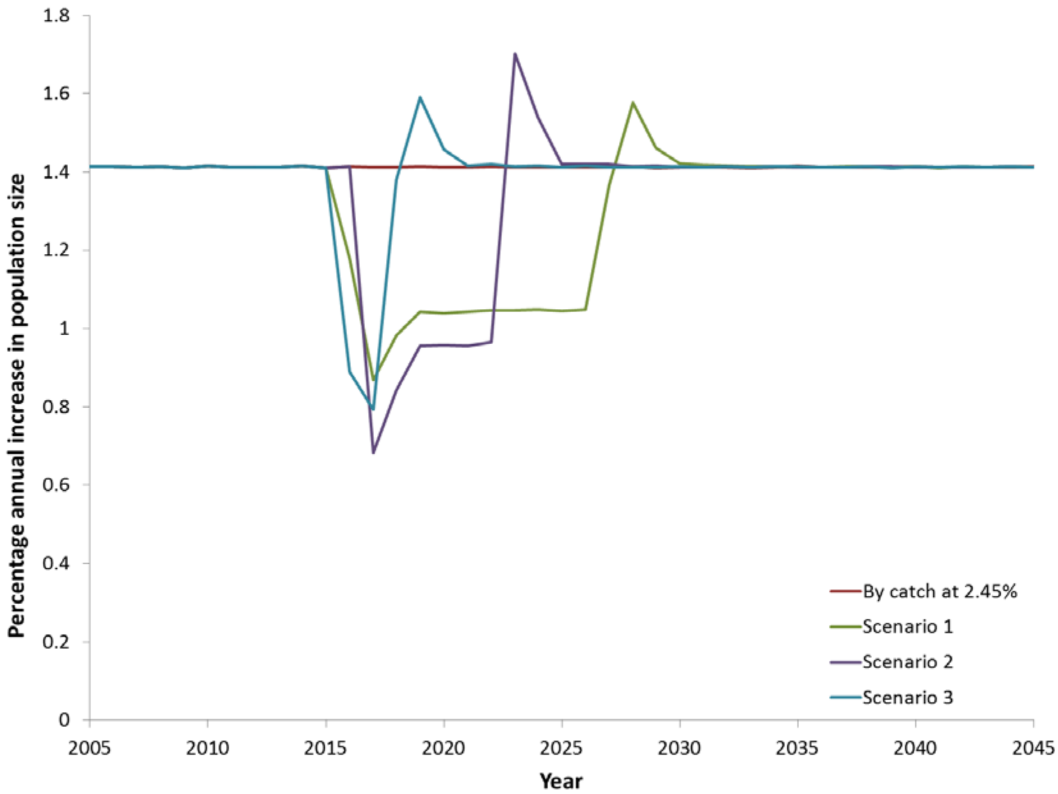

Figure 2 Predicted rates of population increase for each of the Scenarios

4. Discussion

4.1.1. The simplistic modelling exercise presented here has been undertaken to explore the potential impact from disturbance due to pile driving noise on the long term population dynamics of harbour porpoise within the North Sea Management Unit.

4.1.2. The modelling is based on a number of assumptions, which leads to a precautionary assessment. There is a large amount of engineering (in terms of construction timings, duration, and exact methods), modelling (in terms of the noise modelling assessment) and biological (in terms of the individual responses and fitness consequences of those responses of harbour porpoise to pile driving noise) uncertainty which is accounted for in the assessment through this precautionary approach. It is therefore very likely that the potential population level effects have been over-estimated.

4.1.3. The number of individuals displaced calculated in **Table 8** assumes the maximum hammer energy of 3,000kJ has been used. However, if pile driving was used to install jacket foundations a 2,300kJ hammer would be used. The use of a lower maximum hammer energy will lead to smaller impact ranges, and therefore less animals may be displaced. A simple comparison of the 12 concurrent piling vessel scenario (combination C in **Table 8**) suggests that the impacted area would be reduced by approximately 2000km2, with around 1,000 fewer harbour porpoise being displaced (9,177 compared to 10,255) if the 2,300kJ hammer was used.

4.1.4. There is also a large amount of uncertainty affecting the baseline, in terms of by-catch levels, and underlying population growth rates. The model here is deterministic, which only provide one trajectory for each scenario. However, Winship (2009) uses a more complex modelling approach to considering by-catch and estimating the population growth rate of harbour porpoise in the North Sea. Although the North Sea Management Unit, and the population considered by Winship (2007) are not identical, they are broadly the same. Winship estimated in the absence of by-catch between 1987 and 2005 the harbour porpoise population had a low growth rate: around zero with a 95% probability interval ranging between a 5% decrease and a 6% increase per year in a density independent model, and around 2% per year increase (with a 95% probability interval between 0 and 7% per year). These low growth rates are a function of harbour porpoise, life history, and the growth rate modelled here is also low (at around 3.96% per year, which falls within the 95% probability intervals from Winship 2009).

4.1.5. The simplistic model used here also does not take account of any effect of density dependence on population growth. More complicated models can be developed to take account of density dependence on birth rates, However, Winship (2007) found there was little information in the available data which reflected density-dependence including carrying capacity, current population depletion (size relative to carrying capacity), and maximum population growth rate.

4.1.6. It should be re-iterated that the modelled impact and actual impact of by-catch and disturbance from pile driving on the population growth will be largely dependent on the underlying growth rates. These will be a function of the life history of the individuals and the carrying capacity of the environment (which is unknown).

4.1.7. The PVA offers a more realistic indication of the number of animals that could be displaced within any year than the ES does by refining some of the assumptions. However, the maximum duration of the pile driving within the construction period is likely to be a significant overestimate in Scenario 1 and Scenario 2.

4.1.8. Disturbance to more than 5% of the reference population within a year within the ES chapters highlights the potential for a significant impact in EIA terms. However, this PVA suggests that, following consideration of the individual fitness consequences of disturbance, there it is unlikely that the impact from pile driving across the Dogger Bank Zone would lead to an impact which would be detectable in the long-term, and the population will continue to increase during the construction period.

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