CHAPTER 8

MODELLING THE IMPACT OF PILE DRIVING ON PORPOISE POPULATIONS IN THE BELGIAN PART OF THE NORTH SEA

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Abstract

In this study we used the interim Population Consequences of Disturbance model (iPCOD; Harwood & King 2014) to quantify how differences in regulatory regimes with regards to offshore wind farm construction impact a simulated harbour porpoise population. We modelled the likely construction schedules for the Rentel, Norther and Seastar wind farms and tested 17 scenarios with and without various mitigating measures.

The value in these simulations lies in the relative differences between the scenarios rather than in absolute outcomes of the model as there are some inherent issues both with the iPCOD model itself (*e.g.*, disturbance per day, not spatially explicit) and the assumptions that we made about the effectiveness of noise mitigation measures such as the big bubble curtain (BBC) and/or the noise mitigation screen (NMS).

Our results indicate that the impact of pile driving on the harbour porpoise population is strongly influenced by the timing of the activities, but that this effect is reduced when effective noise mitigation measures, *i.e.* BBC and/or NMS, is used. The combination of a seasonal pile driving restriction and an acoustic deterring device (ADD) was not enough to lower the impact on the porpoise population to acceptable values. In our simulation, building a wind farm every year affected the harbour porpoise population more than building two wind farms at the same time.

1. Introduction

It is of vital importance for both mankind and the natural environment to limit and mitigate anthropogenic climate change. However, the measures taken to mitigate climate change should not, by themselves, have a negative impact on the natural environment which endangers good environmental status. For offshore wind farms, the production of high levels of impulsive underwater sound, when large steel turbine foundations are hammered into the seabed, is one of these negative effects on the environment.

Potential effects on marine mammals caused by anthropogenic underwater sound can include physical injury, physiological dysfunction, behavioral modification and masking. For individual organisms, these effects and their secondary consequences vary in significance from negligible to fatal

(Marine Mammal Commission 2007). The harbour porpoise (*Phocoena phocoena*) is the most common marine mammal in the Belgian part of the North Sea (BPNS) and is protected by both national and EU law. In the North Sea, the harbour porpoise is considered vulnerable because of high by-catch levels and increasing noise pollution. Impulsive pile driving noise originating from the construction of offshore wind farms (OWF) has been shown to affect porpoises up to distances of 20 km from the noise source (Haelters *et al.* 2013; Brandt *et al.* 2016). As we have gained insight into both the seasonally fluctuating porpoise densities in the BPNS (Haelters *et al.* 2016) as well as the spatial and temporal extent of pile driving induced deterrence (Rumes *et al.* 2017), we can start to more accurately determine the number of porpoises affected by wind farm construction. This is part of the information we need to draw up the consequences of pile driving at (local) population scale using demography-based modelling, such as the interim Population Consequences of Disturbances model (PCoD, Harwood *et al.* 2014). This model will be applied to estimate the cumulative effects of the planned piling in the BPNS and is expected to contribute to an informed choice of appropriate sound mitigation measures.

2. Material and methods

2.1. Study area

The Southern bight of the North Sea includes the Belgian continental shelf or BPNS with a surface of approximately 3457 km². The BPNS only covers 0.5% of the entire area of the North Sea. The Belgian continental shelf is characterised by shallow waters with a maximum depth of 45 m and a complex system of sandbanks.

The harbour porpoise (*Phocoena phocoena*) is by far the most common marine mammal in the BPNS, after several years of virtual absence (Haelters *et al.* 2011). The estimation of the harbour porpoise density ranges from 0.05 to 1.03 individuals per km², leading to an abundance of 186 to 3,697 animals (Haelters *et al.* 2011). The animals show a distinct spatial and temporal distribution in Belgian waters with relatively high densities from January to April and lower numbers from May to August, plus they tend to stay in more northerly and offshore waters (Haelters *et al.* 2011; 2016).

In the western part of the BPNS, a 238 km² zone has been designated for renewable energy. Nine projects have been granted permits to build and operate wind farms in this part of the BPNS (fig. 1). For this study we focused on the three wind farms that were to be built between 2017 and 2019, namely Rentel, Nother and Seastar, to construct the scenarios reflecting the impact of pile driving sound on the modelled population of harbour porpoises.

- Rentel NV was granted an environmental permit on 15 February 2013 to build and operate its offshore wind farm. The wind farm will be built at a distance of 31 km from the coastline in the north west of Thornton Bank and the south east of Lodewijk bank. The total capacity of this wind farm of 294 MW is provided by 42 turbines, each with an output of 7 MW.
- The second wind farm, NV Norther, will be placed at 21 km off the coast of Zeebrugge in the south east of Thornton Bank. It was granted an environmental permit on 18 January 2012. The planned capacity for the Norther wind farm of 378 MW is based on 45 wind turbines, each with a capacity of 8.4 MW.
- NV Seastar, the last wind farm in this simulation, was granted an environmental permit on 7 February 2014 to build and operate an offshore wind farm. This wind farm will be placed at a distance of 41 km from the coastline, to the north west of Lodewijk Bank and the south east of Bligh Bank. Seastar will contain 41 wind turbines with a total capacity of 246 MW.

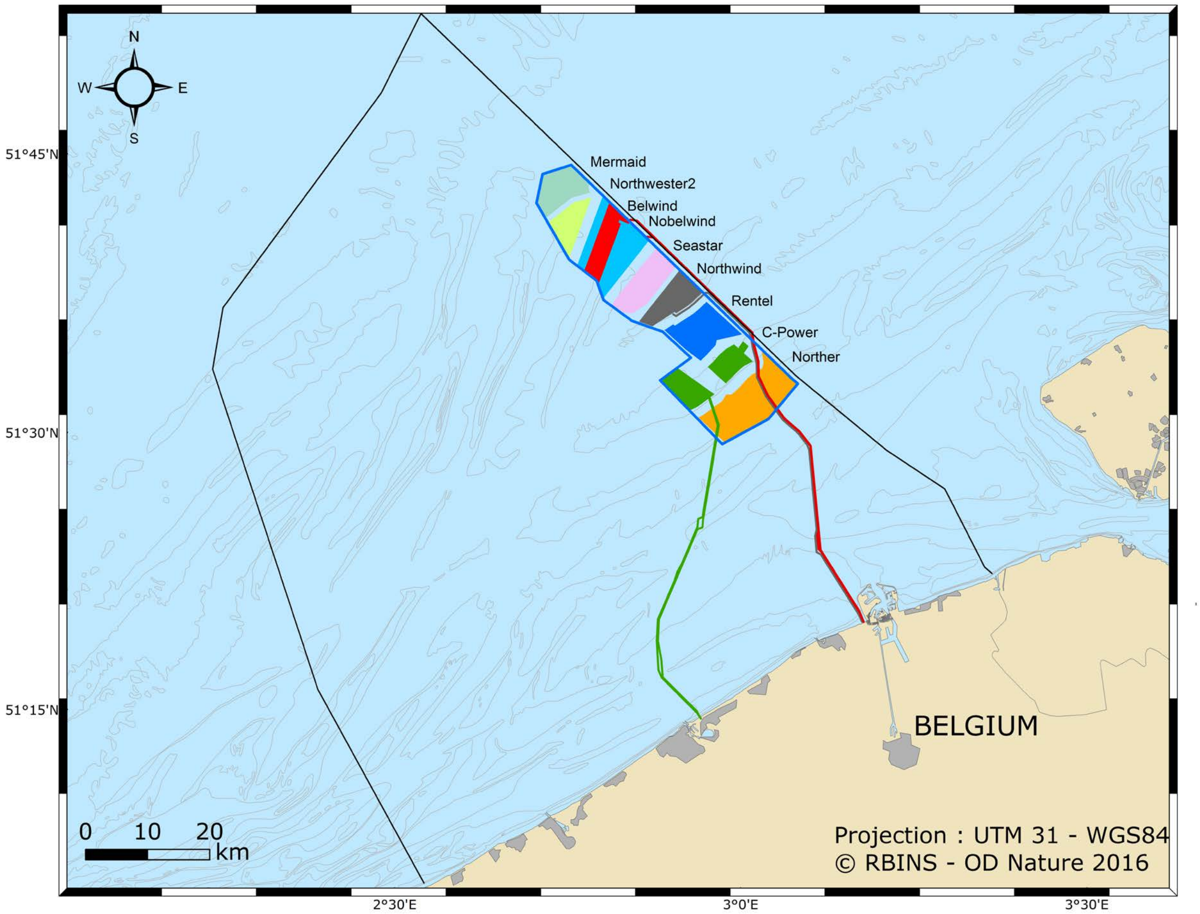

Figure 1. Position of offshore wind farms in the BPNS.

Based on feedback from the developers (Rentel/Seastar), construction was simulated under two different construction speeds, namely with either a slow piling calendar or a fast piling calendar. In case of a slow piling calendar, piling happens every other day (2 h of pile driving per foundation) and the next day there is no piling, over an eight-day period, per block of 14 days allowing for transit of the vessel carrying the foundations. Piling based on a fast piling calendar happens in 4 consecutive days per block of 10 days, starting from the 4th day.

2.2. Legal framework

The countries bordering the Southern part of the North Sea (*i.e.*, Belgium, the Netherlands, the United Kingdom, Germany and Denmark) are dealing differently with the uncertainties associated with the impacts of high levels of impulsive sound associated with the installation of offshore wind farm foundations on marine mammals. This study will focus on three countries that span the range of legal regimes with regards to the mitigation of piling noise, namely the United Kingdom, Belgium and Germany (table 1).

In this study different scenarios for the construction of offshore wind farms will be modelled to determine the impact and thus usefulness of various mitigation measures such as seasonal piling restrictions, acoustic deterring devices (ADD) and noise mitigation systems on the modelled population of harbour porpoises. These were selected to reflect the impact of the different regulatory regimes shown in table 1.

These differences in regulatory regimes were used to perform the simulations. A baseline scenario was based on the regulatory

Table 1. Summary of the regulatory regimes and required mitigation techniques for the production of underwater sound during pile driving of offshore foundations (Alstom *et al.* 2015)

	United Kingdom	Belgium	Germany
Noise thresholds	No	185 dB re µPa SPL at 750 m from piling event	160 dB SEL and 190 dB SPL at 750 m from piling event
OWF development forbidden in Natura 2000 areas	No	Yes*	Yes
Seasonal restrictions	No	Yes	No
Marine mammal observers (MMO)	Yes	No	No
Soft start	Yes	Yes	Yes
Acoustic deterring devices (ADD)	No	Yes	Yes
Obligatory noise mitigation systems (NMS)	No	Yes	Yes

* Based on the proposal for a new zone for marine renewable energy in the draft of the marine spatial plan 2020-2026; this is likely to change in the near future.

regime of the UK where no noise threshold nor seasonal restriction is enforced (scenario 1). The piling calendar for this scenario starts in March as the winter months of January and February are often characterised by adverse weather conditions.

The pre-Marine Strategy Framework Directive guidelines used by the Belgian government forms the base of the second scenario (scenario 2): it includes seasonal piling restrictions (*e.g.*, the start of the piling event is forbidden in a certain period, so the piling starts in May instead of March) and the environmental license obliges the use of acoustic deterring devices (ADD).

The third management scenario (scenario 3) is based on the current (2017-2018) environmental license conditions enforced by the Belgian government and comprise seasonal piling restrictions (*e.g.*, start in May), the use of ADD and a noise mitigation system, namely the big bubble curtain (BBC). For this scenario we assumed that a BBC reduces Sound Exposure Level (SEL) at 750 m by 10 dB re 1µPa/s. This was less than the a priori estimate of 17 dB re 1µPa/s provided by the developer (DEME 2017) but in line with data from literature (Lucke *et al.* 2011; Bellman *et al.* 2015). To determine the impact of the seasonal pile driving restrictions, this scenario was also simulated with a start in March.

The regulatory regime of Germany gave inspiration for the final scenario (scenario 4), which included seasonal pile driving restrictions (*i.e.*, start in May), the use of ADD and a strict noise threshold, which in practice has resulted in the use of two combined noise mitigation systems. Here we simulated a combination of BBC and NMS. For this scenario we assumed that such a combination reduces SEL at 750 m by 20 dB re 1µPa/s. This is in line with data from literature (Rumes *et al.* 2016). Thus, the effect of an extra noise mitigation system (the noise mitigation screen) becomes visible when this scenario is compared with scenario 3.

An additional mitigation measure that was tested is the – no longer enforced – Dutch prohibition of piling activities by two nearby wind farms with overlapping construction periods. The influence of two wind farms built in one year was modelled with two new scenarios: a first scenario where two wind farms (here: Norther and Seastar) are built simultaneously (piling days overlap) and a second situation with serially built wind farms (no overlap in piling days).

Table 2. Overview of the 17 different scenarios simulated in iPCOD. When there is no seasonal pile driving restriction, construction is assumed to commence March 1st. Otherwise construction starts May 1st. Construction of the Norther and Seastar projects in the same year is either assumed to overlap (O) or to be serial (Se). Construction was simulated either with a fast (F) or slow (S) piling calendar

	Scenario 1				Scenario 2				Scenario 3					Scenario 4			
	A	B	C	D	A	B	C	D	A	B	C	D	E	A	B	C	D
Seasonal restriction					X	X	X	X	X	X	X	X		X	X	X	X
ADD					X	X	X	X	X	X	X	X	X	X	X	X	X
BBC									X	X	X	X	X	X	X	X	X
IHC														X	X	X	X
Norther & Seastar			O	Se			O	Se			O	Se				O	Se
Construction	S	F	S	S	S	F	S	S	S	F	S	S	S	S	F	S	S

Seventeen different scenarios were selected to investigate the impact of the range of noise mitigation measures on a harbour porpoise population (Table 2).

2.3. interim Population Consequences of Disturbance model (iPCOD model)

To assess the potential effects of anthropogenic noise, associated with offshore renewable energy developments, on harbour porpoise populations, the interim Population Consequences of Disturbance (iPCOD) model was developed (Nabe-Nielsen & Harwood 2016). In this model population dynamics are simulated based on the birth and average survival rates, derived from data from North Sea animals. iPCOD runs fast which makes it possible to compare many different scenarios and to take a wider range of uncertainties into account. Independent estimates of the number of animals, that may be disturbed by the offshore activity, combined with the results from an expert elicitation process (Donovan *et al.* 2016) are used in the iPCOD model. It is called an interim approach, as the values given by experts should be replaced with empirically derived values, when these become available (Nabe-Nielsen & Harwood 2016). iPCOD does not currently include density dependent population regulation. As a result, a population that is reduced in size as result of a disturbance activity will only be predicted to recover when the disturbance activity ceases if the population was increasing in size before the disturbance. Please note that the iPCOD model is not spatially explicit. Every scenario was simulated 500 times.

To parameterise the model the following data is required (Nabe-Nielsen & Harwood 2016):

- basic life-history parameters (*e.g.*, birth rate, calf, juvenile and adult survival, age of maturity);
- timing and spatial distribution of activities likely to cause disturbance (see 2.1. and 2.2.);
- for each of the developments being modelled, an estimation of the number of animals predicted to be disturbed by one day of piling;
- number of animals that experience permanent threshold shift (if any);
- residual days of disturbance;
- population size;
- years of disturbance;
- values for the parameters determining the relationship between the survival or birth rate of an individual and the number of days, the individual experiences disturbance;

- expected inter-annual variation in juvenile and adult survival and birth rate due to environmental variation.

For harbor porpoise, these latter two were obtained by expert elucidation at the time of the development of the iPCOD model.

2.3.1. Basic life history parameters

A script for harbour porpoise containing the basic life-history parameters is included in the iPCOD model (Harwood & King 2014). Here we applied the low adult survival rate as this was determined to be more representative for the North Sea harbour porpoise population (Winship & Hammond 2008).

2.3.2. Estimation of the number of animals predicted to be disturbed by one day of pile driving

As the three simulated wind farms are located in the same area and are expected to use the same techniques to install similar monopiles, each wind farm was assumed to have both the same harbour porpoise density and (noise) effect radius. Based on 13 aerial surveys (from 2008 to 2016), we assumed the following seasonally fluctuating porpoise densities for the BPNS:

- March – April = 2.7 individuals/km²
- May – July = 0.9 individuals/km²
- August – September = 1.4 individuals/km²
- October – February = 0.9 individuals/km²

For these simulations, the number of animals disturbed by one day of pile driving was calculated by multiplying the density of harbour porpoise by the area affected by the pilling event. Brandt *et al.* (2016) indicate that all affected individuals are classified as disturbed when noise levels are above 160 dB re 1 μPa²s or when porpoises are avoiding the pile driving event due to the use of acoustic deterrents. Robrecht Moelans (G-TEC) used an acoustic model to calcu-

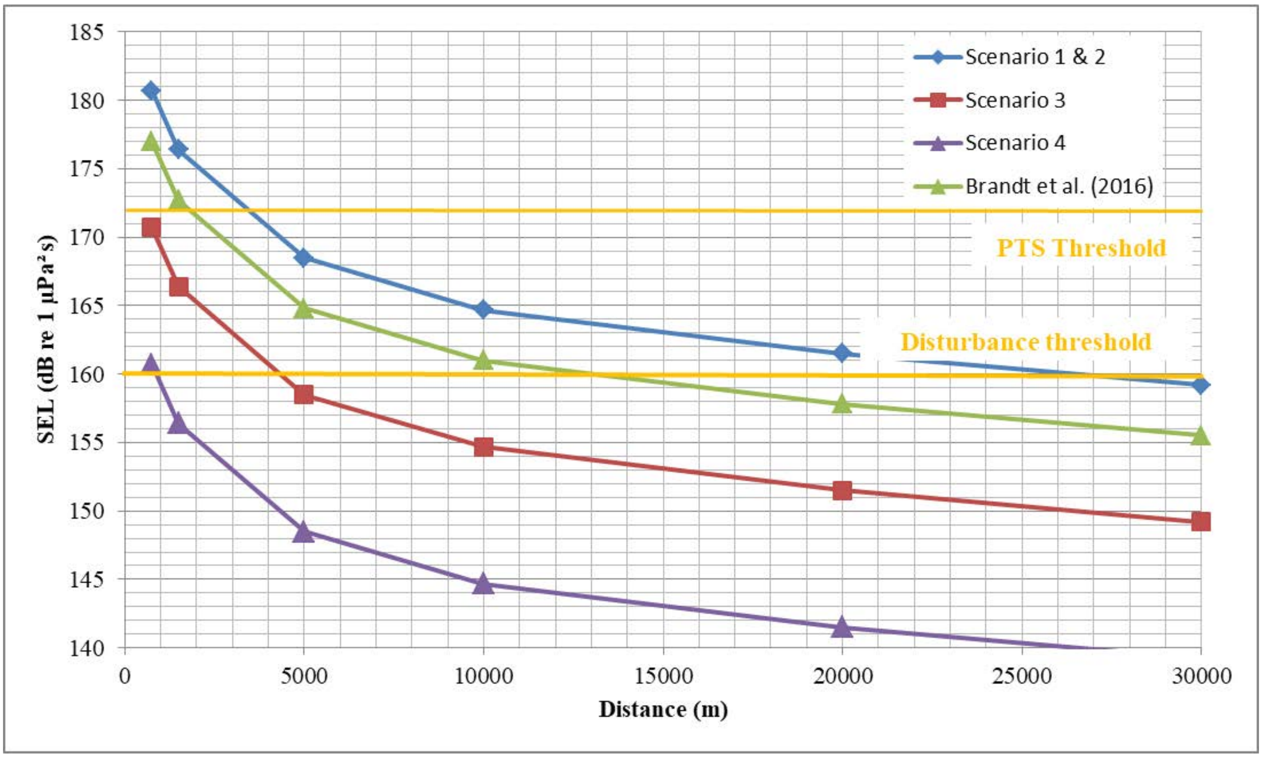

Figure 2. Anticipated Sound Exposure Level (SEL) re 1μPa.s. for the Rentel offshore wind farm under scenario 1 & 2 (blue), scenario 3 (red), scenario 4 (purple), and data from Brandt *et al.* (2016) (green) (data R Moelans, GTEC).

Table 3. Illustration of the fast (top) and slow (piling) calendars showing the days when pile driving takes place (red) and residual days of disturbance (orange)

Day	1	2	3	4	5	6	7	8	9	10				
Fast piling calendar				P1	P2	P3	P4							
Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Slow piling calendar				P1		P2		P3		P4				

late the anticipated Sound Exposure Level (SEL) at various distances. From these simulations, the effect radius could be deduced for the different scenarios: scenarios 1 and 2 – 26 km, scenario 3 – 4.2 km, scenario 4 – 1 km (fig. 2) .

For the simulations with two wind farms built in the same year, the effect radius of both wind farms overlapped as the distance between these wind farms (Norther and Seastar: 15 km) was smaller than the impact radius. Under scenarios 1 and 2, an overlap of 1012 km² was calculated thus reducing the total area of disturbance for days when construction activities coincide.

2.3.3. Number of animals that experience permanent threshold shift (PTS)

The number of animals that experience permanent threshold shift is calculated in the same way as the number of disturbed animals (*i.e.*, density multiplied by the affected area). Under the assumption that PTS in harbour porpoise occurs at a SEL of 172 dB re 1µPa²s (see Brandt *et al.* 2016) and using the above-mentioned pile driving sound model, we computed an effect radius of 3.5 km for scenario 1. For scenario 2, a circular area with a radius of 1 km is subtracted from the affected circular area calculated for scenario 1, due to the assumption that the ADD scares the harbour porpoises away up to 1 km from the piling event (Brandt *et al.* 2012; 2013). Actual observed deterrence distance will be determined by the characteristics of deployed ADDs (source levels and frequency) and local environmental conditions (Hermannsen *et al.* 2015). The number of animals that suffer from PTS is set to zero for scenarios 3 and 4, as due to noise mitigation measures a SEL > 172 dB re 1µPa²s is only exceeded in the first kilometer from the source and here the harbour porpoise were assumed to have been driven away (disturbed) by the ADD.

2.3.4. Residual days of disturbance

In theory each pile driving event could lead to two residual days of disturbance due to reduction of detection rates up to one day before as well as two days after piling (Brandt *et al.* 2016; Rumes *et al.* 2017). In practice this is dependent on the piling calendar. For the scenarios with a fast piling calendar, there were only three days of residual disturbance per set of four foundations (rounded up to one per pile to fit the structure of the iPCOD model) versus six days for the slow piling calendar (rounded up to two per pile – table 3). Animals were only vulnerable to PTS on the first day of disturbance, as piling only occurs on one day per piling event.

2.3.5. Population size

The North Sea porpoise population consists of 345,000 specimens as defined by SCANS III (with lower and upper 95% confidence limits of abundance of 246,000 and 496,000 – Hammond *et al.* 2017). However, for this study, we set the local porpoise population size on 9326 individuals *i.e.*, – at that time – the maximum number of porpoises

Table 4. Overview of the outcome of the 17 scenarios simulated with the iPCOD model, showing the median decrease (%) in porpoise population size and the added risk of a 1% and 5% decline in porpoise population between an undisturbed population (baseline *i.e.* no pile driving) and a disturbed population (construction of three wind farms) six years after the start of the piling calendar under four different regulatory regimes. When there is no seasonal pile driving restriction, construction is assumed to commence March 1st. Otherwise construction starts May 1st. Construction of the Norther and Seastar projects is the same year is either assumed to overlap (O) or to be serial (S). Construction was simulated either with a fast (F) or slow (S) piling calendar. Probabilities exceeding 50% or 10% are indicated in red or bold respectively

Regulatory regime	**Scenario 1**				**Scenario 2**				**Scenario 3**					**Scenario 4**			
	A	**B**	**C**	**D**	**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**	**E**	**A**	**B**	**C**	**D**
Seasonal restriction					X	X	X	X	X	X	X	X		X	X	X	X
ADD					X	X	X	X	X	X	X	X	X	X	X	X	X
BBC									X	X	X	X	X	X	X	X	X
IHC														X	X	X	X
Norther & Seastar			O	S			O	S			O	S				O	S
Construction speed	S	F	S	S	S	F	S	S	S	F	S	S	S	S	F	S	S
Median decrease in porpoise population (in %)	**6.71**	**5.12**	**4.56**	**5.72**	**5.39**	**3.61**	**4.28**	**4.69**	0.18	0.07	0.13	0.20	0.49	0.03	0.00	0.00	0.02
Added risk 1% decline	0.72	0.71	0.67	0.68	0.61	0.56	0.67	0.67	0.05	0.00	0.03	0.05	**0.10**	0.00	0.00	0.00	0.01
Added risk 5% decline	0.76	**0.49**	**0.46**	0.63	0.57	**0.30**	**0.38**	**0.47**	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00

reported from the BPNS and assumed that this entire population could potentially be affected by the pile driving (*i.e.*, could move into the impact radius). We chose to use this smaller population to emphasise the differences between management scenarios.

2.3.6. Years of disturbance

It takes three years to build the three wind farms (between 2017 and 2019) but the number of piling years is set on four. As the iPCOD model requires that the start date of the piling years should be the beginning of the breeding season *i.e.*, the first of June for harbour porpoise, the piling calendar starts in June 2016 and ends in May 2020.

3. Results

An overview of the outcome of the iPCOD model for the different scenarios is given in table 4. The median decrease in porpoise population after six years exceeded 1% for all scenarios where the pile driving sound was not reduced. For these scenarios, the additional risk of a 1% decline in porpoise population (due only to the effects of pile driving) was more than 50%.

Reducing the number of additional days of disturbance under the fast piling calendar, significantly reduced the risk of a porpoise population decline (*e.g.*, by 35 and 47% under scenario 1 and 2 respectively for a 5% decline).

The use of a seasonal piling restriction (start of works in May rather than March) and an acoustic deterrent device reduced the impact on the porpoise population, but this was minor compared to the effect of the reduction in excessive underwater sound of the simulated big bubble curtain (BBC). Here we anticipated that such a noise mitigation system would reduce pile driving sound by 10 dB re 1 µPa/s which resulted in a decreased radius of disturbance from 26 to 4.2 km. The further 10 dB re 1µPa/s reduction in pile driving sound, obtained by adding a second type of noise mitigation (IHC Screen), would theoretically reduce the impact radius to about 1 km, which is why there is hardly any impact on porpoise populations under scenario 3.

The effect of having two wind farms constructed in the same year is two-fold. On the one hand, more porpoises are disturbed during a single construction year, this is especially true for serial construction of two wind farms. On the other hand, the porpoise population is subjected to only two years with pile driving works. In these scenarios, having two of the three wind farms constructed in the same year was less detrimental to the porpoise population than three consecutive construction years. In this model, this is especially true for wind farms that are closely located as an overlap in space and time of disturbance will reduce the number of porpoises affected.

4. Discussion

The Belgian government plans to double the amount of operational offshore wind farms by 2020 (see Chapter 1). At a North Sea scale, construction of offshore wind farms is expected to increase for the next 30 years. How pile driving sound impacts harbour porpoise populations remains one of the major concerns identified by the intergovernmental Cumulative Environmental Assessment Framework (CEAF) working group. At present, the different North Sea countries have all defined different regulatory regimes with regards to offshore wind farm construction and anthropogenic underwater sound mitigation. In this study we used the iPCOD model to test how applying different management options to the construction of the same wind farms will influence the harbour porpoise population.

4.1. Effect of a seasonal pile driving restriction

In the iPCOD model, the main factor that will determine impact on the porpoise population is the number of animals that is (permanently or temporarily) affected by the construction works. This can be minimized by reducing or eliminating the number of foundations installed by pile driving. The first could be done by installing fewer, larger, foundations whereas the second would require the use of a different installation technique such as suction bucket. An alternative way to minimize impact is by avoiding construction works during periods of high porpoise density or when the animals are particularly sensitive to disturbance. In our simulations, shifting the start of construction by two months (from March 4th to May 4th) reduced the risk significantly. The main advantage of this measure is that it is easily enforceable. The main disadvantages are that it requires good knowledge of interannual variability in seasonal porpoise densities.

4.2. Effect of noise mitigation

In the iPCOD model, noise mitigation affects the impact on porpoise population by reducing the area of disturbance. A reduction of the Sound Exposure Level (SEL) by 10 dB re 1µPa resulted in a reduction of the area of disturbance by 97%. As a result, independently of the other factors (fast or slow piling/one or multiple parks constructed per year), no major impact on porpoise population was observed. Effective noise mitigation would thus seem to be the most promising way to reduce porpoise population level impacts. However, initial measurements from Rentel indicate that noise levels are higher than assumed, even with the BBC (chapter 2).

4.3. Effect of simultaneous construction

When construction of multiple wind farms in the same year overlapped in both space and time, then this resulted in a reduction of the number of porpoise disturbance days and thus a lower impact on the population than if the construction did not overlap in space and time.

4.4. Effect of time schedule and adverse weather

Weather conditions impact the speed of construction of a wind farm. Transport of the foundations and pile driving is not possible under adverse weather conditions and, in that case, the wind farm will be piled based on a piling calendar which will more closely resemble the slow piling calendar (*e.g.*, 56 foundations piled in 149 days at Belwind – winter 2009-2010). The fast piling calendar is only possible in good weather conditions (*e.g.*, 43 foundations piled in 64 days at Rentel – summer 2017), which – in the North Sea – are most frequent from late spring to early autumn.

4.5. Some words of caution

The values obtained in our scenarios should not be interpreted as absolute or even indicative of the magnitude of the changes to be expected following the construction of the three studied wind farms. They merely serve to identify the relative effectiveness of possible management measures. As explained in the methodology section, population size was set artificially low to exaggerate consequences and allow us to identify differences between the management scenarios. In addition, Marine Scotland emphasises the interim nature of the iPCOD model, which was developed to deal with the current situation, where there is limited data on how changes in behaviour and hearing sensitivity may affect the ability of individual marine mammals to survive and to reproduce. The values provided by experts should be replaced with empirically derived values as soon as they become available.

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