CHAPTER 10

AN ANALYSIS OF HARBOUR PORPOISE STRANDINGS AFTER A DECADE OF OFFSHORE WIND FARM CONSTRUCTION IN THE SOUTHERN NORTH SEA

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Abstract

The Southern North Sea is an important hub for offshore wind energy with nearly 40 operational offshore wind farms, and many more planned. In most cases, the construction of offshore wind farms requires the installation of large hollow steel piles using high-energy impact hammers. In addition, geophysical site surveys regularly include seismic airgun surveys which operate over large areas for prolonged periods of time. Both of these processes generate very high sound levels in the surrounding waters, which can be detrimental to marine mammals if these are exposed to them. Increased noise levels over a large area can affect marine mammals in several ways, ranging from behavioural responses, masking of acoustic signal detection and temporary to permanent hearing loss and physical injury. All of these can lead indirectly to an increased mortality rate or, due to stress, to a compromised reproduction. In this study we examined, over a period of fourteen years, whether prolonged periods of intermittent high intensity impulsive sound influenced the temporal pattern of strandings on Belgian beaches of the harbour porpoise (*Phocoena phocoena*), the most common cetacean in the Southern North Sea. Generalized Additive Mixed modelling revealed a strong seasonal pattern in strandings, with a first peak in strandings in spring (March-May) and a second, less pronounced, in September. In addition, our analysis revealed a significantly higher occurrence of stranded harbour porpoise on Belgian beaches in months with prolonged periods of intermittent high intensity impulsive sound which is suggestive of increased mortality. An in-depth analysis of age, sex, cause of death, and overall health (prior to death) of the stranded specimens will help determine what drives this additional mortality and reduce the uncertainty due to the biases associated with the use of this strandings data.

1. Introduction

Harbour porpoises (*Phocoena phocoena*) are the most consistently present cetacean observed in the North Sea (Hammond *et al.* 2002) and the Belgian part of the North Sea (BPNS) (Haelters *et al.* 2011). The species is protected by both national (Belgian Government 2001) and EU law (EU 1992). In the North Sea, the harbour porpoise is considered vulnerable because of high bycatch levels and its sensitivity to increasing noise pollution. In the last two decades, there has been a strong increase in activities generating prolonged periods with intermittent high intensity impulsive underwater sound (Slabbekoorn *et al.* 2010; Shannon *et al.* 2016). High levels of impulsive underwater sound are generated when large steel turbine foundations are hammered into the seabed as well as during seismic surveys. Concerns over the possible impact of high intensity impulsive sound generated during the construction of offshore wind farms on marine mammals in general, and harbour porpoise in particular, has been a driving force in determining national regulations in North Sea countries *(*Rumes *et al.* 2016). These concerns originate from the fact that exposure to high intensity impulsive underwater sound affects porpoises over large distances (Haelters *et al.* 2013; Brandt *et al.* 2016; Rumes *et al.* 2017). Potential effects include physical injury, physiological dysfunction, behavioural modification and masking of sound used by the animals themselves (see *e.g.* Carstensen *et al.* 2006; Parvin *et al.* 2007; Bailey *et al.* 2010). At the level of individual porpoises these effects and their consequences on vital rates (survival, maturation, reproduction) vary in significance from negligible to fatal (Marine Mammal Commission 2007; Brandt *et al.* 2016). When the vital rates of large numbers of individuals are influenced, this will ultimately result in population level effects in line with the Population Consequences of Acoustic Disturbance (PCAD) conceptual model (NRC 2005). Both the iPCOD (interim Population Consequences of Disturbance; Harwoord *et al.* 2014; Nabe-Nielsen & Harwood 2016) and DEPONS (disturbance effects on the Harbour Porpoise population in the North Sea; Nabe-Nielsen *et al.* 2018) models aim to quantitatively assess population consequences of such sub-lethal behavioural effects. Resultant predictions for the impact of wind farm construction in the North Sea on harbour porpoise population have ranged from indistinguishable from the baseline scenario (Nabe-Nielsen *et al.* 2018) to a 40% chance of exceeding a 5% overall population reduction (SEANSE-study, TNO). However, due to a lack of data on the behaviour and fitness of those porpoises that are exposed to high levels of underwater sound, we must rely on indirect measures of activity such as changes in click rates and feeding buzzes to determine disturbance and use the aforementioned demography (iPCoD) and process-based (DEPONS) models to translate these to population consequences.

The investigation of strandings may provide additional insights into the state of the porpoise population. Strandings provide a sample of this population and show variability in the incidence of disease and causes of death. Ten Doeschate *et al.* (2017) demonstrated how examination of baseline patterns can facilitate the detection of unusual variability in stranding rates of harbour porpoises. In this report, we determined whether temporal patterns in observed porpoise strandings at the Belgian coastline (as a proxy for local population mortality) are influenced by prolonged (multiple consecutive months) periods of intermittent high intensity impulsive sound.

2. Material and methods

2.1. Data collection

In Belgium, strandings are reported to the national strandings netwerk (Haelters *et al.* 2013b). Given the relatively short length of the coastline (66.6 km) and the dense habitation and intensive recreational use along most of the coast, we assume that the large majority of stranded animals is reported within 24 hours. For this study, we have analysed strandings data from 2005 to 2018. Only those strandings that included data on

Table 1. Overview of the number of harbour porpoise (HP) strandings per month along the Belgian coastline between 2005 and 2018. Underlined numbers indicate months when pile driving was taking place.

Year	January	February	March	April	May	June	July	August	September	October	November	December	Total HP strandings
2005	3	6	4	21	18	7	3	13	6	4	2	2	89
2006	2	2	20	18	17	9	1	13	5	1	3	3	94
2007	1	9	9	13	14	4	4	13	12	4	3	0	86
2008	1	3	11	9	8	7	5	4	3	8	3	0	62
2009	6	3	6	5	5	5	3	10	13	8	1	1	66
2010	2	2	4	6	7	4	2	8	5	3	3	2	48
2011	3	2	6	25	10	4	16	25	7	5	5	8	116
2012	4	4	18	13	11	2	9	6	18	5	1	5	96
2013	3	7	11	38	26	20	13	6	8	13	2	2	149
2014	3	4	23	14	7	18	14	9	24	5	0	6	127
2015	2	2	5	6	7	8	6	3	5	5	3	0	52
2016	1	4	31	23	14	6	14	5	17	12	6	4	137
2017	1	5	8	5	5	9	19	13	4	13	5	6	93
2018	0	1	3	16	12	16	11*	3	7	15	0	2	86

The asterisk (*) indicates the seismic survey in July 2018.

stranding date and location were included in this analysis as animals that were reported floating at sea were excluded. We decided not to use data before 2005, as piling only started in 2009, and in the late 1990s and the early 21st century a major shift occurred in the distribution of porpoises in the North Sea, from the northwest to the Southern North Sea, (Hammond *et al.* 2013), leading to a major increase in numbers of stranded animals in the SSouthern North Sea. For the same time period, information on hydraulic pile driving activity in the Belgian North Sea was derived from the OD Nature pile driving dataset. No pile driving took place in the adjacent Dutch and French parts of the North Sea in this period.

The dataset thus includes strandings on Belgian beaches for fourteen years. Pile driving was ongoing in seven of these years and, in addition, in 2018 an experimental seismic survey took place in the month prior to the start of pile driving (table 1). The purpose of this latter survey was to test the response of tagged cod to the sound levels produced by during oil and gas exploration surveys (PCAD4COD-project).

Exposure to intermittent high intensity impulsive sound has the potential to affect porpoise survival on multiple time scales. A disturbed animal may not be able to feed for a certain period time (different iterations of the iPCoD models assume 6-24 hours – Harwoord *et al.* 2014, Nabe-Nielsen & Harwood 2016; Booth *et al.* 2019) but this alone is unlikely to result in direct mortality in adult porpoises (Kastelein *et al.* 2018). However, repeated exposures may result in starvation or reduced resistance to pathogens, thus resulting in indirect mortality. For our analysis we focused on changes in the numbers of strandings at the Belgian coast in those months with ongoing intermittent high intensity impulsive sound. We acknowledge that, for some individuals exposed to high intensity impulsive sound, mortality may occur only at a later date. However, harbour porpoises are highly mobile and there are major seasonal changes in porpoise distribution in the Southern North Sea (Gilles *et al.* 2016). Thus, those individuals that do die at a later date as an indirect result of cumulative exposure to impulsive sound generated in our waters are less likely to end up stranding at the Belgian coast.

2.2. Data analyses

We explored whether there was a linear relationship between the number of porpoise strandings over a whole year and the number of months of intermittent high

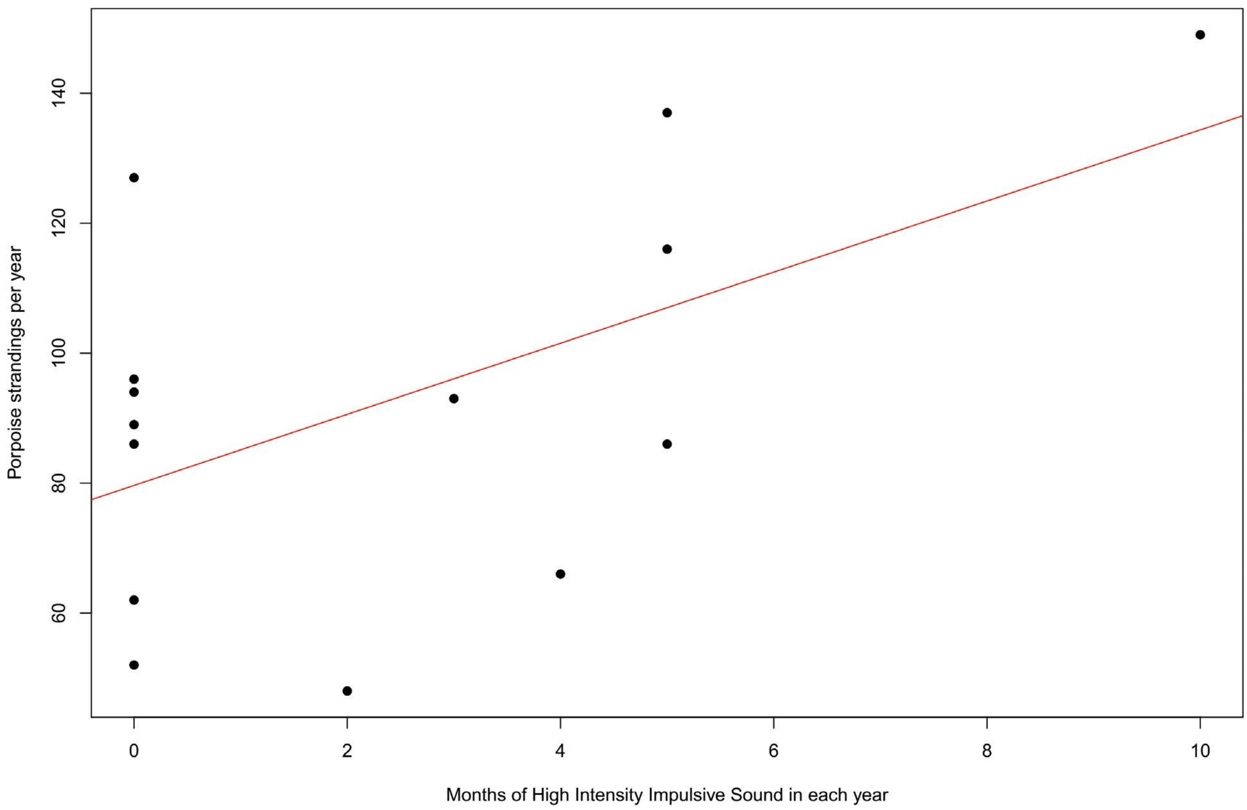

Figure 1. Yearly number of porpoise strandings at the Belgian coast in the period of 2005-2018 in relation to the number of months high intensity impulsive sound in these years.

intensity impulsive sound using the e1071 package (Meyer *et al.* 2019) available in R (R Core Team 2013).

We investigated the effect of high intensity impulsive sound on temporal stranding patterns through General Additive Mixed Modeling, using the *gamm4* package (Wood & Scheipl 2017) available in R (R Core Team 2013). Total number of strandings per month was modelled as function of a circular cubic spline for month, and presence/absence of high intensity impulsive sound generating activities in that month. Year was considered as a random variable (Ten Doeschate *et al.* 2017). A preliminary data-exploration (Zuur & Leno 2016) did not reveal any outliers, hence all data were used in the analyses. As data are counts, and therefore equal or larger than zero, we initially applied the GAMM using a Poisson error distribution, which resulted in an overdispersed model. Therefore, we applied GAMM using a Negative Binomial error distribution. As *gamm4* does not calculate the minimum value of the dispersion parameter *k*, we ran the model with a range of *k*-values and calculated approximate AICs. The k-value resulting in the lowest AIC was selected to run the final GAMM. Model validation was performed according to Zuur & Leno (2016) and mainly consisted of checking homogeneity of residuals and inspecting graphs of residuals *versus* all covariates in the model.

3. Results

For the period of 2005-2018, there is a weak, but positive correlation between the number of porpoise strandings per year and the number of months of intermittent high intensity impulsive sound ($r = 0.54$; $p < 0.05$; fig. 1). Exploratory analysis showed that, especially during late spring and summer, high numbers of stranded porpoises were observed during months with high intensity impulsive sound (fig. 2).

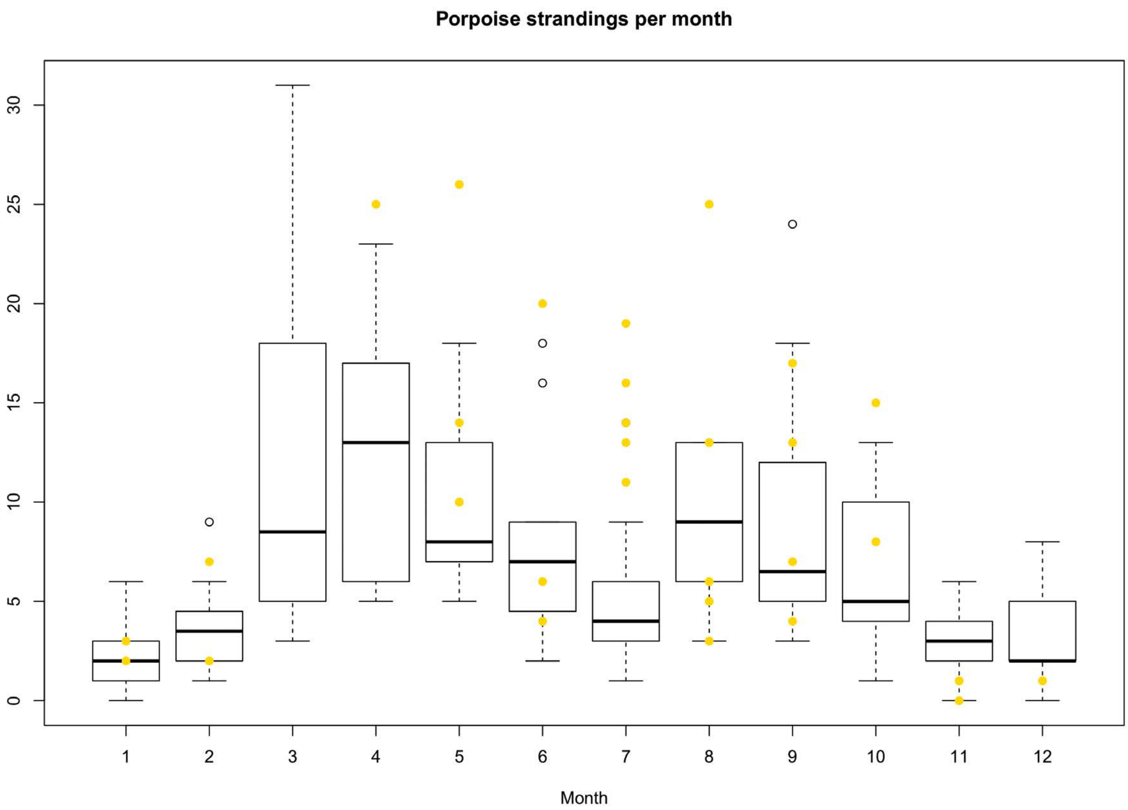

Figure 2. Monthly number of porpoise strandings at the Belgian coast in the period of 2005-2018. Boxplots only include months without high intensity impulsive sound. Yellow dots represent data of months with high intensity impulsive sound.

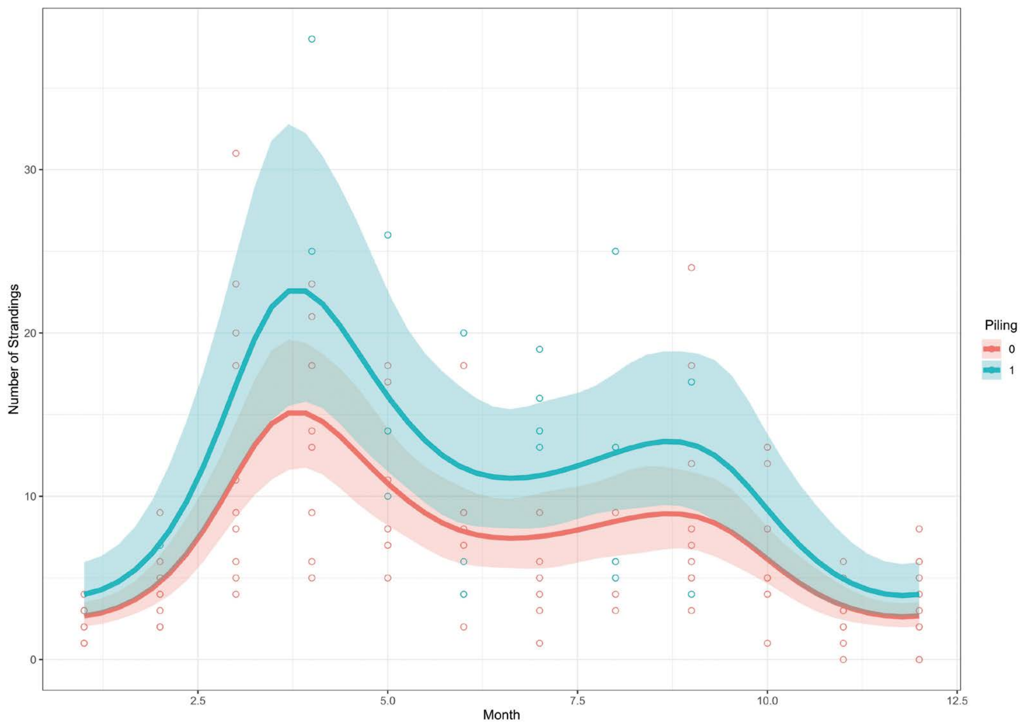

Figure 3. GAMM predicted number of harbour porpoise strandings in months with (solid blue line) and without high intensity impulsive sound (solid red line) for an average year. Shaded areas represent the confidence intervals. Actual data are displayed as dots (data: monthly number of porpoise strandings at the Belgian coast in the period of 2005-2018).

Generalized Additive Mixed modelling revealed a strong seasonal pattern in porpoise strandings along the Belgian coastline, with a low amount of strandings in winter, a first peak in spring (March-May) and a second, less pronounced, in late summer (September). The selected model suggested number of porpoise strandings was significantly related to month of the year (smoother estimated degrees of freedom = 5.6; p-value < 0.001; fig. 3). If we look at the effect of high intensity impulsive sound on this temporal stranding pattern, then a picture emerges with significantly higher numbers of strandings in those months with intermittent high intensity impulsive underwater sound (p-value < 0.01).

4. Discussion

In previous years, 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) and have used this information to model the consequences of pile-driving at (local) population scale (Rumes *et al.* 2018) using demography-based modelling, such as the interim Population Consequences of Disturbances model (iPCoD). In this report we discuss the seasonal pattern in porpoise strandings along the Belgian coastline and show that there is an increased number of strandings of harbour porpoise during months when high intensity impulsive sound is present in the BPNS.

4.1. Temporal stranding pattern

We observed a strong seasonal pattern in porpoise strandings along the Belgian coastline, with a low amount of strandings in winter, a first peak in spring (March-May) and a second, less pronounced, in late summer (September). This pattern is consistent with the results of aerial surveys (Haelters *et al.* 2015) and passive acoustic monitoring (Haelters *et al.* 2016; Augustijns 2018), with both also showing a seasonal pattern with higher detection rates in the end of winter to early spring. Gilles *et al.* (2016) found that, in spring, harbour porpoise hotspots were situated mainly inshore in the southern and south-eastern part of the North Sea and shifted offshore and to western areas in summer. Thus, from winter to summer, changes in porpoise distribution are likely to be the main driver for the observed pattern in observations and strandings. The second peak, in late summer, would appear not to reflect porpoise density in Belgian waters as determined by aerial surveys (Haelters *et al.* 2015). Passive acoustic monitoring (Haelters *et al.* 2016; Augustijns 2018) does observe a second and lower peak in detections around September-October. Part of the increase in strandings in late summer may be due to a temporary increase in mortality amongst juvenile porpoise failing to find enough food. Starvation is a common cause of death for porpoises in Belgian and adjacent French waters with necropsies showing that up to 70% of porpoises examined had an empty gastro-intestinal tract, indicating no recent food intake (Jauniaux *et al.* 2002).

Given the strong seasonal pattern in porpoise abundance in Belgian waters and the variability in timing of high intensity impulsive underwater sound generating activities, it is perhaps unsurprising that there is no clear linear relationship between the yearly number of porpoise strandings and the number of months of intermittent high intensity impulsive sound. However, if we look at the number of strandings over multiple months then prolonged periods with intermittent high intensity impulsive underwater sound do coincide with increased numbers of strandings. Further, more detailed analysis is required to determine whether this is due to causation (strandings reflect increased albeit indirect mortality) or correlation (with pile driving coinciding with periods of increased – natural – mortality).

4.2. Further analysis

There were considerable differences both in timing (winter *vs* spring/summer) and intensity of high intensity impulsive sound generating works (ranging from 14 days to 72 days of impulsive sound in 2010 and 2013 respectively). As the impact of disturbance on vital rates of porpoises is assumed to be exponential only once a certain threshold is exceeded (Booth *et al.* 2019) and, is likely subject to seasonal changes, we intend to repeat the analysis using only those years where prolonged high intensity impulsive sound was generated during spring-summer which coincides with the peak calving period (Lockyer 1995).

In addition, it may be advisable to include data on the sex and age of those stranded porpoises as vulnerability to disturbance is likely going to be different for *e.g.* calves and pregnant females (Booth *et al.* 2019). Data on the physical condition of stranded porpoises prior to death (*e.g.* blubber thickness and stomach content) may also reveal possible knock-on effects of disturbance. However, it should be noted that these data are not always available and depend on the state of decomposition at the time of stranding.

5. Conclusion

An exploratory analysis of the effect of high intensity impulsive sound on temporal stranding patterns along the Belgian coast suggests that these periods of high intensity impulsive sound often coincide with significantly increased overall porpoise stranding rates and is suggestive of increased mortality. In order to test this hypothesis, further analyses need to be conducted taking into account those factors that will influence porpoise mortality due to disturbance and thus indirectly stranding rates. These factors include cumulative exposure, age, sex and seasonal variation in vulnerability, and density dependent responses.

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