Effects of Offshore Pile Driving on Harbor Porpoises (*Phocoena phocoena*)

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1 Introduction

The world's growing demand for sustainable and environmentally friendly energy has led a growing number of countries to explore the options for the installation of offshore wind farms. In particular, noise emissions during the construction phase, when, in many cases, steel foundations are driven into the seafloor, are expected to cause temporal avoidance of the area by marine mammals and even have the potential to inflict physical damage to their sensory system (Madsen et al. 2006).

The harbor porpoise (*Phocoena phocoena*) is the only regularly occurring cetacean species in the German North Sea. Due to its wide distribution, all wind farm constructions in the North Sea inevitably affect this species to a certain extent. To assess these impacts, a profound knowledge of the behavior of the species in relation to noise levels created by offshore pile driving is essential. The main task is to describe the temporal and spatial extent of disturbance and thereby assess the scale of habitat exclusion.

During two different wind farm construction projects in the North Sea, we examined the impacts of offshore pile driving on harbor porpoises using passive acoustic monitoring (T-PODs).

2 Methods

The responses of harbor porpoises to wind farm construction were monitored by continuous registration of echolocation clicks using hydrophones with data loggers (T-PODs, version 4, www.chelonia.demon.co.uk). The T-POD is accompanied by the software package T-POD.exe (version 7.41) that uses a train detection algorithm (version 3.0) to discriminate cetacean trains from other sources. Clicks are then appointed to different probability classes depending on the likelihood of being of porpoise origin. We only used the two highest probability classes for analyses.

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T-PODs were placed in the water column ~1 m above the sea bottom. At Horns Rev II, six T-PODs were deployed along a transect line reaching from inside the wind farm area to a maximum distance of ~22 km to the southeast. The distance of the T-POD positions to single wind turbines ranged from 0.5 to 25 km. Water depth was 9-18 m. At Horns Rev II, data were recorded during the construction of 95 monopile foundations in 2009. Pile-driving events lasted on average 46 min. At Alpha Ventus offshore wind farm, seven T-PODs were deployed at a mean distance of 1.7–3.1 km, two at 8.3–9.1 km, and three at 15.6–19.6 km to single turbines. Water depth was ~30 m. Here four piles were rammed into the seabed during construction of the transformer platform in 2008. In 2009, 42 piles were driven into the seabed during the constructions of 6 jacket and 6 tripod foundations. Ten pile-driving events (separated by at least 60 min) lasting on average 5.5 h could be identified during construction of the tripod foundations, and 64 pile-driving events lasting on average 60 min could be identified during construction of the jacket foundations.

T-POD data were analyzed using GAM procedures where the parameter “porpoise-positive minutes per hour (PPM/H)” was used as the response variable; hour after pile driving, distance to pile, and time of day were entered as continuous nonlinear predictor variables; and in the case of Alpha Ventus data, T-POD position and year and in the case of Horns Rev II, month were entered as factors. One model was calculated for each of the three distance categories at Alpha Ventus and for each T-POD position at Horns Rev II. The duration of the effect was then visually defined as the time between the points when porpoise activity reached the first local maximum.

3 Results

At Horns Rev II, hour after pile driving had a significant effect on PPM/H at all positions. The curve that the GAM fitted to the data was of different shapes at the different T-POD positions (Fig. 1). At position 1, PPM/H steadily increased after the pile-driving event. PPM/H was substantially below the overall mean up to 24 h after pile driving. However, PPM/H continued to increase, with a narrow confidence interval, until leveling off at ~72 h after pile driving. At positions 2 and 3, the patterns are similar. At position 2, the effect lasted between 18 and 40 h; at position 3, it was between 17 and 42 h. At positions 4 and 5, the effects were substantially shorter: 9–21 h and 10–31 h, respectively. At position 6, the shape of the curve differed: PPM/H was higher than the overall average up to ~35 h after pile driving while decreasing and fluctuating around the overall mean afterward.

A similar pattern was found at Alpha Ventus. Here the effect of hour after pile driving was significant at 1.7–3.1 and 8.3–9.1 km but not at 15.6–19.6 km from the pile-driving site. The effect lasted between 20 and 35 h at 1.7–3.1 km and 9–12 h at 15.6–19.6 km (Fig. 1).

4 Discussion

We found a clear negative impact of pile driving during wind farm construction on porpoise acoustic activity. Porpoise activity measured as PPM/H was temporarily reduced during and after pile driving at a minimum distance of up to 17.8 km at Horns Rev II, whereas no such effect was found at a mean distance of 21.7 km. At the closest distance studied (2.5 km), porpoise activity was reduced between 24 and 70 h after pile driving. Results at Alpha Ventus were similar, with an effect still being detectable up to 9 km and no effect between 16 and 20 km. In the near vicinity, porpoise activity was reduced for 20–35 h after pile driving. Sound pressure levels during pile driving were

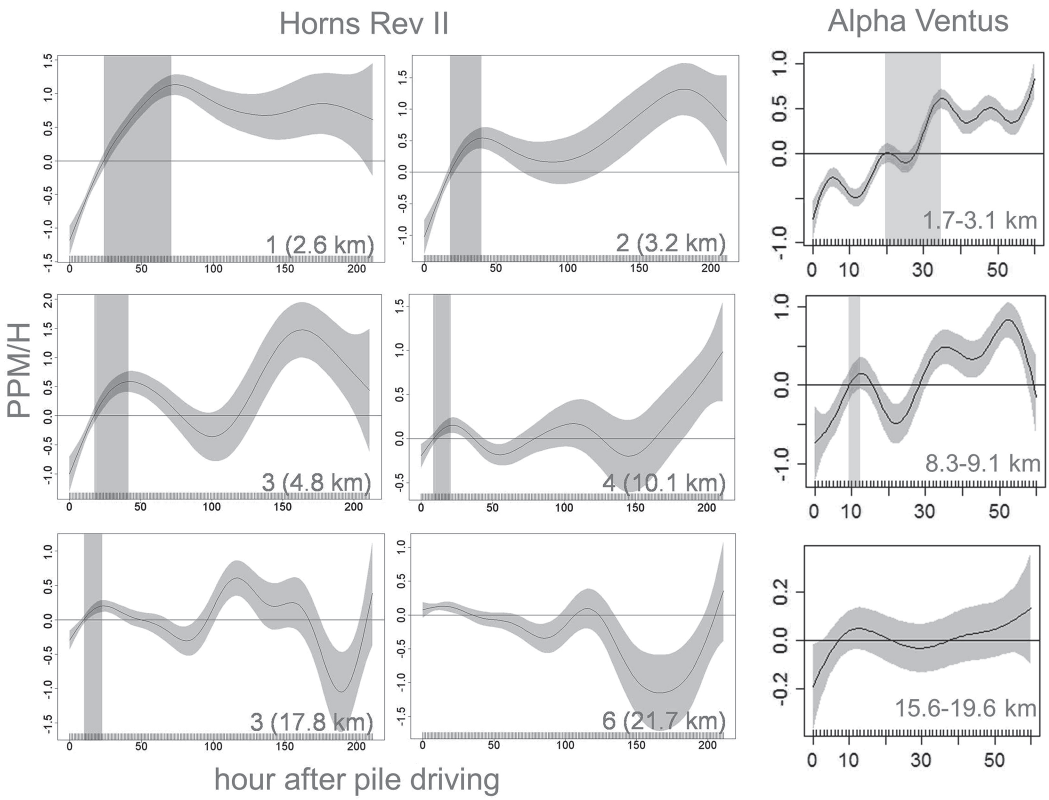

Fig. 1 Deviance of the overall mean of porpoise-positive minutes per hour (PPM/H) at different hours after pile driving at the offshore wind farms Horns Rev II and Alpha Ventus as calculated by GAM. Gray shaded areas, confidence intervals; gray vertical bars, duration of the negative effect as defined in Methods. The Figures from Horns Rev II are taken from Brandt et al. (2011)

higher at Horns Rev II than at Alpha Ventus. At Horns Rev II, 176 dB re 1 μPa (sound exposure level [SEL]) were measured 720 m from the pile driving. At Alpha Ventus, a sound pressure level of between 167 and 170 dB re 1 μPa (SEL) was calculated at 750 m based on measurements at greater distances. During both studies, the duration of the negative effect on porpoise activity decreased with distance. The mean time between pile-driving events was 38 h during both projects. This is within the time it took for porpoise activity to recover in the near vicinity to the construction site. Thus porpoise activity was lower for the whole construction period lasting 5 mo at Horns Rev II and 4 mo at Alpha Ventus.

Our results partly confirm findings by Tougaard et al. (2009) who found an effect up to a similar distance of ~20 km. However, the effect we found at both construction sites lasted considerably longer then the increase from 5.9 to 7.5 h between porpoise encounters after pile driving that they found. Unlike them, we also found a spatial gradient in the duration of the effect during both projects.

To keep negative effects on harbor porpoises at a minimum, these results should be taken into account for future spatial and temporal planning of pile-driving activities in the North Sea.

References

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