CHAPTER 2

CHARACTERIZATION OF THE UNDERWATER SOUND EMITTED DURING THE INSTALLATION OF MONOPILE STEEL FOUNDATIONS AT THE NOBELWIND OFFSHORE WINDFARM AND CUMULATIVE EFFECTS

NORRO Alain

Royal Belgian Institute of Natural Sciences (RBINS), Operational Directorate Natural Environment (OD Nature), Aquatic and Terrestrial Ecology (ATECO), Marine Ecology and Management Section (MARECO), Gulledelle 100, 1200 Brussels, Belgium.

Abstract

The construction works of the Nobelwind wind farm offshore on the Belgian coast was monitored for the emission of energy into the sea by means of underwater sound (pressure). Five complete piling events which cover the driving to full depth of 5 steel monopiles of 5 m diameter using a hydraulic hammer with a maximum power of 1400 kJ are described. No direct mitigation of the produced sound pressure was used and at 750 m distance, measured maximum SEL_{ss} ranged from 166 to 174 dB re 1µ Pa^2 s. Different metrics are proposed for the assessment of the cumulative effect of the piling works. SEL_{cum} ranged from 201 to 209 dB re 1µ Pa^2 s. Number of strokes used ranged from 2582 to 3696 while the energy used ranged respectively from 1764080 to 4048143 kJ. During piling work foreseen for 2018 and 2019, the behavioural response zone for the harbour porpoise could reach some 2800 km^2.

1. Introduction

High intensity impulsive sound like the one produced by underwater explosions, pile driving or seismic surveys using air-guns are known to affect marine life adversely (Hawkins & Popper 2016). Most of the available studies characterize local exposition to impulsive underwater sound (de Jong & Ainslie 2008; Bailey *et al.* 2010; Norro *et al.* 2013; Haelters *et al.* 2015; Popper & Hawkins 2012; 2016). Today, the development of marine renewable energy (MRE) in the North Sea shows numerous new projects. The risk exists that cumulative effects resulting from simultaneous construction or operation may affect marine life not anymore at the individual level but at a population level. Underwater sounds propagate at about 1500 ms^{-1} over large distances and are not stopped by national boundaries making the assessment of cumulative sound pressure a regional matter.

The purpose of this report was (1) to characterize the emitted underwater sound during piling events, (2) to evaluate the emitted sound during the piling of the foundation of the Nobelwind offshore high voltage station (OHVS) that is, currently the largest pile ever piled in the Belgian part of the North Sea (BPNS), and (3) to quantify cumulative effects and define the spatial extent of behavioural response zone for the harbour porpoise.

2. Material and methods

2.1. Study area

The Nobelwind wind farm is situated offshore the Belgian North Sea coast on the Bligh Bank (fig. 1). The wind farm actually represents the second phase of construction extending the Belwind wind farm operational since January 2011. This second phase of the wind farm construction requires the installation of 50 steel monopiles of 5 m diameter (lower end) and of lengths ranging from 54 m to 76 m. One additional monopile for the offshore high voltage station (OHVS) was installed in the concession zone. This steel monopile of 6.8 m diameter (lower end) and a length of 72 m represents the largest monopile ever driven into the Belgian seabed.

The first steel monopile of the Nobelwind offshore wind farm was installed on 16 May 2016 (BBK01) and the last one was piled on 22 September 2016 (BBI04). During the piling construction works underwater sound emitted during five complete pile driving events was recorded by means

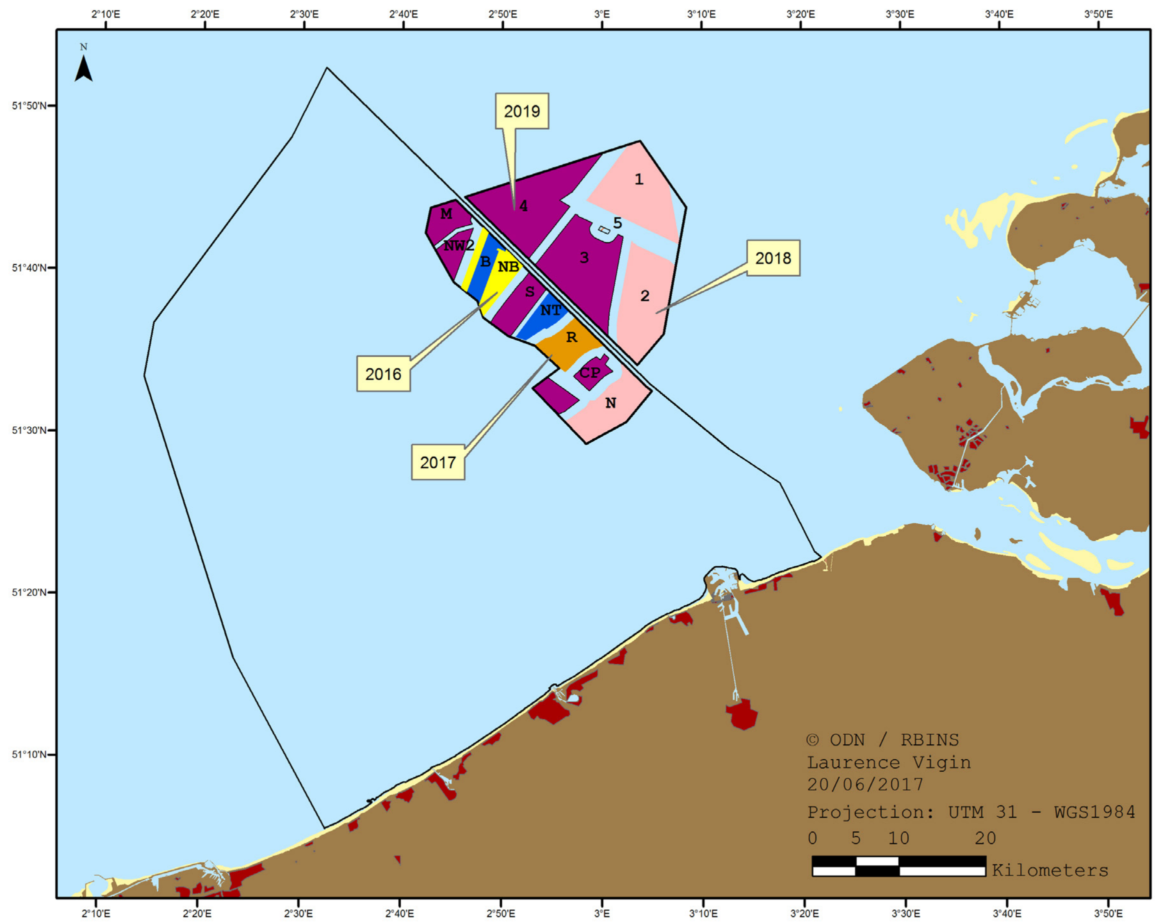

Figure 1. Implementation of the Nobelwind windfarm (NB on the map). In pink what is foreseen for construction in 2018 and in purple what is foreseen for 2019.

of a moored station. A 1400 kJ hammer operated from a jacking-up platform was used for the piling job. No directly emitted sound mitigation was in place but the construction permit (granted in 2008 and extended in 2015) required the use of an acoustic deterrent (Lofitech seal scarer), to be deployed one hour before piling starts and for a "ramp up" or "soft start" procedure to be used at the beginning of every piling event.

2.2. Underwater sound measurement equipment

Underwater sound was recorded from a moored station consisting of an instrumented tripod (fig. 2). The tripod was equipped with a complete measurement chain including a recorder RTsys EA-SDA14 and one hydrophone B&K 8104. RTsys calibrated the complete measurement chain prior to shipping from the factory. The calibration was verified using a calibrator B&K 4229 (piston-phone) prior to every deployment.

The instrumented tripod was deployed on 14 August 2016 using an acoustic release to lower it to the seabed in the vicinity of the planned piling location (WGS84 N 51° 39,875; E 002° 50,590 by 38 m depth relative to mean sea level). As such, the distance between the measuring equipment and the piling locations ranged from 850 to 3600 m. No surface marker was left on site to reduce navigation risk inside the construction zone as well as to avoid any perturbing sound originating from a line linking a surface buoy to the tripod. Scientific divers serviced the instrument on 27 August 2016 and retrieved the recording instrument on 25 October 2016.

2.3. Underwater sound measurements and post-treatment

Sound pressure was recorded continuously at a sampling rate of 78125 Hz and stored on hard drive coded in WAVE format.

During the period of deployment, the following piling events (table 1) were fully recorded.

Homemade routines in MATLAB were used for the post treatment of the records.

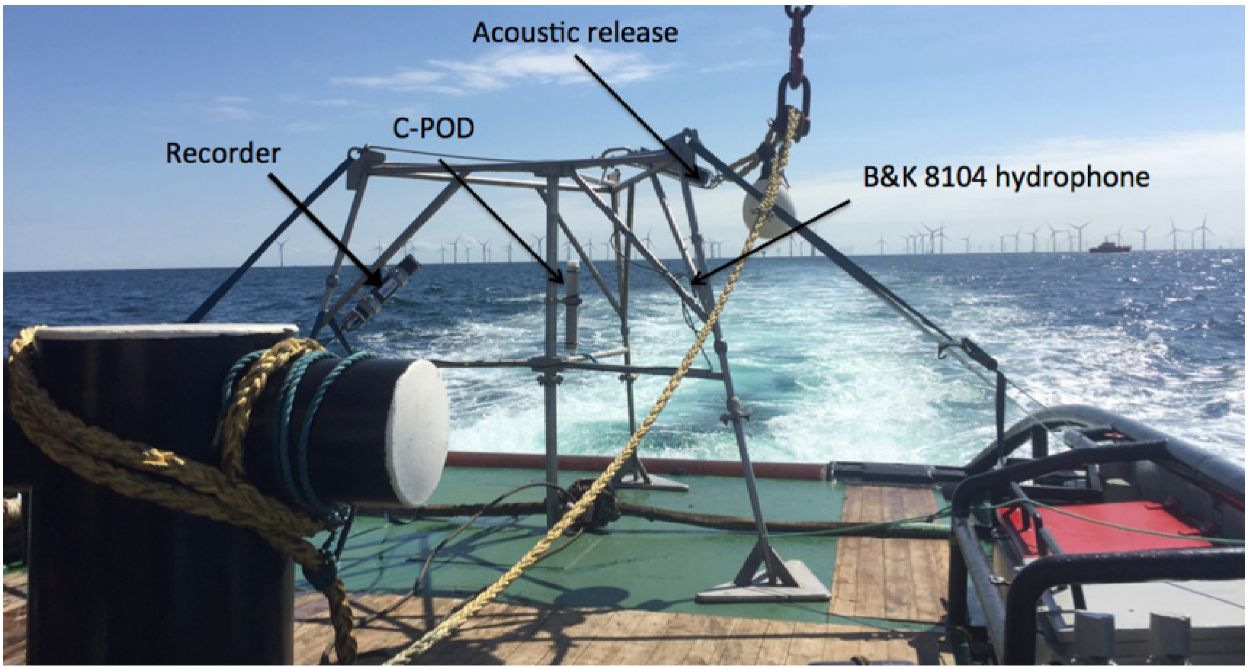

Figure 2. Tripod with RTsys sound recorder and B&K 8104 hydrophone mounted, C-POD and acoustic release ready for deployment on the rear deck of the MTS Valour (© Alain Norro/RBINS).

Table 1. Data available for the Nobelwind windpark piling phase

Pile name	Distance from recorder (m)	Start	End	Total duration
BBH01	1600	18/8/16	18/8/16	2h09
BBH03	860	17/8/16	17/8/16	4h32
BBH05	2100	30/8/16	30/8/16	4h24
BBH06	2000	27/8/16	27/8/16	2h46
BBH07	3400	31/8/16	31/8/16	2h10

Sound exposure level for a single strike and for a full piling event (SEL_{ss} and SEL_{cum}) as well as the normalization of levels to the reference distance of 750 m were computed according to Norro *et al.* 2013.

Because the intensity of the sound emitted depends on the size of the sound source, the intensity of the sound increases with the pile diameter. ITAP in Germany proposes an experimental model (Bellmann *et al.* 2017) that permits estimation of both SEL and L_{z-p} from the diameter of the monopile to be driven into the sediment. The ITAP model will be used to estimate level generated by the piling of the OHVS.

2.4. Cumulative effects

Cumulative effects characterize the effects resulting from the total number of strokes required for the installation of a single monopile or for a complete wind farm or even for the construction of a cluster of wind farms forming a zone of energy production. Metrics are elaborated to try to provide such integrated information. The cumulative sound exposure level (SEL_{cum}) is one of those metrics. In such context, the total energy spent during the complete operation of the piling of one monopile or wind farm or cluster of wind farms is another metric.

Worst-case scenarios for cumulative assessment occur here when construction in both Belgian and Netherland waters are simultaneously conducted (fig. 1). In this case large zones around these works may impact the behaviour of harbour porpoises. De Jong *et al.* (2017) estimated that a SEL_{ss} level of 140 dB re 1µPa^2 s should not be exceeded to guarantee absence of behavioural response for the harbour porpoises. Based on such threshold and the propagation model proposed by Norro *et al.* (2013), impact area size are estimated by drawing circles centered on every new project foreseen for a given year.

3. Results

Not considering the OHVS, the measured L_{z-p} ranged from 190 to 198 dB re 1µPa while SEL_{ss} ranged respectively from 166 to 174 dB re 1 µPa^2 s. Piling of the 6.8 m diameter monopile used for the OHSV is modelled to increase the maximum reported L_{z-p} by 5 dB and the SEL_{ss} by 4 dB.

The installation of the OHVS required about twice the number of strokes compared to BBH03 and about three times the energy spent for piling BBH03. When considering the sound levels to be similar to the one measured for other monopiles ($OHSV_{similar}$), a SEL_{cum} reaching 211 dB re 1 µPa^2 s is estimated for piling the OHVS pile. When applying the ITAP model ($OHSV_{mod\ Itap}$), a L_{z-p} of 203 dB re 1 µPa and a maximum SEL_{ss} of 178 dB re 1 µPa^2 s was estimated.

The propagation model proposed by Norro *et al.* (2013) estimated a 20 km radius impact zone centered on the sound emission point (OHVS not considered here).

Based on this and on the location of future piling sites presented at fig. 1, one can estimate a 2800 km^2 behavioural response zone for harbour porpoise in the worst case scenario presented in this paper.

4. Discussion

There is not only one adequate metric that could be used to translate the loudness of the

Table 2. Nobelwind construction phase

Pile name	L_{z-p} in dB re 1µ Pa	Max SEL_{ss} in dB re 1µ Pa^2 s	SEL_{cum} in dB re 1µ Pa^2 s	Total energy (kJ)	Number of strokes
BBH01	197	174	209	2977919	3297
BBH03	198	174	205	1764080	2582
BBH05	196	171	206	2892379	3123
BBH06	190	166	201	2229876	2753
BBH07	191	169	205	4048143	3696
$OHVS_{similar}$	≈	≈	≈ 211	5180744	5157
$OHVS_{mod\ Itap}$	203	178	215		

Measured parameters Lz-p , Max SELss and SELCUM normalized at 750m distance from the pile. Total energy & number of strokes provide from the hammer log (Nobelwind data). Offshore High Voltage Station (OHVS) not monitored *in situ* but estimation proposed here in two options (see text).

produced sound to an effect on the marine biota. Hawkins and Popper (2016) showed that the cumulative sound exposure level (SEL_{cum}) introduced for marine mammals is not the appropriate metric to be used for fishes and invertebrates. Hawkins and Popper (2016) propose characterizing the emitted sound using other metrics such as the sound exposure level of a single stroke (SEL_{ss}) together with the total time of piling and the total number of strokes.

The figures proposed here for a limited number of monopile installations can be extrapolated to the complete construction resulting in very high levels (above 185 dB re 1 µPa L_{z-p}) of underwater sound in the vicinity of the construction site.

Moreover, because of the concentration of the zones reserved for energy production (fig. 1), a cross-border strategy on cumulative sound emissions needs to be encouraged should a reduction of excessive underwater sound be strived for in the near future.

The 20 km circle radius of behavioural disturbance for harbour porpoise (*Phocoena phocoena*) confirms the radius of 16 km that was already proposed by Norro *et al.* (2013) for the major behavioural disturbance zone based on a level peak uto peak (L_{p-p}) of 155 dB re 1 µPa. That radius was further confirmed by Haelters *et al.* (2015) investigating harbour porpoise distribution changes during piling activities. There is a need for more research and standardization from the bio-acoustician in the development of behavioural response thresholds for marine mammals as well as for other animals like fishes and invertebrates.

In 2018, construction of three new wind farms in the zone is planned. Two of them will be installed in Dutch waters and one in Belgian waters. For 2019, the construction of another five wind farms is planned for, with three inside Belgian and two inside Dutch waters. From the above it is clear that any construction inside the Belgian zone will impact Dutch waters and any construction inside most of the Dutch Borssele zone will impact Belgian waters.

5. Conclusion

For a monopile of 5 m diameter and a hydro-hammer of 1400 kJ without direct underwater sound mitigation, a L_{z-p} ranging from 190 to 198 db re 1 µPa at 750 m from the source was detected, while at the same distance the SEL_{ss} ranged from 166 to 174 dB re 1 µPa^2 s. An estimation of the emitted underwater sound resulting from the installation of a 6.8 m monopile used for the OHVS gave a L_{z-p} of about 200 dB re 1µPa at 750 m and a SEL_{ss} of about 180 dB re 1 µPa^2 s.

A zone of 20 km radius was confirmed as a behavioural response zone for harbour porpoise and concerns are highlighted for the coming year 2018 and 2019 when construction of seven new windfarm projects is scheduled in the Belgian and adjacent Dutch (Borssele) offshore energy zones. During the year 2018 and 2019 the zone of behavioural response for harbour porpoises may reach some 2800 km^2.

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