# CHARACTERIZATION AND COMPARISON OF DIFFERENT NOISE SOURCES SUCH AS AN OFFSHORE WIND FARM AND SHIPPING IN THE ÖRESUND STRAIT

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## 1 INTRODUCTION

Man-made activities at sea have intensified during the last decade and are expected to further increase in terms of shipping activities, wind farms, and sonar campaigns and as a result underwater acoustic noise levels are expected to rise[1]. However, there are gaps in our understanding of the impact of noise on fish[2,3]. In specific areas shipping activity has to be compared to other sources in order to achieve an effective management of sound. The received levels of shipping noise are site, frequency and range dependent. The use of wave propagation models with measured ship signatures or by shipping noise models is a well established method[4]. In this study we perform noise analysis from an offshore wind farm located in a narrow and shallow strait (depth less than 10 m) with high shipping intensity. The ship traffic creates an almost omni-present sound field in the frequency band 100–1000 Hz. By combining measured data and a numerical model, we deduce noise levels generated both from a single wind turbine and the whole wind farm. These results are finally compared to the noise levels induced by nearby ship traffic.

## 2 METHODS AND RESULTS

### 2.1 Study Area and Acoustic Measurements

The Lillgrund wind farm became operational in 2007 with 48 wind turbines in the Öresund strait (N 55° 30', E 12° 45') between Sweden and Denmark, each with a capacity of 2.3 MW. The turbines are mounted on a steel tower connected to a concrete gravitational foundation. No measurements were done prior to construction of the wind far, why acoustical measurements was performed at the Sjollen area, 10 km north of the wind farms, since it was expected that Sjollen resembles the Lillgrund area prior the wind farm in terms of ambient noise. The Sjollen site is 600 m from the shipping lane while the closest turbine in the wind farm is 1300 m from the shipping lane. Two hydrophone systems were used; one, which was a moveable autonomous acoustic recorder system, and one permanently deployed at 80 m distance from the A07 and cable-connected to the same turbine. Both systems were mounted one meter above the seafloor. Recordings were made to estimate the spectral properties of the noise, at various distances from the A07 turbine (80 m, 160 m, 400 m and 1000 m). The recordings were made during six weeks starting May 2009. The ambient noise recordings were 5-minutes long and repeated every half an hour using the autonomous system. The cabled system was used at 80 m for establishing the attenuation of noise as a function of distance from the A07 wind turbine.

### 2.2 Measured and Modelled Wind Farm Noise

The wind turbine noise showed a broadband character with some characterizing tones (10, 40, 127 and 533 Hz, at full speed) where the 127 Hz was the dominating tone in the spectrum. These results agree with manufacturer's measurements performed at the gearbox. A frequency spreading below the 127 Hz tone was observed due to tones sliding down in frequency when the rotation rate decreased[5]. Data from other turbines showed similar spectral characteristics, why it is assumed that the turbines within the wind farm were generating similar noise. Recordings near to the A07 turbine showed large variations in the noise spectrum. The amplitude of the 127 Hz tone was determined by integrating energy in two frequency intervals namely; 123–132 Hz and 53–343 Hz. By using these two intervals the source level of the A07 turbine was observed to be 136 and 138 $dB_{(RMS)}$ re. 1μPa at 1m. The same intervals were applied on recorded data at various distances for transmission loss (TL) estimation. A closer look at the wind farm data revealed that the wind park was running between 60 and 99 % efficiency even though A07 was operating on full speed. A corresponding variation was also observed in noise levels, suggesting that there was a cumulative effect due to the park (here called park effect) that was necessary to take into account. This was further supported by the observation that the TL was not showing a clear exponential decay. A numerical model was developed, based on the geometry of the wind park with all 48 turbines treated as separate sources. The noise level at each location was estimated by integrating the incoherent intensity of each turbine over the two frequency intervals. The sound propagation from a turbine was assumed to follow $p=C/r^k$, where $p$ is the pressure, $C$ the sound pressure relative to 1μPa at 1m, where $r$ is the distance in meter and $k$ the decay exponent. The exponent was estimated by fitting the measured data at 80 m, 160 m, 400 m and 1000 m when the A07 turbine was on full power. By adjusting the efficiency of the park (as measured by the operator) in the model, it was possible to adjust the estimated sound levels. Hence, the noise levels were determined by taking the whole park into account. The best model fit was achieved with an attenuation of 17·log (distance) (corresponding to $k$ = 0.86) for a single turbine. The model result shows that the sound pressure was dominated by the closest turbine at close range (less than 80 m). In the range 100 m to 7000 m the sound levels is the result of the park effect, resulting in an attenuation that is less than at close range. At distances larger than 7000 m the park appears to be a point source (distance to park larger than the size of the park) with a level about 7 dB higher compared to a single turbine.

## 2.3 Ambient Noise and Shipping Model

The ambient noise at Sjollen was generally higher than what was observed for high (12–14 m/s) and low (0–2 m/s) wind speeds without nearby shipping, and also higher than the ambient noise at Lillgrund. The standard deviation was 5 to 10 dB per √Hz for the ambient sound pressure with and without nearby shipping. Somewhat surprisingly the Sjollen data revealed that the noise including nearby shipping had a bimodal character in the frequency range 20-1000 Hz with a spectral trough at 150 Hz. The reason for this effect is unknown. It was observed that the spectral energy density between 30 and 150 Hz rose dramatically when distance between hydrophone and ship were below 1000 m. The Sjollen data will, thus, greatly overestimate the ambient noise levels. Instead the analysis reverted to the Lillgrund data to estimate the ambient noise. The analysis showed that the unexplained spectral increase below 150 Hz was not present in the Lillgrund data. Moreover, the power spectrum density was dominated by broadband noise generated by shipping and by the 127 Hz tone generated by the park. The distance between the A07 turbine and the shipping lane was about 3400 m, indicating that the sudden rise was only present in the near field. These results suggest that the Lillgrund data set gives a better estimate of the shipping noise in the far field (excluding the energy of the 127 Hz tone). The analysis showed that the average noise levels at Lillgrund are in general high compared to established noise level obtained at strong winds and high waves. The conclusion is that in the Öresund region ships constitute the dominating sound source and they need to be considered in environmental studies. A fair comparison between wind parks and ships requires a ship model super imposed on the wind park model. The ship-induced noise was treated as a finite line populated with point sources emitting sound. The noise model was based on a Monte Carlo simulation. A generic ship with a source level of 100 dB re 1μPa at 1 m was randomly placed on the line and the sound pressure level was calculated at the mid point and orthogonal to the line using a 17·times log (distance) attenuation. This scheme was iterated 5000 times resulting in a mean sound pressure level as a function of distance to the modelled shipping line. The model shows that the attenuation at close range to the shipping line was weaker than at longer distances. Our explanation is that the shipping line is longer than the distance to the line and thus the ship has a line-source character. At longer distances the finite length line becomes point source like, hence asymptotically approaching 17·log(distance)[6]. Mainly two factors influence the results: the number of ships on the line and the length of the line. Due to the fact that only one ship was detected in each 5-minute recording and that the modelled sound levels varied weakly as a function of ships, as long as the numbers of ships were kept low, suggests that only one ship should be randomly placed on the ship line. Further, the length of the line was varied to investigate its effect on the estimated sound pressure levels. It was noted that the equivalent source level of the shipping line decreased with increasing line length. The observed changes were, however, small. The sound pressure level was found to vary with ±5 dB with varying line length. Finally, the length of the ship line was chosen to 10 nautical miles. Finally the numerical established sound level was adjusted to the observed level at Lillgrund. The described shipping model was super imposed on to the wind farm model at the location of the shipping lane. The acoustical field of both the wind farm and the shipping lane using the second type of spectral interval showed that the wind farm noise is dominating in an area of about twice the wind farm size during full production. At 60% efficiency, the area decreases to cover the outer edge of the wind farm. However, the result for the tonal component 127 Hz is very different. The wind farm noise dominates the area within several kilometres even though shipping noise is present. This is due to the low acoustic intensity (the spectral trough) of the shipping noise at this particular frequency band.

# 3 DISCUSSION

This study shows that the aggregated contribution of noise from the wind farm is significant at distances larger than 80 m from a single turbine, indicating a "park effect". To predict the received level of noise farther away, the noise from all 48 turbines have to be taken into account. Therefore, a numerical model was developed and validated against field observations. In the model all 48 turbines were adjustable to different production levels (0-100 %). Numerical experiments were done where the transmission loss was varied and validated against measured data. The model results showed that the transmission loss based on measurements at different distances from the wind farm area was 17·log(distance)[6]. The ship-induced noise was handled by employing a ship model where a generic ship was placed iteratively on a line, thereby avoiding complications associated with modelling of the individual ships. The ambient noise including nearby shipping was found to be substantially stronger compared to only wind-induced noise (with possible interference of distant shipping) strongly suggesting that shipping is the major source of ambient noise in the Öresund Strait. An important result is that the narrowband tone of the wind turbines at 127 Hz dominates the noise in the region, adding sound energy in a frequency band where ambient noise is comparable low, which might disturb communication between marine animals or affect behaviour and as a result give rise to adverse effects on the aquatic life.

# 4 REFERENCES

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