THEORETICAL DETERMINATION OF THE LONG TERM CONTRIBUTIONS TO AMBIENT NOISE LEVELS FROM OFFSHORE WIND FARM CONSTRUCTION.

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1 INTRODUCTION

Marine pile driving during offshore wind farm construction may increase the anthropogenic component of ocean ambient noise and has led to increasing concerns regarding its effects on the marine fauna (receptors)[1]. In the case of many static offshore developments two commonly used foundation techniques are tripod and jacket constructions involving installation of a series of smaller diameter piles surrounding a central structure and mono-piles using a single larger diameter pile. Pile installation itself may involve sequences of percussive piling at different hammer energies, vibro-piling (more rapid, lower level vibrations) and drilling. In some cases all three techniques are used on a single pile installation, with the construction phase lasting several hours for each pile, and with perhaps 50 - 100 turbine supports in a typical windfarm development.

The long term contribution to ambient noise levels from construction of a typical offshore wind farm development is assessed in this paper by examining the overall radiated acoustic energy from a typical construction phase per foundation and the relative positioning and motion of likely receptors. Using Monte Carlo modelling methods the relative total exposure to a complete wind farm construction can then be estimated. Statistical analysis of the relative total or dose profiles can then be calculated for various scenarios allowing estimation of overall influence on receptors over an entire construction period. A test case of nine typical foundation constructions are considered in an area of varying bathymetry. The contribution to the overall ambient noise budget and the overall Sound Exposure Level is estimated for receptors in the vicinity assuming various response patterns.

2 SOUND FIELD PREDICTION

Using range dependent modeling the sound field per strike can be estimated. As a test case a theoretical construction of a nine foundation linear array in a relatively complex bathymetry is used.

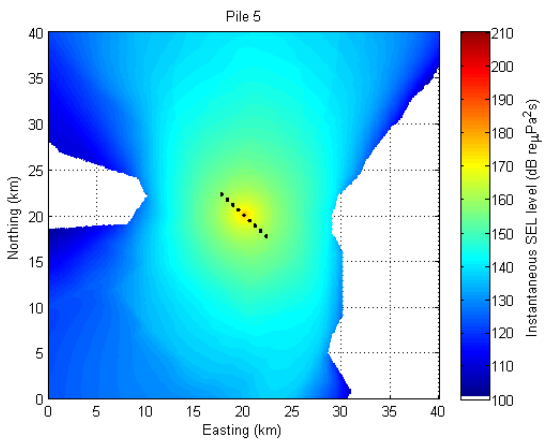

Figure 1: Modeled broadband SEL levels for a single hammer strike during piling of the middle (pile 5) foundation.

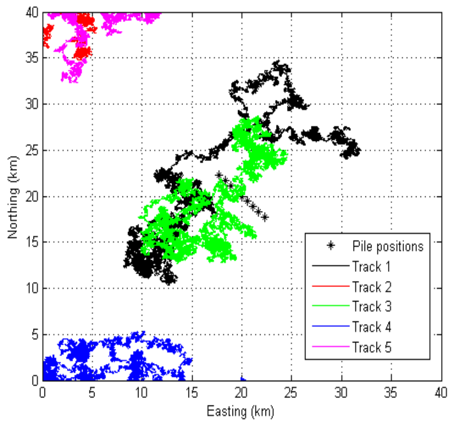

Figure 2: Example receptor swim patterns across entire construction period with an assumed swim speed of 3 ms^{-1}.

The model covers a 40 km square grid centered on the linear array of nine foundations running from north-west to south-east. The foundations are spaced 800 m apart in approximately 35 m of water. The bathymetry profile includes a shallow beaching to east and sand bars to west with deeper water profile associated with shipping lanes to the south-west. A uniform sandy sediment profile was used across model. Using range dependent propagation models the three dimensional sound field was then estimated. Figure 1 shows an example of the broadband sound field model for a single hammer strike on pile 5 in the example bathymetry. This process is then repeated for each hammer strike in a typical sequence and for each foundation position. Models include variation in source level over time for example a typical a 'soft-start' associated with initial use of lower hammer energies.

3 ACOUSTIC DOSE MODEL

3.1 Cumulative exposure models

Using a typical piling sequence (inclusive of soft start, number of strikes etc.) Robinson *et al*[2] , the received level at specific locations can then be estimated for each strike. The energy from successive hammers strikes can then be added up to estimate total exposure. Using this approach the total contributed additional sound energy at any fixed location could be estimated associated with the entire construction period. This approach is then further extended to allow the receiver to move using various response behaviours.

3.2 Receptor models

In the case of windfarm construction the period between piling sequences may vary from days to weeks. The delay dictated by the physical movement of piling vessel and set-up periods, weather windows, breakdowns etc. Under good conditions periods between piling sequences less than 24 hours have been achieved. During these periods some recovery from acoustic dose levels is likely. Currently very little data exists for hearing recovery response for most marine spices. A limited number of studies to measure recovery responses from Temporary Threshold Shift (TTS) for bottlenose dolphins (*Tursiops truncatus*) have been conducted Finneran *et al,*[3] and for harbour porpoise (*Phocoena phocoena*) by Lucke *et al.*[4]. Currently no data exists for the recovery response from sub-TTS cumulative exposure thresholds, however a recovery process must exist. To address this in the models a hypothetical recovery over a 24 hour period is included for illustrative purposes. Comparison with and without recovery is then made.

4 BEHAVIOURAL MODELS

In order to estimate received levels for individual hammer strikes some assumption about the receptors relative position to the source must be made at. In the case of simples models a source could be assumed to static, or fleeing. Various studies have looked at tripod foundation construction in which gaps of hours often occur between individual piling sequences. In these cases scenarios including static, fleeing, fleeing and stopping (during quite periods) and fleeing and return were considered. In the current study and Monte Carlo approach was used where an animal was placed at a random point in the 40 km square sound field. The animal then is given eight degrees of freedom representing motion in horizontal plane. Movements are the randomly generated at an assumed swim speed for the duration of the construction of all nine piles. Figure 2 shows an example of 5 randomly generated tracks for an animal swimming at 3 ms^{-1} during entire construction period of nine piles. An interval of 30 hours is assumed between sequences leading to a total construction period of around 12 days. During each piling sequence the total cumulative exposure is estimated and then recovery included during gaps between sequences. This model was then run many times and the statistical distribution of animal motion and dose profile and total exposure estimated. In addition hybrid behaviours may be modelled including for example combinations of fleeing-response during piling and relative random movements before and after, migratory paths etc.

5 RESULTS

In the case of a without recovery model (figure 3) it can be see that two of the potential tracks would exceed an arbitrary SEL threshold level of 190 dB re 1μPa^{2}s for a large proportion of the entire construction piling sequence. This can be compared with the recovery model case (figure 4) where only two tracks during two piles exceed this threshold. In one example (track 3) the animal passes through the array during the construction period (figure 2) resulting in significantly higher cumulative does in the case of the 5th pile. The percentage time in excess of a threshold level for example a TTS threshold could then be estimated per track. In the case of a 190 dB threshold the animal is in excess of this threshold around 1% of entire piling period assuming recovery and around 80% without for this one track. Using numerous Monte Carlo simulations the statistical distribution of likelihood of exposure durations in excess of threshold for multiple tracks can then be estimated.

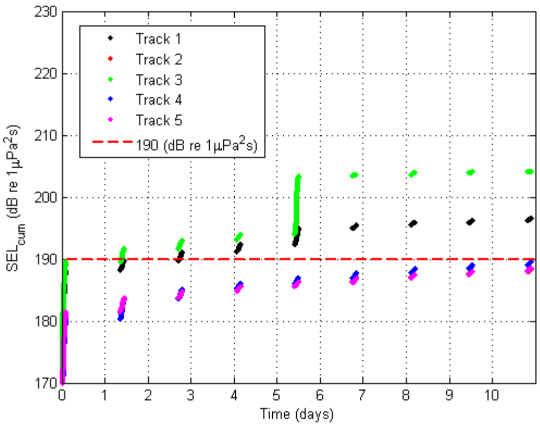

Figure 3: Cumulative SEL levels across entire piling sequence for each example track shown in figure 2 assuming no recovery between piling sequences.

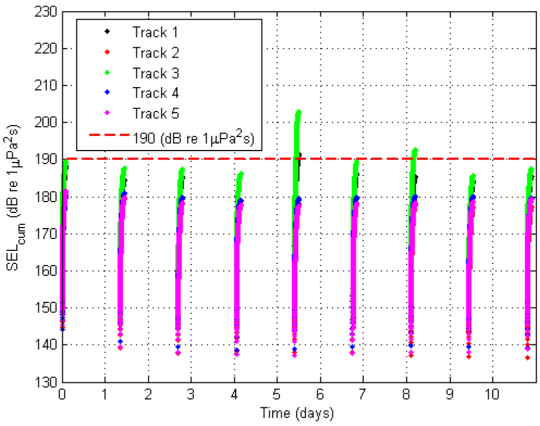

Figure 4: Cumulative SEL levels across entire piling sequence for each example track shown in figure 2 assuming a linear recovery rate between piling sequences.

6 CONCLUSIONS

A combination of both numerical propagation loss modelling and Monte Carlo simulations potentially provide a useful impact metric. The modelling would be run through many (100's-1000's) iterations providing the statistical distributions for a specific impact (for example percentage time in excess of a threshold level) over an entire construction period for randomly distributed species. In the case of a temporary shift threshold (TTS) this could be used as an indicator of the likely percentage of time that an animal would have potential impaired performance. In addition more complex behavioural response / mitigation methods may be tested and consequences evaluated.

7 REFERENCES

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