

Supporting information for the article

Making marine noise pollution impacts heard: the case of cetaceans in the North Sea within Life Cycle Impact Assessment

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S1: Choice of impact pathway

In the decision making matrix of Table S.1, three aspects of the impact pathways of the available studies were assessed; (1) the quality and quantity of the data, (2) whether the number of the specific emission source is increasing or decreasing, and (3) the modelling potential toward a Potentially Disappeared Fraction (PDF). These three aspects were weighted on a scale from 0 to 5 according to their importance for this study, where the third aspect received the highest weight (5) and the second aspect received the lowest weight (1). The studies were then rated on a scale from 0 to 5 for the three different aspects.

Table S.1: The decision-making matrix that was used for choosing an impact pathway, showing the top 5 of the total of 23 assessed studies. The total of 23 studies are included in the Excel file that is also made available as Supporting Information.

| General information about the studies | | | | | | | Decision making matrix | | | |
|---|-------------------------|---------------------------------|-------------------|---------------------------------|-----------------|-----------------------------|--------------------------------------|---|--|-------------|
| Title | Author | Source of noise | Impacted species | Impact pathway | Location | Quantitative data available | Quality&quantity of data (weight: 3) | Increasing/decreasing emissions (weight: 1) | Modelling potential to PDF (weight: 5) | Final score |
| Framework for assessing ecological and cumulative effects of offshore wind farms - Cumulative effects of impulsive underwater sound on marine mammals | TNO (2015) | Seismic surveying | Harbour porpoises | Avoidance | North Sea | ✓ | 4 | 4 | 5 | 4.56 |
| An interim framework for assessing the population consequences of disturbance | King et al (2015) | Offshore wind farm construction | Harbour porpoises | Avoidance | North Sea | ✓ | 4 | 3 | 5 | 4.44 |
| Framework for assessing ecological and cumulative effects of offshore wind farms - Cumulative effects of impulsive underwater sound on marine mammals | TNO (2015) | Offshore wind farms | Harbour porpoises | Avoidance | North Sea | ✓ | 4 | 3 | 5 | 4.44 |
| The effects of seismic airguns on cetaceans in UK waters | Stone and Tasker (2006) | Seismic activity | Several | Avoidance & Change in behaviour | United Kingdom | ✓ | 4 | 4 | 4 | 4.00 |
| Killer whale presence in relation to naval sonar activity and prey abundance in northern Norway | Kuningas et al (2013) | Naval sonar | Orcas | Avoidance | Northern Norway | ✓ | 3 | 4 | 4 | 3.67 |

S2: Sound propagation

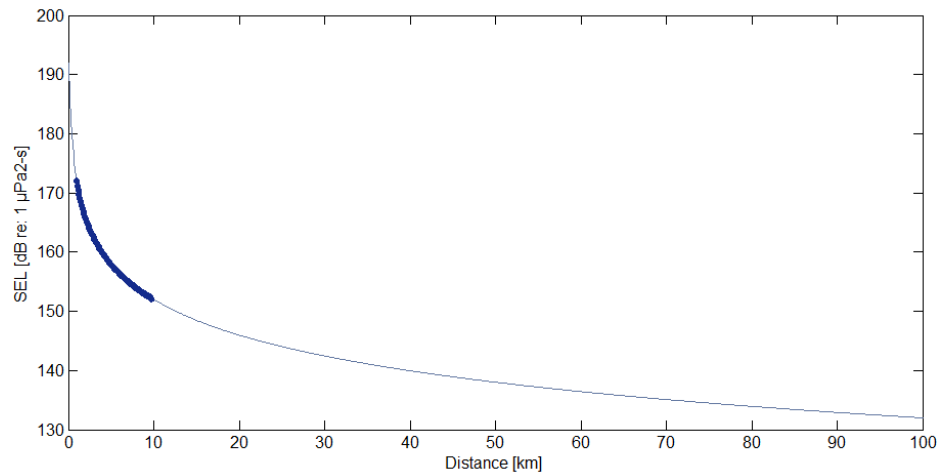


Figure S.1: SEL over distance from pile-driving of the Prinses Amalia wind park, calculated using the spherical propagation propagation loss. The bold part of the graph indicates the range over which this relation was said to be valid by De Jong and Ainslie (2012).

S3: Abundance data for cetaceans in the North Sea

Table S.2: Abundance data for cetaceans in the North Sea. Taken from Hammond et al. (2013).

| Block | | Surface area [km2] | | Mid-frequency | | | | | |
|-------|--|--------------------|--|---------------------|---------|------|--------------------|---------|------|
| | | | | Whitebeaked dolphin | | | Common dolphin | | |
| | | | | Abundance | Density | CV | Abundance | Density | CV |
| B | | 123825 | | 0 | 0.0000 | 0 | 4919 | 0.04 | 0.82 |
| H | | 10964 | | 0 | 0.0000 | 0 | 0 | 0 | |
| J | | 37477 | | 1078 | 0.0290 | 0.85 | 0 | 0 | 0.87 |
| L | | 20844 | | 0 | 0.0000 | 0 | 0 | 0 | |
| M | | 12931 | | 0 | 0.0000 | 0 | 0 | 0 | |
| S | | 68372 | | 0 | 0.0000 | 0 | 0 | 0 | |
| T | | 134206 | | 1530 | 0.0110 | 0.67 | 0 | 0 | |
| U | | 156972 | | 501 | 0.0030 | 0.97 | 0 | 0 | |
| V | | 160517 | | 7557 | 0.0470 | 0.47 | 0 | 0 | |
| Y | | 11776 | | 0 | 0.0000 | 0 | 0 | 0 | |
| TOTAL | | 737884 | | 10666 | 0.0143 | | 4919 | 0.00671 | |
| | | | | | | | Bottlenose dolphin | | |
| | | | | | | | Abundance | Density | CV |
| | | | | | | | 395 | 0.0032 | 0.74 |
| | | | | | | | 0 | 0.0000 | |
| | | | | | | | 412 | 0.0110 | 0.87 |
| | | | | | | | 0 | 0.0000 | |
| | | | | | | | 0 | 0.0000 | |
| | | | | | | | 0 | 0.0000 | |
| | | | | | | | 151 | 0.0011 | 1.05 |
| | | | | | | | 0 | 0.0000 | |
| | | | | | | | 157 | 0.0010 | 1.14 |
| | | | | | | | 0 | 0.0000 | |
| | | | | | | | 1115 | 0.0015 | |

| Block | | Surface area [km2] | | High-frequency | | | | | |
|-------|--|--------------------|--|----------------|--------|------|------------------|-------|------|
| | | | | Low-frequency | | | Harbour porpoise | | |
| | | | | Minke whale | | | | | |
| B | | 123825 | | 1199 | 0.01 | 0.98 | 40927 | 0.331 | 0.08 |
| H | | 10964 | | 0 | 0 | 0 | 3891 | 0.355 | 0.45 |
| J | | 37477 | | 833 | 0.022 | 1.04 | 10254 | 0.274 | 0.36 |
| L | | 20844 | | 0 | 0 | 0 | 11575 | 0.555 | 0.43 |
| M | | 12931 | | 0 | 0 | 0 | 3948 | 0.305 | 0.38 |
| S | | 68372 | | 0 | 0 | 0 | 19129 | 0.280 | 0.36 |
| T | | 134206 | | 1783 | 0.013 | 0.6 | 19396 | 0.145 | 0.34 |
| U | | 156972 | | 3655 | 0.023 | 0.69 | 93938 | 0.598 | 0.28 |
| V | | 160517 | | 4515 | 0.028 | 0.51 | 47048 | 0.293 | 0.36 |
| Y | | 11776 | | 0 | 0 | 0 | 1473 | 0.125 | 0.47 |
| TOTAL | | 737884 | | 11985 | 0.0161 | | 251579 | 0.341 | |

S4: Frequency-weighting curves

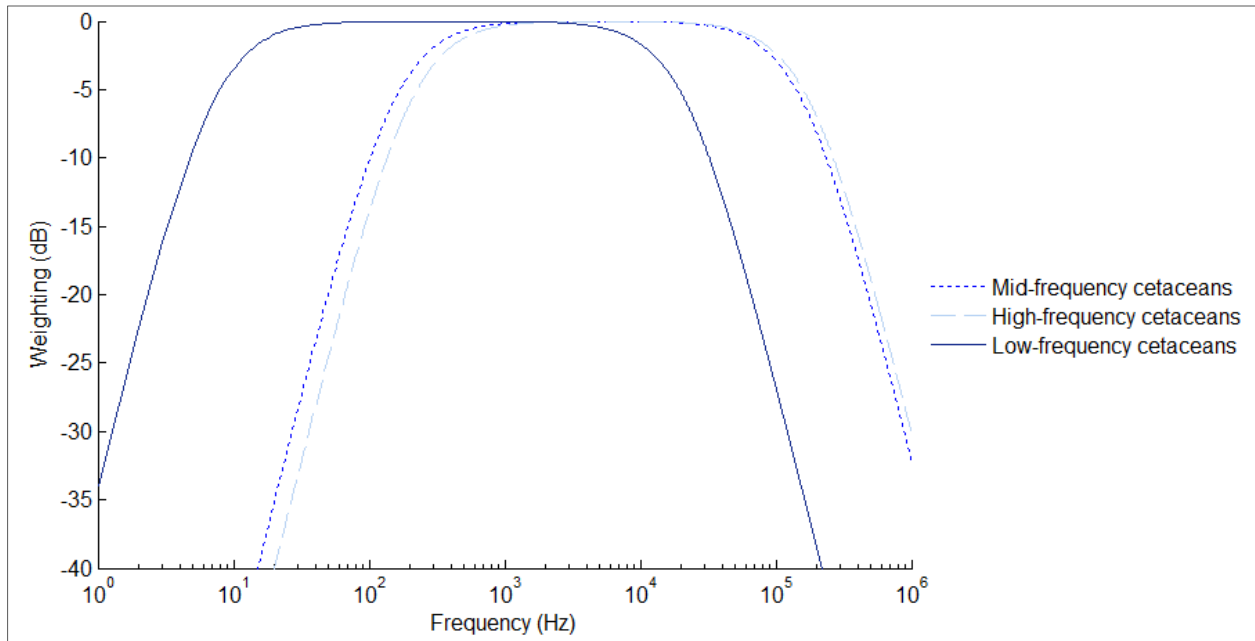


Figure S.2: Frequency-weighting curves for the three functional hearing groups of cetaceans.

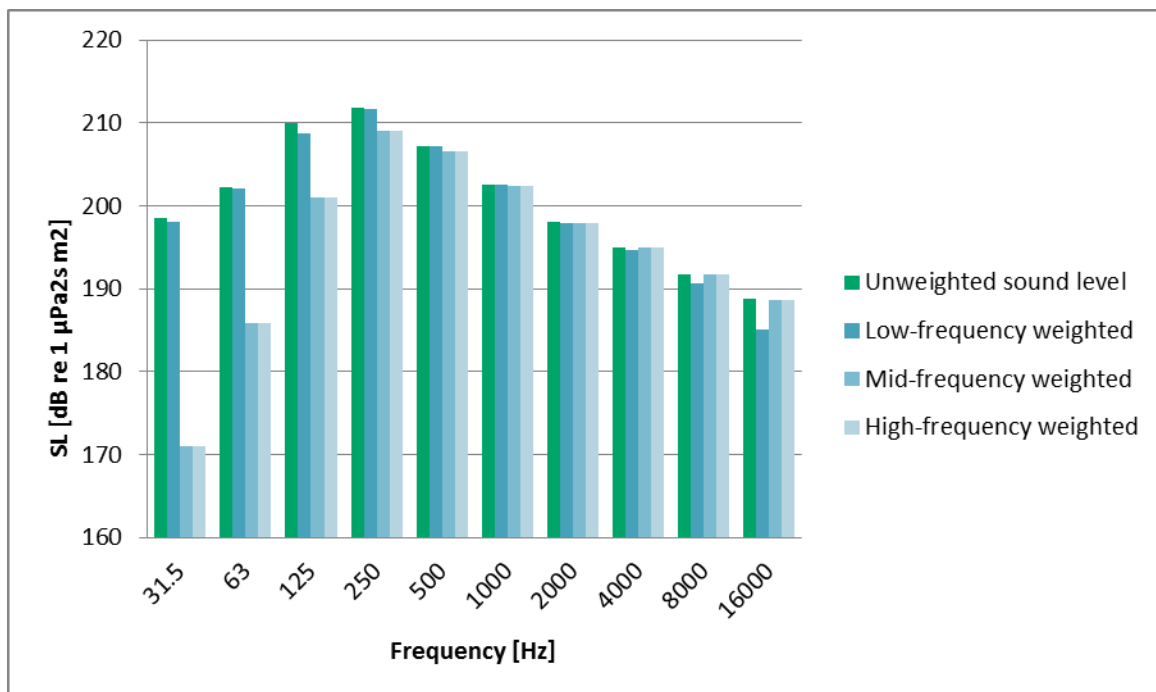


Figure S.3: Frequency-weighted 1/3-octave energy sound spectrum of a pile strike for the three functional hearing groups of cetaceans.

S5: Additional results

Table S3Error! Reference source not found. shows the results for the species specific parameter of the characterization factor. The frequency-weighted sound spectrum of a pile strike that was used to determine the weighted threshold SEL can be found in the SI.

Table S3: Results for the species specific parameters of the characterization factor; the frequency-weighted threshold level, its corresponding avoidance area, and the animal abundance data for the segment of the Dutch continental shelf (local) and the North Sea (regional).

| Functional hearing group | Unweighted threshold SPL [dB re: 1 μ Pa] | Weighted threshold SEL [dB re: 1 μ Pa ² -s] | Avoidance distance [km] | Avoidance area [km ²] |
|---|---|---|-------------------------|-----------------------------------|
| Low-frequency cetaceans | | | | |
| Minke whale (<i>B. acutorostrata</i>) | 141 | 130 | 140.0 | 31 443 |
| Mid-frequency cetaceans | | | | |
| Bottlenose dolphin (<i>T. truncates</i>) | 169 | 161 | 6.3 | 125 |
| Whitebeaked dolphin (<i>L. albirostris</i>) | 169 | 161 | 6.3 | 125 |
| Short-beaked common dolphin (<i>D. delphis</i>) | 169 | 161 | 6.3 | 125 |
| High-frequency cetaceans | | | | |
| Harbour porpoise (<i>P. phocoena</i>) | 150 | 142 | 44.7 | 5 324 |

| Functional hearing group | Local animal density [ind/km ²] | Regional animal density [ind/km ²] | Total population North Sea [ind] |
|---|---|--|----------------------------------|
| Low-frequency cetaceans | | | |
| Minke whale (<i>B. acutorostrata</i>) | 0.0100 | 0.0161 | 11 985 |
| Mid-frequency cetaceans | | | |
| Bottlenose dolphin (<i>T. truncates</i>) | 0.0032 | 0.0015 | 1 115 |
| Whitebeaked dolphin (<i>L. albirostris</i>) | 0.0000 | 0.0143 | 10 666 |
| Short-beaked common dolphin (<i>D. delphis</i>) | 0.0400 | 0.0067 | 4 919 |
| High-frequency cetaceans | | | |

| | | | |
|---|--------|--------|---------|
| Harbour porpoise (<i>P. phocoena</i>) | 0.3310 | 0.3410 | 251 579 |
|---|--------|--------|---------|

The total model uncertainties that result from the error propagation calculation are shown in Table S.4.

Table S.4: Model uncertainties for both the local calculation and the regional calculation.

| Functional hearing group | SD local | SD regional |
|---|-------------|-------------|
| Low-frequency cetaceans | | |
| Minke whale (<i>B. acutorostrata</i>) | 115 % | 51 % |
| Mid-frequency cetaceans | | |
| Bottlenose dolphin (<i>T. truncatus</i>) | 90 % | 22 % |
| Whitebeaked dolphin (<i>L. albirostris</i>) | | 22 % |
| Short-beaked common dolphin (<i>D. delphis</i>) | 118 % | 22 % |
| High-frequency cetaceans | | |
| Harbour porpoise (<i>Phocoena phocoena</i>) | 30 % | 25 % |
| Total | 88 % | 43% |