5.2.2. Sound Levels from High-Frequency Sources

Table 31 shows ranges to received sound levels between 200 and 100 dB re 1 µPa for the active hydrographic survey sources. Maps are not presented for these sources because modelling was not performed for the full area.

Table 31. Estimated threshold radii for engineered sources, based on geometric spreading loss and directional source characteristics.

<table>
<thead>
<tr>
<th>SPL (dB re 1 µPa)</th>
<th>Radius (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sonardyne Ranger, 18 to 36 kHz*</td>
</tr>
<tr>
<td>200</td>
<td>0.002</td>
</tr>
<tr>
<td>190</td>
<td>0.005</td>
</tr>
<tr>
<td>180</td>
<td>0.008</td>
</tr>
<tr>
<td>170</td>
<td>0.018</td>
</tr>
<tr>
<td>160</td>
<td>0.036</td>
</tr>
<tr>
<td>150</td>
<td>0.066</td>
</tr>
<tr>
<td>140</td>
<td>0.17</td>
</tr>
<tr>
<td>130</td>
<td>0.35</td>
</tr>
<tr>
<td>120</td>
<td>0.56</td>
</tr>
<tr>
<td>110</td>
<td>1.1</td>
</tr>
<tr>
<td>100</td>
<td>2.2</td>
</tr>
</tbody>
</table>

* Based on empirical spreading loss estimate measured by Warner and McCrodan (2011).

5.3. Regional Study Area

Figures 33 to 37 show aggregate cumulative SEL over a 24 hour period for ConocoPillips’, Maersk’s, and Shell’s August seismic survey operations with different M-weighting filters applied.
Figure 33. Cumulative flat-weighted SEL over 24 hours for Maersk’s, ConocoPhillips’, and Shell’s seismic survey operations in August. *186 dB re 1 µPa²:s denotes the cSEL injury threshold for pinnipeds. Bathymetry contours are labelled in metres.
Figure 34. Cumulative LFC-weighted SEL over 24 hours for Maersk's, ConocoPhillips', and Shell's seismic survey operations in August. *186 dB re 1 µPa²-s denotes the cSEL injury threshold for pinnipeds. Bathymetry contours are labelled in metres.
Figure 35. Cumulative MFC-weighted SEL over 24 hours for Maersk’s, ConocoPhillips’, and Shell’s seismic survey operations in August. *186 dB re 1 μPa²·s denotes the cSEL injury threshold for pinnipeds. Bathymetry contours are labelled in metres.
Figure 36. Cumulative HFC-weighted SEL over 24 hours for Maersk’s, ConocoPhillips’, and Shell’s seismic survey operations in August.*186 dB re 1 μPa²-s denotes the cSEL injury threshold for pinnipeds. Bathymetry contours are labelled in metres.
Figure 37. Cumulative PINN-weighted SEL over 24 hours for Maersk’s, ConocoPhillips’, and Shell’s seismic survey operations in August.*186 dB re 1 μPa²-s denotes the cSEL injury threshold for pinnipeds. Bathymetry contours are labelled in metres.

5.4. Sound Propagation Beyond the Regional Study Area

Table 32 lists the maximum-over-depth rms SPL at each of the four receiver locations in Figure 5 from each of the source locations in the same map. Figure 38 shows sound levels as a function of range and depth along the four transects connecting the Maersk 4240 in³ airgun array to each receiver location. Levels are given in SEL units (dB re 1 μPa²-s) which can be assumed to be equal to or greater than rms SPL (see section 3.8).
Figure 38. Range-depth sound level contour plots for sounds from the Maersk 4240 in$^3$ airgun array propagating to receivers R1 (a), R2 (b), R3 (c), and R4 (d). Sound levels are in units of SEL (dB re 1 μPa$^2$s), which are assumed to be numerically greater than rms SPL (see Section 3.8).

Table 32. Maximum-over-depth rms SPL at the 4 receivers for airgun operations from ConocoPhillips, Maersk, and Shell airguns surveys.

<table>
<thead>
<tr>
<th>Receiver</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>120.9</td>
<td>126.7</td>
<td>127.2</td>
<td>127.1</td>
<td>122.4</td>
</tr>
<tr>
<td>R2</td>
<td>129.3</td>
<td>121.1</td>
<td>122.8</td>
<td>123.7</td>
<td>117.2</td>
</tr>
<tr>
<td>R3</td>
<td>125.2</td>
<td>122.2</td>
<td>128.1</td>
<td>123.0</td>
<td>115.4</td>
</tr>
<tr>
<td>R4</td>
<td>116.9</td>
<td>111.8</td>
<td>116.5</td>
<td>119.8</td>
<td>106.8</td>
</tr>
</tbody>
</table>
6. Summary

The results of this sound propagation modelling study show the greatest underwater sound levels associated with Maersk’s planned activities are those generated by the 4240 in³ airgun array, which dominates the sound levels from the sources on the hydrographic survey vessel. The sound levels from the airgun array exceed the NMFS injury criteria of 180 and 190 dB re 1 µPa at maximum ranges of 730 m (R₉₅% of 590 m) and 180 m (R₉₅% of 170 m), respectively. By comparison, the maximum ranges for these thresholds are 50 m and 18 m for the sources on the hydrographic survey vessel. The maximum range from the airgun array to the behavioural threshold of 160 dB re 1 µPa rms is 6.3 km (5.4 km R₉₅%). These maximum propagation ranges correspond to model Scenario 1, with water properties representative of conditions in July. The ranges to the impact criteria drop less than 3% using a water column sound speed profile for conditions in August. The difference between the sound speed profile in July compared to August does not significantly affect the overall sound propagation. Ranges to the above stated impact thresholds are also slightly reduced when the source is moved to a deeper water location (as considered in Scenarios 2 and 3) because at these ranges sound disperses more freely and attenuates more rapidly than in shallow water. Bathymetry strongly influences sound propagation. The modelled sound fields are asymmetric due to the variability of the bathymetry throughout the region, but also due to the directionality of the source.

Based on the criteria for injury from multiple pulses, that is cSEL values of 198 dB re 1 µPa²s for cetaceans and 186 dB re 1 µPa²s for pinnipeds (Southall et al., 2007), the cumulative and aggregate cumulative sound exposure levels indicate the potential for injury remains localized within 2.5 kilometres range of the modelled Maersk survey lines. Inside the Tooq block, the total areas ensonified to cumulative levels at or above the M-weighted injury criteria are 23.8 km² (low-frequency cetaceans), 5.5 km² (mid-frequency cetaceans), 1.9 km² (high-frequency cetaceans), and 57.9 km² (pinnipeds).

The water column sound speed profile used in the model is a typical arctic profile that causes sound to be refracted upwards away from the seafloor and supports propagation to very long ranges. The model transects that extend beyond the regional study area show received sound exposure levels of 128 dB re 1 µPa²s can be expected over 500 km away from the seismic survey areas.
Literature Cited


Glossary

1/3-octave band levels
Frequency resolved SPLs in non-overlapping passbands that are 1/3 of an octave wide (where an octave is a doubling of frequency). Three adjacent 1/3-octave bands make up one octave. 1/3-octave bands become wider with increasing frequency.

90% energy window
Time interval over which the cumulative energy rises from 5% to 95% of the total pulse energy, abbreviated with the symbol $T_{90}$. This interval contains 90% of the total pulse energy.

absorption
Dissipation of sound energy through viscosity or chemical reactions.

attenuation
The acoustic energy loss due to absorption and scattering.

azimuthal
The horizontal angular component of direction.

bar
Pressure unit equal to 100 kPa, which is approximately equal to the atmospheric pressure on Earth at sea level. 1 Bar is equal to $10^5$ Pa or $10^{11}$ µPa.

broadband sound level
The total sound pressure level measured over a specified frequency range. If the frequency range is unspecified, it is understood to be the entire measurement range.

broadside
Perpendicular to the travel direction of the source array.

compressional wave
A mechanical vibration wave where the direction of particle motion is parallel to the direction of propagation. Compressional waves are sometimes referred to as P-waves in the field of geophysics.

decibel
A logarithmic unit of the ratio of a quantity to a specific reference level (abbrev. dB).

decibel
A logarithmic unit of the ratio of a quantity to a specific reference level (abbrev. dB).

endfire
Parallel to the travel direction of a source array.

ensonified
Exposed to sound.

far-field
The zone where, to an observer, sound originating from an array of sources (or a spatially-distributed source) appears to radiate from a single point in space. The distance to the acoustic far-field increases with frequency.

frequency
Rate of oscillation measured in units of cycles-per-unit-time: e.g. 1 Hertz (abbrev. Hz) = 1 cycle / second.
geoacoustic
Relating to the acoustic properties of the seabed.

intensity
Sound energy flowing through a unit area perpendicular to the direction of propagation per unit time.

M-weighting
The process of band-pass filtering loud sounds to reduce the importance of inaudible or less-audible frequencies for broad classes of marine mammals.

Parabolic Equation (PE) method
A computationally-efficient solution to the acoustic wave equation that is used for modelling transmission loss (TL). The PE approximation simplifies the computation of TL by neglecting the back-scattered component of the acoustic field. This component is very small for most ocean-acoustic propagation problems.

peak sound pressure level
Maximum instantaneous sound pressure, expressed in decibels, sometimes referred to as zero-to-peak level. Peak-to-peak level is the difference between the maximum and minimum instantaneous sound pressures, expressed in decibels.

percentile
Value below which an event occurs some percentage of the time. The $n^{\text{th}}$ percentile level gives the level below which the signal is $n\%$ of the time.

permanent threshold shift (PTS)
Permanent loss of hearing sensitivity due to excessive noise exposure. PTS is considered auditory injury.

power spectrum density
The acoustic signal power per unit frequency as measured at a single frequency (units $\mu$Pa$^2$/Hz).

power spectrum density level
The dB level (10log10) of the power spectrum density, usually presented in 1 Hz bins (units dB re 1 $\mu$Pa$^2$/Hz).

pressure (hydrostatic)
The pressure at any given depth in a static liquid that is the result of the weight of the liquid acting on a unit area at that depth, plus any pressure acting on the surface of the liquid (SI unit Pa).

pressure (acoustic)
The deviation from the ambient hydrostatic pressure caused by a passing sound wave (SI unit Pa). Also referred to as overpressure.

pulsed sound
Discrete sounds with very short durations (less than a few seconds). Sounds with longer durations are called continuous sounds.

rms sound pressure
The root-mean-square average of the instantaneous sound pressure (symbol $L_p$) as measured over some specified time interval (symbol $T_{90}$). The 90% energy time window
(T_{90}) is typically used for pulse sounds. Consequently, the rms SPL for pulse sounds is often referred to as the 90% rms SPL (L_{p90}).

**shear wave**
A mechanical vibration wave where the direction of particle motion is perpendicular to the direction of propagation. Shear waves are sometimes referred to as S-waves in the field of geophysics. Shear waves only propagate in solid media, such as sediments or rock. Shear waves in the seafloor can be converted to compressional waves in water at the water-seafloor interface.

**signature**
Pressure signal generated by a particular source.

**sound**
A time-varying pressure disturbance that is generated by mechanical vibration waves travelling through a fluid medium (e.g., air or water).

**sound exposure level (SEL)**
A measure of the total sound energy contained in one or more pulses. SEL is measured in units of dB re 1 µPas.

**sound pressure level (SPL)**
The decibel ratio of sound pressure to some reference pressure. Numerically, the dB level is equal to 20×Log_{10}(P/P_{ref}), where P is the sound pressure and P_{ref} is the reference pressure. In underwater acoustics, the standard reference pressure is 1 µPa and the units of SPL are written: dB re 1 μPa. Unless otherwise stated, SPL refers to the root mean square (rms) sound pressure.

**spectrum**
The representation of an acoustic signal in terms of its power (or energy) distribution versus frequency (see Power Spectrum Density).

**source level (SL)**
The SPL that would be measured at 1 metre distance from a point-like source that radiates the same total amount of sound power as an actual source. Source levels are expressed in units of dB re 1 µPa at 1 m.

**surface duct**
The upper portion of the water column where the sound speed profile gradient causes sounds to constantly turn upwards and therefore reflect off the surface, resulting in comparatively long range sound propagation with little loss.

**temporary threshold shift (TTS)**
Temporary loss of hearing sensitivity due to excessive noise exposure.

**transmission loss (TL)**
The dB reduction in sound level that results from the spreading of sound away from an acoustic source, subject to the influence of the surrounding environment. Also referred to as propagation loss.

**wavelength**
Distance over which a wave completes one cycle of oscillation, abbreviated with the symbol λ.