Terminal A Extension Project

Technical Note:

Response to CRS-0002 - Application Review - Information Request - Pile driving effects to fish and marine mammals

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1 INTRODUCTION

In response to the British Columbia (BC) Environmental Assessment Office's (EAO) request for the inclusion of mitigation for assessment of the acoustic effects to marine mammals and fish from impact pile driving related to the Terminal A Extension Project (Project), updated acoustic models were prepared by JASCO Applied Sciences (Canada) Ltd. The updated models included refined equipment specifications and an example of the available potential mitigation methods for noise propagation reduction described further in Section 3 (Mathews et al. 2015).

In response to the EAO's request for inclusion of other projects occurring in the area, a cumulative effects model was developed to quantitatively estimate the combined underwater acoustic effects of pile driving, in the event that it occurs at the Project and LNG Canada sites simultaneously (Schlesinger et al. 2015). A summary is below, and the full reports (Mathews et al. 2015, Schlesinger et al. 2015) have been provided to the EAO for reference with this response.

2 PROPONENT'S RESPONSE

As with the previous acoustic modelling for the Project (Wladichuk et al 2015), assumptions providing conservative estimates were used to estimate the "worst-case" scenarios from impact pile driving. Sound fields were modelled using January sound speed profiles, which estimate much larger effects distance radii because cooler winter temperatures near the sea surface (surface duct) favour longer-range propagation (Mathews et al 2015). It was also assumed that two hammers would be operating simultaneously, with marine mammal exposure assumed over a 24 hour duration. Impact pile driving parameters, including the pile size (1067 mm) are similar to the parameters of the previous model (1060 mm); however the refined models include a higher hammer energy than previously modelled (Wladichuk et al. 2015), with fewer blows per day (605 kJ hammer energy at 10,000 blows per day from two simultaneously operating hammers, compared to the previous 150 kJ hammer energy at 15,000 blows per day from two simultaneously operating hammers). An air bubble curtain was selected as the example of the marine noise reducing mitigation systems available and often used in pile driving operations, this methodology is described further in Section 3.

The same acoustic impact criteria were used for marine mammals (MMPA 2007 and Southall et al. 2007) as in the previous work (Wladichuk et al. 2015). These criteria are widely used and accepted. However, an updated set of criteria were used to evaluate the cumulative sound exposure levels (cSEL) and sound pressure levels (SPL) to fish (Popper et al. 2014) because these new criteria are based on the best scientific knowledge to date (Mathews et al. 2015). Under the new guidelines, fish are divided into three groups: those without a swim bladder, those with a swim bladder that is not involved in hearing, and those with a swim bladder used for hearing (Popper et al. 2014).

As before, the model results (Schlesinger et al. 2015) are presented as R_{max} and $R_{95\%}$ distance radii. $R_{95\%}$ is the predicted range encompassing at least 95% of the area that would be exposed to sound at or above that level, while R_{max} is the maximum range that would be exposed to sound at or above that level (Mathews et al. 2015). R_{max} tends to overestimate the geographic extent of the sound levels due to conservative model assumptions, while $R_{95\%}$ is used to reflect a more realistic scenario that takes into account properties such as non-smooth seabed interfaces and heterogeneous sea conditions (Mathews et al. 2015). $R_{95\%}$ results are, therefore, the focus of this response, but both results are included in the full report (Appendix 2).

Assuming 10,000 blows during 24 hours of impact pile driving, the distances ($R_{95\%}$) to the injury threshold for cetaceans (198 dB re 1 µPa^2·s) using cumulative sound exposure levels (cSEL) extends 420–570 m when mitigated with an air bubble curtain (Mathews et al 2015). The distances ($R_{95\%}$) to the injury threshold for pinnipeds (186 dB re 1 µPa2·s M-weighted cSEL) extends to 3,760 m using an air bubble curtain (Mathews et al 2015). It is important to note that these distances assume that the animals are residing within the zone of injury for a continuous period of 24 hours. It is expected that the animals will move in and out of this zone, or avoid it during elevated sound levels, thereby further reducing their exposure levels, and potential for injury (see below) (Mathews et al 2015).

The $R_{95\%}$ distances to the mortality criteria for the three fish groups using cumulative sound exposure levels (207, 210, 219 dB re 1 µPa^2·s unweighted cSEL) are equal to, or smaller than, 120 m when mitigated using an air bubble curtain (Mathews et al 2015). Again, this assumes that the fish will be exposed to the sound levels for a 24 hr period. Therefore it is also appropriate to consider the peak SPL for fish which is anticipated from a single blow. In this instance, the $R_{95\%}$ distances to the mortality criteria for fish are 20 m or less (Mathews et al. 2015).

When the results of the updated models are compared to those from the original Environmental Assessment (EA) Certificate Application models, the distances to auditory injury thresholds for marine mammals are reduced by 72–95% through the reduction in the number of blows from 15 000 to 10 000 in 24 h and using an air bubble curtain to mitigate the sound levels (Mathews et al. 2015).

To gain insight into what the effects may be if the animals are exposed to the RTA impact pile driving for shorter periods of time (based on the assumption that the animals will likely move out of the pile driving area), JASCO Applied Sciences (Canada) computed the cSEL for a 1 hour exposure time. The results of this work indicated that the $R_{95\%}$ distance radii for impact pile driving are reduced to 70–100 m for cetaceans, 760 m for pinnipeds and 20 m or less for fish (Schlesinger and Hannay 2015).

To address concerns over the cumulative acoustic impacts to the marine environment from multiple projects occurring within the same time frame in the same general area, JASCO Applied Sciences (Canada) combined the results for sheet and cylindrical impact pile driving from each of the recent assessments for the Project and LNG Canada. The modelled effects from the combined activities at both sites were prepared to assess potential worst-case effects on marine fauna near the Project site. The inclusion of other projects occurring or likely to occur near the Project (Kitimat LNG and Enbridge Northern Gateway) was considered, but modelled estimates of underwater noise emissions for Kitimat LNG and Enbridge Northern Gateway are not available at this time. Of note, the Kitimat LNG environmental assessment application determined that due to the limited geographic extent of their project area, the short construction phase, and the implementation of an Environmental Protection Plan, the potential effects to marine mammals are predicted to be non-significant (pg. 7.2-62 Kitimat LNG Environmental Assessment Certificate Application).

With regard to the potential combined effects from the Project and LNG Canada, results from the cumulative effects model are again conservative and are based on the assumption that pile driving would operate at a maximum rate of 18 000 blows with a 24 hour exposure (Schlesinger et al. 2015). This rate implies that both activities—cylindrical and sheet impact pile driving—would operate at the same time at both project locations with a 24 hour exposure to marine wildlife (Schlesinger et al. 2015).

Based on this model, the cumulative sound exposure level $R_{95\%}$ distance to the injury threshold for cetaceans (198 dB re 1 µPa^2·s cSEL) is 790 m or less with an air bubble curtain system (Schlesinger et al. 2015). The $R_{95\%}$ distances to the injury threshold for pinnipeds (186 dB re 1 µPa^2·s cSEL) is 5,100 m with an air bubble curtain system (Schlesinger et al. 2015). The distances to the $R_{95\%}$ mortality thresholds for fish (at 207, 210, and 219 dB re 1 µPa^2·s unweighted cSEL) are modelled to be a maximum of 780 m when mitigated with an air bubble curtain (Schlesinger et al. 2015). In order to provide the most conservative results, the cumulative effects study focussed on cSELs because these effects radii exceeded those of the peak SPLs.

Because the modelled radii for the maximum number of impact blows are based on assumptions that the animals reside in the area around the impact pile driving location for 24 continuous hours, the resulting cumulative sound exposure levels are considered conservative and representative of the worst case scenario (Schlesinger et al. 2015).

It is expected that the animals will move in and out of this zone, or avoid it during elevated sound levels, thereby further reducing their exposure levels, and potential for injury (see below) (Mathews et al 2015).

Also, the distances to threshold criteria levels will decrease if the number of impact pile driving activities or number of blows decreases over 24 hours or the hammer energy is reduced from what was modeled (Schlesinger et al. 2015). The significance of the potential reduction was demonstrated with the modelled 1 hour exposure levels modelled for the RTA site (see above). Hence, the results presented here reflect the worst case scenario (Schlesinger et al. 2015). The actual effects to the marine environment are likely to be significantly reduced from what is estimated using the conservative assumptions and options to further reduce the acoustic impacts are being investigated. This includes equipment type, marine mammal monitoring, and mitigation explained in Section 3.

3 MITIGATION

Various mitigation measures will be employed, including a noise propagation reducing technology as included in the refined model results above. The actual system applied will be determined in consultation with the pile driving contractor, but would be expected to have similar or better results. Field measurements at the construction onset will verify that the acoustic effects are reduced as much as practicable from the modeled results and validate that the model results produced by the model accurately reflect the construction operation conditions. Mitigation will also include the implementation, where practicable, of construction timing that takes into account the seasonality of marine mammals and fish. Soft starts will also be implemented such that marine fauna are exposed to a greatly reduced acoustic energy at the onset of all pile driving operations. In addition to noise propagation reduction, suitable alternatives to an impact hammer will be discussed with the pile driving contractor. The pile driving contractor will also be consulted to determine if reducing the impact pile driving hammer energy or pile driving hammer type is practicable for the Project. Impact pile driving will not occur when marine mammal visual monitoring is not possible due to reduced visibility. Alternative methods, such as vibratory hammering, will be explored and implemented when possible on the basis that the acoustic impact threshold criteria are not exceeded by these alternate methods. These mitigation options will be considered in construction schedules and incorporated in environmental management plans.

Monitoring will be implemented during the construction phase to proactively manage pile driving (adaptive management) to meet the defined criteria. Visual and acoustic monitoring by experienced marine mammal observers (MMOs) and underwater noise monitors with direct communication with construction crews will be used to further mitigate the risk to marine mammals. Pile-driving equipment and/or mitigation technology such as bubble curtains will be adjusted if required, based on the results of the field monitoring.

The underwater acoustic models were based on the assumption of two impact hammers operating simultaneously, as well as the cumulative effect from simultaneous operations at the Project and LNG Canada. There will be a reduction in effects if only one hammer is operating at a time, or if the two sites do not impact pile drive simultaneously.

It is anticipated that simultaneous operations at both sites will be infrequent; therefore the RTA specific modelled results most accurately reflect the majority of the anticipated effects to the marine environment. As such, the results from just the RTA model most accurately reflect what is likely to be the acoustic impact on the marine environment. If coordination between RTA and LNGC is possible to avoid simultaneous work, this will then be included in the construction plan and implemented when possible. This will be further addressed in the construction plan and in consultation with the pile driving contractor, and implemented where possible.

Air bubble curtains have been shown to significantly reduce the underwater sound levels away from the pile driving source location through creation of a disruptive barrier of air bubbles that surrounds the pile driving equipment (Mathews et al. 2015). The air bubble curtain is created by forcing air through underwater tubing that surrounds the pile driving equipment. While air pressure is adjustable, currents and water depth can affect the bubbles size and density (Mathews et al. 2015). The estimated acoustic attenuation from an air bubble curtain was determined based on review of the published data in the frequency range of 63-6300 Hz (Mathews et al. 2015).

The mitigation and monitoring for underwater noise will be further defined in the Marine Activities Plan and the Marine Monitoring Plan.

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Appendix 1 JASCO Applied Sciences (Canada) Ltd. Revised Underwater Acoustic Assessment of Marine Terminal Construction Rio Tinto Alcan Terminal and Extension Project, Kitimat BC

Revised Underwater Acoustic Assessment of Marine Terminal Construction

Rio Tinto Alcan Terminal and Extension Project, Kitimat BC

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1. Introduction

Rio Tinto Alcan (RTA) has proposed expanding the existing Terminal facilities near Kitimat, British Columbia, hereafter referred to as the Project. Terminal construction will generate underwater noise that has the potential to affect marine mammals and fish. An earlier study by JASCO Applied Sciences (Canada) Ltd. presented underwater noise emissions and resulting noise levels that would occur near construction activities based on model inputs (Wladichuk et al. 2015). Those results included predictions of noise levels near pile driving activities without noise mitigation system in place. This report provides updated noise level estimates accounting for the noise-reducing abilities of a bubble curtain mitigation system. The results for impact pile driving activities here also account for revised pile driving equipment specifications. The results are appropriate to assess potential effects on marine fauna near the Project site.

2. Project Activities

In the current project plan, 413 cylindrical steel piles will be installed using vibratory hammering followed by impact hammering at the proposed marine terminal extension area. The marine mammals commonly encountered in the study area, which are the focus of this effects assessment, were humpback whales (*Megaptera novaeangliae*), killer whales (*Orcinus orca*), and harbour porpoises (*Phocoena phocoena*). To conservatively estimate the effects of sound on marine mammals and fish, we estimated instantaneous sound pressure level (SPL) and cumulative sound exposure level (cSEL) for impact pile driving. The recent regulatory thresholds in Canada and the U.S. are based on these metrics.

Although the pile driving parameters, including pile size that was used here are similar to those in the original study, the current study proposes higher hammer energy and fewer blows per day. The number of blows per day is an important consideration in assessing cumulative noise levels because the cumulative metric is directly proportional to the number of blows. Table 1 lists the impact pile driving specifications of the original study and current study.

Table 1. Original and current impact pile driving specifications.

Specifications	Original Study (Wladichuk et al. 2015)	Current Study
Pile sizes (diameter)	1060 mm	1067 mm*
Hammer Type	S-150 hydraulic hammer	APE D180-42
Hammer energy	150 kJ	605 kJ
Number of blows in 24 h	15 000 when two hammers operate simultaneously)	10 000 when two hammers operate simultaneously)
Mitigation system	none	Air bubble curtain

* Because 98% of the piles (404 out of 413 piles) are 1067 mm in diameter, this revised assessment only considered this pile size.

3. Methods

3.1. Source Levels

The current study reflects a change from RTA's original hammer selection, an S-150, which has a maximum energy of 150 kJ, to a D-180, which has maximum hammer energy of 605 kJ.

The methodology for estimating the 1/3-octave-band source levels for cylindrical pile driving was not otherwise revised from (Wladichuk et al. 2015). Source levels for impact cylindrical pile driving were estimated by averaging source level measurements for several source in 1/3-octave-bands, and then scaling the results based on the ratio of hammer energies (Wladichuk et al. 2015). The broadband sound exposure level (SEL) source level for each modelled hammer was estimated at 210.2 dB re 1 µPa^2·s @ 1 m. Figure 1 presents the estimated 1/3-octave-band source levels of cylindrical impact pile driving from the current study. Note that the estimated source levels presented in the original study represent the operation of two 150-kJ hammers, while those present in the current study represent the operation of one 605-kJ hammer. The qualitative analysis of the propagated sound fields presented in current report accounts for the maximum energy of each hammer (605 kJ) and the fact that two hammers could operate simultaneously by considering a maximum of 10 000 blows per 24 h.

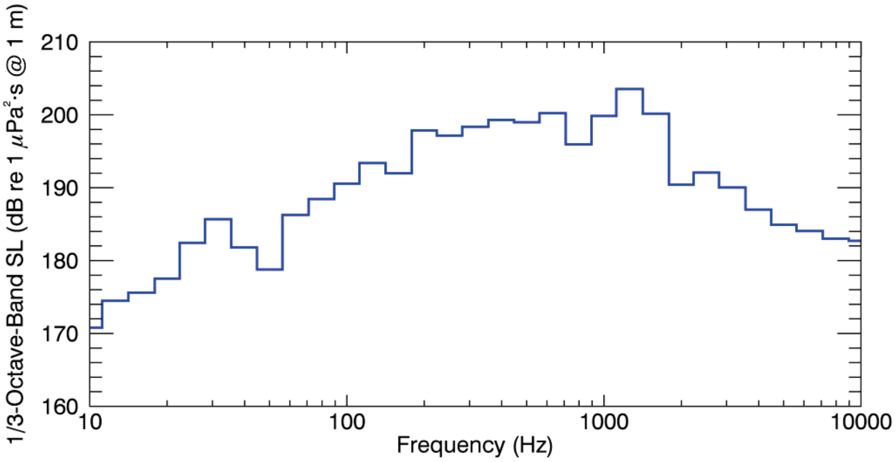

Figure 1. Estimated 1/3-octave-band source levels for cylindrical impact pile driving using a D-180 hammer with a maximum energy of 605 kJ;The broadband source level is 210.2 dB re 1 µPa^2·s @ 1 m.

3.2. Sound Propagation Model

The acoustic propagation model, Marine Operations Noise Model (MONM) by JASCO Applied Sciences (Hannay and Racca 2005), was used in the original study (Wladichuk et al. 2015) to calculate the noise emissions and sound propagation for all construction activity scenarios. MONM's inputs include source specifications of all equipment, ocean bathymetry, water sound speed profiles, and seabed geoacoustic parameters. The model generates sound exposure level (SEL) fields in several frequency bands that can be frequency weighted to allow for specific effects assessment. The MONM results used in the original study (Wladichuk et al. 2015) were also used here, but updated source levels and attenuation curves from mitigation system were applied.

MONM does not directly predict the 90% rms sound pressure levels (SPL) or peak SPL for evaluation against accepted noise threshold criteria. We derived these metrics from modelled SEL by applying conversion factors obtained from empirical results for SEL, 90% rms SPL, and peak SPL measured in locations with similar acoustic environments.

M-weighting frequency coefficients (Southall et al. 2007) were applied to the modelled 1/3-octave band SEL values. The accumulated sound energy was then computed for sequences of pile driving blows that could be acquired over 24 h. The number of blows per day was reduced from 15 000 in the original study to 10 000 (for the two hammers) in the current study. Because all of the piles are adjacent to each other, we assumed that all blows originated only at the modelled source location. This is a valid assumption as the pile locations will not change significantly within a 24 hour period – which is the integration time for SEL effects thresholds.

3.3. Mitigation Systems: Bubble Curtain

Enclosing the pile in an air bubble curtain is the most commonly used system for pile driving activities. Air Bubble Curtain. Air bubble curtain systems have been shown to significantly reduce underwater sound levels away from the pile (Illingworth and Rodkin 2001, ICF Jones & Stokes and Illingworth and Rodkin 2009, WSDOT 2010, MacGillivray et al. 2011). Most systems produce air bubbles at a manifold deployed on the seafloor that rise through the water column (Figure 2).

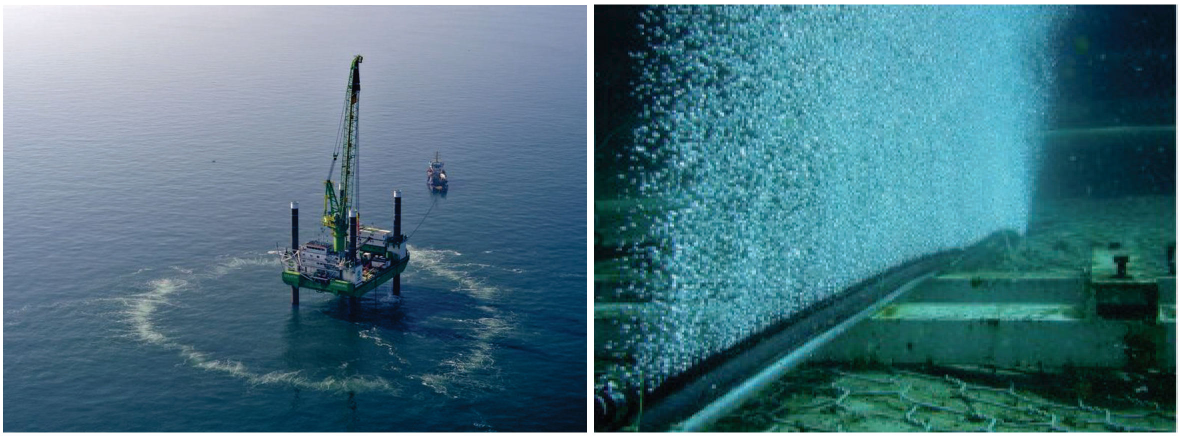

Figure 2. Example of air bubble curtain. (Left): Active air bubble curtain around pile driving activities. (Right): Tubing for an active air bubble curtain.

MacGillivray et al. (2011) reviewed literature that compiled air bubble curtain sound attenuation measurements. Of the available data, some compared attenuated and non-attenuated impact pile driving sound levels per-frequency. Table 2 and Figure 3 show the compiled and averaged measurements.

Table 2. Air bubble curtain specifications and reported attenuation level for impact driving of steel shell piles (MacGillivray et al. 2011). Airflow rate is measured in cubic feet per minute (CFM). Air pressure is measured in pounds per square inch (PSI).

Air bubble curtain	Airflow/ pressure	Pile diameter (ft)	Measurement distance (ft)	Broadband attenuation (dB)	Source
Steel isolation casing with single bubble ring	680–700 CFM 105–115 PSI	2.5	33	35	WSDOT SR-520 (WSDOT 2010)
Steel isolation casing 12.1 ft diameter with bubble ring	Unknown	7.9	177	21	Benicia-Martinez Bridge (ICF Jones & Stokes and Illingworth and Rodkin 2009)
Fabric mantle 13.1 ft diameter with bubble ring	1500 CFM	8.5	330	5–10	East Span PIDP (Illingworth and Rodkin 2001)
PVC isolation casing 4 ft diameter with single bubble ring	300–350 CFM	2.0	33	9	WSF Eagle Harbor (MacGillivray and Racca 2005)

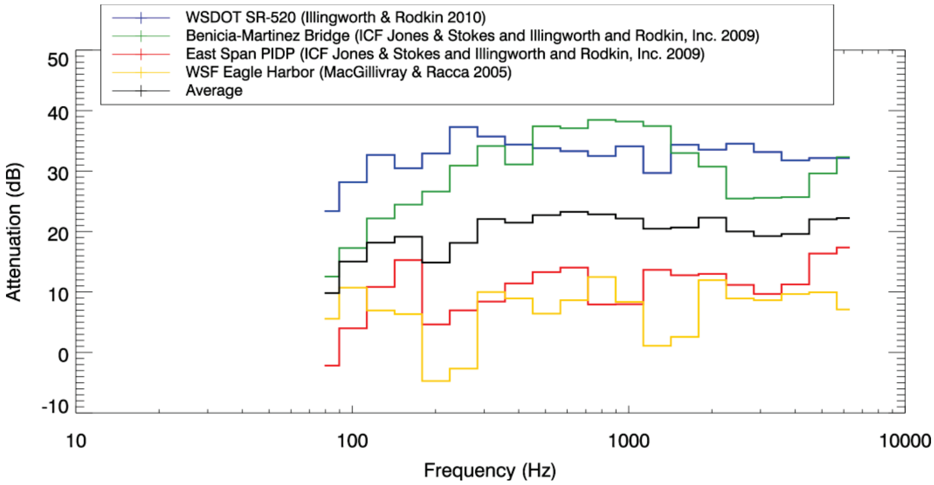

Figure 3. Reported measurements of acoustic attenuation for air bubble curtains in 1/3-octave-bands (MacGillivray et al. 2011). The black line is the average attenuation in each frequency band.

The 1/3-octave-band attenuation levels were averaged in the frequency range for which all publications reported data overlap (63–6300 Hz). The mean broadband attenuation was approximately 20 dB. The various air bubble curtain sound attenuation measurements indicated substantial variations in their effectiveness, with quoted broadband sound level reductions ranging from 5 to 36 dB. Based on assessment guidelines (ICF Jones & Stokes and Illingworth and Rodkin 2009, WSDOT 2010), it was determined on precautionary grounds that 10 dB mean attenuation would realistically estimate mitigation system performance. Thus, the average attenuation trend from the reported measurements was decreased so that the mean 1/3-octave-band attenuation in the 63–6300 Hz range equalled 10 dB (Figure 4). This adjustment resulted in no mitigation effect below 63 Hz (extrapolated attenuation values of approximately 0 dB), which reflects typical air bubble curtain performance at low frequencies. The derived attenuation values of an air bubble curtain are presented in Figure 4.

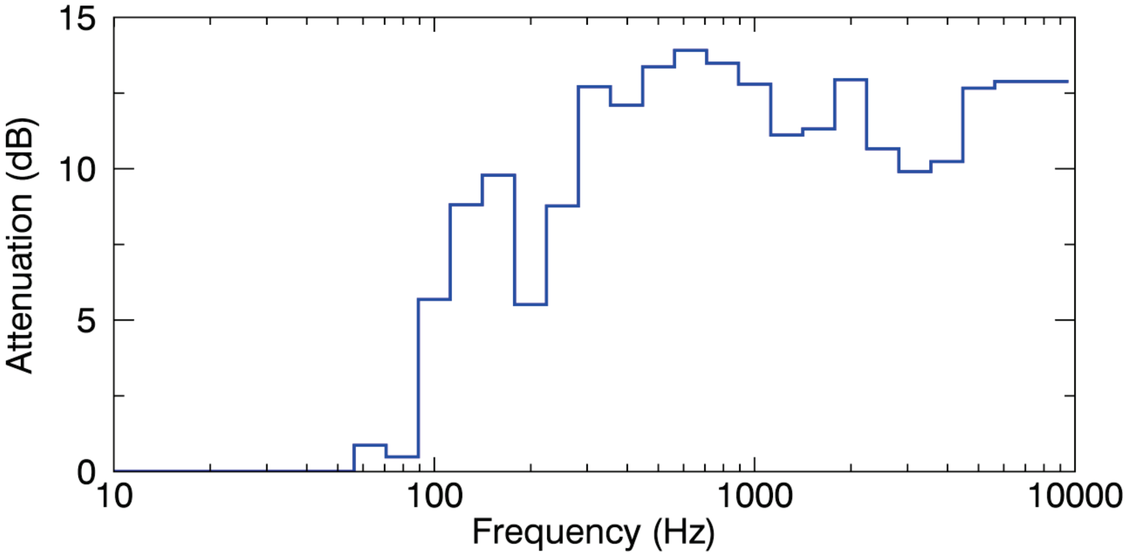

Figure 4. Estimated acoustic attenuation in 1/3-octave-bands for an air bubble curtain (MacGillivray et al. 2011).

3.4. Acoustic Impact Criteria

For marine mammals, the U.S. National Marine Fisheries Service (NMFS) regulatory criteria (MMPA 2007) and Southall et al. (2007) recommend two widely-acknowledged sets of injury and disturbance criteria for sound exposure, which both distinguish between continuous and impulsive sounds.

Current NMFS injury criteria for marine mammals exposed to impulsive sounds are defined by an rms SPL metric representing the estimated onset of permanent hearing threshold shift (PTS). The NMFS behavioural disturbance criterion for impulsive sounds is also based on rms SPL metric. Southall et al. (2007) criteria include both peak SPL and cumulative Sound Exposure Level (cSEL) with marine mammal frequency weightings (M-weighting); cSELs originate from single or multiple exposure events over a 24 h period. Southall et al. (2007) and NMFS criteria are determined by the estimated onset of permanent threshold shift (PTS) for marine mammals. A received sound exposure is assumed to cause injury if it exceeds either the peak SPL or the SEL criterion. Southall et al. (2007), however, do not recommend SPL thresholds for marine mammal injury criteria.

Table 3 shows the NMFS and Southall et al. (2007) auditory injury, disturbance, and onset of temporary threshold shift (TTS) criteria for impulsive sounds.

Table 3. NMFS and Southall et al. (2007) auditory injury, disturbance, and TTS onset criteria for impulsive sounds. LF = low-frequency, MF = mid-frequency, and HF = high-frequency, TTS = Temporary Threshold Shift.

Marine mammal group		NMFS		Southall et al. (2007)			
		rms SPL (dB re 1 µPa)		M-weighted SEL (dB re 1 µPa²·s)		Peak SPL (dB re 1 µPa)	
		Injury	Disturbance	Injury	TTS onset	Injury	TTS onset
Cetaceans	LF, MF, HF	180	160	198	183	230	224
Pinnipeds	in water	190	160	186	171	218	212

In 2014, the Fisheries Hydroacoustic Working Group (FHWG) published guidelines on sound exposure effects for fish and sea turtles (Popper et al. 2014). The original study had been based on interim results from the same group (FHWG 2008), and we have updated this assessment based on the revised final criteria. The new guidelines are defined for various animal groups, and are based on how these animals detect sound and various sound sources. Fish are divided into three groups: those without a swim bladder, those with a swim bladder that is not involved in hearing, and those with a swim bladder used for hearing. Table 4 presents the recommended criteria for impact pile driving activities. A received sound exposure is assumed to cause injury if it exceeds either the peak SPL or the SEL criteria, or both.

Table 4. FHWG mortality and impairment criteria for impact pile driving (Popper et al. 2014).

Fish group		Mortality and potential mortal injury		Impairment		
				Recoverable injury		TTS
		SEL (dB re 1 μPa²·s)	peak SPL (dB re 1 μPa)	SEL (dB re 1 μPa²·s)	peak SPL (dB re 1 μPa)	SEL (dB re 1 μPa²·s)
I	No swim bladder (particle motion detection)	> 219	> 213	> 216	> 213	>> 186
II	Swim bladder is not involved in hearing (particle motion detection)	210	> 207	203	> 207	>> 186
III	Swim bladder is involved in hearing (primary pressure detection)	207	> 207	203	> 207	186

4. Results

The 95th percentile radius, $R_{95\%}$, and the maximum radius, R_{max}, for each noise threshold criterion are tabulated in the next sections. R_{max} is the maximum range from pile driving activity at which the given criterion sound level is predicted to be exceeded. The $R_{95\%}$ is the same maximum range but excluding the 5% of directions of highest emission. This value accounts for the finding that models often predict a small number of narrow sectors of enhanced sound propagation. These anomalies arise due to assumptions about smooth seabed interfaces and homogeneous ocean conditions. In practice, seabed roughness and inhomogeneity in the water cause acoustic scattering that disrupts the enhanced propagation. The $R_{95\%}$ radius in any case encompasses at least 95% of the area that would be exposed to sound at or above that level.

4.1. Cumulative Sound Exposure Levels

Results in this study are based on the assumption that pile driving will operate at a maximum rate of 10 000 blows for 24 h. This rate implies the use of two hammers. The radii in Table 5 correspond to marine mammal injury and disturbance criteria (Southall et al. 2007) and fish injury criteria (Popper et al. 2014) for 24 h cSEL.

Table 5. Radii (m) of unweighted and M-weighted 24 h cSEL contours for impact cylindrical pile driving with an air bubble curtain. The cSEL calculation included 10 000 blows. TTS = Temporary Threshold Shift, PTS = Permanent Threshold Shift, MOR = Mortality, RI = Recoverable Injury, PINN = Pinnipeds, CET = Cetaceans. Fish I = No swim bladder; Fish II = Swim bladder not involved with hearing; Fish III = Swim bladder involved with hearing.

cSEL (dB re 1 µPa²·s)	Criteria	Unweighted		LFC		MFC		HFC		PINN	
		R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
171	TTS–PINN									16800	14400
183	TTS–CET			14370	7240	8520	6380	8510	6050		
186	PTS–PINN TTS-Fish I, II, III	6190	3910							6080	3760
198	PTS–CET			630	570	540	460	510	420		
203	RI–Fish II, III	280	220								
207	MOR–Fish III	150	120								
210	MOR–Fish II	88	70								
216	RI–Fish I	31	30								
219	MOR–Fish I	16	16								

4.2. rms Sound Pressure Levels

Table 6 presents the $R_{95\%}$ and R_{max} to the rms SPL thresholds (NMFS criteria). The 95th percentile radii at 160 dB re 1 µPa rms SPL is 1.9 km for cylindrical pile driving using an air bubble curtain. The radii injury thresholds are significantly lower: 110 for the 180 dB re 1 µPa, and 25 for the 190 dB re 1 µPa.

Table 6. Radii (m) of rms SPL contours for impact cylindrical pile driving mitigated using an air bubble curtain. PINN = Pinnipeds, CET = Cetaceans.

rms SPL (dB re 1 µPa)	Criteria	Air bubble curtain	
		R_{max}	$R_{95\%}$
160	Disturbance–PINN & CET	3720	1900
180	Injury–PINN	125	110
190	Injury–CET	30	25

4.3. Peak Sound Pressure Level

Table 7 presents the R_{max} and $R_{95\%}$ that correspond to the peak SPLs (dB re 1 µPa) for impact cylindrical pile driving. The levels presented in the table are based on Southall et al. (2007) auditory injury and disturbance criteria for marine mammals and Popper et al. (2014) criteria for morality and injury to fish. The distance to the 207 dB re 1 µPa injury threshold for fish is estimated to be no greater than 23 m for mitigated pile driving activities.

Table 7. Radii (m) of peak SPL contours for impact cylindrical pile driving mitigated using an air bubble curtain. TTS = Temporary Threshold Shift, PTS = Permanent Threshold Shift, MOR = Mortality, RI = Recoverable Injury, PINN = Pinnipeds, CET = Cetaceans. Fish I = No swim bladder; Fish II = Swim bladder not involved with hearing; Fish III = Swim bladder involved with hearing.

peak SPL (dB re 1 µPa)	Criteria	Air bubble curtain	
		R_{max}	$R_{95\%}$
207	MOR & RI–Fish II, III	20	20
212	TTS–PINN	< 10	< 10
213	MOR & RI–Fish I	< 10	< 10
218	PTS–PINN	< 10	< 10
224	TTS–CET	< 10	< 10
230	PTS–CET	--	--

5. Discussion

This study investigated potential acoustic disturbances to local marine fauna that would be generated by construction activities associated with RTA's proposed terminal extension project. JASCO had completed a similar study for Shell at an adjacent terminal to RTA's proposed terminal extension. Shell allowed RTA to use the model results to qualitatively assess the acoustic footprints produced by construction activities. The original modelling results for impact pile driving activities presented by (Wladichuk et al. 2015) were adjusted to represent the new hammer energy and the use of a mitigation system.

JASCO's MONM was used to model sound propagation in the Shell study. These sound fields were adjusted using estimated source levels for a D-180 hammer with a maximum energy of 605 kJ, and attenuation from an air bubble curtain system. Cumulative sound exposure levels (cSEL) were computed to estimate the acoustic footprints of two pile driving hammers operating simultaneously over 24 hours. Instantaneous sound pressure levels (SPL) were calculated by applying empirical results of durations of impulses measured in locations with similar acoustic environments.

The main species in the Project area that could be affected by construction activities are humpback whales, killer whales, harbour porpoise, pinnipeds, and fish. Distances to auditory injury and disturbance criteria were calculated from the resulting unweighted and M-weighted cSEL, peak SPL, and rms SPL fields.

In general, where uncertainties in operating conditions existed, we chose reasonable model inputs that predicted higher noise levels. We also applied the following conservative assumptions to our models:

- Radii ($R_{95\%}$ and $R_{\max}$) and sound level isopleth maps (Appendix A) were computed using the maximum sound level over all depths along the water column, although in reality marine mammals might spend time at depths with lower sound levels.
- Sound fields were modelled using January sound speed profiles, which estimate much larger radii because cooler winter temperatures near the sea surface (surface duct) favour longer-range propagation. In summer, sound exposures for animals near the surface are substantially lower than in winter because downward-refracting sound speed directs sound energy into the seabed, increasing bottom loss.
- Cumulative sound fields were computed for two 605 kJ hammers operating simultaneously.

The modelled distances to cSEL thresholds are longer than that to peak and rms SPL thresholds. Therefore, $R_{95\%}$ values in Table should be considered the distances to auditory injury and disturbance criteria for marine mammals and fish.

Assuming 10 000 blows during 24 hours of impact pile driving, the distances ($R_{95\%}$) to 198 dB re 1 μPa^2·s M-weighted cSEL (PTS for cetaceans) extended 420–570 m when mitigated with an air bubble curtain. The distances ($R_{95\%}$) to 186 dB re 1 μPa^2·s M-weighted cSEL (PTS for pinnipeds) extended to 3 760 m using an air bubble curtain mitigation system. The distances ($R_{95\%}$) to mortality criteria for various fish groups (207, 210, 219 dB re 1 μPa^2·s unweighted cSEL) are equal to or smaller than 120 m when mitigated using an air bubble curtain. These distances assume that the animals are residing within the zone of injury for a period of 24 h. Most animals likely move in and out of this zone, thus their exposure levels are reduced.

When the current results are compared to those from the original study (Wladichuk et al. 2015), the distances to auditory injury thresholds for marine mammals could be reduced by 72–95% by reducing the number of blows from 15 000 to 10 000 in 24 h and using an air bubble curtain to mitigate the sound levels.

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Appendix A. Cumulative Sound Exposure Levels Isopleth Maps

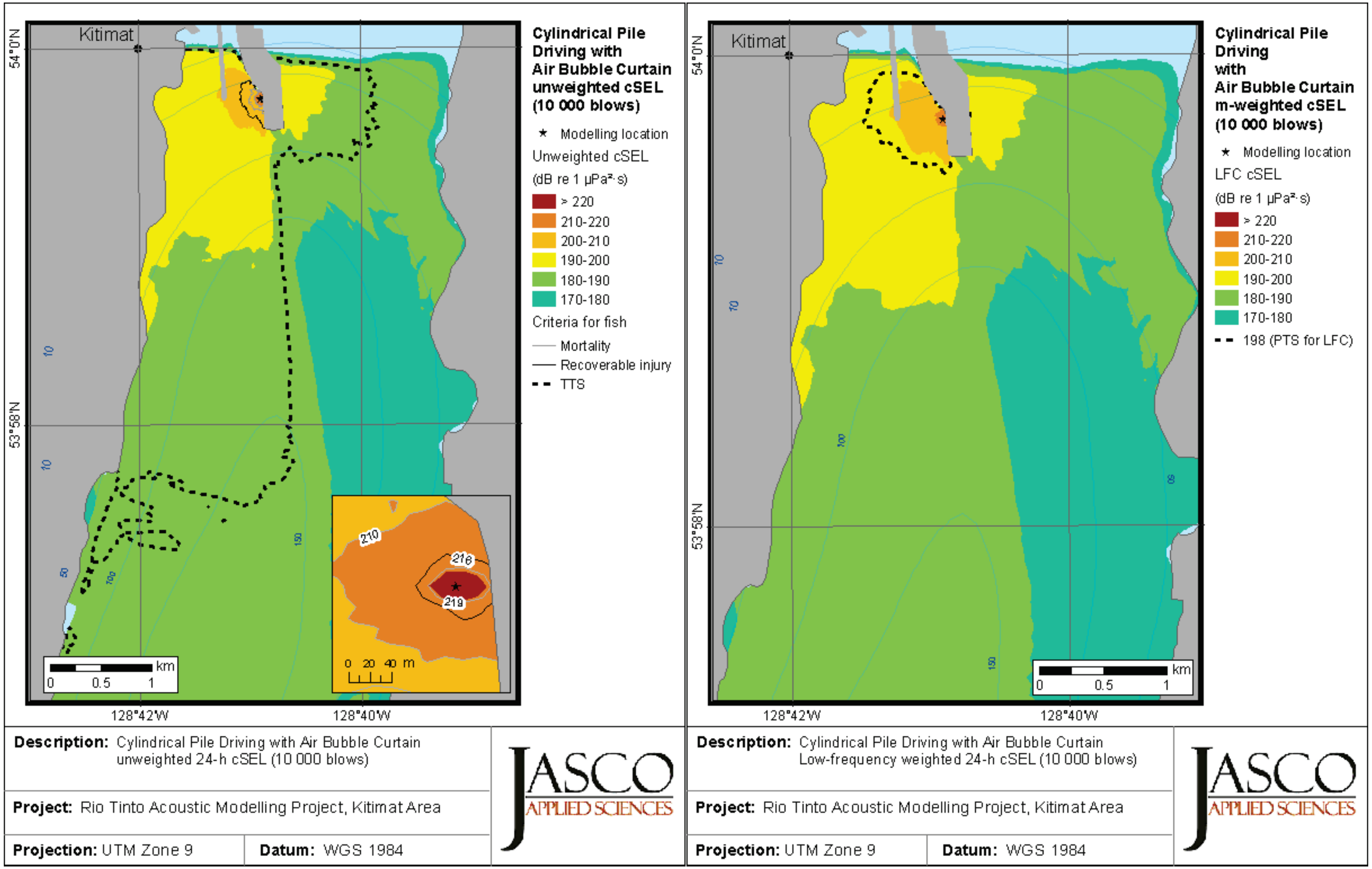

Figure A-1. (Left) Unweighted 24 h cSEL (dB re 1 µPa^2·s) and (Right) low-frequency weighted 24 h cSEL (dB re 1 µPa^2·s) for impact cylindrical piling with an air bubble curtain mitigation. The cSEL was calculated with 10 000 blows in 24 h

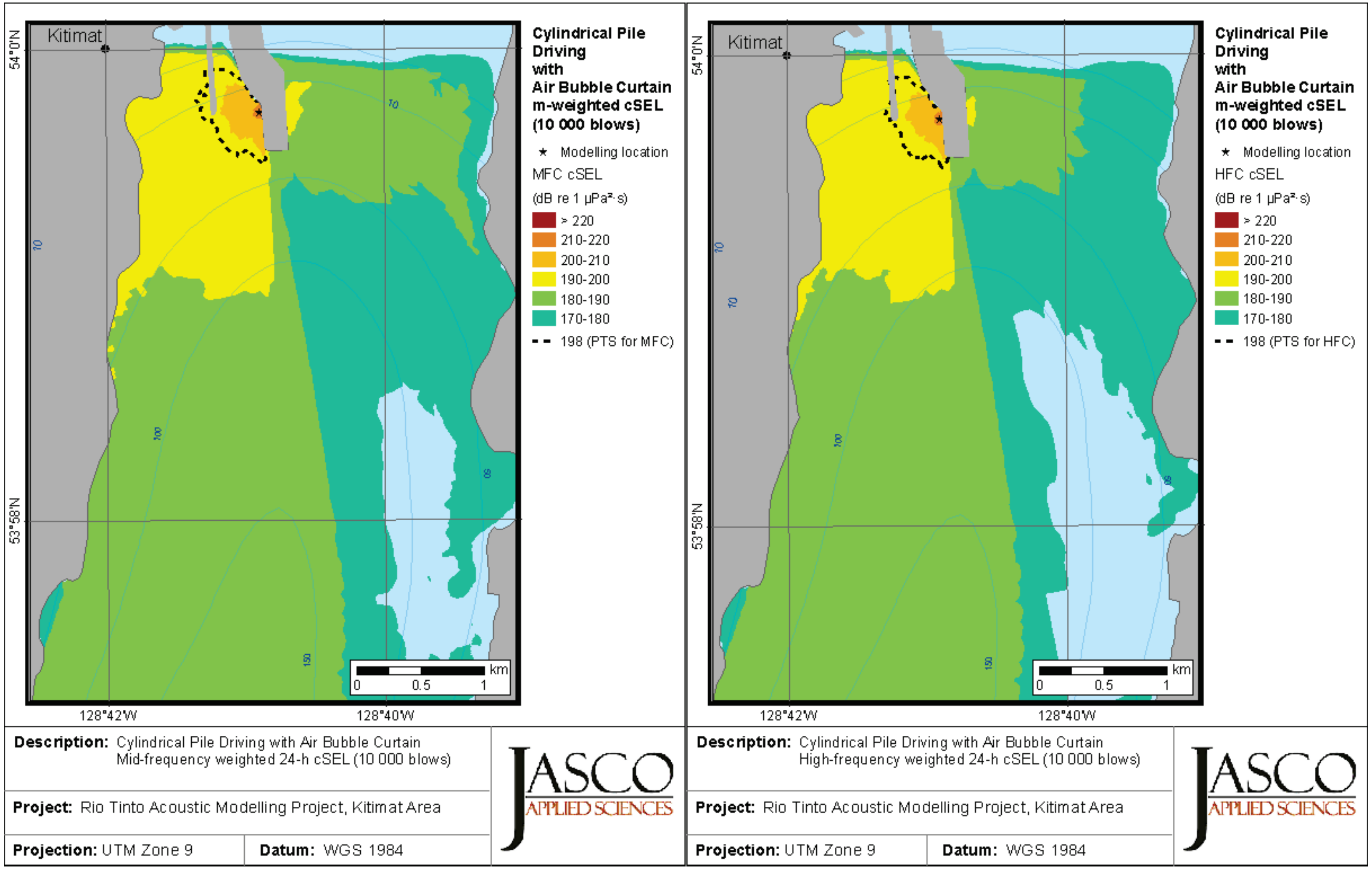

Figure A-2. (Left) Mid-frequency weighted (MFC) 24 h cSEL (dB re 1 µPa^2·s) and (Right) high-frequency weighted (HFC) 24 h cSEL (dB re 1 µPa^2·s) for impact cylindrical piling with an air bubble curtain mitigation. The cSEL was calculated with 10 000 blows in 24 h

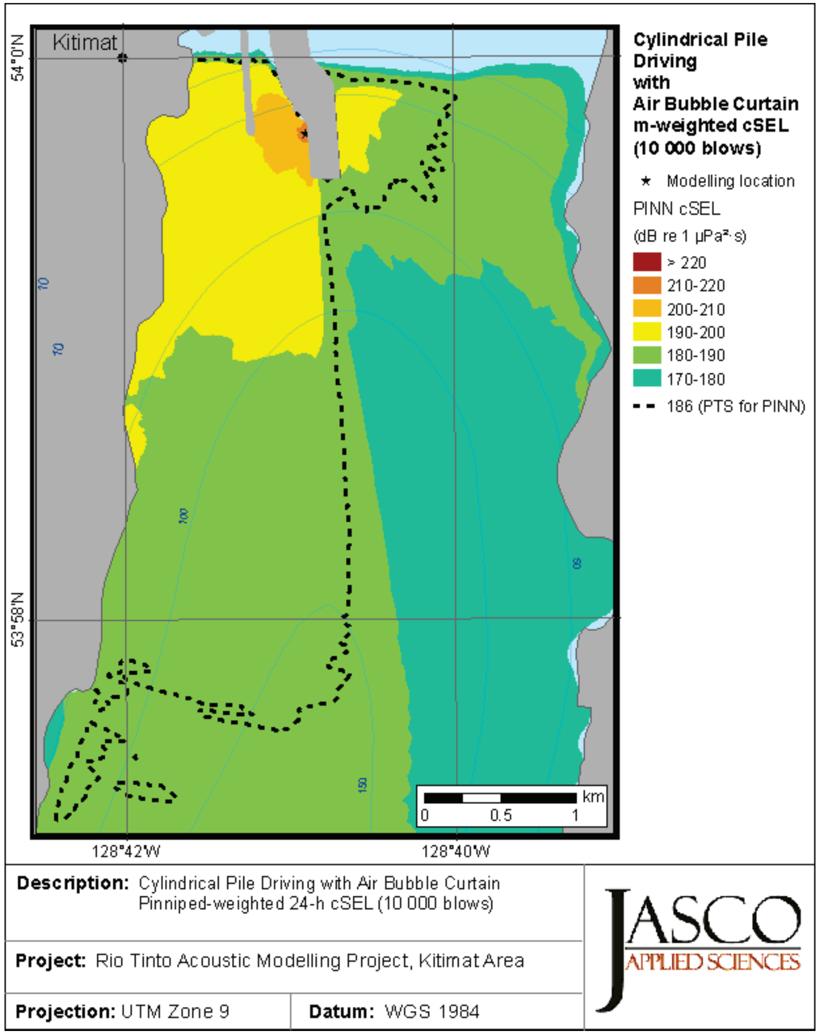

Figure A-3. Pinniped-weighted (PINN) 24 h cSEL (dB re 1 µPa^2·s) for impact cylindrical piling with an air bubble curtain mitigation. The cSEL was calculated with 10 000 blows in 24 h

Appendix 2 JASCO Applied Sciences (Canada) Ltd. Underwater Acoustic Assessment of Marine Terminal Construction Combined Rio Tinto Alcan and LNG Canada Terminal Projects, Kitimat, BC

Underwater Acoustic Assessment of Marine Terminal Construction

Combined Rio Tinto Alcan and LNG Canada Terminal Projects, Kitimat, BC

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1. Introduction

Rio Tinto Alcan (RTA) has proposed constructing marine terminal facilities in the Kitimat area, British Columbia, for liquefied natural gas (LNG) export by ocean-going LNG carriers. Concurrently, LNG Canada (LNGC) has proposed expanding the marine terminal adjacent to the RTA construction site. Terminal construction at each site will generate underwater noise that could affect marine mammals and fish. Previous studies by JASCO Applied Sciences (Canada) Ltd. for RTA and LNGC presented underwater noise emissions and resulting noise levels from construction activities and vessel activities near the marine terminal location (Matthews et al. 2015, Schlesinger et al. 2015). The current study, hereafter referred to as the Project, combines the results for impact sheet and cylindrical pile driving activities from each of the recent assessments. This report discusses effects from the combined activities at both sites (RTA and LNGC). The results are appropriate to assess potential effects on marine fauna near the Project site.

2. Project Activities

The Project plans to use vibratory hammering followed by impact hammering to install cylindrical steel pipe piles with 914 mm and 1060 mm diameter at the proposed marine terminal extension area. Additionally, AZ28-700 sheet piles will be driven with vibratory and impact hammering at the terminal location. The marine mammals commonly encountered in the study area, which are the focus of this effects assessment, are humpback whales (*Megaptera novaeangliae*), killer whales (*Orcinus orca*), and harbour porpoise (*Phocoena phocoena*). To conservatively estimate the effects of sound on marine mammals and fish, we modelled cumulative sound exposure levels (cSEL) for both impact pile driving activities. The recent regulatory thresholds in Canada and the U.S. are based on these metrics.

The previous assessments showed separate unweighted and M-weighted levels for each pile driving activity. This study shows the combined cSEL for all pile driving operations with applied mitigation by an air bubble curtain.

Based on the previous studies (Matthews et al. 2015, Schlesinger et al. 2015) two modelling locations were chosen for the two types of pile driving activities. Pile driving parameters differ for each activity Table 1. The presented sound fields account for the different pile size, hammer energies, and blow rate. The number of blows per day is an important consideration in assessing cumulative noise levels because the cumulative metric is directly proportional to the number of blows.

Table 1. Current impact cylindrical and sheet pile driving specifications.

Specifications	RTA - Cylindrical	LNGC - Cylindrical	LNGC - Sheet
Pile sizes (diameter)	1060 mm	914 mm	n/a
Hammer Type	S-150 hydraulic hammer	APE D-100-42	MENCK MHU 3000/J&M Model 115
Hammer Energy	605 kJ	330 kJ	300 kJ
Number of blows in 24 h	10 000 when two hammers operate simultaneously	4000	4000

3. Methods

3.1. Source Levels

The methodology for estimating the 1/3-octave-band source levels for impact sheet and cylindrical pile driving was not revised from (Matthews et al. 2015, Schlesinger et al. 2015). RTA proposed a new hammer (APE D-180) with maximum hammer energy of 605 kJ. The broadband source level for the modelled hammer was estimated at 210.2 dB re 1 µPa^2·s @ 1 m. LNG Canada proposed using an APE D-100 hammer with hammer energy of 330 kJ for cylindrical pile driving and a MENCK MHU 3 000 hammer with hammer energy of 300 kJ for sheet pile driving. The broadband source levels are 206.2 and 207.1 dB re 1 µPa^2·s @ 1 m for impact sheet and cylindrical pile driving, respectively.

Figure 1 shows the 1/3-octave-band source levels for the sheet pile driving and cylindrical pile driving activities associated with each activity.

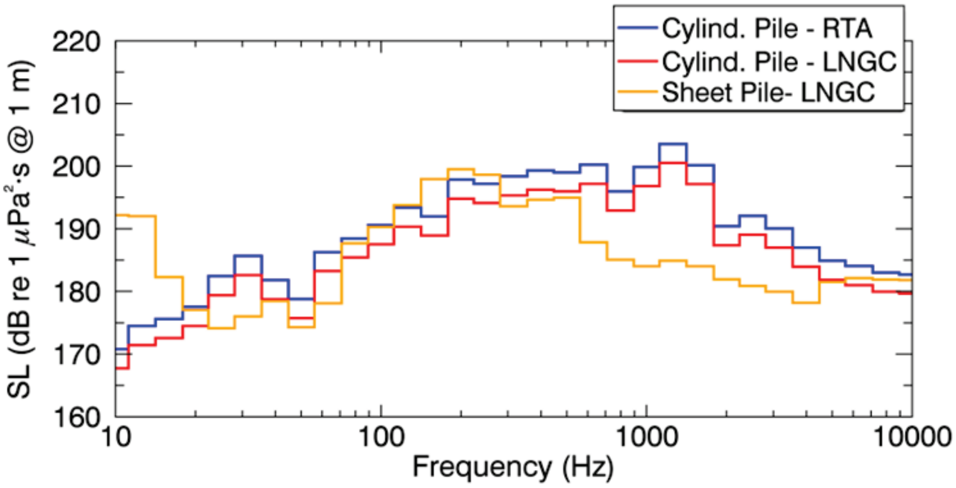

Figure 1. Estimated 1/3-octave-band source levels of cylindrical and sheet pile driving for each project activity.

3.2. Sound Propagation Model

The acoustic propagation model, Marine Operations Noise Model (MONM) by JASCO Applied Sciences (Hannay and Racca 2005), was used in the previous studies (Matthews et al. 2015, Schlesinger et al. 2015) to calculate the noise emissions and sound propagation for all construction activity scenarios. MONM's inputs include source specifications of all equipment, ocean bathymetry, water sound speed profiles, and seabed geoacoustic parameters. The model generates sound exposure level (SEL) fields in several frequency bands that can be frequency weighted to allow for specific effects assessment. The MONM results used in the previous studies (Matthews et al. 2015, Schlesinger et al. 2015) were also used here, and an attenuation curve from an air bubble curtain mitigation system was applied.

M-weighting (Southall et al. 2007) were applied to the modelled 1/3-octave band SEL values. The accumulated sound energy was then computed for sequences of pile driving blows that could be acquired over 24 hours.

3.3. Mitigation Systems: Bubble Curtain

Enclosing the pile in a bubble curtain is the most commonly used system for pile driving activities. Bubble curtain systems have been shown to significantly reduce underwater sound levels away from the pile (Illingworth and Rodkin 2001, ICF Jones & Stokes and Illingworth and Rodkin 2009, WSDOT 2010, MacGillivray et al. 2011). Most systems produce air bubbles at a manifold deployed at the seafloor that rise through the water column (Figure 2).

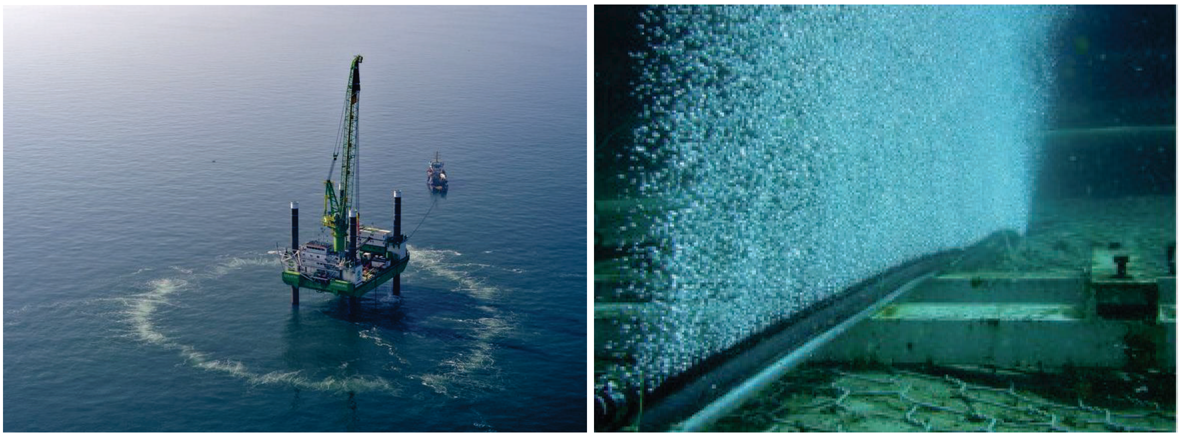

Figure 2. Example of air bubble curtain. (Left): Active air bubble curtain around pile driving activities. (Right): Tubing for an active air bubble curtain.

MacGillivray et al. (2011) reviewed literature that compiled bubble curtain sound attenuation measurements. Of the available data, some compared attenuated and non-attenuated impact pile driving sound levels per-frequency. Table 2 and Figure 3 show the compiled and averaged measurements.

Table 2. Bubble curtain specifications and reported attenuation levels for impact driving of steel shell piles (MacGillivray et al. 2011). Airflow rate is measured in cubic feet per minute (CFM). Air pressure is measured in pounds per square inch (PSI).

Bubble curtain	Airflow/ pressure	Pile diameter (ft)	Measurement distance (ft)	Broadband attenuation (dB)	Source
Steel isolation casing with single bubble ring	680–700 CFM 105–115 PSI	2.5	33	35	WSDOT SR-520 (WSDOT 2010)
Steel isolation casing 12.1 ft diameter with bubble ring	Unknown	7.9	177	21	Benicia-Martinez Bridge (ICF Jones & Stokes and Illingworth and Rodkin 2009)
Fabric mantle 13.1 ft diameter with bubble ring	1500 CFM	8.5	330	5–10	East Span PIDP (Illingworth and Rodkin 2001)
PVC isolation casing 4 ft diameter with single bubble ring	300–350 CFM	2.0	33	9	WSF Eagle Harbor (MacGillivray and Racca 2005)

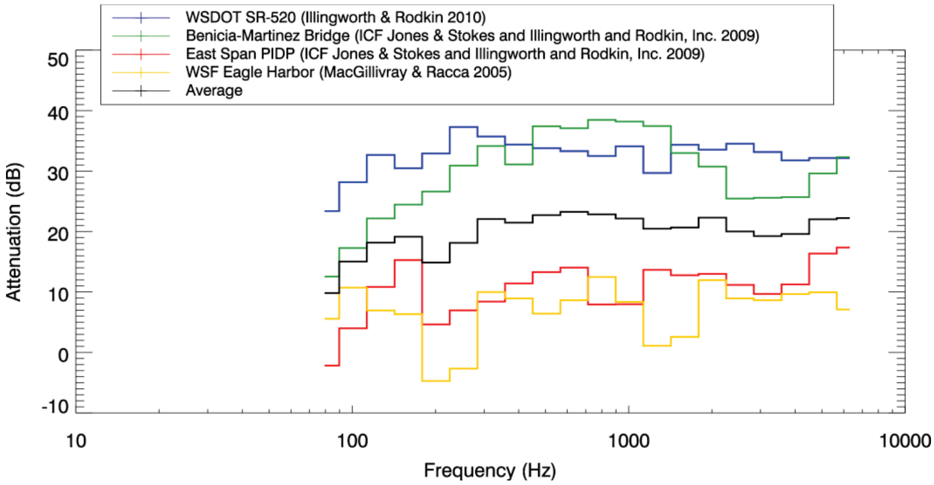

Figure 3. Reported measurements of acoustic attenuation for bubble curtains in 1/3-octave-bands (MacGillivray et al. 2011). The black line is the average attenuation in each frequency band.

The 1/3-octave-band attenuation levels were averaged in the frequency range for which all publications reported data overlap (63–6300 Hz). The mean broadband attenuation was approximately 20 dB. The various bubble curtain sound attenuation measurements indicated substantial variations in their effectiveness, with quoted broadband sound level reductions ranging from 5 to 36 dB. Based on assessment guidelines (ICF Jones & Stokes and Illingworth and Rodkin 2009, WSDOT 2010), it was determined on precautionary grounds that a 10 dB mean attenuation would realistically estimate how well each mitigation system performed. Thus, the average attenuation trend from the reported measurements was decreased so that the mean 1/3-octave-band attenuation in the 63–6300 Hz range equalled 10 dB (Figure 4). This adjustment resulted in no mitigation effect below 63 Hz (extrapolated attenuation values of approximately 0 dB), which reflects typical bubble curtain performance at low frequencies. The derived attenuation values of the bubble curtain are presented in Figure 4.

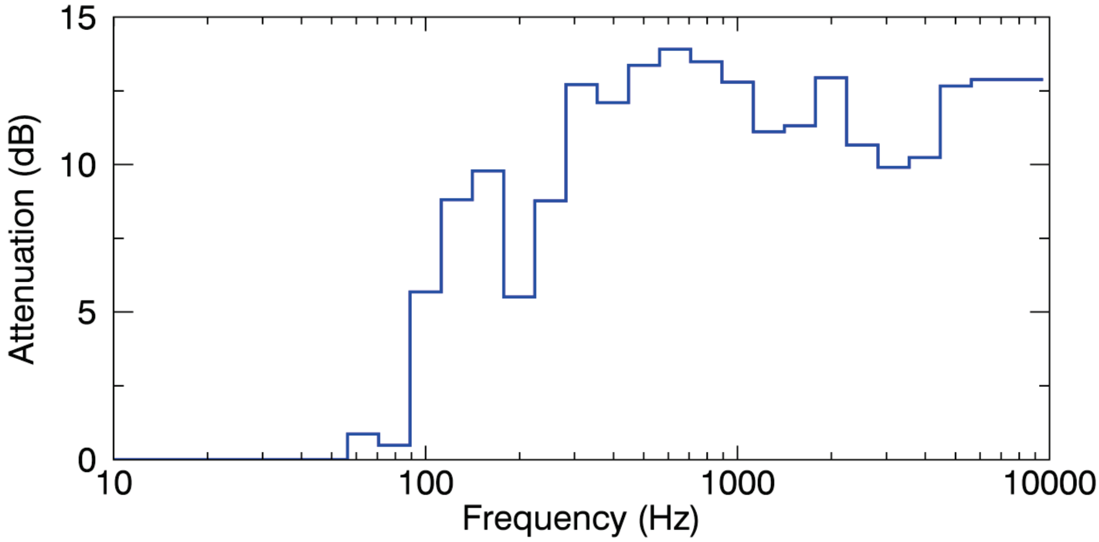

Figure 4. Estimated acoustic attenuation in 1/3-octave-bands for a bubble curtain (MacGillivray et al. 2011).

3.4. Acoustic Impact Criteria

For marine mammals, the U.S. National Marine Fisheries Service (NMFS) regulatory criteria (MMPA 2007) and Southall et al. (2007) recommend two widely-acknowledged sets of injury and disturbance criteria for sound exposure, which both distinguish between continuous and impulsive sounds.

Current NMFS injury criteria for marine mammals exposed to impulsive sounds are defined by an rms SPL metric representing the estimated onset of permanent hearing threshold shift (PTS). The NMFS behavioural disturbance criterion for impulsive sounds is also based on rms SPL metric. Southall et al. (2007) criteria include both peak SPL and cumulative Sound Exposure Level (cSEL) with marine mammal frequency weightings (M-weighting); cSELs originate from single or multiple exposure events over a 24 h period. Southall et al. (2007) and NMFS criteria are determined by the estimated onset of permanent threshold shift (PTS) for marine mammals. A received sound exposure is assumed to cause injury if it exceeds either the peak SPL or the SEL criterion. Southall et al. (2007), however, do not recommend SPL thresholds for marine mammal injury criteria.

Table 3 shows the Southall et al. (2007) auditory injury, disturbance, and onset of temporary threshold shift (TTS) criteria for impulsive sounds.

Table 3. Southall et al. (2007) auditory injury and TTS onset criteria for impulsive sounds. LF = low-frequency, MF = mid-frequency, and HF = high-frequency, TTS = Temporary Threshold Shift.

Marine mammal group		Southall et al. (2007)			
		M-weighted SEL (dB re 1 µPa²·s)		Peak SPL (dB re 1 µPa)	
		Injury	TTS onset	Injury	TTS onset
Cetaceans	LF, MF, HF	198	183	230	224
Pinnipeds	in water	186	171	218	212

In 2014, the ANSI-accredited Fisheries Hydroacoustic Working Group (FHWG) published interim guidelines on sound exposure for fish and sea turtles (Popper et al. 2014). The original studies (Matthews et al. 2015, Schlesinger et al. 2015) had been based on interim results from the same group (FHWG 2008), and we have updated this assessment based on the revised final criteria. The new guidelines are defined for various animal groups, and are based on how these animals detect sound and various sound sources. Fish are divided into three groups: those without a swim bladder, those with a swim bladder that is not involved in hearing, and those with a swim bladder used for hearing. Table 4 presents the recommended criteria for impact pile driving activities. A received sound exposure is assumed to cause injury if it exceeds either the peak SPL or the SEL criteria, or both.

Table 4. FHWG 2014 mortality and impairment criteria for impact pile driving (Popper et al. 2014).

Fish group		Mortality and potential mortal injury		Impairment		
				Recoverable injury		TTS
		SEL (dB re 1 µPa^2·s)	peak SPL (dB re 1 µPa)	SEL (dB re 1 µPa^2·s)	peak SPL (dB re 1 µPa)	SEL (dB re 1 µPa^2·s)
I	No swim bladder (particle motion detection)	> 219	> 213	> 216	> 213	>> 186
II	Swim bladder is not involved in hearing (particle motion detection)	210	> 207	203	> 207	>> 186
III	Swim bladder involved in hearing (primary pressure detection)	207	> 207	203	> 207	186

4. Results

The 95th percentile radius, $R_{95\%}$, and the maximum radius, R_{max}, for each noise threshold criterion are tabulated in the next sections. R_{max} is the maximum range from pile driving activity at which the given criterion sound level is predicted to be exceeded. The $R_{95\%}$ is the same maximum range but excluding the 5% of directions of highest emission. This value accounts for the finding that models often predict a small number of narrow sectors of enhanced sound propagation. These anomalies arise due to assumptions about smooth seabed interfaces and homogeneous ocean conditions. In practice, seabed roughness and inhomogeneity in the water cause acoustic scattering that disrupts the enhanced propagation. The $R_{95\%}$ radius in any case encompasses at least 95% of the area that would be exposed to sound at or above that level.

Results in this study are based on the assumption that pile driving would operate at a maximum rate of 18 000 blows for 24 hours. This rate implies that both activities—cylindrical and sheet pile driving—would operate at the same time at all project locations (RTA and LNGC). The radii in Table 5 correspond to marine mammal injury and disturbance criteria (Southall et al. 2007) and fish injury criteria (Popper et al. 2014) for 24 h cSEL. The ranges were calculated from each source location, where the largest ranges are provided in Table 5 .

Since the individual assessments (Matthews et al. 2015, Schlesinger et al. 2015) showed that peak SPL thresholds are reached at much smaller ranges than cSEL thresholds, only the cSEL matrix was considered here. Appendix A has sound level maps for unweighted and M-weighted 24 h cSEL levels.

Table 5. Radii (m) of unweighted and M-weighted 24 h cSEL contours for impact cylindrical and sheet pile driving with an air bubble curtain. The cSEL calculation included 18 000 blows for both pile driving activities operating simultaneously. TTS = Temporary Threshold Shift, PTS = Permanent Threshold Shift, MOR = Mortality, RI = Recoverable Injury, PINN = Pinnipeds, CET = Cetaceans. Fish I–No swim bladder; Fish II–Swim bladder not involved with hearing; Fish III–Swim bladder involved with hearing.

cSEL (dB re 1 µPa²·s)	Criteria	Unweighted		LFC		MFC		HFC		PINN	
		R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
171	TTS–PINN									17000	14600
183	TTS–CET			14 610	9 360	14 590	8 270	14 560	7 840		
186	PTS–PINN & TTS-Fish I, II, III	7 520	5 370							6 400	5 100
198	PTS–CET			950	790	840	770	830	770		
203	RI–Fish II, III	810	780								
207	MOR–Fish III	790	780								
210	MOR–Fish II	790	780								
216	RI–Fish I	770	770								
219	MOR–Fish I	760	760								

5. Discussion

This study investigated potential acoustic disturbances to local marine fauna that would be generated by construction activities associated with RTA's and LNGC's proposed terminal extension projects. To model sound levels for two representative pile driving scenarios, the original modelling results for impact pile driving activities (Matthews et al. 2015, Schlesinger et al. 2015)were revised to include the air bubble curtain mitigation system. M-weighting was applied to estimate sound levels from impact pile driving that could cause auditory damage or disturb marine fauna. Cumulative sound exposure was computed to estimate the acoustic footprints of impact pile driving that operates over 24 hours. Both unweighted and weighted sound levels are presented in this study in tables of distances and isopleth maps.

JASCO's Marine Operations Noise Model (MONM) was used to model sound propagation in the previous studies (Matthews et al. 2015, Schlesinger et al. 2015). The generated sound fields were adjusted using attenuation from an air bubble curtain mitigation system. Cumulative sound exposure levels (cSEL) were computed to estimate the acoustic footprints of three simultaneous pile driving scenarios: one impact sheet and two impact cylindrical pile driving, over 24 hours

The main species in the Project area that could be affected are humpback whales, killer whales, harbour porpoise, and fish. Distances to auditory injury and disturbance criteria were calculated from the resulting unweighted and M-weighted cSEL.

In general, where uncertainties in operating conditions existed, we chose reasonable model inputs that predicted higher noise levels. We also applied the following conservative assumptions to our models:

- Radii ($R_{95\%}$ and $R_{\max}$) and sound level isopleth maps (Appendix A) were computed using the maximum sound level over all depths along the water column, although in reality marine mammals might spend time at depths with lower sound levels.
- The radii were calculated from each source location; only the largest ranges to each criterion were tabulated.
- Sound fields were modelled using January sound speed profiles. These profiles estimate much larger radii because cooler winter temperatures near the sea surface (surface duct) favour longer-range propagation. In summer, sound exposures for animals near the surface are substantially lower than winter because downward-refracting sound speed directs sound energy into the seabed and increases bottom loss.
- Cumulative sound fields were computed assuming that impact sheet and cylindrical pile driving activities from both projects (RTA and LNGC) operate concurrently with a maximum number of 18 000 blows in 24 hours.

The distances ($R_{95\%}$) to the injury thresholds 198 dB re 1 µPa^2·s cSEL (PTS for cetaceans) extended to 790 m when an air bubble curtain mitigation was applied. The distances ($R_{95\%}$) to the injury threshold to 186 dB re 1 µPa^2·s cSEL (PTS for pinnipeds) extended to 5.1 km when an air bubble curtain mitigation was applied. The distances ($R_{95\%}$) to mortality thresholds for fish (207, 210, and 219 dB re 1 µPa^2·s unweighted cSEL) extended to less than 780 m.

Because the modelled radii for the maximum number of blows are based on methods that assumed that the animals reside in the area around the pile driving location, the resulting cumulative sound exposure levels are considered conservative. A logical assumption is that the animals will leave the area when construction activities begin and will therefore, not be exposed to as much noise.

The modelled distances to the injury and TTS thresholds for all the species are based on the assumption that all pile driving activities occur over 24 h. The distances will decrease if the number of activities or number of blows decreases over 24 h. Hence, the results in this study reflect the worst case.

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Appendix A. Sound Levels Isopleth Maps

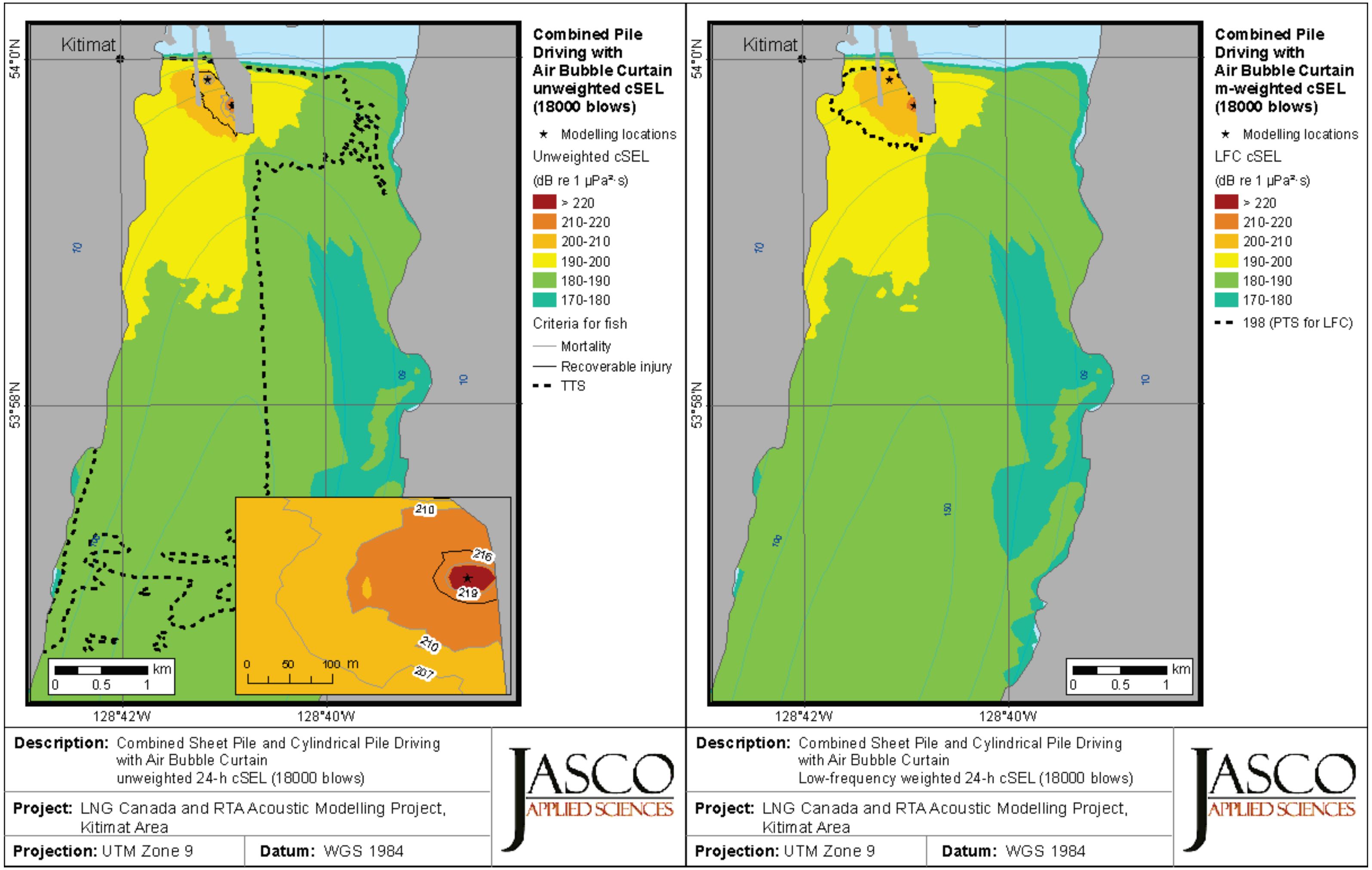

Figure A-1. (Left) Unweighted 24 h cSEL (dB re 1 µPa^2·s) and (Right) low-frequency weighted (LFC) 24 h cSEL (dB re 1 µPa^2·s) for operating impact sheet pile driving and cylindrical pile driving with an air bubble curtain. The cSEL was calculated with 18 000 blows in 24 hours for simultaneous operation of both activities.

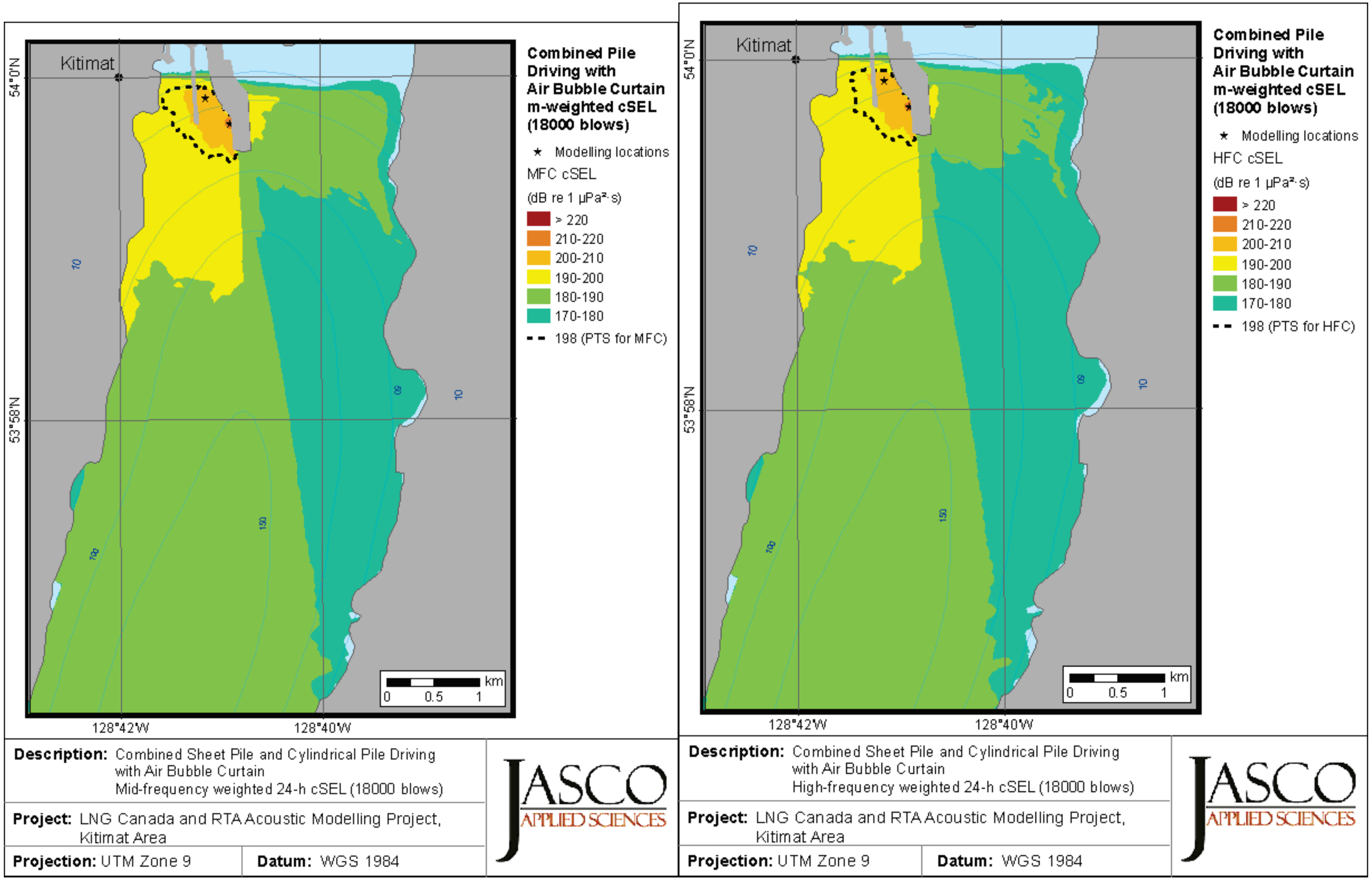

Figure A-2. (Left) Mid-frequency weighted (MFC) 24 h cSEL (dB re 1 µPa^2·s) and (Right) high-frequency weighted (HFC) 24 h cSEL (dB re 1 µPa^2·s) for operating impact sheet pile driving and cylindrical pile driving with an air bubble curtain. The cSEL was calculated with 18 000 blows in 24 hours for simultaneous operation of both activities.

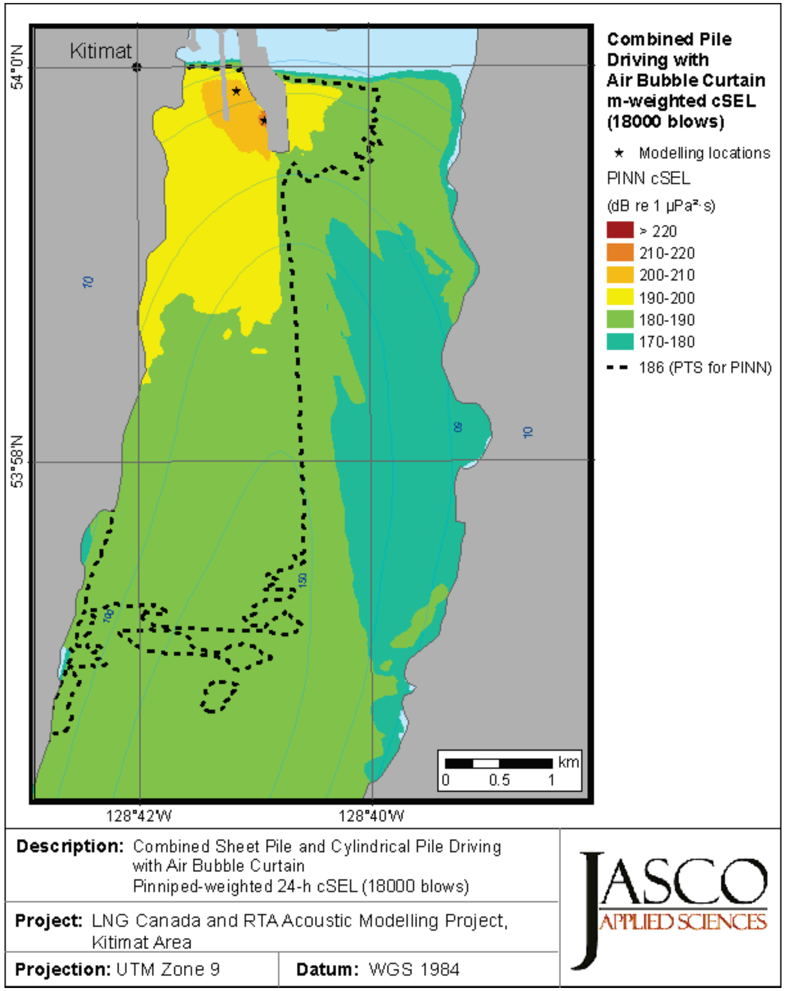

Figure A-3. Pinniped-weighted (PINN) 24 h cSEL (dB re 1 µPa^2·s) for operating impact sheet pile driving and cylindrical pile driving with an air bubble curtain. The cSEL was calculated with 18 000 blows in 24 hours for simultaneous operation of both activities.

Appendix 3 JASCO Applied Sciences (Canada) Ltd. Response to Reviewers Comments

Response to Reviewers Comments

Rio Tinto Alcan Terminal and Extension Project, Kitimat BC

Submitted to:
Anna Hall
WorleyParsons Canada

Authors:
Angela Schlesinger
David Hannay

6 August 2015

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Version 1.0

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Schlesinger, A., D. Hannay. 2015. Response to Reviewers Comments: Rio Tinto Alcan Terminal and Extension Project, Kitimat BC. JASCO Version 1.0. Technical report by JASCO Applied Sciences for WorleyParsons Canada.

1. Cumulative Sound Exposure Levels for 1 hr of cylindrical pile driving

Table 1. Radii (m) of unweighted and M-weighted 1 h cSEL contours for impact cylindrical pile driving with an air bubble curtain. The cSEL calculation included 1 000 blows. TTS = Temporary Threshold Shift, PTS = Permanent Threshold Shift, MOR = Mortality, RI = Recoverable Injury, PINN = Pinnipeds, CET = Cetaceans. Fish I = No swim bladder; Fish II = Swim bladder not involved with hearing; Fish III = Swim bladder involved with hearing.

cSEL (dB re 1 µPa²·s)	Criteria	Unweighted		LFC		MFC		HFC		PINN	
		$R_{\max}$	$R_{95\%}$	$R_{\max}$	$R_{95\%}$	$R_{\max}$	$R_{95\%}$	$R_{\max}$	$R_{95\%}$	$R_{\max}$	$R_{95\%}$
171	TTS–PINN									14400	9900
183	TTS–CET			1530	1190	1380	1090	1310	1060		
186	PTS–PINN TTS-Fish I, II, III	1010	860							880	760
198	PTS–CET			110	100	100	80	90	70		
203	RI–Fish II, III	50	50								
207	MOR–Fish III	20	20								
210	MOR–Fish II	13	13								
216	RI–Fish I	<10	<10								
219	MOR–Fish I	<10	<10								

2. Per-pulse sound exposure levels (SEL) and root-mean square (rms) sound levels

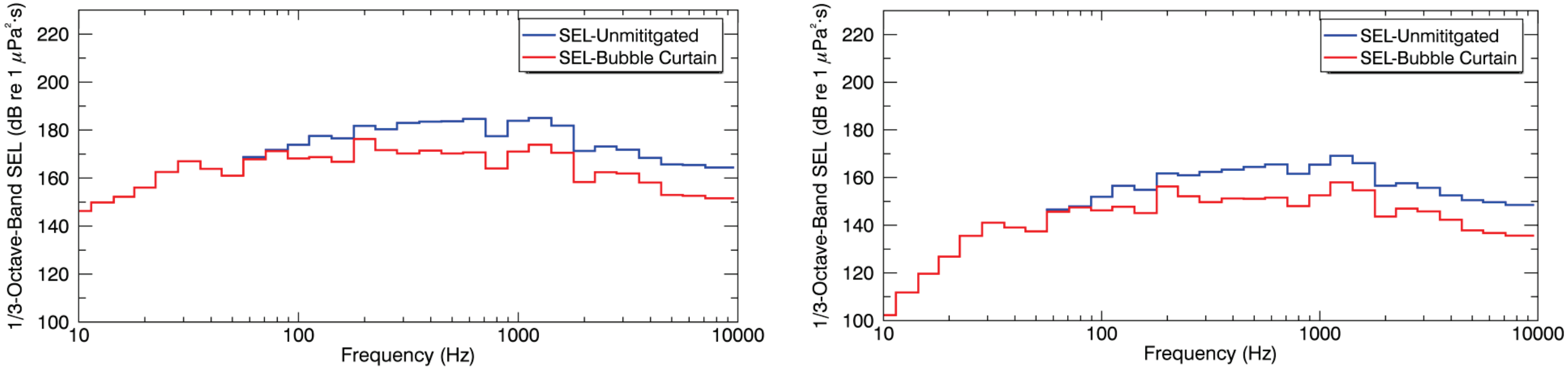

Figure 1. 1/3-octave band per-pulse SEL for (left) 10 m and (right) 500 m range from the source

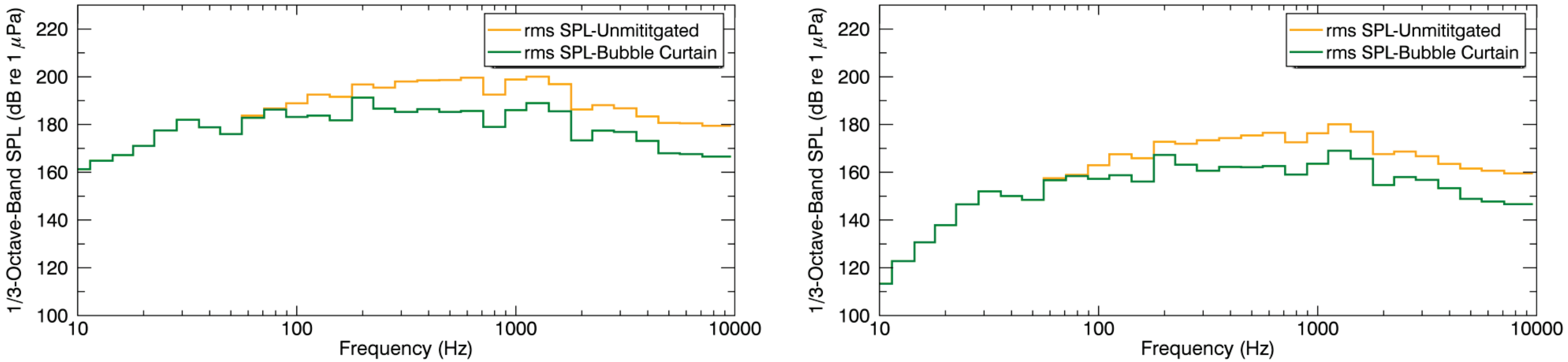

Figure 2.1/3-octave band rms SPL for (left) 10 m and (right) 500 m range from the source.

3. Summary

The current document addresses the requests from the reviewers of the revised report by Matthews et al. (2015). It includes threshold radii based on marine mammal injury and disturbance criteria (Southall et al. 2007) and fish injury criteria (Popper et al. 2014) for cumulative sound exposure computed over a period of 1 hour.

Cumulative sound exposure levels (cSEL) were computed to estimate the acoustic footprints of two pile driving hammers operating simultaneously. Assuming 1 000 blows during 1 hour of impact pile driving, and mitigation with an air bubble curtain, the distances ($R_{95\%}$) to 198 dB re 1 µPa^2·s M-weighted cSEL (PTS for cetaceans) extended between 70 and 100 m depending on the cetacean hearing group from high to low frequency. The distance ($R_{95\%}$) to 186 dB re 1 µPa^2·s M-weighted cSEL (PTS for pinnipeds in water) extended to 760 m. The distances ($R_{95\%}$) to mortality criteria for various fish groups (207, 210, 219 dB re 1 µPa^2·s unweighted cSEL) are within 50 m. These estimates assume that the animals are residing within the zone of injury for the full period of 1 h. Most animals likely move in and out of this zone, and thus their exposure levels are reduced.

Per-pulse sound exposure levels (SEL) and root-mean-square sound pressure levels (rms SPL) were calculated in third-octave frequency bands for two representative distances from the source, 10 m and 500 m. Figures 1 and 2 show received band levels at the two ranges respectively, both unmitigated and mitigated with an air bubble curtain system. The acoustic propagation model used to compute these estimates, the Marine Operations Noise Model (MONM) by JASCO Applied Sciences (Hannay and Racca 2005), does not directly predict the 90% rms sound pressure levels (SPL). We derived these metrics from the modelled SEL by applying conversion factors obtained from empirical measurements of SEL and 90% rms SPL in locations with similar acoustic environments. The conversion factors from SEL to rms SPL were determined to be 15 dB at 10m and 11 dB at 500 m range. The air bubble curtain system has no perceptible mitigation effect below 63 Hz, hence the overlap of the unmitigated and mitigated levels curves for those low frequencies.

4. Literature

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