6 CONCLUSIONS

Marine habitats in the facility RSA support a wide variety of marine fish and invertebrates, including fish that are part of or support CRA fisheries. The RSA encompasses portions of the Kitimat River estuary and Kitimat Arm. It overlaps with IAs for eulachon, tanner crab, and cloud sponge, and encompasses Pacific salmon spawning rivers, eulachon spawning rivers, and Pacific herring spawning areas. Eight marine fish species at risk may occur in the facility RSA; an additional seven marine fish species at risk may occur in the shipping RSA.

The intertidal zone of the facility LSA is characterized by a large tidal flat, with riprap and rock as the dominant substrate types in the high intertidal zone and soft substrates in the mid- and low intertidal zones. The salt marsh is characterized by mud substrate, a network of tidal channels, and marsh vegetation. Subtidal habitat in the LSA is characterized by soft substrates, with limited structural complexity. Observed species of marine fish, invertebrates, and vegetation were typical of north coast fjord habitats. No species at risk were observed during the intertidal, salt marsh, or subtidal surveys; however, eulachon were observed in the northern portion of BSA 3.

Freshwater processes and input from Kitimat River have a strong influence on marine habitat within the estuary and may be a limiting factor in the establishment of some marine species that cannot tolerate variation in salinity. Industrial developments, including an aluminum smelter, a pulp and paper mill, a methanol plant, and log storage and handling facilities, are located in or adjacent to the facility LSA, and the intertidal zone of the LSA consists almost entirely of constructed shore types.

Sediment in the facility LSA contains elevated concentrations of PAHs and some metals. Copper levels are above federal guidelines in the facility LSA; but copper levels are high in many parts of Kitimat Arm and the Kitimat River, suggesting natural sources. Uptake of PAHs by biota in Kitimat Arm is low, indicating limited bioavailability.

Despite the influence of human development and activities on fish and fish habitat in the facility LSA, there are several notable features of ecological value. The salt marsh located between RTA Wharf “B” and the Methanex jetty provides habitat for marine fish, including juvenile Pacific salmon and sculpin. Thirteen small eelgrass patches covering an estimated area of 83 m^2 were observed in the LSA during the intertidal surveys; and, additional patches were observed during the subtidal surveys. Eelgrass was concentrated near Hospital Beach on the western shore of the LSA.

The shipping RSA and LSA included the full extent of the marine access route within the confined channels (e.g., Kitimat Arm, Douglas Channel, Squally Channel, Principe Channel), Whale Channel, Caamaño Sound, and waters to the pilot station area near Triple Island in the north. Cetacean species that are known to occur in the area, and sighted during marine mammal surveys, include baleen whales (humpback whales, fin whales, minke whales) and toothed whales (northern resident killer whales, Bigg’s killer whales, Dall’s porpoise, harbour porpoise, Pacific white-sided dolphins). Steller sea lions, harbour seals, and sea otters are also present.

The shipping RSA overlaps with areas designated by DFO as important for various species of marine mammals that frequent the area. Designated critical habitat for humpback whales is located in the shipping RSA, encompassing the area around Gil Island. Potential critical habitat for northern resident killer whales also overlaps the RSA, encompassing the area around Gil Island and extending into Caamaño Sound and Estevan Sound. Fisheries and Oceans Canada has also defined IAs in the RSA based on expert opinion, historical whaling data, and sightings of humpback whales, northern resident killer whales, and fin whales. Seven marine mammal species that are known to occur in the shipping RSA are also species at risk: humpback whale, fin whale, killer whale (Bigg's and northern resident), harbour porpoise, Steller sea lion, and sea otter.

Marine mammal density surface modelling results highlighted several areas in the shipping RSA as seasonal areas of high use, or seasonal hot spots, for several marine mammal species. The northern end of Kitimat Arm was predicted to be used by harbour seals throughout the year; whereas, Douglas Channel was predicted to have seasonal high use by Dall's porpoises. Predictions for Squally Channel suggested that fin whale relative abundance peaked in mid-summer; whereas, humpback whale relative abundance peaked in late summer. High abundance for harbour seals was predicted in summer for the northern coastal areas of Squally Channel. Whale Channel predictions had higher Dall's porpoise abundance in mid-summer, with the addition of higher abundance of humpback whales in late summer. Harbour porpoise were predicted to be present in higher numbers in Whale Channel in spring through to late summer. High numbers of Pacific white-sided dolphins were predicted for winter. Predicted Steller sea lion hot spots occurred throughout the year, primarily around Ashdown Island. The models predicted fin whale, harbour porpoise, and harbour seal summer hot spots for Caamaño Sound, which extended up into Estevan Sound for harbour porpoise and harbour seals. Principe Channel had very few marine mammal sightings and, therefore, only had predicted hot spots for harbour seals hauled out. Triple Island had predicted hot spots for humpback whales and seasonal hot spots for Dall's porpoise, Pacific white-sided dolphin, and Steller sea lions.

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APPENDIX A

Sediment and Tissue Data in Kitimat Arm

Table A-1: Sediment Data in the Local and Regional Study Areas (Facility)

Reference Study	Study Date	PAHs: Sum PAHs in Project marine resources LSA sediment	PAHs: Sum PAHs in wider Kitimat Arm sediment (outside the Project marine resources LSA)	PAHs: Guideline Exceedances	Metals	Guideline Exceedances	Total PCBs	Guideline Exceedances	Dioxins and Furans	Guideline Exceedances	Other Notes (e.g., depth sampled)
Golder Associates Ltd. 2014a	2013 to 2014	Sonic boreholes ▪ 0.139–207.7 mg/kg ∑16 PAHs	N/A	Some individual PAH guideline exceedences ▪ 31 locations > DAS standard for ∑16 PAHs of 2.5 mg/kg ▪ typically greatest [∑16 PAHs] between 1.5 m and 5.5 m below mudline	▪ Copper: 13.4–71.8 mg/kg ▪ Zinc: 27.2–391 mg/kg	▪ Copper: 162 of 180 samples in all borehole location > CCME ISQG of 18.7 mg/kg ▪ Zinc: 3 of 180 samples in 2 borehole locations > CCME ISQG	▪ 9 samples < DL of 0.020 mg/kg	▪ 1 samples > ISQG of 0.0215 mg/kg	TEQs ranged from 0.13 pg/g to 12.64 pg/g using TEQ factors for fish described in CCME (1999a) and up to 32.16 pg/g using TEQ for mammals (U.S. EPA 2008)	6 samples from 3 locations > ISQG	▪ Sonic boreholes at 42 locations between 0 m and 14 m below mudline ▪ Greatest [∑16 PAH] concentrations between 1.5 m and 5.5 m below mudline in northwest central portion of harbor
Golder Associates Ltd. 2013	2012	Vibracores ▪ <0.050–163.4 mg/kg Rotary drill ▪ 1.37–5.86 mg/kg	N/A	Some individual guideline exceedences Vibracores ▪ 46 locations > DAS standard for ∑16 PAHs of 2.5 mg/kg, typically increase in [∑16 PAH] with depth (deeper than 1 m, higher concentrations than shallower, near to mudline concentrations) Rotary Drill ▪ 1 location > DAS standard for ∑16 PAH of 2.5 mg/kg	Vibracores ▪ Cadmium: <0.050-1.62 mg/kg ▪ Copper: 11.2–176 mg/kg ▪ Zinc: 27.2–391 mg/kg Rotary Drill ▪ Copper: 14.1–42.1 mg/kg	One vibracore sample (zinc) > PEL Vibracores ▪ Cadmium: 3 locations > DAS standard of 0.060 mg/kg, depth 1-2 m ▪ Copper: 59 of 133 vibracore samples > DAS standard of 18.7 mg/kg; 2 locations > CCME PEL of 108 mg/kg and CSR TCS of 130 mg/kg ▪ Zinc: 2 locations > DAS of 124 mg/kg, depth <2 m Rotary Drill ▪ Copper: 21 of 26 samples > DAS standard of 18.7 mg/kg	Vibracores ▪ no samples > DL of 0.030 mg/kg Rotary Drill ▪ no samples > DL of 0.030 mg/kg	none	Vibracores ▪ TEQ(0.0DL) 0.01–5.89 ▪ TEQ(0.5DL) 0.12–5.89 Rotary Drill ▪ none analyzed	none	▪ Vibracores at 64 locations between 0.26 m to 2.53 m below mudline ▪ Barge-based rotary drill samples at 5 locations between 1.5 m and14.3 m below mudline ▪ Most vibracore samples with PAH < DAS guidelines were: • collected at more than 1 m below mudline, where exceedance(s) at that location were noted in surficial sediment • collected from the northernmost section of the harbour • collected from the southeastern section of the harbour ▪ most relevant - cores taken at proposed dredge location

Table A-1: Sediment Data in the Local and Regional Study Areas (Facility)

Reference Study	Study Date	PAHs									
		Sum PAHs in Project marine resources LSA sediment	**Sum PAHs in wider Kitimat Arm sediment (outside the Project marine resources LSA)**	**Guideline Exceedances**	**Metals**	**Guideline Exceedances**	**Total PCBs**	**Guideline Exceedances**	**Dioxins and Furans**	**Guideline Exceedances**	**Other Notes (e.g., depth sampled)**
Jacques Whitford 2010	2006	N/A	<0.05–3.16 mg/kg	▪ total PAH exceeded DAS criteria at 2 locations outside LSA (western side of Kitimat Arm north of Bish Cove) ▪ individual PAH exceedances throughout sample area		▪ exceedances of CCME ISQG for Chromium, Copper ▪ exceedances of NOAA AET for Barium, Cobalt, Manganese, Vanadium	<DL at all locations except one (at the DL)	none	TEQs ranged from 1.24 to 2.34 using TEFs for fish described in CCME (1999a) and up to 4.35 using various conventions for calculation (Van den Berg et al. 1998)	TEQs exceeded CCME ISQG of 0.85 pg/g but fell below the PEL of 21.5 pg/g	▪ 30–100 m depth ▪ 16 parent PAHs plus methylated naphthalene ▪ 12 locations for sediment/water sampling further south in Kitimat Arm (all outside LSA); 2 reference sites on east side of Kitimat Arm not analyzed for PCBs or dioxans and furans ▪ Also sampled bottom water [∑PAHs] = <0.05–11.5 μg/L ▪ Also did toxicity tests for marine invertebrates in sediment: 80%–88% survival of amphipods (though statistically lower survival [*p* = 0.05] in 5 of 8 samples in comparison to tests done with sediment from a reference site), 100% survival of polychaete worms (no statistical difference from reference area samples). Suggests contaminants not bioavailable to cause toxicity to these marine organisms
NOAA 2009	2000–2004	▪ Alcan Inner Harbour: 26 mg/kg ▪ Hospital Beach: 5 mg/kg	Eurocan Beach (inside LSA), Kitamaat Village, Emsley Cove: 1–3 mg/kg	▪ no individual concentrations reported	N/A (focus on PAHs)		N/A (focus on PAHs)		N/A (focus on PAHs)		▪ Extension to tissue data, bioaccumulation (salmon, flatfish) ▪ Surface sediment samples only (Ponar) ▪ Focus on PAHs, organochlorines in fish ▪ Eurocan Beach inside LSA but not reported on separately so lumped with others
Yunker et al. 2011	1995–2000	▪ not easy to tease out - concentrations cited as individual PAH groups/ratios			N/A (focus on PAHs)		N/A (focus on PAHs)		N/A (focus on PAHs)		▪ Also analyzed soft shell clam tissue and reported clam/sediment BSAFs; found that while smelter PAHs may not be bioavailable to benthic organisms, those released by pulp and paper mills (e.g., plant terpenes) are bioavailable and have demonstrated toxic properties

Table A-1: Sediment Data in the Local and Regional Study Areas (Facility)

Reference Study	Study Date	PAHs: Sum PAHs in Project marine resources LSA sediment	PAHs: Sum PAHs in wider Kitimat Arm sediment (outside the Project marine resources LSA)	PAHs: Guideline Exceedances	Metals	Guideline Exceedances	Total PCBs	Guideline Exceedances	Dioxins and Furans	Guideline Exceedances	Other Notes (e.g., depth sampled)
Eickhoff et al. 2003	1995–1996	N/A (crab tissue data only)									▪ Focus on crab tissue and hepatopancreas concentrations; only analyzed for 10 of the 16 U.S. EPA PAHs; crabs collected from Hospital Beach (in RSA) and 4 locations outside of RSA
Harris 1999	1995–1996	▪ reported as individual congeners (1 location - see Table 8-2)	reported as individual congeners (2 locations - see Tables 8-3 and 8-4)		N/A (focus on PAHs)		reported as individual congeners - see Table 8-6 for data from within and outside LSA)		N/A (focus on PAHs)		▪ Surficial sediment grabs to 10 cm depth at 1 location in LSA and 2 outside LSA ▪ Modelling/BSAF approach for PCDDs and PCDFs as well as PAH ▪ Dungeness crab PCB tissue data
Paine et al. 1996	1994	▪ inner harbour intertidal: 0.085-58.3 mg/kg ▪ inner harbour: 1.31–9890 mg/kg ▪ lagoon foreshore: 3.56-533 mg/kg	Five sites throughout Kitimat Arm: 0.66-2.85 mg/kg	▪ upper ranges at each location in LSA exceed effects range median cited in study (44.792 mg/kg for total PAH); no exceedances of this value outside LSA	N/A (focus on PAHs)		N/A (focus on PAHs)		N/A (focus on PAHs)		▪ Surface samples (top 2-5 cm) ▪ Sediment quality triad approach: looked at toxicity and benthic community composition (collected crabs for tissue analysis and benthic infauna); concluded PAHs not bioavailable. ▪ "Concentrations of PAHs near smelter (within LSA) generally exceed Effects Range Median values (above which effects are usually observed), and other sediment criteria and objectives. Outside the Inner Harbour, there is no evidence of pollution-induced degradation. Inside the Inner Harbour, PAHs appear to have limited bioavailability in the most contaminated area - presence of a contaminant not necessarily synonymous with adverse effects (i.e., contamination is not pollution)." ▪ Eickhoff et al. (2003) say the less sensitive analytical procedures used in this study (higher DLs) is the reason for the low bioavailability conclusion.

Table A-1: Sediment Data in the Local and Regional Study Areas (Facility)

Reference Study	Study Date	PAHs									
		Sum PAHs in Project marine resources LSA sediment	Sum PAHs in wider Kitimat Arm sediment (outside the Project marine resources LSA)	Guideline Exceedances	Metals	Guideline Exceedances	Total PCBs	Guideline Exceedances	Dioxins and Furans	Guideline Exceedances	Other Notes (e.g., depth sampled)
Simpson et al. 1998	1990s	Reported by five size fractions: ▪ >1,180 μm: 1.661–3,576.574 mg/kg ▪ 1,180–300 μm: 1.656–1,593.184 mg/kg ▪ 300–180 μm: 1.708–465.060 mg/kg ▪ 180–38 μm: 1.798-171.443 mg/kg ▪ <38 μm: 1.169-64.667 mg/kg	Reported by five size fractions: ▪ >1,180 μm: 3.450–21.753 mg/kg ▪ 1,180-300 μm: 3.368–33.549 mg/kg ▪ 300–180 μm: 3.284–11.521 mg/kg ▪ 180–38 μm: 3.566-18.068 mg/kg ▪ <38 μm: 3.292-5.821 mg/kg	▪ difficult to quantify because sum PAHs are not U.S. EPA PAHs	N/A (focus on PAHs)		N/A (focus on PAHs)		N/A (focus on PAHs)		▪ Surface samples (15 cm depth) collected from 3 sites in LSA and 2 sites outside LSA but in upper Kitimat Arm ▪ Reports individual PAH concentrations and ΣPAHs by 5 size fractions for each sample ▪ Total PAHs = 16 parent U.S. EPA PAHs + benzo[e]pyrene + perylene ▪ Comments on enrichment of PAHs in specific particle size classes in marine sediments (selective association with low density, large particle size sediment fraction [>64 μm]) ▪ "No trends with sediment depth, associated with compound-specific weathering or biotransformation, were noted in the composition of anthropogenically generated PAHs. This may indicate a limited chemical and biological availability of the aluminum smelter derived PAHs."

Table A-1: Sediment Data in the Local and Regional Study Areas (Facility)

Reference Study	Study Date	PAHs			Metals	Guideline Exceedances	Total PCBs	Guideline Exceedances	Dioxins and Furans	Guideline Exceedances	Other Notes (e.g., depth sampled)
		Sum PAHs in Project marine resources LSA sediment	Sum PAHs in wider Kitimat Arm sediment (outside the Project marine resources LSA)	Guideline Exceedances							
Simpson 1997	1990s	▪ 6.7–528 mg/kg	10–40 mg/kg	▪ DAS criteria exceeded in and outside LSA ▪ need to look at individual PAH concentrations in comparison to PEL	N/A (focus on PAHs)		N/A (focus on PAHs)		N/A (focus on PAHs)		▪ Investigated PAH concentrations in sediment and soft-shell clams ▪ Surface sediment samples (15 cm depth) ▪ Total sediment PAH includes all 16 U.S. EPA PAHs ▪ Location of lowest concentration in LSA is dredged to maintain access to Alcan dock; hence, anomalously low PAH levels ▪ Also displays some results by particle size fraction (as done by Simpson et al. 1998) in a weighted total PAH calc equal to the total PAH concentration in each PSF times the fraction of the total sed dry wt contributed by that PSF ▪ General trend of highest PAH levels closest to smelter, declining with increasing distance from the smelter ▪ Clam data found on p. 135 (sum 15 PAHs) ▪ Overall conclusion: PAHs in the area have limited bioavailability
Simpson et al. 1996	1990s	▪ upper inlet (near smelter): 12-528 mg/kg	▪ east side: 21 mg/kg ▪ west side: 41 mg/kg ▪ range: 2.5-297 mg/kg	▪ DAS criteria exceeded in and outside LSA ▪ need to look at individual PAH concentrations in comparison to PEL	N/A (focus on PAHs)		N/A (focus on PAHs)		N/A (focus on PAHs)		▪ Total PAH includes all 16 U.S. EPA PAHs ▪ PAHs declined rapidly with increasing distance from the smelter, although some more distant sites from smelter had elevated levels - PAH distribution in fjord system consistent with aeolian and fluvial transport of PAHs emitted by smelter (combustion-generated PAHs)

Table A-1: Sediment Data in the Local and Regional Study Areas (Facility)

Reference Study	Study Date	PAHs									
		Sum PAHs in Project marine resources LSA sediment	Sum PAHs in wider Kitimat Arm sediment (outside the Project marine resources LSA)	Guideline Exceedances	Metals	Guideline Exceedances	Total PCBs	Guideline Exceedances	Dioxins and Furans	Guideline Exceedances	Other Notes (e.g., depth sampled)
Cretney et al. 1983	1978–1979	▪ within LSA: 3.0-8.5 mg/kg ▪ upper inlet (down from smelter, outside LSA): 0.3-10 mg/kg	▪ east side (near Kitamaat Village): 2.4 mg/kg ▪ west side: 5.0 mg/kg ▪ west side just south of smelter: 10 mg/kg ▪ just outside to east of LSA: 0.3 mg/kg	▪ DAS criteria exceeded in and outside LSA ▪ need to look at individual PAH concentrations in comparison to PEL	N/A (focus on PAHs)		N/A (focus on PAHs)		N/A (focus on PAHs)		▪ Total PAH doesn't include all 16 U.S. EPA PAHs ▪ Surface grabs (10–20 cm) ▪ Pre changes to smelter process that reduced contaminant effluent
Albright et al. in Bell and Kallman 1976		N/A (focus on water quality, air quality)									▪ pollution section is in Part 2; focus on water quality monitoring, air pollution ▪ Part 2, p. 18: PCBs in Dungeness crabs in Kitimat Arm avg. 0.25 ± 0.09 ppm (range 0.1430–0.3950)

NOTES:

Σ – sum
AET – apparent effects threshold
DAS – disposal at sea
DL – detection limit
N/A – not applicable
PCDD – polychlorinated dibenzo-*p*-dioxins
PCDF – polychlorinated dibenzofurans
PSF – particle size fraction
TCS – Triclosan
U.S. EPA – United States Environmental Protection Agency

Table A-2: Tissue Chemistry Data in the Local and Regional Study Areas

Reference Study	Study Date	PAHs			Metals	Total PCBs	PCDD/F	Other Notes (e.g. depth sampled)
		PAHs in Project marine resources LSA tissue	PAHs in wider Kitimat Arm marine tissues (reference samples)	Guideline Exceedances	Guideline Exceedances	Guideline Exceedances	Guideline Exceedances	
NOAA 2009	2000–2004	▪ Sediment: ◦ high concentrations of PAHs in sediments 10,000–100,000 ng/g dw near smelter/Hospital Beach ▪ Clams: ◦ ∑PAHs in clams (*Mya arenaria*) ranged from 5,000–6,000 ng/g dw ◦ at intertidal beach sites near Kitamaat Village and the Eurocan pulp and paper mill concentrations of ∑PAHs were approximately 1,100 ng/g dw ▪ Salmon: ◦ mean concentrations of ∑HPAHs in salmon stomach averaged 500 ± 370 ng/g ww at Hospital Beach ◦ 120–160 ng/g ww ∑LPAHs in salmon stomachs at Alcan Inner Harbour, Hospital Beach, and Eurocan Beach ◦ BaP equivalents highest in juvenile Chinook salmon bile @ Alcan Inner Harbour (2,800 ng/g bile) for ∑HPAHs and 140,000 ng/g bile for ∑LPAHs ▪ English Sole" ◦ ∑HPAHs in Alcan Inner Harbour 1,700 ng/g ww ◦ ∑LPAH at Hospital Beach 120 ng/g ww ◦ BaP equivalents in English Sole bile 1,200 ng/g bile at Hospital Beach	▪ Clams: ◦ at Kildala Beach in Kildala Arm (reference) ∑PAHs in clams mean concentrations were 83 ng/g dw ▪ Salmon: ◦ mean concentration of ∑HPAHs in salmon stomach ranged from 4.3–11 ng/g ww at Kildala Beach ◦ 19 ng/g ww ∑LPAHs in salmon stomachs at Kildala Beach ◦ BaP equivalents in Chinook salmon bile from hatchery stock for ∑HPAHs (290–330 ng/g mean) and 8.200–11,000 ng/g in bile for ∑LPAHs ▪ English Sole: ◦ ∑HPAHs at Kildala Arm 59 ng/g ww ◦ ∑LPAHs at Kildala Arm 37 ng/g ww ◦ BaP equivalents in English sole bile 600 ng/g bile		Concentrations of heavy metals low in English sole tissue (<DL for nearly every metal). Detectable concentrations of cadmium in one sample and	▪ Concentrations of DDTs and organochlorines very low in stomach contents of juvenile Chinook salmon (1 ng/g ww at reference to 7 ng/g ww Hosp. Beach) ▪ Concentrations of PCBs highest in juvenile Chinook stomachs in Alcan Inner Harbour – 44 ng/g ww ▪ ∑DDT in English sole stomach 0.61 ± 0.35 ng/g ww ▪ ∑PCBs in English sole stomach 1 ng/g ww at reference, 22 ng/g ww at Hospital Beach	N/A - focus on PAHs	▪ Organochlorines and PAHs in fish ▪ Bioaccumulation in salmon and flatfish ▪ Primary PAH contamination in Inner Harbour near Alcan smelter ▪ Low bioavailability of PAHs given attachment to soot particulate ▪ Elevated concentrations of high molecular PAHs in sediment near the Alcan smelter ▪ Wood-derived PAHs common in sediment near the Eurocan pulp and paper mill ▪ No significant DNA damage to salmon in Kitimat Arm ▪ English sole showed DNA damage from mutagenic PAHs, and 10%–20% had PAH-associated liver damage compared to 0%–2% for reference. ▪ Yellowfin sole had 5%–10% of PAH-associated liver damage compared to 0%–2% for reference. ▪ PAH concentrations have been shown to be decreasing, and new methods of reducing smelter particulate have been implemented by Alcan. ▪ Retene, a derivative of wood products often associated with pulp mills found in salmon at all sites, with higher concentrations at beaches near the Eurocan pulp mill (~17% of LPAH at Inner and Outer Eurocan Beaches but only 1%–2% at Alcan Inner Harbour ▪ DNA adducts relatively low in juvenile salmon ▪ Concentrations in flatfish muscle tissue determined to be low as PAHs are metabolized in comparison to shellfish which accumulate PAHs in edible tissue. Shellfish were not included in this study.
Yunker et al. 2011	1995–2000	▪ 16 parent PAHs defined by U.S. EPA, several alkyl PAHs analyzed. ▪ DLs for PAHs and alkyl-PAHs averaged 0.09 ng/g ww and 0.58 ng/g dw	▪ 16 parent PAHs defined by U.S. EPA, several alkyl PAHs analyzed.	DLs for PAHs and alkyl-PAHs averaged 0.09 ng/g ww and 0.58 ng/g dw	N/A - focus on PAHs	N/A - focus on PAHs	N/A - focus on PAHs	▪ Analyzed soft shell clam tissue, reported clam/sediment BSAFs; smelter PAHs may not be bioavailable to benthic organisms, but pulp mill sources of PAHs (aromatized plant terpenes/diterpenes), oil discharges and natural plant sources are bioavailable and have demonstrated toxicity ▪ BSAFs <1 for pitch and coke and <10 for anode combustion ▪ Pulp mill constituents exhibited higher bioaccumulation (>500 for unsaturated and monoaromatic diterpenes and >200 for retene. ▪ Specific plant terpenes that form chemical defence mechanisms in conifers that may be bioavailable to shellfish include retene, totarol, ferruginol, manool, dehydroabietane ▪ Low PAH bioavailability due to binding with organic carbon and/or pitch and coke globules and tight binding of PAHs to oxides and soot particles

Table A-2: Tissue Chemistry Data in the Local and Regional Study Areas

Reference Study	Study Date	PAHs			Metals	Total PCBs	PCDD/F	Other Notes (e.g. depth sampled)
		PAHs in Project marine resources LSA tissue	PAHs in wider Kitimat Arm marine tissues (reference samples)	Guideline Exceedances	Guideline Exceedances	Guideline Exceedances	Guideline Exceedances	
Van Eickhoff et al. 2003	1995–1996	▪ Only analyzed for 10 of 16 U.S. EPA priority PAH pollutants. Dungeness crabs collected from Hospital Beach.	▪ Four dungeness crab samples collected from locations outside the RSA and analyzed for 10 of 16 U.S. EPA PAHs	0.1–0.3 μg/kg	N/A - focus on PAHs	N/A - focus on PAHs	N/A - focus on PAHs	▪ Detectable levels of PAHs in hepatopancreas and muscle tissue ▪ Highest concentrations observed closest to aluminum smelter near effluent discharge of smelter lagoons, low concentrations in Douglas Channel ▪ PAHs discharged by smelter were bioavailable to Dungeness crabs ▪ Concentrations in hepatopancreas strongly correlated to water solubility ▪ ANOVA test used to interpret data
Van Eickhoff 2004 (Ph.D. Thesis)	1994–1996	▪ BaP mean conc in crab hepato at Hospital Beach (near smelter) 0.81 ± 1.3 ng/g ww (used in HHRA) ▪ BaP mean conc in crab hepato at Wathlsto and Kidala Arm reference sites 0.14 ± 0.13 and 0.18 ± 0.47 ng/g ww ▪ BaP mean conc in crab muscle tissue at Hospital Beach 0.74 +/- 1.4 and 0.14 +/- 0.09 at Kitamaat Village (Haisla Nation) ▪ Acenaphthene and phenanthrene significantly higher at Hospital Beach vs. Wathlsto/Kidala Arm (reference) – 19 ng/g ww max vs. <1 ng/g ww ▪ 10 PAH analytes ▪ BaP TEQs @ Hospital Beach (HHRA): mean 1.36, Max 9.91. Reference mean 0.20–0.24, max 0.48–2.78 (Wathlsto and Kidala)	▪ Reference locations significantly lower, see column C ▪ Total PAH concentrations from sites in Kitimat Arm (near smelter and village) ranged from 0.7–307 μg/kg ww based on 10 PAH analytes	DLs for hepato: 0.1–0.3 ng/g and 0.01–0.09 ng/g in muscle using U.S. EPA 8290 method (U.S. EPA 1994)	N/A - focus on PAHs	N/A - focus on PAHs	N/A - focus on PAHs	▪ Excess cancer risk determined in HHRA for crabs consumed from Hospital Beach near the smelter source ▪ 187 crab samples collected near smelter (Hospital Beach) to Kidala Arm (reference site) ▪ Results statistically significant. ANOVA Tukey-Kramer *a* = 0.05 $p < 0.0001$ ▪ Low molecular weight PAHs found in higher concentrations, similar to other studies, particularly acenapthene and phenanthrene (Paine et al. 1996) ▪ Higher PAH water solubility = higher concentration in hepato ▪ Concentrations of PAHs in tissues 2–3 orders of magnitude lower than sediment decreasing with distance from the smelter ▪ Overall conclusion is PAHs are bioavailable to Dungeness crabs in Kitimat Arm and Douglas Channel. ▪ Consumption of crab hepato at Hospital Beach exceeds the ILCR of 1E-6 for every age group based on Haisla consumption rates survey. Maximum risk to male children is 9.0E-6 and 8.5E-6 for senior adult males.
Paine et al. 1996	1994			DL = 5–20 μg/kg (DL found to be high in Eickhoff et al. 2003 as most concentrations below 10 μg/kg)	N/A - focus on PAHs	N/A - focus on PAHs	N/A - focus on PAHs	▪ Eickhoff et al. (2003) concluded that the low bioavailability conclusion was based on higher DLs used in this study (<0.02). ▪ Similar conclusions to NOAA (2009) stating that bioavailability is limited given adsorption of PAHs to particulate matter such as soot ▪ Sediment quality triad approach: looked at toxicity and benthic community composition (collected crabs for tissue analysis and benthic infauna); concluded PAHs not bioavailable. ▪ Abnormality and mortality for echinoderm toxicity tests in sediment were ≤10% abnormality, ≤30% mortality and ≤50% combined

Table A-2: Tissue Chemistry Data in the Local and Regional Study Areas

Reference Study	Study Date	PAHs			Metals	Total PCBs	PCDD/F	Other Notes (e.g. depth sampled)
		PAHs in Project marine resources LSA tissue	PAHs in wider Kitimat Arm marine tissues (reference samples)	Guideline Exceedances	Guideline Exceedances	Guideline Exceedances	Guideline Exceedances	
Simpson 1997 (Ph.D. Thesis)	1997	▪ PAHs detected in clams (*Mya arenaria*) 0.8–5.7 ng/g ww from three beaches: Hospital Beach, Eurocan Beach, and Kitamaat Beach. Kildala Beach was reference. ▪ ∑PAH for 15 U.S. EPA priority PAHs (not including perylene, benzo(e) pyrene or naphthalene): ▪ Kildala Beach (ref) - 83 ng/g dw mean ▪ Kitamaat Beach - 1,110 ng/g dw mean ▪ Eurocan Beach - 1,100 ng/g dw mean ▪ Hospital Beach - 5,657 ng/g dw mean		DL = 5–20 µg/kg	N/A - focus on PAHs	N/A - focus on PAHs	N/A - focus on PAHs	▪ Theoretical partitioning between sediment-tissue (BSAFs) used ▪ Concentration of PAHs in sediments found to be 200–300 times greater at Hospital Beach (near smelter) than other beaches in Kitimat Arm. ▪ Tissue concentrations in *Mya arenaria* are five times greater at Hospital Beach than other beaches in Kitimat Arm

NOTES:
BaP—Benzo(a)pyrene
DL – detection limit
HPAH – high molecular weight polynuclear aromatic hydrocarbon
HHRA – human health risk assessment
LPAH – low molecular weight polynuclear aromatic hydrocarbon
U.S. EPA – United States Environmental Protection Agency

APPENDIX B

Marine Fish and Invertebrate Species List – Kitimat Arm

Table B-1: Marine Fish and Invertebrates in the Regional Study Area (Facility)

Taxa	Common Name	Description
ANNELIDA		
Class Polychaeta	Polychaete worm	Worm
Subclass Oligochaeta	Oligochaete worm	Worm
Family Sabellidae	Feather duster worm	Worm
Sedentaria	Parchment worm	Worm
Apotamus sp.	Ball-stopper worm	Worm
Crucigera sp.	Tube worm	Tube worm
Protula pacifica	White tube worm	Tube worm
ARTHROPODA		
Suborder Gammaridea	Gammarid amphipod	Amphipod
Family Pandalidae	Shrimp/prawn	Shrimp/prawn
Pandalus danae	Coonstripe shrimp	Shrimp
Lebbeus grandimanus	Candy stripe shrimp	Shrimp
Spirontocaris lamellicornis	Dana's blade shrimp	Shrimp
Pandalus hypsinotus	Humpback shrimp	Shrimp
Pandalus eous	Spiny pink shrimp	Shrimp
Pandalus platyceros	Spot shrimp	Shrimp
Pandalopsis dispar	Sidestripe shrimp	Shrimp
Crangonidae	Crangonid shrimp	Shrimp
Order Tanaidacea	Tanaid crustacean	Crustacean
Chionoecetes bairdi	Tanner crab	Crab
Chionecetes tanneri	Grooved tanner crab	Crab
Metacarcinus magister	Dungeness crab	Crab
Paralithodes camtschaticus	Alaska king crab	Crab
Hemigrapsus nudus	Purple shore crab	Crab
Hemigrapsus oregonensis	Green shore crab	Crab
Superfamily Paguroidea	Hermit crab	Crab
Elassochirus tenuimanus	Widehand hermit	Hermit crab
Pagurus armatus	Blackeyed hermit	Hermit crab
Pagurus hirsutiusculus	Hairy hermit	Hermit crab
Placetron wosnessenskii	Scaly lithode	Lithodid crab
Superfamily Majoidea	Decorator crab	Decorator crab
Chorilia longipes	Longhorn decorator	Decorator crab
Hyas lyratus	Lyre crab	Crab
Balanus glandula	Common acorn barnacle	Barnacle

Taxa	Common Name	Description
Gnorimosphaeroma oregonensis	Stubby isopod	Isopod
Idotea wosnesenskii	Rockweed isopod	Isopod
Halobisium occidentale	Intertidal pseudoscorpion	Pseudoscorpion
Munida quadraspina	Squat lobster	Squat lobster
Neomolgus littoralis	Red velvet mite	Mite
BRACHIOPODA		
Terebratalia transversa	Lampshell	Lampshell
Laqueus californianus	Lampshell	Lampshell
BRYOZOA		
Order Cheilostomata	Bryozoan	Bryozoan
Heteropora magna	Staghorn bryozoan	Bryozoan
CHORDATA		
Squalus acanthias	Spiny dogfish	Dogfish shark
Family Rajidae	Skate	Skate
Raja rhina	Longnose skate	Skate
Baja binoculata	Big skate	Skate
Hydrolagus colliei	Spotted ratfish	Chimaera
Oncorhynchus gorbuscha	Pink salmon	Anadromous fish
Oncorhynchus kisutch	Coho salmon	Anadromous fish
Oncorhynchus tshawytscha	Chinook salmon	Anadromous fish
Oncorhynchus keta	Chum salmon	Anadromous fish
Oncorhynchus nerka	Sockeye salmon	Anadromous fish
Oncorhynchus mykiss	Steelhead trout	Anadromous fish
Salmo clarki clarki	Cutthroat trout	Anadromous fish
Salvelinus malma	Dolly Varden	Anadromous fish
Thaleichthys pacificus	Eulachon	Anadromous fish
Clupea pallasii	Pacific herring	Marine fish
Family Osmeridae	Smelt	Marine fish
Hypomesus pretiosus	Surf smelt	Marine fish
Mallotus villosus	Capelin	Marine fish
Ammodytes hexapterus	Sand lance	Marine fish
Gadus macrocephalus	Pacific cod	Marine fish
Theragra chalcogramma	Walleye pollock	Marine fish
Microgadus proximus	Tom cod	Marine fish
Ronquilus jordani	Northern ronquil	Marine fish
Cymatogaster aggregatus	Shiner perch	Marine fish

Taxa	Common Name	Description
Sebastes spp.	Rockfish	Marine fish
Sebastes maliger	Quillback rockfish	Marine fish
Sebastes diploproa	Splitnose rockfish	Marine fish
Sebastes crameri	Darkblotched rockfish	Marine fish
Sebastes reedi	Yellowmouth rockfish	Marine fish
Sebastes wilsoni	Pygmy rockfish	Marine fish
Sebastes caurinus	Copper rockfish	Marine fish
Anoplopoma fimbria	Sablefish	Marine fish
Hexagrammos decagrammus	Kelp greenling	Marine fish
Hexagrammos stelleri	White-spotted greenling	Marine fish
Ophiodon elongates	Lingcod	Marine fish
Family Pleuronectidae	Flatfish	Marine fish
Citharichthys sordidus	Pacific sanddab	Marine fish
Hippoglossus stenolepis	Pacific halibut	Marine fish
Platichthys stellatus	Starry flounder	Marine fish
Isopsetta isolepis	Butter sole	Marine fish
Parophrys vetulus	English sole	Marine fish
Psettichthys melanostictus	Sand sole	Marine fish
Limanda aspera	Yellowfin sole	Marine fish
Microstomus pacificus	Dover sole	Marine fish
Errex zachirus	Rex sole	Marine fish
Family Cottidae	Sculpin	Marine fish
Asemichthys taylori	Spinynose sculpin	Marine fish
Artedius fenestralis	Padded sculpin	Marine fish
Blepsias bilobus	Crested sculpin	Marine fish
Cottus asperrimus	Rough spine sculpin	Marine fish
Cottus asper	Prickly sculpin	Marine fish
Cottus aleuticus	Aleutian sculpin	Marine fish
Dasycottus setiger	Spinyhead sculpin	Marine fish
Enophrys bison	Buffalo sculpin	Marine fish
Icelinus filamentosus	Threadfin sculpin	Marine fish
Icelinus tenuis	Spotfin sculpin	Marine fish
Leptocottus armatus	Pacific staghorn sculpin	Marine fish
Myoxocephalus polyacanthocephalus	Great sculpin	Marine fish
Myoxocephalus scorpioides	Northern sculpin	Marine fish
Nautichthys oculofasciatus	Sailfin sculpin	Marine fish

Taxa	Common Name	Description
Oligocottus maculosus	Tidepool sculpin	Marine fish
Scorpaenichthys marmoratus	Cabezon	Marine fish
Synchirus gilli	Manacled sculpin	Marine fish
Porichthys notatus	Plainfin midshipman	Marine fish
Gasterosteus aculeatus	Threespine stickleback	Marine fish
Aulorhynchus flavidus	Tubesnout	Marine fish
Syngnathus leptorhyncus	Bay pipefish	Marine fish
Anoplarchus purpurescens	High cockscomb	Marine fish
Eumicrotremus orbis	Pacific spiny lumpsucker	Marine fish
Family Zoarcoidae	Eelpout	Marine fish
Lycodes diapterus	Black eelpout	Marine fish
Lycodopsis pacifica	Blackbelly eelpout	Marine fish
Lycodes brevipes	Shortfin eelpout	Marine fish
Family Stichaeidae	Prickleback	Marine fish
Lumpenus sagitta	Snake prickleback	Marine fish
Lumpenella longirostris	Longsnout prickleback	Marine fish
Family Pholidae	Gunnel	Marine fish
Apodichthys flavidus	Penpoint gunnel	Marine fish
Pholis laeta	Crescent gunnel	Marine fish
Pholis ornata	Saddleback gunnel	Marine fish
Lampetra sp.	Lamprey	Marine fish
family Agonidae	Poacher	Marine fish
Family Liparidae	Snailfish	Marine fish
CNIDARIA		
Epizoanthus scotinus	Zoanthid	Zoanthid
Order Actiniaria	Anemone	Anemone
Metridium farcimen	Plumose anemone	Anemone
Metridium senile	Short plumose anemone	Anemone
Cribrinopsis fernaldi	Crimson anemone	Anemone
Stomphia coccinea	Swimming anemone	Anemone
Liponema brevicornis	Pom-pom anemone	Anemone
Pachycerianthus sp.	Tube dwelling anemone	Anemone
Hydrozoa	Hydroid	Hydroid
Ptilosarcus gurneyi	Orange sea pen	Sea pen
Virgularia sp.	White sea pen	Sea pen
Halipteris willemoesi	Sea whip	Sea whip

Taxa	Common Name	Description
Class Anthezoa	Cup coral	Coral
ECHINODERMATA		
Family Strongylocentrotidae	Sea urchin	Sea urchin
Strongylocentrotus franciscanus	Red urchin	Sea urchin
Strongylocentrotus droebachiensis	Green sea urchin	Sea urchin
Class Holothuroidea	Sea cucumber	Sea cucumber
Parastichopus californicus	California cucumber	Sea cucumber
Chiridota albatrossii	White-dotted sea cucumber	Sea cucumber
Class Asteroidea	Sea star	Sea star
Amphiodia occidentalis	Brittle star	Sea star
Gorgoncephalus eucnemis	Basket star	Sea star
Pteraster tesselatus	Cushion star	Sea star
Dermasterias imbricata	Leather star	Sea star
Pycnopodia helianthoides	Sunflower star	Sea star
Evasterias troschelii	Mottled star	Sea star
Orthasterias koehleri	Painted star	Sea star
Stylasterias forreri	Long ray star	Sea star
Henricia leviuscula	Blood star	Sea star
Geyphyreaster swifti	Gunpowder star	Sea star
Orthasterias koehleri	Rainbow star	Sea star
MOLLUSCA		
Cryptochiton stelleri	Chinese slipper	Chiton
Tonicella lineata	Lined chiton	Chiton
Cryptochiton stelleri	Giant pacific chiton	Chiton
Lepidochiton sp.	Chiton	Chiton
Class bivalvia	Bivalve mollusc	Bivalve
Mytilus edulis spp. Complex	Blue mussel	Bivalve
Modiolus modiolus	Northern horse mussel	Bivalve
Macoma balthica	Baltic macoma clam	Bivalve
Class Bivalvia	Clam	Bivalve
Family Cardiidae	Cockle	Bivalve
Clinocardium nuttallii	Nuttall's cockle	Bivalve
Pododesmus machrochisma	Green false-jingle	Bivalve
Chlamys sp.	Swimming scallop	Scallop
Gastropoda	Limpet	Limpet
Cranopsis cucullata	Hooded puncturella	Limpet

Taxa	Common Name	Description
Charonia sp.	Triton	Sea snail
Fusitriton oregonensis	Oregon triton	Sea snail
Littorina sitkana	Sitka periwinkle	Sea snail
Haliotis kamtschatkana	Northern abalone	Sea snail
Nucella lamellosa	Frilled dogwinkle	Whelk
Octopus dofleini	Giant pacific octopus	Octopus
Benthoctopus leioderma	Smoothskin octopus	Octopus
Rossia pacifica	Stubby squid	Squid
Berryteuthis magister	Red squid	Squid
Loligo opalescens	Opalescent squid	Squid
Dendronotus rufus	Red dendronotid	Nudibranch
Nudibranchia	Dorid nudibranch	Nudibranch
Dirona aurantia	Gold dirona	Nudibranch
Cadlina luteomarginata	Yellow margin nudibranch	Nudibranch
NEMERTEA		
Tetrastemma nigrifrons	White-lined ribbon worm	Ribbon worm
PORIFERA		
Class Demospongiae	Encrusting sponges	Sponge
Class Hexactinellida	Glass sponge	Sponge
Family Rossellidae	Boot sponge	Sponge
Aphrocallistes vastus	Cloud sponge	Sponge
Heterochone calyx	Goblet sponge	Sponge
SIPUNCULIDA		
Golfingia sp.	Peanut worm	Worm
UROCHORDATA		
Boltenia villosa	Hairy sea squirt	Sea squirt
Styelia gibbsii	Peanut sea squirt	Sea squirt
Halocynthia igaboja	Spiny sea squirt	Sea squirt
Halocynthia aurantium	Sea peach	Sea squirt
Cnemidocarpa finmarkiensis	Shiny orange squirt	Sea squirt
Pyura haustor	Wrinkled sea squirt	Sea squirt
Corella willmeriana	Transparent squirt	Sea squirt
Ciona savignyi	Sea vase	Sea squirt
Ascidia columbiana	Flattened sea squirt	Sea squirt

SOURCES:

Levings (1976); MacDonald and Shepherd (1983); Jacques Whitford (2005); Clarke and Jamieson (2006b); Hyatt et al. (2007); Schweigert et al. (2007); Jacques Whitford (2010); Powell (2011, 2013); DFO (2013c); Calliou Group (2014); Golder Associates Ltd. (2014; Appendix D); Satterfield et al. (2012, 2014); Stantec Consulting Ltd. (2012); and LNG Canada marine field surveys

APPENDIX C

Data Tables

Table C-1: Intertidal Survey: Relative Density of Marine Fish and Invertebrates in the Facility LSA

Taxon	Units	Transect 1	Transect 2	Transect 3	Transect 4	Transect 5	Transect 6	Transect 7	Transect 8	Transect 9	Transect 10	Transect 11	Transect 12	Transect 13	Transect 14	Transect 15	Transect 16	Transect 17	Transect 18	Total Average
Penpoint gunnel *Apodichthys flavidus*	no.	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0	0
Gunnel *Pholis* sp.	no.	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0	0	0
Sculpin Family Cottidae.	no.	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Common acorn barnacle *Balanus glandula*	%	0.1	0	0	0	0	0.1	0.2	0.4	0.6	0	0	0	0	0	6.0	1.7	4.3	1.7	0.8
Blue mussel *Mytilus* spp. complex	%	0.1	0	0.1	0	0	0	0.1	0	0.4	0	0	0	0	0	0.3	0.7	2.2	3.8	0.4
Unidentified bivalve Class Bivalvia	%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.1	0	0	0
Sitka periwinkle *Littorina sitkana*	no.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0
Crangonid shrimp *Crangon* sp.	no.	0	0	0	0.1	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0	0
Amphipod Suborder Gammaridea	no.	0.1	0	2.8	0.1	0	4.3	15.9	0	2.0	3.5	5.2	12.5	0.1	14.1	14.7	13.3	5.6	5.1	5.5

Taxon	Units	Transect 1	Transect 2	Transect 3	Transect 4	Transect 5	Transect 6	Transect 7	Transect 8	Transect 9	Transect 10	Transect 11	Transect 12	Transect 13	Transect 14	Transect 15	Transect 16	Transect 17	Transect 18	Total Average
Purple shore crab *Hemigrapsus nudus*	no.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0
Green shore crab *Hemigrapsus oregoneneis*	no.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0
Stubby isopod *Gnorimosphaeroma oregonensis*	no.	5.3	0.2	1.1	0.1	0.7	0.9	2.5	0.3	8.4	3.1	0.2	5.2	0.1	0	2.7	8.0	4.5	1.5	2.5
Intertidal pseudoscorpion *Halobisium occidentale*	no.	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0.1	0	0
Rockweed isopod *Idotea wosnesenskii*	no.	0	0	0.6	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0.1	0
Ribbon worm Phylum Nemertea	no.	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0

NOTE:
Relative density is expressed as average percent cover per quadrat for sessile invertebrates, and number of individuals per quadrat for fish and motile invertebrates.

Table C-2: Intertidal Survey: Relative Density of Marine Vegetation in the Facility LSA

Taxon	Transect 1	Transect 2	Transect 3	Transect 4	Transect 5	Transect 6	Transect 7	Transect 8	Transect 9	Transect 10	Transect 11	Transect 12	Transect 13	Transect 14	Transect 15	Transect 16	Transect 17	Transect 18	Total Average
Green rope *Acrosiphonia* sp.	1.1	25.7	5.2	0.6	0	13.1	30.3	13.4	9.5	0	0	7.9	3.8	1.5	0.5	5.3	0.9	0.5	6.6
Sea moss Cladophora sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33.3	5.3	6.7	2.5
Green ribbon *Ulva intestinalis*	1.7	0.2	0.6	3.0	0	3.0	1.4	3.4	9.1	0	7.5	0.7	13.1	1.6	8.7	2.5	0.3	0.9	3.2
Sea lettuce *Ulva* sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.7	2.1	0.2
Rockweed (form A) *Fucus gardneri*	0	0	0	0	0	0	4.4	0	6.0	5.0	0	6.7	0	26.1	35.9	34.0	57.7	55.7	12.9
Rockweed (form B) *Fucus gardneri*	16.9	4.9	13.2	3.7	10.3	32.3	0	22.3	28.6	30.5	56.5	19.6	35.2	0	0	0	0	0	15.2
Sugar wrack kelp *Laminaria saccharina*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0
Brown filamentous algae	7.9	1.7	11.4	2.2	0	7.5	8.0	16.0	6.2	0	0	0	9.6	0	0	0	0	0	3.9
Rusty rock *Hildenbrandia* sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.7	0	0.2
Turkish washcloth *Mastocarpus* sp. (blade)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.0	0.7	0.1
Tar spot seaweed *Mastocarpus* sp. (crust)	3.7	1.8	1.1	0.1	0	4.2	5.9	4.2	7.5	0	0	0.4	0.5	0.4	2.5	10.3	20.7	21.7	4.7
Sea brush *Odonthalia* sp.	0	0	1.9	0	0	0	0.3	0.7	0	0	0	0	0	0	1.1	0.3	15.7	14.0	1.9

Taxon	Transect 1	Transect 2	Transect 3	Transect 4	Transect 5	Transect 6	Transect 7	Transect 8	Transect 9	Transect 10	Transect 11	Transect 12	Transect 13	Transect 14	Transect 15	Transect 16	Transect 17	Transect 18	Total Average
Red ribbon *Palmaria* sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.7	1.2	2.8	0.3
Colonial diatoms Family Bacillariaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	7.9	7.7	4.9	4.7	4.0	1.6
Silverweed *Potentilla anserina* ssp. *pacifica*	0	0	0	0	0	0.2	0	0	0	3.3	0	0	3.1	0	0	0	0	0	0.4
Lyngbye's sedge *Carex lyngbyei*	0	0	0	10.0	61.3	0	0	0	0	3.5	48.3	20.8	18.5	0	0	0	0	0	9.0
Tufted hair-grass *Deschampsia caespitose*	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0
Seaside arrowgrass *Triglochin maritimum*	0	0	0	0	1.3	0	0	0	0	8.0	0	0	0.4	0	0	0	0	0	0.7
Horned pondweed *Zannichellia palustris*	0	0	0	0	0	0	0	0	0	0	0	0	3.1	0	0	0	0	0	0

NOTE:

Relative density is expressed in average percent cover per quadrat.

Table C-3: Salt Marsh Survey: Relative Density of Marine and Marsh Vegetation in the Salt Marsh

Taxon	Units	Transect 1	Transect 2	Transect 3	Transect 4
Rockweed (Form B) *Fucus gardneri*	%	57.9	63.1	50.6	57.2
Brown filamentous algae	%	0.8	0	0	0.3
Silverweed *Potentilla anserina* ssp. *pacifica*	%	1.7	0	6.4	2.7
Lyngbye's sedge *Carex lyngbei*	%	21.8	30.2	21.4	24.5
Tufted hair-grass *Deschampsia caespitose*	%	0	0	1.3	0.4
Water mudwort *Limosella aquatica*	%	2.1	0	1.2	1.1
Seaside arrowgrass *Triglochin maritimum*	%	0	0	5.2	1.7
Horned pondweed *Zannichellia palustris*	%	0	0.3	6.8	2.4
Amphipod Suborder Gammaridea	No.	0	22.8	15.7	12.8
Stubby isopod *Gnorimosphaeroma oregonensis*	No.	0	15.4	5.8	7.1

NOTE:
Relative density is expressed in average percent cover per quadrat.

Table C-4: Subtidal Survey: Relative Density of Marine Fish in the Facility LSA

Taxon	Transect 1	Transect 2	Transect 3	Transect 4	Transect 5	Transect 6	Transect 7	Transect 8	Transect 9	Transect 10	Transect 11	Transect 12	Total Average
Poacher Family Agonidae	0.0	0.0	0.0	1.3	0.0	4.5	12.8	9.9	12.3	0.0	0.0	16.5	4.8
Ronquil Family Bathymasteridae	0.0	0.0	3.4	0.0	11.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3
Spotted ratfish *Hydrolagus colliei*	0.0	0.0	1.4	4.0	1.0	0.0	0.0	6.6	0.0	0.0	0.0	0.0	1.1
Spinyhead sculpin *Dasycottus setiger*	0.8	0.0	0.7	1.3	0.0	0.0	0.0	1.1	1.1	2.2	0.0	0.0	0.6
Pacific staghorn sculpin *Leptocottus armatus*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	0.0	0.0	0.0	0.2
Sculpin Family Cottidae	0.0	0.6	0.0	2.7	1.0	3.0	6.4	2.2	24.6	0.0	0.0	2.4	3.6
Shiner perch *Cymatogaster aggregata*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.4	0.2
Pile perch *Rhacochilus vacca*	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Perch Family Embiotocidae	40.4	6.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	37.7	7.0
Walleye pollock *Theragra chalcogramma*	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Cod Family Gadidae	0.0	1.2	23.6	4.0	0.0	0.0	0.0	37.4	17.9	0.0	0.0	42.4	10.5

Taxon	Transect 1	Transect 2	Transect 3	Transect 4	Transect 5	Transect 6	Transect 7	Transect 8	Transect 9	Transect 10	Transect 11	Transect 12	Total Average
Gobie Family Gobiidae	0.0	0.0	2.0	2.7	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
Whitespotted greenling *Hexagrammos stelleri*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	4.7	0.5
Gunnel Family Pholidae	0.0	0.0	0.0	6.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6
Yellowfin sole *Limanda aspera*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.5	0.0	0.0	0.0	0.4
Dover sole *Microstomus pacificus*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0	0.1
Righteye flounder Family Pleuronectidae	8.9	3.1	17.6	45.6	23.5	15.1	44.7	37.4	72.6	0.0	2.8	42.4	26.1
Skate Family Rajidae	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	1.1	0.0	1.4	2.4	0.5
Longsnout prickleback *Lumpenella longirostris*	0.0	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.4	0.3
Pacific snake prickleback *Lumpenus sagitta*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	0.0	0.0	7.1	0.8
Whitebarred prickleback *Poroclinus rothrocki*	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.4	0.3
Prickleback Family Stichaeidae	0.0	0.0	1.4	71.1	31.3	28.6	19.2	53.9	98.3	6.6	5.7	40.1	29.7
Shortfin eelpout *Lycodes brevipes*	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1

Taxon	Transect 1	Transect 2	Transect 3	Transect 4	Transect 5	Transect 6	Transect 7	Transect 8	Transect 9	Transect 10	Transect 11	Transect 12	Total Average
Black eelpout *Lycodes diapterus*	0.0	0.0	0.0	0.0	1.0	0.0	0.0	1.1	2.2	0.0	0.0	14.1	1.5
Blackbelly eelpout *Lycodes pacificus*	1.6	1.2	4.1	5.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	23.6	3.0
Eelpout *Lycodes* sp.	19.4	13.4	53.4	91.2	31.3	4.5	0.0	83.6	44.7	0.0	0.0	75.4	34.7
Unid fish	0.0	0.0	0.0	2.7	2.0	7.5	0.0	39.6	15.6	0.0	1.4	4.7	6.1

NOTE:
Relative density is expressed as number of individuals per kilometre transect.

Table C-5: Subtidal Survey: Relative Abundance of Marine Invertebrates in the Facility LSA

Taxon	Transect 1	Transect 2	Transect 3	Transect 4	Transect 5	Transect 6	Transect 7	Transect 8	Transect 9	Transect 10	Transect 11	Transect 12	Total Average
Common acorn barnacle *Balanus glandula*	0	0	0	0	0	0	0	0	0	0	0	47.2	3.9
Dungeness crab *Metacarcinus magister*	11.3	15.9	4.7	6.7	21.5	10.6	0	8.8	31.3	35.0	7.1	16.5	14.1
Cancer sp. Crab	0	0.6	0	0	0	0	0	0	0	0	0	0	0.1
Chionoecetes sp Tanner crab	0	0	0	0	0	0	0	1.1	0	0	0	2.4	0.3
Chionoecetes tanneri Grooved tanner crab	0	0	0	0	0	0	0	1.1	0	0	0	0	0.1
Decorator crab Superfamily Majoidea	0	0	0	0	0	0	0	0	0	2.2	0	0	0.2
Crab Infraorder Brachyura	0	0	0.7	0	0	0	0	0	0	0	0	0	0.1
Hermit crab Superfamily Paguroidea	2.4	1.2	2.7	2.7	3.9	6.0	0	2.2	17.9	6.6	0	0	3.8
Squat lobster *Munida quadraspina*	0	0	0	0	0	0	0	4.4	0	0	0	0	0.4
Coonstripe shrimp *Pandalus danae*	9.7	0.6	2.7	0	0	0	0	0	0	0	0	0	1.1
Humpback shrimp *Pandalus hypsinotus*	0	0.6	0	1.3	6.8	0	0	49.5	32.4	0	0	92.0	15.2
Shrimp *Pandalus* spp.	0	0	15.5	32.2	20.5	0	0	27.5	2.2	0	2.8	42.4	11.9

Taxon	Transect 1	Transect 2	Transect 3	Transect 4	Transect 5	Transect 6	Transect 7	Transect 8	Transect 9	Transect 10	Transect 11	Transect 12	Total Average
Crimson anemone *Cribrinopsis fernaldi*	0	0.6	0.7	1.3	0	0	0	0	0	0	0	0	0.2
Short plumose anemone *Metridium senile*	0	1.8	0	0	0	0	0	0	0	0	0	0	0.2
Plumose anemone *Metridium* sp.	0	0.6	0	0	0	0	0	0	0	0	0	0	0.1
Anemone Order Actiniaria	0	0	0	0	0	0	0	1.1	0	0	0	0	0.1
Orange sea pen *Ptilosarcus gurneyi*	0.8	27.5	97.3	242.8	9.8	776.4	0	0	19.0	0	11.3	0	98.7
White-dotted sea cucumber *Chiridota albatrossii*	0	0	0	217.3	0	0	0	0	3041.2	0	0	198.0	288.0
Mottled star *Evasterias troschelli*	7.3	0.6	0	1.3	3.9	0	0	0	0	0	0	0	1.1
Rainbow star *Orthasterias koehleri*	0	0	0	0	0	0	0	0	0	2.2	0	0	0.2
Sea star Class Asteroidea	0.8	1.8	0	0	1.0	0	6.4	0	0	4.4	2.8	0	1.4
Green sea urchin *Strongylocentrotus droebachiensis*	0	47.0	0	0	0	0	0	0	0	0	0	0	3.9
Triton *Charonia* sp.	0	0	0	0	0	4.5	0	0	1.1	0	0	0	0.5

Taxon	Transect 1	Transect 2	Transect 3	Transect 4	Transect 5	Transect 6	Transect 7	Transect 8	Transect 9	Transect 10	Transect 11	Transect 12	Total Average
Stubby squid *Rossia pacifica*	0	0	0.7	0	0	1.5	0	0	0	0	1.4	0	0.3
Unid bivalve	24.2	0	0	0	0	0	0	0	0	0	0	0	2.0

NOTE:
Relative density is expressed as number of individuals per kilometre transect.

Table C-6: Subtidal Survey: General Water Chemistry Measurements

Station	Depth (m)	Temperature (°C)	Salinity (PSU)	Dissolved Oxygen (mg/L)	Turbidity (NTU)	pH	Conductivity (mS/cm)
WQ1	1	10.17	24.08	10.83	0.3	8.16	38.11
WQ1	2	10.00	25.26	10.90	0.3	8.16	39.69
WQ1	3	10.00	25.79	10.91	0.2	8.17	40.52
WQ1	4	9.84	26.25	10.89	0.3	8.16	41.16
WQ1	5	9.58	27.41	10.76	0.4	8.12	42.81
WQ1	6	9.27	28.40	10.38	0.3	8.08	44.16
WQ1	7	9.12	28.77	10.14	0.3	8.03	44.77
WQ1	8	9.04	28.94	9.92	0.3	8.00	45.05
WQ1	9	8.80	29.31	9.64	0.2	7.97	45.59
WQ1	10	8.68	29.43	9.32	0.3	7.94	45.78
WQ2	1	10.26	25.81	10.82	0.1	8.18	37.30
WQ2	2	9.94	25.19	10.72	0.2	8.17	39.86
WQ2	3	9.66	25.57	10.60	0.3	8.16	40.17
WQ2	4	9.77	26.28	10.48	0.1	8.13	41.25
WQ2	5	9.57	27.43	10.45	0.2	8.10	42.89
WQ2	6	9.28	28.26	10.25	0.2	8.05	44.09
WQ2	7	9.04	28.79	10.07	0.2	8.03	44.75
WQ2	8	8.94	29.05	9.91	0.4	8.01	45.22
WQ2	9	8.90	29.05	9.47	0.3	7.98	45.26
WQ2	10	8.76	29.30	9.24	0.3	7.96	45.55
WQ2	11	8.65	29.46	8.97	0.3	7.93	45.81
WQ2	12	8.52	29.64	8.82	0.3	7.91	46.09
WQ2	13	8.40	29.78	8.63	0.1	7.89	46.27
WQ2	14	8.26	29.93	8.42	0.1	7.87	46.51
WQ2	15	8.16	30.02	8.03	0.6	7.83	46.69
WQ2	16	7.92	30.28	7.83	0.8	7.81	47.06
WQ2	17	7.77	30.41	7.46	0.5	7.78	47.28
WQ2	18	7.73	30.46	7.27	0.2	7.76	47.33
WQ2	19	7.69	30.50	7.17	0.4	7.74	47.40
WQ2	20	7.61	30.61	7.08	0.2	7.73	47.52
WQ3	1	10.22	23.76	10.60	0.2	8.21	37.10
WQ3	2	9.69	24.80	10.21	0.1	8.16	39.12
WQ3	3	9.68	25.49	10.16	0.1	8.14	40.00
WQ3	4	9.73	26.43	10.28	0.3	8.12	41.49
WQ3	5	9.62	27.16	10.33	0.4	8.10	42.47

Station	Depth (m)	Temperature (°C)	Salinity (PSU)	Dissolved Oxygen (mg/L)	Turbidity (NTU)	pH	Conductivity (mS/cm)
WQ3	6	9.18	28.49	10.06	0.4	8.06	44.26
WQ3	7	9.08	28.68	9.67	0.4	8.00	44.70
WQ3	8	8.96	28.95	9.46	0.3	7.98	45.09
WQ3	9	8.95	28.97	9.46	0.3	7.98	45.13
WQ3	10	8.90	29.13	9.48	0.2	7.98	45.26
WQ3	11	8.79	29.24	9.32	0.1	7.97	45.53
WQ3	12	8.65	29.49	9.16	0.1	7.95	45.86
WQ3	13	8.49	29.67	8.84	0.3	7.92	46.14
WQ3	14	8.16	29.98	8.11	0.4	7.86	46.63
WQ3	15	7.97	30.20	7.68	0.5	7.81	46.94
WQ3	16	7.90	30.27	7.45	0.3	7.79	47.06
WQ3	17	7.84	30.34	7.27	0.3	7.77	47.16
WQ3	18	7.72	30.46	7.14	0.4	7.76	47.36
WQ3	19	7.56	30.65	6.82	0.4	7.73	47.64
WQ3	20	7.39	30.84	6.62	0.4	7.70	47.93
WQ4	1	10.25	23.30	10.42	0.3	8.18	36.42
WQ4	2	9.74	24.29	10.18	0.2	8.16	38.20
WQ4	3	9.64	25.10	10.08	0.4	8.15	39.79
WQ4	4	9.46	25.84	9.83	0.4	8.12	40.65
WQ4	5	9.44	26.26	9.83	0.3	8.10	41.22
WQ4	6	9.57	26.57	9.99	0.4	8.11	41.58
WQ4	7	9.17	28.47	9.88	0.2	8.08	44.38
WQ4	8	9.02	28.82	9.74	0.2	8.03	44.87
WQ4	9	8.96	28.93	9.55	0.3	8.00	45.07
WQ4	10	8.85	29.14	9.28	0.2	7.98	45.37
WQ4	11	8.85	29.13	9.19	0.2	7.97	45.36
WQ4	12	8.84	29.15	9.12	0.2	7.97	45.38
WQ4	13	8.74	29.29	8.97	0.3	7.95	45.63
WQ4	14	8.41	29.72	8.62	0.3	7.91	46.22
WQ4	15	8.36	29.79	8.34	0.2	7.89	46.33
WQ4	16	8.18	29.99	8.07	0.1	7.86	46.64
WQ4	17	7.99	30.20	7.61	0.2	7.82	46.92
WQ4	18	7.79	30.39	7.24	0.2	7.78	47.23
WQ4	19	7.65	30.53	6.69	0.2	7.75	47.45
WQ4	20	7.57	30.62	6.79	0.2	7.73	47.59
WQ5	1	10.10	23.76	10.40	0.3	8.15	37.28

Station	Depth (m)	Temperature (°C)	Salinity (PSU)	Dissolved Oxygen (mg/L)	Turbidity (NTU)	pH	Conductivity (mS/cm)
WQ5	2	9.86	24.27	10.30	0.1	8.16	38.38
WQ5	3	9.60	24.99	10.14	0.2	8.14	39.36
WQ5	4	9.66	25.53	10.00	0.2	8.13	40.14
WQ5	5	9.52	25.69	9.94	0.2	8.12	40.41
WQ5	6	9.60	25.78	9.95	0.2	8.12	40.54
WQ5	7	9.64	26.92	10.11	0.2	8.10	42.12
WQ5	8	9.25	28.33	10.12	0.2	8.08	43.97
WQ5	9	9.14	28.56	9.79	0.4	8.04	44.52
WQ5	10	9.01	28.89	9.53	0.3	8.01	44.91
WQ5	11	8.95	28.96	9.43	0.2	7.99	45.10
WQ5	12	8.86	29.12	9.25	0.4	7.98	45.32
WQ5	13	8.70	29.32	8.98	0.3	7.96	45.62
WQ5	14	8.47	29.66	8.51	0.7	7.90	46.12
WQ5	15	8.27	29.76	7.92	0.3	7.88	46.45
WQ5	16	8.17	29.99	7.72	0.3	7.89	46.54
WQ5	17	7.98	30.08	7.32	0.4	7.81	47.02
WQ5	18	7.85	30.32	7.27	0.2	7.78	47.11
WQ5	19	7.69	30.96	6.97	0.1	7.75	47.38
WQ5	20	7.56	30.64	6.84	0.2	7.73	47.59

NOTES:

PSU – practical salinity unit

NTU – nephelometric turbidity unit

mS/cm – millisiemens per centimetre

Table C-7: Kitimat Arm/Douglas Channel Marine Mammal Estimated Abundance from Density Surface Modelling

Estimate	Winter	Spring	Early summer	Mid summer	Late summer	Fall
Humpback whale						
$\hat{N}$	–	–	–	–	–	4.64
95% CI ($\hat{N}$)	–	–	–	–	–	3.68–5.84
%CV	–	–	–	–	–	11.80
Dall's porpoise						
$\hat{N}$	94.20	25.57	–	46.30	–	60.86
95% CI ($\hat{N}$)	82.10–108.07	20.72–31.56	–	38.63–55.50	–	51.97–71.27
%CV	7.02	10.76	–	9.26	–	8.07
Harbour porpoise						
$\hat{N}$	–	–	5.99	–	–	–
95% CI ($\hat{N}$)	–	–	4.99–7.18	–	–	–
%CV	–	–	9.26	–	–	–
Pacific white-sided dolphin						
$\hat{N}$	238.45	–	–	–	–	–
95% CI ($\hat{N}$)	210.00–270.76	–	–	–	–	–
%CV	6.49	–	–	–	–	–
Harbour seal – hauled out						
$\hat{N}$	5.44	4.22	31.86	84.46	51.37	21.64
95% CI ($\hat{N}$)	4.11–7.19	3.22–5.54	25.44–39.90	68.37–104.34	41.12–64.18	17.12–27.34
%CV	14.34	13.90	11.52	10.82	11.40	11.98
Harbour seal – in water						
$\hat{N}$	40.54	22.12	34.44	72.22	–	27.44
95% CI ($\hat{N}$)	34.42–47.74	18.79–26.04	29.05–40.82	61.54–84.76	–	22.95–32.80
%CV	8.36	8.34	8.70	8.18	–	9.13
Steller sea lion – hauled out						
$\hat{N}$	8.85	40.19	–	–	–	–
95% CI ($\hat{N}$)	6.74–11.64	32.57–49.59	–	–	–	–
%CV	14.0	10.75	–	–	–	–
Steller sea lion – in water						
$\hat{N}$	5.44	9.08	–	–	–	–
95% CI ($\hat{N}$)	4.19–5.98	8.18–10.75	–	–	–	–
%CV	9.11	7.80	–	–	–	–

NOTES:
– not calculated because less than three sightings

Table C-8: Squally Channel Marine Mammal Estimated Abundance from Density Surface Modelling

Estimate	Winter	Spring	Early summer	Mid summer	Late summer	Fall
Humpback whale						
$\hat{N}$	–	–	11.4	31.15	83.14	33.28
95% CI ($\hat{N}$)	–	–	9.44–13.89	27.46–35.33	75.32–91.78	29.47–37.60
%CV	–	–	9.88	6.43	5.05	6.22
Fin whale						
$\hat{N}$	–	–	–	5.48	3.10	–
95% CI ($\hat{N}$)	–	–	–	4.73–6.36	2.58–3.72	–
%CV	–	–	–	7.58	9.37	–
Dall's porpoise						
$\hat{N}$	–	–	–	22.19	8.12	17.54
95% CI ($\hat{N}$)	–	–	–	17.96–27.41	6.33–10.42	14.45–21.28
%CV	–	–	–	10.81	12.77	9.91
Harbour porpoise						
$\hat{N}$	–	–	3.78	1.95	–	–
95% CI ($\hat{N}$)	–	–	3.12–4.57	1.58–2.40	–	–
%CV	–	–	9.72	10.60	–	–
Pacific white-sided dolphin						
$\hat{N}$	288.15	–	–	–	–	–
95% CI ($\hat{N}$)	259.13–320.43	–	–	–	–	–
%CV	5.42	–	–	–	–	–
Harbour seal – hauled out						
$\hat{N}$	5.46	3.72	41.35	98.58	49.76	14.50
95% CI ($\hat{N}$)	4.13–7.22	2.83–4.89	33.66–50.80	82.10–118.35	40.60–60.99	11.81–17.80
%CV	14.32	14.01	10.53	9.35	10.41	10.49
Harbour seal – in water						
$\hat{N}$	9.84	5.45	–	9.11	2.65	6.35
95% CI ($\hat{N}$)	8.29–11.68	4.55–6.54	–	7.32–11.34	2.00–3.50	5.10–7.92
%CV	8.77	9.32	–	11.19	14.30	11.28
Steller sea lion – hauled out						
$\hat{N}$	–	26.82	13.41	–	–	29.89
95% CI ($\hat{N}$)	–	21.00–34.24	9.63–18.67	–	–	23.90–37.38
%CV	–	12.51	16.99	–	–	11.44
Steller sea lion – in water						
$\hat{N}$	–	5.24	1.70	–	–	–
95% CI ($\hat{N}$)	–	4.41–6.16	1.32–2.17	–	–	–
%CV	–	8.03	10.35	–	–	–

NOTE:
– not calculated because less than three sightings

Table C-9: Whale Channel Marine Mammal Estimated Abundance from Density Surface Modelling

Estimate	Winter	Spring	Early summer	Mid summer	Late summer	Fall
Humpback whale						
$\hat{N}$	–	–	–	9.46	27.71	10.25
95% CI ($\hat{N}$)	–	–	–	8.03–11.13	24.13–31.81	8.79–11.95
%CV	–	–	–	8.32	7.06	7.84
Dall's porpoise						
$\hat{N}$	12.77	8.25	7.72	26.03	9.95	21.80
95% CI ($\hat{N}$)	10.48–15.56	6.27–10.85	5.84–10.21	21.00–32.27	7.74–12.80	18.04–26.40
%CV	10.11	14.07	14.34	10.99	12.88	9.77
Harbour porpoise						
$\hat{N}$	–	2.01	15.61	7.61	–	–
95% CI ($\hat{N}$)	–	1.57–2.58	13.52–18.02	6.48–8.94	–	–
%CV	–	12.75	7.34	8.20	–	–
Pacific white-sided dolphin						
$\hat{N}$	490.77	–	–	–	–	–
95% CI ($\hat{N}$)	441.31–545.79	–	–	–	–	–
%CV	5.42	–	–	–	–	–
Harbour seal – hauled out						
$\hat{N}$	2.01	–	–	–	–	–
95% CI ($\hat{N}$)	1.44–2.80	–	–	–	–	–
%CV	17.19	–	–	–	–	–
Steller sea lion – hauled out						
$\hat{N}$	49.84	221.83	174.20	101.79	251.78	244.24
95% CI ($\hat{N}$)	40.12–61.43	181.15–270.77	152.71–202.53	86.95–119.34	220.93–285.50	214.41–279.88
%CV	11.37	10.67	14.30	8.60	6.91	7.16
Steller sea lion – in water						
$\hat{N}$	3.78	10.89	2.98	–	–	6.39
95% CI ($\hat{N}$)	2.88–4.08	9.52–12.43	2.43–3.62	–	–	5.55–7.50
%CV	9.05	7.84	10.14	–	–	8.33

NOTE:
– not calculated because less than three sightings

Table C-10: Caamaño Sound/Estevan Sound Marine Mammal Estimated Abundance from Density Surface Modelling

Estimate	Winter	Spring	Early summer	Mid summer	Late summer	Fall
Humpback whale						
$\hat{N}$	–	–	7.98	28.31	22.18	27.22
95% CI ($\hat{N}$)	–	–	6.30–10.13	24.28–32.99	18.78–26.21	23.22–31.92
%CV	–	–	12.19	7.83	8.52	8.13
Fin whale						
$\hat{N}$	–	–	–	9.74	9.50	–
95% CI ($\hat{N}$)	–	–	–	8.49–11.17	8.14–11.07	–
%CV	–	–	–	6.98	7.85	–
Dall's porpoise						
$\hat{N}$	–	–	16.33	34.84	15.42	27.05
95% CI ($\hat{N}$)	–	–	13.07–20.40	28.91–42.00	12.20–19.50	22.34–32.75
%CV	–	–	11.39	9.55	11.99	9.78
Harbour porpoise						
$\hat{N}$	–	–	15.59	7.90	8.13	2.54
95% CI ($\hat{N}$)	–	–	13.60–17.87	6.76–9.24	6.84–9.66	2.02–3.18
%CV	–	–	6.97	7.98	8.82	11.60
Harbour seal – hauled out						
$\hat{N}$	11.54	17.62	99.69	109.43	111.40	62.20
95% CI ($\hat{N}$)	8.45–15.77	14.66–21.18	82.10–121.06	93.90–127.54	94.48–131.35	52.30–73.95
%CV	16.03	9.41	9.93	7.82	8.42	8.87
Harbour seal – in water						
$\hat{N}$	6.42	3.92	6.64	–	–	–
95% CI ($\hat{N}$)	5.24–7.87	3.32–4.62	5.50–8.02	–	–	–
%CV	10.41	8.48	9.63	–	–	–
Steller sea lion – in water						
$\hat{N}$	–	6.30	6.70	3.22	2.22	3.08
95% CI ($\hat{N}$)	–	5.44–7.38	5.55–8.01	2.84–4.29	1.75–2.82	2.47–3.85
%CV	–	8.30	8.98	12.70	14.14	10.36

NOTE:
– not calculated because less than three sightings

Table C-11: Principe Channel Strata Marine Mammal Estimated Abundance from Density Surface Modelling

Estimate	Winter	Spring	Early summer	Mid summer	Late summer	Fall
Dall's porpoise						
$\hat{N}$	–	–	13.92	24.50	13.35	24.83
95% CI ($\hat{N}$)	–	–	10.99–17.63	19.83–30.26	10.52–16.94	20.19–30.54
%CV	–	–	12.11	10.81	12.21	10.58
Harbour seal – hauled out						
$\hat{N}$	–	10.04	60.59	106.90	117.68	51.93
95% CI ($\hat{N}$)	–	8.20–12.29	49.77–73.75	90.80–125.86	99.79–138.78	43.50–61.99
%CV	–	10.37	10.06	8.34	8.43	9.06
Harbour seal – in water						
$\hat{N}$	–	3.14	–	8.49	–	–
95% CI ($\hat{N}$)	–	2.60–3.79	–	6.92–10.41	–	–
%CV	–	9.68	–	10.44	–	–
Steller sea lion – in water						
$\hat{N}$	–	3.11	–	–	–	1.68
95% CI ($\hat{N}$)	–	2.35–3.70	–	–	–	1.30–2.12
%CV	–	11.59	–	–	–	12.21

NOTE:
– not calculated because less than three sightings

Table C-12: Triple Island Strata Marine Mammal Estimated Abundance from Density Surface Modelling

Estimate	Winter	Spring	Early summer	Mid summer	Late summer	Fall
Humpback whale						
$\hat{N}$	–	93.39	51.29	36.00	110.19	35.96
95% CI ($\hat{N}$)	–	75.53–115.48	39.67–66.31	26.99–48.00	86.41–140.51	26.60–48.63
%CV	–	10.86	13.16	14.77	12.45	15.48
Dall's porpoise						
$\hat{N}$	–	–	32.08	102.19	38.38	58.51
95% CI ($\hat{N}$)	–	–	25.01–41.16	84.82–123.12	29.45–50.02	47.66–71.81
%CV	–	–	12.76	9.53	13.57	10.48
Harbour porpoise						
$\hat{N}$	–	–	11.79	–	–	–
95% CI ($\hat{N}$)	–	–	9.90–14.04	–	–	–
%CV	–	–	8.93	–	–	–
Pacific white-sided dolphin						
$\hat{N}$	–	–	6.99	–	–	–
95% CI ($\hat{N}$)	–	–	5.34–9.14	–	–	–
%CV	–	–	13.77	–	–	–
Harbour seal – hauled out						
$\hat{N}$	–	6.66	31.47	32.26	39.89	28.52
95% CI ($\hat{N}$)	–	5.19–8.54	25.91–39.14	26.05–39.95	31.35–50.76	22.69–35.86
%CV	–	12.75	11.15	10.94	12.34	11.71
Harbour seal – in water						
$\hat{N}$	–	–	3.78	–	–	–
95% CI ($\hat{N}$)	–	–	2.97–4.81	–	–	–
%CV	–	–	12.29	–	–	–
Steller sea lion – hauled out						
$\hat{N}$	–	311.18	344.03	283.49	671.18	464.17
95% CI ($\hat{N}$)	–	258.57–374.49	289.14–410.68	236.56–339.06	568.32–793.30	399.78–540.59
%CV	–	9.47	9.65	9.14	8.39	7.68
Steller sea lion – in water						
$\hat{N}$	–	4.33	7.06	–	–	–
95% CI ($\hat{N}$)	–	3.47–5.53	5.61–8.94	–	–	–
%CV	–	10.94	10.68	–	–	–

NOTE:
– not calculated because less than three sightings

APPENDIX D

ROV Video Survey: Overview of Marine Benthic Community in Potential Disposal at Sea Sites

click here to view

APPENDIX E

ROV Video Survey: Potential Glass Sponge Occurrences within Disposal at Sea Candidate Sites

click here to view

APPENDIX F

JASCO Applied Sciences: Field Measurements Report

LNG Canada Underwater Noise Studies

Field Measurements Report

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Contents

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Tables

List of Abbreviations

This list contains abbreviations used in this report. For full explanations of these and additional terms, see the Glossary.

AMAR	Autonomous Multichannel Acoustic Recorder
FFT	Fast Fourier Transform
LNG	Liquefied Natural Gas
M/V	Motor Vessel
PSD	Power Spectral Density
PTS	Permanent Threshold Shift
SEL	Sound Exposure Level
SPL	Sound Pressure Level
TTS	Temporary Threshold Shift
UTC	Universal Coordinated Time

1. Introduction

LNG Canada proposes to construct a marine terminal near Kitimat, British Columbia, for liquefied natural gas (LNG) export. JASCO Applied Sciences (JASCO), under subcontract to Stantec, has made underwater acoustic measurements of sound levels near the proposed terminal site and at three locations along the proposed vessel route. These measurements provide relevant information to support the Environmental Impact Assessment (EIA) in addressing key environmental concerns associated with potential effects of noise exposure due to increased vessel traffic on marine mammals and fish.

The objectives of this acoustics measurement study were to:

- Measure baseline ambient noise levels and their variability.
- Quantify existing vessel traffic through acoustic detections.
- Describe the spatio-temporal acoustic presence of killer whales (*Orcinus orca*), humpback whales (*Megaptera novaeangliae*), and fin whales (*Balaenoptera physalus*) along the marine access route.

Several studies have been conducted to measure ambient noise in Douglas Channel and its outer sounds. In September 2005, Austin et al. (2010) measured ambient noise in the 10 Hz to 20 kHz frequency band over 24 hours at four locations—Principe Channel, Caamaño Sound, Wright Sound, and Emsley Creek Estuary—for the Enbridge Northern Gateway project. From 2008 to 2010, Williams et al. (2013) conducted ambient noise measurements at 12 sites along the BC coast, of which two of the monitoring sites were located on LNG Canada's marine access route: one in Kitimat and the other near Kitkiata Inlet. Recordings at these two locations were collected from 25 Aug to 26 Sep, 2010 in the frequency band 10–11,000 Hz.

This report provides ambient noise measurements over a longer period (four months), in a wider frequency band (10–60,000 Hz), and at four locations along the marine access route. Longer monitoring times allowed improved ability to characterize variability in ambient noise conditions. Measurements were performed during the summer (April to September), which is the busiest time of the year for marine traffic. The higher sampling frequency used here captured sound frequencies up to 60 kHz, which covers most of the auditory frequency range of killer whales.

Four Autonomous Multichannel Acoustic Recorders (AMARs) were deployed from 27 Apr to 2 Sep 2013 at the following locations:

- Site S1 near Kitimat: This site was selected to characterize the acoustic baseline levels that construction sounds and berthing sounds would be contributing too. Recordings included sounds from commercial and recreational vessels, and vocalizations from marine mammals.
- Site S2 in Douglas Channel: This monitoring site was selected to characterize the soundscape of an acoustically enclosed environment and to detect vocalizations of marine mammals moving in and out of the channel.
- Site S3 in Wright Sound: Several marine mammal species commonly use this busy vessel route. This large sound is similar to Squally Channel and Whale Channel in that it is enclosed by islands, and therefore does not open directly to Hecate Strait.

- Site S4 in Browning Entrance: This location is the transition from the enclosed Principe Channel to open ocean and is influenced by acoustic energy arriving from Hecate Strait.

The acoustic data were downloaded from each AMAR and processed with a specialized high-speed computing system. Standard signal processing algorithms were applied to the acoustic waveform data to determine sound pressure levels (SPLs) and power spectral density (PSD) levels at 1-minute intervals. The SPL and PSD data were analyzed to determine ambient noise statistics over several frequency bands and time scales. Manual and automated analyses were used to detect and classify vocalizations from killer whales, humpback whales, and fin whales.

2. Methods

Underwater sound was recorded at four stations from 27–29 Apr through 1–3 Sep 2013 (depending on deployment and retrieval dates). The data were analyzed with JASCO's software suite to detect sounds from killer, fin, and humpback whales and to quantify the ambient noise levels and vessel presence at each site. A portion of the data was also reviewed manually to verify the accuracy of the automated marine mammal call and vessel detectors.

2.1. Acoustic Data Acquisition

Underwater acoustic data were recorded with four JASCO AMARs (Figure 1) along the marine access route from the LNG terminal in Kitmat to Browning Entrance (Figure 2 and Table 1). These AMARs were deployed 15 m above the sea floor—two in shallow water (< 120 m) at Sites S1 and S4 and two in deeper water (> 300 m) at Sites S2 and S3.

Figure 1. Autonomous Multichannel Acoustic Recorder (AMAR; JASCO Applied Sciences).

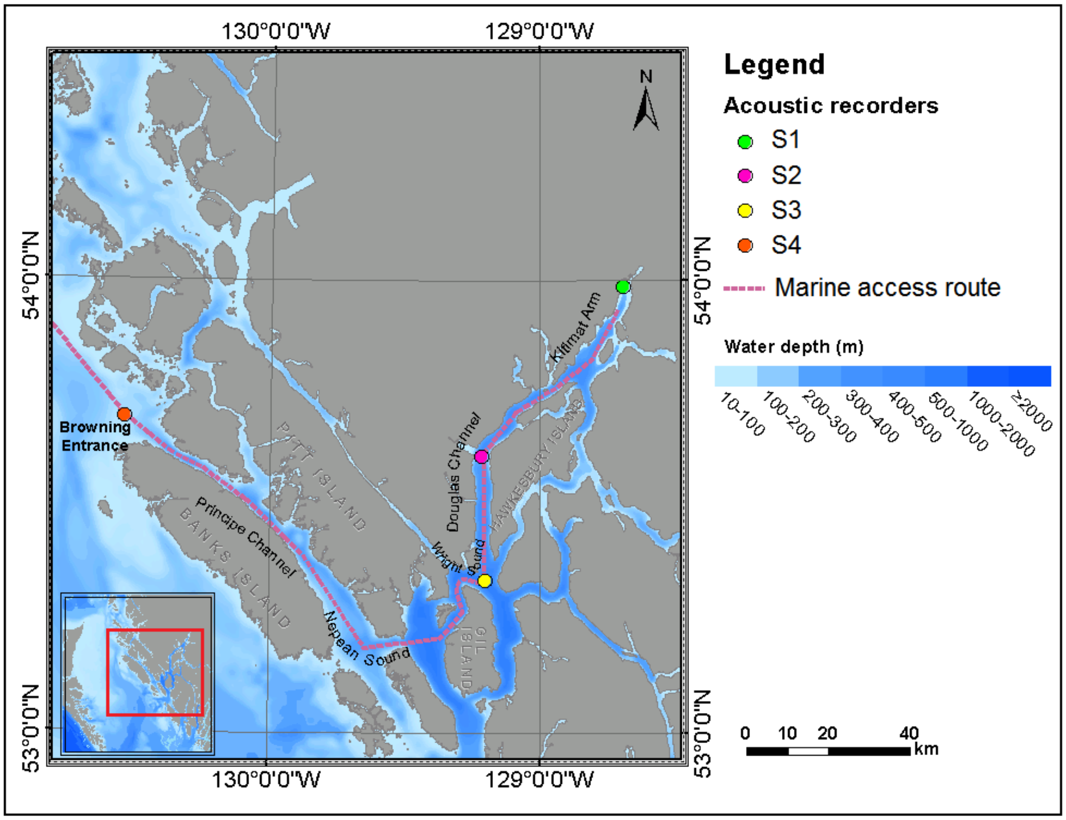

Figure 2. AMAR deployment locations.

Table 1. AMAR locations and recording durations.

Location	Latitude	Longitude	Water depth (m)	Deployment (UTC)	Retrieval (UTC)
S1—Proposed LNG terminal	53°59.077′ N	128°40.564′ W	117	29 Apr	3 Sep
S2—Douglas Channel	53°36.695′ N	129°12.664′ W	312	29 Apr	3 Sep
S3—Wright Sound	53°20.218′ N	129°12.026′ W	502	28 Apr	2 Sep
S4—Browning Entrance	53°41.785′ N	130°32.594′ W	58	27 Apr	1 Sep

AMARs were configured to record in duty cycles, which means they were not recording continuously but intermittently. Higher sampling rates require more memory storage and can typically not be recorded continuously for long periods of time. In the current study, each AMAR was configured to record 121 seconds (~2 minutes) of acoustic data every 484 seconds (~8 minutes) at a sampling rate of 128 ksps, which allowed to maximize the detection of vessels near the recorders, and allowed us to monitor for four months. The recording channel had 24-bits resolution, a broadband dynamic range of 104 dB and a spectral noise floor equivalent to 16 dB re 1 µPa^2/Hz. The maximum measurable signal was 171 dB re 1 µPa. Data were stored on 1.7 TB of internal solid-state flash memory. In total, 3.8 TB of acoustic data were collected. Each AMAR was equipped with a calibrated Geospectrum M8E hydrophone that had a nominal sensitivity of −164 ± 1 dB re 1 V/µPa. The AMARs were calibrated with a GRAS 42AC pistonphone calibrator upon deployment and retrieval. The pistonphone generates a 250 Hz reference tone on the hydrophone sensor with an rms SPL of 152.1 ± 0.1 dB re 1 µPa. The mean pressure sensitivity obtained from the pistonphone was used to calibrate the received sound levels.

The AMARs were deployed and retrieved from the M/V *Ocean Royal* (Figure 3). Each AMAR was attached to a 25 m long mooring that consisted of two floats, dual acoustic releases, and an anchor. The AMARs deployed at Sites S1 and S4 had PVC pressure housings. The AMARs deployed at Sites S2 and S3 had aluminum pressure housings to protect the recorders in the deeper waters. The shallow site moorings included a satellite beacon to track the position of the mooring in case of accidental release (Figure 4); they were also equipped with a ground line on the seabed that was hooked with a grapple and allowed retrieval of all anchors. Nothing was left on the seabed at these sites. No ground lines were added to the deeper moorings (S2 and S3) because the water was too deep for grappling. In September 2013, all mooring components were recovered except two anchors at Sites S2 and S3.

Figure 3. The M/V *Ocean Royal* of Canadian Fish Company, from which the acoustic moorings were deployed and retrieved.

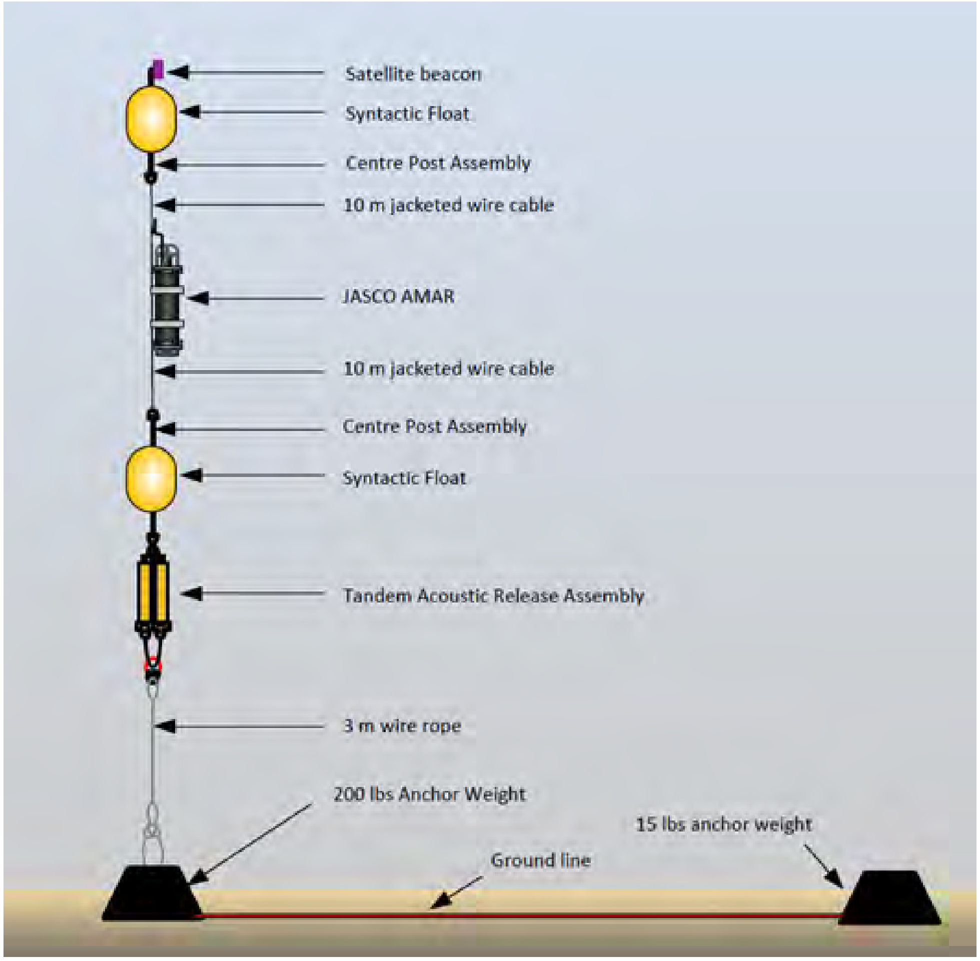

Figure 4. Acoustic moorings. Mooring design used for the shallow Sites (S1 and S4). The deep site moorings were not equipped with ground lines or satellite beacons.

2.2. Ambient Noise Analysis

The objective of the ambient noise analysis was to provide a quantitative characterization of the underwater soundscape along the marine access route (Figure 2). The raw acoustic data were processed with JASCO's acoustic analysis software to calculate ambient sound levels. Statistical analysis techniques were applied to the ambient noise data to determine the range and frequency of occurrence of sound levels at each site.

The raw pressure waveform data were scaled using the calibration coefficients and adjusted for frequency responses of the hydrophone sensors. Time domain pressure waveforms were analyzed to find root-mean-square (rms) sound pressure levels (SPLs) for each minute of data. SPLs were averaged over time and integrated within several frequency bands. The frequency bands examined in this study included broadband (10 Hz to 63 kHz), decade bands, and 1/3-octave-bands. Power spectral density (PSD) was computed for each minute of data according to Welch's method (Oppenheim and Schafer 1999), using a normalized Hamming window with 50% overlap. For the PSD calculation, the fast Fourier transform (FFT) length was 131 072 ($=2^{17}$) points and the frequency bin width was 0.977 Hz. The 1-minute averaged, 1 Hz PSD levels were summed over standard ISO 1/3-octave-bands from 10 Hz to 50 kHz (Appendix 1) and decade bands (10–100 Hz, 100–1000 Hz, etc.) to obtain 1-minute averaged band levels (dB re 1 µPa). These values were compared with the Wenz curves (Figure 5), which represent typical ranges of sound level spectra in the ocean.

Sound exposure level (SEL) measures total noise energy, which was used to evaluate the effects of cumulative noise exposure on marine mammals (Southall et al. 2007). Daily SELs were computed by adding $10\log_{10}(T)$ to the average daily rms SPL, where T is the number of seconds in a day (i.e., 86,400).

To determine the distribution of the recorded ambient noise levels, cumulative sound level probability curves for the 1 minute decade and broadband levels over the entire recording period were computed; these show the fraction of time that SPL levels exceed a particular sound level. To determine the distribution of the 1/3-octave-band and PSD levels, we calculated the percentile levels L_5, L_{25}, L_{50}, L_{75}, and L_{95} for 1 minute SPLs.

Strong currents at the monitoring sites caused the mooring cable to vibrate, which created intermittent strumming and flow noise in the recordings. Because such noise is not part of the soundscape, times where it occurred were omitted from the ambient noise analysis. By inspecting 24-hour long spectrograms and listening to the recordings, analysts were able to select periods of recordings not affected by this type of noise, as it was easily identifiable by its spectrogram signature at low frequencies (< 20 Hz) and its aurally recognizable characteristic. Mooring noise was often correlated with tidal cycles, helping analysts identify its occurrence, but it sometimes appeared outside of the expected tidal cycle. That may be due to unusual current features at some locations.The recorder deployed at Site S2 was particularly affected by mooring noise.

On 12 Jul, the hydrophone cable from the mooring deployed at Site S1 became damaged; this introduced some impulsive electronic noise in the recordings. Consequently, data collected after 12 Jul at Site S1 were omitted from the ambient noise analysis. This issue did not affect the ability to acoustically detect vessels and marine mammals. Table 2 indicates the total amount of acoustic data used from each site for the ambient noise analysis. Although the amount of data used for the ambient analysis was reduced, it was sufficient to accurately quantify the distribution of sound levels at all monitoring sites.

Table 2. Data used for the ambient noise analysis.

Site	Hours of data analysed for ambient analysis (% of the dataset collected)	Start date	Stop date
S1—Proposed LNG terminal	388.8 (51.5 %)	29 Apr	12 Jul
S2—Douglas Channel	77.8 (10.2 %)	1 May	31 Aug
S3—Wright Sound	192.2 (25.5 %)	29 Apr	31 Aug
S4—Browning Entrance	397 (52.6 %)	29 Apr	31 Aug

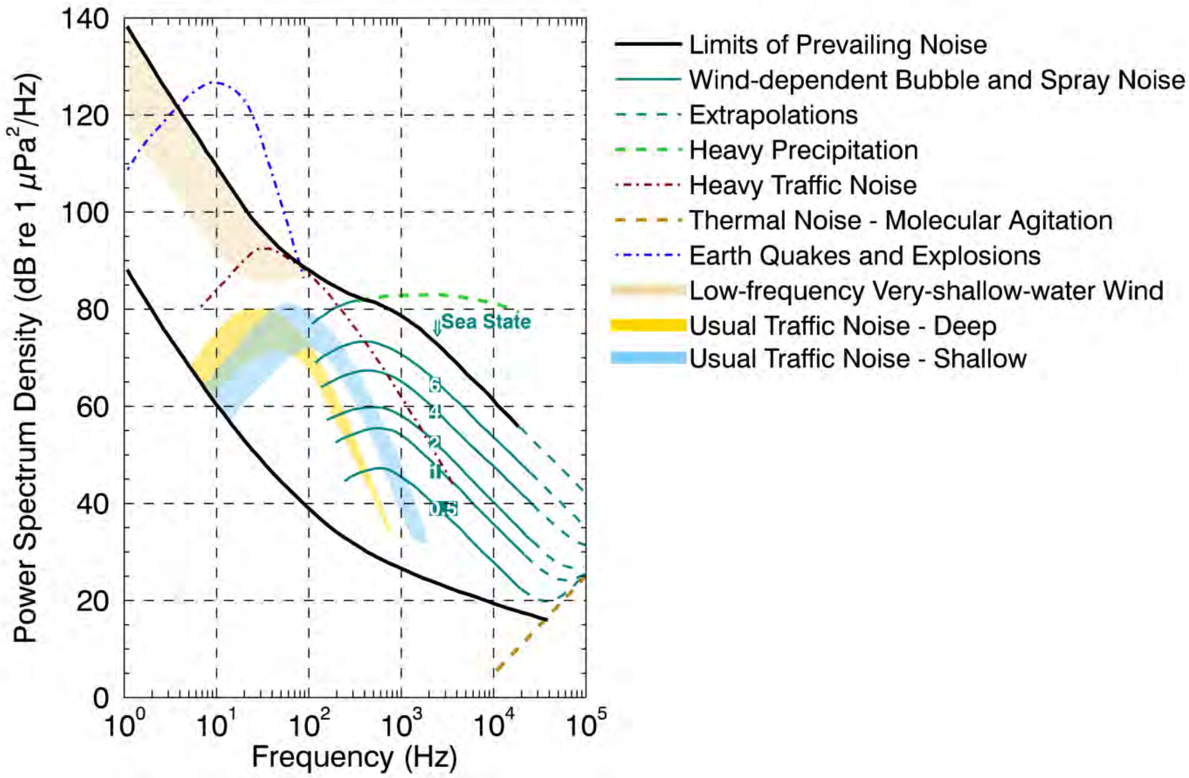

Figure 5. Wenz curves (NRC 2003, adapted from Wenz 1962) describing pressure spectral density levels of marine ambient noise from weather, wind, geologic activity, and commercial shipping..

2.3. Vessel Detection

Vessels produce narrowband sinusoidal tones from their propulsion and other rotating machinery, and broadband sound energy from propeller cavitation (Arveson and Venditis 2000). We automatically detected vessel sounds in recordings using the detector implemented by Martin (2013). The detector finds the number of constant tones in recordings and measures the rms SPL in the 40–315 Hz (shipping band) and 10–64,000 Hz (broadband) frequency bands.

A vessel detection is confirmed if all of the following are true:

- The rms SPL in the shipping band is at least 3 dB above the median.
- There are at least five shipping tonals present.
- The rms SPL in the shipping band is within 8 dB of the total rms SPL.

Appendix 2 has more details on the vessel detector.

To ensure the automated vessel detections were accurate, three trained analysts manually verified ~ 30 vessel detections for each site by inspecting spectrograms and listening to the recordings. Strumming noise from the moorings at Sites S2 and S3 caused the vessel detectors’ performance to be poorer than expected so, for both sites, the team of analysts manually annotated the hourly presence of vessels for the entire monitoring period.

2.4. Marine Mammal Detection

Killer whales produce three types of sounds: clicks, whistles, and pulsed calls.

- Clicks are short pulses that usually occur in a series. Click duration ranges from 0.1 to 25 ms (Ford 1989).
- Whistles are single narrow-band tones in the 1.5–18 kHz frequency band. They have little harmonic structure and their duration ranges from 50 ms to 12 s (Ford 1989).
- Pulsed calls are harmonically structured with frequency ranges between 80 Hz and 12 kHz (Miller 2002).

Humpback whales produce three main types of sounds: songs, social sounds, and megapclicks.

- Songs are tonal sounds produced between 30 Hz and 8 kHz (Thompson et al. 1979, Payne and Payne 1985). Songs are mostly associated with breeding behaviours but have also been recorded outside the breeding season in feeding grounds (Stimpert et al. 2007, Stimpert et al. 2012).
- Social sounds include moans, grunts, cries, and growls produced in the frequency band 25–2500 Hz (Thompson et al. 1986, Dunlop et al. 2007).
- Megapclicks are low frequency impulses produced between 800 and 1700 Hz (Stimpert et al. 2007). They are not often recorded and are therefore less relevant for passive acoustic monitoring.

Fin whales produce downsweeps, 140 Hz tones, and backbeats.

- The downsweeps are 1 second long stereotyped sounds between 15 Hz and 50 Hz and are usually repeated in long sequences (Schevill et al. 1964, Thompson and Friedl 1982, Thompson et al. 1992).
- The 140 Hz tones (Edds 1988) and the backbeats (Samaran 2004) are less frequent and, consequently, less relevant for acoustic monitoring purposes.

Table 3 summarizes the frequency ranges of the vocalizations for each species.

Table 3. Vocalizations of humpback whales, killer whales, and fin whales.

Species	Vocalization characteristics	Frequency (Hz)		References
		Observed range	Dominant range	
Humpback whale	Songs	30–8000	120–4000	Thompson et al. (1979) Payne and Payne (1985)

Species	Vocalization characteristics	Frequency (Hz)		References
	Social sounds (including moans, grunts, cries, growls)	25–2500		Thompson et al. (1986) Dunlop et al. (2007)
	Megapclicks	< 2000	800 and 1700	Stimpert et al. (2007)
Killer whale	Pulsed calls	500–25000	1000–6000	Awbrey et al. (1982) Ford and Fisher (1983) Moore et al. (1988)
	Whistles	4000−68000		Riesch et al. (2006) Samarra et al. (2010) Simonis et al. (2012)
	Clicks	4000–50000	4000–18000	Barrett-Lennard (1996)
Fin whale	Downsweeps	14–100	20–40	Thompson et al. (1992)
	Backbeat	15–20		Samaran (2004)
	140 Hz tone	140		Edds (1988)

Sounds from these three species were detected using specialized automated detectors. The automatic detections were then manually verified by analysts. This process allowed analysis of the recordings to proceed more quickly and efficiently, while maintaining the precision of human analysts.

Our study used three automated methods:

- A tonal detector combined with a random forest classifier was used to detect killer whale pulsed calls and whistles, and humpback whale songs and social sounds (Mellinger and Clark 2000, Mouy et al. 2013). Appendix 2.2 has more details on this detector.
- An energy detector associated with a classifier, based on the energy ratios between several frequency bands was used to detect killer whale clicks. Appendix 2.3 has more details on this detector.
- A spectrogram template-matching detector was used to detect fin whale stereotyped downsweeps (Mellinger and Clark (1997, 2000), Mouy et al. (2009). Appendix 2.4 has more details on this detector.

Automated detectors can miss faint calls or create false detections depending on how the detection threshold is set. Choosing a very low detection threshold allows faint calls to be detected, but produces more false alarms. Conversely, choosing a high detection threshold lowers the number of false alarms, but increases the number of missed calls. For this study the detection thresholds for all three detectors were intentionally set low to capture most of the vocalizations of interest. An experienced analyst then manually confirmed the presence or absence of marine mammals for each 24-hour period by inspecting the spectrograms and listening to the acoustic sounds identified as calls by the automated detectors.

3. Results

This section reports ambient noise levels, vessel presence, and marine mammal detections at the four monitoring sites over the full 4-month recording period.

3.1. Ambient Noise Analysis

3.1.1. Broadband and decade band spectral analysis

Figure 6 shows the spectrogram of four months of acoustic data collected at Site S1. Low frequency events after 12 Jul (Figure 6) correspond to the electronic noise generated by some damage to the hydrophone cable (Section 2.2). Month-long spectrograms for all monitoring sites are in Appendix 3.

Acoustic events in the data included industrial noise (S1 only), vessel noise, wind and wave noise, marine mammal vocalizations, and water flow noise from tidal currents. Figure 7 shows an example of impulsive sounds recorded at Site S1 likely generated by geo-technical or other industrial activities in Kitimat harbour. Sounds from transiting vessels were recorded at all sites (e.g., Figure 8). Echosounders from vessels passing close to the recorders were also detected (e.g., Figure 9).

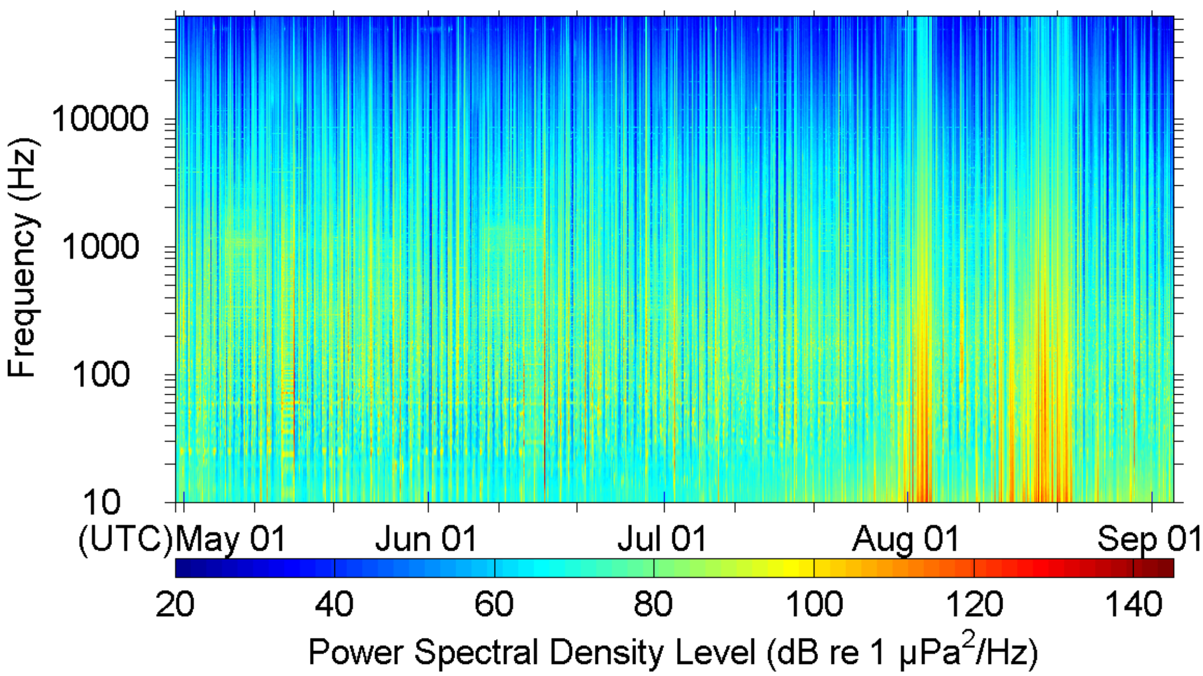

Figure 6. Spectrogram of underwater sound over the entire 4-month recording period at Site S1. Frequency scale is logarithmic.

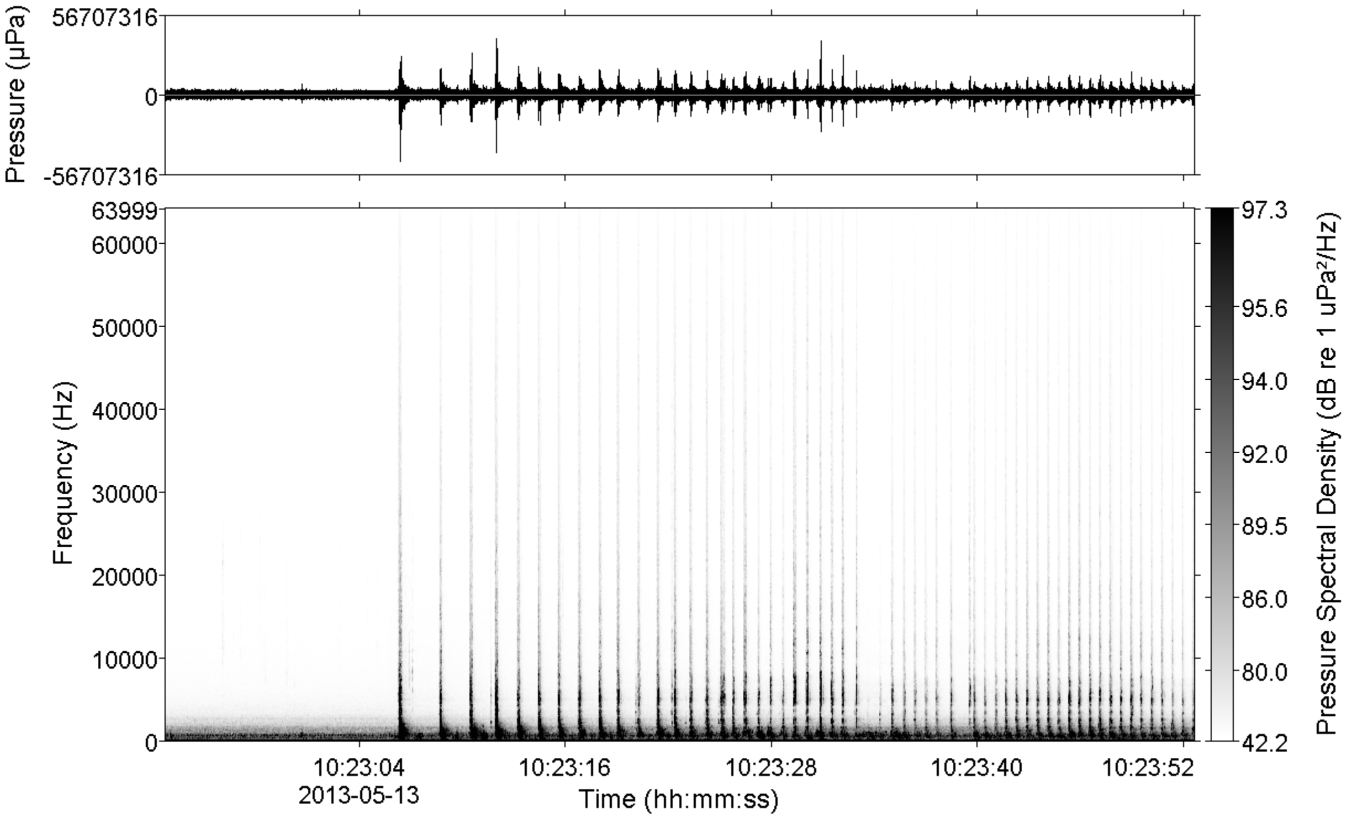

Figure 7. Impulsive sounds recorded at Site S1 on 13 May. Time is in UTC. These pulses may be due to geo-technical or other industrial activities.

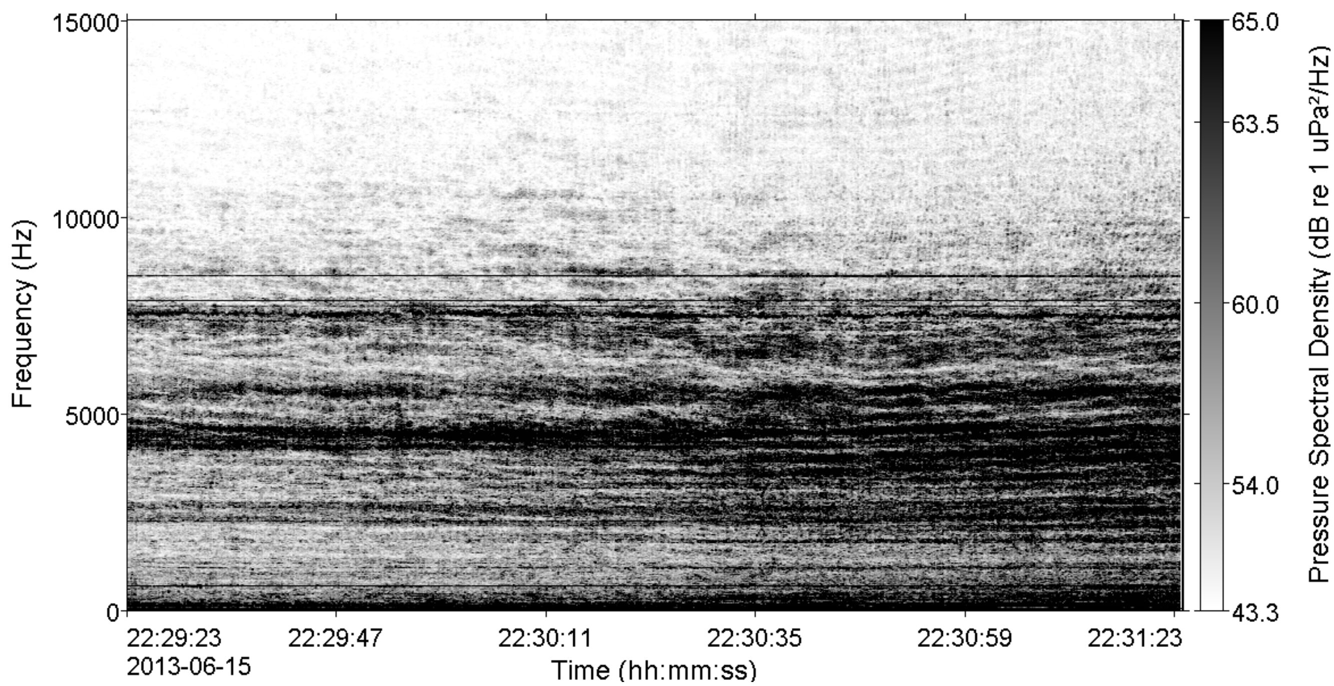

Figure 8. Example of vessel sounds recorded at Site S1 on 15 Jun. Time is in UTC.

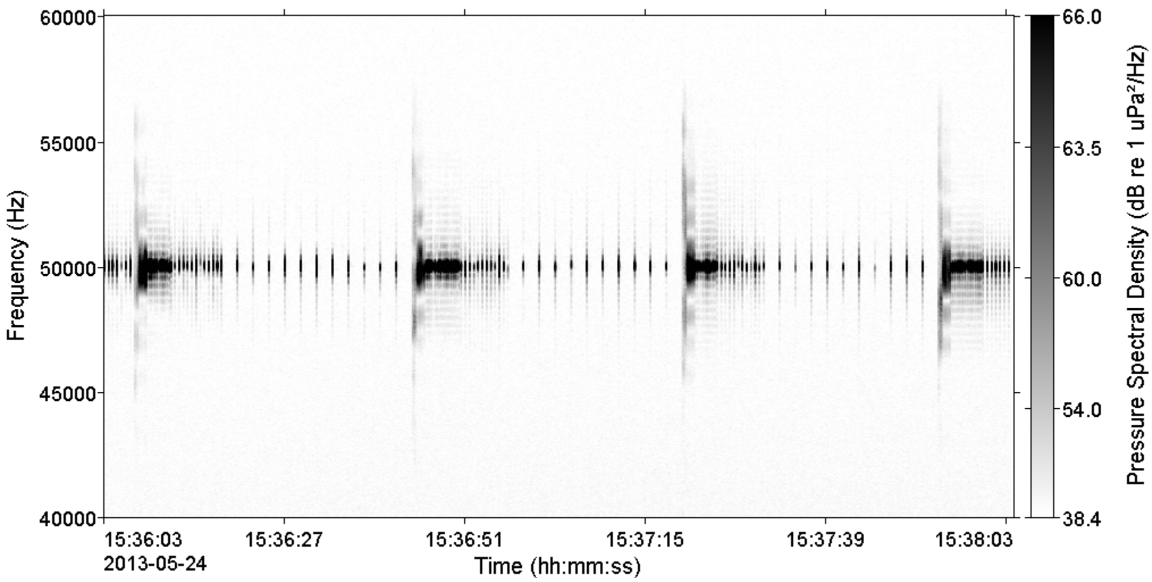

Figure 9. Vessel's echosounder centred around 50 kHz recorded at Site S3 on 24 May. Time is in UTC.

Figure 10 describes the distribution of the broadband and decade band SPLs at Site S1. Appendix 4 has similar figures for Sites S2 through S4. Table 4 lists the mean, median, maximum, and minimum values of the decade bands and broadband SPLs at each site. Median broadband SPL at Site S1 (99.1 dB re 1 µPa) was higher than at the other sites. The highest broadband SPL recorded was 153.6 dB re 1 µPa; this occurred at Site S1 and was caused by a vessel transiting close to the recorder. The lowest broadband SPL recorded was 82.1 dB re 1 µPa; this was measured at Sites S1 and S2. SPLs at Sites S1, S2, and S3 were the highest in the decade bands 100–1000 Hz and 1000–10000 Hz. At Site S4, the decade bands 10–100 Hz and 100–1000 Hz contained the highest SPLs.

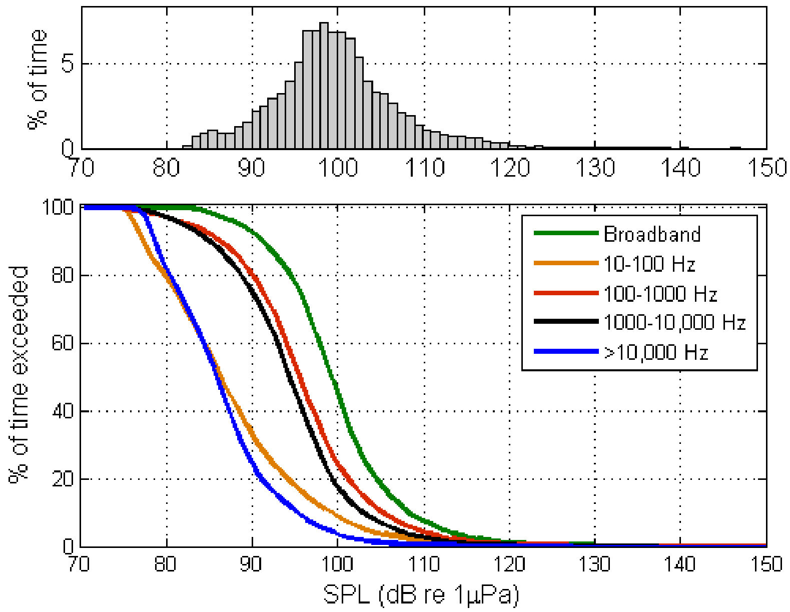

Figure 10. SPL distribution at Site S1. (Top) Histogram of the broadband SPLs (1 minute average) using 1 dB bins. (Bottom) Distribution of decade band and broadband SPLs (1 minute average).

Table 4. Decade and broadband SPLs: Minimum, mean, median, and maximum from each site.

Site		10–100 Hz	100–1000 Hz	1000–10000 Hz	> 10000 Hz	Broadband
S1	Min.	74.0	70.4	74.8	76.0	82.1
	Mean	112.7	111.4	103.7	96.2	115.5
	Median	86.2	95.5	94.3	85.8	99.1
	Max.	150.8	150.2	137.1	127.3	153.6
S2	Min.	77.0	70.5	72.2	77.3	82.1
	Mean	104.1	98.1	94.9	90.5	105.9
	Median	84.8	88.2	89.2	83.6	95.6
	Max.	134.2	124.8	114.4	111.7	134.4
S3	Min.	73.4	69.7	72.3	78.1	81.2
	Mean	110.1	104.6	97.6	89.1	112.3
	Median	86.1	93.4	88.6	80.9	96.7
	Max.	138.3	123.2	116.7	115.6	139.9
S4	Min.	74.7	73.6	71.3	77.4	81.4
	Mean	104.7	107.4	100.4	92.5	109.9

Site		10–100 Hz	100–1000 Hz	1000–10000 Hz	> 10000 Hz	Broadband
	Median	89.0	92.6	86.1	82.0	96.6
	Max.	137.3	141.6	133.3	128.3	143.3

3.1.2. One-third-octave-band and power spectral density levels

Figures 11–14 show the statistical distribution of 1-minute rms SPLs in each 1/3-octave-band (top) and power spectral density levels (bottom) over the monitoring period. Tables with 1/3-octave-band level values are presented in Appendix 5 for each site.

Tones below 200 Hz and above 4000 Hz were present over the entire monitoring period at Site S1 (Figure 11), as indicated by peaks in the power spectral density, which were present in all percentile contours.

The L_5 levels (Section 2.2) were within the limits of prevailing noise for all sites except for the 7.9 kHz tone at Site S1. L5 levels at all sites increased between 10 and 30 kHz, which is typical of noise generated by rain (Ma et al. 2005). Hourly meteorological data were not available at the monitoring locations. Consequently, it was not possible to correlate the SPLs in the 10 20 kHz frequency band with precipitations. However, experienced analysts aurally confirmed the presence of rain noise in recordings. Figure 15 shows examples of such rain events. Median SPLs were peaked in the 1000 Hz and 1250 Hz 1/3-octave-band for Sites S1 and S2, and in the 315 Hz and 125 Hz 1/3-octave-band for Sites S3 and S4. The mean 1/3-octave-band SPLs were greater than the median SPLs at all sites, which indicates that a small number of relatively high-amplitude noise events (e.g., intermittent shipping) contributed most of the sound energy at these locations.

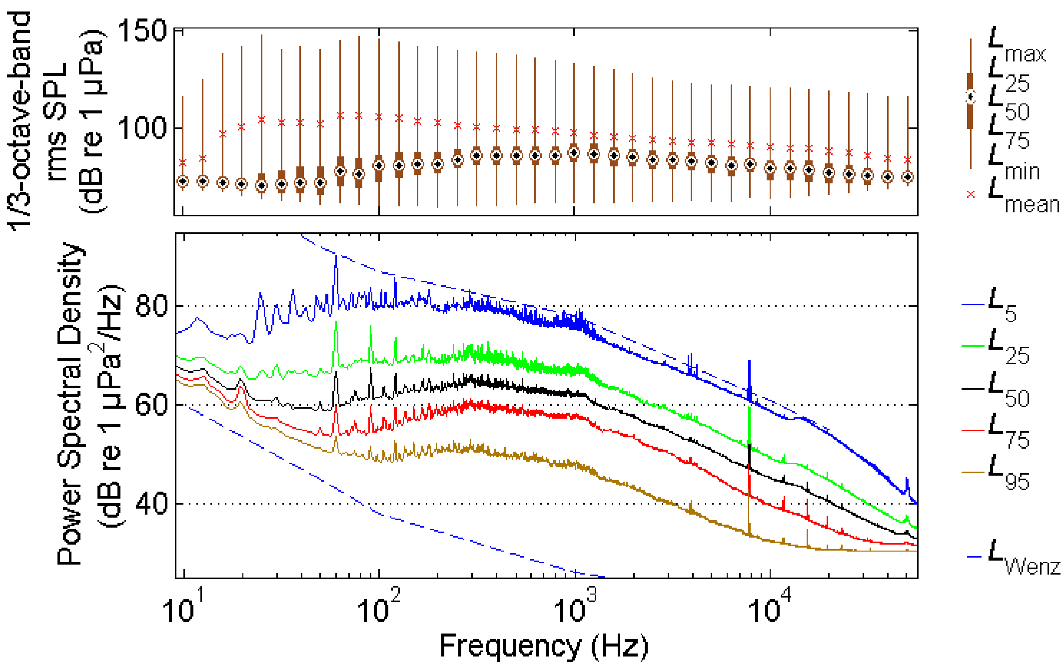

Figure 11. (Top) Box plot showing 1/3-octave-band sound pressure levels (SPLs) at Site S1. (Bottom) Percentile 1-minute power spectral density levels. The dashed lines are the limits of prevailing noise from the Wenz curves (see Figure 5.)

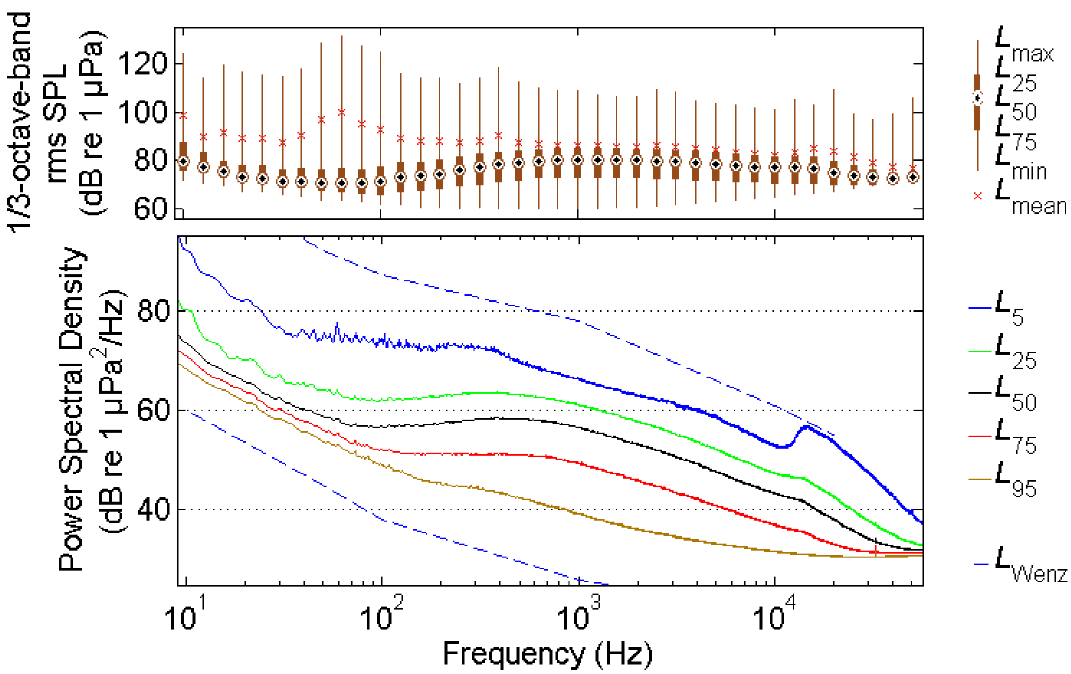

Figure 12. (Top) Box plot showing 1/3-octave-band sound pressure levels (SPLs) at Site S2. (Bottom) Percentile 1-minute power spectral density levels. The dashed lines are the limits of prevailing noise from the Wenz curves (see Figure 5.)

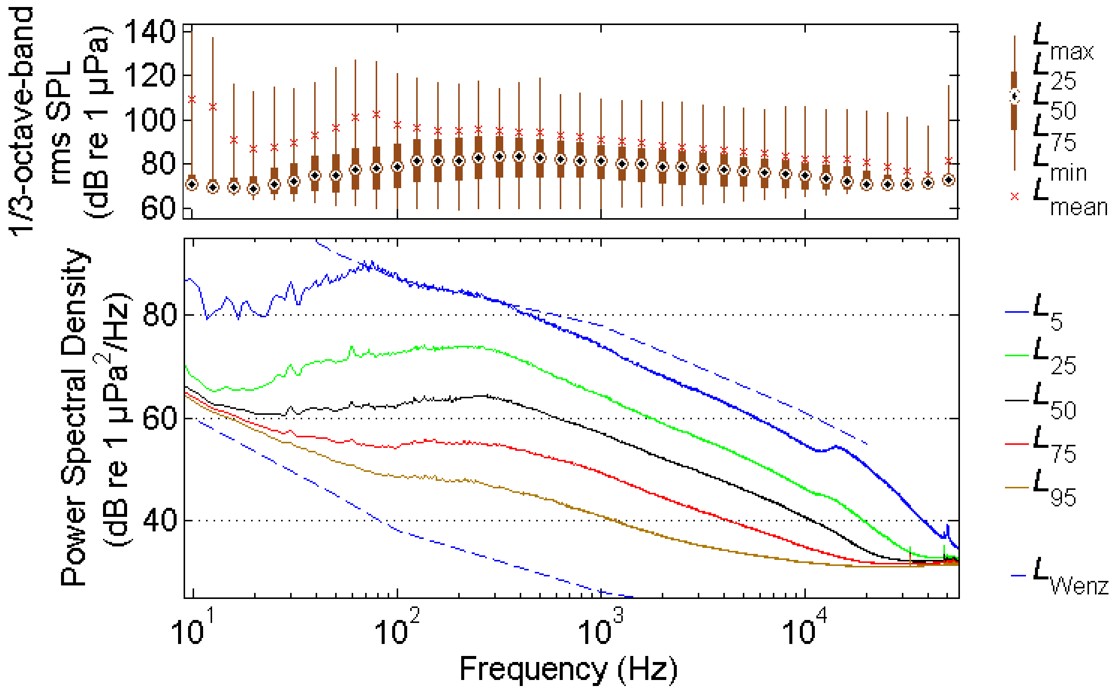

Figure 13. (Top) Box plot showing 1/3-octave-band sound pressure levels (SPLs) at Site S3. (Bottom) Percentile 1-minute power spectral density levels. The dashed lines are the limits of prevailing noise from the Wenz curves (see Figure 5.)

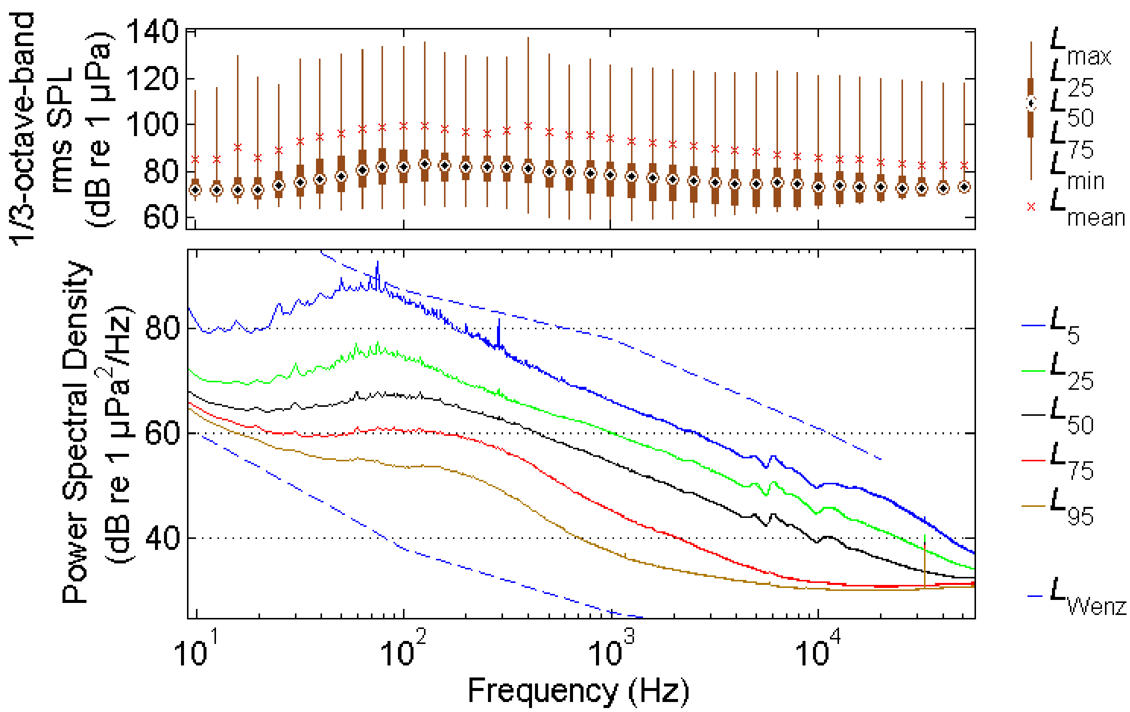

Figure 14. (Top) Box plot showing 1/3-octave-band sound pressure levels (SPLs) at Site S4. (Bottom) Percentile 1-minute power spectral density levels. The dashed lines are the limits of prevailing noise from the Wenz curves (see Figure 5.)

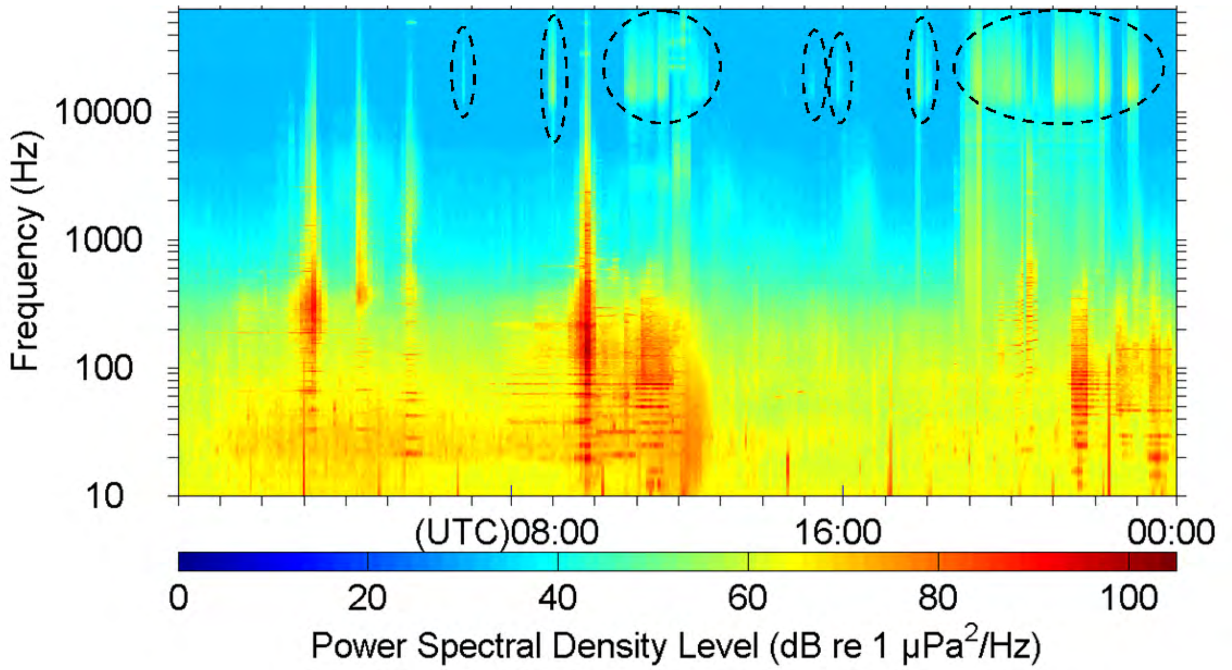

Figure 15. Example of rain events (circled) recorded at Site S4 (29 Aug). Time is in UTC.

3.1.3. Sound exposure levels

Figures 16–19 show the daily SEL at Sites S1, S2, S3, and S4 respectively. Days without SEL values correspond to periods that had higher non-acoustic signals from underwater currents (see Section 2.2). Table 5 indicates the median, mean, minimum, and maximum daily SELs for each site. Notice that subtracting 49.36 dB (i.e., $10\log_{10}(86400)$, see Section 2.2) from the daily SEL values provides the average rms SPL for each day. Site S3 had the maximum daily SEL (175.4 dB re 1 µPa^2·s). Median daily SELs for all sites ranged from 150.0 to 154.5 dB re 1 µPa^2·s. The daily SEL plots show that, while there was a moderate amount of variation between days, there was no apparent systematic trend in the overall noise levels during the monitoring period. The variability is partly due to proximity of vessel passes; a single vessel pass can account for a substantial part of the daily SEL.

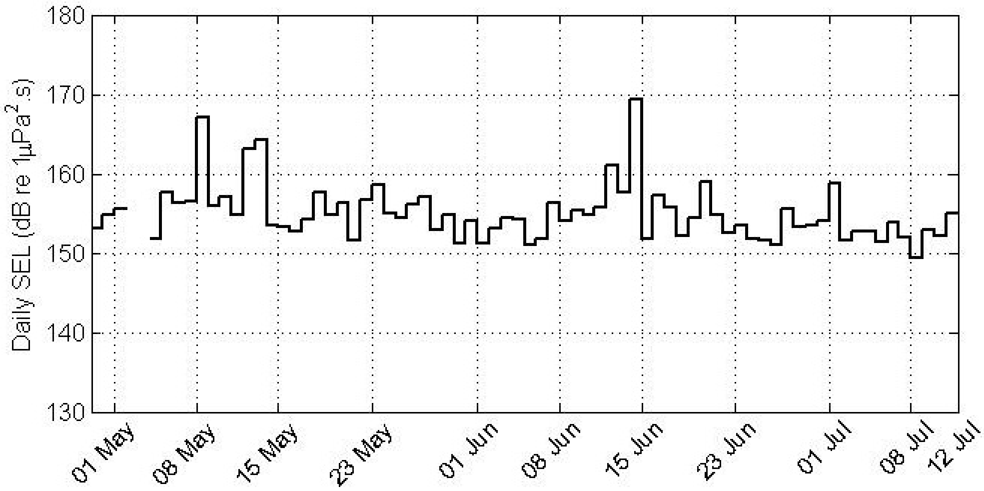

Figure 16. Daily sound exposure levels (SELs) at Site S1.

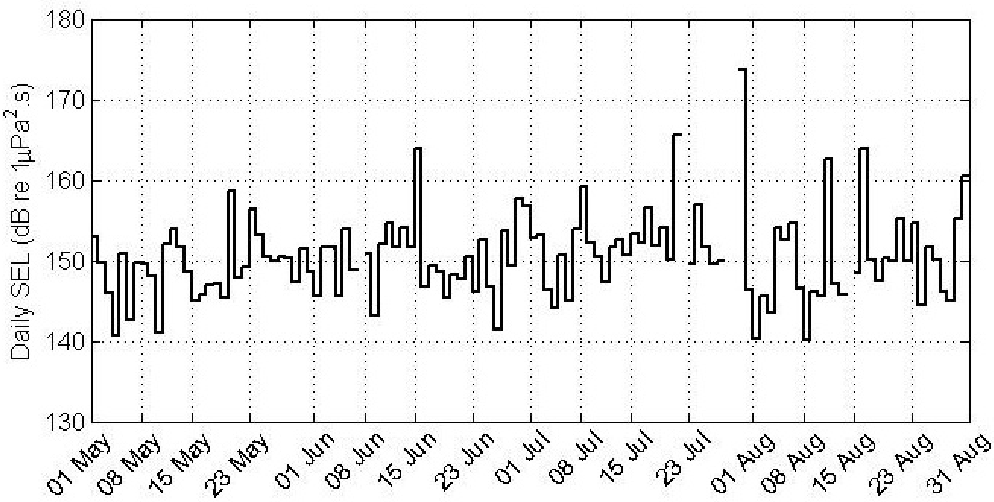

Figure 17. Daily sound exposure levels (SELs) at Site S2.

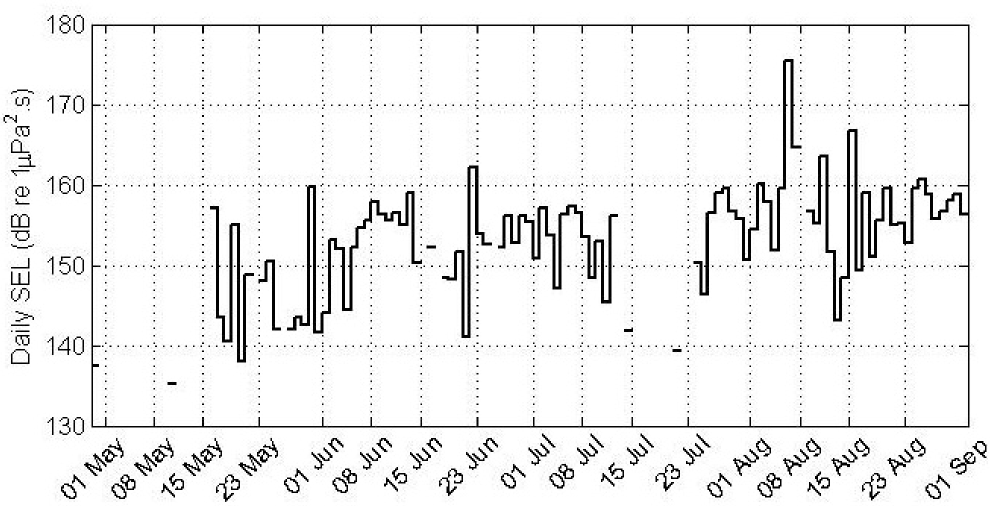

Figure 18. Daily sound exposure levels (SELs) at Site S3.

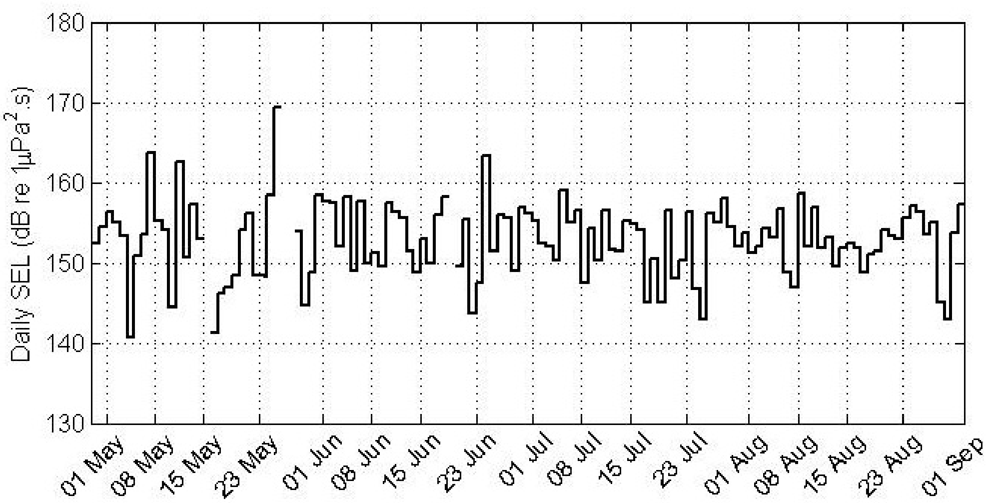

Figure 19. Daily sound exposure levels (SELs) at Site S4.

Table 5. Daily SELs: Minimum, mean, median, and maximum from each site.

Daily SEL (dB re 1 µPa²·s)				
Site	Min.	Mean	Median	Max.
S1	149.4	157.4	154.5	169.4
S2	140.1	156.3	150.0	173.6
S3	135.1	158.9	154.4	175.4
S4	140.6	155.6	153.1	169.3

3.2. Vessel Detections

Hourly presence of vessels at Sites S1, S2, S3, and S4 is presented in Figure 20. Figure 21 and Table 6 indicate the total number of hours with vessel detections for each day of the monitoring period. Site S1 had the most vessel traffic detections with an average of 17.7 hours of vessel presence per day, followed by Sites 3, 4, and 2 in order of decreasing detection time (Table 6). Vessels were detected up to 23 hours per day at Sites S1 and S3. Figure 22 shows an example of daily vessel noise presence at Site S3. At Sites S2, S3, and S4, vessel presence was generally higher from June to August than in May (Figure 21). Vessel traffic at Sites S1 and S2 is clearly correlated with periods of daylight and all sites show some level of systematic variation of traffic with time of day (Figure 20). Figure 23 illustrates the diurnal pattern of the ambient noise observed at Site S1.

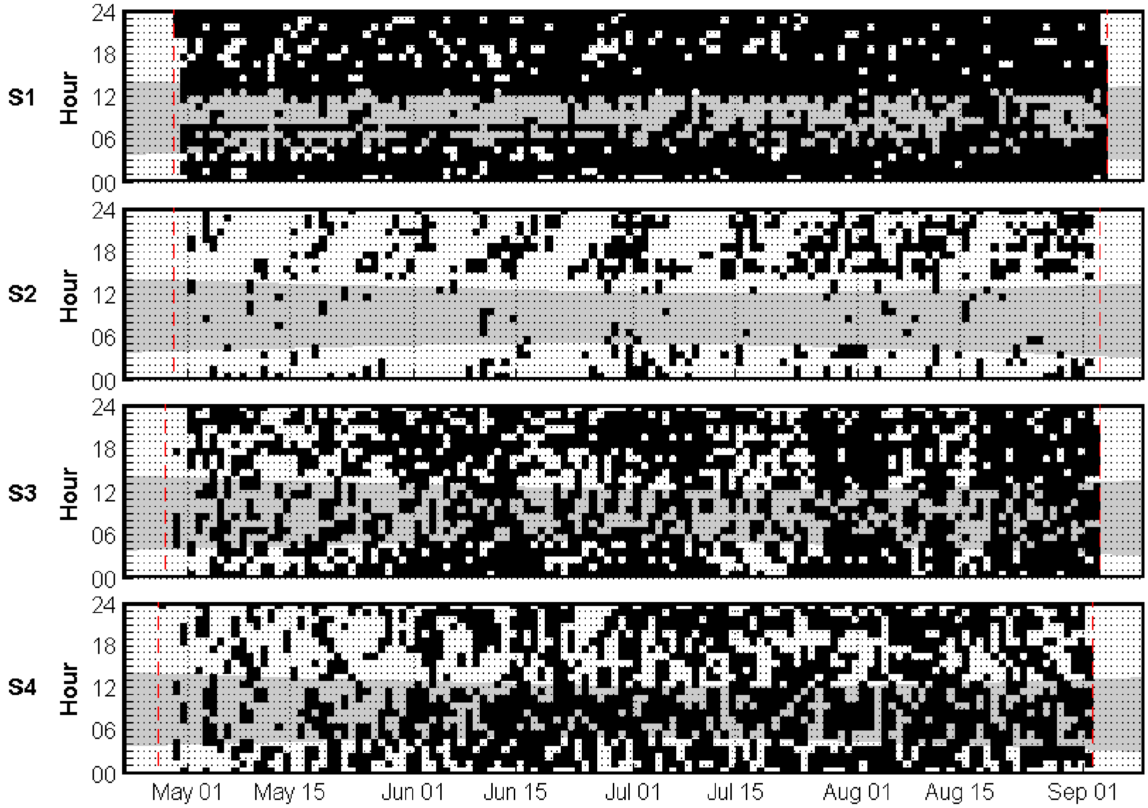

Figure 20. Hourly presence of vessel noise detections at Sites S1, S2, S3, and S4 from 29 Apr to 2 Sep (UTC). The grey areas indicate hours of darkness. Red dashed lines indicate AMAR deployment and retrieval times.

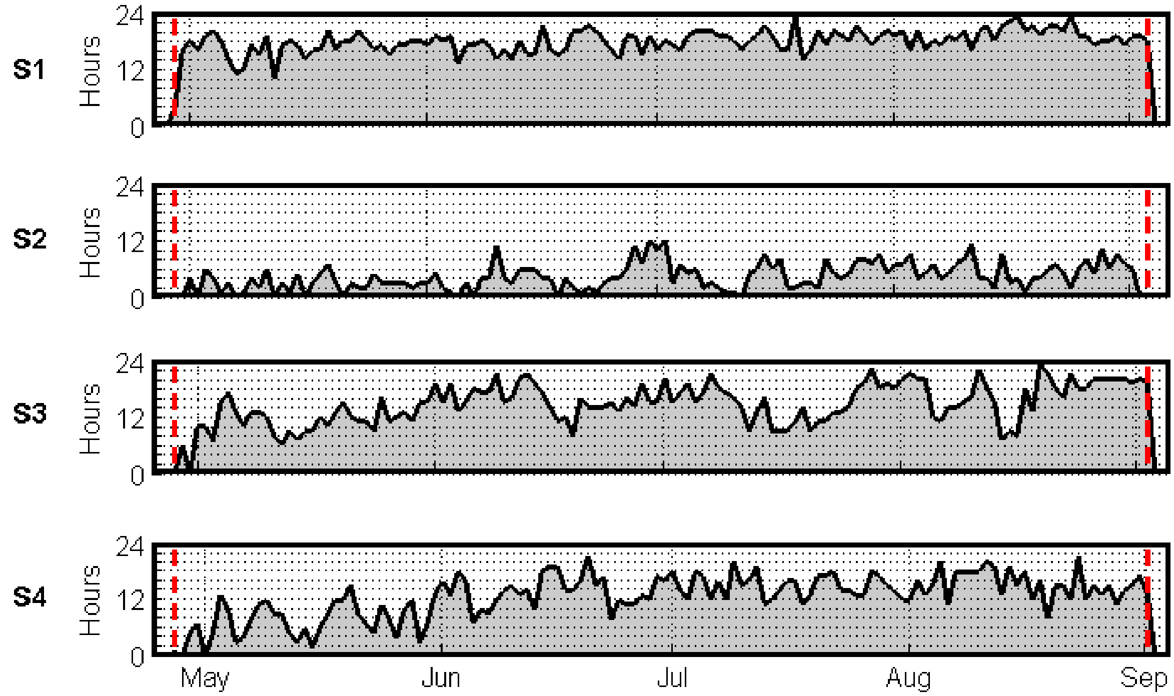

Figure 21. Number of hours per day with vessel detections at Sites S1, S2, S3, and S4 from 29 Apr to 2 Sep (UTC). Red dashed lines indicate AMAR deployment and retrieval times.

Table 6. Daily vessel presence: Minimum, mean, median, and maximum (in hours).

Site	Min.	Mean	Median	Max.
S1	10	17.7	18	23
S2	0	4.3	4	12
S3	0	14.5	15	23
S4	0	12.7	13	21

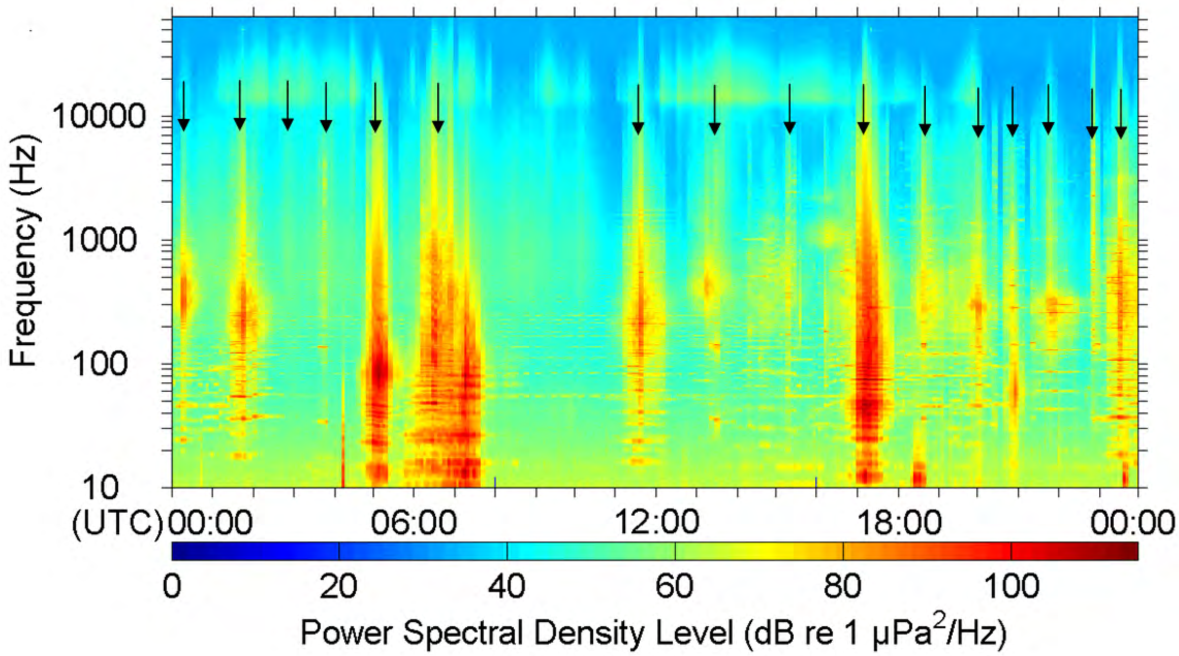

Figure 22. 24-hour spectrogram at Site S3 (9 Jun). Black arrows indicate clear vessel passes, but there are many other weaker vessel signatures in this recording period.

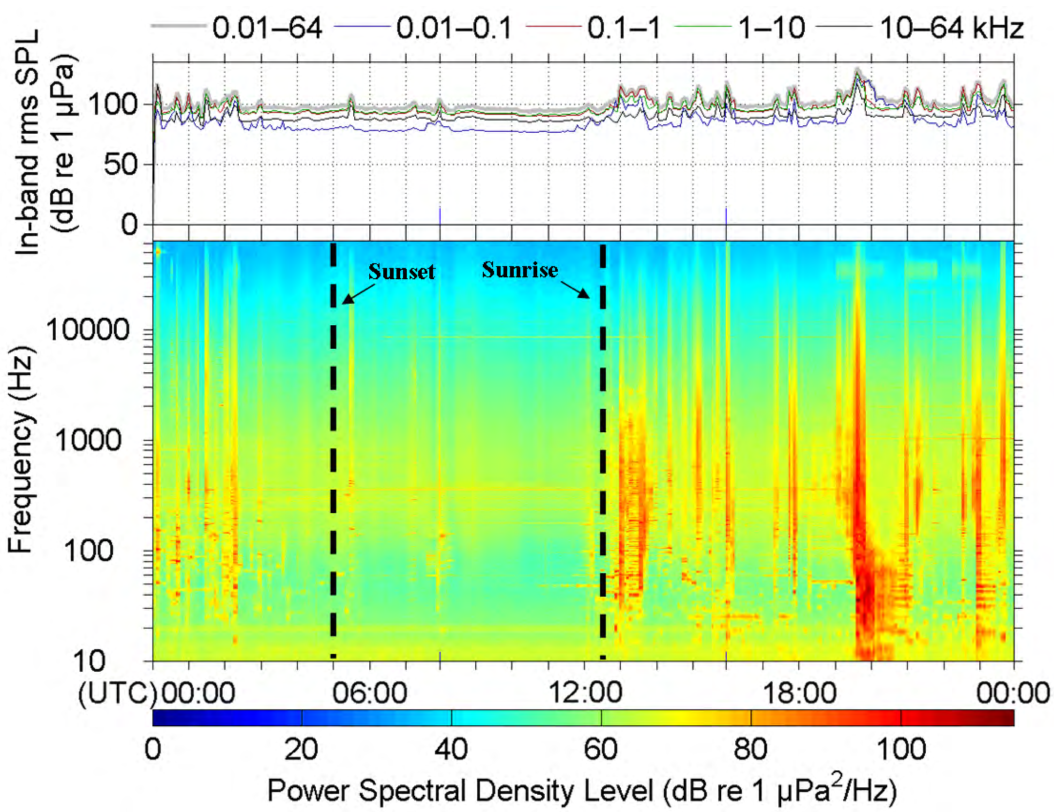

Figure 23. Example of a diurnal pattern of ambient noise at Site S1 (17 Jun). Time is in UTC.

3.3. Marine Mammal Vocalizations

3.3.1. Killer whales

Killer whale calls were detected at all sites (Figure 24). Sites S3 and S4 had the most detection days at 30 and 51 respectively (Table 7). Killer whales were detected from early May through mid- to late-August at all sites except Site S1 where the first detection occurred later, on 13 May and the last detection occurred on 21 Jun. The number of killer whale detection days increased moving westward between Sites S1 and S4. Types of killer whale call detections included whistles, pulsed calls, and clicks. Figure 25 shows examples of detected pulsed calls and clicks.

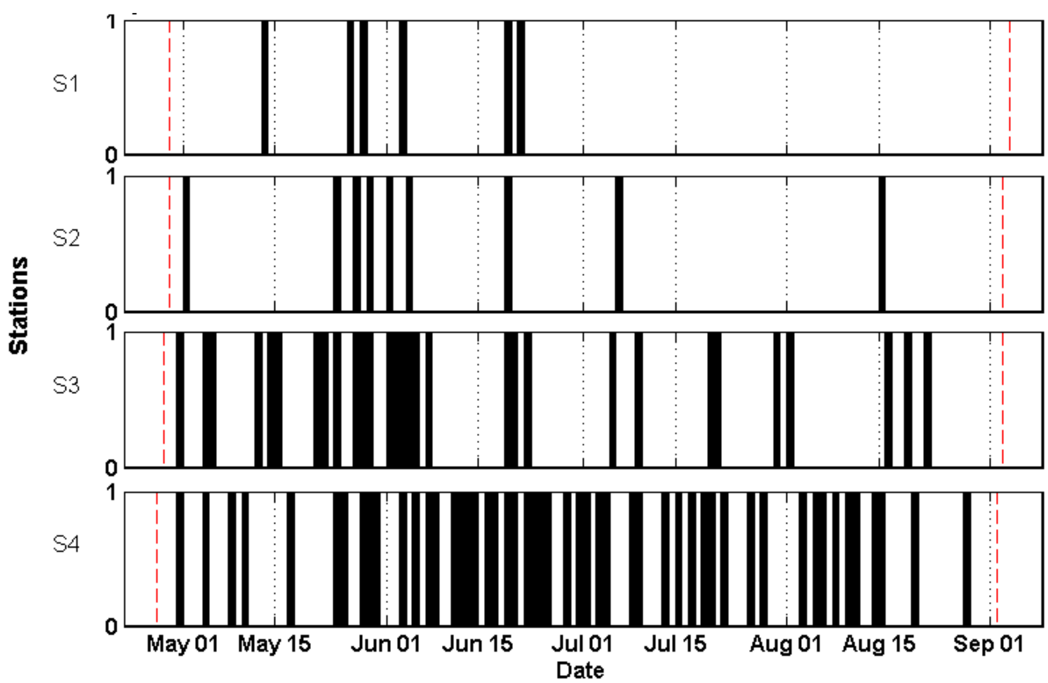

Figure 24. Daily killer whale call detections at Sites S1, S2, S3, and S4 during the monitoring period. Red dashed lines indicate AMAR deployment and retrieval times.

Table 7. Dates of first and last killer whale call detections, recording duration, and the total number of detection days.

Location	Deployment	First detection	Last detection	Recording duration (days)	Detection days
S1	29 April	13 May	21 June	128	6
S2	29 April	1 May	15 Aug	127	9
S3	28 April	30 Apr	22 Aug	128	30
S4	27 April	30 Apr	28 Aug	128	51

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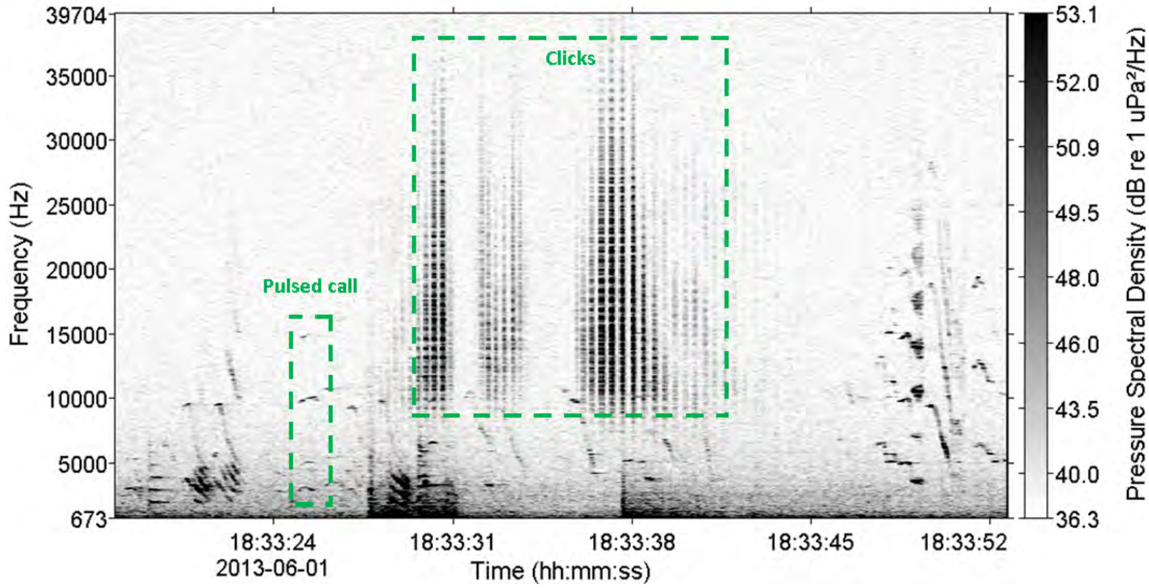

Figure 25. Spectrogram of a killer whale sound segment recorded at Site S3 on 1 Jun 2013 (UTC) (24 Hz frequency resolution, 62.5 ms time window, 25 ms time step, Reisz window).

3.3.2. Humpback whales

Humpback whale calls were detected from May to September at Sites S3 and S4 (Figure 26). No humpback whale calls were detected at Sites S2 and S1. Humpback whales at Site S4 were detected on 102 days of the total 128-day monitoring period (Table 8). Humpback whale call detections included mostly moans, grunts, wavers, cries, and trills. Figure 27 shows examples of detected humpback whale moans and cries.

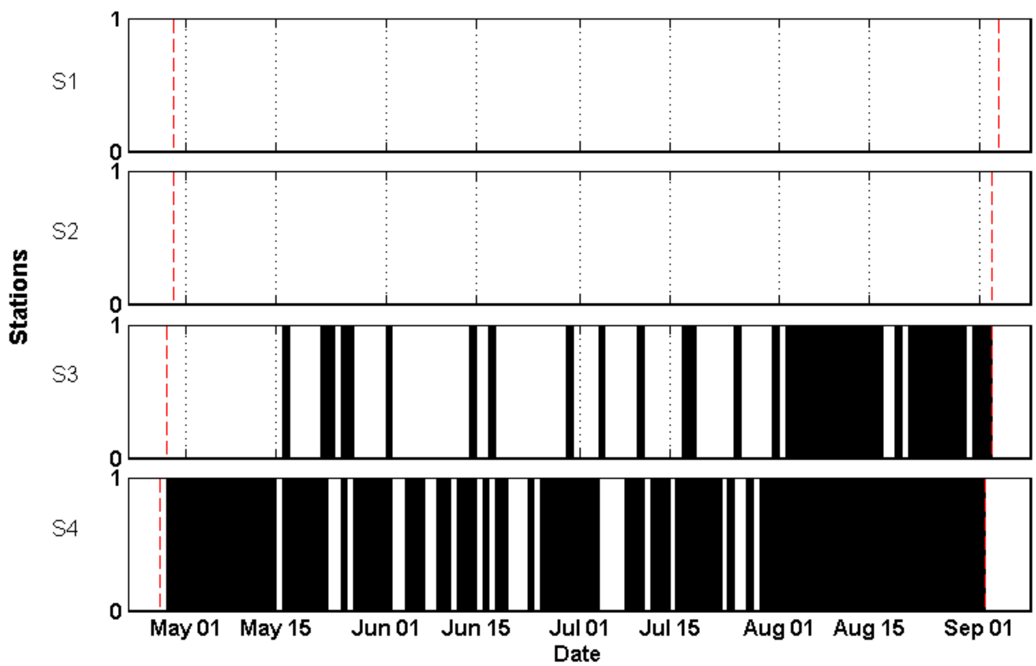

Figure 26. Daily humpback whale call detections at S1, S2, S3, and S4. Red dashed lines indicate AMAR deployment and retrieval times.

Table 8. Dates of first and last humpback whale call detection, recording duration, and the number of detection days.

Location	Deployment	First detection	Last detection	Recording duration (days)	Detection days
S1	29 April 2013	None	None	128	0
S2	29 April 2013	None	None	127	0
S3	28 April 2013	16 May	2 Sep	128	43
S4	27 April 2013	28 Apr	1 Sep	128	102

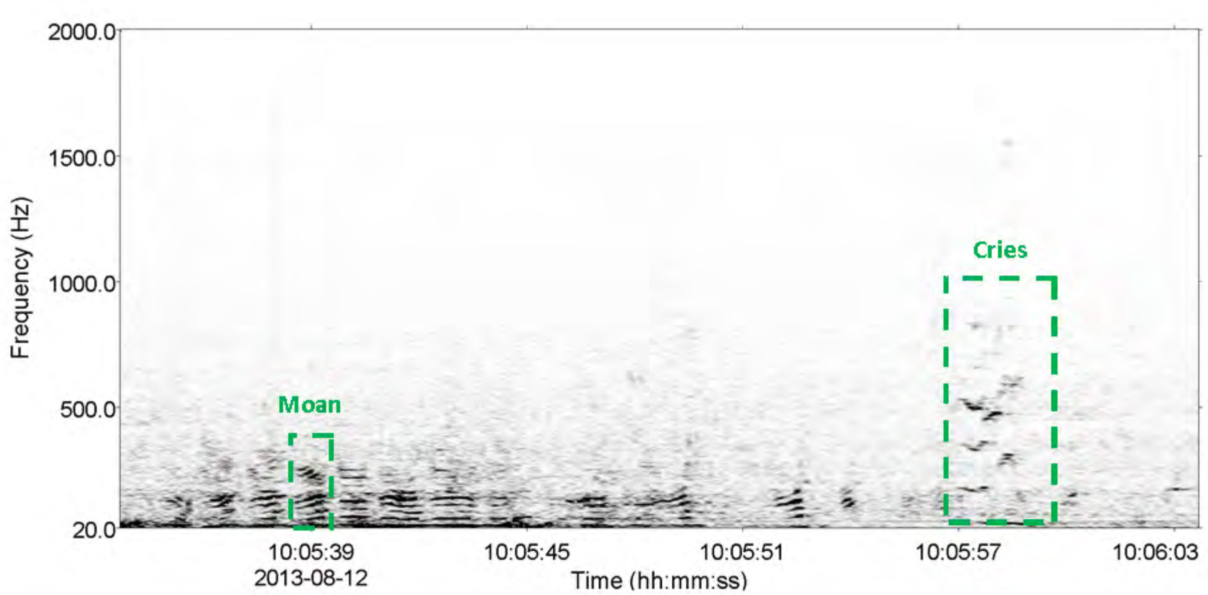

Figure 27. Spectrogram of a humpback whale sound segment recorded at Site S3 on 12 Aug 2013 (UTC) (2 Hz frequency resolution, 256 ms time window, 50 ms time step, Reisz window).

3.3.3. Fin whales

The only confirmed fin whale detection occurred on 18 Aug 2013 at Site S4. Figure 28 shows the detected fin whale downsweeps. Sounds recorded at Site S3 on 1 Sep 2013 and 31 May 2013 and at Site S4 from 18-20 Jul, on 3 Aug, and on 1 Sep 2013 were similar to fin whale downsweeps, but could not be confirmed due to the sound sequence being of shorter duration than typical fin whale vocalizations and the presence of vessel noise in these recordings.

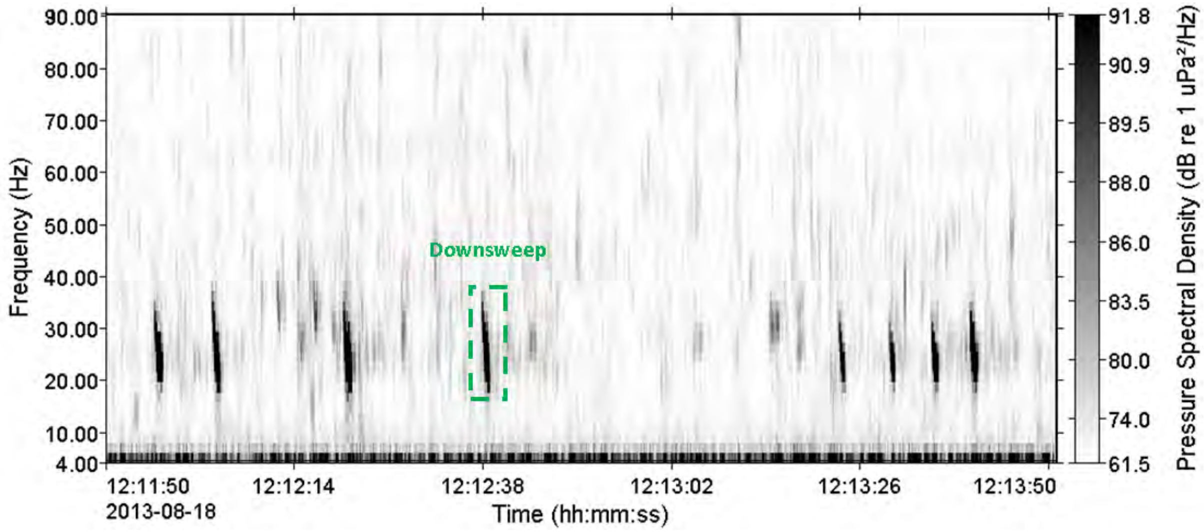

Figure 28. Spectrogram of fin whale downsweeps recorded at Site S4 on 18 Aug 2013 (UTC, 2 Hz frequency resolution, 256 ms time window, 50 ms time step, Reisz window).

3.3.4. Other detected species

Pacific white-sided dolphins were detected at Site S4 on Aug 16, 26, 29, and 31; however, the detection of this species was not carried out in a systematic way, so it is possible that other calls were present. Further analyses could result in more detections. Detected sounds included clicks and whistles. Figure 29 shows an example of sounds produced by a Pacific white-sided dolphin encountered at Site S4 on 31 Aug.

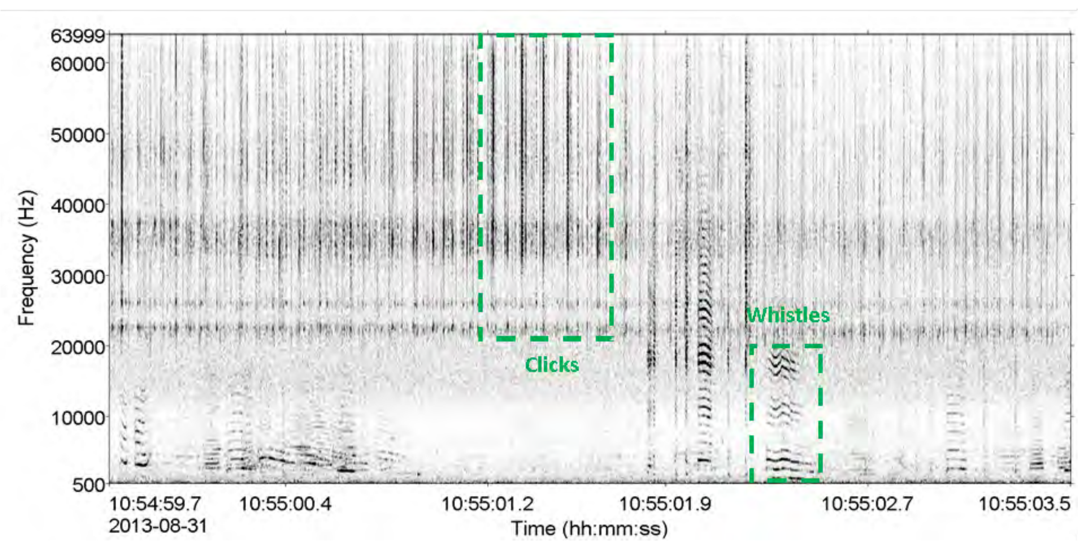

Figure 29. Spectrogram of sounds produced by Pacific white-sided dolphins recorded at Site S4 on 31 Aug 2013 (UTC) (24 Hz frequency resolution, 5 ms time window, 2.5 ms time step, Reisz window).

4. Discussion and Conclusion

This study characterized the existing ambient noise conditions, vessel traffic, and presence of killer whales, humpback whales, and fin whales at four key locations along the marine access route. These measurements provide a baseline of the existing underwater acoustic noise environments along the shipping routes leading through confined channels to open water. Measurements were conducted during the summer, which is the period of the year with the highest vessel traffic. The results are relevant for evaluating LNG shipping noise on marine fauna.

Noise levels at Site S1 were higher than at the other three sites, mostly driven by anthropogenic activities and local vessel traffic near Kitimat. Ambient noise levels at S1 were higher during daylight hours due to higher daytime vessel traffic and industrial activity (Figure 23). Williams et al. (2013) also observed this diurnal pattern in underwater noise levels near Kitimat in summer 2010. Tones below 200 Hz and above 4,000 Hz were always present at Kitimat, likely generated by industrial plants on Kitimat harbour.

There were fewer vessels in Wright Sound (S3) than near Kitimat (S1), but a similar number to Browning Entrance (S4), and more than near Kitkiata Inlet on Douglas Channel (S2). This result is expected since Sites S3 and S4 are on the primary inside-passage coastal shipping route. Wright Sound is located at the convergence of five different channels on the inside passage and therefore experiences high vessel traffic from cruise ships, cargo ships, tugs, fishing vessels, and ferries. It also experiences local vessel traffic from the community of Hartley Bay that is only accessible by water. Browning Entrance experiences noise from vessels on the inside passage and from vessels transiting from southern Hecate Strait into Port of Prince Rupert.

Site S2, located in a deep channel acoustically isolated from surrounding areas, was the quietest site with the least vessel traffic (Figure 20). Williams et al. (2013) measured ambient noise at several sites along the BC coast and reported that the channels from Kitimat to Caamaño Sound had lower low-frequency sound levels than other coastal monitoring sites. The L_5 (highest 5th percentile) power spectral densities at all sites showed increases of spectral density with frequencies between 10 and 30 kHz. This was aurally confirmed to be caused by periods of rain.

Killer whale audiogram data suggest that this species' hearing range extends from ~0.1-100 kHz, with highest sensitivity between 10-40 kHz. The shape of their audiogram indicates that they have poor hearing below 1 kHz, but relatively good hearing above a few kHz. Median 1/3-octave-band levels at all sites were above the killer whale hearing threshold for frequencies between approximately 2-60 kHz (Figure 30). Median 1/3-octave-band SPL in frequency bands below 1 kHz, which contain most vessel sound energy, were below the killer whale audible threshold.

The hearing range for baleen whales (including fin and humpback whales) extends from 0.01–20 kHz and is the most sensitive between 0.1 and 10 kHz. Median 1/3-octave-band SPL for all sites were above humpback whale hearing thresholds for bands between 30 Hz and approximately 20 kHz (Figure 30).

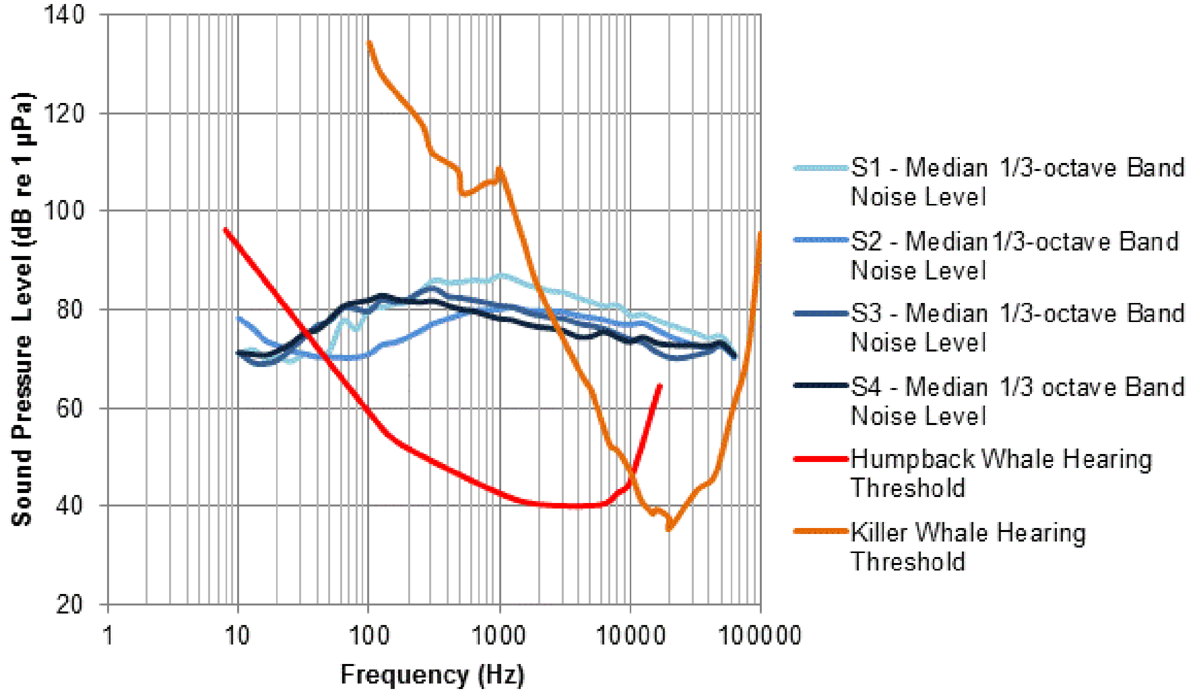

Figure 30. Comparison of killer whale and humpback whale audiograms to median 1/3-octave-band SPLs measured over the study period. The killer whale audiogram below 20 kHz is from (Erbe 2002). Killer whale audiogram values above 20 kHz are averaged behavioural data from Szymanski et al. (1999). Humpback whale audiogram values below 200 Hz are from Clark and Ellison (2004). Humpback whale audiogram values above 200 Hz are from Houser et al. (2001).

High ambient noise levels can mask vocalization sounds that animals use to forage and communicate. The killer whale communication call range extends from ~0.5–18 kHz (Ford 1989); their click range extends from ~8–80 kHz (Au and Wursig 2004). Recent evidence suggests that killer whales increase the levels of their calls to compensate for elevated background noise, presumably to reduce the effect of masking (Holt et al. 2009). Nonetheless, heightened ambient noise above 1 kHz decreases potential echolocation distance and reduces the effective communication space for killer whales (Miller 2006).

The U.S. National Marine Fisheries Service (NMFS) regulatory criteria for marine mammals (MMPA 2007) and an expert panel (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. Impulsive sounds refer to sounds produced, for example, by impact pile driving activities or seismic airguns. Noise from vessels is considered as continuous-type sound. Only continuous sound level criteria are discussed here.

Table 9 shows the NMFS auditory disturbance criteria for continuous sounds. The NMFS disturbance criteria for marine mammals is the broadband 120 dB re 1 µPa rms threshold. SPLs greater than this threshold were measured at all sites (Table 4) when vessels passed close to the recorders (see Figure 23, top panel). Behavioural studies of killer whales, however, showed that they can exhibit behavioural responses to broadband (~0.1–24 kHz) noise below the NMFS threshold [e.g., 116 dB re 1 µPa rms (Williams et al. 2002)]. No injury criteria are defined by NMFS for continuous sounds.

Table 9. NMFS auditory injury and disturbance criteria for continuous sounds.

Marine mammal group	rms SPL (dB re 1 µPa)	
	Injury	Disturbance
Cetaceans	--	120
Pinnipeds (in water)	--	120

Southall et al. (2007) used M-weighted SEL[1] and the peak SPL metric to define Permanent Threshold Shift (PTS) and Temporary Threshold Shift (TTS) criteria for continuous and impulsive sounds. The PTS is a permanent loss of hearing sensitivity and is considered as an injury. The TTS corresponds to a recoverable loss of hearing sensitivity. Table 10 shows the Southall et al. (2007) auditory criteria for continuous sounds. Southall et al. (2007) suggest that to injure cetaceans to a stage that results in some permanent loss of hearing ability (PTS), the M-weighted sound exposure level of non-impulsive acoustic sources such as vessels, must exceed 215 dB re 1 µPa^2·s. The M-weighted sound exposure level that would cause TTS in cetaceans was defined 20 dB lower than the PTS threshold.

In this study, unweighted daily SELs measured at all sites were far below the PTS and TTS thresholds (Table 5). The highest mean and maximum daily SEL levels were 158.9 and 175.4 dB re 1 µPa^2·s respectively; both occurred at Site S3. Mid-frequency cetacean M-weighting, appropriate for killer whales, would be lower than the broadband SEL levels reported here. Southall et al. (2007) also suggested that peak SPLs higher than 230 dB re 1 µPa and 224 dB re 1 µPa could cause PTS and TTS, respectively, in cetaceans. All measured sound levels from this study were far below these thresholds.

Table 10.Southall et al. (2007) PTS and TTS onset criteria for continuous sounds. LF=low-frequency, MF=mid-frequency, and HF= high-frequency, TTS=Temporary Threshold Shift.

Marine mammal group	M-weighted SEL (dB re 1 µPa^2•s)		Peak SPL (dB re 1 µPa)	
	PTS onset	TTS onset	PTS onset	TTS onset
Cetaceans	215	195	230	224
Pinnipeds (in water)	203	183	218	212

Presence of marine mammals was consistent with other studies conducted in the area (Wheeler et al. 2010). In our study, humpback whale was the most frequently detected species in Browning Entrance (Site S4) and Wright Sound (Site S3). Killer whales were present at all sites; their detections increased from East (Site S1) to West (Site S4). This is consistent with visual observations conducted by Wheeler et al. (2010), which indicated that the number of sightings tended to be higher in the more open water regions of this study area than the northeastern confined regions. Fin whales were only detected one day in Browning Entrance, which corresponds to observations that fin whales are considered uncommon or rare in the study area (Money and Trites 1998, Wheeler et al. 2010, Williams and O'Hara 2010). Recent field studies

[1] Southall et al. (2007) defined M-weighted sound exposure levels, which account for frequency-dependent hearing sensitivities of various species.

observed fin whales in Caamaño Sound, Campania Sound, and areas south of Gil Island (Wheeler et al. 2010, Pilkington 2011). Because fin whale call frequencies fall in the range where sound levels generated by shipping activities are highest (NRC 2003, Figure 5), loud shipping noise could have potentially masked fin whale calls at the monitoring sites, making this species' calls difficult to detect. AMARs were configured to record 121 seconds (~2 minutes) of acoustic data every 484 seconds (~8 minutes). This duty cycle was selected to maximize the detection of vessels near recorders. During the summer, northeast Pacific fin whales produce irregular sequences of downsweeps (Soule and Wilcock 2013) which make them harder to identify in short recordings. Using a duty cycle with a recording period greater than 2 minutes may allow better detection of fin whale calls during the summer.

Acknowledgements

Caitlin O'Neill and David Hannay of JASCO deployed and recovered the AMARs. They were assisted by Michel Jutras and the crew of M/V *Ocean Royal*. Jesse Anaka of Triton Environmental Consultants Ltd. and Ian Munson of Bear Creek Contracting helped store and ship the acoustic monitoring equipment. Zizheng Li and Eric Lumsden, both from JASCO, helped manually analyze acoustic data. Dr. John Ford of Fisheries and Ocean Canada helped identify killer whale and Pacific wide-sided dolphin vocalizations. Barbara Koot of University of British Columbia helped define the parameters for the fin whale detector. Katherine Williams and David Hannay of JASCO provided editorial and scientific reviews of this report.

Glossary

1/3-octave-band levels

Frequency resolved sound pressure levels in non-overlapping passbands that are one-third 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.

audiogram

A curve of hearing threshold (SPL) as a function of frequency that describes the hearing sensitivity of an animal over its normal hearing range.

AMAR

Autonomous Multichannel Acoustic Recorder, used for long-term acoustic monitoring.

ambient noise

All-encompassing sound at a given place, usually a composite of sounds from many sources near and far (ANSI S1.1-1994 R2004) (e.g., shipping, seismic activity, precipitation, sea ice movement, wave action, and biological activity).

automated detector

A computer program that automatically finds a specific type of signal in acoustic recordings.

broadband sound level

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

decibel

A logarithmic unit of the ratio of a quantity to a reference quantity of the same kind. Unit symbol: decibel (dB). (ANSI S1.1-1994 R2004).

fast Fourier transform (FFT)

A computational algorithm used to calculate the Fourier transform for discretely sampled data.

Fourier transform

Mathematical operation that defines the frequency content (i.e., spectrum) of a signal.

frequency

The rate of oscillation of a periodic function measured in units of cycles-per-unit-time. The reciprocal of the period. Unit: hertz (Hz). Symbol: f. For example, 1 Hz = 1 cycle per second.

hydrophone

A passive electronic sensor for recording or listening to underwater sound.

M-weighting

The process of band-pass filtering loud sounds that reduces the importance of inaudible or less-audible frequencies for broad classes of marine mammals. “Generalized frequency weightings for various functional hearing groups of marine mammals, allowing for their functional bandwidths and appropriate in characterizing auditory effects of strong sounds" (Southall et al. 2007).

masking

Interfering noise that obscures sounds of interest at similar frequencies.

median

The 50th percentile of a statistical distribution.

percentile level, exceedance

The sound level exceeded *n*% of the time during a measurement.

permanent threshold shift (PTS)

A permanent loss of hearing sensitivity due to excessive noise exposure. PTS is considered auditory injury.

power spectral density (PSD)

The acoustic signal power per unit frequency as measured at a single frequency. Unit: μPa^2/Hz, or $\mu Pa^2 \cdot s$.

power spectral density level

The decibel level ($10\log_{10}$) of the power spectrum density, usually presented in 1 Hz bins. Unit: dB re 1 μPa^2/Hz.

sound exposure level (SEL)

A measure of the total sound energy received over a specified time. Unit: dB re 1 $\mu Pa^2 \cdot s$.

spectrogram

A time-frequency representation of acoustic data. The spectrogram is a sequence of power spectra for successive time windows that shows how the frequency content of the data varies over time.

sound pressure level (SPL)

The decibel ratio of the time-mean-square sound pressure, in a stated frequency band, to the square of the reference sound pressure (ANSI S1.1-1994 R2004). Unit: decibel (dB). Symbol: L_p.

For sound in water, the reference sound pressure is one micropascal (p_o = 1 µPa) and the unit for SPL is dB re 1 µPa:

$$L_P = 10\log_{10}\left(p^2 / p_o^2\right) = 20\log_{10}\left(p / p_o\right)$$

Unless otherwise stated, SPL refers to the root-mean-square sound pressure level (rms SPL).

split window normalizer

A signal processing technique that is used to increase the signal to noise ratio for an automated detector.

UTC

Universal coordinated time. UTC was the time reference the AMAR used to time stamp digital recordings.

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Appendix 1. 1/3-Octave-Band frequencies

Table 1-1. 1/3-octave-band frequencies

Band number	Frequency (Hz)			Band number	Frequency (Hz)		
	Lower	Nominal centre	Upper		Lower	Nominal centre	Upper
10	8.9	10.0	11.2	29	708	794	891
11	11.2	12.6	14.1	30	891	1 000	1 122
12	14.1	15.8	17.8	31	1 122	1 259	1 413
13	17.8	20.0	22.4	32	1 413	1 585	1 778
14	22.4	25.1	28.2	33	1 778	1 995	2 239
15	28.2	31.6	35.5	34	2 239	2 512	2 818
16	35.5	39.8	44.7	35	2 818	3 162	3 548
17	44.7	50.1	56.2	36	3 548	3 981	4 467
18	56.2	63.1	70.8	37	4 467	5 012	5 623
19	70.8	79.4	89.1	38	5 623	6 310	7 079
20	89.1	100	112	39	7 079	7 943	8 913
21	112	126	141	40	8 913	10 000	11 220
22	141	158	178	41	11 220	12 589	14 125
23	178	200	224	42	14 254	16 000	17 959
24	224	251	282	43	17 818	20 000	22 449
25	282	316	355	44	22 272	25 000	28 062
26	355	398	447	45	28 063	31 500	35 368
27	447	501	562	46	35 636	40 000	44 898
28	562	631	708	47	44 545	50 000	56 123

Appendix 2. Description of the Automated Detectors

2.1. Automated Detection of Vessels

The shipping detector was implemented based on overlapped FFTs (Martin 2013). The number of seconds of data input to the FFT determines its spectral resolution. Arveson and Venditis (2000) used both 0.5 and 0.125 Hz resolutions. For this study spectral analysis was performed at 0.125 Hz resolution by using 8 seconds of real data with a 2-second advance. This frequency resolution separates the tones from each other for easy detection, and the 2-second advance provides suitable temporal resolution. Higher frequency resolutions can reduce the ability to detect shipping tones, which are often unstable within 1/16 Hz over long periods.

Tonal detection was performed on the 2-minute WAV files from the data set, and then a 120 second long spectrogram with 0.125 Hz frequency resolution and 2-second time resolution (1048576-point FFTs, 1024000 real data points, 256000-point advance, Hamming window) was created. A split window normalizer (Struzinski and Lowe 1984) selects the tonal peaks from the background (16-point window, 6-point notch, and detection threshold of 4 times the median). The peaks are joined with a 3 × 3 kernel to create contours, which, if they occur at the same time, are dubbed frequency associations. The event time and number of tones for any event at least 20 s long and 40 Hz in bandwidth were recorded for further analysis.

The shipping detection is performed for each WAV file. We define a 'shipping band' of 40–315 Hz and obtain an rms SPL for the band once per minute. Background estimates of the shipping band rms SPLs and the total rms SPLs are compared to their median values over the 12-hour window centred on the analyzed time frame.

A vessel detection is confirmed if these conditions are true:

- The rms SPL in the shipping band is at least 3 dB above the median.
- There are at least five shipping tonals present.
- The rms SPL in the shipping band is within 8 dB of the total rms SPL.

2.2. Automated Detection of Killer Whale and Humpback Whale Vocalizations

Humpback whale and killer whale vocalizations were detected and classified in three steps:

1. Time-frequency contours were detected and extracted from a normalized spectrogram using a tonal detector developed by Mellinger et al. (2011). The spectrogram was normalized with a split window normalizer (Struzinski and Lowe 1984).
2. Each contour was represented by 46 features that described the contour's frequency content, duration, and shape (slopes, number of inflection points, etc.). Some of the features, as indicated in (Mouy et al. 2013):
    - Slopes of the beginning and ending sweeps
    - Duration

- Beginning and end frequency
- Frequency range
- Mean and median frequency
- Frequency standard deviation
- Upsweep-downsweep ratio

3. Contour features were presented to a binary random forest classifier, which defined whether the extracted contour was a killer whale/humpback whale call, or some other noise type.

A random forest is a collection of decision trees, where each tree is grown using binary partitioning of the data based on the value of one variable randomly chosen at each node (Breiman 2001). Each tree in the forest produces a classification result (i.e., either "killer whale/humpback whale" or "noise"). A contour was classified as killer whale/humpback whale only if the percent of trees in the random forest that voted "killer whale/humpback whale" exceeded the decision threshold T_{RF} defined by the user. This decision threshold was purposely set low to allow faint vocalizations to be detected. The random forest algorithm is a supervised machine learning algorithm that needs to be trained before it can be used (Duda et al. 2000). The training phase was performed using noise and humpback whale and killer whale vocalizations from a set of recordings that JASCO collected in British Columbian waters. Figure 2-1 illustrates the detection and classification process.

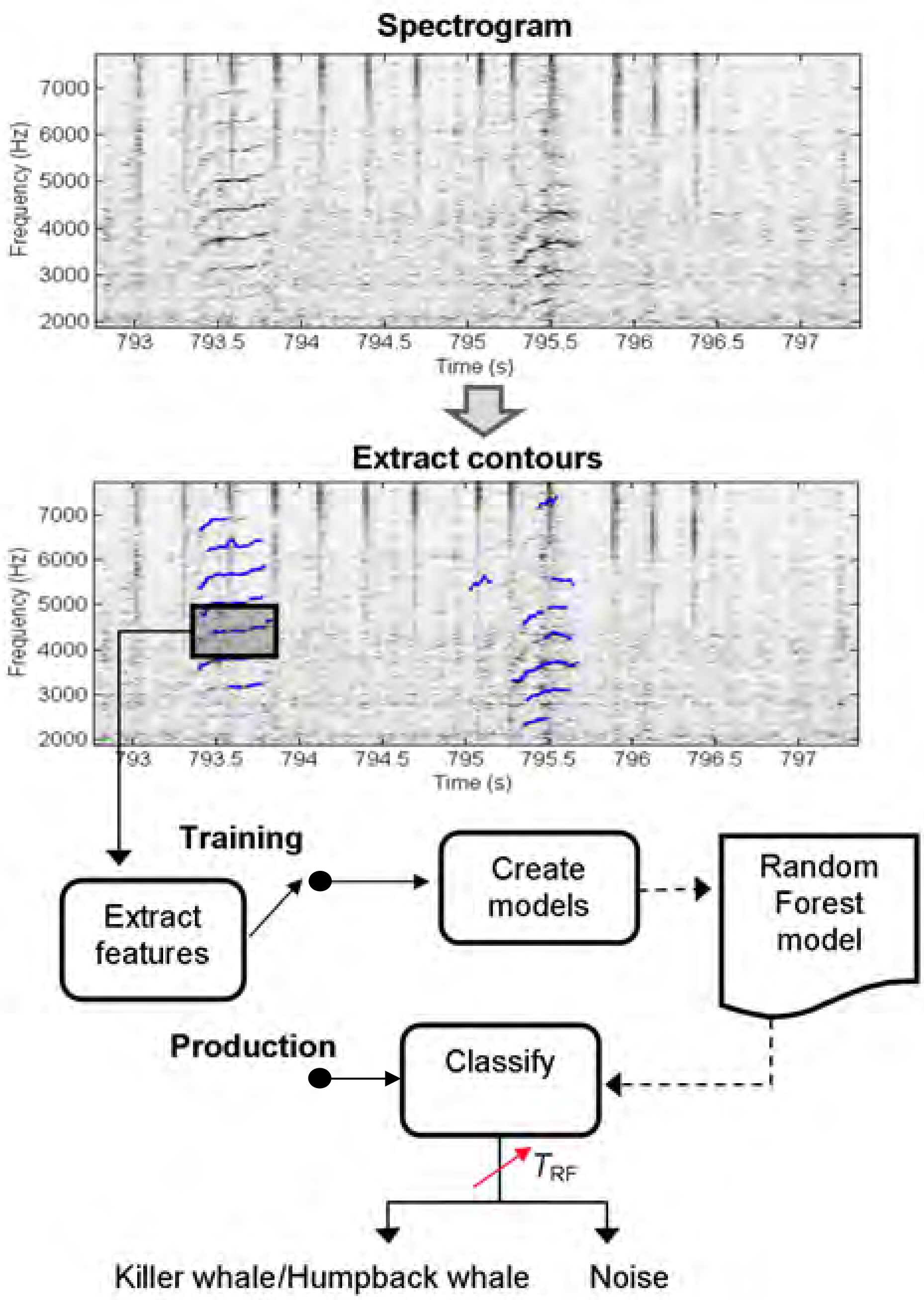

Figure 2-1. Process used to detect and classify killer whale/humpback whale vocalizations and to distinguish them from noise.

2.3. Automated Detection of Killer Whale Clicks

These three steps were followed to detect and classify killer whale clicks:

1. The spectrogram was normalized with a split window normalizer (Struzinski and Lowe 1984). Bins in the normalized spectrogram that had normalized energy less than the threshold T_{norm} =3.5 were set to zero.

2. To create a detection function, for each time step of the spectrogram, the ratio of the number of positive bins over the number of null bins in the frequency band 10–30 kHz were defined. The occurrences of potential killer whale click detections were defined by parts of the detection function that exceeded the empirically chosen threshold T_{detec}.
3. The normalized spectrogram for each of the potential killer whale click detections was used to calculate ratios R_1 and R_2 of the energy in these frequency bands:
    - 35–40 kHz and 42–48kHz
    - 10–30 kHz and 1–10 kHz

A detection was attributed to a killer whale click only if the overall energy ratio score, $R = (R_1+R_2)/2$, exceeded the decision threshold T_{ER}.

Figure 2-2 illustrates the killer whale click detection process.

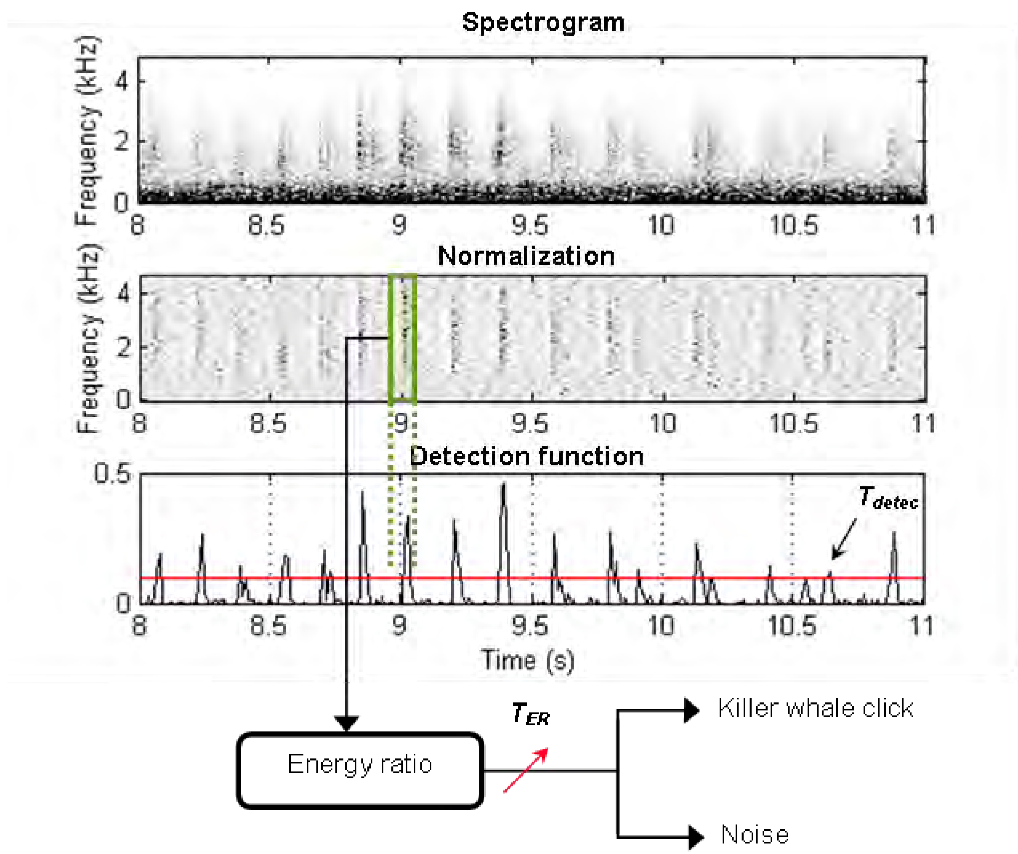

Figure 2-2. Killer whale click detection process.

2.4. Automated Detection of Fin Whale Vocalizations

Fin whale downsweeps were automatically detected using a spectrogram template matching method similar to what Mellinger and Clark (1997, 2000) and Mouy et al. (2009) described.

The detection process follows:

1. The spectrogram was first normalized with a split window normalizer, then the normalized spectrogram was binarized by setting the frequency bins with energy less than the threshold (T_{norm} = 2) to 0, and the frequency bins with a normalized energy higher than T_{norm} to 1.
2. A synthetic binary time-frequency template representing a typical fin whale downsweep was created with the following parameters:
   - Starting frequency (F_1 = 32 Hz)
   - Ending frequency (F_2 = 15 Hz)
   - Duration (D = 1.5 s)
   - Frequency width (df = 5 Hz)
   - Frequency span (FB = 5 to 40 Hz)
   - Silence duration before and after the call (dt= 0.2 s)

   These parameters were empirically determined using a set of fin whale call recordings, collected by JASCO, as well as frequency characteristics of fin whale calls recorded in BC, provided by Barbara Koot (University of British Columbia).
3. To create a detection function, a correlation index that measured how well the synthetic template matched the binary spectrogram was defined for each time step of the spectrogram. A correlation index of 1 indicates a perfect match between the synthetic template and the binary spectrogram. The occurrences of fin whale call detections were defined by parts of the detection function that exceeded the empirically chosen threshold T_{detec}.

Figure 2-3 illustrates the fin whale call detection process.

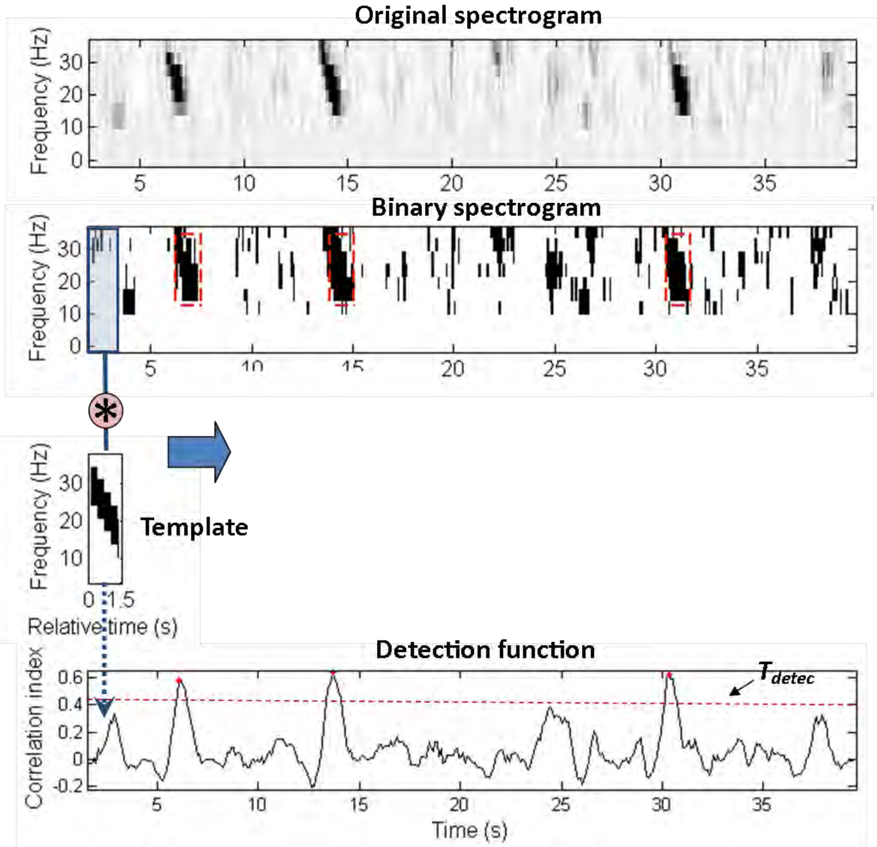

Figure 2-3. Fin whale call detection process

Appendix 3. Month-Long Spectrograms

This appendix presents the month-long spectrograms of the recordings collected at Sites S1, S2, S3, and S4.

Figure 3-1 to Figure 3-4 show the month-long spectrograms of the recordings collected at Site S1 for May, June, July, and August respectively. Low frequency events after 12 Jul correspond to the electronic noise generated by the hydrophone.

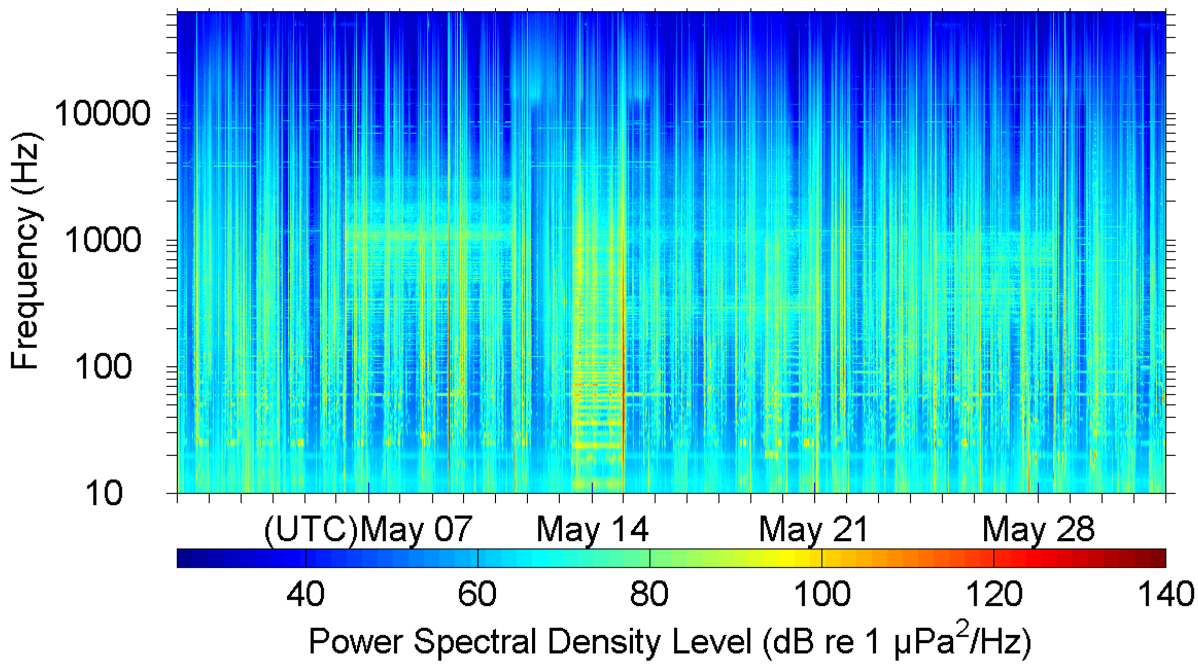

Figure 3-1. Ambient noise spectrogram (1 hour averages) at Site S1 from 1 May to 31 May. Frequency scale is logarithmic.

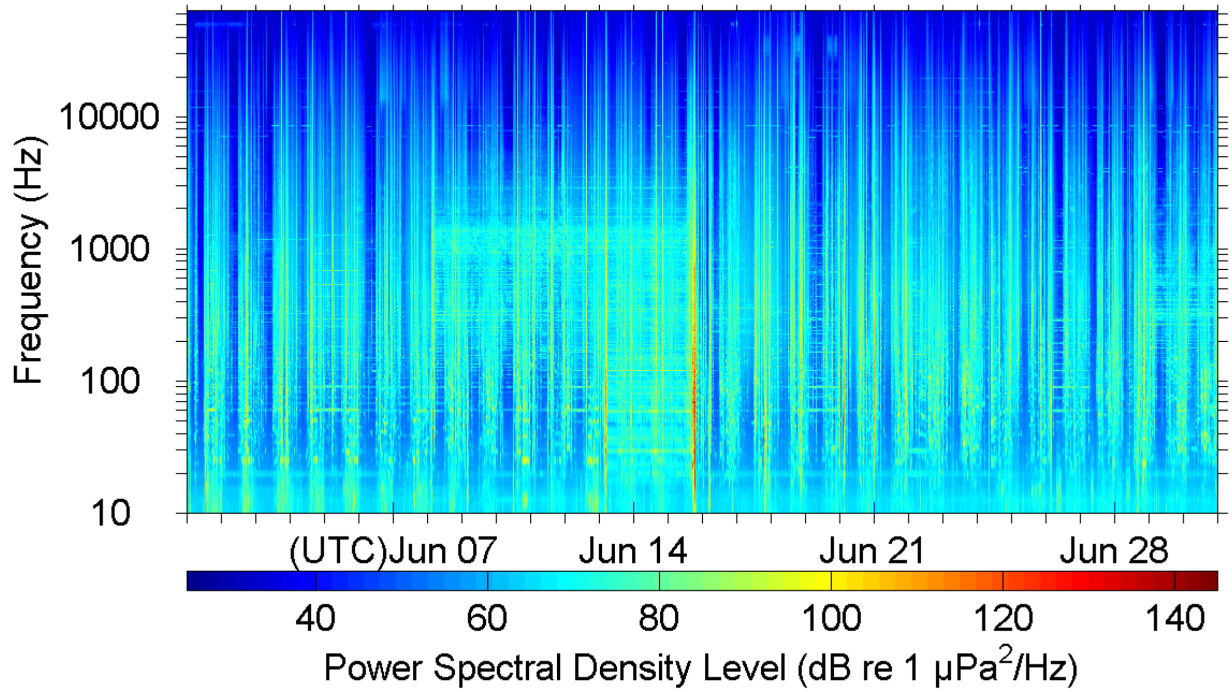

Figure 3-2. Ambient noise spectrogram (1 hour averages) at Site S1 from 1 Jun to 30 Jun. Frequency scale is logarithmic.

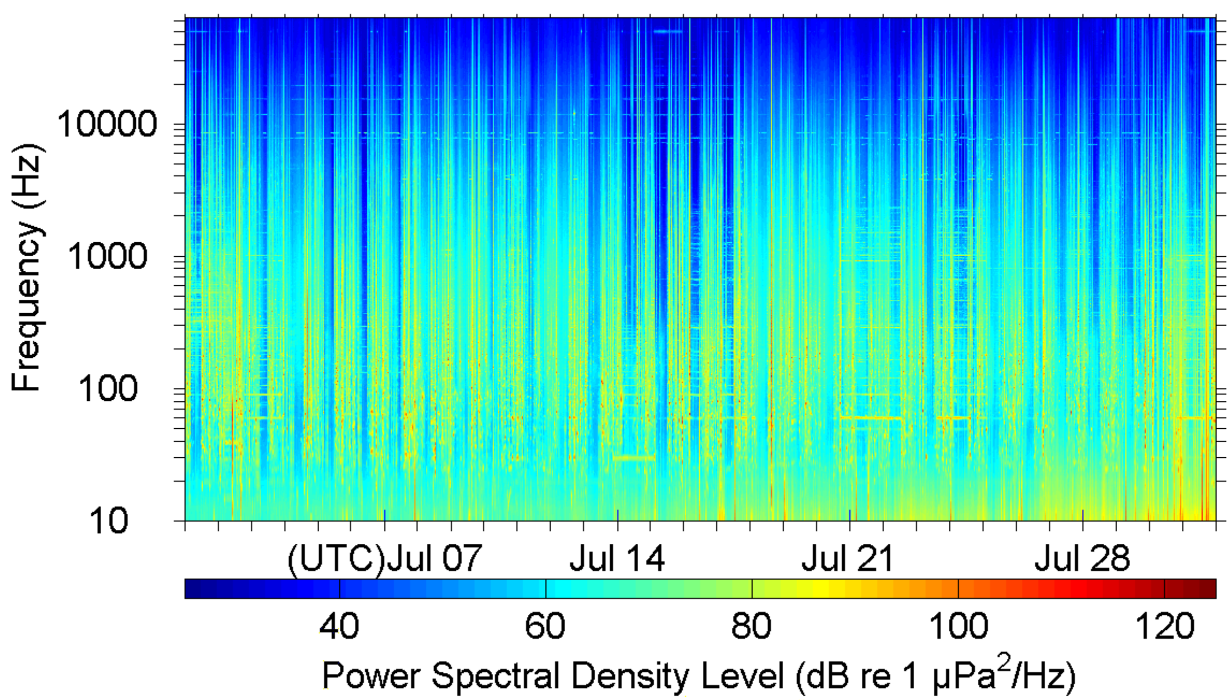

Figure 3-3. Ambient noise spectrogram (1 hour averages) at Site S1 from 1 Jul to 31 Jul. Frequency scale is logarithmic.

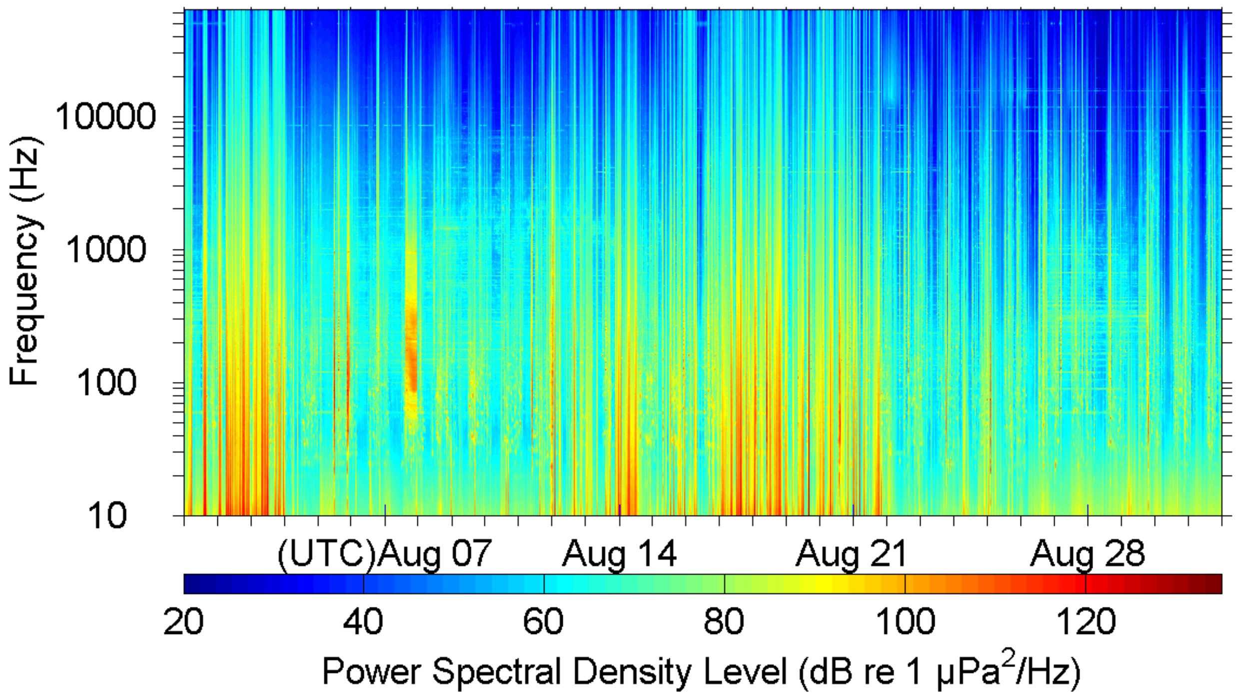

Figure 3-4. Ambient noise spectrogram (1 hour averages) at Site S1 from 1 Aug to 31 Aug. Frequency scale is logarithmic.

Figure 3-5 to Figure 3-8 show the month-long spectrograms of the recordings collected at Site S2 for May, June, July, and August respectively. Low frequency events with most of the energy below 100 Hz correspond to the pseudo-noise (i.e., strumming and flow noise) caused by the effect of tidal currents on the mooring.

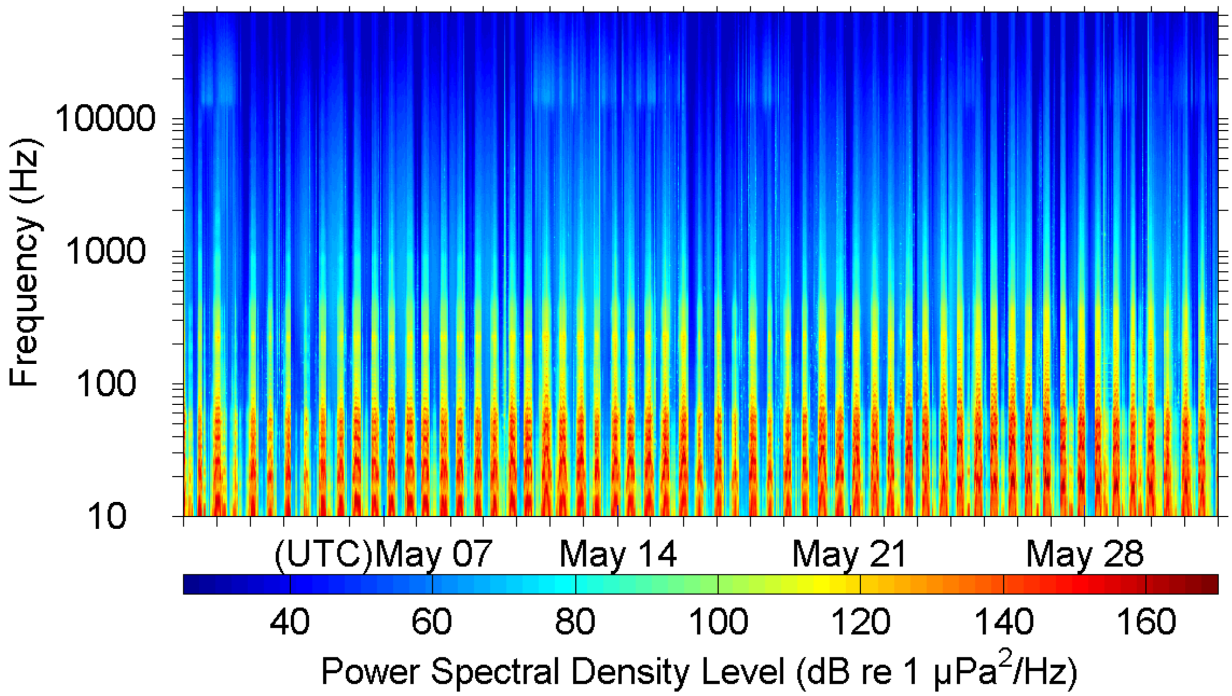

Figure 3-5. Ambient noise spectrogram (1 hour averages) at Site S2 from 1 May to 31 May. Frequency scale is logarithmic.

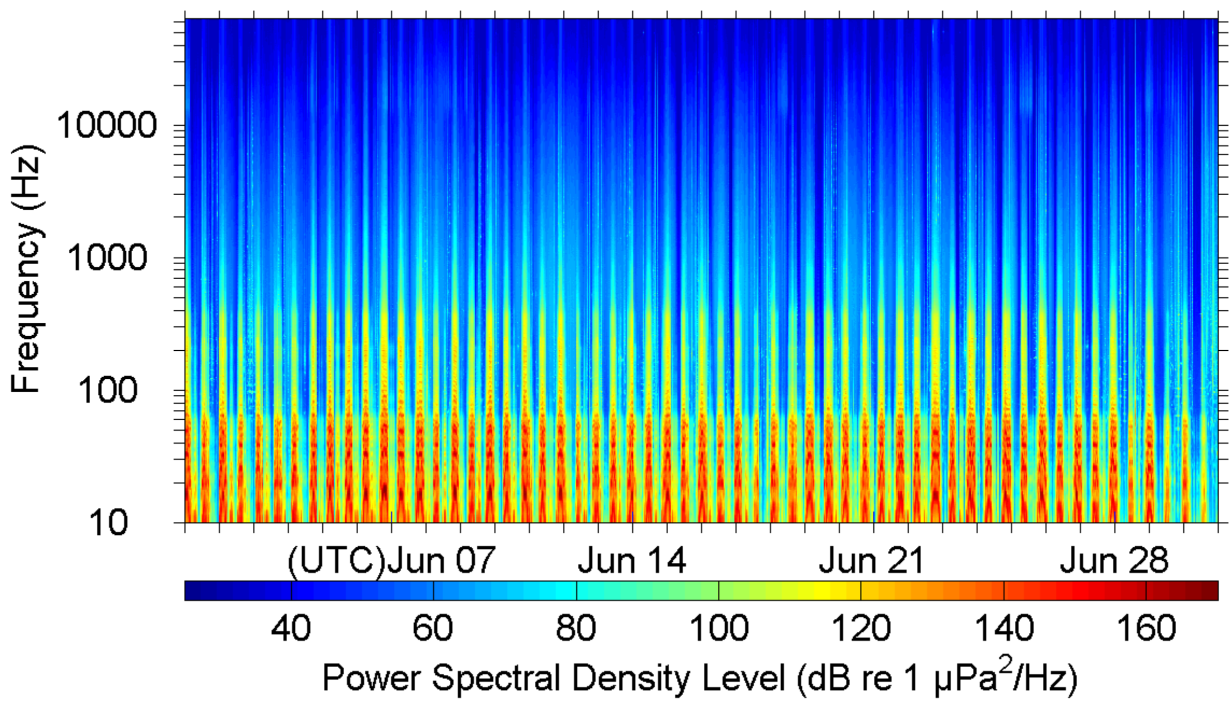

Figure 3-6. Ambient noise spectrogram (1 hour averages) at Site S2 from 1 Jun to 30 Jun. Frequency scale is logarithmic.

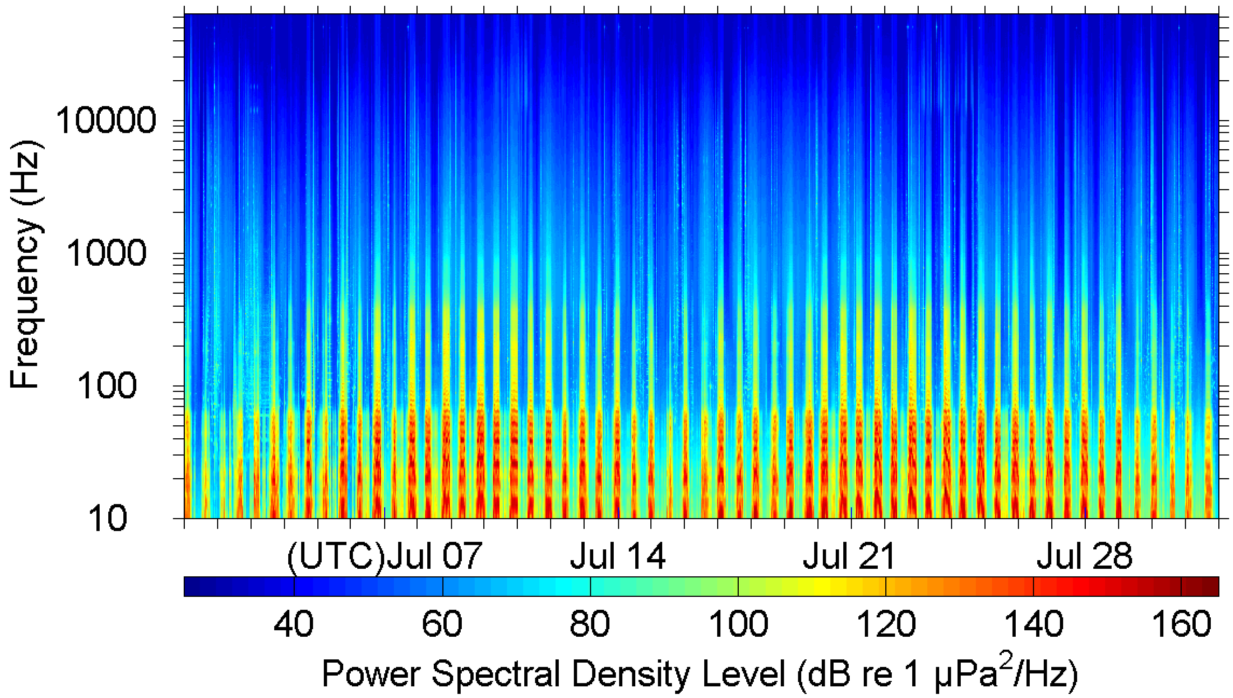

Figure 3-7. Ambient noise spectrogram (1 hour averages) at Site S2 from 1 Jul to 31 Jul. Frequency scale is logarithmic.

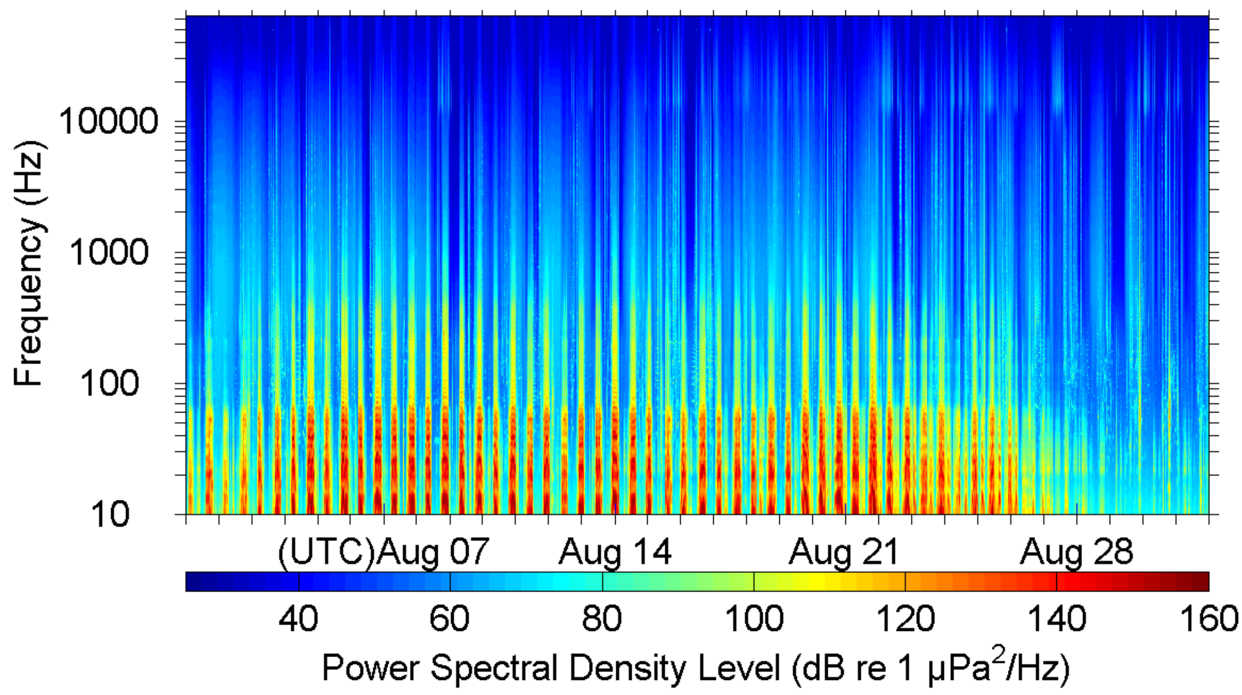

Figure 3-8. Ambient noise spectrogram (1 hour averages) at Site S2 from 1 Aug to 31 Aug. Frequency scale is logarithmic.

Figure 3-9 to Figure 3-12 show the month-long spectrograms of the recordings collected at Site S3 for May, June, July, and August respectively. Low frequency events with most of the energy below 100 Hz correspond to the pseudo-noise (i.e., strumming and flow noise) caused by the effect of underwater currents on the mooring.

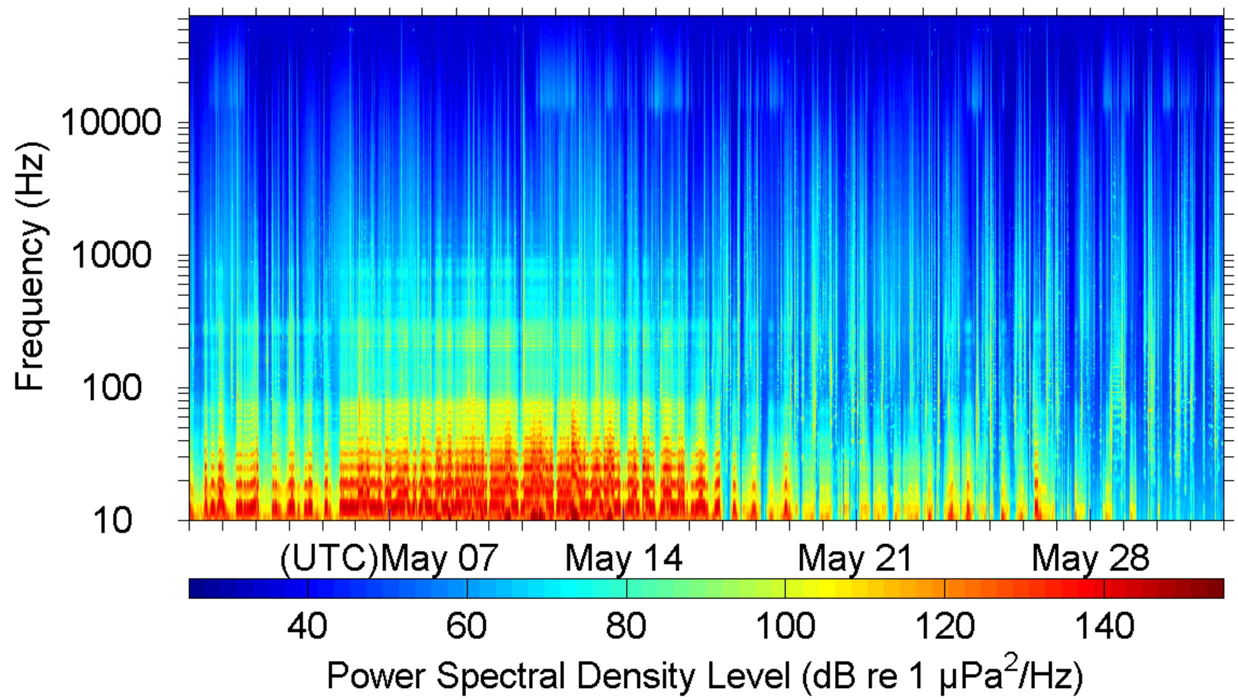

Figure 3-9. Ambient noise spectrogram (1 hour averages) at Site S3 from 1 May to 31 May. Frequency scale is logarithmic. Low frequency events with most of the energy below 100 Hz between 1 May and 19 May correspond to periods of pseudo-noise, which were due to effects of underwater currents on the mooring.

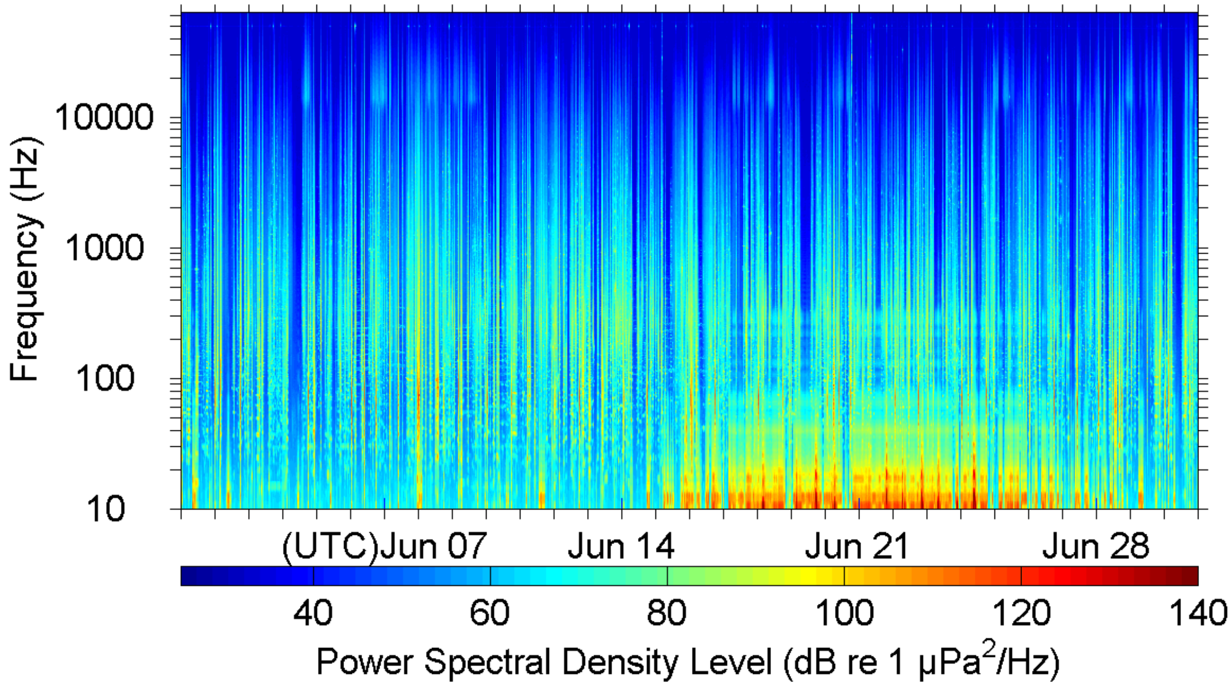

Figure 3-10. Ambient noise spectrogram (1 hour averages) at Site S3 from 1 Jun to 30 Jun. Frequency scale is logarithmic. Low frequency events with most of the energy below 50 Hz between 14 Jun and 27 Jun correspond to periods of pseudo-noise, which were due to effects of underwater currents on the mooring.

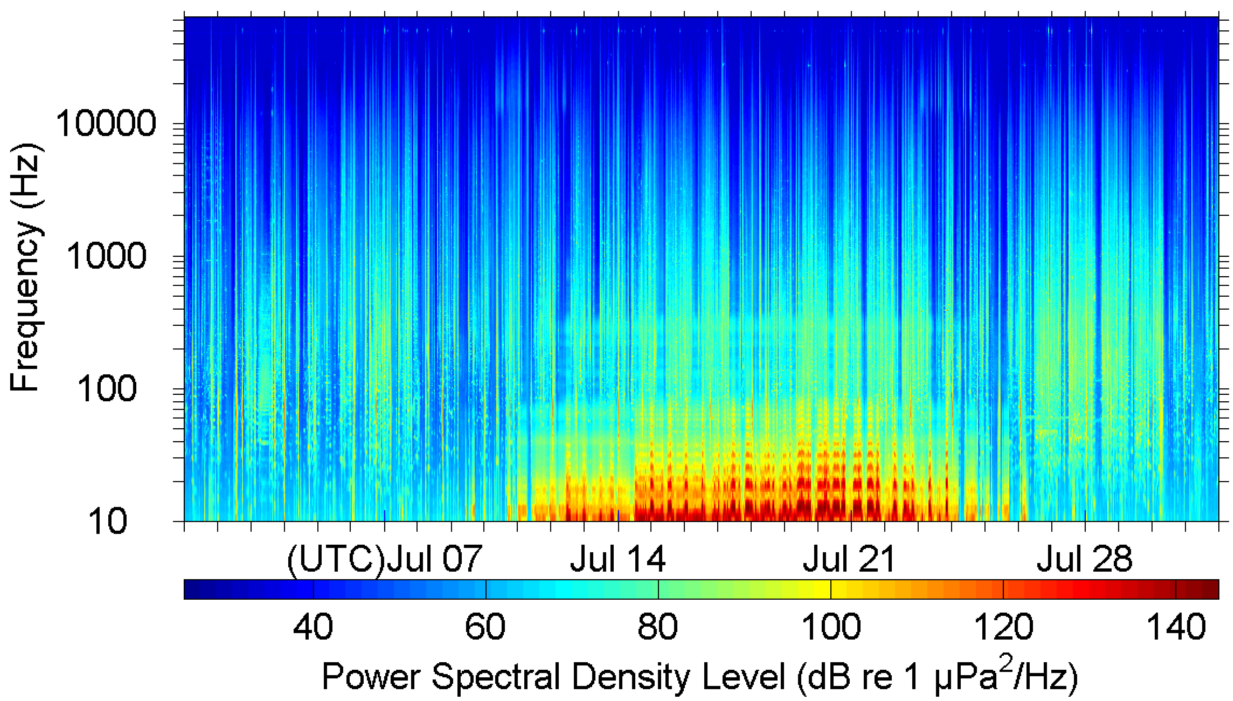

Figure 3-11. Ambient noise spectrogram (1 hour averages) at Site S3 from 1 Jul to 31 Jul. Frequency scale is logarithmic. Low frequency events with most of the energy below 100 Hz between 11 Jul and 24 Jul correspond to periods of pseudo-noise, which were due to effects of underwater currents on the mooring.

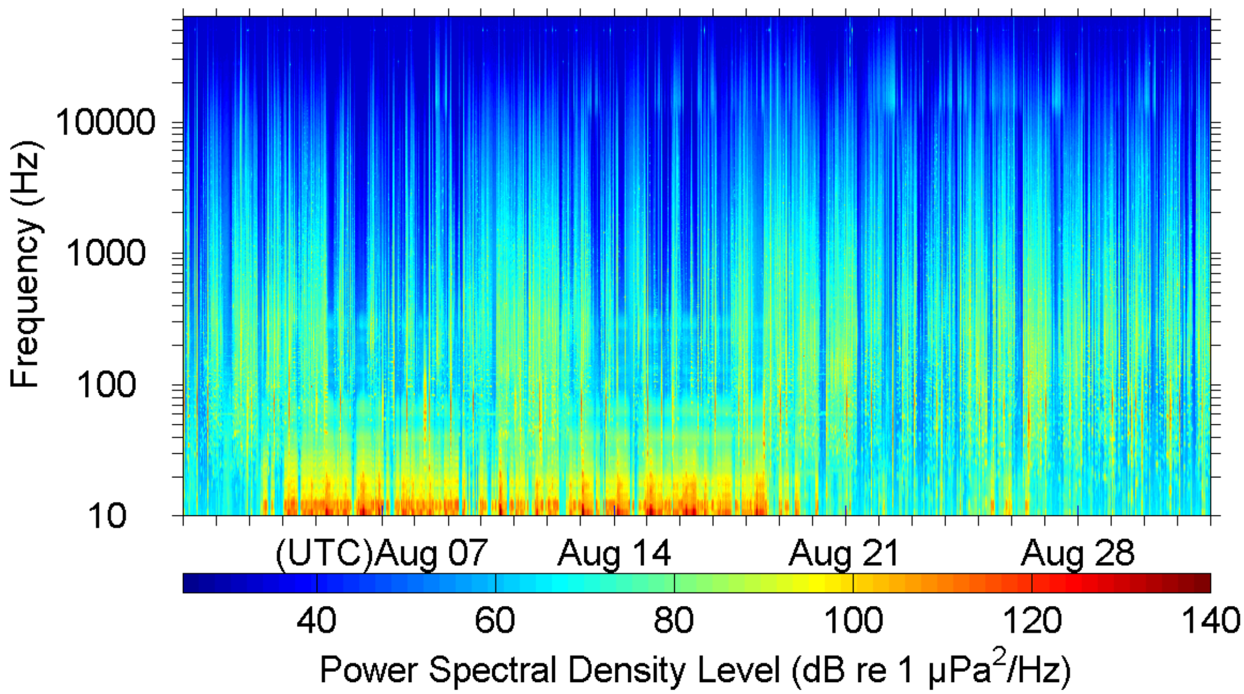

Figure 3-12. Ambient noise spectrogram (1 hour averages) at Site S3 from 1 Aug to 31 Aug. Frequency scale is logarithmic. Low frequency events with most of the energy below 50 Hz between 4 Aug and 19 Aug correspond to periods of pseudo-noise, which were due to effects of underwater currents on the mooring.

Figure 3-13 to Figure 3-16 show the month-long spectrograms of the recordings collected at Site S4 for May, June, July, and August respectively. Low frequency events with most of the energy below 20 Hz between 1 May and 31 Aug correspond to periods of pseudo-noise.

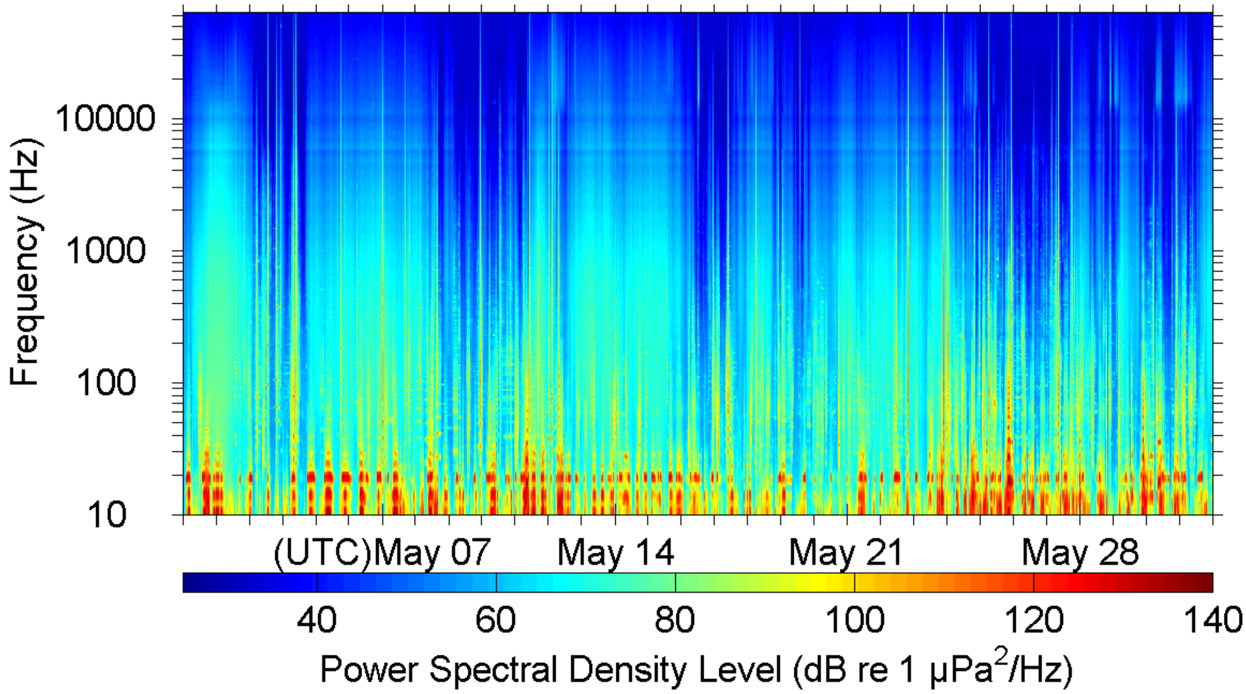

Figure 3-13. Ambient noise spectrogram (1 hour averages) at Site S4 from 1 May to 31 May. Frequency scale is logarithmic. Short acoustic events with high acoustic levels below 20 Hz correspond to periods of pseudo-noise, which were due to effects of underwater currents on the mooring.

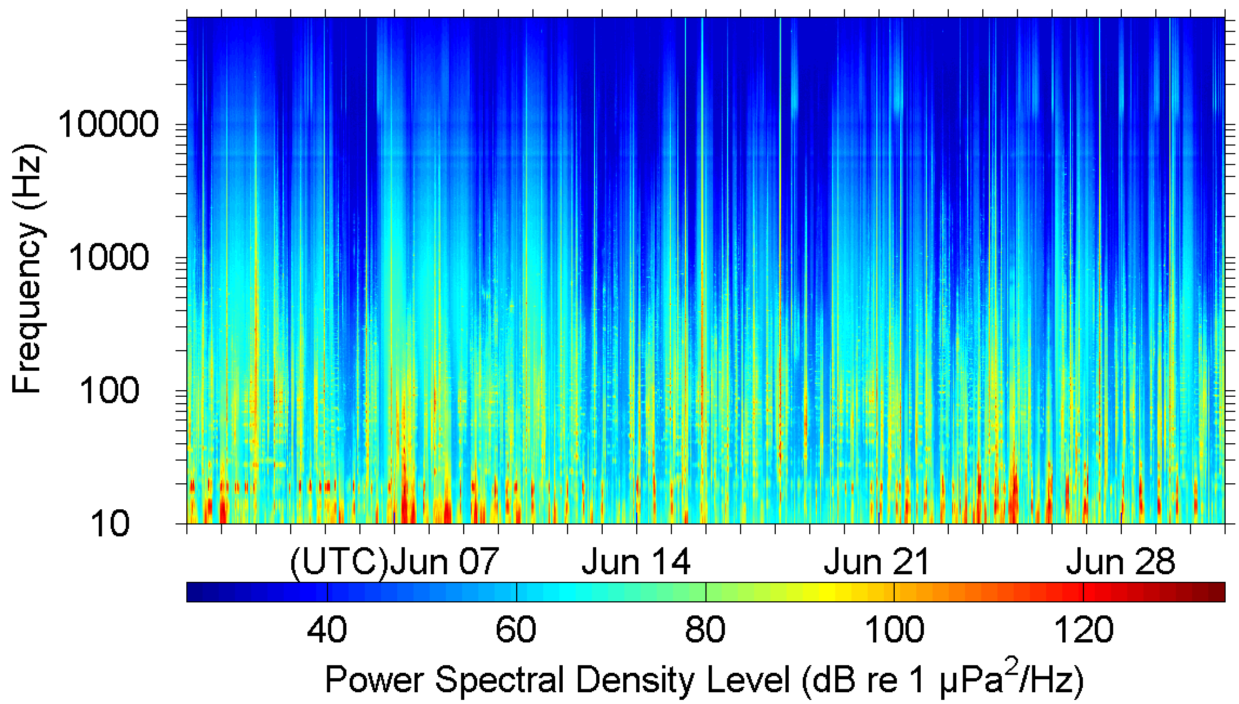

Figure 3-14. Ambient noise spectrogram (1 hour averages) at Site S4 from 1 Jun to 30 Jun. Frequency scale is logarithmic.

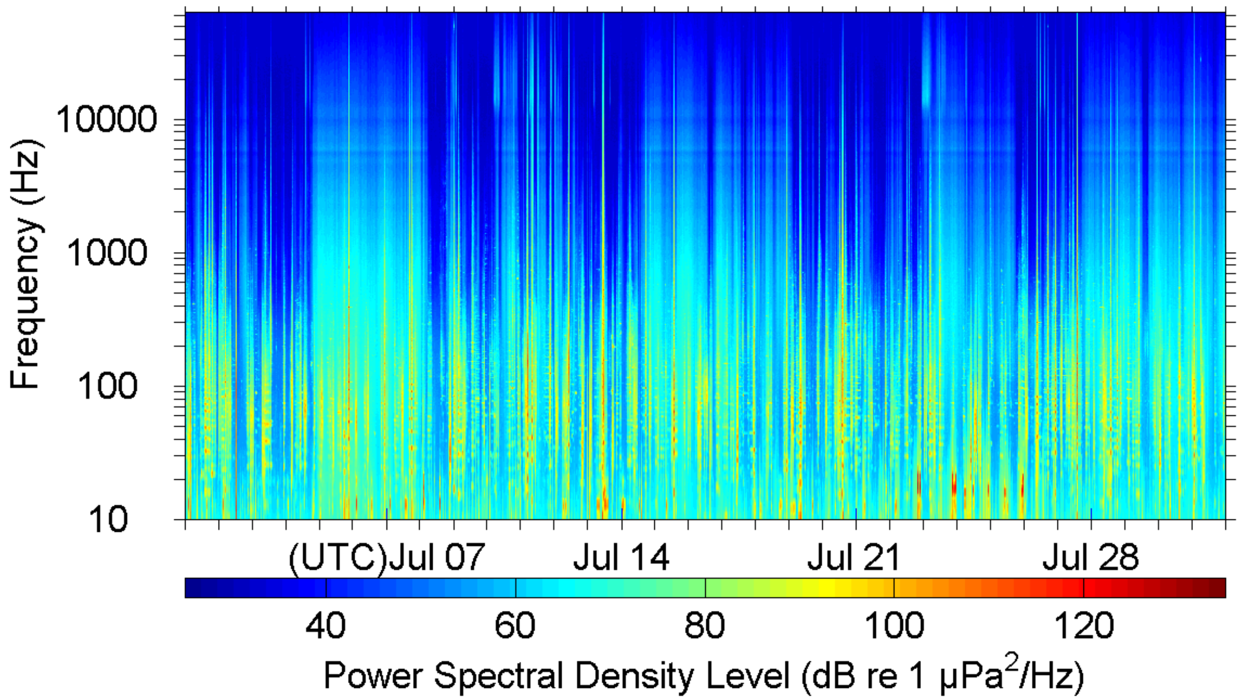

Figure 3-15. Ambient noise spectrogram (1 hour averages) at Site S4 from 1 Jul to 31 Jul. Frequency scale is logarithmic.

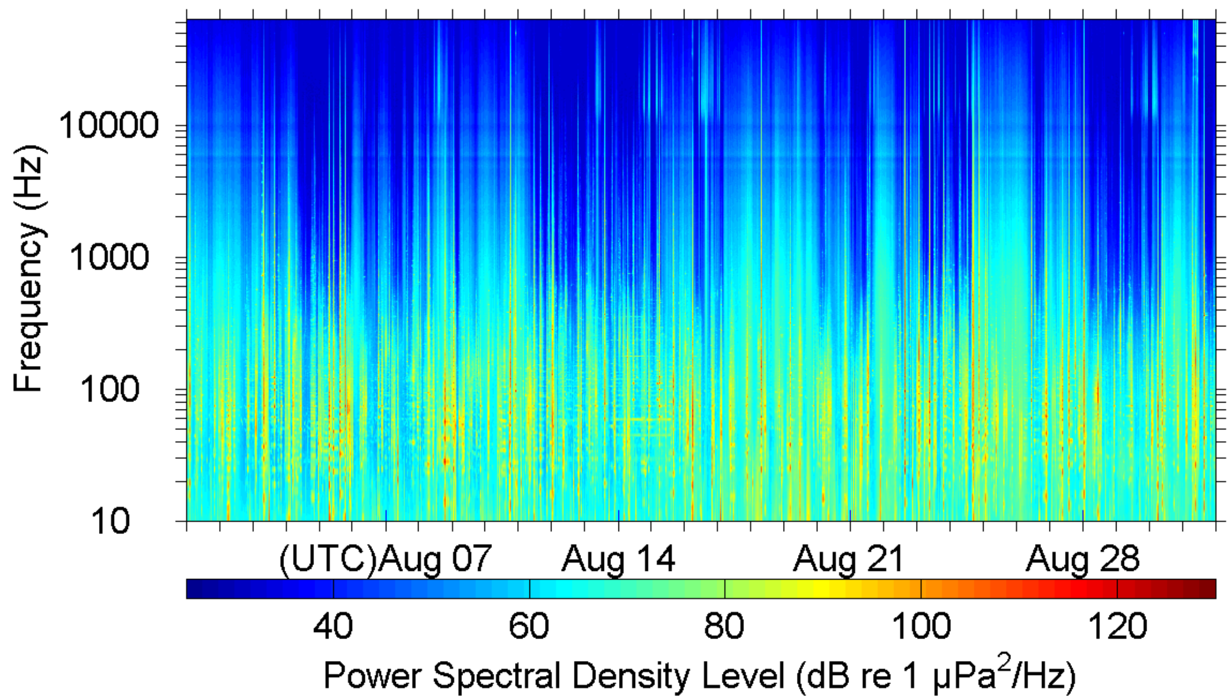

Figure 3-16. Ambient noise spectrogram (1 hour averages) at Site S4 from 1 Aug to 31 Aug. Frequency scale is logarithmic.

Appendix 4. Distribution of the Broadband and Decade Band SPLs

Figure 4-1 to Figure 4-4 show the distribution of the broadband and decade band SPLs at Sites S1, S2, S3, and S4.

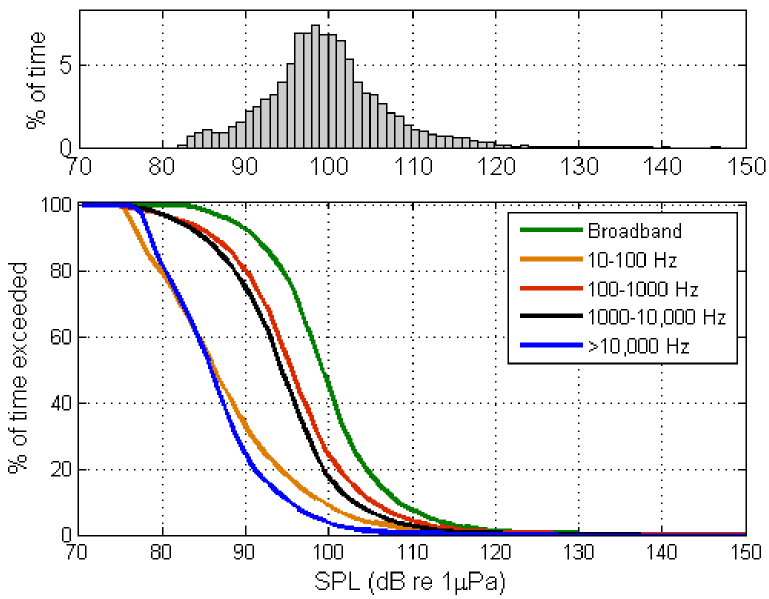

Figure 4-1. SPLs of the recordings collected at Site S1. (Top) Histogram of the broadband SPLs (1 minute average) using 1 dB bins. (Bottom) Distribution of decade band and broadband SPLs (1 minute average).

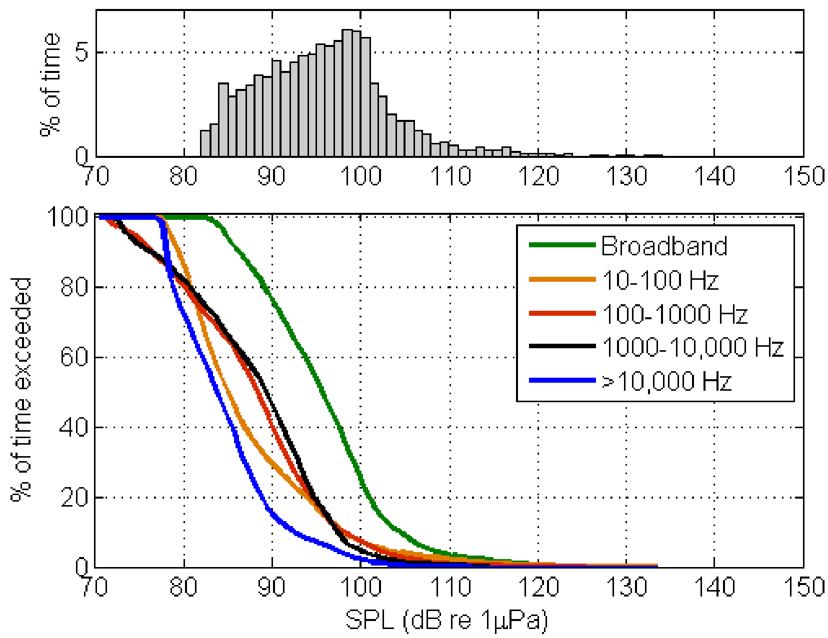

Figure 4-2. SPLs of the recordings collected at Site S2. (Top) Histogram of the broadband SPLs (1 minute average) using 1 dB bins. (Bottom) Distribution of decade band and broadband SPLs (1 minute average).

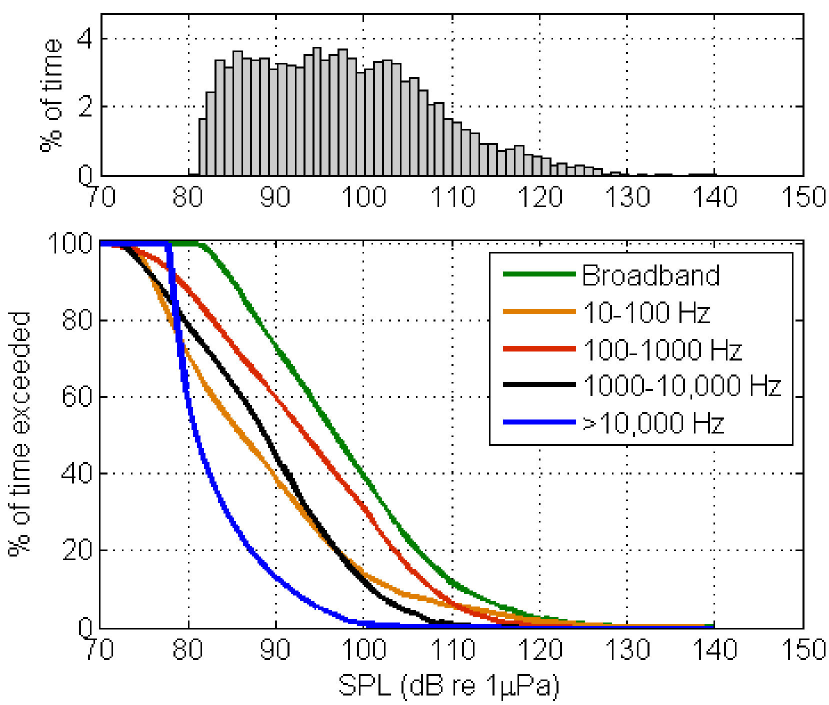

Figure 4-3. SPLs of the recordings collected at Site S3. (Top) Histogram of the broadband SPLs (1 minute average) using 1 dB bins. (Bottom) Distribution of decade band and broadband SPLs (1 minute average).

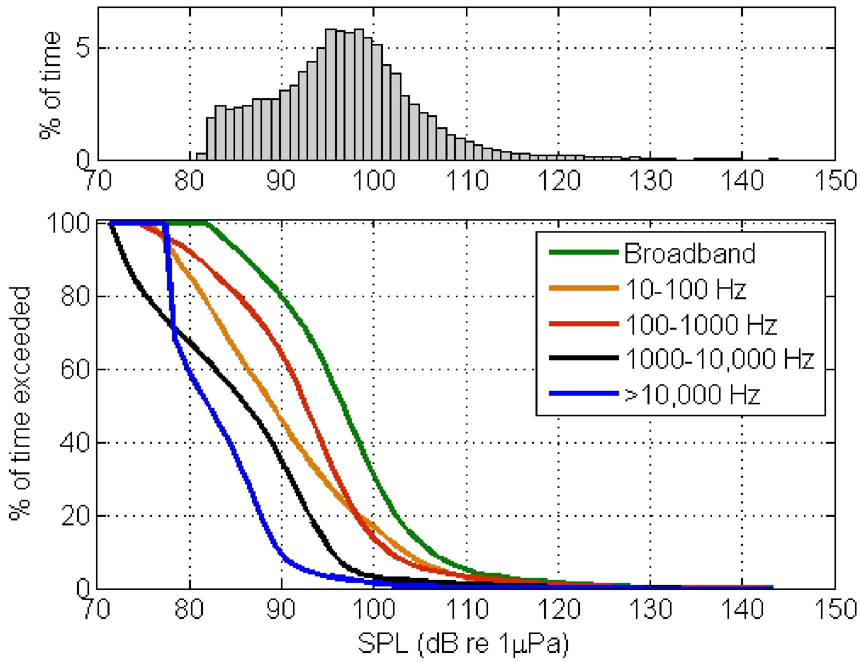

Figure 4-4. SPLs of the recordings collected at Site S4. (Top) Histogram of the broadband SPLs (1 minute average) using 1 dB bins. (Bottom) Distribution of decade band and broadband SPLs (1 minute average).

Appendix 5. 1/3-Octave-Band Levels

Table 5-1 to Table 5-4 provide statistics of the 1/3-octave-band levels at Sites S1, S2, S3, and S4 respectively.

Table 5-1. Statistics of the 1/3-octave-band levels at Site S1 over the monitoring period. L_{95}, L_{75}, L_{50}, L_{25}, and L_5 correspond to the 95th, 75th, 50th, 25th, and 5th percentiles, respectively.

1/3-octave-band (centre frequency in Hz)	L_{95} (dB re 1 µPa)	L_{75} (dB re 1 µPa)	L_{50} (dB re 1 µPa)	L_{25} (dB re 1 µPa)	L_5 (dB re 1 µPa)
10	68.27	69.51	71.08	73.29	78.36
13	68.89	70.16	71.79	74.34	82.07
16	66.67	68.01	70.04	73.03	79.94
20	66.45	68.65	70.44	73.6	81.13
25	63.97	65.84	69.45	75.09	88.56
32	63.52	65.89	70.84	77.51	88.61
40	62.29	65.17	70.51	78.73	91.23
50	61.98	65.88	71.77	79.65	93.30
63	64.06	69.66	77.81	84.69	96.49
80	63.26	69.1	76.02	83.69	97.68
100	65.17	72.53	80.19	85.38	96.97
125	67.53	74.62	80.41	87.14	97.07
160	68.64	75.92	81.17	87.52	98.70
200	69.91	77.06	81.49	87.12	97.63
250	71.28	79.65	83.85	88.51	98.35
315	71.92	81.27	85.96	90.49	99.49
400	71.24	80.69	85.46	90.03	99.90
500	71.92	81.13	85.55	89.87	99.59
630	72.46	81.72	86.04	90.36	99.41
800	71.48	81.19	85.78	90.26	99.54
1000	72.57	82.32	86.89	91.54	99.46
1250	72.94	81.76	86.36	91.41	98.88
1600	70.53	80.41	85.07	89.09	97.71

1/3-octave-band (centre frequency in Hz)	L_{95} (dB re 1 µPa)	L_{75} (dB re 1 µPa)	L_{50} (dB re 1 µPa)	L_{25} (dB re 1 µPa)	L_{5} (dB re 1 µPa)
2000	70.07	80.15	84.44	88.33	97.06
2500	69.51	79.33	83.72	87.72	96.54
3150	69.12	79.16	83.41	87.63	96.41
4000	68.75	78.06	82.38	86.67	95.45
5000	67.23	76.77	81.58	85.93	94.98
6300	68.1	75.58	80.69	84.98	94.31
8000	72.7	77.64	80.95	84.32	93.36
10000	65.93	73.27	78.77	82.85	92.28
12500	67.08	73.44	79.02	83.21	92.26
16000	66.69	72.19	77.83	82.3	91.96
20000	67.36	71.53	76.92	81.25	90.58
25000	68.41	71.27	76.07	80.06	88.96
31500	69.44	71.18	75.27	78.82	87.09
40000	70	71.29	74.22	77.2	84.41
50000	71.2	72.5	74.63	76.99	82.66

Table 5-2. Statistics of the 1/3-octave-band levels at Site S2 over the monitoring period. L_{95}, L_{75}, L_{50}, L_{25}, and L_{5} correspond to the 95th, 75th, 50th, 25th, and 5th percentiles, respectively.

1/3-octave-band (centre frequency in Hz)	L_{95} (dB re 1 µPa)	L_{75} (dB re 1 µPa)	L_{50} (dB re 1 µPa)	L_{25} (dB re 1 µPa)	L_{5} (dB re 1 µPa)
10	72.44	75.1	78.24	86.08	98.19
13	71.26	73.44	76.07	81.52	93.77
16	69.64	71.47	73.7	78.03	90.77
20	68.73	70.67	72.7	77.18	89.18
25	67.76	69.54	71.61	76.35	87.47
32	66.88	68.73	71.01	75.72	84.96
40	65.61	67.65	70.35	75.63	85.48
50	64.85	67.19	70.32	75.67	86.31

1/3-octave-band (centre frequency in Hz)	L_{95} (dB re 1 µPa)	L_{75} (dB re 1 µPa)	L_{50} (dB re 1 µPa)	L_{25} (dB re 1 µPa)	L_{5} (dB re 1 µPa)
63	64.34	66.65	70.19	75.92	88.38
80	63.44	65.96	70.27	75.9	88.15
100	62.71	66.04	71	76.97	90.49
125	62.61	67.01	72.78	78.68	89.95
160	61.92	67.42	73.35	78.96	89.83
200	61.90	68.24	74.44	79.98	90.68
250	62.49	69.19	75.76	81.24	91.37
315	63.31	70.14	77.2	82.59	92.11
400	63.11	70.93	78.13	83.16	92.24
500	63.17	71.86	78.99	83.84	90.86
630	63.2	72.71	79.76	84.6	90.43
800	62.89	72.76	79.88	84.5	89.78
1000	62.65	72.82	80.05	84.6	89.81
1250	62.98	73.17	80.46	85.05	90.06
1600	62.44	72.48	79.83	84.48	89.57
2000	62.56	72.41	79.76	84.37	89.64
2500	62.94	72.41	79.69	84.25	89.99
3150	63.3	72.26	79.46	84.02	90.14
4000	63.28	71.62	78.76	83.27	89.79
5000	63.77	71.49	78.39	82.85	89.39
6300	64.41	71.26	77.94	82.24	88.53
8000	64.59	70.61	77.15	81.39	87.38
10000	65.13	70.37	76.9	80.89	86.51
12500	66.22	70.93	77.23	81.62	89.79
16000	66.52	70.09	75.84	80.65	91.38
20000	67.37	69.61	74.61	79.19	90.10
25000	68.52	69.7	73.56	77.61	87.87
31500	69.67	70.34	72.69	76.13	85.48

1/3-octave-band (centre frequency in Hz)	L_{95} (dB re 1 µPa)	L_{75} (dB re 1 µPa)	L_{50} (dB re 1 µPa)	L_{25} (dB re 1 µPa)	L_{5} (dB re 1 µPa)
40000	70.37	70.95	72.18	74.6	82.32
50000	71.58	72.13	72.71	74.22	79.99

Table 5-3. Statistics of the 1/3-octave-band levels at Site S3 over the monitoring period. L_{95}, L_{75}, L_{50}, L_{25}, and L_{5} correspond to the 95th, 75th, 50th, 25th, and 5th percentiles, respectively.

1/3-octave-band (centre frequency in Hz)	L_{95} (dB re 1 µPa)	L_{75} (dB re 1 µPa)	L_{50} (dB re 1 µPa)	L_{25} (dB re 1 µPa)	L_{5} (dB re 1 µPa)
10	67.43	68.15	69.31	73.61	89.80
13	66.55	67.22	68.31	71.13	89.53
16	65.34	66.24	67.91	71.87	88.92
20	64.63	65.79	68.22	73.67	88.89
25	63.88	65.69	69.73	77.18	91.69
32	63.64	66.41	71.87	80.11	94.3
40	62.91	66.73	73.8	82.76	96.90
50	62.59	67.28	74.87	84.19	98.16
63	62.76	68.68	77.53	86.65	101.80
80	62.4	68.55	77.74	87.47	102.18
100	63.08	69.53	79.06	88.87	101.95
125	64.61	71.98	81.38	90.74	101.49
160	64.82	71.99	81.35	90.91	101.11
200	65.33	72.56	81.79	91.53	101.36
250	66.21	73.30	82.93	92.18	101.69
315	65.87	73.94	83.44	92.30	101.44
400	65.38	73.72	82.83	91.44	100.58
500	65.57	73.94	82.66	90.97	100.26
630	65.52	73.87	81.98	90.21	99.71
800	64.98	73.49	81.4	89.11	98.81
1000	64.79	73.24	80.92	88.43	97.94

1/3-octave-band (centre frequency in Hz)	L_{95} (dB re 1 µPa)	L_{75} (dB re 1 µPa)	L_{50} (dB re 1 µPa)	L_{25} (dB re 1 µPa)	L_{5} (dB re 1 µPa)
1250	64.57	72.93	80.61	87.92	97.03
1600	63.89	71.84	79.48	86.54	95.58
2000	63.56	71.25	78.87	85.73	94.72
2500	63.69	70.90	78.49	85.21	94.31
3150	63.94	70.7	78.21	84.73	93.69
4000	63.8	69.99	77.26	83.76	92.56
5000	64.17	69.74	76.8	83.11	91.97
6300	64.71	69.5	76.21	82.24	91.04
8000	64.85	68.76	75.17	80.90	89.57
10000	65.38	68.36	74.18	79.74	88.28
12500	66.5	68.58	73.65	79.85	88.83
16000	66.84	68.01	71.78	77.97	88.95
20000	67.77	68.3	70.58	76.01	87.05
25000	68.99	69.18	70.29	74.25	84.87
31500	70.33	70.39	70.77	72.82	82.11
40000	71.26	71.28	71.39	72.19	78.7
50000	72.71	72.74	72.78	73.11	77.55

Table 5-4. Statistics of the 1/3-octave-band levels at Site S4 over the monitoring period. L_{95}, L_{75}, L_{50}, L_{25}, and L_{5} correspond to the 95th, 75th, 50th, 25th, and 5th percentiles, respectively.

1/3-octave-band (centre frequency in Hz)	L_{95} (dB re 1 µPa)	L_{75} (dB re 1 µPa)	L_{50} (dB re 1 µPa)	L_{25} (dB re 1 µPa)	L_{5} (dB re 1 µPa)
10	67.89	69.17	71.23	75.81	87.22
13	66.84	68.44	70.89	75.34	85.27
16	65.74	67.62	70.68	75.96	86.48
20	65.35	67.85	71.65	76.94	87.06
25	65.06	68.16	73.03	79.61	91.6
32	65.37	69.31	75.16	82.25	94.11

1/3-octave-band (centre frequency in Hz)	L_{95} (dB re 1 µPa)	L_{75} (dB re 1 µPa)	L_{50} (dB re 1 µPa)	L_{25} (dB re 1 µPa)	L_{5} (dB re 1 µPa)
40	65.1	69.97	75.89	83.92	96.04
50	66	71.45	78.11	86.22	98.7
63	67.28	73.45	80.64	88.74	100.16
80	67.38	74.56	81.46	89.58	101.13
100	67.82	75.16	81.91	89.08	99.49
125	69.29	76.28	82.86	89.05	99.04
160	69.19	76.18	82.11	87.62	97.27
200	68.99	76.32	81.63	86.49	96.13
250	68.57	76.18	81.51	86.25	95.56
315	67.71	76.12	81.73	86.22	94.71
400	65.95	74.72	80.84	85.15	93.37
500	64.48	73.09	80.04	84.71	92.24
630	63.15	71.86	79.69	84.76	91.38
800	61.84	70.20	78.86	84.21	90.63
1000	61.21	69.15	78.14	83.72	89.88
1250	61.11	68.53	77.88	83.66	89.54
1600	60.56	67.41	76.96	82.82	88.65
2000	60.74	67.03	76.45	82.33	88.03
2500	61.1	66.56	76.2	82.17	87.8
3150	61.56	66	75.61	81.55	87.1
4000	61.68	65.11	74.44	80.35	85.82
5000	62.35	64.91	74.52	80.49	85.68
6300	63.02	64.91	75.49	81.54	86.35
8000	63.41	64.74	74.33	80.23	84.98
10000	64.23	65.19	73.43	79.04	83.64
12500	65.49	66.27	74.4	80.07	85.13
16000	65.99	66.53	73.17	78.72	84.78
20000	66.99	67.38	72.83	78.15	84.44

1/3-octave-band (centre frequency in Hz)	L_{95} (dB re 1 µPa)	L_{75} (dB re 1 µPa)	L_{50} (dB re 1 µPa)	L_{25} (dB re 1 µPa)	L_{5} (dB re 1 µPa)
25000	68.25	68.56	72.67	77.61	83.58
31500	69.65	69.88	72.75	76.99	82.4
40000	70.62	70.81	72.59	75.92	80.38
50000	72.01	72.15	73.2	75.56	79.03

APPENDIX G:

JASCO Applied Sciences: Underwater Acoustic Modelling of Marine Terminal Construction and Vessel Activities

Underwater Acoustic Modelling of Marine Terminal Construction and Vessel Activities

LNG Canada Project, Kitimat, BC

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Contents

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Abbreviations

Abbreviation	Definition
2-D	two-dimensional
µPa	micropascal (derived pressure unit)
AMAR	Autonomous Multichannel Acoustic Recorder
BC	British Columbia
BCEAA	British Columbia Environmental Assessment Act
CEAA	Canadian Environmental Assessment Act
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CTD	conductivity-temperature-depth measurement device
dB	decibel
DFO	Fisheries and Oceans Canada
EEZ	Exclusive Economic Zone
GSC	Geological Survey of Canada
HT	hearing threshold
Hz	hertz
J	joule
kHz	kilohertz
kJ	kilojoule
km	kilometre
kts	knots
LNG	liquefied natural gas
m	metre
MONM	Marine Operations Noise Model
NMFS	U.S. National Marine Fisheries Service
PE	parabolic equation
ppt	parts per thousand
PTS	permanent threshold shift
RAM	Range-dependent Acoustic Model
re	relative to (as an absolute reference for decibel scales)
rms	root-mean-square
SEL	sound exposure level
SL	source level (received level measured or estimated 1 m from the source)
SPL	sound pressure level

Abbreviation	Definition
SSP	sound speed profile
TL	transmission loss
TSHD	trailing suction hopper dredge
TTS	temporary threshold shift
UTM	Universal Transverse Mercator geographic coordinate system
USGS	U.S. Geological Survey

1. Introduction

LNG Canada proposes to construct marine terminal facilities in the Kitimat area, British Columbia, for liquefied natural gas (LNG) export by ocean-going LNG carriers (the Project). At full build out, the marine terminal expects to have 170–350 LNG carriers visiting per year. Terminal construction and increased marine traffic will generate underwater noise that has the potential to negatively affect local marine mammals. This study assesses the expected underwater noise emissions from Project activities in relation to identifying potential effects on marine fauna.

JASCO Applied Sciences Ltd. (JASCO), under contract to Stantec, performed an underwater acoustic modelling study to predict the underwater sound levels generated by terminal construction (pile driving and dredging) and vessel activities (transiting and berthing), specifically associated with the Project. The goal of this study was to use computer models to predict the extent of ensonification from these activities and to define zones of potential effects based on accepted sound level effects thresholds. The modelled results are intended to be used in support of the assessment of potential acoustic impacts on selected species for the Project's environmental assessment being developed by Stantec, per requirements under the British Columbia Environmental Assessment Act (BCEAA) and the Canadian Environmental Assessment Act (CEAA) 2012.

The modelling study considered three scenarios for proposed marine terminal construction and five scenarios for configurations of LNG carriers and tugs transiting along the shipping route. The construction scenarios included impact sheet pile driving, impact cylinder pile driving and dredging. The vessel scenarios were defined by specific configurations of carriers and tugs during berthing at the terminal and during transits in Douglas Channel, Wright Sound, Nepean Sound, and from Principe Channel into open water at Browning Entrance.

A complementary acoustic propagation model, Marine Operations Noise Model (MONM) by JASCO Applied Sciences (Hannay and Racca 2005), was used to calculate the noise emissions and sound propagation near each of the defined scenarios. MONM accepts the source specification of all equipment, and the ocean bathymetry, water sound speed profile, and seabed geoacoustic parameters as inputs. It generates sound level maps in several frequency bands that can be frequency weighted to allow for species-specific effects assessment, according to the audiometric sensitivity of the species (using audiogram weighting or M-weighting).

The marine mammals of focus in the study area are humpback whales (*Megaptera novaeangliae*), fin whales (*Balaenoptera physalus*), killer whales (*Orcinus orca*), and harbour porpoises (*Phocoena phocoena*). Audiogram weighting and M-weighting (Southall et al. 2007) were applied to the modelled results. The sound level estimates were presented in sound field isopleth maps, which show the planar distribution of sound levels with range and azimuthal direction, and in tables, which list distances from the source to threshold sound levels. This study also estimated the cumulative sound exposure levels from multiple strikes from impact pile driving activities.

To aid interpretation of the results, the acoustic metrics used in this report are defined and discussed in Section 2. Section 3 describes the terminal construction and vessel traffic activities and the corresponding acoustic modelling scenarios. Section 4 presents acoustic source levels of the project equipment, discusses the sound propagation models, describes the acoustic environment, frequency weighting methods, acoustic effects criteria, and the ambient noise at modelled sites. Results are provided in Section 5 with a discussion of these results and a summary in Sections 6 and 7, respectively.

2. Acoustic Metrics

Underwater sound amplitude is commonly measured in decibels (dB). The dB scale is a logarithmic scale that expresses a quantity relative to a predefined reference level. Sound pressure, in dB, is expressed in terms of the sound pressure level (SPL), symbolized L_p:

$$L_p = 20\log_{10}(P / P_{ref}) \tag{1}$$

where P is the pressure amplitude and P_{ref} is the reference sound pressure. For underwater sound, the reference pressure is 1 μPa (10^{-6} Pa or 10^{-11} bar).

Sounds composed of single frequencies or very narrow bands of frequencies are commonly referred to as tones. Most sounds are generally composed of a broad range of frequencies (broadband sound) rather than pure tones.

2.1. Continuous Sound

Continuous sound is characterized by gradual changes of sound pressure levels over time, e.g., the propeller noise from a transiting vessel. Given a measurement of the time varying sound pressure, $p(t)$, for a given noise source, the root-mean-square (rms) SPL (symbol L_p) is computed according to the following formula:

$$L_p = 10\log_{10} \frac{1}{T}\int_T p(t)^2\,dt / P_{ref}{}^2 \tag{2}$$

In this formula, T is the time over which the measurement was obtained. Figure 1 shows an example of a continuous sound pressure waveform and the corresponding rms sound pressure.

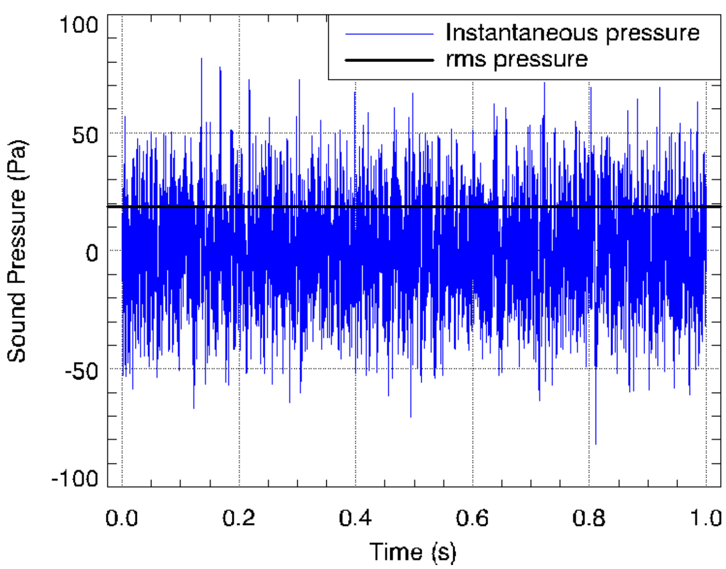

Figure 1. Example waveform showing a continuous noise measurement and the corresponding root-mean-square (rms) sound pressure.

2.2. Impulsive Sound

Sounds with very short durations (less than a few seconds) are referred to as impulsive. These are typically characterised by abrupt increases of sound pressure over less than a second, followed by rapid decay back to pre-existing levels (within a few seconds). Noise from impact pile driving is typically considered impulsive.

The zero-to-peak, or peak SPL (L_{pk}, dB re 1 µPa) is the maximum instantaneous sound pressure level attained by a pulse, *p(t)*:

$$L_{pk} = 20\log_{10}\left(\max\left|p(t)\right| / P_{ref}\right) \tag{3}$$

In this formula, $p(t)$ is the instantaneous sound pressure as a function of time, measured over the pulse duration $0 \le t \le T$. This metric is commonly quoted for impulsive sounds, but does not take into account the duration or bandwidth of the noise. At high sound pressures (e.g., for shock fronts) the peak SPL can be a valid criterion for assessing whether a sound is potentially injurious; however, because the peak SPL does not consider pulse duration, it is not a good indicator of perceived loudness. A similar metric, the peak-to-peak SPL ($L_{pk\text{-}pk}$) measures the difference between the maximum and minimum instantaneous sound pressure levels.

The root-mean-square (rms) SPL (L_p, dB re 1 µPa) is measured over the pulse duration according to the following equation:

$$L_p = 10\log_{10}\left(\frac{1}{T}\int_T p(t)^2\,dt / P_{ref}^2\right) \tag{4}$$

Some ambiguity remains in how the duration T is defined because in practice the beginning and end of a pulse can be difficult to identify precisely. In studies of impulsive noise, T is often accepted as the interval over which the cumulative energy curve rises from 5% to 95% of the total energy. This interval contains 90% of the total pulse energy (T_{90}); the SPL computed over this interval is commonly referred to as the 90% rms SPL (L_{p90}). The relative energy, $E(t)$, of the pulse is computed from the time integral of the square pressure:

$$E(t) = \int_0^t p(\tau)^2\,d\tau / P_{ref}^2 \tag{5}$$

According to this definition, if the time corresponding to n% of the total relative energy of the pulse is denoted t_n, then the 90% energy window is defined such that $T_{90} = t_{95} – t_5$. Figure 2 shows an example of an impulsive noise pressure waveform, with the corresponding peak pressure, rms pressure, and 90% energy time interval.

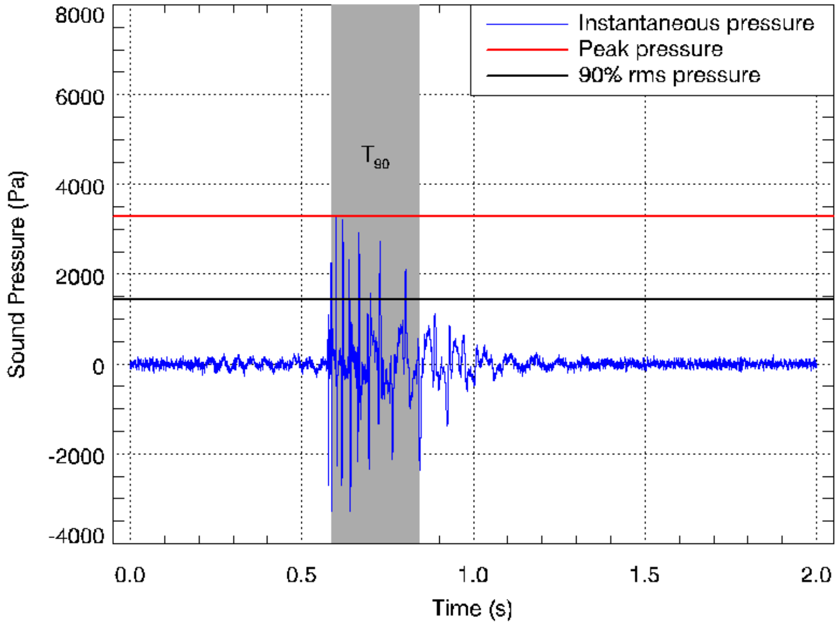

Figure 2. Example waveform showing an impulsive noise measurement. Horizontal lines indicate the peak pressure and 90% rms pressure for this pulse. The grey area indicates the 90% energy time interval (T_{90}) over which the rms pressure is computed.

The sound exposure level (SEL) measures the total sound energy contained in one or more pulses. The SEL (L_E, dB re 1 µPa^2·s) for a single pulse is computed from the time-integral of the squared pressure over the pulse duration:

$$L_E = 10\log_{10}\left(\int_{T_{100}} p(t)^2\,dt / P_{ref}^2\right) = 10\log_{10}\left(E(t_{100})\right) \quad (6)$$

SELs for impulsive noise sources (i.e., impact pile driving) presented in this report refer to single pulse SELs.

Because the 90% rms SPL and SEL for a single pulse are both computed from the integral of square pressure, these metrics are related by an expression that depends only on the duration of the 90% energy time window T_{90}:

$$L_E = L_{P90} + 10\log_{10}(T_{90}) + 0.458 \quad (7)$$

In this formula, the 0.458 dB factor accounts for the remaining 10% of the pulse energy that is excluded from the 90% time window.

In addition to these acoustic metrics, this study also considers cumulative SEL (cSEL, symbolized as L_{EC}, dB re 1 µPa^2·s). The cSEL is calculated by summing sound energy over multiple pulses; it provides a conservative measure that does not account for any hearing recovery that may occur between pulses. The cSEL is computed by summing (in linear units) the SELs of the N individual pulses (L_{Ei}):

$$L_{EC} = 10\log_{10}\left(\sum_{i=1}^{N} 10^{\frac{L_{Ei}}{10}}\right) \qquad (8)$$

where N is the total number of pulses, and L_{Ei} is the SEL of the ith pulse event. Alternatively, given the mean (or expected) SEL for single pulse events, L_E, the cumulative SEL from N pulses may be computed according the following formula:

$$L_{EC} = L_E + 10\log_{10}(N) \qquad (9)$$

3. Project Activities and Model Scenarios

In the current project plan, 200 m Combi-Wall sheet piles will be installed using an impact hammer to construct a material offloading facility (MOF) in the proposed marine terminal area. In addition, 42 of 600 mm steel piles will be installed with impact pile driving to build the concrete deck. A backhoe dredge is likely to be used to remove the top 4 m of contaminated sediments; a cutter suction dredge (CSD) or a trailing suction hopper dredge (TSHD) will be used to remove the remaining sediments. The berthing of an LNG carrier in the marine terminal will require the assistance of three harbour tugs. A single escort tug will accompany the LNG carrier transiting along the shipping route through Kitimat Arm, Douglas Channel, Wright Sound, Nepean Sound, Principe Channel, and Browning Entrance. The proposed transit speed will be 12 kts with a mitigation speed of 10 kts along the planned transportation route.

The LNG carrier and one accompanying escort tug were modelled at four representative locations along the planned transportation route, with additional reduced-speed mitigation scenarios. At the proposed marine terminal, the acoustic footprint of an LNG carrier and three harbour tugs berthing, sheet and cylinder pile driving, and a dredge dredging were modelled. We modelled a trailing suction hopper dredge since backhoe dredges are relatively quiet compared to trailing suction hopper dredges (CEDA 2011). Table 1 and Figure 3 show modelled locations. Figure 4 shows a detailed map of the LNG carrier and tugs during transiting and berthing.

This study considered the following scenarios:

- Scenario 1: In the proposed marine terminal area, an LNG carrier berthing assisted by three harbour tugs. The tugs are expected to operate in high-power mode as they hold the carrier alongside the berth while moorings are secured.
- Scenario 2: In Douglas Channel, an LNG carrier and one accompanying tug, tethered to the tanker's stern at 100 m, at a normal transiting speed of 12 kts, with a mitigation transiting speed of 10 kts.
- Scenario 3: At Wright Sound, an LNG carrier and one accompanying tug, tethered to the tanker's stern at 100 m, at a normal transiting speed of 12 kts, with a mitigation transiting speed of 10 kts.
- Scenario 4: At Nepean Sound, an LNG carrier and one accompanying tug, tethered to the tanker's stern at 100 m, at a normal transiting speed of 12 kts, with a mitigation transiting speed of 10 kts.
- Scenario 5: In Browning Entrance area, an LNG carrier and one accompanying tug, tethered to the tanker's stern at 100 m, at a normal transiting speed of 12 kts, with a mitigation transiting speed of 10 kts.
- Scenario 6: In proposed marine terminal area, Combi-Wall sheet piles installed with impact hammer.
- Scenario 7: In proposed marine terminal area, 600 mm steel piles installed with impact hammer.
- Scenario 8: In proposed marine terminal area, a trailing suction hopper dredge removing sediment. A cutter suction dredge may be used for this operation, in which case the TSHD estimates could be considered conservative as TSHD noise emission levels are higher.

Table 1. Modelled source locations. UTMN=Universal Transverse Mercator Northing. UTME=Universal Transverse Mercator Easting. UTM zone=9N.

Scenario	Source	Latitude	Longitude	UTMN (m)	UTME (m)	Approximate Water Depth (m)
1	LNG tanker	53°59.590′ N	128°40.893′ W	520877	5982808	21–39
	Harbour tug	53°59.728′ N	128°40.960′ W	520803	5983064	
	Harbour tug	53°59.659′ N	128°40.960′ W	520804	5982936	
	Harbour tug	53°59.593′ N	128°40.961′ W	520803	5982814	
2	LNG tanker	53°36.703′ N	129°12.247′ W	486496	5940341	300
	Escort tug	53°36.778′ N	129°12.250′ W	486493	5940480	
3	LNG tanker	53°20.481′ N	129°12.585′ W	486035	5910265	500
	Escort tug	53°20.538′ N	129°12.503′ W	486126	5910370	
4	LNG tanker	53°11.200′ N	129°38.700′ W	456901	5893231	190
	Escort tug	53°11.209′ N	129°38.576′ W	457039	5893245	
5	LNG tanker	53°41.949′ N	130°32.348′ W	398388	5951149	54
	Escort tug	53°41.903′ N	130°32.249′ W	398495	5951062	
6	Impact hammer	53°59.881′ N	128°41.133′ W	520613	5983346	8
7	Impact hammer	53°59.730′ N	128°40.892′ W	520877	5983067	13
8	Trailing suction hopper dredge	53°59.700′ N	128°41.054′ W	520701	5983012	28

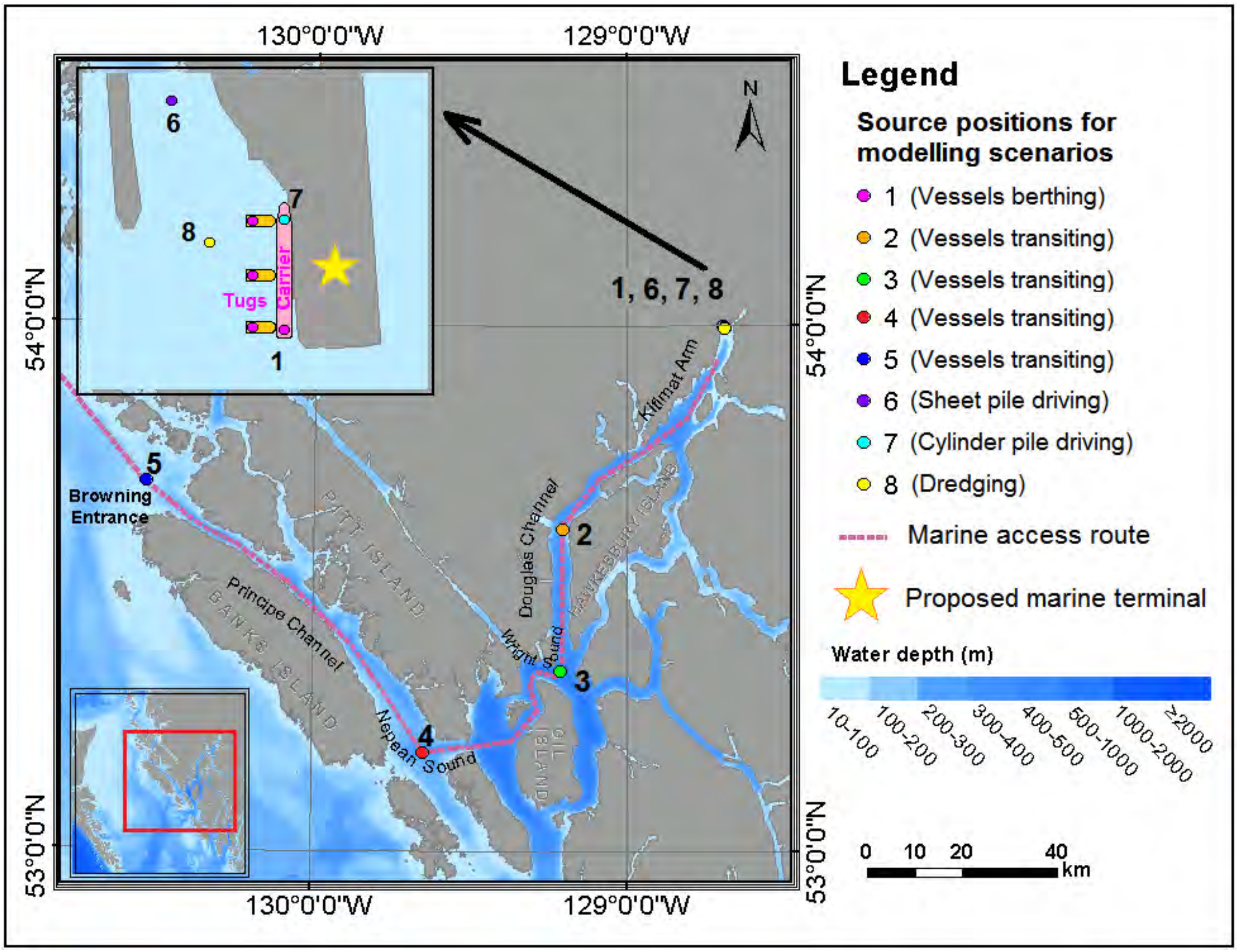

Figure 3. Map of study area showing marine access route, proposed marine terminal, and modelled source locations.

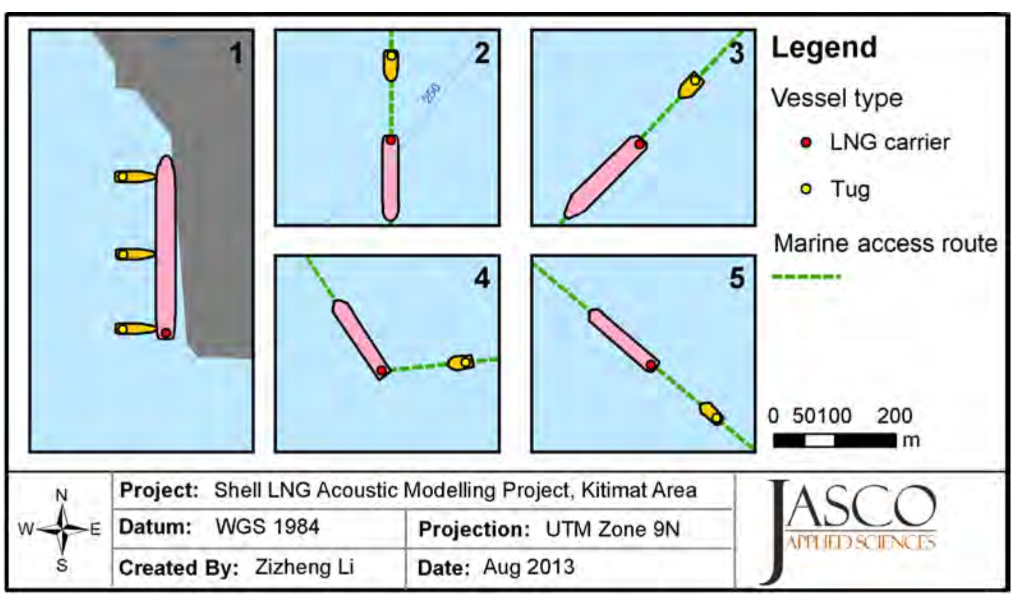

Figure 4. Map of study area showing LNG carrier and tug locations for berthing and transiting scenarios.

4. Methods

4.1. Acoustic Sources and Source Levels

At the time of writing this report, the specific equipment associated with construction activities (i.e., pile driving and dredging) and harbour tugs had not yet been identified. As such, sample model scenarios were constructed based on possibly conservative assumptions. The actual source levels can vary for a given activity, depending on the specific equipment used and how it is operated, etc.

4.1.1. Vessels

The LNG carriers proposed for the Project vary in size from an LNG standard carrier (295 m length, 145 000 m^3 capacity) to a Qmax (345 m length, 264 000 m^3 capacity). The proposed escort tugs are similar to a Robert Allan RAstar 3900 class tug, which is 39.1 m × 14.7 m × 6.55 m (length × width × draft), and total power of 6100 kW (Robert Allan Ltd. 2013). The proposed harbour tugs are with 65 t bollard pull.

Source levels (SL) for an LNG carrier during transit were based on published measurements of three crude oil tankers under normal operating conditions in Santa Barbara Channel (McKenna et al. 2012). The average transiting speed for these oil tankers was 13.5 kts; the average source levels for these measurements were presented in standard 1/3-octave-bands ranging from 20 to 800 Hz, with broadband SL of 180.5 dB re 1 µPa @ 1 m. Based on measurements of the modern cargo ship M/V *Overseas Harriette*, which transited at speeds of 8–16 kts (Arveson and Venditis 2000), we extrapolated 1/3-octave-band source levels to lower (10–20 Hz) and higher frequencies (800 Hz–31.5 kHz). We based our estimates of escort tug source levels on the similar sized offshore tug *Britoil 51* (Hannay et al. 2004). The source levels for the LNG carrier berthing were obtained from the measurements of a bulk gravel carrier *Nelvana* at standby (Hannay et al. 2004). The source levels for the harbour tugs were obtained by measuring a harbour tug, with unspecified details, as it assisted the *Nelvana* during berthing at the Sechelt gravel loading facility in British Columbia (Hannay et al. 2004). Table 2 lists specifications for the source surrogate vessels.

Table 2. Specifications of surrogate vessels used to derive source levels for the acoustic model.

Type	Vessel	Size (m)			Power (kW)	Speed (kts)	Broadband SL (dB re 1 µPa @ 1 m)
		Length	Breadth	Draft			
Crude oil tanker*	*Singapore Voyager*	241.0	42.0	14.0	11931	12.6	180.5
	NS Century	243.0	42.0	14.4	13721	12.8	
	Chemtrans Sky	229.0	32.0	11.7	9694	14.6	
Cargo ship**	*Overseas Harriette*	172.9	22.8	10.2	8352	8–16	178.2–192.1
Bulk gravel carrier†	*Nelvana*	243.0	32.0	14.0	N/A	Stern thrusters	167.8
Escort tug†	*Britoil 51*	45.0	11.8	5.6	4922	13.0	202.7
Harbour tug†	N/A	N/A	N/A	N/A	N/A	Assist berthing	182.6

* Source level measurements from McKenna et al. (2012).
** Source level measurements from Arveson and Venditis (2000).
† Source level measurements from Hannay et al. (2004).

The 1/3-octave-band source levels for transiting surrogate vessels were adjusted to the specifications and transit speeds of the proposed vessels using the power-law equation of Ross (1976):

$$S(f,V,L,P) = S_0(f) + c_V 10\log\left(\frac{V}{V_0}\right) + c_L 10\log\left(\frac{L}{L_0}\right) + 10\log\left(\frac{P}{P_0}\right) \qquad (10)$$

where S is the source spectrum level, f is the frequency, S_0, V_0, L_0, and P_0 are the reference source level spectra, speed, length, and power, respectively. The constants, c_V and c_L, are taken to be 6 and 2, respectively (Wales and Heitmeyer 2002). In addition, we extrapolated modelled source levels to 31.5 kHz based on an empirical relationship that describes the typical high-frequency trend of source spectrum levels for surface vessels (Ross 1976):

$$S(f) \propto -20\log f \qquad f \geq 100\,\text{Hz} \qquad (11)$$

where S is the source spectrum level (dB re 1 µPa^2/Hz @ 1 m) at frequencies above 100 Hz.

Since the dominant source of underwater noise from shipping is generally propeller cavitation (Ross 1976, §8.6), we estimated vessel source depths based on their propeller dimensions. The source of radiated noise was assumed to be at a point midway between the shaft and the top of the propeller disk, therefore we estimated the source depth, Zs, of the modelled ships with the following equation (Gray and Greeley 1980):

$$Z_s = D - 0.85 \times d \qquad (12)$$

where D is the vessel draft and d is the propeller diameter. The source depth for the LNG carrier was based on the loaded draft of 12.5 m, which is a conservative assumption, since sources farther away from the sea surface are more efficient radiators of sound (Brekhovskikh and

Lysanov 2003). The modelled LNG carrier source depth was calculated as 6 m, based on an 8 m propeller diameter (Leggat et al. 1981). The escort and harbour tugs have a 4 m modelled source depth. The estimated 1/3-octave-band source levels for above sources are shown in Figure 5.

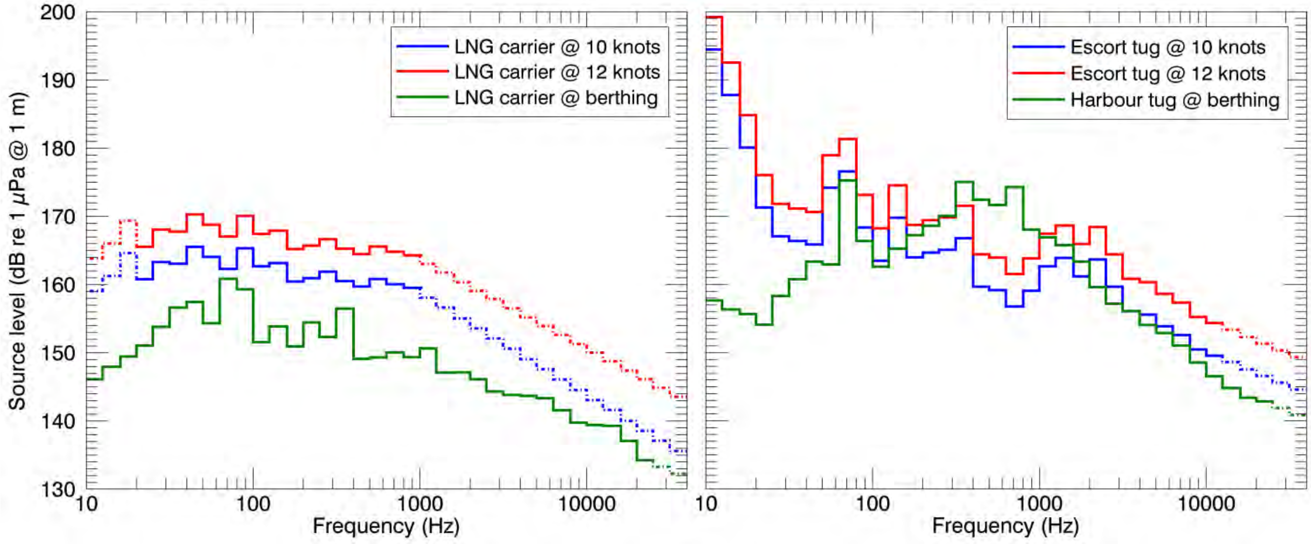

Figure 5. 1/3-octave-band source levels for (left) LNG carrier and (right) escort and harbour tugs at different transiting speeds and berthing. The dashed lines are extrapolated source levels.

4.1.2. Dredge

The backhoe dredge and trailing suction hopper dredge (TSHD) will remove sediment according to the construction plan. The noise sources from backhoe dredges are the barge-installed power plant and possibly scraping sounds as the bucket digs into hard sediment. TSHDs navigate using the vessel's main propulsion system while sucking the water and bottom materials into a hopper or onto shore with a wide pipe and high power pump. In this study, a trailing suction hopper dredge was modelled because it is relatively louder than a backhoe dredge (CEDA 2011).

Robinson et al. (2011) studied underwater noise levels radiating from marine aggregate dredges, mainly trailing suction hopper dredges, that were operating normally. Their research concluded: 1) Noise levels below 500 Hz are similar to noise levels generated from a cargo ship (Arveson and Venditis 2000) travelling at 8–16 kts; 2) Noise levels above 1 kHz during dredging operations are higher than those from cargo ships; 3) Major sources of noise from 1 to 2 kHz are generated by the impact and abrasion of the sediment passing through draghead, suction pipe, and pump; and 4) Source levels depend on the type of sediment being extracted.

In this study, we used the source levels of the surrogate TSHD *City of Westminster* (Table 3) measured by Robinson et al. (2011) for frequencies from 31.5 Hz–31.5 kHz and source levels calculated by Parvin et al. (2008) for frequencies from 10–31.5 Hz as the inputs to the model. As shown in Table 4, we used modelled source depths of 5 m (f <1 kHz) and 1 m above the seabed (f ≥1 kHz) with source levels from *City of Westminster*. Above 1 kHz, we added an additional source with 5 m depth and source levels of cargo ship transits at 12 kts (Arveson and Venditis 2000). This is a conservative assumption because the upward refracting sound speed profiles (Section 4.3.1) support better near-surface source propagation, and the *City of Westminster* source levels above 1 kHz already include the propeller cavitation noise near the water surface. Figure 6 shows the 1/3-octave-band source levels for the surrogate trailing suction hopper dredge.

Table 3. Surrogate trailing suction hopper dredge specifications.

Dredge Name	Length (m)	Capacity (m^3)	Pump power (kW)	Dredging depth (m)	Broadband SL (dB re 1 µPa @ 1 m)
*City of Westminster**	99.7	5200 t	1100	46 (max)	185.6

* Source level measurements from Robinson et al. (2011).

Table 4. Modelled source depths for surrogate dredge.

Frequency *f*	Source	Source depth
10 Hz ≤ *f* < 1 kHz	TSHD *City of Westminster**	5 m
1 kHz ≤ *f* ≤ 31.5 kHz	TSHD *City of Westminster**	1 m above seabed
1 kHz ≤ *f* ≤ 31.5 kHz	Cargo ship transiting at 12 kts†	5 m

* Source level measurements from Robinson et al. (2011).
† Source level measurements from Arveson and Venditis (2000).

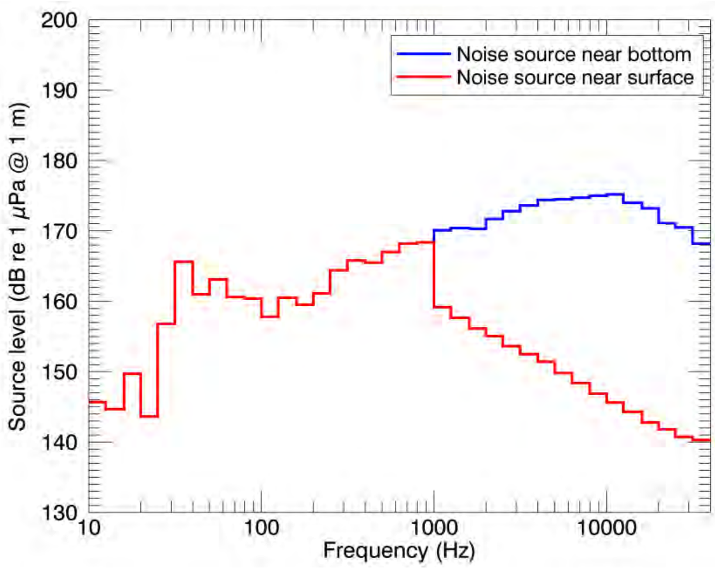

Figure 6. 1/3-octave-band source levels for the surrogate trailing suction hopper dredge. Noise source near surface has a source depth of 5 m. Noise source near bottom has a source depth of 1 m above the seabed.

4.1.3. Pile driving

The planned pile driving for construction includes Combi-Wall sheet piles and 600 mm steel piles driven to the projected penetration depth with impact hammer pile drivers. Noise from pile driving varies with the energy required to drive piles, which depends on the sediment resistance encountered. Sediment types with greater resistance mean pile drivers must deliver higher energy blows. The maximum noise levels from pile driving usually occur at the last stage (Betke 2008). The pile is a distributed sound source because its entire length excites pressure waves in the water. In this study, we assumed the pile was a point source located at a mid-water depth. Because the specifications for the Project impact hammer were not provided, we reviewed the literature for data from which we could estimate source levels for pile driving.

To obtain the conservative source level estimation of impact sheet pile driving, we used the maximum source levels from J&M Model 115 hydraulic free-fall hammer and Menck MHU 3000 Hydraulic hammer (specifications in Table 5). The source levels for J&M Model 115 were calculated using a back propagation method based on 20log*r* (*r* is the measured distance to the pile in metres) from two worst-case scenario measurements provided by Scientific Fishery Systems Inc (2009). The source levels for the Menck MHU 3000 were obtained from Gaboury et al. (2010) who based their estimation on measurement by Greene and Davis (1999) and broadband SELs calculated by Malme et al. (1998).

Table 5. Specifications of surrogate impact hammer for sheet pile driving. Blow rate is at maximum energy.

Impact hammer (sheet pile driving)	Energy (kJ/blow)	Blow rate (blow/minute)	Note
J&M Model 115 Free-fall hydraulic hammer*	15–62.4	45	Operating at 75% energy
Menck MHU 3000 hydraulic hammer†	300–3000	32	Large impact hammer

* Scientific Fishery Systems Inc (2009).
† Gaboury et al. (2010).

To estimate source levels for impact cylinder pile driving, we averaged several source level measurements across 1/3-octave-bands. Table 6 shows the pile diameters, hammer energy, measurement ranges, and frequency ranges for the measurements used to derive acoustic source levels for cylinder pile driving. MacGillivray et al. (2011) concluded that the broadband source level depends on the pile diameter and the impact energy of the pile driver. The corresponding source levels from Table 6 were estimated using a back propagation method based on 20log*r* and scaled to a reference hammer energy of 300 kJ for comparison by adding $10\log(E_{ref}/E_{ham})$ (E_{ref} is a reference energy; E_{ham} is the maximum rated energy of the hammer used during the particular measurement). These referenced piles are with sizes of 910 mm and 1000 mm, which are larger than the 600 mm cylinder piles in this study, so the source level estimation was probably conservative.

Table 6. Impact pile driving specifications for cylinder piles, from published literature.

Project	Pile diameter (m)	Rated hammer energy (kJ)	Measurement range (m)	Frequency range (Hz)
Washington State Ferries*	0.91	187	10	10–8000
Naikun 2007**	0.91	320	10	10–16000
Alameda 2006†	1	300	10	10–5000

* MacGillivray and Racca (2005)
** Racca et al. (2007)
† Illingworth and Rodkin (2006)

Figure 7 shows the 1/3-octave-band source levels for sheet pile driving and cylinder pile driving with broadband source levels of 206.2 and 207.1 dB re 1 µPa^2·s @ 1 m, respectively.

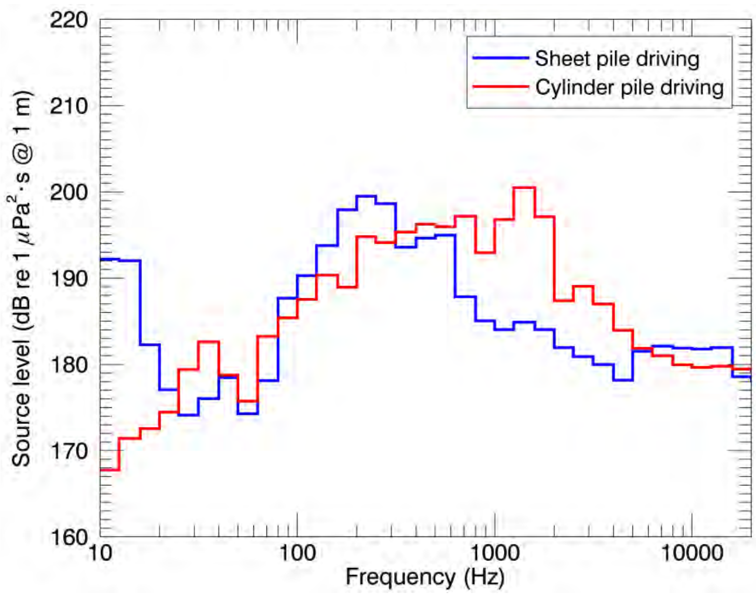

Figure 7. Estimated 1/3-octave-band source levels of sheet pile driving and cylinder pile driving.

4.2. Sound Propagation Models

4.2.1. Marine Operations Noise Model

JASCO's Marine Operations Noise Model (MONM) predicts underwater sound propagation. MONM computes sound propagation in range-varying acoustic environments through a wide-angled parabolic equation (PE) solution to the acoustic wave equation (Collins 1993). The PE method has been extensively benchmarked and is widely employed in the underwater acoustic community (Collins et al. 1996). The PE code used by MONM is based on a version of the Naval Research Laboratory's Range-dependent Acoustic Model (RAM), which has been modified to account for an elastic seabed (Zhang and Tindle 1995). Elastic seabeds support both compressional and shear wave propagation. The default version of RAM approximates the seabed as a fluid that supports only compressional wave propagation.

MONM computes acoustic fields in three dimensions by modelling transmission loss along evenly spaced 2-D radial traverses covering a 360° swath from the source, an approach commonly referred to as N × 2-D. The model fully accounts for depth and/or range dependence of several environmental parameters including bathymetry and sound speed profiles for the water column and the sea floor. It also accounts for the additional reflection loss at the seabed that is due to partial conversion of incident compressional waves to shear waves at the seabed and sub-bottom interfaces through a complex density approximation (Zhang and Tindle 1995). It includes wave attenuation in all layers. The acoustic environment is sampled at a fixed range step along radial traverses. MONM treats frequency dependence by computing acoustic transmission loss (TL) at the center frequencies of 1/3-octave-bands. Broadband received levels are summed over the received 1/3-octave-band levels, which are computed by subtracting band TL values from the corresponding source levels. MONM's predictions have been validated against experimental data from several underwater acoustic measurement programs (Hannay and Racca 2005, Aerts et al. 2008, Funk et al. 2008, Ireland et al. 2009, O'Neill et al. 2010, Warner et al. 2010).

The transmission loss computed by MONM was further corrected to account for the attenuation of acoustic energy by molecular absorption in seawater. The volumetric sound absorption is quantified by an attenuation coefficient, expressed in units of decibels per kilometer (dB/km). The absorption coefficient depends on the temperature, salinity, and pressure of the water as well as the sound frequency. In general, the absorption coefficient increases with the square of frequency. The absorption of acoustic wave energy has a noticeable effect (> 0.05 dB/km) at frequencies above 1 kHz. At 10 kHz, the absorption loss over 10 km distance can exceed 10 dB. This coefficient for seawater can be computed according to the formulae of François and Garrison (1982b, 1982a), which consider the contribution of pure seawater, magnesium sulfate, and boric acid. The formulae apply to all oceanic conditions and frequencies from 200 Hz to 1 MHz.

In this study, the absorption coefficients were calculated based on water temperature at 7.9 °C and salinity of 30.6 parts per thousand (ppt). Temperature and salinity were estimated from temperature and salinity profiles (Section 4.3.1) at a depth of 30 m, and averaged over all modelled locations that have similar values. The absorption coefficients were applied to the transmission loss above 1 kHz.

A 10 m radial step size was used for the PE model computational grid. Sound levels were modelled at 21 different receiver depths, distributed vertically in the water column, as follows:

- Five receivers were spaced 2 m apart, 2–10 m below the water's surface.
- Nine receivers were spaced 10 m apart, 20–100 m below the water's surface.
- Four receivers were spaced 100 m apart, 200–500 m below the water's surface.
- Two receivers were spaced 1000 m apart, 1000–2000 m below the water's surface.
- One receiver was on the sea floor.

Modelled received levels were gridded separately in each horizontal plane (i.e., at each modelled receiver depth). To generate a conservative estimate, the modelled results in this study were obtained by collapsing the stack of grids into a single plane using a maximum-over-depth rule, which means that the sound levels at each planar point are taken to be the maximum value from all modelled depths in the water column for that point.

To model continuous sources such as the LNG carrier, tug, and dredge, we used MONM to predict the SPLs on the N×2-D grid for the frequencies of 10 Hz–31.5 kHz. For the impulsive source—impact pile driving—we used MONM to model the SELs per blow for frequencies from 10 Hz–20 kHz, and then converted the SELs to SPLs based on the conversion curve described in Section 4.2.2. The predicted received SPLs (in dB re 1 µPa) were converted to noise contour maps that show the estimated acoustic footprint for each scenario. Noise contours were converted to GIS layers for rendering on thematic maps. For each scenario, the 95th percentile radius, $R_{95\%}$, and the maximum radius, R_{max}, for each noise threshold level were tabulated. The $R_{95\%}$ is the radius of a circle that encompasses 95% of grid points whose value equals or is greater than the threshold value. For a given threshold level, this radius always provides a range beyond which no more than 5% of a uniformly distributed population would be exposed to sound at or above that level, regardless of the geometrical shape of the noise footprint. The R_{max} is the maximum distance from the source to the given noise threshold in any direction (equivalent to $R_{100\%}$). R_{max} can be a reference for the most conservative case compared to using $R_{95\%}$. For cases where the ensonification to a specific level is discontinuous and small pockets of higher received levels occur far beyond the main ensonified volume (e.g., due to convergence of sound rays), R_{max} would be much larger than $R_{95\%}$ and could therefore be misleading if not given alongside $R_{95\%}$.

4.2.2. Estimating 90% rms SPL and peak SPL from SEL

For impulsive sound sources, MONM computes per-pulse SEL in 1/3-octave-bands, but does not directly predict the 90% rms SPL or peak SPL for evaluation against accepted noise threshold criteria. Although the 90% rms SPL and peak SPL are easily measured in situ, the metrics are generally more difficult to model than per-pulse SEL. In addition, the adaptive integration period to model rms SPL, implicit in the definition of the 90% rms SPL, is highly sensitive to the specific multipath arrival pattern from an acoustic source and can vary greatly with distance from the source or with receiver depth.

The 90% rms SPL can be computed from MONM output SEL with predicated integration period T_{90} via Equation 7. There are several ways to predict T_{90} variation. A full-waveform modelling of acoustic pressure can be used to synthetize the propagation pulse shape and duration, although it is computationally expensive for very deep range-dependent environments. Unfortunately, the full-waveform model requires pile driving signal waveforms, which were not available for this study. Another method that predicts T_{90} variation, and the one we used in this study, is to apply empirical results of impulse noise pulse duration measured in the field with environments similar to this study.

Figure 8 shows the curves for rms SPL to SEL offset and peak SPL to SEL offset as a function of distance. These curves were fitted with field measurement data of impact cylinder and sheet pile driving (MacGillivray et al. 2007, Oestman et al. 2009) and data calculated from logarithmic regression estimated by Blackwell (2005). The maximum offsets of rms SPL and peak SPL are at the source (15 dB, red line, and 30 dB, pink line, in Figure 8). The offsets decrease to 3 dB and 18 dB at 1000 km from the source.

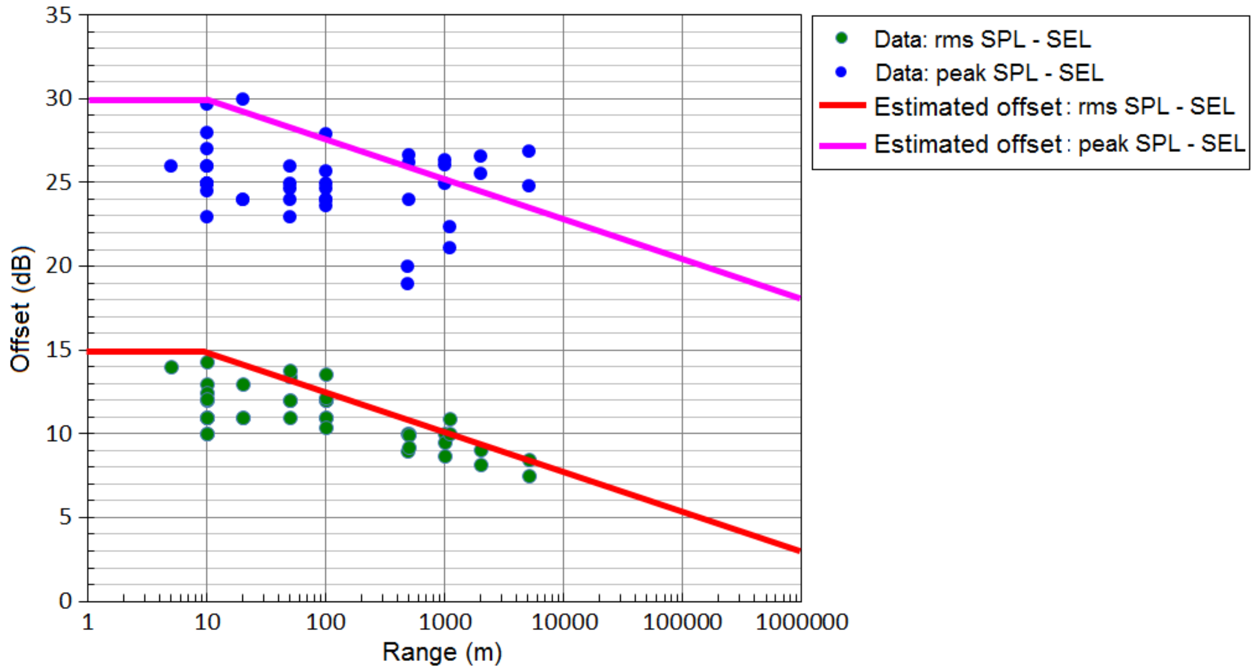

Figure 8. The rms SPL to SEL and peak SPL to SEL offsets based on reported in situ measurements. The red and pink lines are the range-dependent offsets added to the modelled SELs to obtain the rms SPLs and peak SPLs, respectively.

4.2.3. Cumulative sound exposure

Long-term increases in anthropogenic noise in the ocean can have negative effects on marine animals and their habitats. Possible effects of chronic noise exposure include auditory masking, increased stress, and permanent reduction of hearing sensitivity. Cumulative noise exposure is generally measured in terms of the total sound energy an organism receives over some period, calculated by Equation 8 or 9.

The SEL contribution of impact pile driving to the overall noise budget was modelled over 24 hours. During impact pile driving, a concentrated addition of acoustic energy was introduced into the environment during each blow. The accumulated sound energy was computed for sequences of pile driving blows that could be acquired over 24 hours. Since the pile driving operation had not been identified yet, we assumed that the sheet and cylinder impact pile driving would operate at 45 blows per minute, 45 minutes of each hour, 12 hours per day. To represent 24 hours of pile driving, the model needs to include thousands of blows. Because all the piles are adjacent to each other, we assumed that all the blows operated only at the modelled source locations in Scenarios 6 and 7. Equation 9 calculates the corresponding noise footprint.

4.3. Acoustic Environment

4.3.1. Water sound speed profile

The sound speed profile (SSP) in the water column can be derived from temperature and salinity profiles according to equations from Coppens (1981):

$$\begin{aligned} c(z,T,S,\phi) &= 1449.05 + 45.7T - 5.21t^2 - 0.23t^3 \\ &\quad + (1.333 - 0.126t + 0.009t^2)(S-35) + \Delta \\ \Delta &= 16.3Z + 0.18Z^2 \\ Z &= (z/1000)(1 - 0.0026\cos(2\phi)) \\ t &= T/10 \end{aligned} \tag{13}$$

where z is depth (m), T is water temperature (°C), S is salinity (psu), and ϕ is latitude (radians).

For each modelled location, vertical temperature and salinity profiles were from a catalogue of conductivity-temperature-depth (CTD) profiles measured in September 2005 and in January 2006 (Fissel et al. 2010). The SSPs vary by season due to changing water temperature and salinity. The SSP vary from strongly upward refracting in winter, when near-surface layers are relatively cold, to downward refracting during summer, when near-surface layers are warmer. Transiting vessels occur year-round and marine terminal construction is planned for between November and February. Because the January profiles minimize bottom loss, they are more favourable for supporting long-range underwater acoustic propagation; hence, we used these profiles as inputs for the acoustic model to produce more conservative results for noise assessments. Figure 9 shows the temperature, salinity, and sound speed profiles for each modelled site.

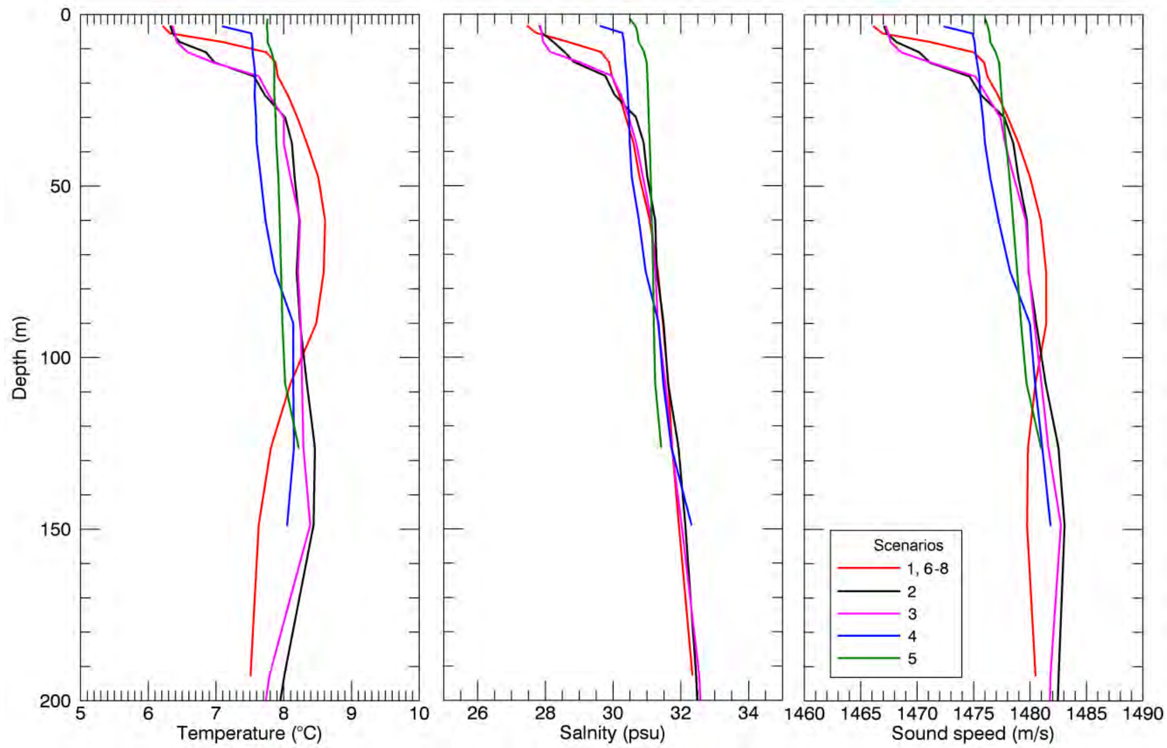

Figure 9. January temperature, salinity, and sound speed profiles for Scenarios 1–8.

4.3.2. Geoacoustic parameters

Sound propagation in shallow water is strongly influenced by the geoacoustic parameters of the sea floor, including the density, the compressional wave (P-wave) speed, the shear wave (S-wave) speed, the compressional wave attenuation, and the shear wave attenuation of seabed sediments. The project vessels transit through Kitimat Arm, Douglas Channel, Wright Sound, Nepean Sound, Principe Channel, and Browning Entrance (Figure 3), which are within the Kitimat fjord system. Three different sedimentary basin types are in the fjord system: Kitimat Arm, Gil Basin, and Maitland Basin (Bornhold 1983). The profiles for these three basin types were based on survey data taken by the Geological Survey of Canada (GSC) and Fisheries and Oceans Canada (DFO); they are characterized by muds, sandy muds, and surface deposits. The geoacoustic profiles for Kitimat Basin (Scenario1 and Scenario 6–8) were derived from studies by Bornhold (1983) using Hamilton’s geoacoustic model (Hamilton 1980). The geoacoustic profiles for Gil Basin (Scenarios 2–4) were adapted from previous acoustic modelling studies and validated by transmission loss measurements (Austin et al. 2006). The geoacoustic profiles for Browning Entrance (Scenario 5) were obtained from a geoacoustic database of Hecate Strait (MacGillivray 2006). Tables 7 to 9 present the geoacoustic parameters for the modelled scenarios in this study.

Table 7. Geoacoustic parameters for Kitimat Basin sediments used to model Scenarios 1 and 6–8.

Depth (mbsf)	Sediment Type	Density (g/cm^3)	P-wave speed (m/s)	P-wave attenuation (dB/λ)	S-wave speed (m/s)	S-wave attenuation (dB/λ)
0–5	Chaotic, stiff gray muds	1.488–1.600	1549–1586	0.07–0.22	259	8.65
5–40	Stratified muddy sands and muds	1.600–1.500	1586–1862	0.22–0.50		
40–600	Highly reflective stratified sediments	1.500–2.500	1862–3000	0.50–0.10		
> 600	Bedrock	2.500	3000	0.10		

Table 8. Geoacoustic parameters for Gil Basin sediments used to model Scenarios 2–4. The parameters were adjusted based on transmission loss measurement (Austin et al. 2006).

Depth (mbsf)	Sediment Type	Density (g/cm^3)	P-wave speed (m/s)	P-wave attenuation (dB/λ)	S-wave speed (m/s)	S-wave attenuation (dB/λ)
0–60	Transparent muds glaciomarine outwash	1.388–1.400	1550–1862	0.20–0.25	259	8.65
60–75	Highly reflective stratified glacial and glaciomarine sediments	1.400–1.500	1862–2500	0.25–0.27		
75–90		1.500–1.400				
90–105		1.400–1.500				
105–120		1.500–1.400				
120–135		1.400–1.500				
135–150		1.500–1.400				
150–165		1.400–1.500				
165–600	Non-reflective stratified glacial and glaciomarine sediments	1.500–2.300				
> 600	Bedrock	2.300	2500	0.27		

Table 9. Geoacoustic parameters for Browning Entrance sediments used to model Scenario 5.

Depth (mbsf)	Sediment Type	Density (g/cm^3)	P-wave speed (m/s)	P-wave attenuation (dB/λ)	S-wave speed (m/s)	S-wave attenuation (dB/λ)
0–3	Sand	1.941	1700–729	0.425–0.432	70	0.90
3–8			1729–1754	0.432–0.439		
8–15			1754–1771	0.439–0.443		
15–20			1771–1776	0.443–0.445		
20–100	Bedrock	2.200	2200–2298	0.100		
> 100			2298	0.100		

4.3.3. Bathymetry

Bathymetry data for the modelled area were obtained from British Columbia Marine Conservation Analysis (BCMCA2013). These data were created by SciTech Environmental Consulting based on the source data from Living Oceans Society, U.S. Geological Survey (USGS), and Committee on the Status of Endangered Wildlife in Canada (COSEWIC). The data are in a 100 m raster grid showing water depth information of the Canadian Pacific Exclusive Economic Zone (EEZ). The data were converted to a format accepted by JASCO's acoustic models in UTM Zone 9N coordinates with 100 m resolution (Figure 10).

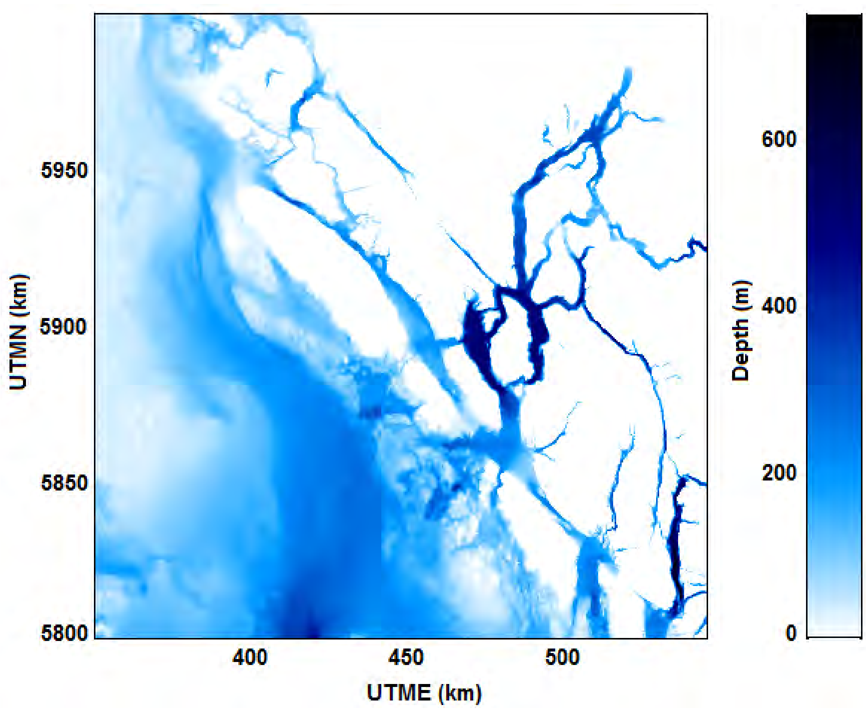

Figure 10. Bathymetry grid used for acoustic modelling.

4.4. Frequency Weighting

4.4.1. Audiogram weighting

The potential for anthropogenic noise to affect marine animals depends on how well the animal can hear the noise; noises at frequencies animals cannot hear well are less likely to disturb or injure them except when the sound pressure is so high that it causes physical injury. For sound levels that are too low to cause physical injury, frequency weighting based on audiograms relevant to those species' hearing sensitivities can be used to weight the importance of those sound levels (Nedwell and Turnpenny 1998, Nedwell et al. 2007).

Audiograms represent the hearing threshold for tonal sounds (single-frequency sinusoidal signals) as a function of the tone frequency. These species-specific sensitivity curves are generally U-shaped, with higher hearing thresholds at very low and very high frequencies. Noise levels above hearing threshold were calculated by subtracting species-specific audiograms from the received 1/3-octave-band noise levels. The audiogram-weighted 1/3-octave-band levels were summed to yield broadband noise levels relative to each species' hearing threshold. Audiogram-weighted levels are expressed in units of dB re HT, which is the dB level of sound above hearing threshold. Sound levels less than 0 dB re HT are below the typical hearing threshold for a species and are therefore expected to be inaudible.

Audiogram weighting was applied to adjust the importance of sound from the LNG carrier, tug, and dredge. The species concerned in the modelled area are humpback whales (*Megaptera novaeangliae*), fin whales (*Balaenoptera physalus*), killer whales (*Orcinus orca*), and harbour porpoises (*Phocoena phocoena*). There are no direct audiogram measurements for baleen whales primarily as a result of the difficulty in physically handling such large animals. The audiogram applied here for all baleen whale species is based on models derived from characteristics of humpback sounds and anatomy of the humpback whale's auditory system as described by Clark and Ellison (2004) and Houser et al. (2001). The models predict high and low sensitivity audiogram estimates. We used the high-sensitivity estimates to be conservative. We applied the killer whale audiogram from Erbe (2002), which was obtained by averaging several killer whale measurements taken above 500 Hz. Because no measurements were available below 500 Hz, Erbe extended the audiogram to lower frequencies using averaging audiogram measurements for several belugas and dolphins. The harbour porpoise audiogram was obtained by averaging measurements from several individuals (Andersen 1970, Kastelein et al. 2002).

Figure 11 shows audiograms used in this study. Audiograms for killer whale and harbour porpoise were extrapolated from the lowest measured frequency down to 10 Hz using a 12 dB/octave slope, which represents the hearing rolloff toward the infrasound range for mammals (Marquardt et al. 2007). The audiogram for the humpback whale was extrapolated to higher frequencies—up to 31.5 kHz—based on its slope toward high frequencies. Although the validity of the extrapolation for marine mammals is not physiologically confirmed, it is likely these animals have a higher hearing threshold at frequencies outside their hearing range than the terminal trend of their audiogram would predict.

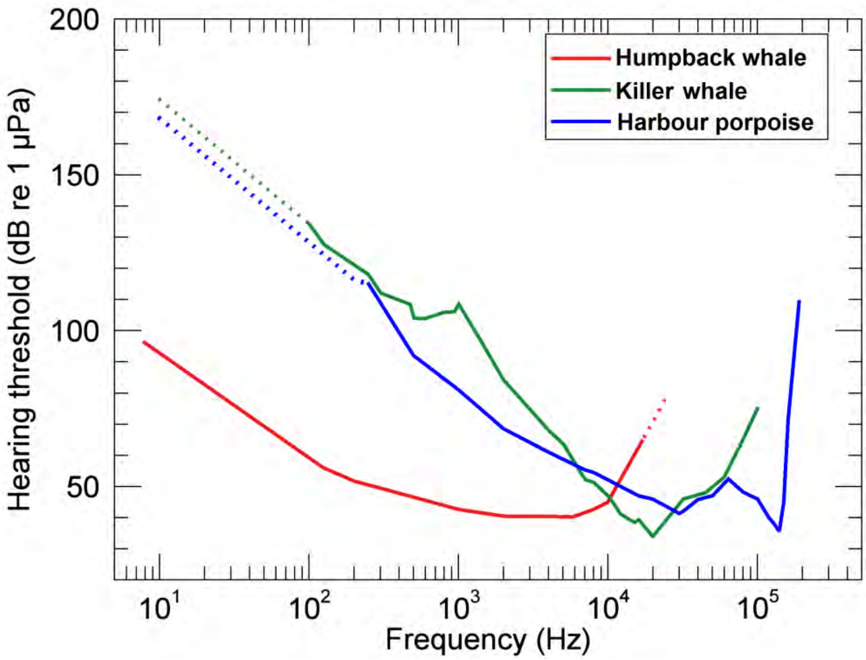

Figure 11. Audiograms for humpback whale, killer whale, and harbour porpoise. Dotted lines represent extrapolated hearing threshold.

Most humpback whales feeding near the BC coast migrate to several Southern wintering grounds without a clear preference in winter (COSEWIC 2011); however, around the northern BC coast, some humpback whales are present year-round. The northern resident killer whale population live year-round in coastal waters between central Vancouver Island and Dixon Entrance; they congregate during spring, summer and fall on the northern BC coast (Ford et al. 2000). Harbour porpoise are found year-round throughout BC shelf waters moving seasonally inshore to offshore rather than from north to south, likely responding to food resource distribution (Olesiuk et al. 2002).

4.4.2. M-weighting

Based on a literature review of marine mammal hearing and on physiological and behavioural responses to anthropogenic sound, Southall et al. (2007) proposed standard frequency weighting functions–referred to as M-weighting functions–for five functional hearing groups of marine mammals:

- Low-frequency cetaceans (LFC)–mysticetes (baleen whales)
- Mid-frequency cetaceans (MFC)–some odontocetes (toothed whales)
- High-frequency cetaceans (HFC)–odontocetes specialized for using high-frequencies
- Pinnipeds in water (PINN)–seals, sea lions, and walrus
- Pinnipeds in air

The discount applied by the M-weighting functions for less-audible frequencies is less than that indicated by the corresponding audiograms (where available) for member species of these hearing groups. The rationale for applying a smaller discount than suggested by audiograms is due in part to an observed characteristic of mammalian hearing that perceived equal loudness curves increasingly have less rapid rolloff outside the most sensitive hearing frequency range as sound levels increase. This is why, for example, C-weighting curves for humans, used for assessing loud sounds, are flatter than A-weighting curves, used for quiet to mid-level sounds. Additionally, out-of-band frequencies, though less audible, can still cause physical injury if pressure levels are sufficiently high. The M-weighting functions are, therefore, primarily intended to be applied at high sound levels where impacts such as temporary or permanent hearing threshold shifts may occur. The use of M-weighting is considered precautionary, in the sense of overestimating the potential for impact, when it is applied to lower level impacts such as onset of behavioural responses. Figure 12 shows the decibel frequency weighting of the four underwater M-weighting functions.

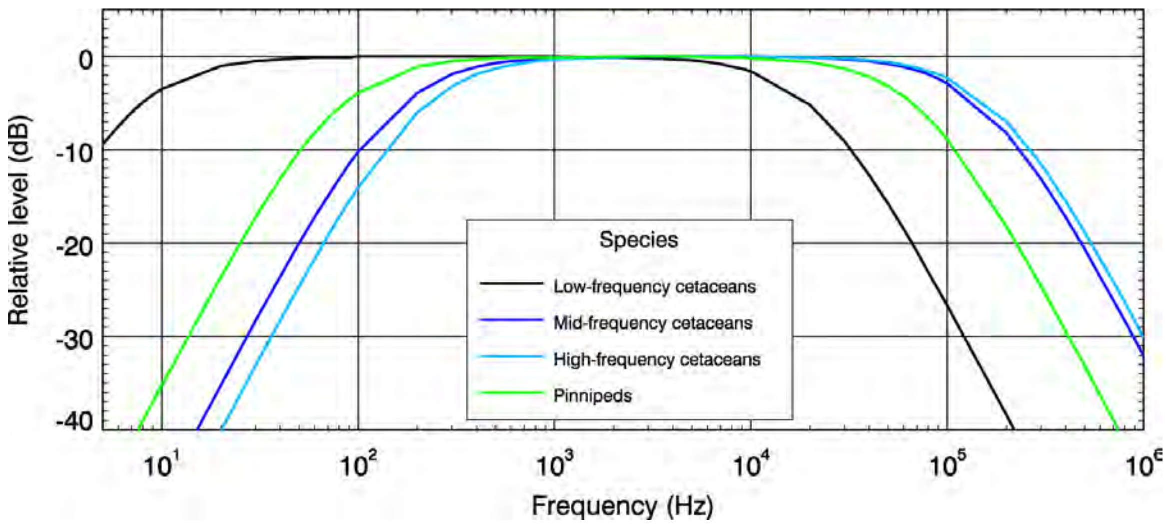

Figure 12. Standard M-weighting functions for low-, mid-, and high-frequency cetaceans and for pinnipeds in water.

The M-weighting functions have unity gain (0 dB) through the passband and their high and low frequency rolloffs are approximately –12 dB/octave. The amplitude response in the frequency domain of the M-weighting functions is defined by:

$$G(f) = -20\log_{10}\left[\left(1+\frac{f_{lo}^2}{f^2}\right)\left(1+\frac{f^2}{f_{hi}^2}\right)\right] \quad (14)$$

The rolloff and passband of these filters are controlled by the two parameters f_{lo} and f_{hi}, which correspond to the estimated upper and lower hearing limits specific to each functional hearing group (Table 10). M-weighting is typically applied to evaluate potential injury and onset of temporary threshold shift (TTS) from exposures to sounds of high amplitude, such as those from impact pile driving (Southall et al. 2007). Sound levels produced from vessel activities are typically well below injury or TTS thresholds based on SEL. Consequently, M-weighting is not commonly used for vessel noise effects analysis.

Table 10. Low- and high-frequency cut-off parameters of M-weighting curves for each marine mammal functional hearing group.

Functional Hearing Group	f_{lo} (Hz)	f_{hi} (Hz)
Low-frequency cetaceans	7	22 000
Mid-frequency cetaceans	150	160 000
High-frequency cetaceans	200	180 000
Pinnipeds in water	75	75 000

4.5. 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.

NMFS criteria are based on an rms SPL metric. NMFS's injury criteria are based on the estimated onset of permanent threshold shift (PTS) for marine mammals. These criteria are based on marine mammal exposure to impulsive sounds. NMFS behavioural disturbance criteria, which are based on a limited set of behavioural data, are widely applied. Table 11 shows the NMFS auditory injury and disturbance criteria for continuous and impulsive sounds.

Southall et al. (2007) criteria use peak SPL of the acoustic wave, and the cumulative SEL with a standard M-weighting (Section 4.4.2) applied to it; cumulative SELs originate from single or multiple exposure events over a 24-hour period. Southall et al. (2007) criteria, as are NMFS, are based on 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, or both. Southall et al. (2007) did not recommend specific SPL thresholds for marine mammal disturbance criteria. Table 12 shows the Southall et al. (2007) auditory injury and onset of temporary threshold shift (TTS) criteria for continuous and impulsive sounds.

Table 11. NMFS auditory injury and disturbance criteria for continuous and impulsive sounds.

Marine mammal group	rms SPL (dB re 1 µPa)			
	Continuous sounds		Impulsive sounds	
	Injury	Disturbance	Injury	Disturbance
Cetaceans	--	120	180	160
Pinnipeds	--	120	190	160

Table 12. Southall et al. (2007) auditory injury and TTS onset criteria for continuous and impulsive sounds. LF=low-frequency, MF=mid-frequency, and HF= high-frequency, TTS=Temporary Threshold Shift.

Marine mammal group	M-weighted SEL (dB re 1 µPa^2·s)				Peak SPL (dB re 1 µPa)	
	Continuous sounds		Impulsive sounds		Continuous and impulsive	
	Injury	TTS onset	Injury	TTS onset	Injury	TTS onset
Cetaceans (LF, MF, HF)	215	195	198	183	230	224
Pinnipeds (in water)	203	183	186	171	218	212

4.6. Ambient Noise

Ambient noise is defined as “the composite noise from all sources in a given environment excluding noise inherent in the measuring equipment and platform” (Bradley 1996); it is comprised of sound from natural and anthropogenic sources, and varies with time and location.

Sound from natural sources includes wind and waves, precipitation, biological sources, and tidal currents. Wind and waves are a main source of naturally occurring ambient noise for frequencies below 1 Hz to above 50 kHz. The interactions between precipitation and ocean surface can be an important component of ambient noise across frequencies from several hundred hertz to greater than 20 kHz. Marine mammals and some fish and shrimp are biological sources for ambient noise in a frequency band ranging from less than 10 Hz to over 200 kHz. Sound from anthropogenic sources includes ship traffic, aircraft, dredging, construction, oil and gas drilling and production, seismic surveys, sonars, explosions, and ocean acoustic studies. Shipping noise is the major contributor to the ambient noise for frequencies from 5–500 Hz (NRC 2003).

For marine mammals, the ambient background will determine the zone of audibility of noise originating from project vessels and construction, although the background itself may contain audible noise from numerous other vessels. To obtain ambient noise levels in the study area, JASCO deployed four Autonomous Multichannel Acoustic Recorders (AMARs) from end of April to end of August 2013. These recorders were deployed 15 m above the sea floor along the shipping route (Figure 13 and Table 13).

Each AMAR was set to record on a duty cycle of 121 seconds of sampling at 128 kHz (24-bit resolution) followed by 363 seconds of sleep. Each AMAR was equipped with a calibrated GeoSpectrum M8E hydrophone with nominal sensitivity of −165 ± 5 dB re 1 V/µPa.

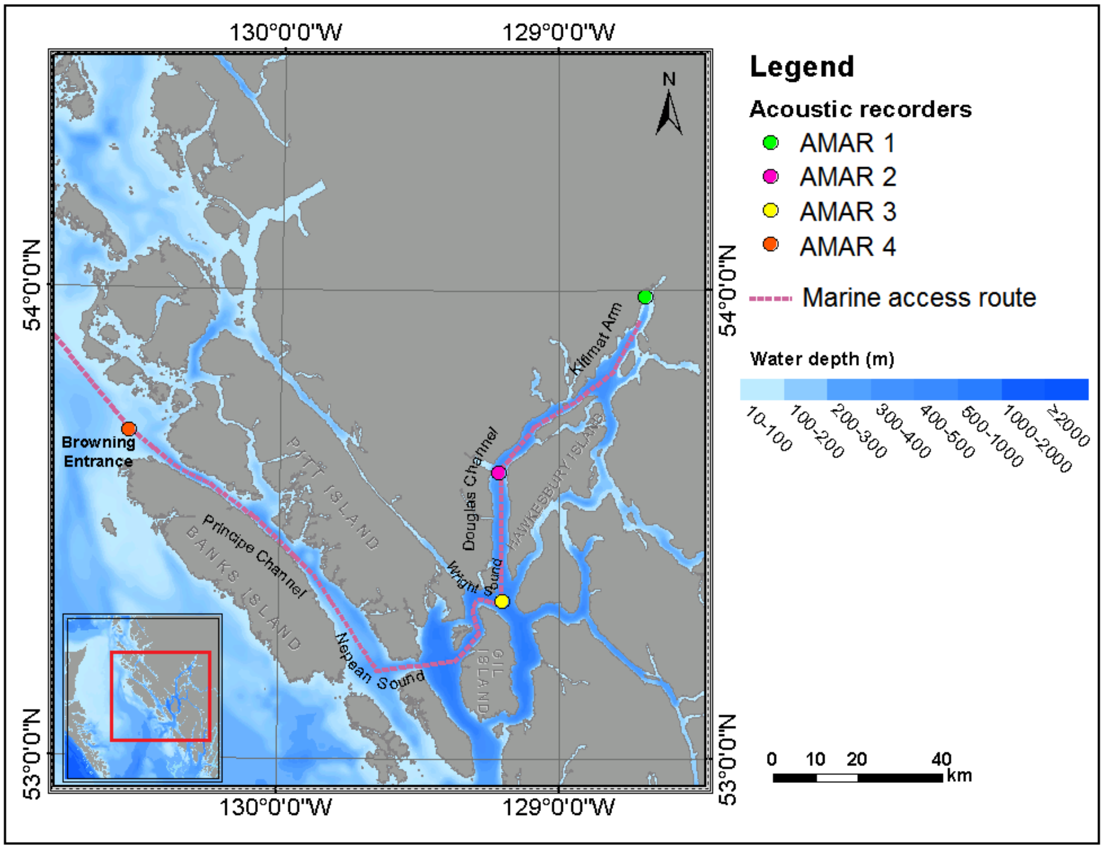

Figure 13. Map of JASCO acoustic monitoring locations.

Table 13. Geographical coordinates for acoustic monitoring locations.

AMAR	Location	Latitude	Longitude	Scenario
1	Proposed LNG terminal	53°59.077' N	128°40.564' W	Scenarios 1 and 8
2	Douglas Channel	53°36.695' N	129°12.664' W	Scenario 2
3	Wright Sound	53°20.218' N	129°12.026' W	Scenario 3
4	Browning Entrance	53°41.785' N	130°32.594' W	Scenario 5

Mouy et al. (2013) estimated baseline ambient noise levels at the monitoring locations. To calculate ambient sound levels, JASCO's acoustic analysis software suite processed the raw acoustic data. Statistical analysis techniques were applied to the ambient noise data to determine the range and frequency of occurrence of sound levels encountered at recording sites. Figure 14 shows the 50th percentile sound pressure levels in 1/3-octave-bands for these four monitoring locations. The 50th percentile curve contains only frequency-dependent levels for noise that occurred more than 50% of the time. Shipping noise was the dominant contributor to ambient noise, especially under 1 kHz. SPLs below 30 Hz were strongly influenced by cable strumming noise, as shown in data collected from AMAR 2. Overall noise levels from AMAR 2 are lower than those from AMAR 1, especially for noise under 1 kHz, which was primarily from shipping and local industrial sources.

If sound levels from a noise source are lower than the ambient noise level or fall below the marine mammal hearing threshold, the animal will not hear that sound and, therefore, will not likely react. Because of this, we applied zones of audibility, which are regions where sound levels were greater than both the ambient noise and the species-specific audiograms. To be conservative, we assumed the animal is likely to detect vessel noise only if the SPL exceeded the ambient noise and the audiogram in any 1/3-octave frequency band. In this study, the measured ambient noise levels were applied to corresponding scenarios to determine zones of audibility (Table 13). The ambient noise levels for Scenario 4 were taken from levels averaged between AMAR 2 and AMAR 4.

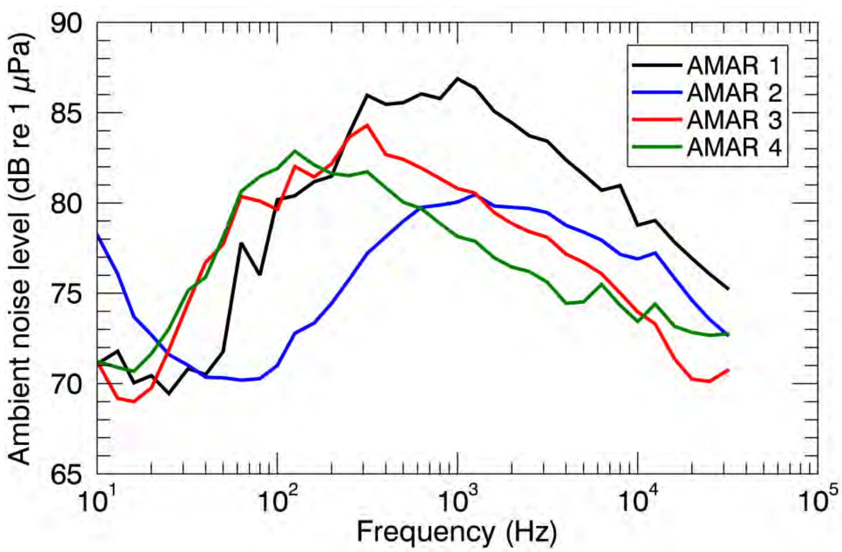

Figure 14. Ambient noise 50th percentile levels for each monitoring location.

5. Results

5.1. Vessel and Dredging Noise

5.1.1. Unweighted sound pressure levels

Figures 15 to 20 show isopleth maps of modelled unweighted maximum-over-depth broadband (10 Hz to 31.5 kHz) sound pressure levels in dB re 1 µPa for scenarios of vessels berthing, transiting, and dredging (Scenarios 1–5, Scenario 8). Table 14 presents the $R_{95\%}$ and R_{max} SPL threshold ranges for the LNG carrier, tug, and dredge scenarios. The 95th percentile radii extended to 8–20 km at 120 dB re 1 µPa rms SPL, and dropped to less than 50 m when the SPL is above 160 dB re 1 µPa.

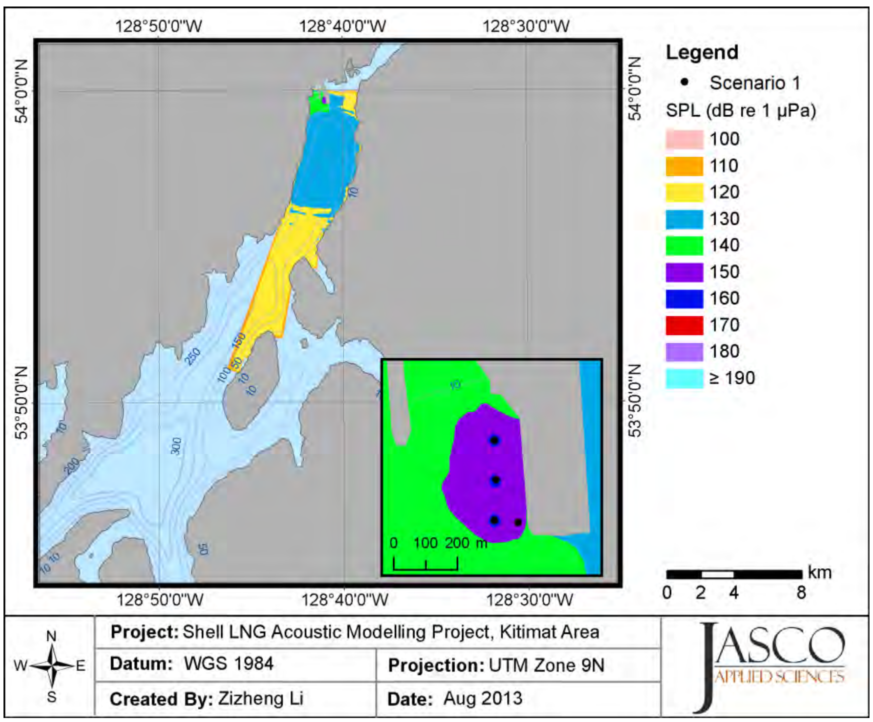

Figure 15. Scenario 1: Sound level isopleth map of unweighted SPL (dB re 1 µPa, maximum-over-depth). An LNG carrier and three harbour tugs are berthing at the proposed marine terminal. A magnified view of the sources appears in the lower right.

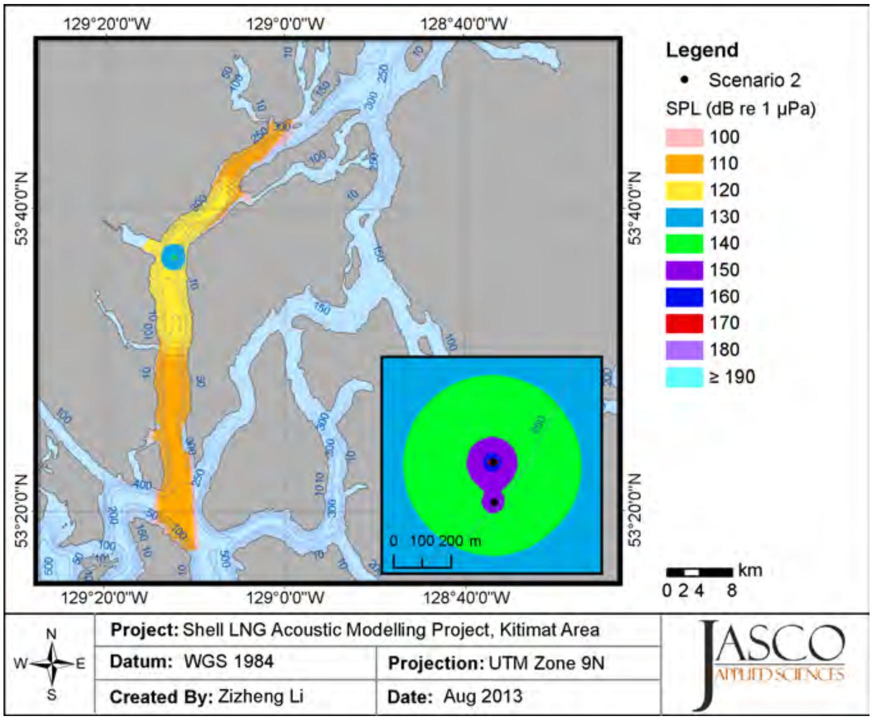

Figure 16. Scenario 2: Sound level isopleth map of unweighted SPL (dB re 1 µPa, maximum-over-depth). An LNG carrier and a tug are transiting at 12 kts along the outbound route in Douglas Channel. A magnified view of the sources appears in the lower right.

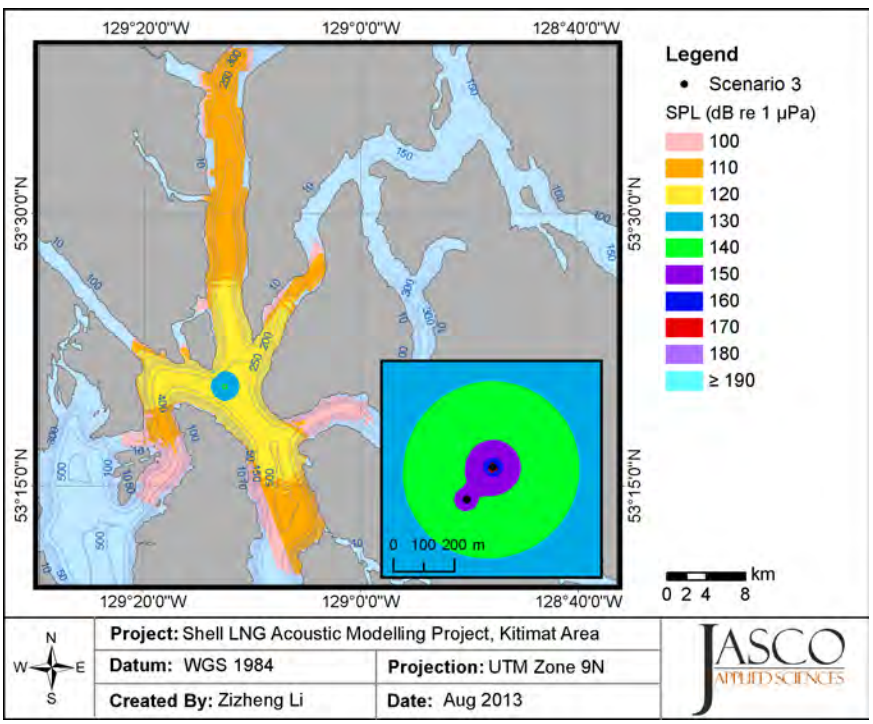

Figure 17. Scenario 3: Sound level isopleth map of unweighted SPL (dB re 1 µPa, maximum-over-depth). An LNG carrier and a tug are transiting at 12 kts along the outbound route in Wright Sound. A magnified view of the sources appears in the lower right.

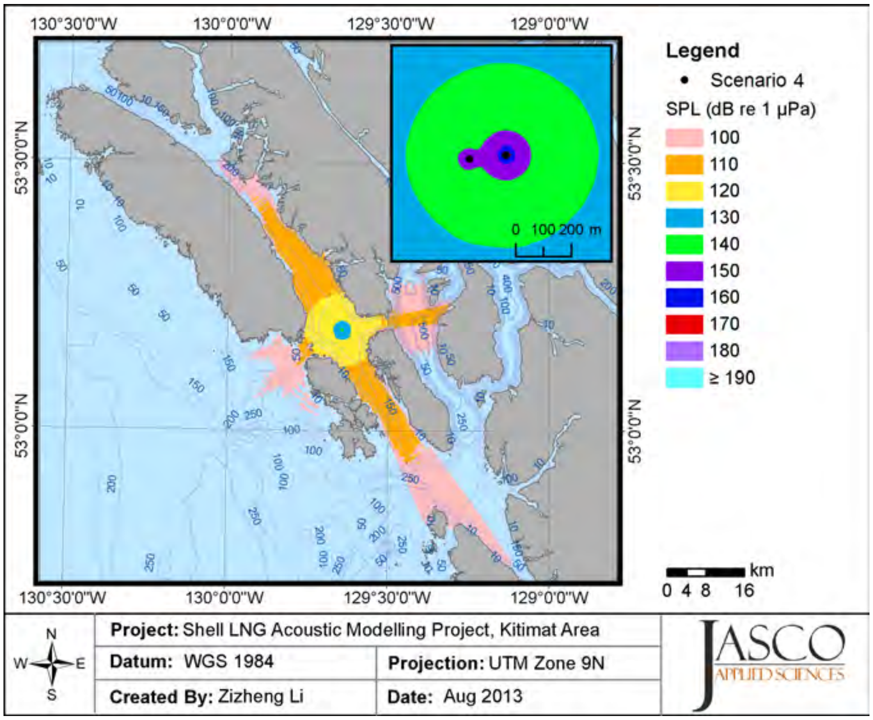

Figure 18. Scenario 4: Sound level isopleth map of unweighted SPL (dB re 1 µPa, maximum-over-depth). An LNG carrier and a tug are transiting at 12 kts along the outbound route in Nepean Sound. A magnified view of the sources appears in the upper right.

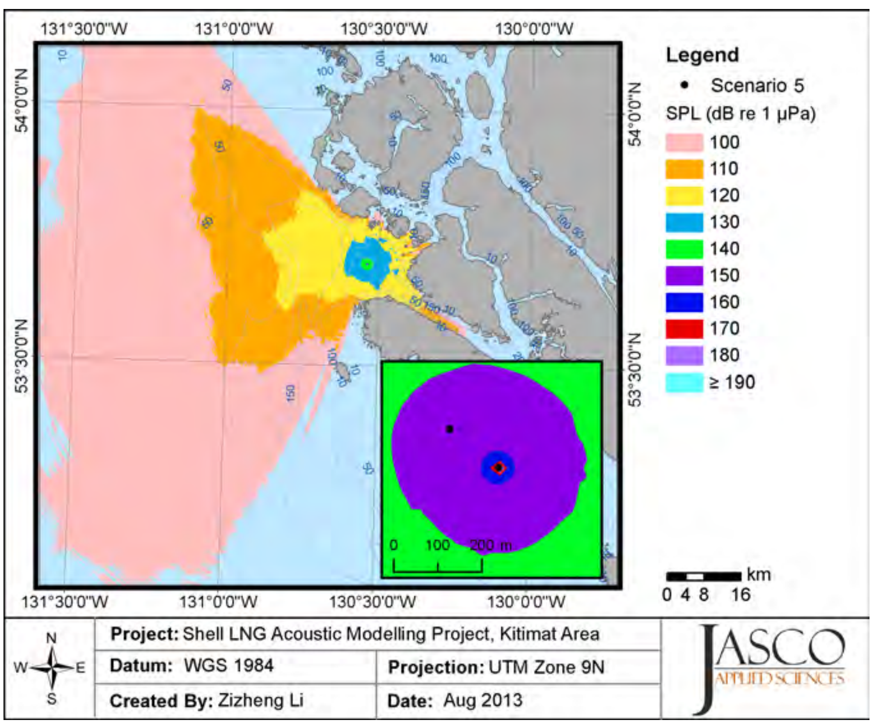

Figure 19. Scenario 5: Sound level isopleth map of unweighted SPL (dB re 1 µPa, maximum-over-depth). An LNG carrier and a tug are transiting at 12 kts along the outbound route in Browning Entrance. A magnified view of the sources appears in the lower right.

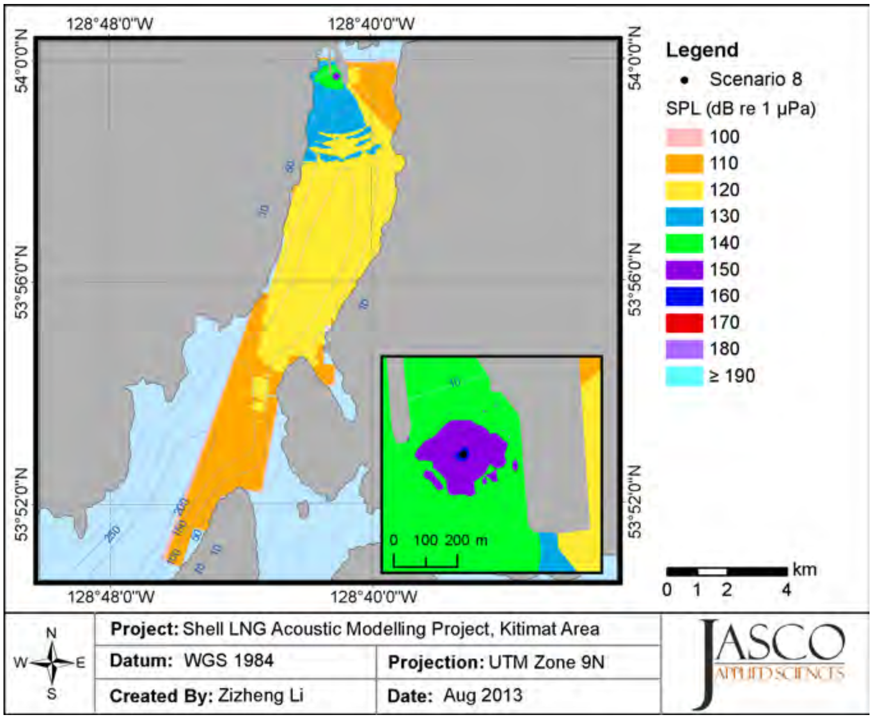

Figure 20. Scenario 8: Sound level isopleth map of unweighted SPL (dB re 1 µPa, maximum-over-depth). The trailing suction hopper dredge is at the proposed marine terminal. A magnified view of the sources appears in the lower right.

Table 14. Radii of unweighted SPL contours for vessels berthing (Scenario 1), transiting (Scenarios 2–5), and dredging (Scenario 8).

SPL (dB re 1 µPa)	Scenario 1 (m)		Scenario 2 (m)		Scenario 3 (m)		Scenario 4 (m)		Scenario 5 (m)		Scenario 8 (m)	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
120	16800	14200	12400	10700	12700	10300	10900	7500	24200	19900	12600	9300
130	8300	6200	2100	1700	1900	1400	2100	1900	7100	5700	3100	2800
140	1300	1000	370	340	350	320	400	360	1400	1300	760	610
150	270	240	150	140	150	140	150	140	260	230	190	150
160	20	20	30	30	30	30	30	30	40	40	20	20
170	< 10	< 10	10	10	10	10	10	10	10	10	< 10	< 10
180	--	--	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	--	--
190	--	--	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	--	--
200	--	--	--	--	--	--	--	--	--	--	--	--

5.1.2. Audiogram-weighted sound pressure levels and zones of audibility

For each species, the 1/3-octave-band hearing thresholds were subtracted from the modelled noise levels (maximized-over-depth in the water column), and the resulting audiogram-weighted 1/3-octave-band levels were summed to yield broadband noise levels above the hearing threshold. Audiogram-weighted SPLs (dB re HT, which is the sound dB level above hearing threshold) are presented in sound level isopleth maps and radii tables for each modelled scenario for killer whale, humpback whale, and harbour porpoise. Audiogram weighting was applied to these sources: LNG carrier, tug, and dredge (Scenarios 1–5, and Scenario 8). Zones of audibility, denoted in solid black line in the maps, were estimated based on the comparisons of modelled noise levels with audiograms and ambient noise.

5.1.2.1. Killer whale

Figures 21 to 26 show sound level isopleth maps of killer whale audiogram-weighted broadband (10 Hz–31.5 kHz) sound pressure levels (SPLs). Table 15 presents the R_{max} and $R_{95\%}$ corresponding to the audiogram-weighted SPLs (dB re HT).

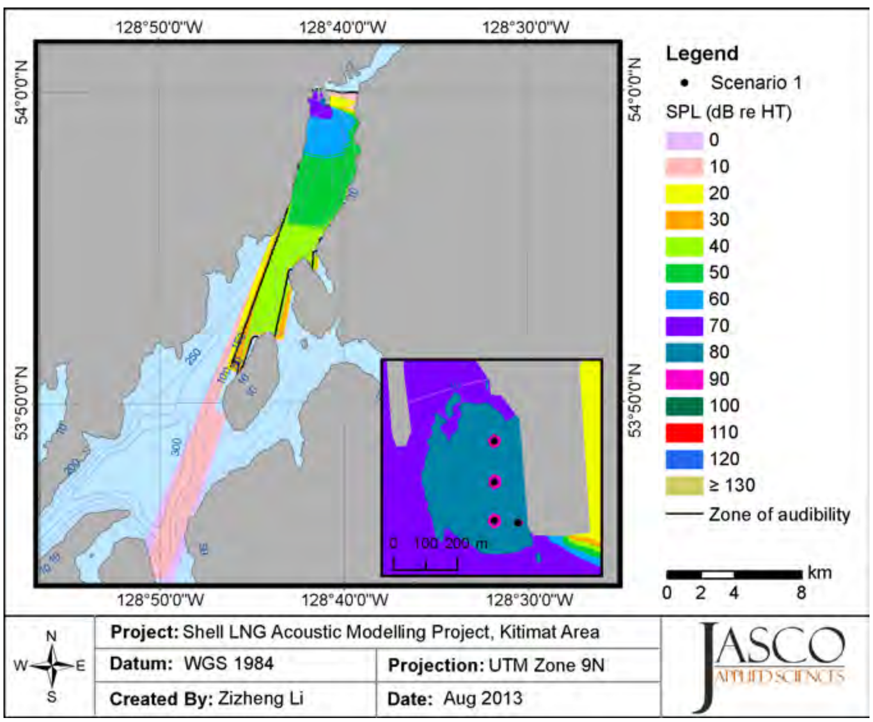

Figure 21. Scenario 1: Sound level isopleth map of killer whale audiogram-weighted SPL (dB re HT, maximum-over-depth). An LNG carrier and three harbour tugs are berthing at the proposed marine terminal. A magnified view of the sources appears in the lower right.

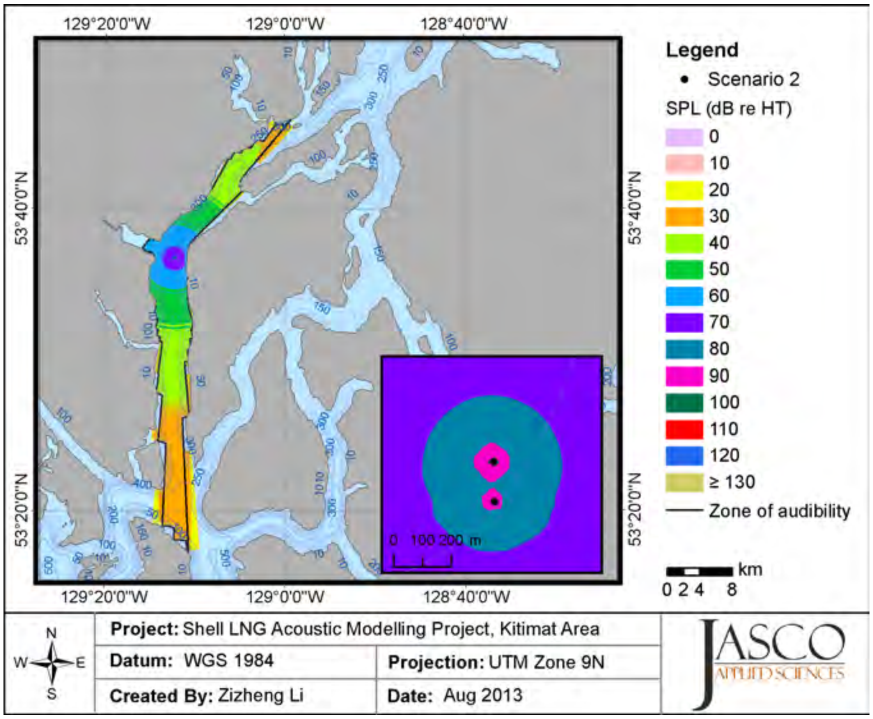

Figure 22. Scenario 2: Sound level isopleth map of killer whale audiogram-weighted SPL (dB re HT, maximum-over-depth). An LNG carrier and a tug are transiting at 12 kts along the outbound route in Douglas Channel. A magnified view of the sources appears in the lower right.

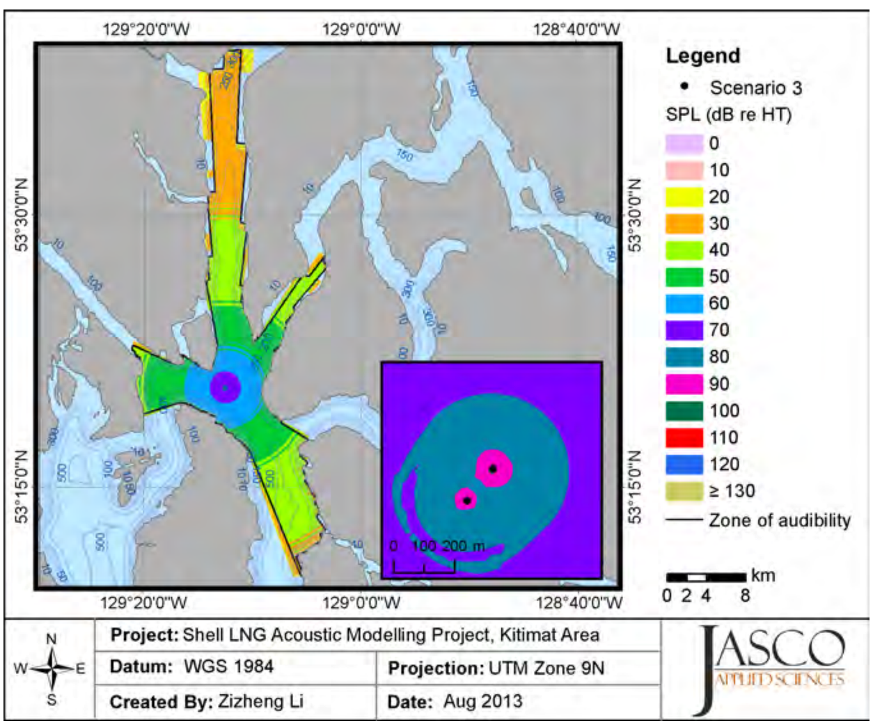

Figure 23. Scenario 3: Sound level isopleth map of killer whale audiogram-weighted SPL (dB re HT, maximum-over-depth). An LNG carrier and a tug are transiting at 12 kts along the outbound route in Wright Sound. A magnified view of the sources appears in the lower right.

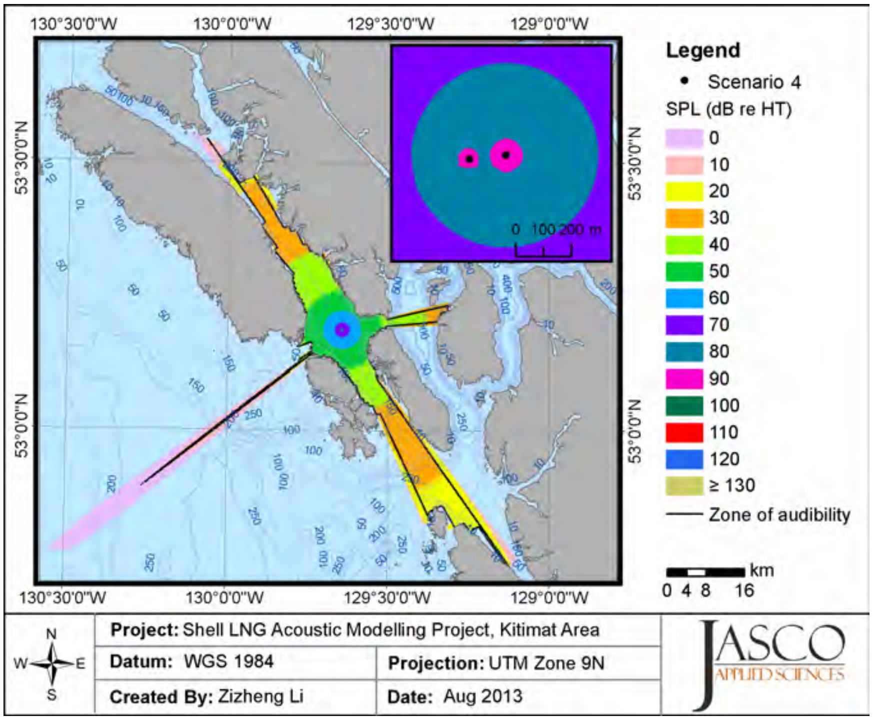

Figure 24. Scenario 4: Sound level isopleth map of killer whale audiogram-weighted SPL (dB re HT, maximum-over-depth). An LNG carrier and a tug are transiting at 12 kts along the outbound route in Nepean Sound. A magnified view of the sources appears in the upper right.

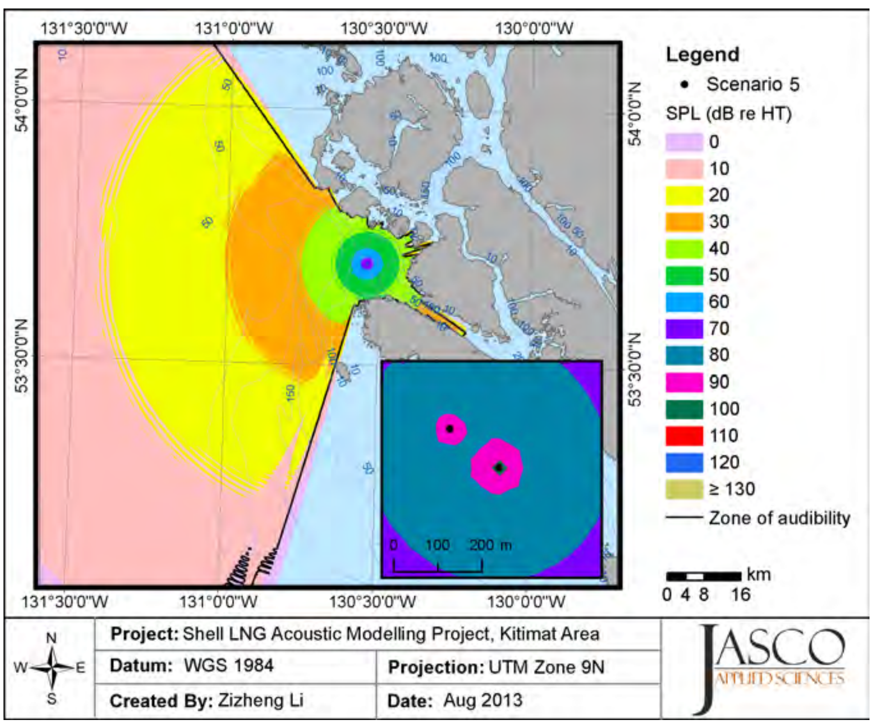

Figure 25. Scenario 5: Sound level isopleth map of killer whale audiogram-weighted SPL (dB re HT, maximum-over-depth). An LNG carrier and a tug are transiting at 12 kts along the outbound route in Browning Entrance. A magnified view of the sources appears in the lower right.

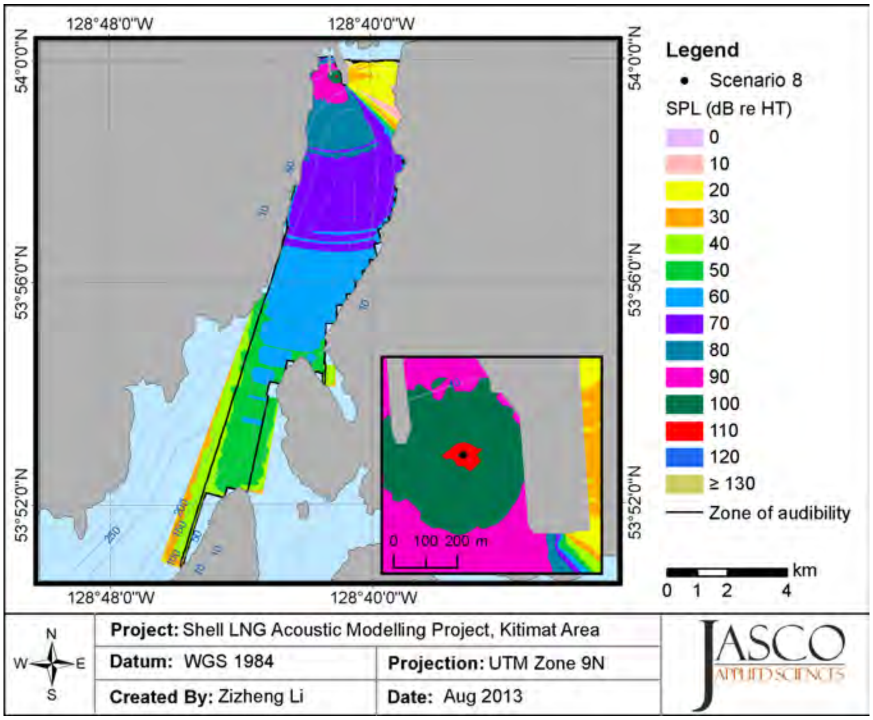

Figure 26. Scenario 8: Sound level isopleth map of killer whale audiogram-weighted SPL (dB re HT, maximum-over-depth). The trailing suction hopper dredge is at the proposed marine terminal. A magnified view of the sources appears in the lower right.

Table 15. Radii of killer whale audiogram-weighted SPL contours for vessels berthing (Scenario 1), transiting (Scenarios 2–5), and dredging (Scenario 8).

SPL (dB re HT)	Scenario 1 (m)		Scenario 2 (m)		Scenario 3 (m)		Scenario 4 (m)		Scenario 5 (m)		Scenario 8 (m)	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
0	30100	28600	36000	32300	34800	30800	76500	62000	100600*	83900*	17200	14300
10	30000	27600	36000	32300	34800	30800	60400	47200	99300*	83200*	17200	14300
20	18800	14500	36000	32200	34800	30600	60100	45200	60700	55500	17200	14300
30	16900	14200	35800	31300	34700	29200	37900	33700	33200	29700	17200	14300
40	16200	13300	19400	16500	18900	16100	18100	16200	15500	13800	17000	13900
50	7500	7000	9200	8100	8900	8100	8800	7800	8200	7100	14400	13000
60	3300	3100	4500	3900	4700	4100	4300	3900	3900	3400	11900	9200
70	1100	1000	1700	1600	1700	1600	1900	1500	1600	1400	5900	5500
80	350	270	300	270	310	290	400	360	320	290	3000	2600
90	20	20	60	60	60	60	110	60	60	60	1000	900
100	< 10	< 10	10	10	10	10	10	10	10	10	330	250
110	--	--	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	80	50
120	--	--	--	--	--	--	--	--	--	--	10	10
130	--	--	--	--	--	--	--	--	--	--	< 10	< 10
140	--	--	--	--	--	--	--	--	--	--	--	--

* Restricted by the modelling boundary.

5.1.2.2. Humpback whale

Figures 27 to 32 show sound level isopleth maps of humpback whale audiogram-weighted broadband (10 Hz–31.5 kHz) sound pressure levels. Table 16 shows the R_{max} and $R_{95\%}$ corresponding to the audiogram-weighted SPLs (dB re HT).

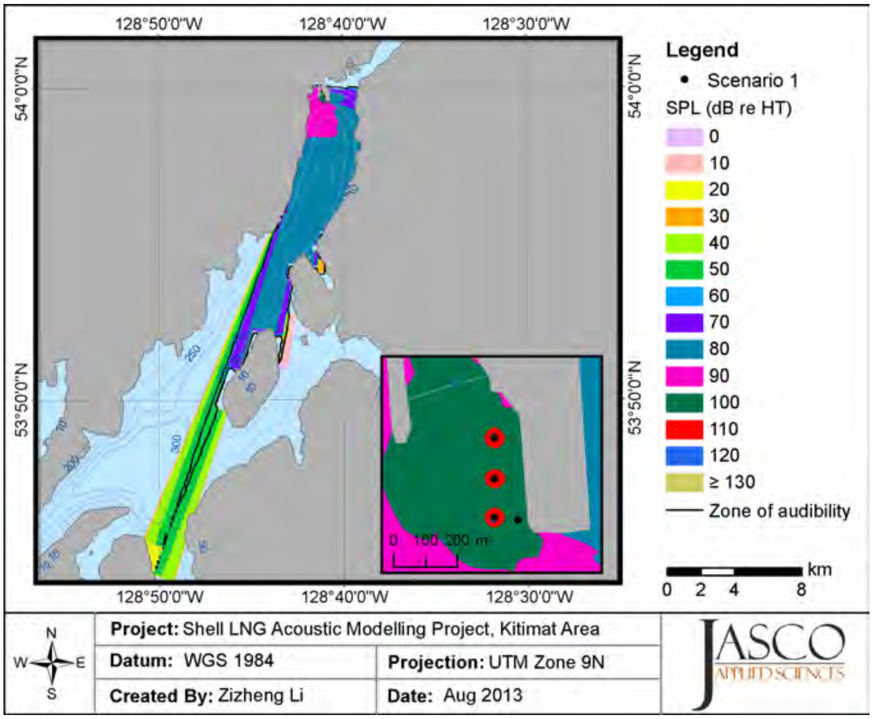

Figure 27. Scenario 1: Sound level isopleth map of humpback audiogram-weighted SPL (dB re HT, maximum-over-depth). An LNG carrier and three harbour tugs are berthing at the proposed marine terminal. A magnified view of the sources appears in the lower right.

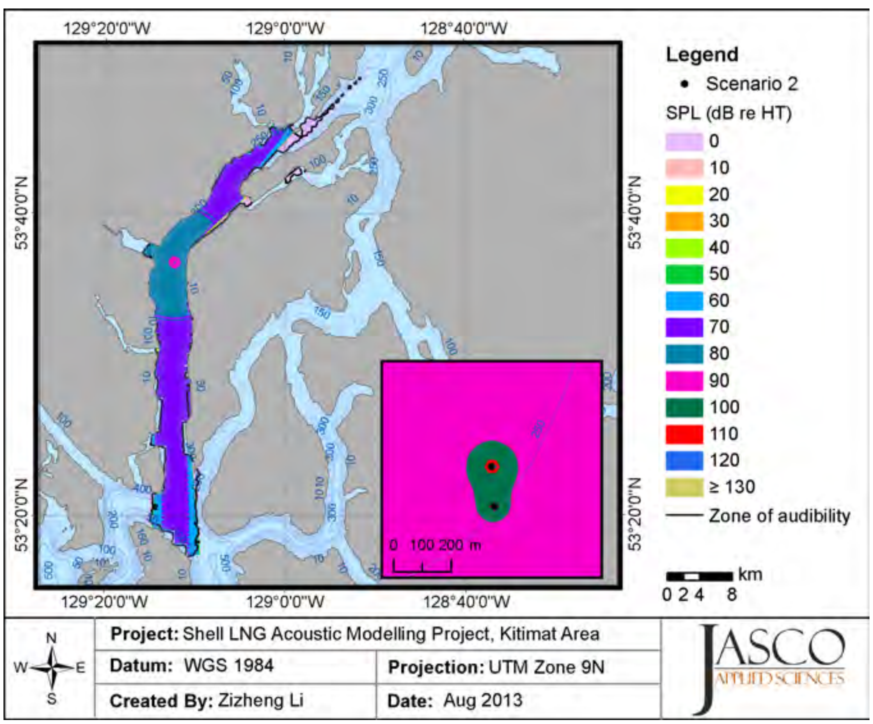

Figure 28. Scenario 2: Sound level isopleth map of humpback audiogram-weighted SPL (dB re HT, maximum-over-depth). An LNG carrier and a tug are transiting at 12 kts along the outbound route in Douglas Channel. A magnified view of the sources appears in the lower right.

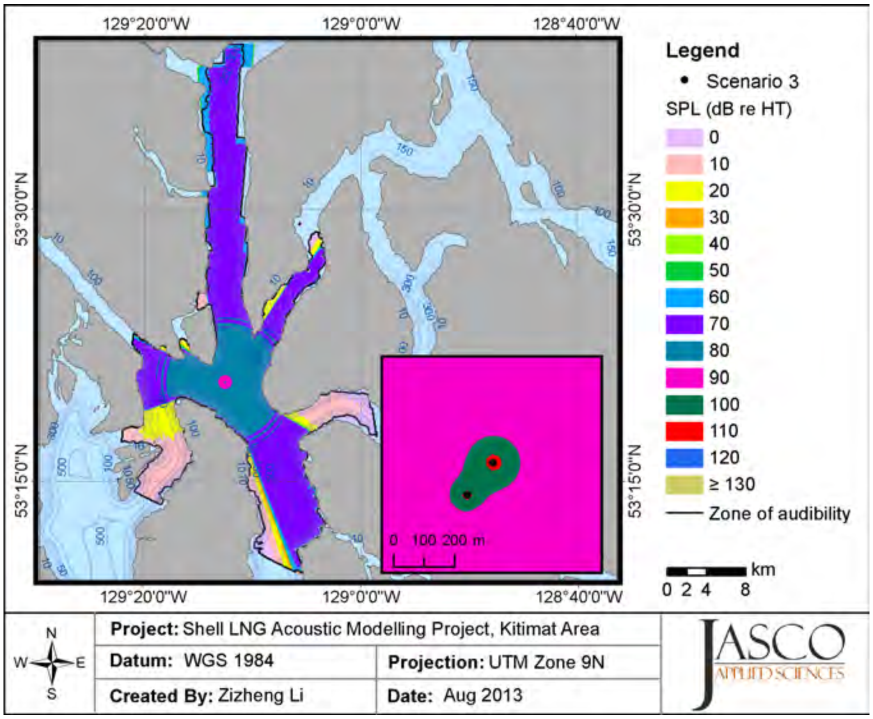

Figure 29. Scenario 3: Sound level isopleth map of humpback audiogram-weighted SPL (dB re HT, maximum-over-depth). An LNG carrier and a tug are transiting at 12 kts along the outbound route in Wright Sound. A magnified view of the sources appears in the lower right.

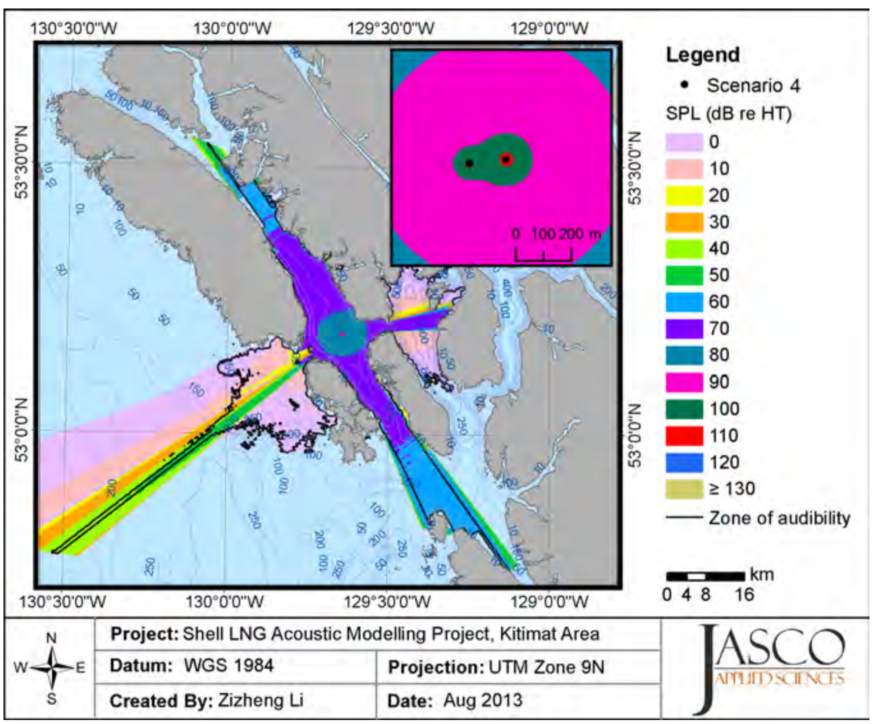

Figure 30. Scenario 4: Sound level isopleth map of humpback audiogram-weighted SPL (dB re HT, maximum-over-depth). An LNG carrier and a tug are transiting at 12 kts along the outbound route in Nepean Sound. A magnified view of the sources appears in the upper right.

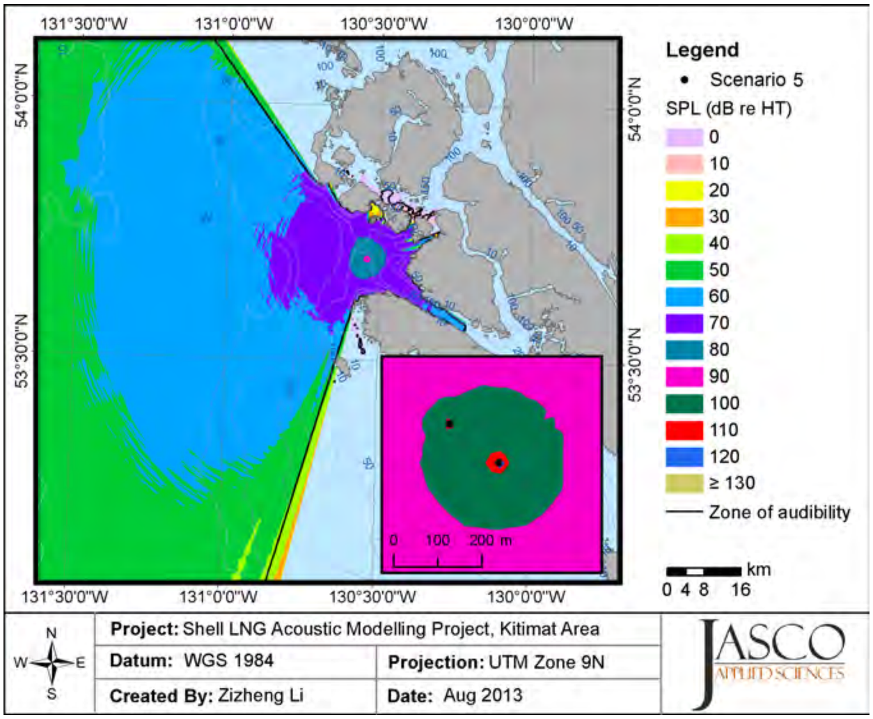

Figure 31. Scenario 5: Sound level isopleth map of humpback audiogram-weighted SPL (dB re HT, maximum-over-depth). An LNG carrier and a tug are transiting at 12 kts along the outbound route in Browning Entrance. A magnified view of the sources appears in the lower right.

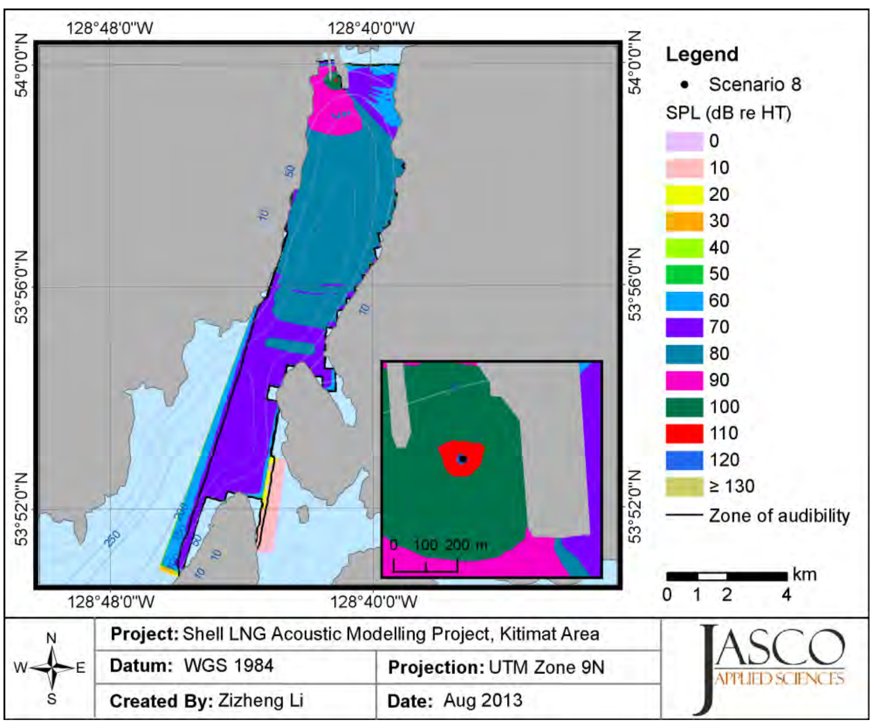

Figure 32. Scenario 8: Sound level isopleth map of humpback audiogram-weighted SPL (dB re HT, maximum-over-depth). The trailing suction hopper dredge is at the proposed marine terminal. A magnified view of the sources appears in the lower right.

Table 16. Radii of humpback audiogram-weighted SPL contours for vessels berthing (Scenario 1), transiting (Scenarios 2–5), and dredging (Scenario 8).

SPL (dB re HT)	Scenario 1 (m)		Scenario 2 (m)		Scenario 3 (m)		Scenario 4 (m)		Scenario 5 (m)		Scenario 8 (m)	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
0	30100	28600	39200	31900	34800	29500	86900	75300	100600*	83800*	17400	15100
10	30100	28600	36000	32300	34800	29800	86900	74900	100600*	83800*	17400	15000
20	30100	28500	36000	32300	34800	30400	86100	70500	100600*	83800*	17400	14400
30	30100	27800	36000	32300	34800	30700	80800	69500	100600*	83800*	17300	14400
40	30100	27700	36000	32300	34800	30700	77500	65500	100600*	83900*	17300	14300
50	30000	26300	36000	32300	34800	30700	61600	48500	100500*	84000*	17200	14300
60	16900	14200	36000	32200	34800	30500	60100	44900	73700	63400	17200	14200
70	16900	14100	35800	31000	34600	28700	30400	23700	28600	20600	17100	13700
80	16300	13200	7300	6500	7800	6000	7300	5100	8200	4400	9800	8000
90	2800	2200	1000	700	760	700	510	460	900	740	2700	1800
100	520	440	150	140	150	140	160	150	230	200	450	370
110	30	30	20	20	30	30	30	30	30	20	90	70
120	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	10	10
130	< 10	< 10	< 10	< 10	--	--	< 10	< 10	< 10	< 10	< 10	< 10
140	--	--	--	--	--	--	--	--	--	--	--	--

* Restricted by the modelling boundary.

5.1.2.3. Harbour porpoise

Figures 33 to 38 show sound level isopleth maps of harbour porpoise audiogram-weighted broadband (10 Hz–31.5 kHz) sound pressure levels (SPLs). Table 17 presents the R_{max} and $R_{95\%}$ corresponding to the audiogram-weighted SPLs (dB re HT).

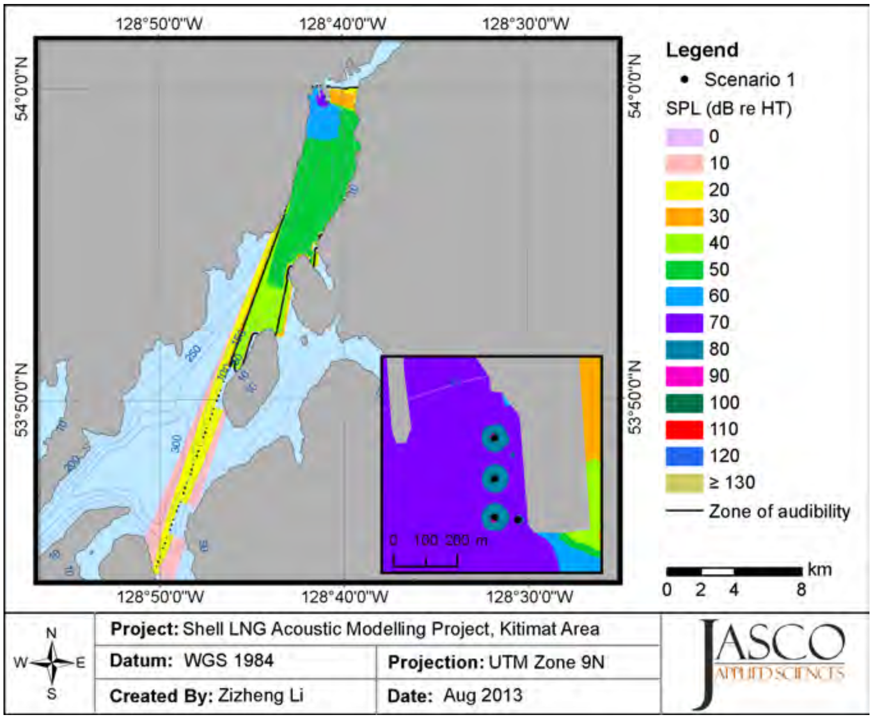

Figure 33. Scenario 1: Sound level isopleth map of harbour porpoise audiogram-weighted SPL (dB re HT, maximum-over-depth). An LNG carrier and three harbour tugs are berthing at the proposed marine terminal. A magnified view of the sources appears in the lower right.

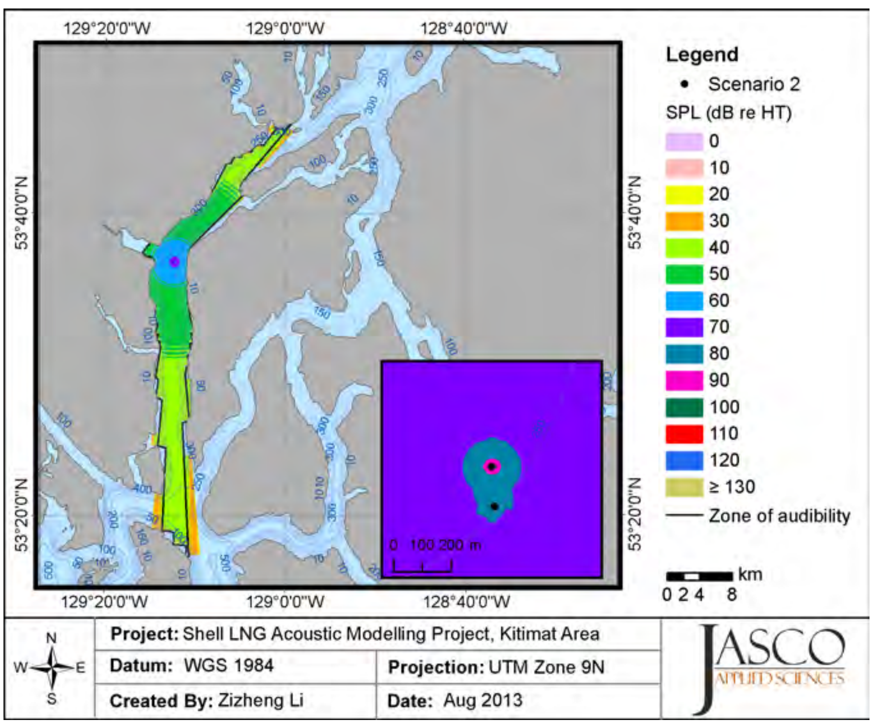

Figure 34. Scenario 2: Sound level isopleth map of harbour porpoise audiogram-weighted SPL (dB re HT, maximum-over-depth). An LNG carrier and a tug are transiting at 12 kts along the outbound route in Douglas Channel. A magnified view of the sources appears in the lower right.

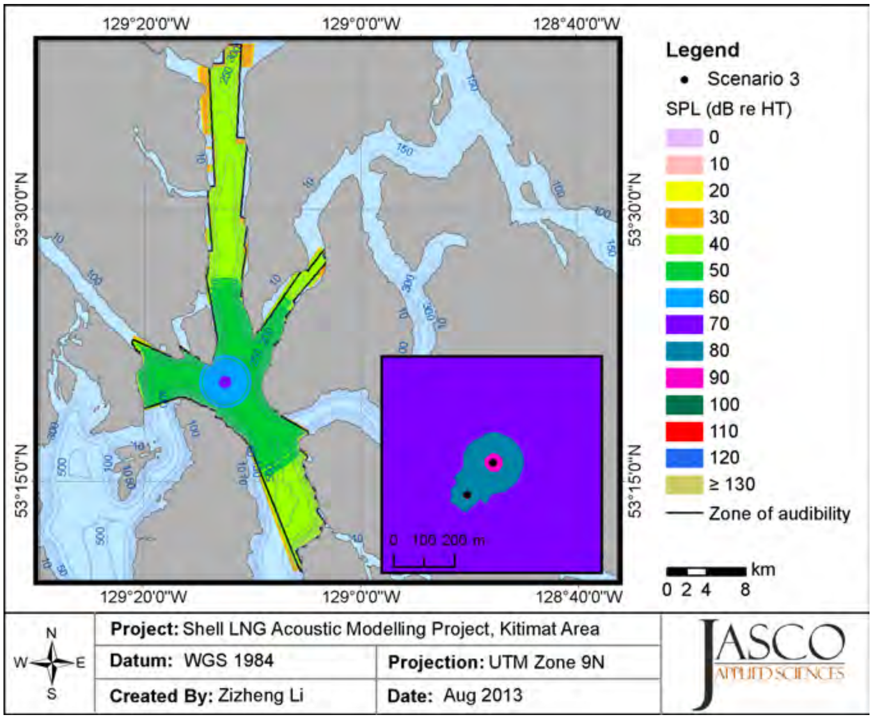

Figure 35. Scenario 3: Sound level isopleth map of harbour porpoise audiogram-weighted SPL (dB re HT, maximum-over-depth). An LNG carrier and a tug are transiting at 12 kts along the outbound route in Wright Sound. A magnified view of the sources appears in the lower right.

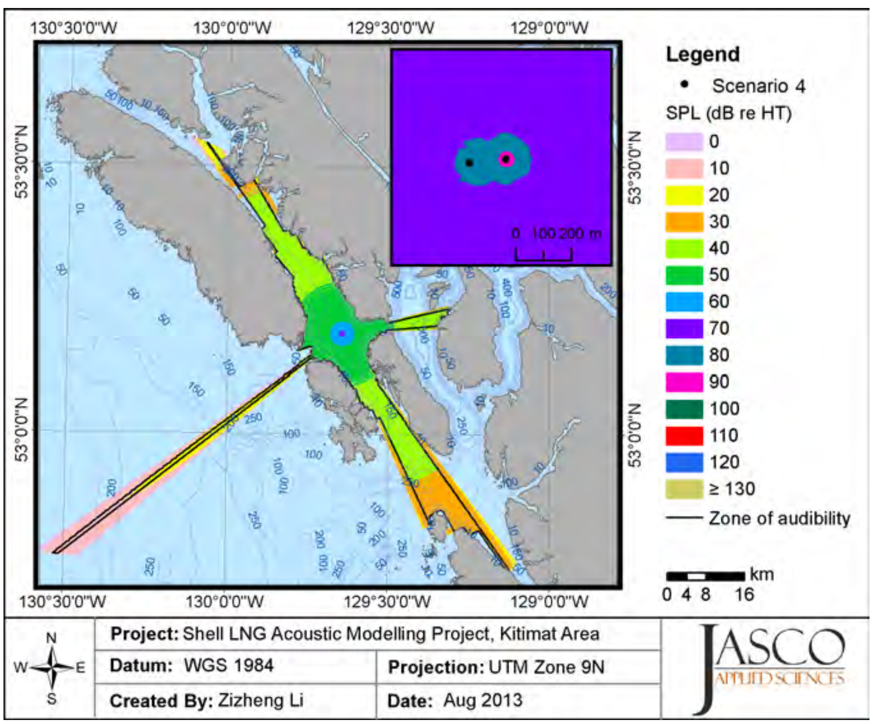

Figure 36. Scenario 4: Sound level isopleth map of harbour porpoise audiogram-weighted SPL (dB re HT, maximum-over-depth). An LNG carrier and a tug are transiting at 12 kts along the outbound route in Nepean Sound. A magnified view of the sources appears in the upper right.

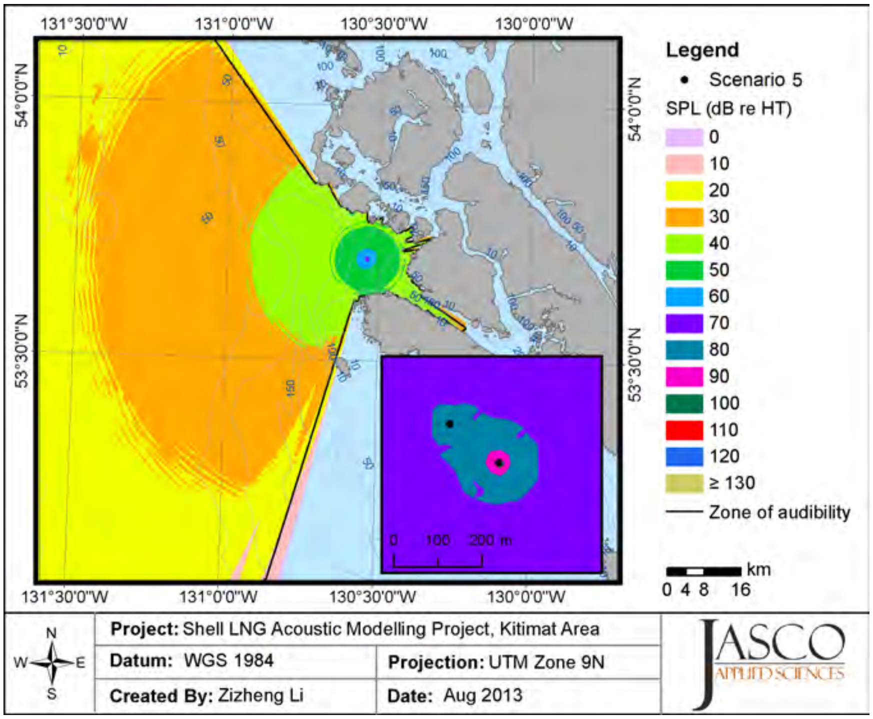

Figure 37. Scenario 5: Sound level isopleth map of harbour porpoise audiogram-weighted SPL (dB re HT, maximum-over-depth). An LNG carrier and a tug are transiting at 12 kts along the outbound route in Browning Entrance. A magnified view of the sources appears in the lower right.

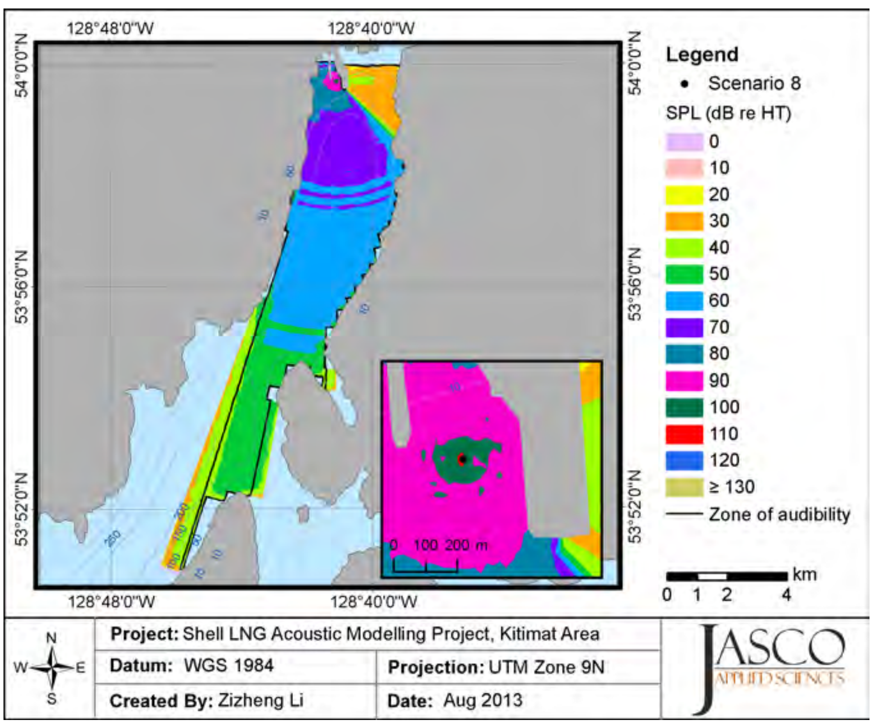

Figure 38. Scenario 8: Sound level isopleth map of harbour porpoise audiogram-weighted SPL (dB re HT, maximum-over-depth). The trailing suction hopper dredge is at the proposed marine terminal. A magnified view of the sources appears in the lower right.

Table 17. Radii of harbour porpoise audiogram-weighted SPL contours for vessels berthing (Scenario 1), transiting (Scenarios 2–5), and dredging (Scenario 8).

SPL (dB re HT)	Scenario 1 (m)		Scenario 2 (m)		Scenario 3 (m)		Scenario 4 (m)		Scenario 5 (m)		Scenario 8 (m)	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
0	30100	28700	36000	32300	34800	30800	78200	66700	100600*	83800*	17300	14400
10	30100	28600	36000	32300	34800	30800	77400	65200	100600*	83900*	17300	14300
20	30000	24700	36000	32300	34800	30700	60400	48500	100500*	83900*	17200	14300
30	16900	14300	36000	32200	34800	30600	60200	45900	70500	60400	17200	14200
40	16900	14100	35800	31000	34700	28700	36900	31700	29600	24100	17100	14000
50	11600	10000	12300	10700	11600	9800	11200	10100	10600	7800	14400	13000
60	2500	2300	3300	3000	2800	2600	2800	2500	2700	2300	9500	8200
70	660	530	730	670	690	640	700	640	570	500	4300	3900
80	100	40	170	150	160	150	160	140	160	150	1600	1300
90	< 10	< 10	30	30	30	30	30	30	30	30	470	380
100	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	190	140
110	--	--	< 10	< 10	< 10	< 10	--	--	< 10	< 10	20	20
120	--	--	--	--	--	--	--	--	--	--	< 10	< 10
130	--	--	--	--	--	--	--	--	--	--	--	--

* Restricted by the modelling boundary.

5.2. Impact Pile Driving Noise

5.2.1. Sound exposure levels

Figures 39 to 40 show sound level isopleth maps of modelled unweighted maximum-over-depth broadband (10 Hz to 20 kHz) sound exposure levels per blow in dB re 1 µPa^2·s for impact pile driving (Scenarios 6 and 7). The M-weighted sound exposure levels and corresponding radii tables are shown in Appendix 2. The M-weighting curves reduce sound at low and high frequencies. However, the LFC and PINN curves are nearly flat for the dominant frequency bands of the source level of surrogate impact hammers. The MFC and HFC weighting had some effect on the sound levels because the weighting curves reduce the low-frequency sound from pile drivers.

These SEL per blow results are not applicable to determine the zone of injury as defined in Section 4.5. Table 18 shows the maximum unweighted and M-weighted cSELs corresponding to number of blows at given source-to-receiver distances. The cumulative SELs were calculated using Equation 9 based on number of blows.

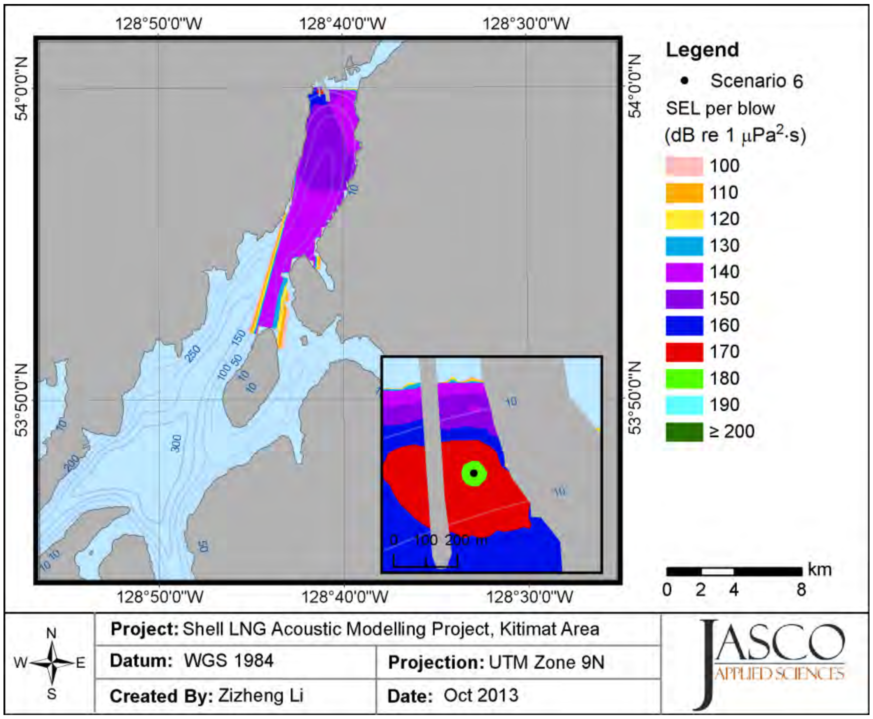

Figure 39. Scenario 6: Sound level isopleth map of unweighted SEL per blow (dB re 1 µPa^2·s, maximum-over-depth). Impact sheet pile driving is operating at the proposed marine terminal. A magnified view of the sources appears in the lower right.

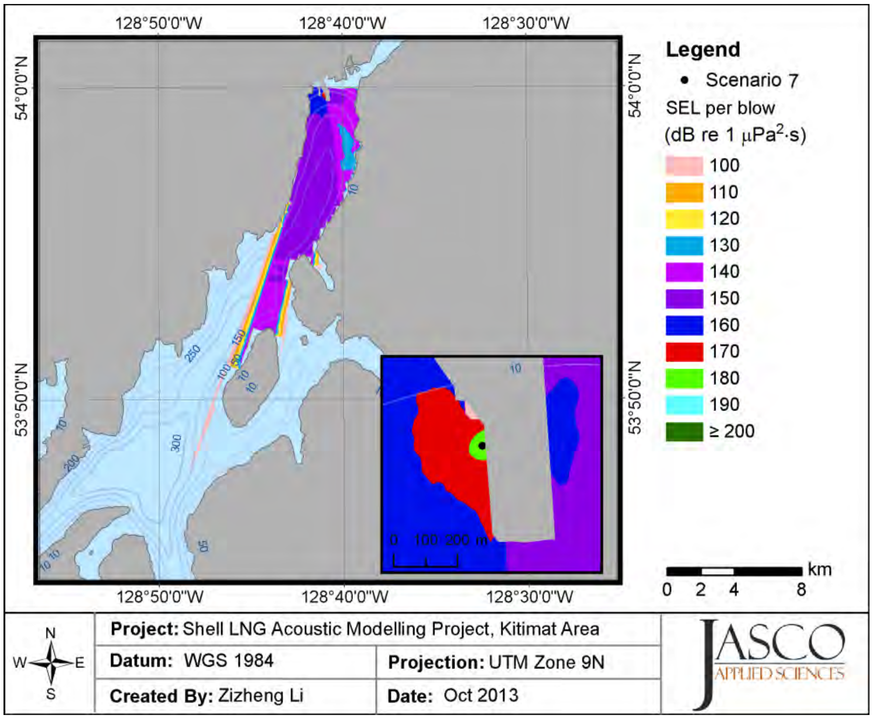

Figure 40. Scenario 7: Sound level isopleth map of unweighted SEL per blow (dB re 1 µPa^2·s, maximum-over-depth). Impact sheet pile driving is operating at the proposed marine terminal. A magnified view of the sources appears in the lower right.

Table 18. Maximum unweighted and M-weighted cSELs corresponding to number of blows (N) at given source-to-receiver distance for impact sheet pile driving (Scenario 6) and impact cylinder pile driving (Scenario 7).

Distance from source (m)	Scenario 6				Scenario 7			
	N=1	N=1000	N=10000	N=25000	N=1	N=1000	N=10000	N=25000
Unweighted cSEL (dB re 1 µPa^2·s)								
10	188.8	218.8	228.8	232.8	188.3	218.3	228.3	232.3
100	176.4	206.4	216.4	220.4	179.1	209.1	219.1	223.1
1000	165.5	195.5	205.5	209.5	165.8	195.8	205.8	209.8
5000	153.9	183.9	193.9	197.9	155.3	185.3	195.3	199.3
LFC weighted cSEL (dB re 1 µPa^2·s)								
10	188.7	218.7	228.7	232.7	188.3	218.3	228.3	232.3
100	176.4	206.4	216.4	220.4	179.0	209.0	219.0	223.0
1000	165.5	195.5	205.5	209.5	165.8	195.8	205.8	209.8
5000	153.9	183.9	193.9	197.9	155.3	185.3	195.3	199.3
MFC weighted cSEL (dB re 1 µPa^2·s)								
10	185.5	215.5	225.5	229.5	187.2	217.2	227.2	231.2
100	174.1	204.1	214.1	218.1	178.4	208.4	218.4	222.4
1000	163.3	193.3	203.3	207.3	165.5	195.5	205.5	209.5
5000	151.4	181.4	191.4	195.4	155.0	185.0	195.0	199.0
HFC weighted cSEL (dB re 1 µPa^2·s)								
10	184.5	214.5	224.5	228.5	186.8	216.8	226.8	230.8
100	173.0	203.0	213.0	217.0	178.1	208.1	218.1	222.1
1000	162.3	192.3	202.3	206.3	165.3	195.3	205.3	209.3
5000	150.8	180.8	190.8	194.8	154.8	184.8	194.8	198.8
PINN weighted cSEL (dB re 1 µPa^2·s)								
10	187.6	217.6	227.6	231.6	187.9	217.9	227.9	231.9
100	175.7	205.7	215.7	219.7	178.8	208.8	218.8	222.8
1000	164.8	194.8	204.8	208.8	165.7	195.7	205.7	209.7
5000	153.0	183.0	193.0	197.0	155.2	185.2	195.2	199.2

As described in Section 4.2.3, we assumed impact pile driving would operate at 45 blows per minute, 45 minutes of each hour, 12 hours per day, resulting in 24300 blows for 24 hours. Under that assumption, we added 10log(24300) = 43.86 dB to the single-blow SEL. The radii corresponding to injury and disturbance criteria by Southall et al. (2007) for 24-hour cSEL for Scenarios 6 and 7 are shown in Tables 19 and 20.

Table 19. Radii of unweighted and M-weighted 24-hour cSEL contours for impact sheet pile driving (Scenario 6). The cSEL calculation included 24300 blows.

cSEL (dB re 1 µPa^2·s)	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	15000	13100	--	--	--	--	--	--	15000	13000
183	14900	12400	14900	12400	14900	12200	14900	12200	--	--
186	14900	12100	--	--	--	--	--	--	14900	12100
198	5800	2500	5800	2500	3000	1900	2900	1500	--	--

Table 20. Radii of unweighted and M-weighted 24-hour cSEL contours for impact cylinder pile driving (Scenario 7). The cSEL calculation included 24300 blows.

cSEL (dB re 1 µPa^2·s)	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	17000	13800	--	--	--	--	--	--	17000	13800
183	16700	13500	16700	13500	16700	13500	16700	13500	--	--
186	16600	13400	--	--	--	--	--	--	16600	13400
198	6100	4600	6100	4600	6000	4300	6000	3800	--	--

5.2.2. rms Sound pressure levels

Figures 41 and 42 show sound level isopleth maps of modelled unweighted maximum-over-depth broadband (10 Hz to 20 kHz) sound pressure levels in dB re 1 µPa for impact pile driving (Scenarios 6 and 7). Table 21 presents the $R_{95\%}$ and R_{max} SPL threshold ranges for impact pile driving scenarios. The 95th percentile radii for these scenarios drop to 0.1 and 0.3 km when the SPL is above 190 and 180 dB re 1 µPa. The 95th percentile radii at 160 dB re 1 µPa rms SPL are 4.2 km for sheet pile driving and 7.3 km for cylinder pile driving.

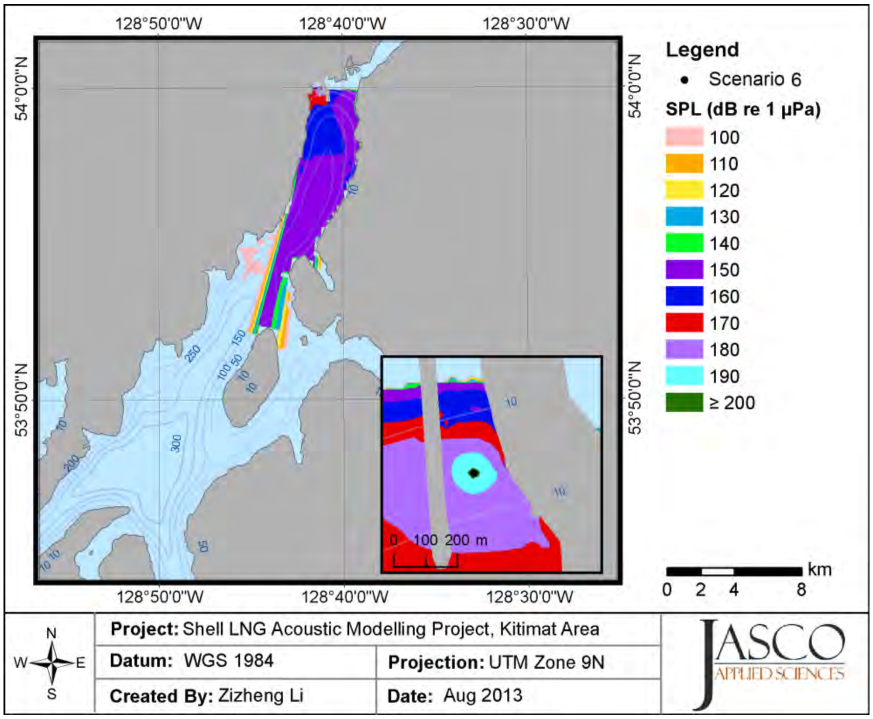

Figure 41. Scenario 6: Sound level isopleth map of unweighted SPL (dB re 1 µPa, maximum-over-depth). Impact sheet pile driving is operating at the proposed marine terminal. A magnified view of the sources appears in the lower right.

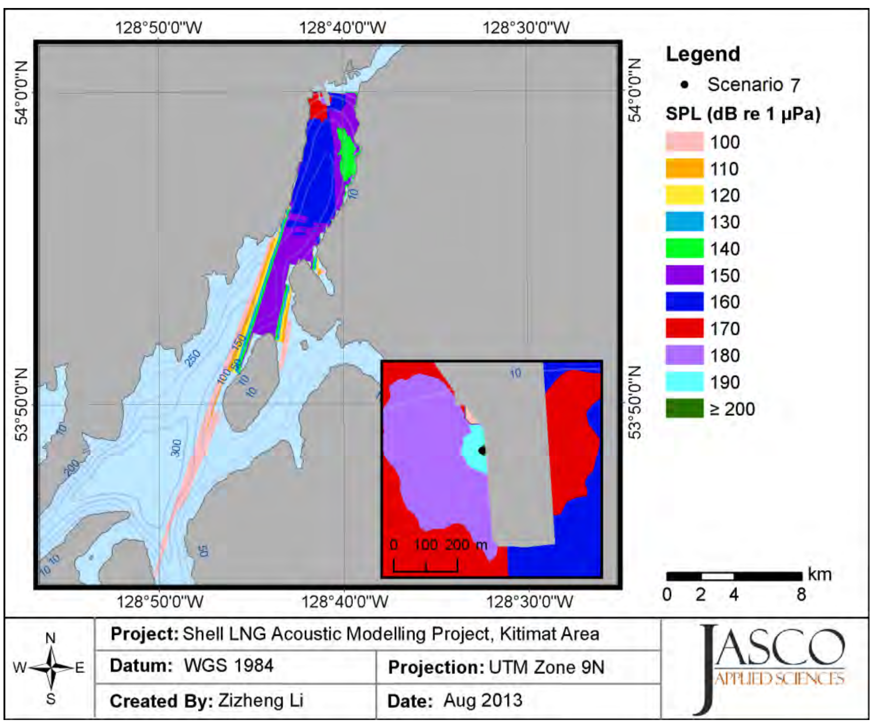

Figure 42. Scenario 7: Sound level isopleth map of unweighted SPL (dB re 1 µPa, maximum-over-depth). Impact 600 mm cylinder pile driving is operating at the proposed marine terminal. A magnified view of the sources appears in the lower right.

Table 21. Radii of unweighted rms SPL contours for impact sheet pile driving (Scenario 6) and impact cylinder pile driving (Scenario 7).

SPL (dB re 1 µPa)	Scenario 6 (m)		Scenario 7 (m)		SPL (dB re 1 µPa)	Scenario 6 (m)		Scenario 7 (m)	
	R_{max}	$R_{95\%}$	R_{max}	R_{max}		R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
120	15500	13600	17100	14200	180	350	310	340	310
130	15400	13300	17100	14000	190	80	70	110	80
140	15000	12900	17000	13600	200	20	20	20	20
150	14900	12100	16600	13400	210	< 10	< 10	< 10	< 10
160	6700	4200	8500	7300	220	< 10	< 10	< 10	< 10
170	1600	1200	1900	1300	230	--	--	--	--

5.2.3. Peak Sound pressure levels

Table 22 presents the R_{max} and $R_{95\%}$ corresponding to the peak SPLs (dB re 1 µPa) for impact sheet and cylinder pile driving scenarios based on the estimated offset curves described in Section 4.2.2. The levels presented in the table are based on Southall et al. (2007) auditory injury and disturbance criteria described in Section 4.5. The 95th percentile radii for pile driving drop down to less than 50 m when the peak SPL is above 212 dB re 1 µPa.

Table 22. Radii of peak SPL contours for impact sheet pile driving (Scenario 6) and impact cylinder pile driving (Scenario 7).

Peak SPL (dB re 1 µPa)	Scenario 6 (m)		Scenario 7 (m)	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
212	30	30	33	29
218	10	10	11	10
224	< 10	< 10	< 10	< 10
230	< 10	< 10	< 10	< 10

6. Discussion

6.1. Vessel and Construction Noise Effects on Marine Mammals

The potential effects of anthropogenic noise on marine mammals depend on many factors, including sound level, exposure duration, type of noise source, habituation, and exposure context (Ellison et al. 2012). Williams et al. (2002a, 2002b) noted northern resident killer whales' responses to whale-watching boats that approached quickly and erratically at approximately 200 m range was overt avoidance; the whales' responses to slowly approaching whale-watching boats at 100 m was subtle avoidance. The broadband sound levels received by the killer whales were estimated to be 116 dB re 1 µPa for overt avoidance and 108 dB re 1 µPa for subtle avoidance and confirmed by R. Williams. In both experiments, the authors noted that factors other than the noise itself (e.g., vessel proximity and speed) could have contributed to the whales' reactions. Nonetheless, applying audiogram weighting to these reported sound levels suggested the whales exhibited overt avoidance at received levels of approximately 64 dB re HT, and subtle avoidance at received levels of approximately 57 dB re HT. These values may be overly conservative since the animals could have been reacting to vessel presence and proximity rather than noise level.

Southall et al. (2007) reviewed the literature on behavioural responses of mysticetes to nonpulsed noise and concluded that responses were seldom observed at received SPLs below 120 dB re 1 µPa; however they also pointed out that response thresholds were quite variable and that exposure context was just as important as sound exposure in determining behavioural reactions. Table 23 lists the $R_{95\%}$ distances of 57 and 64 dB re HT resulting from killer whale and harbour porpoise audiogram-weighted SPLs, and the $R_{95\%}$ distances of 120 dB re 1 µPa of unweighted SPLs for Scenario 1–5 and Scenario 8.

Table 23. Estimated $R_{95\%}$ at potential behavioural response thresholds for vessels berthing (Scenario 1), transiting (Scenarios 2–5), and dredging (Scenario 8).

Threshold	Scenario 1 (m)	Scenario 2 (m)	Scenario 3 (m)	Scenario 4 (m)	Scenario 5 (m)	Scenario 8 (m)
57 dB re $HT_{Killer\ whale}$	4000	4900	5000	4900	4200	11000
64 dB re $HT_{Killer\ whale}$	2000	2900	2600	2700	2600	8000
57 dB re $HT_{Harbour\ porpoise}$	3700	4100	4100	3900	3300	10100
64 dB re $HT_{Harbour\ porpoise}$	1200	1600	1600	1500	1400	6200
120 dB re 1 µPa	14200	10700	10300	7500	19900	9300

As described in Section 4.6, we assumed animals are likely to detect the vessel noise if the SPL exceeded the ambient noise level or species-specific hearing threshold. The zones of audibility ($R_{95\%}$) for Scenarios 1–5 and Scenario 8 are shown in Table 24. This analysis showed that the zone of audibility is mainly determined by ambient noise conditions in the assessment area, rather than species-specific hearing thresholds. The water along the route is noisy mainly due to existing noise sources, especially pre-existing vessel traffic.

Table 24. Estimated zones of audibility ($R_{95\%}$) for vessels berthing (Scenario 1), transiting (Scenarios 2–5), and dredging (Scenario 8).

Zone of audibility	Scenario 1 (m)	Scenario 2 (m)	Scenario 3 (m)	Scenario 4 (m)	Scenario 5 (m)	Scenario 8 (m)
Killer whale	14100	31000	29400	43200	84000*	13400
Humpback whale	17700	31800	28100	43600	84000*	13900
Harbour porpoise	14400	31100	29400	48300	84000*	13400

* Restricted by the modelling boundary.

6.2. Environmental Effects on Sound Propagation

Seasonal changes of sound speed profiles in the water column substantially change sound propagation conditions. In the study area, winter sound speed profiles are upward refracting, trapping energy near the sea surface (i.e., surface duct), and favouring longer-range propagation with minimal attenuation. Summer sound speed profiles are downward refracting due to a warmer sea surface. The shape of the September sound speed profiles (Figure 43), which is mostly downward refracting, directs sound waves toward the bottom, resulting in more sound energy lost to seabed sediments (bottom loss). Figure 44 compares received SPL (dB re 1 µPa) as a function of range and depth between two sound speed profiles: January and September. The received broadband SPL (10 Hz–31.5 kHz) was calculated for a harbour tug berthing (Scenario 1). The surface duct effect from the January sound speed profiles resulted in longer sound propagation, and thus larger predicted threshold distances, than the September sound speed profiles. The 120 dB contours using the January sound speed profile extend to more than 15 km along the sea surface, but extend less than 8 km using the September sound speed profile.

As described in Section 4.4.1, throughout the year killer whales and harbour porpoises are in BC coastal waters, and some humpback whales are around the northern BC coast. Vessels transiting and berthing occur year-round. Terminal construction is expected to happen between November and February. Because conservative estimates of sound propagation are best achieved using January sound speed profiles, we chose the mean profiles from January to model all the scenarios in this study.

In shallow water, sound propagation is strongly influenced by the reflection and absorption of sound energy by the seabed. Sound is more strongly attenuated in shallow water because of increased bottom loss; therefore, changes in the bathymetry influence the shape of the acoustic fields. Soft sediments tend to absorb more sound energy than hard sediments. Sediment layering in the seabed can also have a strong effect on sound propagation at low frequencies. Interference between reflections from multiple sediment layers can enhance or suppress certain frequencies.

Figure 45 shows the effect from geoacoustic parameters; it compares the received SPL of an escort tug transiting at 12 kts at Scenario 5 locations using two sets of geoacoustics: sand sediments (Table 9) and mud sediments (Table 8). The 120 dB contours extend to about 20 km with sand sediments and less than 10 km with mud sediments. In this study, sound propagation at Scenario 5 had more interactions with the ocean bottom compared to other locations due to its less upward-refracting sound speed profile. Scenario 5 had lower propagation loss because of its 20 m layer of sand, which is more acoustically reflective. Other scenarios had higher propagation loss because of their layers of mud, which is more absorptive. However, upward-refracting sound speed profiles for other scenarios minimized sound interaction with the seabed.

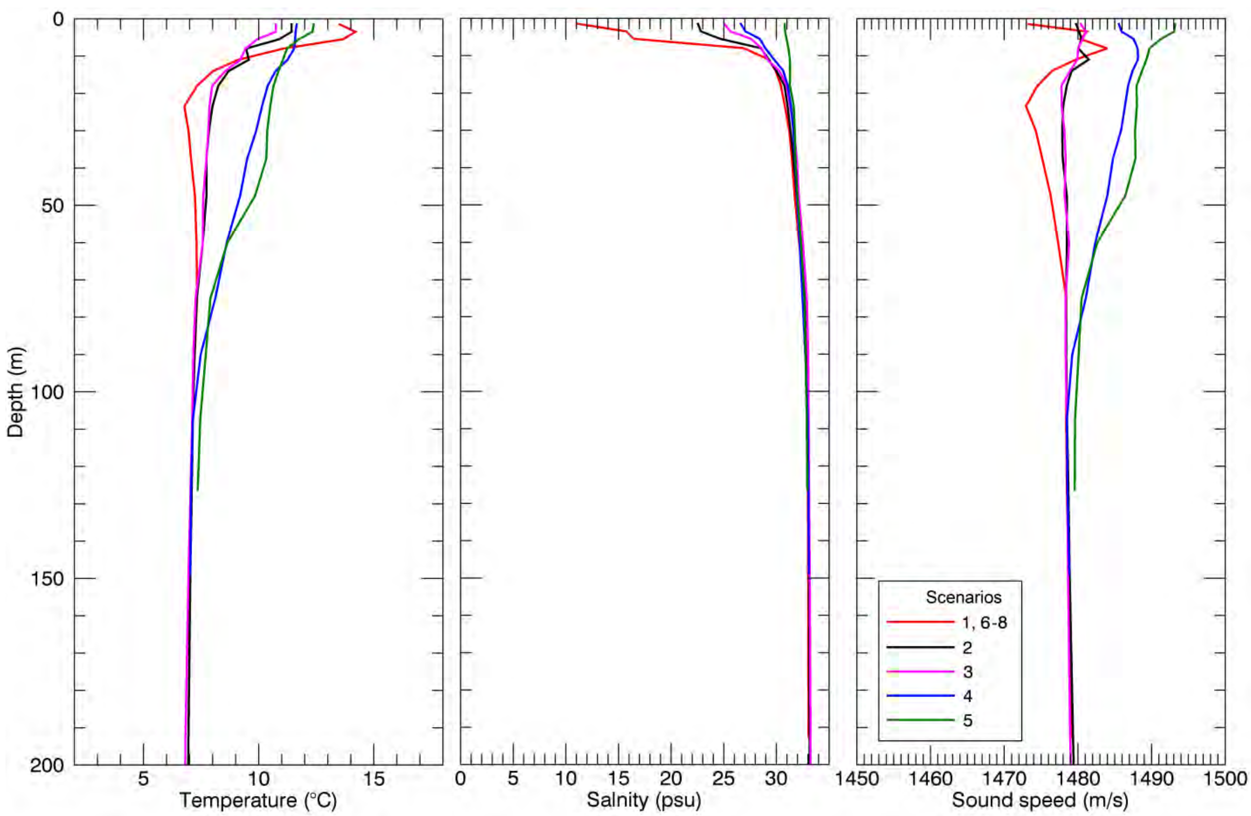

Figure 43. Scenarios 1–8: September temperature, salinity, and sound speed profiles.

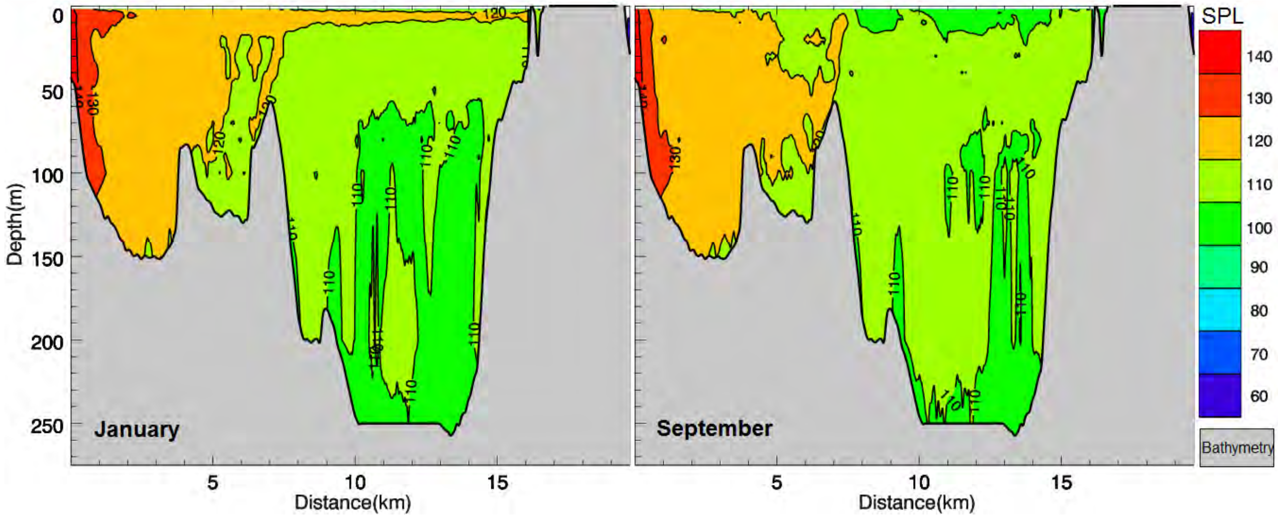

Figure 44. Scenario 1: SPL as a function of range and depth for one transect. The source is a harbour tug berthing at proposed terminal. (Left) January sound speed profile. (Right) September sound speed profile.

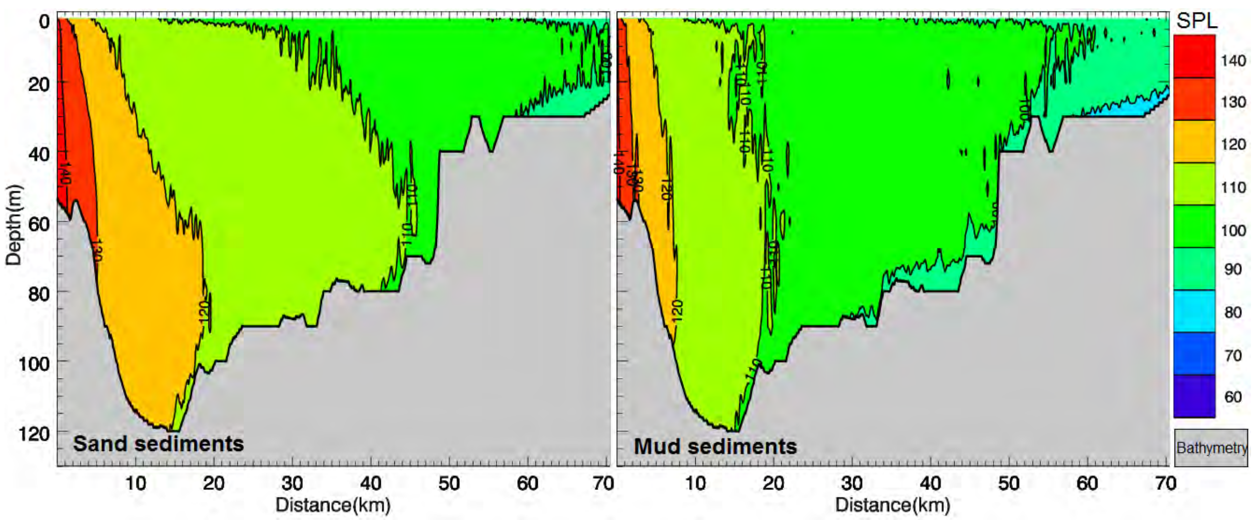

Figure 45. Scenario 5: SPL as a function of range and depth for one transect. The source is an escort tug transiting at 12 kts at Browning Entrance. The sound speed profile is for January. (Left) Geoacoustic profile from Table 9 top with 20 m sand sediments. (Right) Geoacoustic profile from Table 8 top with 60 m mud sediments.

6.3. Effects of Speed Reduction on Ship Noise

One operational procedure that is effective for mitigating ship noise is for vessel operators to reduce their vessels' speeds. Decreasing vessel speed reduces propeller cavitation and other sources of mechanical vibration that contribute to underwater radiated noise from shipping (Ross 1976). The power-law relation of Equation 10 was used to analyze the effect on modelled SPLs of ships travelling at 10 kts, a reduced speed, over the entire transit route.

Tables 25 show the radii for unweighted thresholds at a 10 kt transit speed for Scenarios 2–5. Appendix 1 shows sound level isopleth maps for unweighted and audiogram-weighted SPLs and the radii for audiogram-weighted thresholds. This analysis shows that with speed mitigation, the predicted distances to 120 dB re 1 µPa unweighted SPL were largely reduced. Table 26 lists the $R_{95\%}$ distances of 57 and 64 dB re HT of killer whale and harbour porpoise audiogram-weighted SPL and 120 dB re 1 µPa of unweighted SPL. Table 27 shows the estimated zones of audibility for vessel transiting at mitigated speed.

Table 25. Radii of unweighted SPL contours for vessels transiting (Scenarios 2–5) with mitigation speed.

SPL (dB re 1 µPa)	Scenario 2 (m)		Scenario 3 (m)		Scenario 4 (m)		Scenario 5 (m)	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
120	5300	4300	5300	4300	5000	4300	14200	9500
130	1000	900	630	580	860	800	3300	3000
140	200	200	220	210	230	210	610	560
150	50	50	60	50	50	50	100	100
160	20	20	20	20	20	20	20	20
170	< 10	< 10	< 10	< 10	< 10	< 10	10	10
180	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
190	--	--	--	--	< 10	< 10	< 10	< 10
200	--	--	--	--	--	--	--	--

Table 26. Estimated $R_{95\%}$ at potential behavioural response thresholds for vessels transiting (Scenarios 2–5) with mitigation speed.

Threshold	Scenario 2 (m)	Scenario 3 (m)	Scenario 4 (m)	Scenario 5 (m)
57 dB re $HT_{Killer\ whale}$	3300	3300	3600	2900
64 dB re $HT_{Killer\ whale}$	1800	1600	1700	1500
57 dB re $HT_{Harbour\ porpoise}$	2100	2100	2100	1600
64 dB re $HT_{Harbour\ porpoise}$	690	680	690	560
120 dB re 1 µPa	4300	4300	4300	9500

Table 27. Estimated zone of audibility ($R_{95\%}$) for vessels transiting (Scenarios 2–5) with mitigation speed.

Zone of audibility	Scenario 2 (m)	Scenario 3 (m)	Scenario 4 (m)	Scenario 5 (m)
Killer whale	31000	29300	42500	82200*
Humpback whale	31400	27700	42300	84000*
Harbour porpoise	31000	29400	44900	84000*

* Restricted by the modelling boundary.

7. Summary

This study modelled underwater noise from proposed marine terminal construction, LNG carrier and tug berthing, and traffic associated with the Project, to investigate potential acoustic disturbances to marine mammals. The main species in the Project area that could be affected are humpback whales, fin whales, killer whales, and harbour porpoises. JASCO's MONM was used to model sound levels for eight representative scenarios including pile driving, dredging, and vessel transiting and berthing activities. Species-specific audiogram weighting was applied to the output from MONM to estimate sound levels from vessels that were above each species' hearing thresholds. To analyze auditory injury and disturbance criteria, M-weighting and SEL to SPL conversion was applied to estimate sound levels from impact pile driving. Additionally, cumulative sound exposure was computed to estimate the acoustic footprints of impact pile driving operating over 24 hours. Both unweighted and weighted sound levels are presented in isopleth maps and radii tables.

In general, where uncertainties in operating conditions existed, we chose corresponding model inputs that produced higher predicted noise levels.

Additionally, the following conservative assumptions were also applied to our models:

- Radii ($R_{95\%}$ and R_{max}) and sound level isopleth maps were computed using the maximum sound level over all depths along water column, although in reality marine mammals may spend much of the time at depths with lower sound levels.
- January sound speed profiles result in much larger radii estimates 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.
- Fully-loaded LNG carriers and tugs, which have larger drafts, gave these vessels deeper source depths than those not filled to capacity. Deeper sources more efficiently radiate underwater sound.
- Additional source levels (above 1 kHz) from a cargo ship were added to the source levels of the surrogate dredge *City of Westminster* (0.01–31.5 kHz) because dredge propeller cavitation noise near the sea surface also occurs at higher frequencies (see Section 4.1.2). This assumption resulted in longer-range propagation, especially near the sea surface.

Tables 28 and 29 summarize the radii corresponding to behavioural response thresholds for vessels berthing, transiting, and dredging. The distances to 120 dB re 1 µPa SPL threshold, which is typically used to estimate the onset of behavioural effects, extended to approximately 7.5–19.9 km ($R_{95\%}$) from the vessels. These distances could be reduced by approximately 50% by reducing the transit speed from 12 kts to 10 kts—an effective method to mitigate noise levels from Project traffic. Audiogram-weighted SPLs from vessel activities showed that modelled sensation levels were highest for humpback whales. JASCO's ambient noise levels were used to estimate vessel noise zones of audibility. The estimated detectable range of vessel noise was most likely limited by the relatively high ambient noise due to marine traffic in the assessment area, rather than the mammals' absolute hearing thresholds.

Table 30 summarized the radii for thresholds based on auditory injury and disturbance criteria by Southall et al. (2007) and NMFS (MMPA 2007) for impact sheet and cylinder pile driving. Assuming 24300 blows during a 24-hour period of impact pile driving, the distances ($R_{95\%}$) to 198 dB re 1 µPa^2·s cSEL extended to 1.5–2.5 km for sheet pile driving and 3.8–4.6 km for cylinder pile driving. Based on the same aforementioned assumption of blows, the distances ($R_{95\%}$) to 186 dB re 1 µPa^2·s cSEL extended to approximately 12 km for sheet pile driving and 13.5 km for cylinder pile driving. The distances ($R_{95\%}$) to the injury threshold using single blow peak SPL metric extended to approximately 10 m for both pile driving activities. Using single blow rms SPL metric, the distances ($R_{95\%}$) to 180 and 190 dB re 1 µPa extended to approximately 300 m and less than 100 m, respectively.

Table 28. Summary of estimated $R_{95\%}$ at potential behavioural response thresholds for vessels berthing (Scenario 1), transiting (Scenarios 2–5), and dredging (Scenario 8). For Scenarios 2–5, the LNG carrier and escort tug transited at a normal speed at 12 kts, with a mitigation speed of 10 kts.

Threshold	Berthing scenario	Transit scenarios (12 kts)				Transit scenarios (10 kts)				Dredging scenario
	1 (m)	2 (m)	3 (m)	4 (m)	5 (m)	2 (m)	3 (m)	4 (m)	5 (m)	8 (m)
57 dB re $HT_{Killer\ whale}$	4000	4900	5000	4900	4200	3300	3300	3600	2900	11000
64 dB re $HT_{Killer\ whale}$	2000	2900	2600	2700	2600	1800	1600	1700	1500	8000
57 dB re $HT_{Harbour\ porpoise}$	3700	4100	4100	3900	3300	2100	2100	2100	1600	10100
64 dB re $HT_{Harbour\ porpoise}$	1200	1600	1600	1500	1400	690	680	690	560	6200
120 dB re 1 µPa	14200	10700	10300	7500	19900	4300	4300	4300	9500	9300

Table 29. Summary of estimated zone of audibility ($R_{95\%}$) for vessels berthing (Scenario 1), transiting (Scenarios 2–5), and dredging (Scenario 8). For Scenarios 2–5, the LNG carrier and escort tug transited at a normal speed at 12 kts, with a mitigation speed of 10 kts.

Zone of audibility	Berthing scenario	Transit scenarios (12 kts)				Transit scenarios (10 kts)				Dredging scenario
	1 (m)	2 (m)	3 (m)	4 (m)	5 (m)	2 (m)	3 (m)	4 (m)	5 (m)	8 (m)
Killer whale	14100	31000	29400	43200	84000*	31000	29300	42500	82200*	13400
Humpback	17700	31800	28100	43600	84000*	31400	27700	42300	84000*	13900
Harbour porpoise	14400	31100	29400	48300	84000*	31000	29400	44900	84000*	13400

* Restricted by the modelling boundary.

Table 30. Summary of $R_{95\%}$ of thresholds based on Southall et al. (2007) and NMFS (MMPA 2007) auditory injury and disturbance criteria for impact sheet pile driving (Scenario 6) and impact cylinder pile driving (Scenario 7). The cSEL calculation included 24300 blows and had M-weighting applied. The peak and rms SPLs were unweighted levels per blow.

Metrics	Cetaceans			Pinnipeds		
	Threshold	Scenario 6 (m)	Scenario 7 (m)	Threshold	Scenario 6 (m)	Scenario 7 (m)
Southall et al. (2007) auditory injury and disturbance						
cSEL (dB re 1 µPa^2·s)	198 (TTS onset)	1500–2500	3800–4600	186 (TTS onset)	12100	13400
	183 (Injury)	12200–12400	13500	171 (Injury)	13000	13800
Peak SPL (dB re 1 µPa)	230 (TTS onset)	< 10	< 10	212 (TTS onset)	30	29
	224 (Injury)	< 10	< 10	218 (Injury)	10	10
NMFS auditory injury and disturbance criteria						
rms SPL (dB re 1 µPa)	160 (Disturbance)	4200	7300	160 (Disturbance)	4200	7300
	180 (Injury)	310	310	190 (Injury)	70	80

Glossary

90%-energy time window

The time interval over which the cumulative energy rises from 5% to 95% of the total pulse energy. This interval contains 90% of the total pulse energy. Symbol: T_{90}.

90% rms SPL

The root-mean-square sound pressure levels calculated over the 90%-energy time window of a pulse. Used only for pulsed sounds.

ambient noise

All-encompassing sound at a given place, usually a composite of sounds from many sources near and far (ANSI S1.1-1994 R1999) e.g., shipping, seismic activity, precipitation, sea ice movement, wave action, and biological activity.

audiogram

A curve of hearing threshold (sound pressure levels) as a function of frequency that describes the hearing sensitivity of an animal over its normal hearing range.

audiogram weighting

The process of applying an animal's audiogram to sound pressure levels to determine the sound level relative to the animal's hearing threshold (HT). Unit, dB re HT.

azimuth

A horizontal angle relative to a reference direction, often magnetic north or the direction of travel.

broadband sound level

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

decibel

A logarithmic unit of the ratio of a quantity to a reference quantity of the same kind. Unit symbol: decibel (dB).

ensonified

Exposed to sound.

frequency

The rate of oscillation of a periodic function measured in units of cycles-per-unit-time. The reciprocal of the period. Unit: hertz (Hz). Symbol: *f*. For example, 1 Hz = 1 cycle per second.

geoacoustic

Relating to the acoustic properties of the seabed.

hearing threshold

The sound pressure level that is barely audible for a given individual in the absence of significant background noise during a specific percentage of experimental trials.

M-weighting

The process of band-pass filtering loud sounds that reduces the importance of inaudible or less-audible frequencies for broad classes of marine mammals. "Generalized frequency weightings for various functional hearing groups of marine mammals, allowing for their functional bandwidths and appropriate in characterizing auditory effects of strong sounds" (Southall et al. 2007).

noise

Unwanted sound that interferes with detecting other sounds.

parabolic equation (PE) method

A computationally-efficient solution to the acoustic wave equation that is used to model transmission loss (TL). The PE approximation omits effects of back-scattered sound, which simplifies computing TL. The effect of back-scattered sound is negligible for most ocean-acoustic propagation problems.

peak sound pressure level (peak SPL)

The maximum instantaneous sound pressure level, in a stated frequency band, within a stated period. Also called zero-to-peak sound pressure level. Unit: decibel (dB). Symbol: L_{pk}.

permanent threshold shift (PTS)

A permanent loss of hearing sensitivity due to excessive noise exposure. PTS is considered auditory injury.

pressure, acoustic

The deviation from the ambient hydrostatic pressure caused by a sound wave. Also called overpressure. Unit: pascal (Pa).

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. Unit: pascal (Pa).

rms

root mean square.

rms sound pressure level (rms SPL)

The root-mean-square average of the instantaneous sound pressure (symbol is L_p) as measured over some specified time interval (symbol T). For continuous sound, the time interval is one second.

See also 90% rms SPL.

shear wave

A mechanical vibration wave where the direction of particle motion is perpendicular to the direction of propagation. Sometimes referred to as a secondary wave or S-wave. Shear waves propagate only in solid media, such as sediments or rock. Shear waves in the seabed can be converted to compressional waves in water at the water-seabed interface.

sound

A time-varying pressure disturbance generated by mechanical vibration waves travelling through a fluid medium such as air or water.

sound exposure

Time integral of squared, instantaneous frequency-weighted sound pressure over a stated time interval or event. Unit: pascal-squared second ($Pa^2 \cdot s$). Symbol: *E* (ANSI S1.1-1994 R1999).

sound exposure level (SEL)

A measure of the total sound energy in one or more pulses. Unit: dB re 1 $\mu Pa^2 \cdot s$.

sound field

Region containing sound waves (ANSI S1.1-1994 R1999).

sound pressure level (SPL)

The decibel ratio of the time-mean-square sound pressure, in a stated frequency band, to the square of the reference sound pressure (ANSI S1.1-1994 R1999). Unit: decibel (dB). Symbol: L_p.

For sound in water, the reference sound pressure is one micropascal (p_o = 1 µPa) and the unit for SPL is dB re 1 µPa:

$$L_P = 10\log_{10}\left(p^2 / p_o^2\right) = 20\log_{10}\left(p / p_o\right)$$

Unless otherwise stated, SPL refers to the root-mean-square sound pressure level (rms SPL).

source level (SL)

The sound pressure level measured 1 metre from a point-like source that radiates the same total amount of sound power as the actual source. Unit: dB re 1 µPa @ 1 m.

temporary threshold shift (TTS)

Temporary loss of hearing sensitivity due to excessive noise exposure.

transmission loss (TL)

The decibel reduction in sound level that results from sound spreading away from an acoustic source, subject to the influence of the surrounding environment. Also referred to as propagation loss.

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Appendix 1. Maps for Vessels Transiting at Mitigated Speed

1.1. Unweighted Sound Pressure Levels

Figure 1–1 to Figure 1–4 show isopleth maps of modelled unweighted maximum-over-depth broadband (10 Hz to 31.5 kHz) sound pressure levels in dB re 1 µPa for scenarios of vessels transiting at 10 kts (Scenarios 2–5).

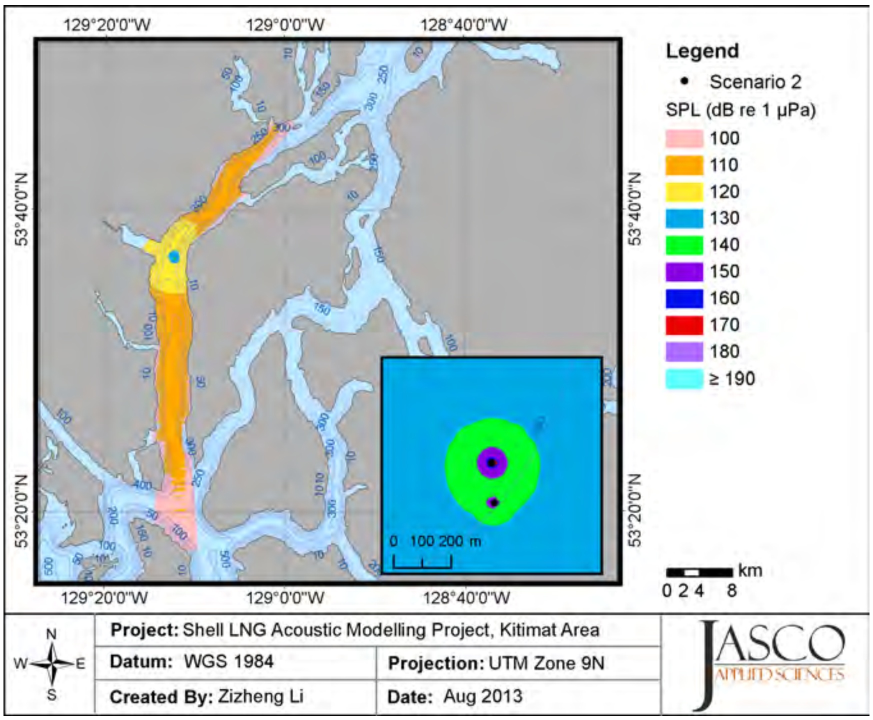

Figure 1–1. Scenario 2: Sound level isopleth map of unweighted SPL (dB re 1 µPa, maximum-over-depth). An LNG carrier and a tug are transiting at 10 kts along the outbound route in Douglas Channel. A magnified view of the sources appears in the lower right.

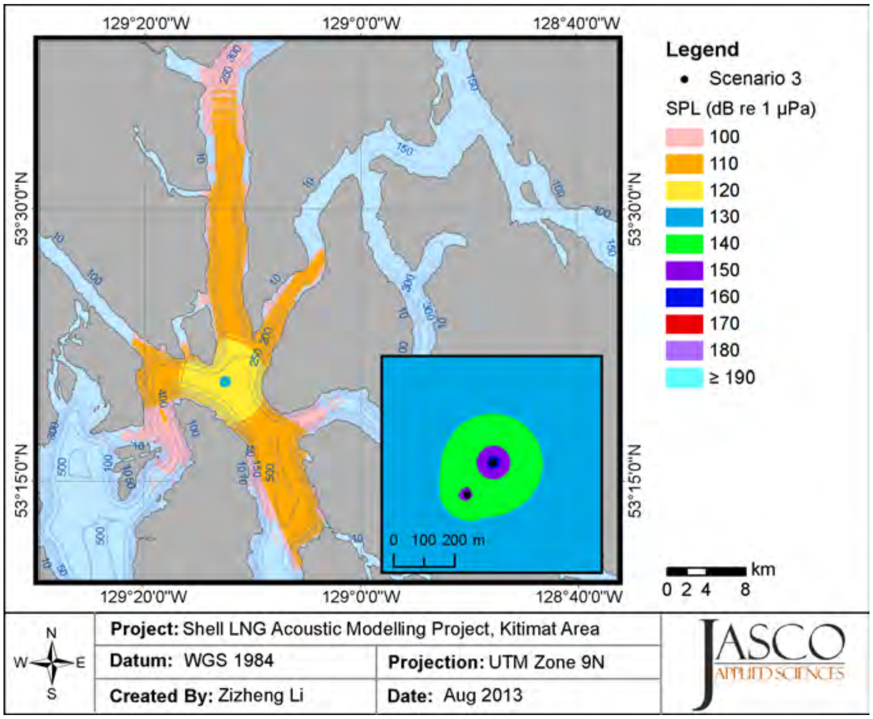

Figure 1–2. Scenario 3: Sound level isopleth map of unweighted SPL (dB re 1 µPa, maximum-over-depth). An LNG carrier and a tug are transiting at 10 kts along the outbound route in Wright Sound. A magnified view of the sources appears in the lower right.

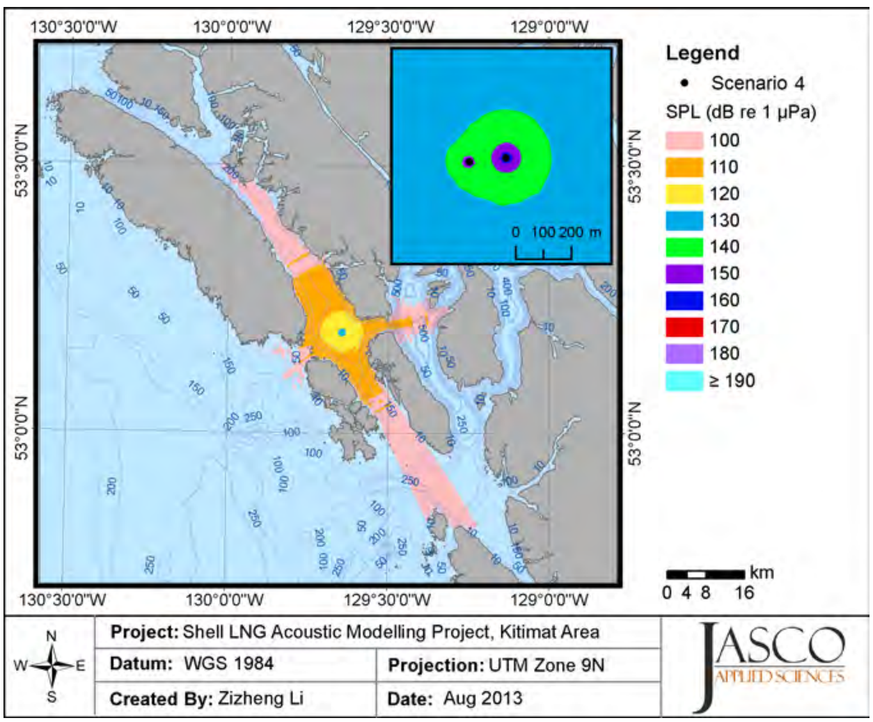

Figure 1–3. Scenario 4: Sound level isopleth map of unweighted SPL (dB re 1 µPa, maximum-over-depth). An LNG carrier and a tug are transiting at 10 kts along the outbound route in Nepean Sound. A magnified view of the sources appears in the upper right.

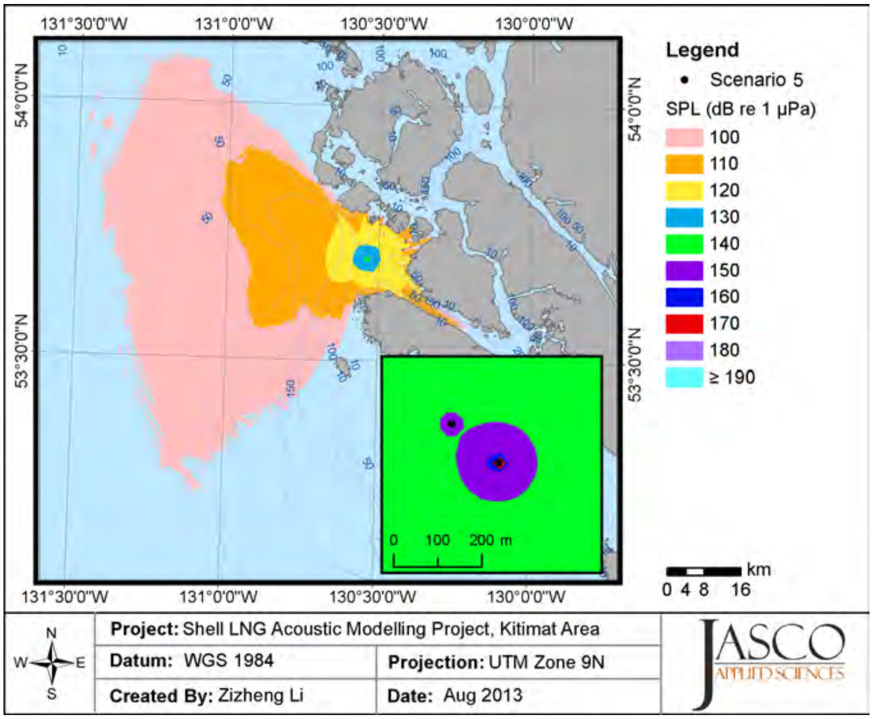

Figure 1–4. Scenario 5: Sound level isopleth map of unweighted SPL (dB re 1 µPa, maximum-over-depth). An LNG carrier and a tug are transiting at 10 kts along the outbound route in Browning Entrance. A magnified view of the sources appears in the lower right.

1.2. Audiogram-weighted sound pressure levels and zones of audibility

Audiogram-weighted SPLs (dB re HT) applied to vessels transiting at 10 kts are presented in sound level isopleth maps for killer whale, humpback whale, and harbour porpoise. Zones of audibility were denoted in solid black line in the maps.

1.2.1. Killer whale

Figure 1–5 to Figure 1–8 show sound level isopleth maps of killer whale audiogram-weighted broadband (10 Hz–31.5 kHz) sound pressure levels. Table 1–1 presents the corresponding $R_{95\%}$ and R_{max} for audiogram-weighted SPLs.

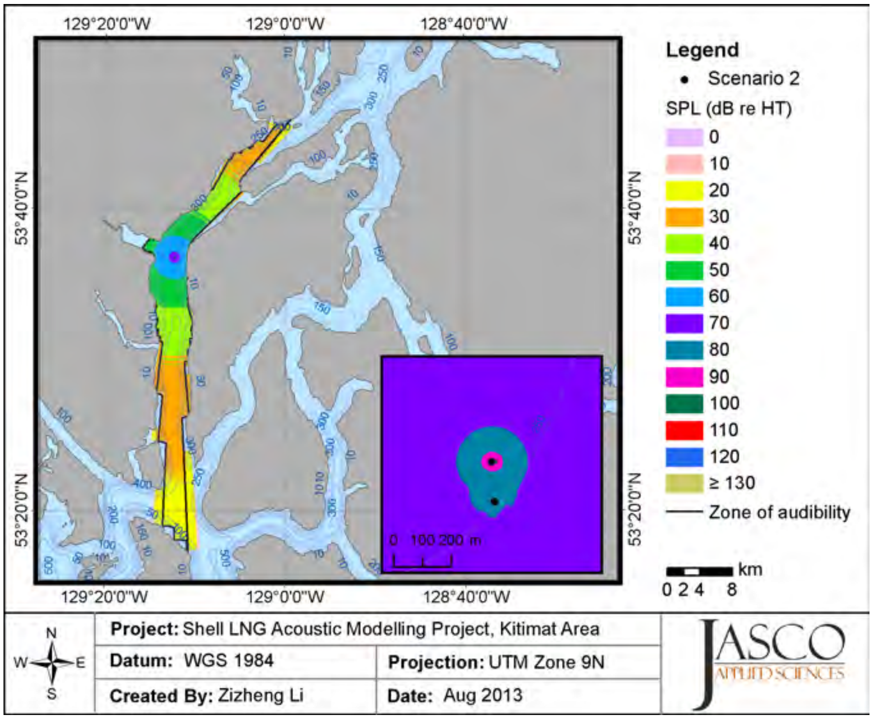

Figure 1–5. Scenario 2: Sound level isopleth map of killer whale audiogram-weighted SPL (dB re HT, maximum-over-depth). An LNG carrier and a tug are transiting at 10 kts along the outbound route in Douglas Channel. A magnified view of the sources appears in the lower right.

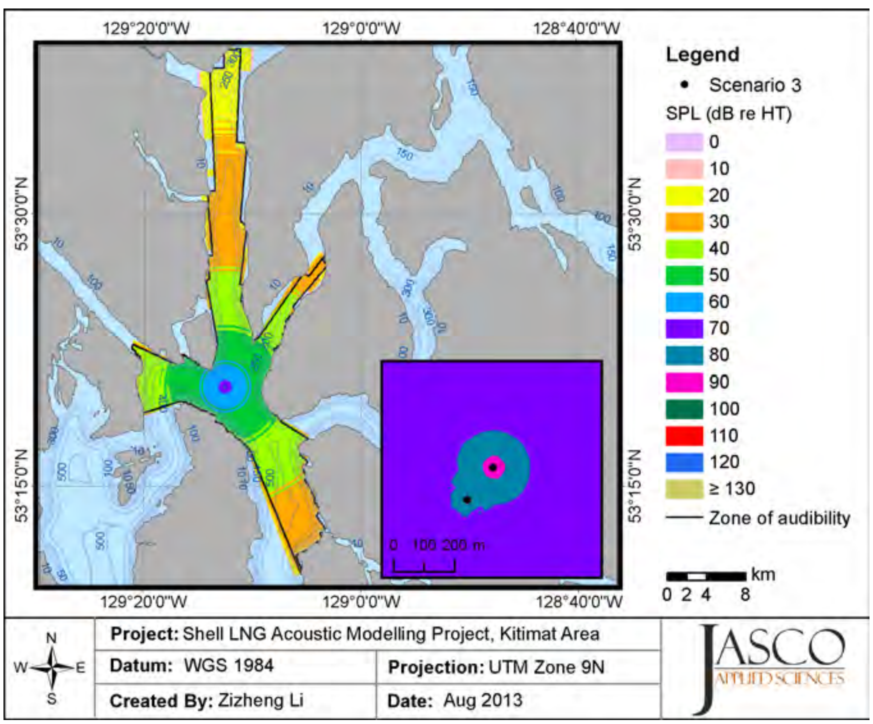

Figure 1–6. Scenario 3: Sound level isopleth map of killer whale audiogram-weighted SPL (dB re HT, maximum-over-depth). An LNG carrier and a tug are transiting at 10 kts along the outbound route in Wright Sound. A magnified view of the sources appears in the lower right.

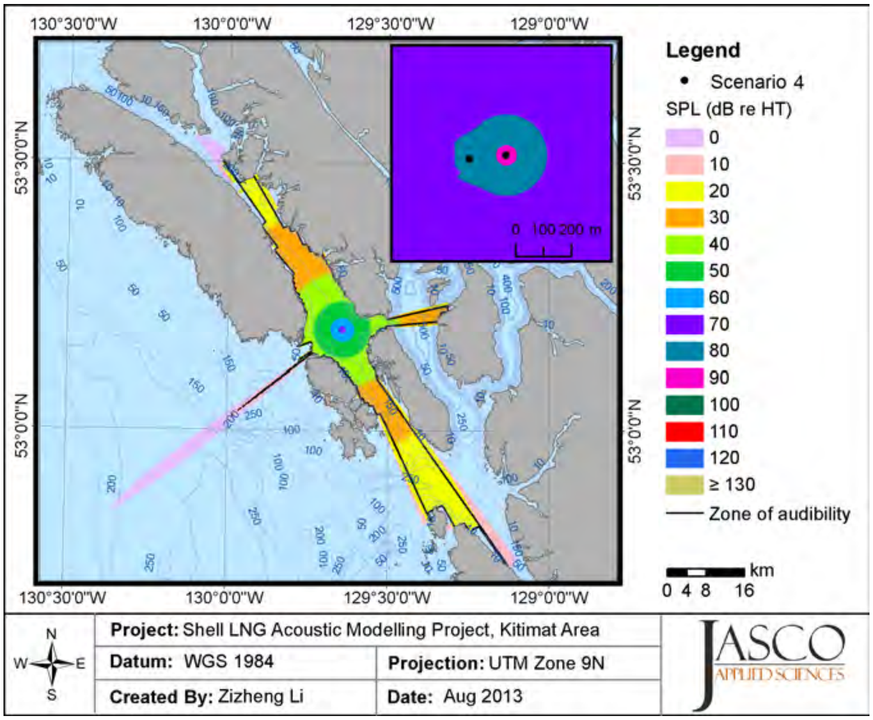

Figure 1–7. Scenario 4: Sound level isopleth map of killer whale audiogram-weighted SPL (dB re HT, maximum-over-depth). An LNG carrier and a tug are transiting at 10 kts along the outbound route in Nepean Sound. A magnified view of the sources appears in the upper right.

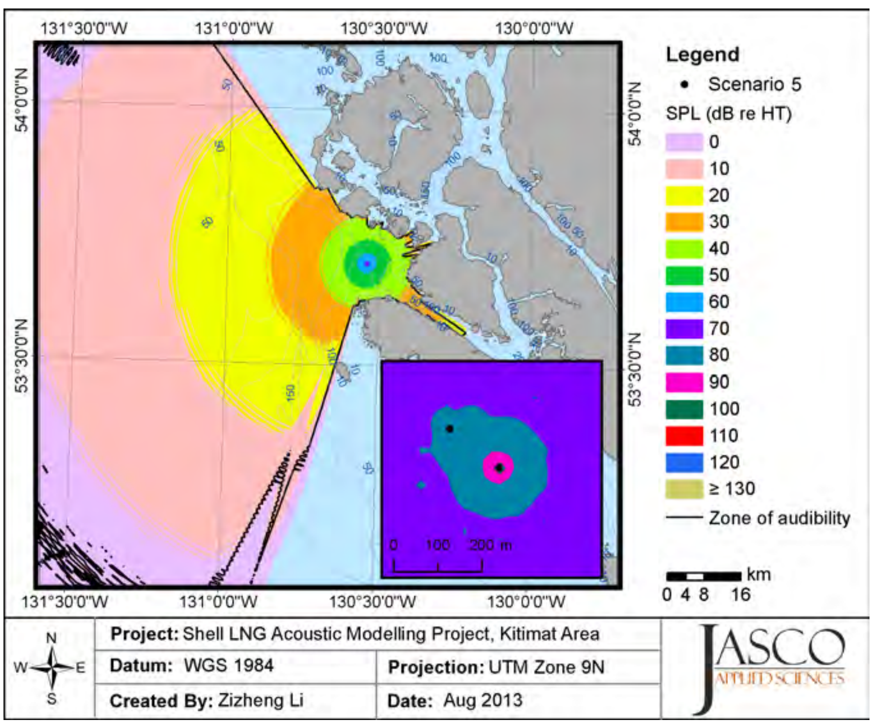

Figure 1–8. Scenario 5: Sound level isopleth map of killer whale audiogram-weighted SPL (dB re HT, maximum-over-depth). An LNG carrier and a tug are transiting at 10 kts along the outbound route in Browning Entrance. A magnified view of the sources appears in the lower right.

Table 1–1. Radii of killer whale audiogram-weighted SPL contours for vessels transiting (Scenarios 2–5) with mitigation speed.

SPL (dB re HT)	Scenario 2 (m)		Scenario 3 (m)		Scenario 4 (m)		Scenario 5 (m)	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
0	36000	32300	34800	30700	62900	50400	100500*	83900*
10	36000	32300	34800	30700	60300	46600	86500*	71600*
20	35900	32000	34800	30300	51800	41900	47900	41300
30	27800	23500	28400	21700	26800	23400	23300	20400
40	13300	11500	13000	11100	12400	11200	11700	9800
50	6300	5700	6700	5800	6400	5700	5500	5100
60	3000	2600	2700	2600	2800	2500	2700	2200
70	770	710	740	700	760	700	780	570
80	190	180	190	170	210	190	270	180
90	40	40	40	40	40	40	30	30
100	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
110	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
120	--	--	--	--	--	--	--	--

* Restricted by the modelling boundary.

1.2.2. Humpback whale

Figure 1–9 to Figure 1–12 show sound level isopleth maps of humpback whale audiogram-weighted broadband (10 Hz–31.5 kHz) sound pressure levels. Table 1–2 presents the corresponding $R_{95\%}$ and R_{max} for audiogram-weighted SPLs.

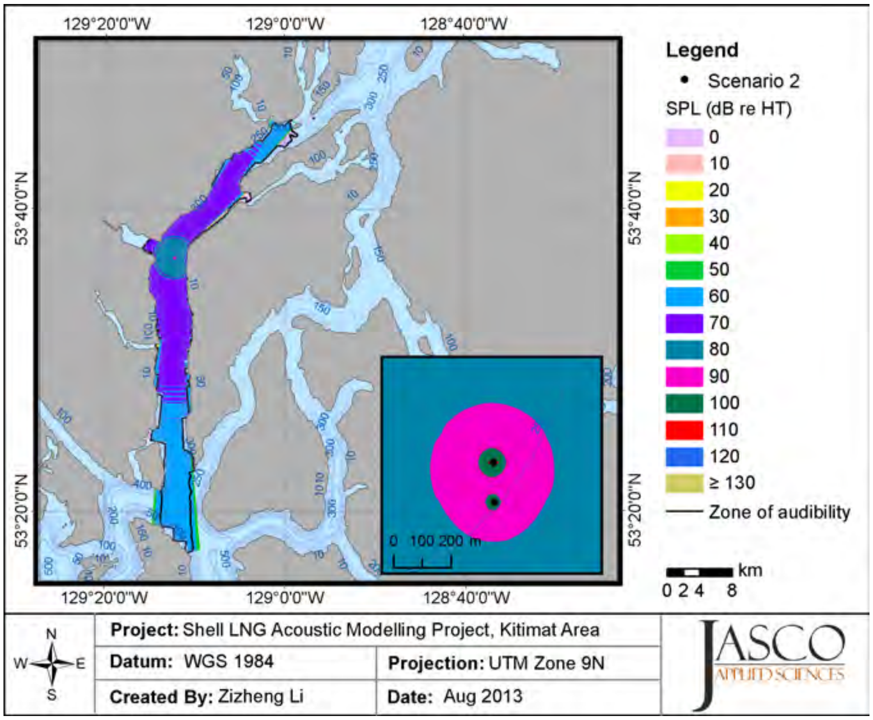

Figure 1–9. Scenario 2: Sound level isopleth map of humpback whale audiogram-weighted SPL (dB re HT, maximum-over-depth). An LNG carrier and a tug are transiting at 10 kts along the outbound route in Douglas Channel. A magnified view of the sources appears in the lower right.

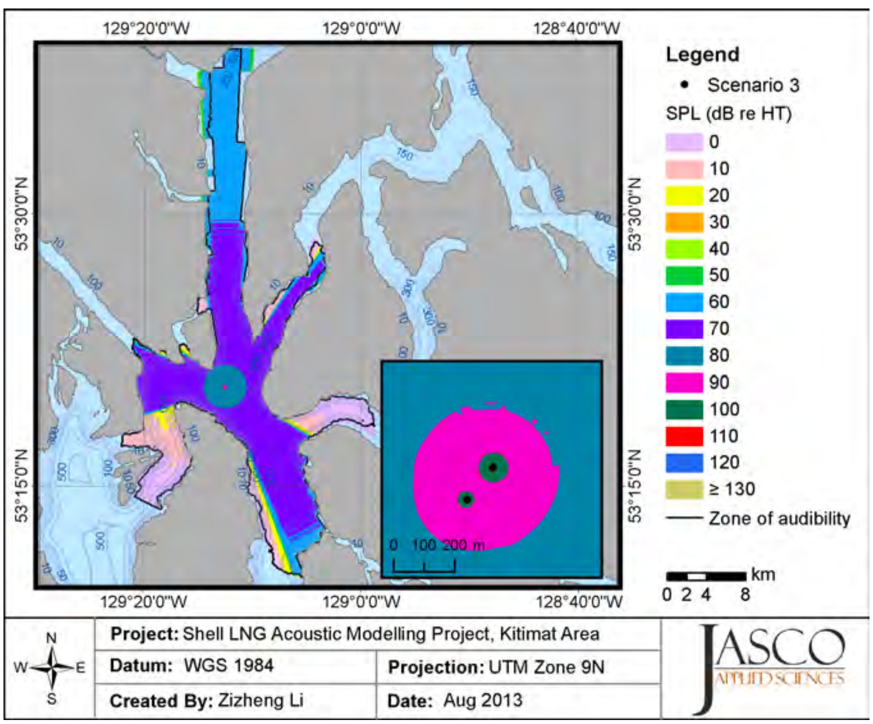

Figure 1–10. Scenario 3: Sound level isopleth map of humpback whale audiogram-weighted SPL (dB re HT, maximum-over-depth). An LNG carrier and a tug are transiting at 10 kts along the outbound route in Wright Sound. A magnified view of the sources appears in the lower right.

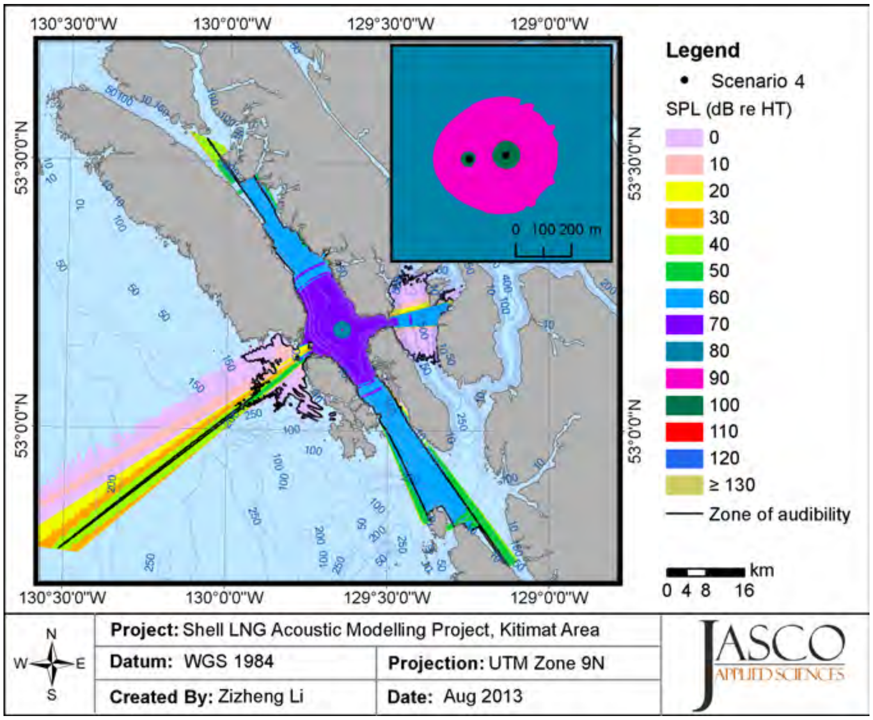

Figure 1–11. Scenario 4: Sound level isopleth map of humpback whale audiogram-weighted SPL (dB re HT, maximum-over-depth). An LNG carrier and a tug are transiting at 10 kts along the outbound route in Nepean Sound. A magnified view of the sources appears in the upper right.

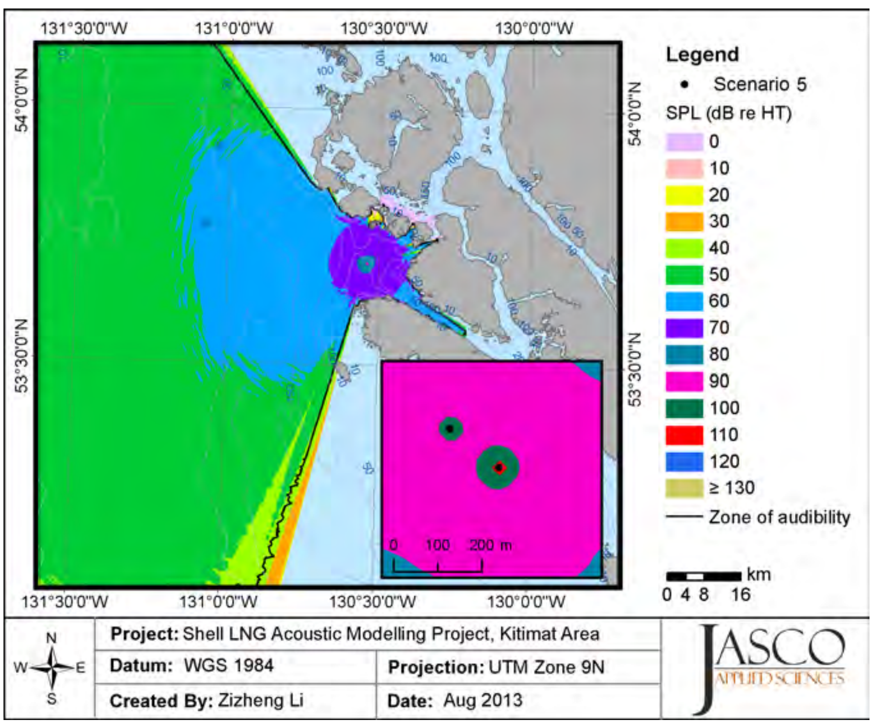

Figure 1–12. Scenario 5: Sound level isopleth map of humpback whale audiogram-weighted SPL (dB re HT, maximum-over-depth). An LNG carrier and a tug are transiting at 10 kts along the outbound route in Browning Entrance. A magnified view of the sources appears in the lower right.

Table 1–2. Radii of humpback whale audiogram-weighted SPL contours for vessels transiting (Scenarios 2–5) with mitigation speed.

SPL (dB re HT)	Scenario 2 (m)		Scenario 3 (m)		Scenario 4 (m)		Scenario 5 (m)	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
0	36000	32100	34800	29600	86900	74900	100600*	83800*
10	36000	32200	34800	30200	86100	71100	100600*	83800*
20	36000	32300	34800	30600	81800	70400	100600*	83800*
30	36000	32300	34800	30700	78200	66800	100600*	83800*
40	36000	32300	34800	30700	75600	60000	100600*	83900*
50	36000	32300	34800	30700	60200	46600	99600*	83700*
60	35900	32000	34800	30200	49300	40500	52400	39900
70	19600	15800	17300	15500	16500	12000	14100	9100
80	4000	2600	2800	2200	2100	1800	2300	2100
90	270	250	270	240	260	230	370	330
100	50	50	120	50	50	50	120	50
110	10	10	10	10	10	10	10	10
120	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
130	--	--	--	--	--	--	--	--

* Restricted by the modelling boundary.

1.2.3. Harbour porpoise

Figure 1–13 to Figure 1–16 show sound level isopleth maps of harbour porpoise audiogram-weighted broadband (10 Hz–31.5 kHz) sound pressure levels. Table 1–3 presents the corresponding $R_{95\%}$ and R_{max} for audiogram-weighted SPLs.

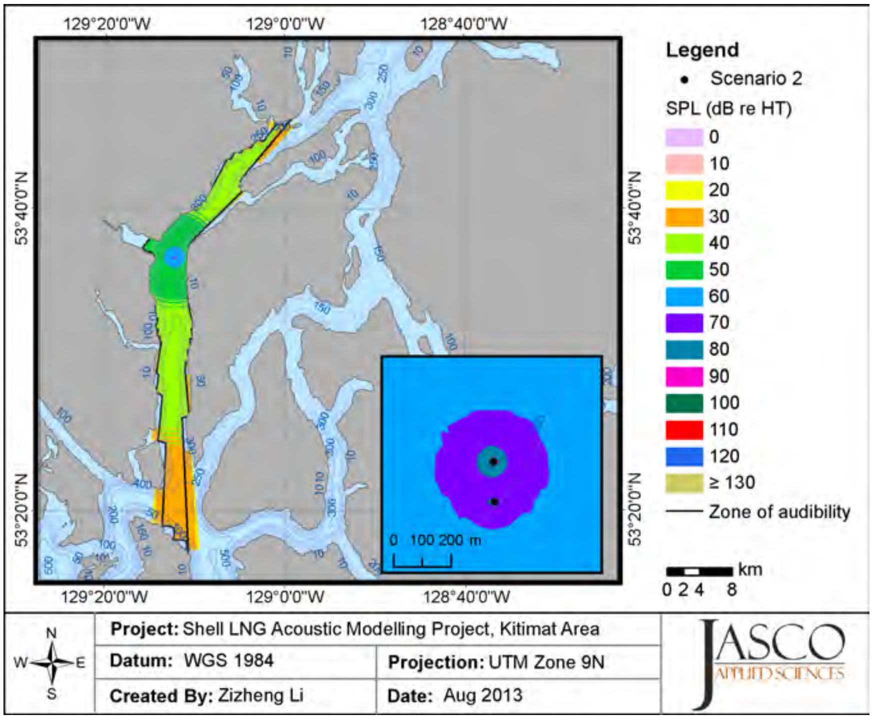

Figure 1–13. Scenario 2: Sound level isopleth map of harbour porpoise audiogram-weighted SPL (dB re HT, maximum-over-depth). An LNG carrier and a tug are transiting at 10 kts along the outbound route in Douglas Channel. A magnified view of the sources appears in the lower right.

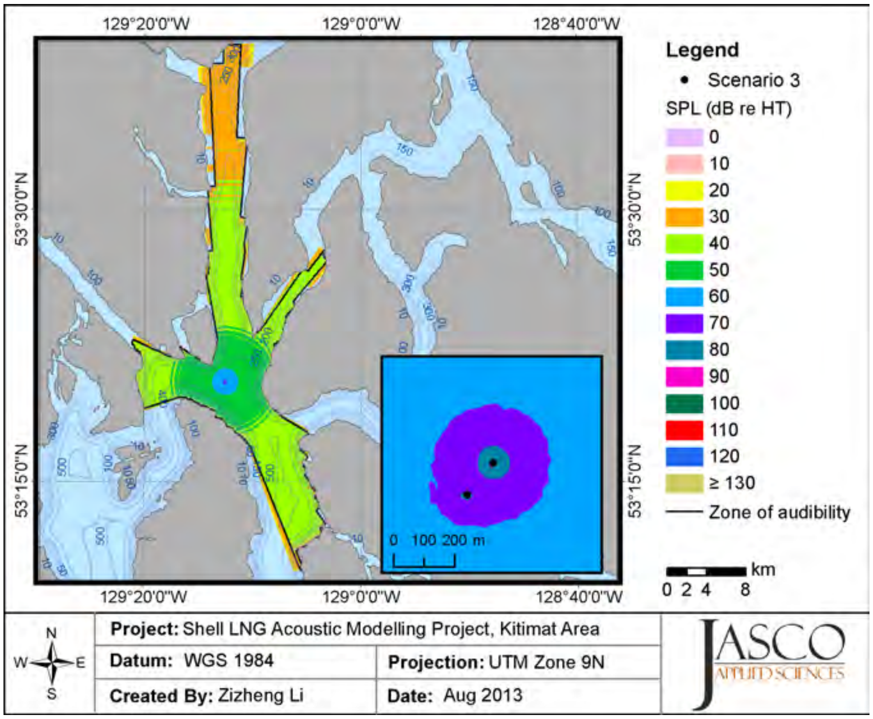

Figure 1–14. Scenario 3: Sound level isopleth map of harbour porpoise audiogram-weighted SPL (dB re HT, maximum-over-depth). An LNG carrier and a tug are transiting at 10 kts along the outbound route in Wright Sound. A magnified view of the sources appears in the lower right.

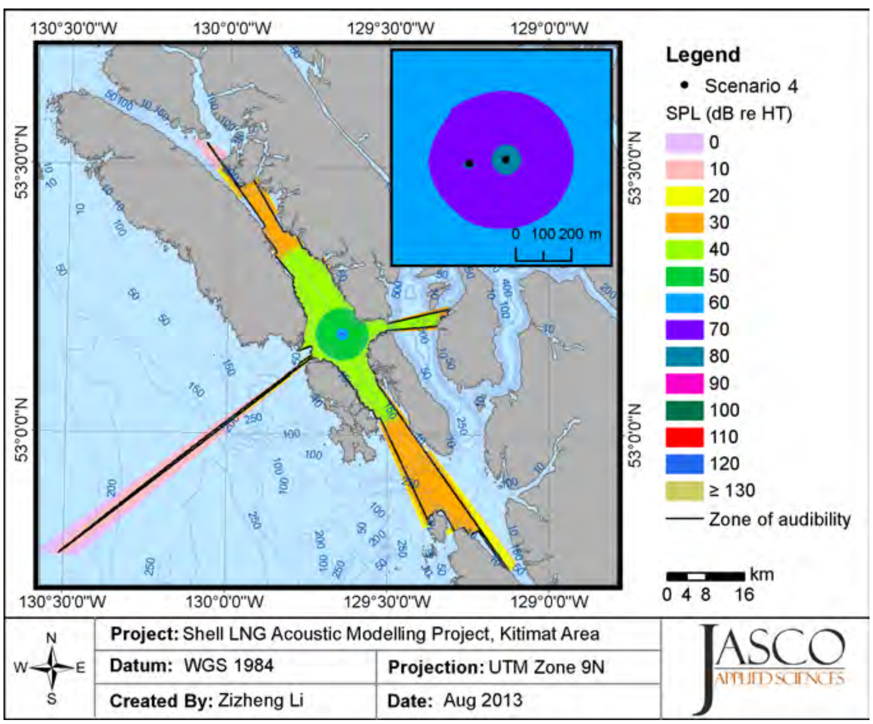

Figure 1–15. Scenario 4: Sound level isopleth map of harbour porpoise audiogram-weighted SPL (dB re HT, maximum-over-depth). An LNG carrier and a tug are transiting at 10 kts along the outbound route in Nepean Sound. A magnified view of the sources appears in the upper right.

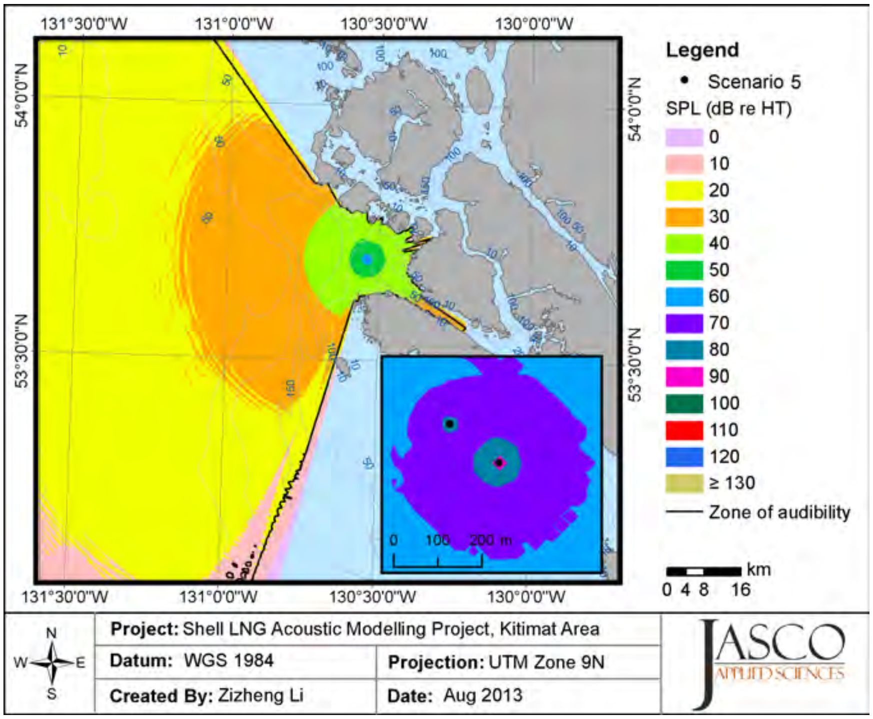

Figure 1–16. Scenario 5: Sound level isopleth map of harbour porpoise audiogram-weighted SPL (dB re HT, maximum-over-depth). An LNG carrier and a tug are transiting at 10 kts along the outbound route in Browning Entrance. A magnified view of the sources appears in the lower right.

Table 1–3. Radii of harbour porpoise audiogram-weighted SPL contours for vessels transiting (Scenarios 2–5) with mitigation speed.

SPL (dB re HT)	Scenario 2 (m)		Scenario 3 (m)		Scenario 4 (m)		Scenario 5 (m)	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
0	36000	32300	34800	30800	77900	66400	100600*	83800*
10	36000	32300	34800	30800	75300	58700	100600*	83900*
20	36000	32300	34800	30700	60300	46700	95800*	80400*
30	35900	32000	34800	30200	56000	42500	50400	40300
40	23300	19600	23800	17500	21100	18900	19600	13300
50	6300	5400	5700	5200	6000	5300	4600	3900
60	1600	1300	1400	1300	1500	1300	1400	1200
70	250	230	260	230	310	280	270	250
80	60	60	60	50	50	50	60	50
90	10	10	10	10	10	10	10	10
100	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
130	--	--	--	--	--	--	--	--

* Restricted by the modelling boundary.

Appendix 2. M-weighted SEL for Impact Pile Driving

Figure 2–1 to Figure 2–8 show sound level isopleth maps of modelled M-weighted maximum-over-depth broadband (10 Hz to 20 kHz) sound exposure levels per blow in dB re 1 µPa^2·s for impact pile driving (Scenarios 6 and 7). Table 2–1 to Table 2–2 present the corresponding $R_{95\%}$ and R_{max} SEL per blow threshold ranges.

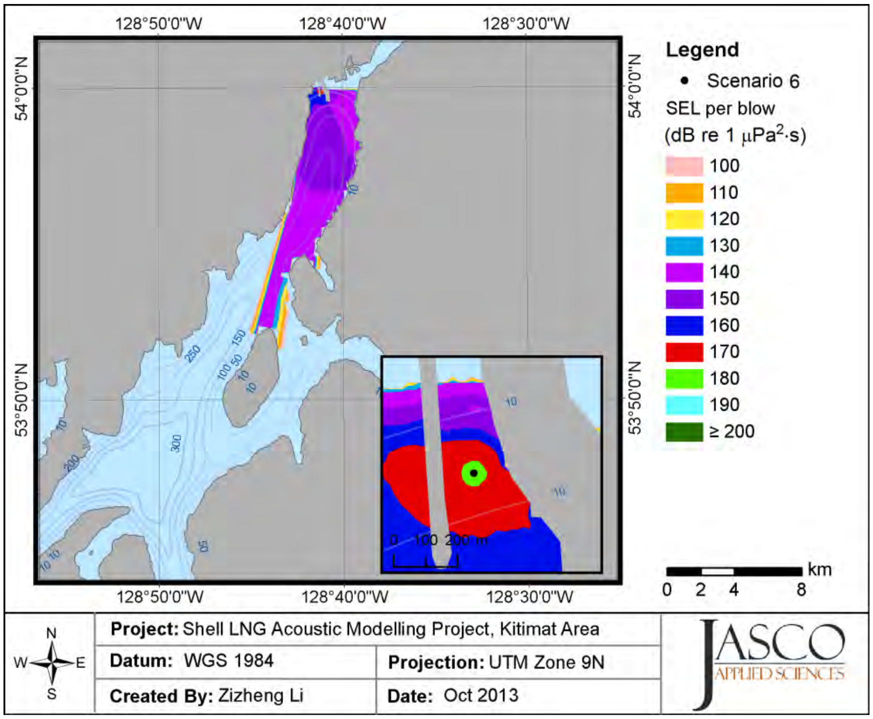

Figure 2–1. Scenario 6: Sound level isopleth map of LFC M-weighted SEL per blow (dB re 1 µPa^2·s, maximum-over-depth). Impact sheet pile driving is operating at the proposed marine terminal. A magnified view of the sources appears in the lower right.

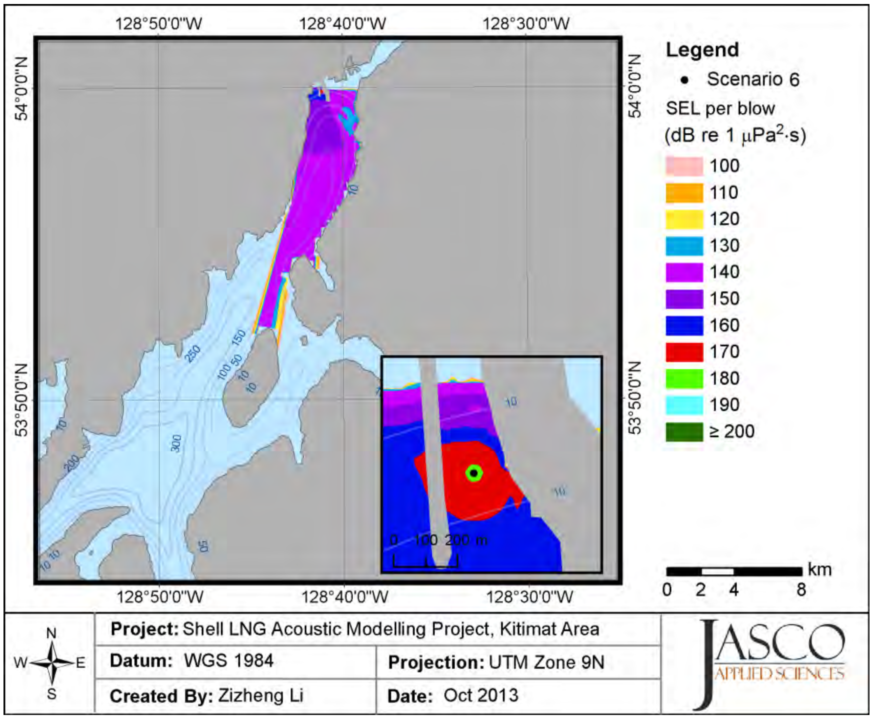

Figure 2–2. Scenario 6: Sound level isopleth map of MFC M-weighted SEL per blow (dB re 1 µPa^2·s, maximum-over-depth). Impact sheet pile driving is operating at the proposed marine terminal. A magnified view of the sources appears in the lower right.

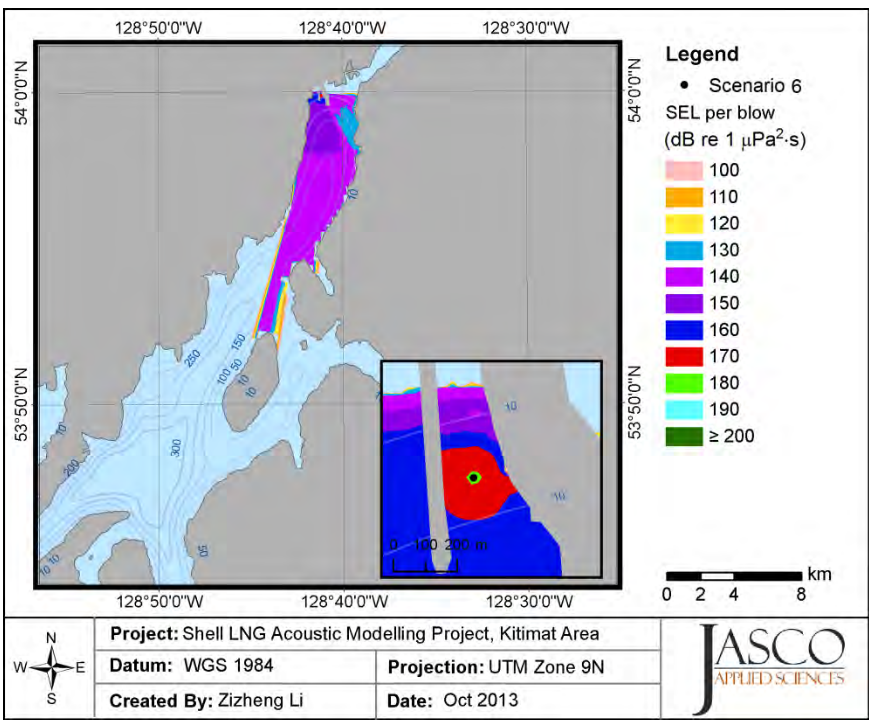

Figure 2–3. Scenario 6: Sound level isopleth map of HFC M-weighted SEL per blow (dB re 1 µPa^2·s, maximum-over-depth). Impact sheet pile driving is operating at the proposed marine terminal. A magnified view of the sources appears in the lower right.

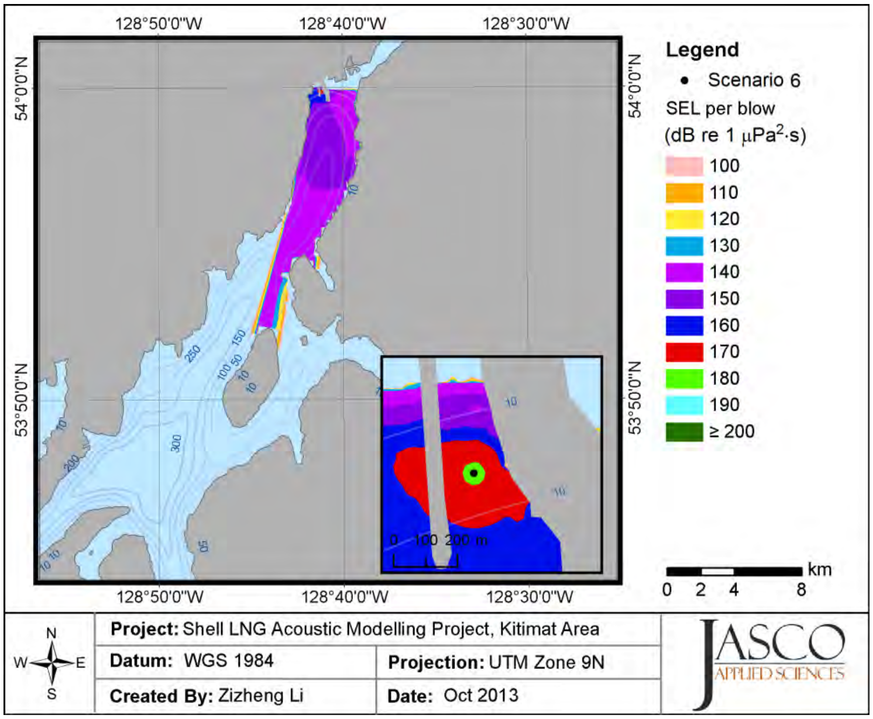

Figure 2–4. Scenario 6: Sound level isopleth map of PINN M-weighted SEL per blow (dB re 1 µPa^2·s, maximum-over-depth). Impact sheet pile driving is operating at the proposed marine terminal. A magnified view of the sources appears in the lower right.

Table 2–1. Scenario 6: Radii of unweighted and M-weighted SEL per blow contours.

SEL per blow (dB re 1 µPa^2·s)	Unweighted		LFC		MFC		HFC		PINN	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
120	15400	13400	15400	13400	15300	13200	15000	13100	15400	13300
130	15000	13000	15000	13000	15000	12800	15000	12700	15000	12900
140	14900	12300	14900	12300	14900	12200	14900	12200	14900	12300
150	10700	5700	10700	5700	5900	3600	5900	3400	7900	5500
160	1600	1200	1600	1200	1200	900	970	780	1500	1100
170	290	250	290	250	190	160	150	130	250	210
180	40	40	40	40	30	30	20	20	40	40
190	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
200	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
210	--	--	--	--	--	--	--	--	--	--

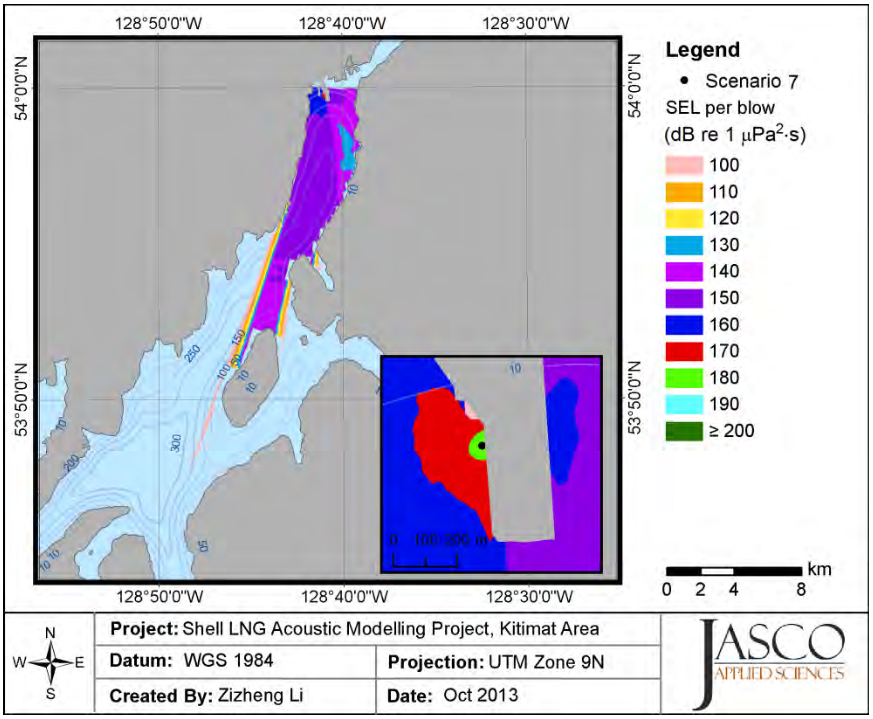

Figure 2–5. Scenario 7: Sound level isopleth map of LFC M-weighted SEL per blow (dB re 1 µPa^2·s, maximum-over-depth). Impact sheet pile driving is operating at the proposed marine terminal. A magnified view of the sources appears in the lower right.

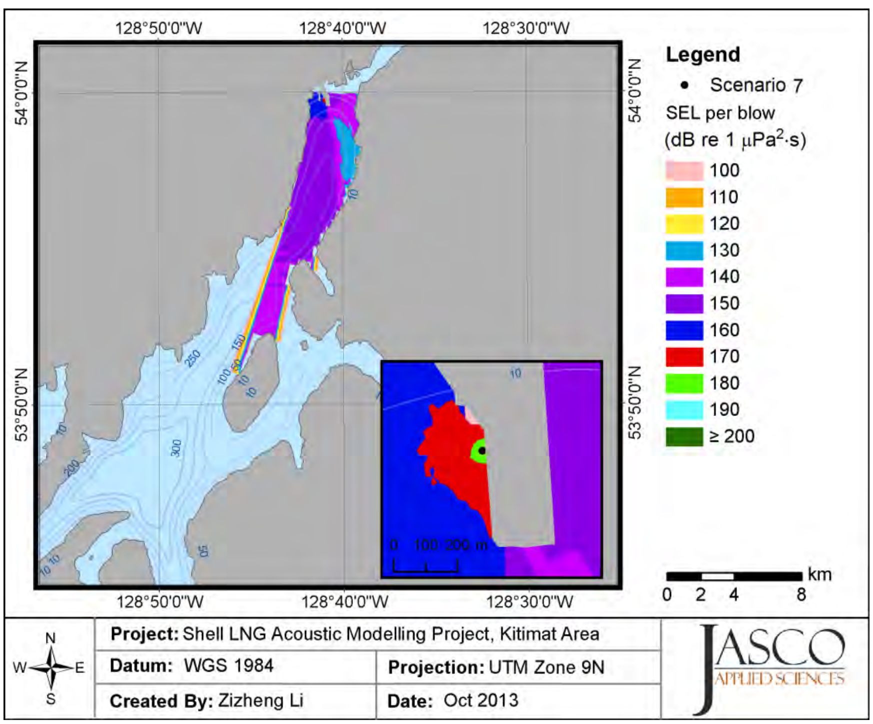

Figure 2–6. Scenario 7: Sound level isopleth map of MFC M-weighted SEL per blow (dB re 1 µPa^2·s, maximum-over-depth). Impact sheet pile driving is operating at the proposed marine terminal. A magnified view of the sources appears in the lower right.

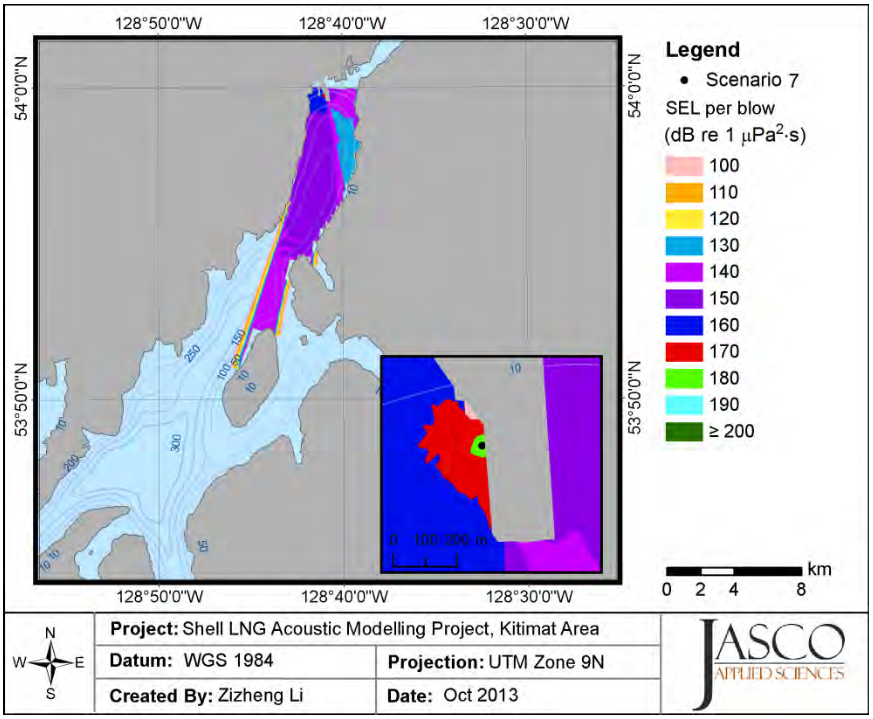

Figure 2–7. Scenario 7: Sound level isopleth map of HFC M-weighted SEL per blow (dB re 1 µPa^2·s, maximum-over-depth). Impact sheet pile driving is operating at the proposed marine terminal. A magnified view of the sources appears in the lower right.

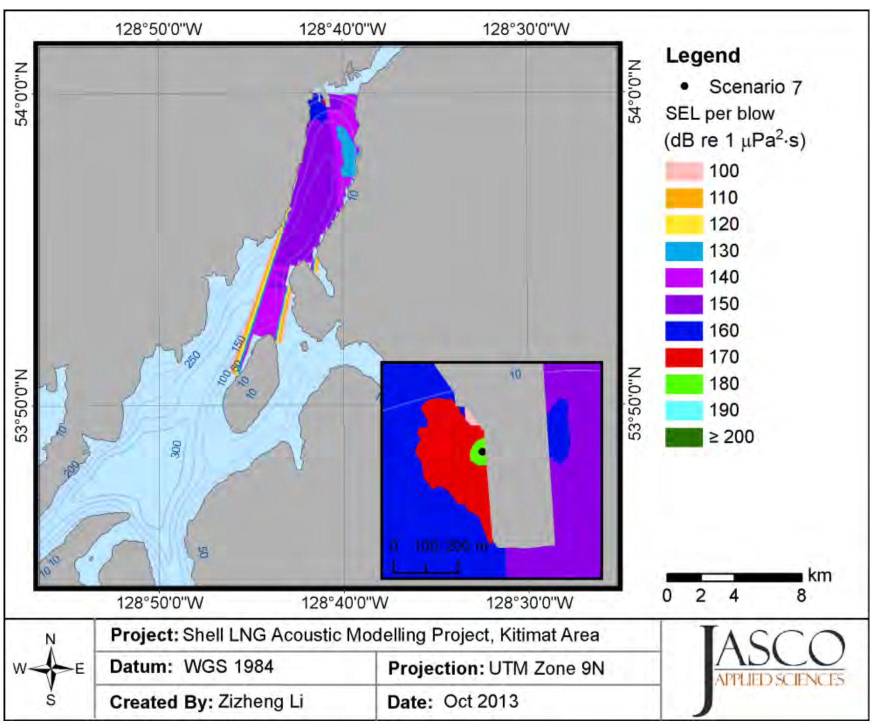

Figure 2–8. Scenario 7: Sound level isopleth map of PINN M-weighted SEL per blow (dB re 1 µPa^2·s, maximum-over-depth). Impact sheet pile driving is operating at the proposed marine terminal. A magnified view of the sources appears in the lower right.

Table 2–2. Scenario 7: Radii of unweighted and M-weighted SEL per blow contours.

SEL per blow (dB re 1 µPa²·s)	Unweighted		LFC		MFC		HFC		PINN	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
120	17100	14000	17100	14000	17100	13900	17100	13900	17100	14000
130	17000	13700	17000	13700	17000	13700	17000	13600	17000	13700
140	16700	13500	16700	13500	16700	13500	16600	13500	16700	13500
150	14400	9900	14400	9900	14400	9400	14400	9100	14400	9700
160	2000	1400	2000	1400	1600	1200	1600	1200	1900	1300
170	300	240	280	230	260	200	260	200	280	220
180	60	50	60	50	60	50	50	40	60	50
190	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
200	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
210	--	--	--	--	--	--	--	--	--	--

APPENDIX H:

Current and Sediment Modelling at LNG Canada Facility in Kitimat Arm

TECHNICAL MEMORANDUM

Prepared for: Stantec

Attn: Chris Burbidge and Sandra Webster

Prepared by: ASL Environmental Sciences Inc

Attn: Andy Lin, David Fissel, and Ryan Clouston

Date: May 28, 2014

Re: Current and Sediment Modeling at LNG Canada facility in Kitimat Arm

1. Overview

An integrated ocean circulation and sediment transport model, ASL-COCIRM-SED, was adapted and implemented for Kitimat Arm to investigate the effect of the alterations to the LNG Canada marine terminal area on currents and potential morphological changes. The alterations include jetty modifications and dredging as shown in Figure 1.

Model runs were conducted for calibration using historical current meter data in 2005 and then for verification using the LNG Canada metocean study interim data collected in 2013. The model was then run over for the existing conditions and for the altered conditions, during the freshet period of the Kitimat River (maximum river discharge) as well as prior to freshet when the river discharge was below the annual average value.

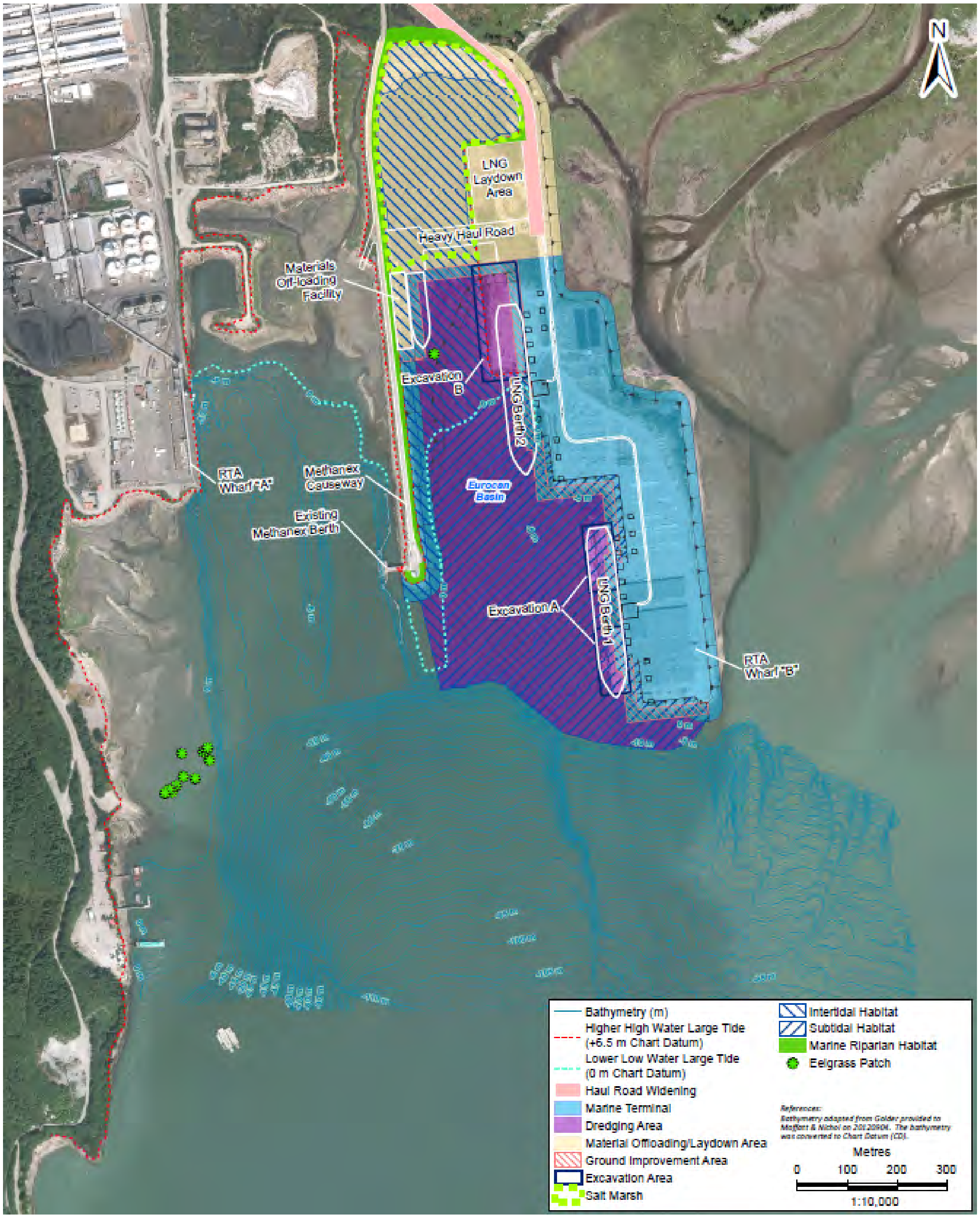

Figure1: Marine terminal layout and detailed bathymetry (adapt from Stantec)

2. Model Setup and Description

The model domain was created for the full area of Kitimat Arm as well as the lower portion of Kildala Arm (Figure 2). The model domain has a total length of 29.8 km and a width of 11.8 km. In the horizontal, the model has grids of size 100 m by 100 m over the full domain, and within 2 km of the marine terminal area, a high resolution nested grid of 20 m by 20 m was used. In the vertical, 20 z-coordinate layers were used, at (chart datum) depths of 0, 2, 4, 6, 9, 12, 15, 18, 21, 25, 30, 40, 50, 60, 80, 110, 150, 200, 260, 310 m.

The model was forced by water level elevations at the open southern boundary, as well as by River discharges at the north boundary (Kitimat River) and represented river inputs through Kildala Arm. Water levels at the southern boundary were reconstructed from historical measurements using Foreman's tidal prediction program (Foreman, 1977). Typical and spatially-uniform winds are applied to the surface, taken from the nearby weather station at Terrace BC by Environment Canada (http://climate.weather.gc.ca/climate_normals/index_e.html). Temperatures and salinities at open boundaries were determined using typical vertical structure built from available observations (Fissel et al., 2010) for each season.

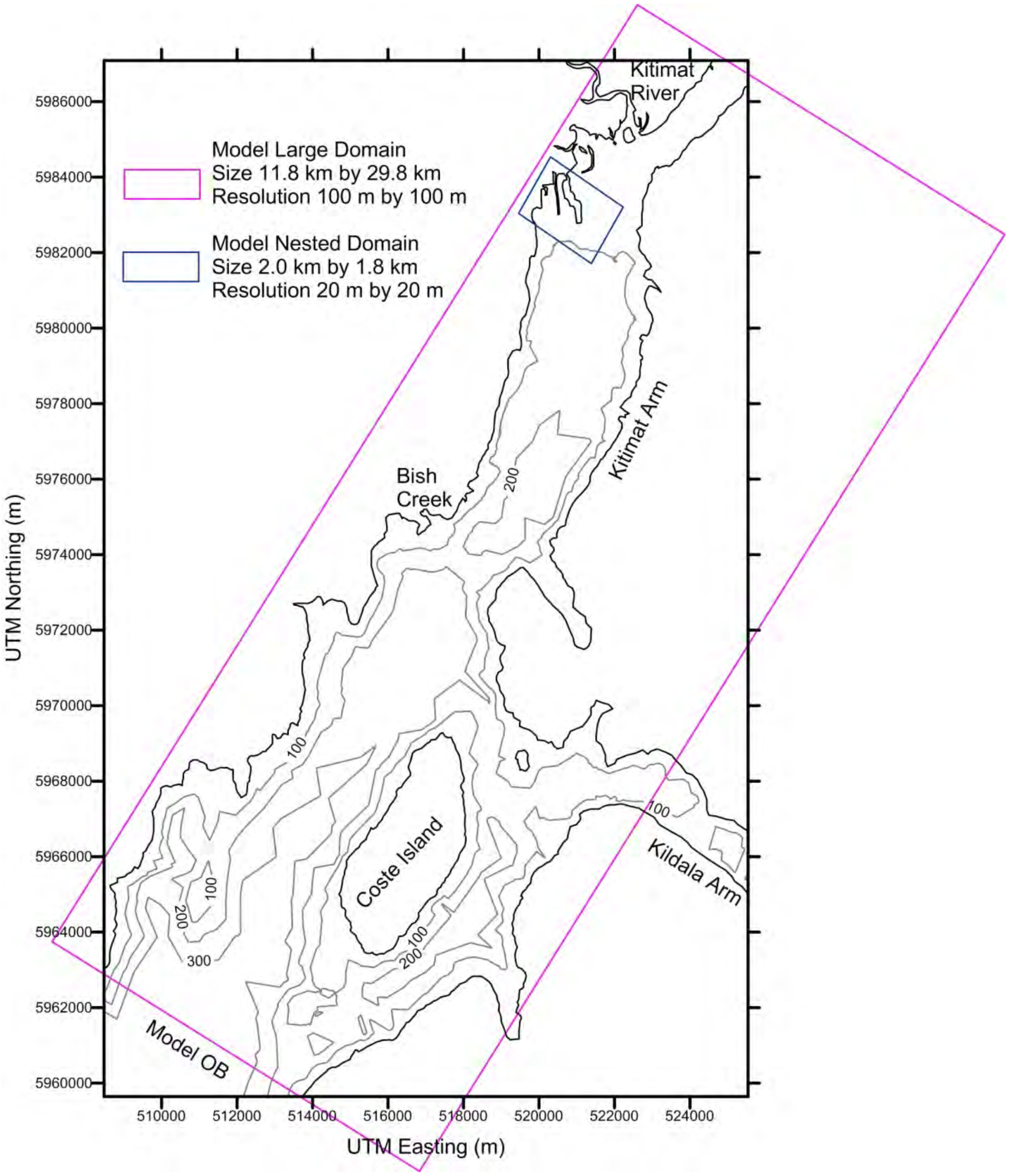

Figure 2: The nested model domains and the open boundaries.

3. Model Calibration

The model was calibrated using historical ocean current data taken from Site 1 offshore of the Enbridge Northern Gateway Project (53° 56.486'N 128° 42.461'W, water depth 179 m, shown in Fissel et al., 2010). Comparison of the observed and modeled currents, as time series plots of speed and direction, are shown in Figures 3-5 for depths at 9, 41, and 81 m.

The comparison results show generally good agreement of the model currents to observations in terms of the range of measured current speeds and directional variability. Both model and observations show that current speeds decrease with increasing depths, with notably higher current speeds in the upper layer (surface to 9-15 m depth) where the buoyant river water is concentrated relative to the deeper waters.

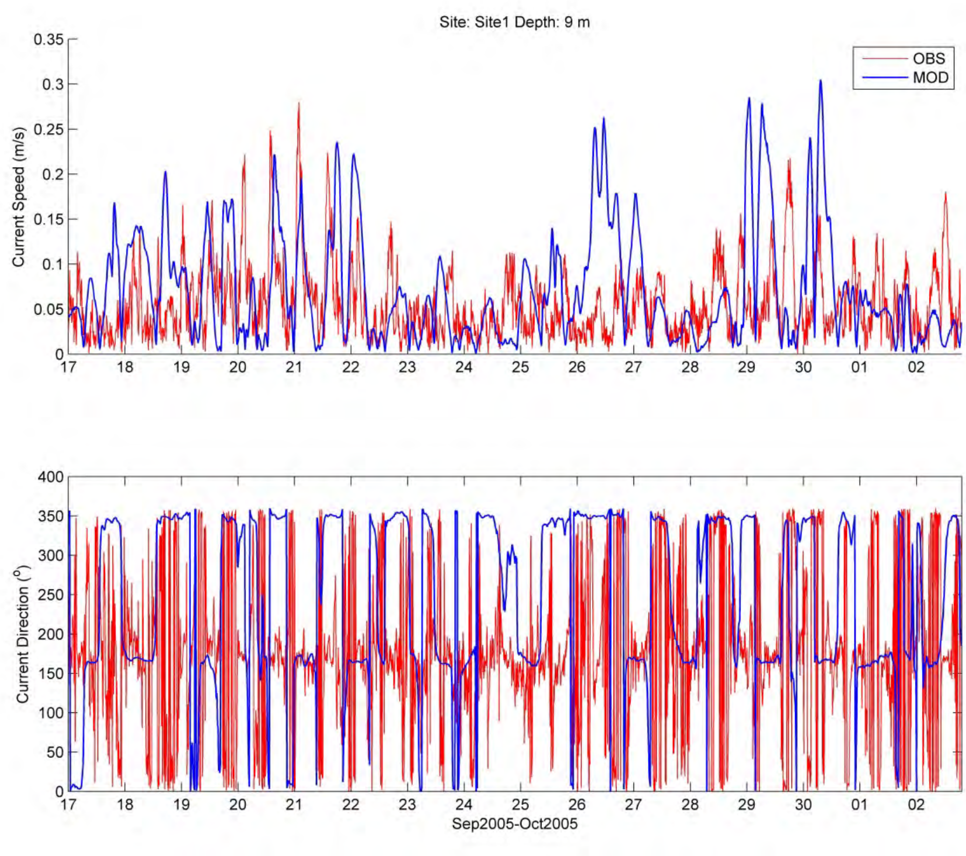

Figure 3: Flow speeds and directions for 9 m depth for observations (red lines) and model results (blue lines) for model calibration at the Site 1.

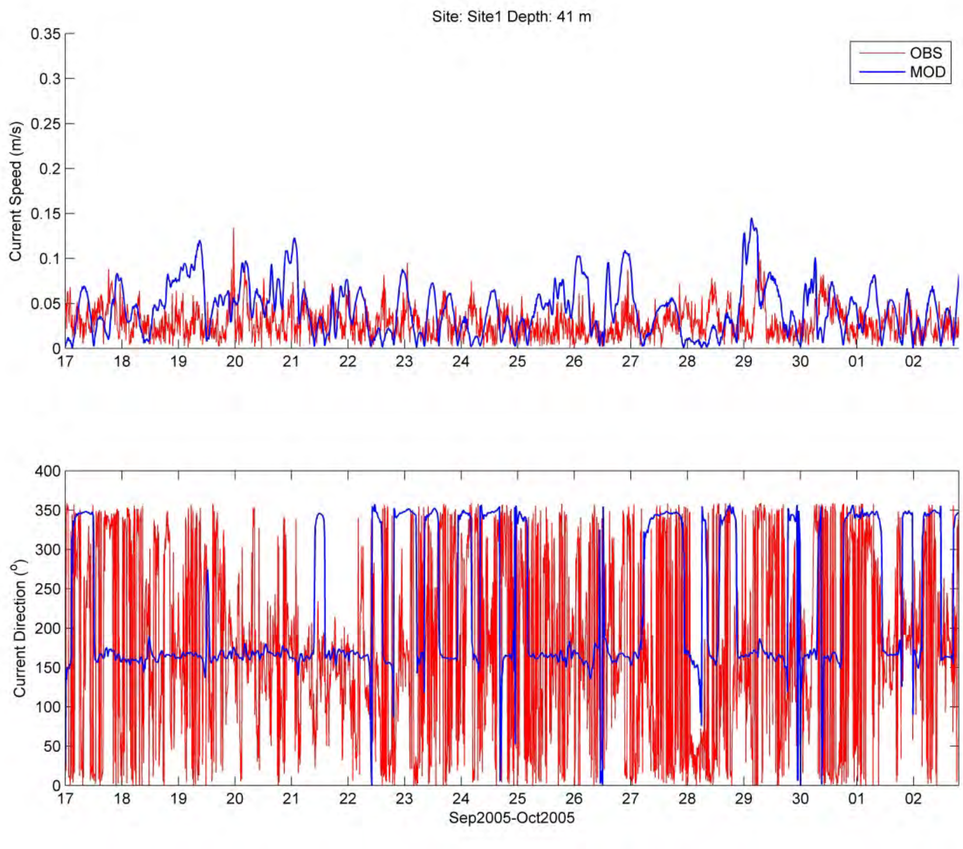

Figure 4: Flow speeds and directions for 41 m depth for observations (red lines) and model results (blue lines) for model calibration at the Site 1.

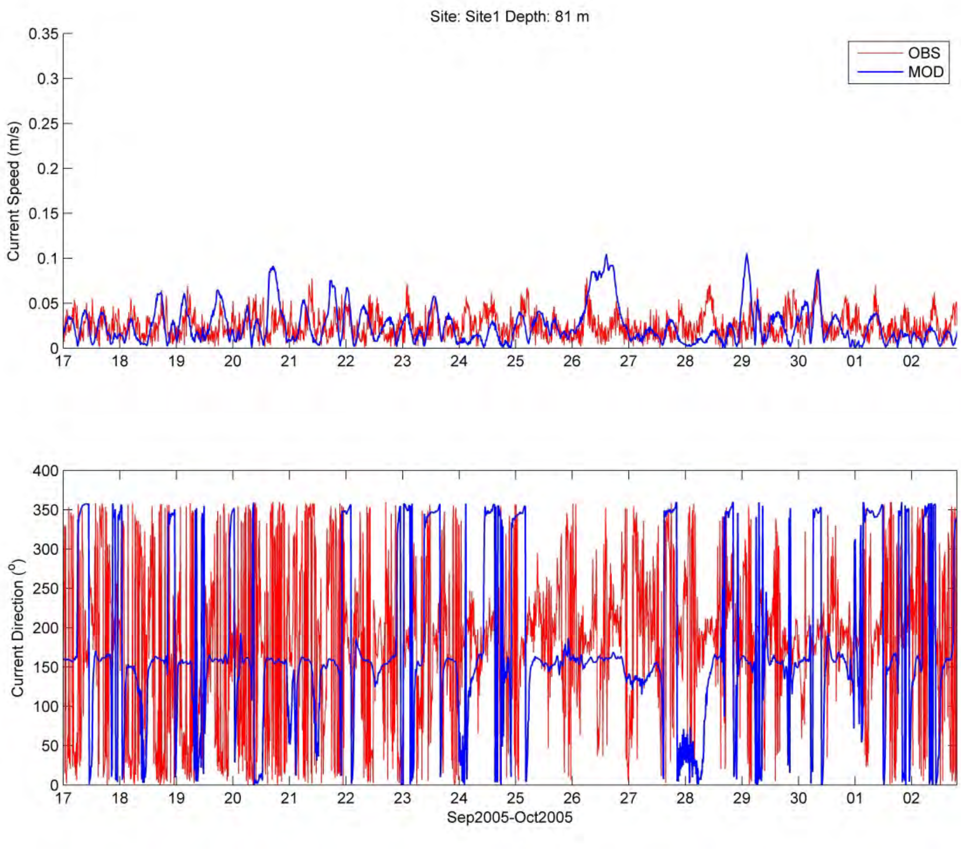

Figure 5: Flow speeds and directions for 81 m depth for observations (red lines) and model results (blue lines) for model calibration at the Site 1.

4. Model Verification

Model verification run was carried out and modeled currents were compared with current meter data collected at the west tautline mooring site (53° 59' 20.582" N 128° 40' 57.846" W, water depth 96 m; see locations in Figure 6) deployed between July and October, 2013. With the vertical stratification resulting from Kitimat River freshwater discharges and the underlying steep bottom slope underneath, strong surface current speeds were observed at the west mooring site. As shown in Figures 7-8, during the 10-day verification period, the model results are generally in agreement with observations and the modeled flow patterns in the model area are physically reasonable. At the upper comparison depth of 7 m, however, a few surface strong current events were missed during the model simulation. The model slightly overestimated the deep flow at 80 m which makes the results conservative for the purposes of sediment transport modeling. It is also notable that the measured surface velocities tend to be mostly northward in flow direction, while model results present a typical estuarine flow structure, i.e. the upper layer water flows mostly southward and the lower layer water flows northward more frequently. The differences between the model and observations reflect uncertainties of the inputs to the model, including the use of winds from Terrace BC, a non-marine location and the spatially variable water column stratification. For the modeling application of the present study, the focus is on the near-bottom currents in the waters of and adjoining the harbour area rather than the upper layer currents in deeper offshore waters.

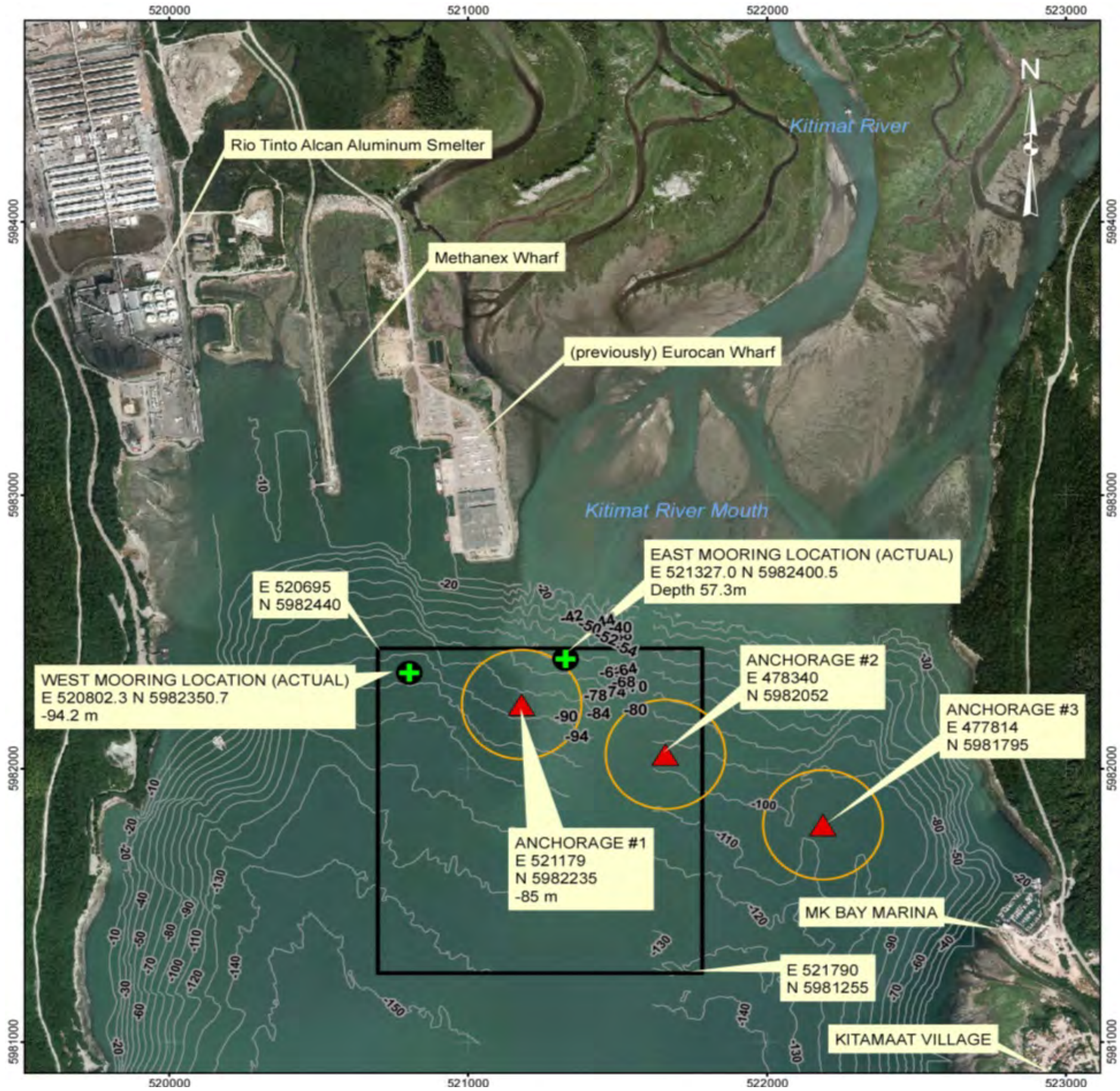

Figure 6: July 2013 Deployment Location of the West and East moorings (extracted from the Metocean Study Report)

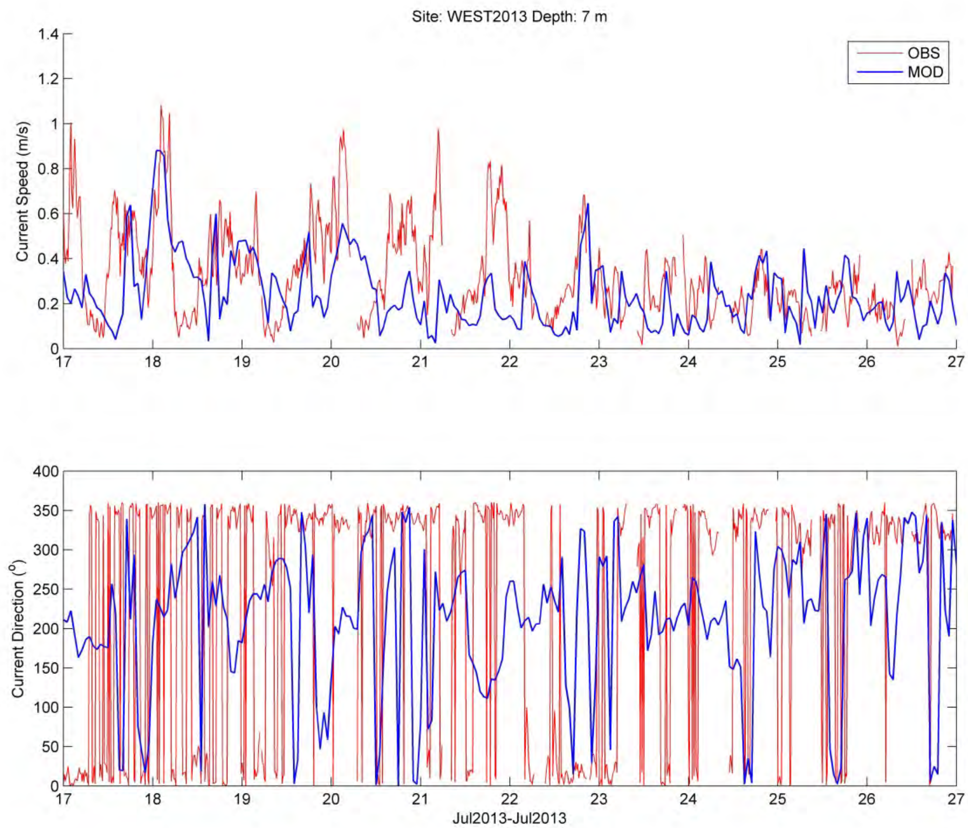

Figure 7: Flow speeds and directions for 7 m depth for observations (red lines) and model results (blue lines) for model verification at the west mooring site.

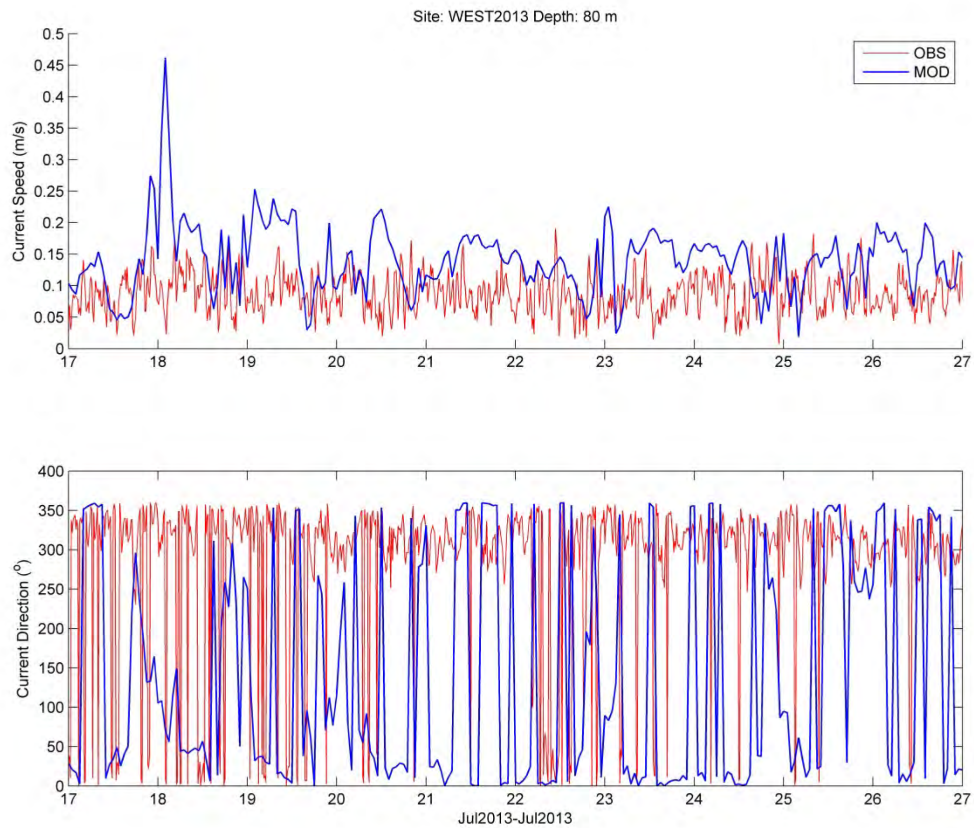

Figure 8: Flow speeds and directions for 80 m depth for observations (red lines) and model results (blue lines) for model verification at the west mooring site.

5. Sediment Transport Modeling

The objective of this modeling component was to examine the effects of the alterations on substrate in the terminal and adjacent areas. In this study, a non-dimensional index of the potential of erosion and deposition (PED) was provided, by simulating the intensity of sediment resuspension, transport, and deposition processes. The model results were normalized and presented based on areal content.

In order to be conservative, the available thickness of total sediment was set to be 5 m in the area marked with blue lines in Figure 9. The input sediment distribution in the study area was determined based on the LNG Canada Marine Sediment Investigation Program, Kitimat, BC in 2013. An average distribution of the substrate material was used in the sediment model as summarized in Table 1. If erosion reaches 1 m or larger, the modeled PED value of the sediment type is set at -1. The PED index is defined to be +1 when sediment deposition is equal or greater than 1 m. It should be noted that the modeled results of bottom erosion and deposition are qualitative.

The model was integrated for two study periods: freshet and non-freshet. During each study period, first, the model was integrated to simulate the sediment transport process for the existing conditions and the altered conditions (12 days for each model run).

Tidal elevations at open boundaries in 2015 were predicted based on known tidal height constituents. Since surface winds and Kitimat River discharges are not predictable over long periods into the future, a representative year of forcing was selected from the past 10 years (2004-2013). Specifically, strong surface winds in 2010 and large Kitimat River discharges in 2011 were used to drive the model. The model results realized from the 12 day periods are representative of typical wind and tidal currents for both river freshet and non-freshet conditions. Therefore, the differences resulting from the changes due to the project can be realized from the results provided for each 12 day period.

Table 1: Summary of sediment input parameters for modeling.

Class	Clay and Fine silt	Silt	Fine Sand	Medium Sand	Coarse Sand	Gravel
Size	<0.0312 mm	0.0312-0.063 mm	0.063-0.25 mm	0.25-0.5 mm	0.5-2 mm	>2 mm
% of total	25.37	9.44	39.69	11.40	5.57	8.52

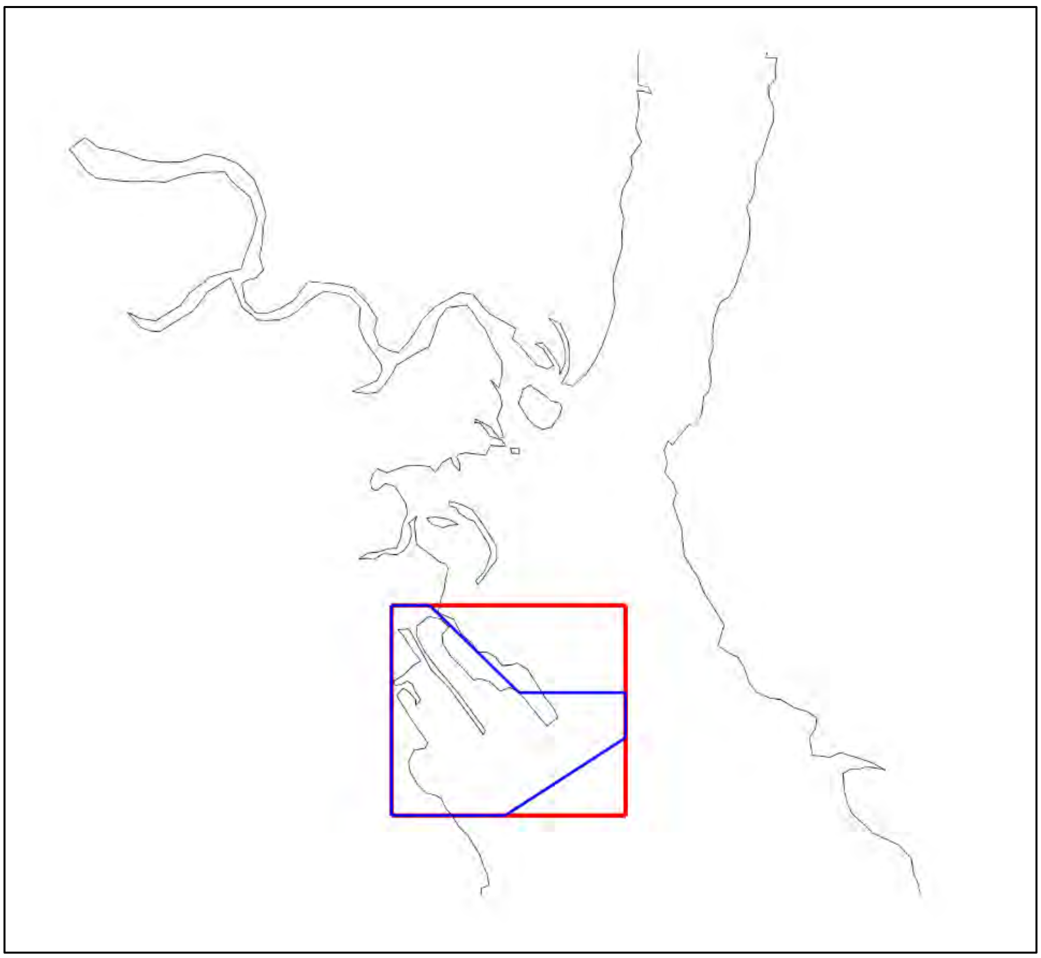

Figure 9: Inner model domain (red box) and area for available bottom sediment (blue polygon).

Model results are presented in Figures 10-11. The difference between the model results indicates the effect of the alterations on the substrate.

Larger changes are limited to a narrow band along the seaward edge of the dredging area which extends about 300 m further to the east. Here, elevated deposition levels of < 1 m occur. In this same narrow band, there are interspersed areas of erosion, which extends northward off the outer part of the western side of the berth area. Those areas are located mostly along the edge of new slope/step generated from the dredging (the south one is between 14m and the original bathymetry, the north one is along the 10m and 14m step, as shown in Figure 1). It reflects a dynamical adjustment of the new slope and step since they are not stable yet.

Erosion and deposition levels at areas other than the slope or step are minor. For both simulated forcing conditions the changes in PED are small at less than ±0.2m within nearly all areas. Some erosion is also seen in a small area (100 by 200 m) off the western shoreline of Kitimat Arm, directly to the west of the southern extent of the berth area.

It should be noted that the difference in depth from dredging is instantaneous, and at that point t=0. Since dredging will occur over a period of approximately 3-5 months, the rate of erosion/deposition from the depth change would be expected to be more gradual than predicted by the model. Therefore, the model is conservative from the point of view of the effects assessment.

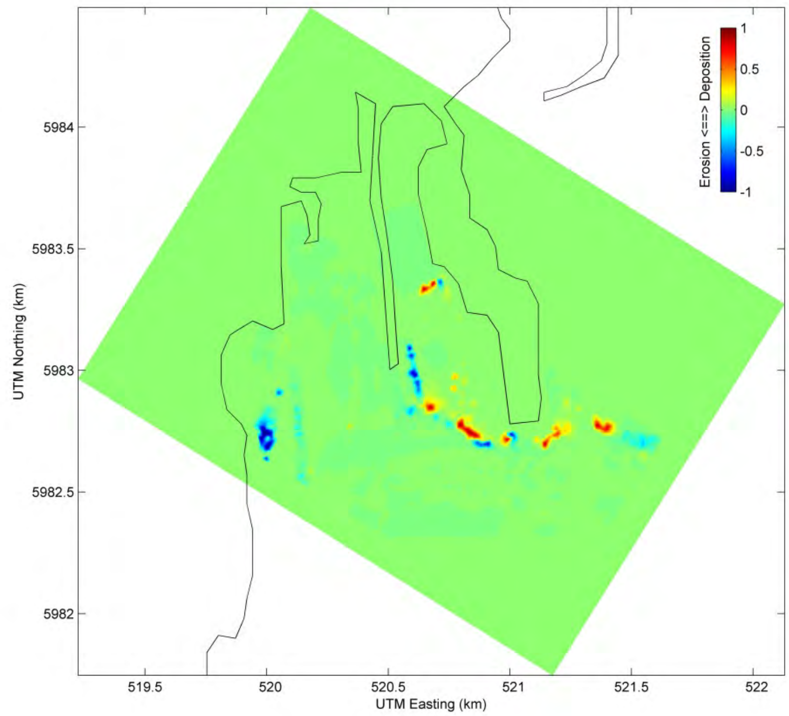

Figure 10: Difference of the potential of erosion and deposition, between before and after alterations during the 12-day freshet period.

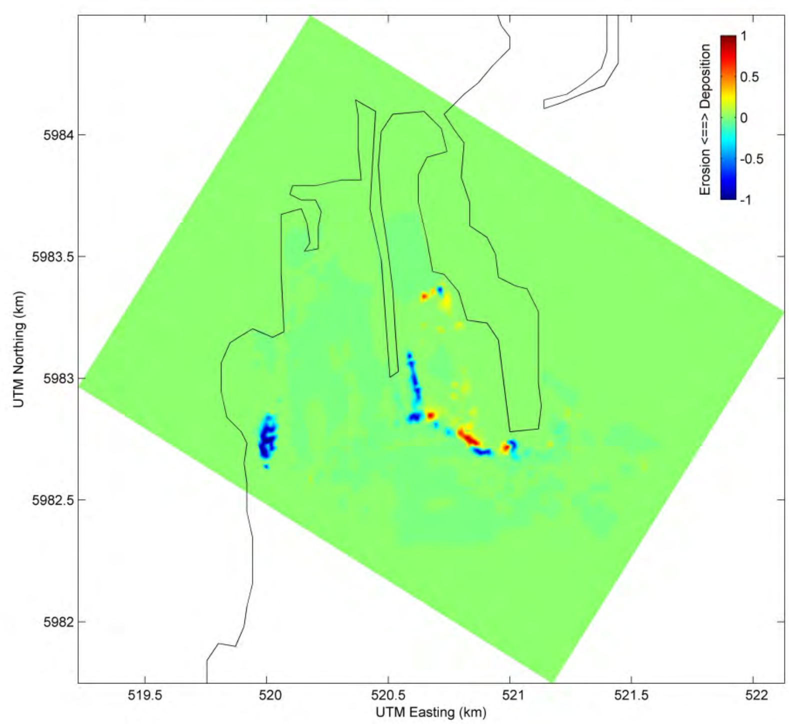

Figure 11: Difference of the potential of erosion and deposition, between before and after alterations during the 12-day non-freshet period.

6. References

Fissel, D.B., K. Borg, D.D. Lemon and J.R. Birch, 2010. Technical Data Report – Marine Physical Environment. Report for Enbridge Northern Gateway Project by ASL Environmental Sciences Inc., Victoria B.C. Canada. 322 p.

Foreman, M.G.G., 1977. Manual for Tidal Heights Analysis and Prediction. Pacific Marine Science Report 77-10, Institute of Ocean Sciences, Patricia Bay, Sidney, B.C., 58 pp. (2004 revision).

APPENDIX I:

Dredgeate Placement in the Upper Kitimat Fjord System (Maitland Basin)

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