AMBIENT UNDERWATER SOUND LEVELS MEASURED AT WINDY CORNER, TURNAGAIN ARM, ALASKA

Prepared for:

LGL Alaska Research Associates, Inc.

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GREENERIDGE SCIENCES, INC.

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CONTENTS

1 EXECUTIVE SUMMARY

In July 2014, the Alaska Department of Transportation and Public Facilities commissioned measurements of ambient underwater sound levels in Turnagain Arm, Alaska, a shallow tidal fjord extending from Cook Inlet southeastward into the Chugach Mountains. The study measured sound characteristics at different tidal stages but under otherwise quiet conditions. These data were intended to inform predictions (by a separate study) of the distances at which highway construction sounds generated near a point of land called Windy Corner might be audible underwater to beluga whales. Acoustic measurements were conducted at Windy Corner on 18 August 2014 using an Acousonde™, a small, self-contained acoustic recorder. The Acousonde was suspended from a remote-controlled boat that brought it to distances of 161–262 ft (49–80 m) from shore, after which it was allowed to drift while recording and then retrieved by tether. The measurements showed ambient sound pressure levels at high and low tide to be 74 and 81 dB re 1 μPa respectively, as computed over a 40 Hz–9.3 kHz band. These levels were 22–34 dB quieter than those measured at ebb and flood tide that measured 103 and 108 dB re 1 μPa, respectively. Ambient sound levels at high and low tide were quieter than expected for such an active body of water, although still stronger than the quietest levels recorded at other locations in Cook Inlet by Blackwell and Greene (2003).

2 INTRODUCTION

In early 2013, the Alaska Department of Transportation and Public Facilities (DOT&PF) began work on a proposed project to improve road safety at and near Windy Corner, a point of land between mileposts (MP) 105 and 107 of the Seward Highway along the north shore of Turnagain Arm, Alaska (Figures 1 and 2). The proposed project would realign the highway and the railroad as well as create space for roadside recreational facilities and wildlife viewing areas with acceleration and deceleration lanes for turning traffic.[1]

The Windy Corner project as envisioned would require blasting and in-water construction work at Windy Corner itself, as well as possible on-shore blasting at materials sites near MP 104 and/or MP 109. These activities are likely to introduce underwater sounds in Turnagain Arm, a tidal fjord frequented by a population of beluga whale (*Delphinapterus leucas*) that in 2008 received endangered status under the Endangered Species Act (NMFS, 2008). It remains unknown how strong these underwater sounds will be either in absolute terms or relative to the natural acoustic background of Turnagain Arm.

Knowledge of background sound levels is essential to estimate the distance at which introduced sounds might be audible above ambient noise; as far as the author knows, however, underwater sounds in Turnagain Arm have never been documented. This lack may owe in part to the profound 30-ft (9-m) tides, strong tidal currents, multiple uncharted and migrating shallows, and quicksand-like mud flats that characterize the region. To address this need, the DOT&PF commissioned LGL Alaska Research Associates, Inc. and its subcontractor Greeneridge Sciences, Inc. to measure ambient underwater sound levels offshore along the MP 104 to MP 109 section of the Seward Highway.

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[1] http://www.dowlhkm.com/projects/windycorner/, retrieved 19 September 2013.

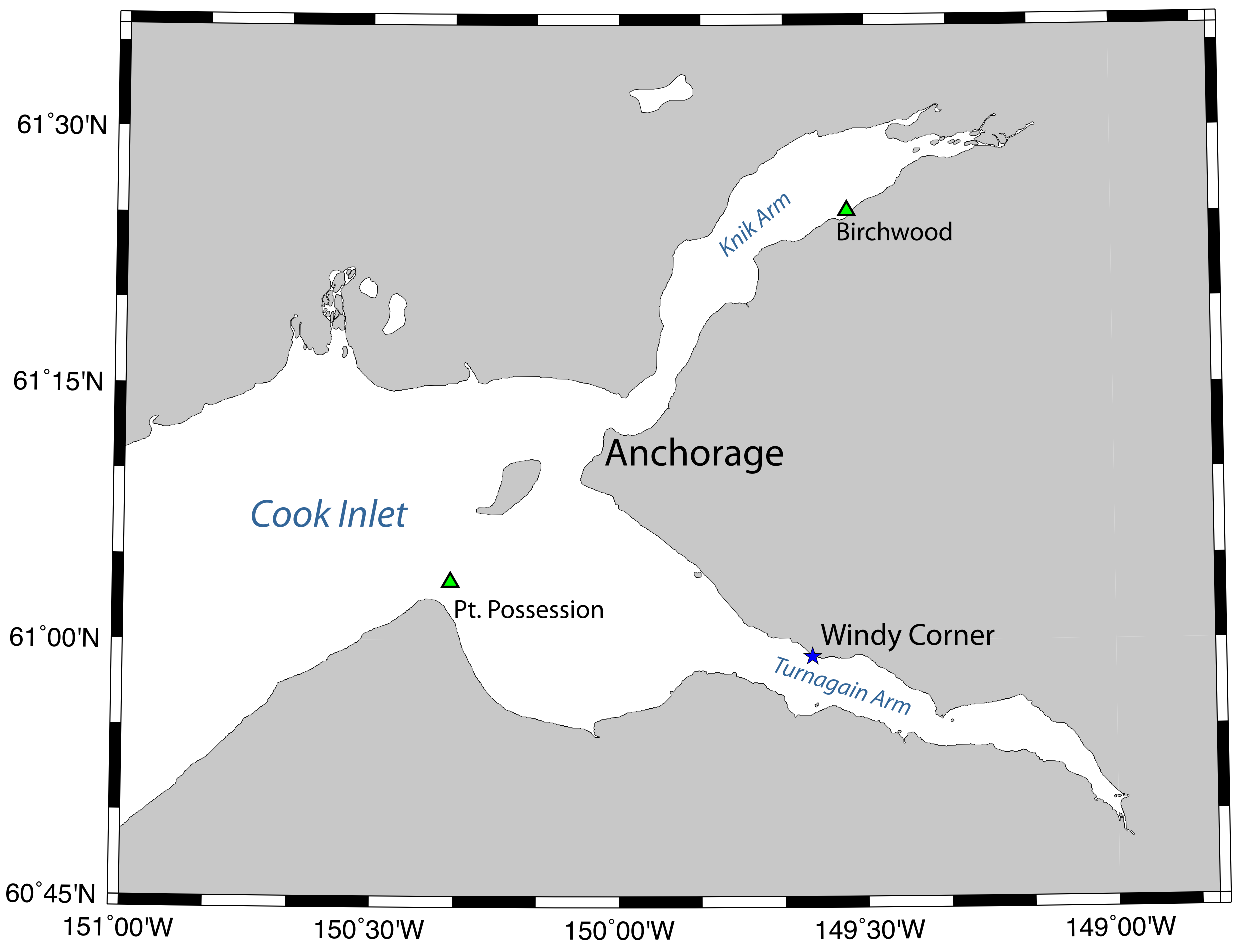

Figure 1. Measurement locations in Cook Inlet, Alaska. The present study focuses on ambient underwater sound levels measured off Windy Corner in August 2014. Underwater acoustic recordings made in August 2001 by Greeneridge Sciences near Birchwood and Pt. Possession (Blackwell and Greene, 2003) provided reference data for comparison.

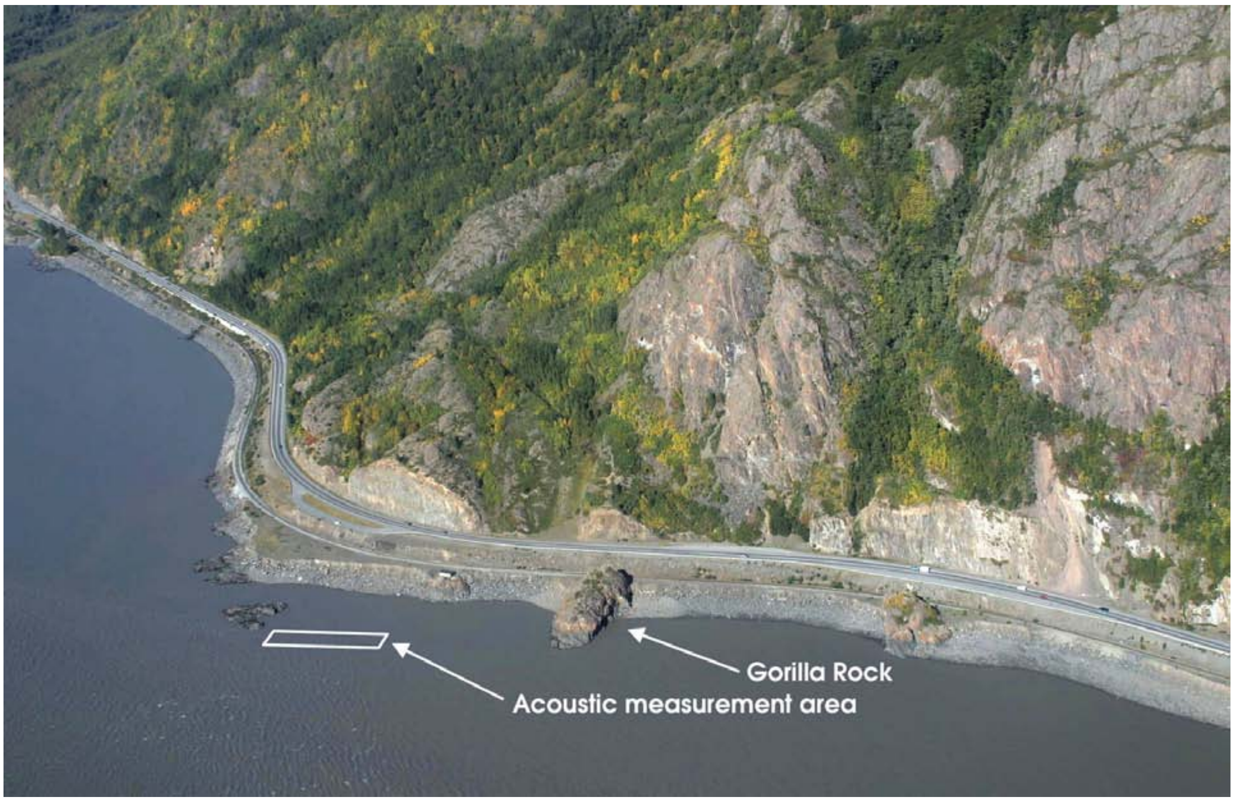

Figure 2. Aerial photograph of the Windy Corner study site. The rectangle shows the location of acoustic measurements made for this study, at the outer edge of a cove bounded by Gorilla Rock (lower center) and an unnamed rock (lower left). *(Photograph courtesy of the Alaska DOT&PF and DOWL HKM via the Facebook page "Seward Highway MP 105–107: Windy Corner Project", retrieved 17 September 2014)*

3 METHODS

3.1 RECORDING PLATFORM

Obtaining the measurements presented a challenge. Dangerous boating conditions on Turnagain Arm prohibited use of a traditional sound-monitoring vessel for reasons of both cost and safety. Strong tidal currents discouraged use of fixed seafloor recorders – another common sound-measurement technique – due to the likelihood that flow noise would severely contaminate the acoustic records, as well as the difficulty and risk involved in positioning and retrieving the instruments. A hydrophone deployed from shore by hand, however, would be in waters too shallow and too close to local shore noise to obtain representative sound measurements.

To overcome these obstacles, a small motorized buoy was configured to suspend an Acousonde™ miniature self-contained underwater acoustic recorder (Greeneridge Sciences, Inc., Santa Barbara California; Figure 3). Once motored into position, the buoy would drift, minimizing contamination of the acoustic record by flow noise. A retrieval tether made of 200-lb braided dacron kite line facilitated instrument recovery.

A commercially-available electric remote-controlled (R/C) "Blast" motorboat served as the motorized buoy (Traxxas L.P., McKinney, Texas; Figure 4). The miniature boat measured 23.8 in (60.4 cm) long with a 5.8-in (14.7-cm) beam. The R/C boat was modified before deployment with an eyebolt in the bow for attachment of a retrieval tether, a v-shaped guide near the stern to retain the tether inline with the direction of the boat during outbound motoring, and a "beaver tail" hoop abaft the transom to discourage fouling of the tether in the prop. Cable ties around the boat at the beam provided a tie-off point at the keel for the line suspending the Acousonde. The weight of the Acousonde depending from the keel served to increase boat stability.

A QStarz BT-Q1000XT miniature GPS receiver/logger (QStarz International Co., Ltd., Taipei, Taiwan) fit inside the R/C boat and logged position information throughout all deployments. This device was equipped with a differential GPS (DGPS) receiver that

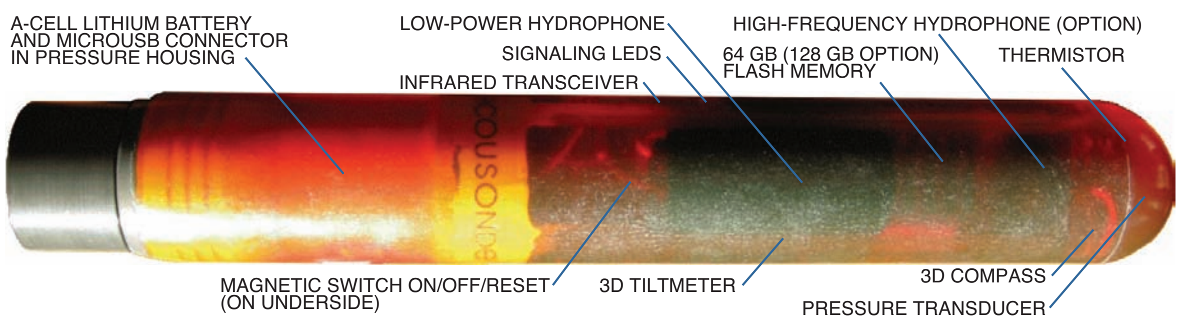

Figure 3. Acousonde™ model 3A self-contained acoustic recorder. The Acousonde 3A measures 8.7 in (22.1 cm) long by 1.25 in (3.2 cm) in diameter, and weighs 9.2 oz (262 g) in air or 3.0 oz (86 g) in water with battery included.

incorporated position-correction transmissions from the U.S. Coast Guard DGPS station in Kenai, Alaska, improving the precision of location fixes.

As deployed, the Acousonde was programmed to record continuously from its embedded HTI-96-MIN hydrophone with custom preamplifier (High Tech, Inc., Long Beach, Mississippi). Hydrophone sensitivity after preamplification was -171.4 dB re 1 μPa, with an additional 22.5 dB of gain added before digitization. Digitizing took place at a 25.811-kHz sample rate after hardware filtering with an 8-pole elliptic anti-alias filter at a 9.3-kHz cutoff frequency. The Acousonde's high-pass cutoff was 19 Hz.

After pool evaluation of stability and towing capability, the recording platform was tested under real-world conditions in the harbor at Ventura, California. It performed well in light chop and winds gusting to 10 kt, and obtained clean sound measurements of passing vessels.

Further tests assessed the risk of radio-frequency interference in the acoustic record originating from the boat remote-control electronics or the BT-Q1000XT GPS receiver/logger. No interference was detected even when the Acousonde was placed adjacent to these electronics.

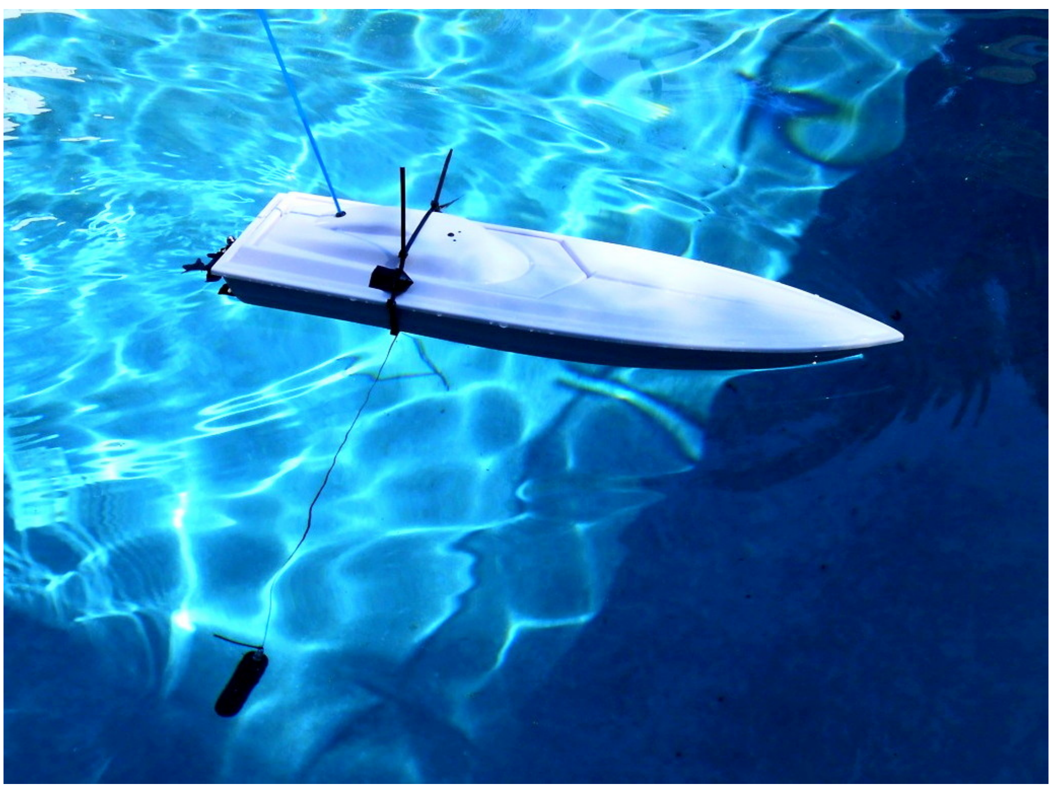

Figure 4. Recording platform. The remote-controlled boat is shown towing an Acousonde™ acoustic recorder at 39-in (1-m) depth during pool tests. The photograph does not show the retrieval-line fairing system, "beaver tail" foul guard, and eyebolt tie-off point that were added before deployment.

3.2 SELECTION OF RECORDING SITE

Selection of the recording site required care. On 17 August 2014, project personnel evaluated multiple potential sites between MP 104 and MP 109 along the Seward Highway according to five criteria:

- personnel safety;
- minimum hazard to recording equipment;
- data quality;
- data relevance; and
- most cost-effective use of field time.

Of the potential launching sites surveyed, only Windy Corner itself, at the midpoint of the area of concern, completely satisfied all five criteria. Other potential sites suffered from unsafe access, possible loss of recording gear in riprap during deployment or retrieval, poor visibility of oncoming trains, or excessive proximity to the railroad tracks. Also, the other sites offered reduced likelihood of data relevance, as none is expected to see in-water construction. Meanwhile the very shallow waters observed at low tide at several of the other sites would have impacted data quality.

A major goal of this effort was to assess underwater ambient sound at different tidal stages. Since all potential recording locations would see the same tidal stage at nearly the same time, attempting measurements of the same tidal stages at multiple sites would have required additional field time. Selecting a single site for all measurements allowed all field work to be completed in one day.

Two beluga were observed and photographed approximately 273 yd (250 m) off Windy Corner at low tide during the site survey, confirming this location as beluga habitat.

3.3 DEPLOYMENTS

All measurements took place on 18 August 2014. Tide tables for Sunrise, Alaska, directly across Turnagain Arm from Windy Corner, identified times of low and high tide for acoustic measurement purposes. Measurements for ebb and flood tide were made at times approximately halfway between neighboring tidal extremes. Table 1 lists the expected times of tidal circumstances and the midpoint of the recording times for the measurements analyzed.

At or near the desired measurement times, the R/C boat and attached Acousonde recorder were launched and motored outward by remote control until visual contact was nearly lost. Position logs show this to have been at distances of 161–262 ft (49–80 m) from shore. Although the launch location differed depending on the tide, the recordings themselves all took place within the rectangle shown in Figure 2. Once the recording platform was in position, the motor was turned off, the retrieval tether kept slack, and the platform allowed to drift. After a drift period of anywhere from 40 s to 4 min depending on currents, the recording platform was retrieved by hauling in the retrieval tether.

All launches took place into a sheltered stretch of water protected from direct exposure to the strongest tidal currents (see Figure 2). Operating in this cove allowed the recording

TABLE 1. Tide and recording times at Windy Corner, 18 August 2014.

Tide	Tidal height above MLLW[a] ft (m)	Time AKDT	Recording time of analyzed data AKDT
Low	2.2 (0.7)[b]	09:34[b]	09:42
Flood, near peak flow		12:23[c]	12:30
High	29.3 (8.9)[b]	15:12[b]	14:44
Ebb, near peak flow		18:33[c]	18:31

[a] A zero value would indicate that water depth corresponds to mean lower low water of the tidal cycle.
[b] From tide tables for Sunrise, Alaska, published at geotides.com.
[c] Calculated as midpoint between neighboring tidal extremes.

platform to measure propagating sounds during strong tidal flow without experiencing direct mechanical contamination of the acoustic record from near-surface turbulence (Figure 5).

The depth of the Acousonde's embedded hydrophone was 3.3 ft (1 m) for all deployments. Boat-based ambient noise surveys typically deploy hydrophones at greater depth to reduce the contribution of sounds local to the survey boat and to maximize reception of low-frequency propagating sound. The depth used here was chosen to minimize the risk of instrument loss due to capture by submerged crevices near shore. This hydrophone depth likely reduced reception of frequencies below about 500 Hz; however, measurements of such frequencies are already less representative near shore due to poor propagation of low frequencies as they approach shallow waters. Low frequencies are also heard poorly by beluga whales, as will be discussed later.

Before and during all deployments of the R/C boat, deployment personnel checked by radio with a dedicated protected-species observer, stationed with good visibility at the nearby Windy Corner turnout of the Seward Highway, to ensure no beluga whales had been seen.

3.4 ANALYSIS

This study aimed to quantify ambient sound levels in Turnagain Arm in order to inform predictions of the distances at which the strength of underwater sounds produced from shore would diminish below those levels. Because these distances might be used to establish the maximum potential influence zones for protected species, it was important to report levels representative of quiet conditions.

In practice, boat-based acoustic recordings often capture transient sounds local to the recording platform that are not part of the propagating sound environment. Such sounds may originate from waves breaking, from strumming of lines or cables, or from events or equipment on the boat itself. Mechanical sources, such as waves slapping the hull, vibrations, clanking metal fixtures, and movement on deck can produce considerable acoustic energy in the vicinity of the vessel at infrasonic and near-infrasonic frequencies (on order 20 Hz).

To minimize the influence of transient sounds local to the recording platform, all acoustic data analyzed for this study were filtered to a bandwidth of 40 Hz to 9.3 kHz, then processed

Figure 5. Recording platform deployed during ebb tide. The arrow indicates the remote-controlled boat. The boat approached turbulent waters but did not enter them, allowing measurement of propagating sounds with minimum exposure to near-surface turbulence that could introduce mechanical noise artifacts.

in short windows of ∼0.3-s duration. This approach was applied both to the new data recorded at Windy Corner and, for comparison, to original data recorded by Greeneridge Sciences in 2001 elsewhere in Cook Inlet (Blackwell and Greene, 2003[2]; Figure 1).

Processing for each ∼0.3-s analysis window computed levels for the 63-Hz through the 8-kHz one-third octave bands, as well as broadband levels across the 40-Hz to 9.3-kHz bandwidth. Once a data window was processed, the window was shifted forward by 1 ms (Windy Corner data) or 5 ms (2001 data) and the analysis repeated until all data selected had been processed. To estimate the quietest levels observed and minimize the influence of transient events, all analysis band results (one-third octave as well as broadband) across all analyzed windows were compared, and only the minimum computed value in a given band was retained.

Table 2 lists the recording and analysis parameters for the Windy Corner data as well as for the original Blackwell and Greene (2003) data reprocessed for this study. Windy Corner water depths are approximate, based on a rough estimate of 11-ft (3-m) depth in the recording area at low tide combined with tidal heights at other times. The depth estimate was derived from extrapolation of the approximate downward slope of the adjacent mud flats.

Like all recording instruments, the Acousonde has a "noise floor" consisting of internally-generated self noise. This noise floor is always present and contributes to any sounds it might

[2] Blackwell and Greene (2003) is a minor revision of Blackwell and Greene (2002).

TABLE 2. Recording and analysis parameters.

Site	Tide	Water depth[a], ft (m)	Hydrophone depth, ft (m)	Analysis window, s	Total duration inspected, s
Pt. Possession[b]	Flood, near peak flow	156 (47.4)	34.4 (10.5)	0.34	49.5
Windy Corner	Flood, near peak flow	24 (7)[c]	3.3 (1)	0.32	3.4
Windy Corner	Ebb, near peak flow	24 (7)[c]	3.3 (1)	0.32	3.4
Windy Corner	Low	11 (3)[c]	3.3 (1)	0.32	134.9
Windy Corner	High	38 (12)[c]	3.3 (1)	0.32	2.6
Birchwood[b]	High	22 (6.7)	19.7 (6)	0.34	148.0

[a] Total water depth, including tidal water height above mean lower low water.
[b] Recordings made by Blackwell and Greene (2003).
[c] Water depths at Windy Corner are approximate, based on an estimate of 11-ft (3-m) depth at low tide.

record; for the medium-to-strong sound environments for which the Acousonde was designed, however, the contribution of the noise floor can be neglected. Here, as the objective was to record a relatively quiet sound environment, it was important to characterize the Acousonde noise floor and if possible remove its contribution. This was done with an equation for removing a known atonal noise-floor level from an atonal measured level:

$$\text{corrected band level (dB)} = 10 \times \log_{10}(10^{0.1\times\text{measured level (dB)}} - 10^{0.1\times\text{noise floor level (dB)}}).$$

This method works well as long as the measured values do not approach the instrumentation noise floor too closely. In such cases an accurate value for the corrected band level cannot be determined.

4 RESULTS

4.1 MINIMUM ONE-THIRD OCTAVE BAND LEVELS

Figure 6 shows minimum one-third octave band levels at Windy Corner computed using the methods described above but not including any correction for the Acousonde noise floor. Also shown for comparison are band levels of data recorded in 2001 by Blackwell and Greene (2003), reprocessed from the original recordings using the same methods as those used for the Windy Corner data. Figure 1 shows the locations of all measurements.

The Windy Corner levels lie largely within the range established by Blackwell and Greene (2003) for ambient sounds in Cook Inlet; they reported that sound levels recorded near Pt. Possession during flood tide were the strongest, and those recorded off Birchwood at high tide the quietest, of all the ambient sounds they recorded.

The Windy Corner levels for flood, ebb, and low tides show peaks in the 250-Hz and 315-Hz bands. These peaks probably reflect an artifact. Close inspection of the acoustic data indicated a resonance, of variable frequency but centered near 290 Hz, originating most likely either from the lines attached to the R/C boat (strumming) or from the R/C boat itself. The

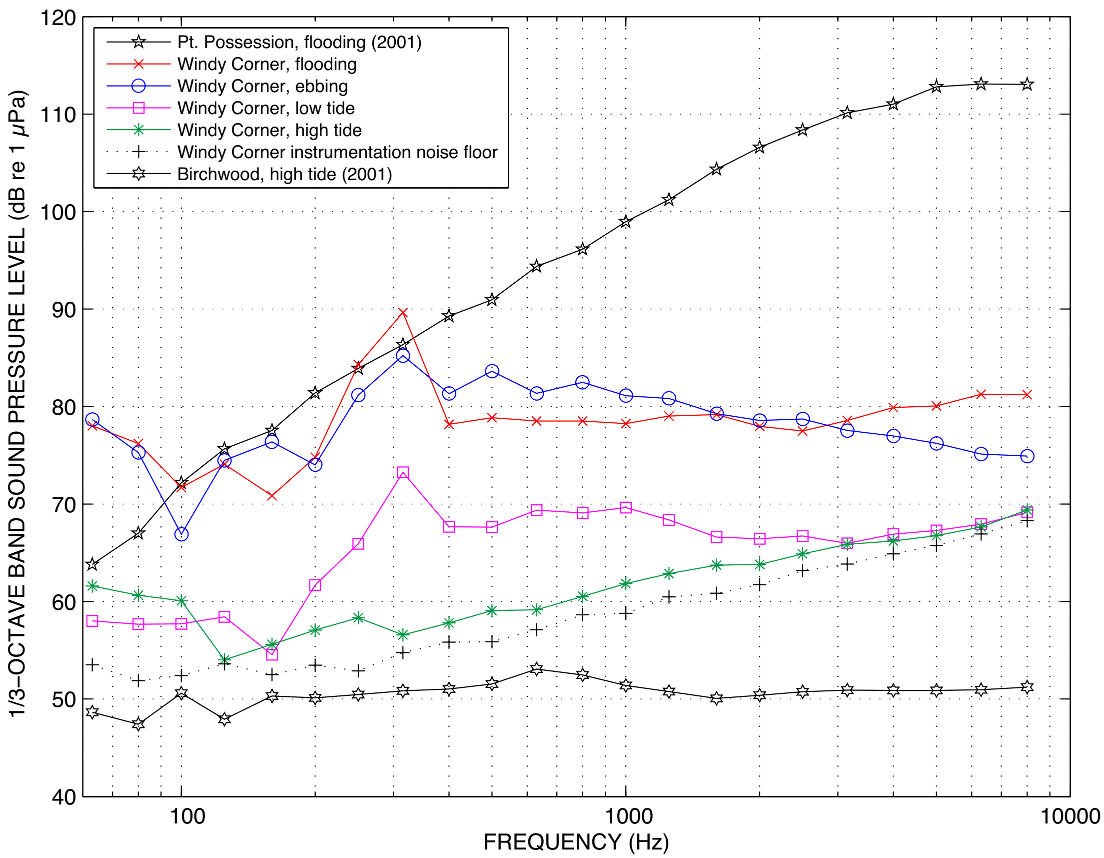

Figure 6. Minimum observed one-third octave band levels of ambient sound (Windy Corner data uncorrected). Band levels recorded at Windy Corner lie largely within the ambient-noise extremes recorded in Cook Inlet by Blackwell and Greene (2003). The weakest sounds recorded at Windy Corner occurred at high tide, when received levels approached the noise floor of the recorder.

levels for high tide show no such peak, possibly because conditions at high tide were very calm with nearly no current and nothing to excite the resonance.

The data show Windy Corner one-third octave band levels at high and low tide to have been quiet enough to approach the instrumentation noise floor in many bands. This means that, at those frequencies, the uncorrected results are representative more of the instrument's noise floor than of ambient conditions.

Correction for the artifact peaks and for the influence of the instrumentation noise floor resulted in Figure 7. The artifact peaks were removed from flood-, ebb-, and low-tide data by estimating the 250- and 315-Hz band levels using interpolation (in dB) between the 200- and 400-Hz band levels. No interpolation was performed for the high-tide data, as the artifact was not evident in that recording. Correction for the instrumentation noise floor was performed as discussed in the previous section. The noise-floor correction only materially influenced levels for low and high tide.

Also plotted in Figure 7 are beluga hearing-threshold values reported by three sources. These are discussed later.

4.2 MINIMUM BROADBAND LEVELS

Broadband levels between 40 Hz and 9.3 kHz were computed with the same approach as that used for the one-third octave band levels, including noise-floor correction for the Windy Corner data. Table 3 lists the results. Unlike the one-third octave band levels shown in Figure 7, the broadband levels for Windy Corner shown in Table 3 were not corrected for the local resonance artifact, as it contributed negligible energy to the full acoustic bandwidth.

5 DISCUSSION

Turnagain Arm appears to have neither the weakest nor the strongest ambient sound levels in Cook Inlet. The one-third octave band levels shown in Figure 7 and broadband levels listed in Table 3 lie between the Cook Inlet ambient-sound extremes recorded in 2001 by Blackwell and Greene (2003). High tide appears quieter than any other part of the tide cycle, with the next quietest part, low tide, exhibiting 7 dB stronger broadband noise than high tide. Flood tide, meanwhile, exhibited the strongest broadband level measured during the study, 32 dB stronger than high tide.

5.1 COMPARISON WITH 2001 VALUES

Readers familiar with Blackwell and Greene (2003) may note that the broadband levels they reported do not match the values presented in Table 3 for the same 2001 data. Specifically, Blackwell and Greene (2003) reported mean levels of 120 and 95 dB re 1 μPa for the Pt. Possession and Birchwood cases, while Table 3 gives 121 and 70 dB, respectively.

TABLE 3. Comparison of ambient sound-pressure levels (SPL).

Site	Tide	SPL[a] dB re 1 μPa	SPL (uncorr.)[a,b] dB re 1 μPa	Wind speed, kt
Pt. Possession	Flood, near peak flow	121[c]		< 5
Windy Corner	Flood, near peak flow	108	108	< 5
Windy Corner	Ebb, near peak flow	103	103	5
Windy Corner	Low	81	83	< 5
Windy Corner	High	74	79	0
Birchwood	High	70[c]		0

[a] Minimum value observed in a sliding ~0.3-s window of bandwidth 40 Hz – 9.3 kHz.
[b] Not corrected for 78-dB noise floor of recording instrumentation.
[c] From recordings made by Blackwell and Greene (2003).

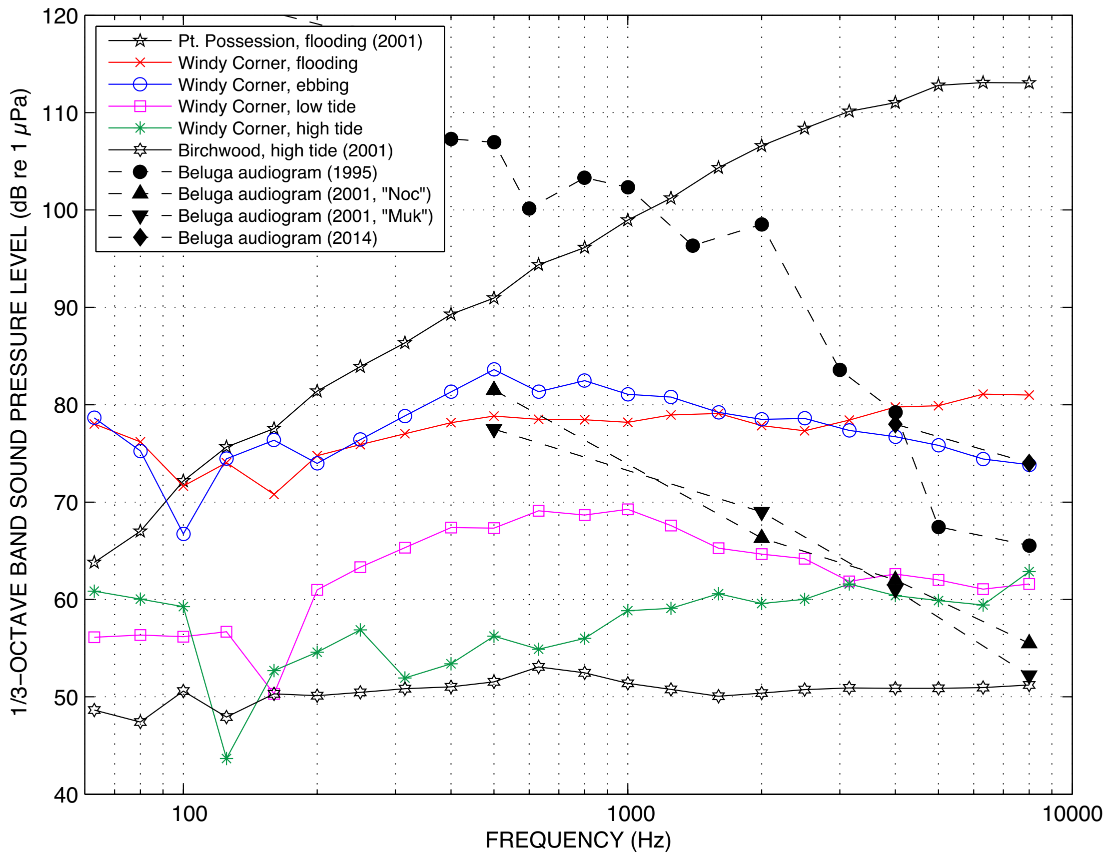

Figure 7. Minimum observed one-third octave band levels of ambient sound (Windy Corner data corrected). Windy Corner data have been corrected for the noise floor of the recording instrumentation; the correction only affects the quieter levels recorded at low and high tide. The exceptionally low 125-Hz band value for high tide at Windy Corner is likely an artifact of noise-floor correction. Probable local-noise artifacts in the 250- and 315-Hz bands have been removed from the flood-, ebb-, and low-tide levels as discussed in the text. Also plotted, with dashed lines, are beluga audiograms from three sources as follows. Dashed line and circles: Richardson *et al.* (1995), who summarized threshold levels published by White *et al.* (1978), Awbrey *et al.* (1988), and Johnson *et al.* (1989); dashed lines and triangles: two subjects reported on by Ridgway *et al.* (2001); dashed line and diamonds: mean values (at 4 and 8 kHz only) presented by Castellote *et al.* (2014).

The data selections for the present analysis surely differed to some degree from those for the earlier work; detailed records of the original data selections were not available. This suffices to explain the difference in the Pt. Possession levels, as those recordings showed fluctuations in acoustic amplitude with time. Blackwell and Greene (2003) confirmed this fluctuation for the Pt. Possession data, pointing out that the Pt. Possession broadband levels reached as high as 124 dB re 1 μPa.

Changing filtering parameters can have a profound impact on computed broadband levels. Blackwell and Greene (2003) reported levels computed in a 10-Hz to 20-kHz band, while this study reports levels across a 40-Hz to 9.3-kHz band. The removal of signal energy between 10 and 40 Hz in particular would be expected to reduce the contribution of sounds local to the recording platform. Blackwell and Greene (2003) pointed out this effect when presenting levels for the same locations that they recomputed over a 20-Hz to 1-kHz band for comparison with Burgess and Greene (1999). This reprocessing caused their mean Birchwood value to shed 7 dB, dropping from 95 to 88 dB re 1 μPa, so it is certain that the 40-Hz high-pass cutoff employed for this study accounts for a substantial reduction in the broadband level computed for the Birchwood data here. The same reprocessing reduced Blackwell and Greene's (2003) mean Pt. Possession value from 120 to 104 dB re 1 μPa, but this reflected the loss of high frequencies much more than that of low frequencies; high frequencies dominated the Pt. Possession data as seen in Figure 7.

Finally, the automated technique applied in this study of calculating all values in multiple $\sim$0.3-s windows, then selecting the quietest of all results within each band, was not used in computing the levels presented in Blackwell and Greene (2003). This technique can reduce the contribution of transient local sounds that need not be very strong to significantly affect results for quiet locations. Inspection of the 2001 Birchwood acoustic data showed numerous transients that would have been cumbersome to avoid with manual data selection.

5.2 COMPARISON WITH BELUGA AUDIOGRAMS

Figure 7 includes beluga audiograms from three sources (see figure caption for references). Note that threshold hearing levels such as those presented are generally measured for pure tones; thus the figure should be interpreted as a rough estimate of whether or not beluga could be expected to detect a pure tone of the given amplitude amidst ambient noise in the same one-third octave band as the tone.

As plotted in Figure 7, the Richardson *et al*. (1995) audiogram indicates that beluga hear poorly at low frequencies. When compared with the Windy Corner measurements, this audiogram suggests that even the strongest ambient noise in Turnagain Arm would not be the limiting factor in tonal sound detection by beluga except at frequencies over 4 kHz. The Ridgway *et al*. (2001) audiograms suggest better hearing at low frequencies, with the strongest ambient noise measured in Turnagain Arm affecting beluga ability to hear tonal sounds at frequencies as low as 500 Hz.

5.3 ANTHROPOGENIC SOUNDS

A secondary goal of this effort was to measure underwater sounds from vessels, aircraft, trains, vehicles, or other anthropogenic sources. No vessels besides the R/C boat were present at any time on 18 August, and no trains passed during the measurements. One low-altitude overflight of a small single-engine aircraft occurred during recording at ebb tide, and associated sounds were present in the underwater acoustic data. One-third octave band analysis showed the overflight to have raised band levels between 500 Hz and 2.5 kHz by about 10 dB above ebb-tide ambient, but only for a few seconds (analysis at lower frequencies was complicated by local noise associated with the recording platform). Many vehicles passed Windy Corner on the Seward Highway during the day, some while recordings were in progress; however, although an acoustic signature suggestive of a passing vehicle was observed in the recordings, it could not be positively identified.

6 ACKNOWLEDGEMENTS

Tamara McGuire (LGL Alaska) provided generous guidance throughout this effort. In addition to offering many helpful suggestions, she also participated in the site survey and served as protected-species observer during the deployments. Patrick Dexter contributed many helpful ideas and mechanical components towards the design of the recording platform and collaborated in the pool and harbor tests. Craig Reiser (LGL Alaska) assisted with deployments at Windy Corner. At Greeneridge Sciences, Katherine Kim proposed the effort, and Debra Martinez and Dave Christian helped find our original 2001 Cook Inlet recordings after two moves and thirteen years of storage.

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