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Notes

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Acoustic detection of the critically endangered North Pacific right whale in the northern Bering Sea

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The eastern population of the North Pacific right whale (hereafter NPRW; *Eubalaena japonica*) is one of the most endangered baleen whale populations in the world (Reilly *et al*. 2008), numbering in the tens of individuals ($n \approx 30$; Wade *et al*. 2011) due to historical whaling (19th and 20th centuries) followed by illegal catches in the 1960s (Scarff 2001, Ivashchenko and Clapham 2012, Ivashchenko *et al*. 2017). Whaling logs indicate that the majority of NPRW catches and sightings within the eastern Bering Sea (east of 175 °W) ranged from the Aleutian Islands to St. Matthew Island, with limited ($n < 20$) detections farther north (Fig. 1; Nasu 1960, Shelden *et al*. 2005). It has been suggested that at least some of the northern range historical sightings were either misidentified as bowhead whales (*Balaena mysticetus*) or were the result of transcription errors (Scarff 1986, Reeves *et al*. 2004). Yet, these northern detections were made over a large expanse of time (1834–1982) by observers of different nations, and included some sightings that were made on a dedicated research survey for endangered species (Brueggeman *et al*. 1984), thereby adding credence to the belief that NPRWs have occupied the northern Bering Sea in the past. Furthermore, Alaska Native whalers who hunt bowhead whales off St. Lawrence Island have on occasion observed right whales in the area, although details of such sightings are not available.

Due to the NPRW's much-reduced population size and poorly understood distribution, long-term passive acoustic monitoring (PAM) has been implemented since 2006 throughout the eastern Bering Sea shelf by the Alaska Fisheries Science Center Marine Mammal Laboratory (Fig. 1); this project represents an attempt to identify

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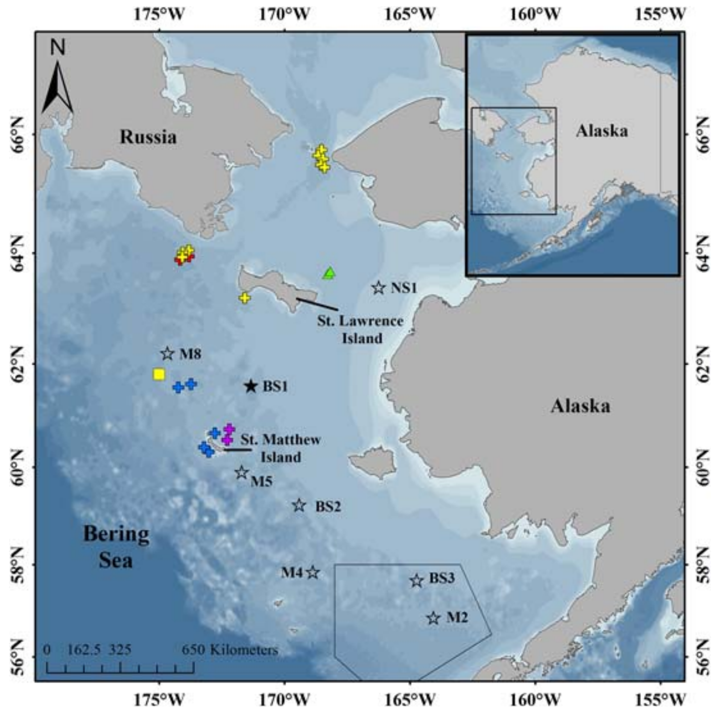

Figure 1. Eastern Bering shelf. Black star demarcates the location of the passive acoustic recorder used in this study (BS1), and open stars indicate additional passive acoustic recorders on the Bering Shelf (M2, BS3, M4, BS2, M5, M8, and NS1). Black pentagon denotes the federally designated right whale critical habitat. Other symbols indicate approximate location of catch(es)/sighting(s) of NPRWs between 60 °N and 66 °N and east of 175 °W (from Nasu 1960 and Shelden *et al.* 2005): crosses = catch, American whaleship (1839–1904); triangle = sighting, Japanese catcher boat (1958), square = sighting, NOAA ship *Surveyor* (1982). Symbol colors denote month of sighting/catch: red = June, yellow = July, green = August, blue = September, and purple = October.

the distribution of this Critically Endangered IUCN Red Listed population (Reilly *et al*. 2008). A subsurface mooring with passive acoustic recorder has been deployed approximately 180 km south of St. Lawrence Island (BS1; 61.59 °N, 171.33 °W; Fig. 1) since 2010 with analysis completed through September 2016. This Note summarizes the results of analyzed recordings from 18 October 2010 to 25 September 2016, which were reviewed for the presence of NPRW. In addition, acoustic detections of humpback (*Megaptera novaeangliae*) and bowhead whales from 1 June 2016 to 25 September 2016 are also presented for context, as this was the only time period with NPRW detections.

The subsurface mooring (BS1; Fig. 1) was comprised of an anchor, acoustic release, passive acoustic recorder, and 76 cm steel float arranged in a linear configuration (Fig. 2). An Ecological Acoustic Recorder (EAR; Lammers *et al*. 2008) was used for the first two deployments (2010 and 2011) and was replaced in 2012 with an AURAL recorder (Autonomous Underwater Recorder for Acoustic Listening;

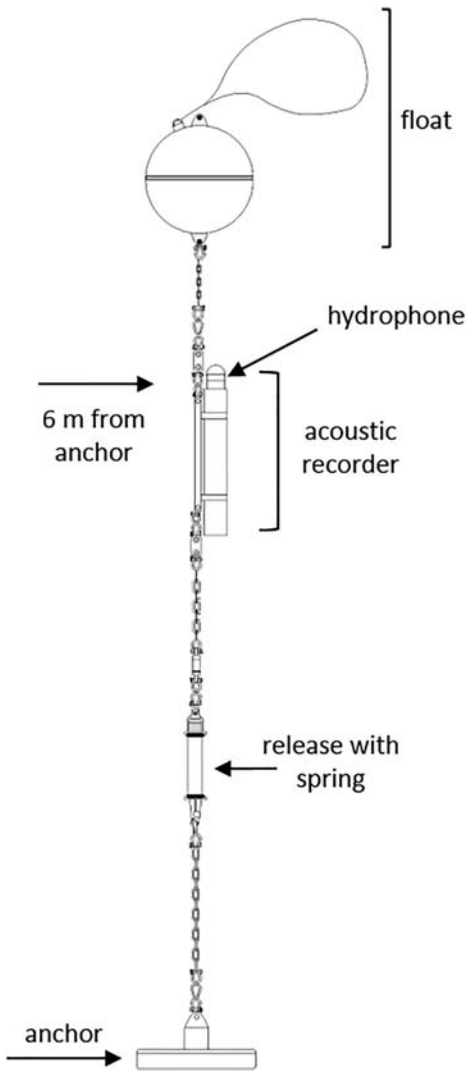

Figure 2. Mooring diagram, including anchor, acoustic release, passive acoustic recorder (either EAR or AURAL), location of hydrophone on acoustic recorder (4–6 m from anchor), and float.

Multi-Électronique, Rimouski, Canada; Table 1). The two omnidirectional hydrophones, EAR (Sensor Technology SQ26-01, −193.5 ± 1.5 dB re 1 V/μPa, −1 Hz to 28 kHz) and AURAL (HTI-96-Min, sensitivity −164 ± 1 dB re 1V/μPa, 2 Hz to 30 kHz), were housed at the top of the recording device facing upward (Fig. 2), placing the sensor approximately 4 m and 6 m above the seafloor, respectively (Table 1). The duty cycle of acoustic recordings varied among deployments (Table 1). The EARs had a sampling rate of 4 kHz with 16-bit resolution, a recorder gain setting of +47.5 dB, and a nominal frequency range of 2–16 kHz. The AURALs sampled at 16 kHz with 16-bit resolution, a recorder gain setting of +16 dB, a nominal frequency range of

Table 1. List of all passive acoustic recorders used in analysis, 2010–2016

Deployment	Recorder type	Hydrophone depth (m)	Recorder start date	Recorder end date	# Days with data	Sampling rate (Hz)	Recorder on (min)	Period (min)	# hours/ day	Total hours	# days with NPRW vocalizations
2010–2011	EAR	52	16 Sep 10	18 Oct 10	32	4,096	4	60	1.6	52	0
2011–2012	EAR	54	04 Sep 11	25 May 12	264	4,096	4	60	1.6	423	0
2012–2013	AURAL	49	13 Aug 12	19 Sep 13	371	16,384	85	300	6.8	2,523	0
2013–2014	AURAL	48	21 Aug 13	29 Sep 14	404	16,384	80	300	6.4	2,586	0
2014–2015	AURAL	47	16 Oct 14	23 Sep 15	342	16,384	80	300	6.4	2,189	0
2015–2016	AURAL	48	25 Sep 14	25 Sep 16[a]	366	16,384	80	300	6.4	2,343	26

[a]Deployment ended 25 September 2016 (02:20:00).

10 Hz to 7.7 kHz (Hannay *et al.* 2013), 90 dB dynamic range, and a spectral noise floor of 65 dB re 1 μPa^2/Hz.

Raw data from the recorder were converted into 10 min sound files (WAV). Image files (PNG) of spectrograms were pregenerated from downsampled (to 1.6 kHz) recordings (FFT 256 points with 200 point zero-padding, 0.85 overlap, Hamming window), which displayed 225 s of data from 0 to 800 Hz (time grid spacing of 24 ms and a frequency grid spacing of 3.5 Hz). This 225 s segment of data is the *analysis interval* of the study.

Given that these data were collected on a staggered duty cycle, daily recording effort varied throughout the study period. Therefore, daily data were normalized by daily recording effort (number of intervals with a species or sound source detected/number of intervals recorded per day), which will be referred to as daily calling activity. It is important to note that, because these are binned data, calling activity does not indicate the number of call detections or number of animals vocalizing.

No autodetection programs were used due to substantial overlap of the acoustic repertoires of many baleen whale species and the low population size of NPRW. Instead, all acoustic data (100% of the image files) were analyzed manually by DLW using an in-house MATLAB-based program, SoundChecker, for the following species: NPRW, humpback whale, bowhead whale, walrus (*Odobenus rosmarus*), gray whale (*Eschrichtius robustus*), minke whale (*Balaenoptera acutorostrata*), and unidentified pinniped. SoundChecker operates on the pre-generated image files, indexed for zoom and sound playback functionality. For each image file, one of three options was chosen to indicate whether a species was detected in that file: "yes," "no," and "maybe." "Yes" was used only to denote intervals the analyst was confident in attribution to a source. The analyst was trained to identify arctic and subarctic sounds using acoustic data from the right whale critical habitat (Fig. 1) and southern Chukchi shelf. Because these data were analyzed for multiple species simultaneously, an interval could be binned for more than one species. Only "yes" intervals are presented here.

Two call types were used to identify NPRWs: the frequency modulated (FM) "upcall" and the impulsive "gunshot call" (Crance *et al.* 2017). The upcall is the most common FM call type of right whale species and is assumed the contact call among conspecifics (Cummings *et al.* 1972, Clark 1982, Matthews *et al.* 2001, McDonald and Moore 2002). Upcalls were defined as FM calls with variable frequency and sweep rate characteristics, on average from 80 Hz to 160 Hz and approximately 1 s in length (Fig. 3a; McDonald and Moore 2002). The upcall classification also included "down-up" calls as defined in McDonald and Moore (2002), although no down-up calls were detected in this data set. Right whale gunshots calls were defined as brief ($<$1 s), broadband, impulsive sounds (20 Hz to 20 kHz; Clark 1983, Parks and Tyack 2005, Crance *et al.* 2017). NPRW gunshot calls ($\sim$500 ms; 50 Hz to 6 kHz) could occur irregularly as single calls or in "patterned gunshot bouts" with consistent intercall intervals (ICI; $\sim$0.5–5 s apart; Fig. 3b; Crance and Berchok 2016, Crance *et al.* 2017).

Both humpback and bowhead whales produce upsweeps similar to the NPRW upcall (Clark and Johnson 1984, Thompson *et al.* 1986). In addition, bowhead whales also produce the gunshot call (Würsig and Clark 1993). In order to differentiate among baleen whale species, call characteristics (*e.g.*, fundamental frequency, ICI, call duration) and contextual clues (*e.g.*, season, association with conspecific sounds, and proximity to nonspecific sounds) were used in tandem.

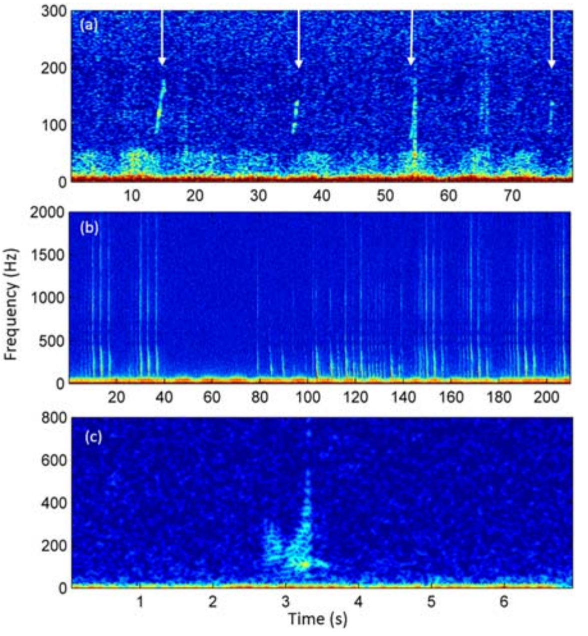

Figure 3. (a) Spectrogram of upcalls (indicated with white arrows), 8 September 2016 (19:06:03–19:07:23). (b) Spectrogram of gunshot calls, 5 September 2016 (06:16:30–06:20:00). (c) Spectrogram of humpback whale grunt (as defined in Thompson *et al.* 1986), 10 September 2016 (16:24:33–16:24:40). The (a) spectrogram has an FFT length of 1,024; the (b) spectrogram has an FFT length of 2,048; the (c) spectrogram has an FFT length of 512. All spectrograms have a Hamming window, 95% overlap, and were downsampled to 1.6 kHz. Note difference in *y*-axis scale and duration of spectrogram.

In general, right and humpback whales upsweeps were distinguished using the criteria from Mellinger *et al.* (2007), namely (1) the presence of conspecific sounds; (2) that humpback whale vocalizations often occur in repetitive patterns, even outside of the breeding season (Payne and McVay 1971); and (3) that humpback sounds often recur with a period of 3–5 s, including song on northern latitude feeding grounds (Thompson *et al.* 1986, McSweeney *et al.* 1989, Clark and Clapham 2004). In contrast, right whale upcall production is often irregular (>5 s) with more time between bouts (3–60+ min; McDonald and Moore 2002; Crance *et al.* 2017). In addition, we added the following criteria: humpback whale vocalizations often vary within a bout (Thompson *et al.* 1986), whereas NPRW produce sequences of solely upcalls in sets of 3–50 (>5 s apart; McDonald and Moore 2002).

To our knowledge, there are currently no published criteria to distinguish right and bowhead whale upsweeps. Bowhead whales are endemic to the Arctic, occurring in the northern Bering Sea primarily during winter and spring months for breeding (December–May; Rugh *et al.* 1993, Würsig and Clark 1993, Noongwook *et al.* 2007, Citta *et al.* 2015). Bowhead song occurs on migration and during the presumed winter/spring breeding season; it is characterized by multiple short songs, often with repetitive, high frequency (up to 5 kHz) complex frequency modulation (Delarue *et al.* 2009, Stafford *et al.* 2018). Neverthless, upsweeps are one of the most common call types of bowhead whales (Clark and Johnson 1984, Blackwell *et al.*

2007, Moore *et al.* 2010) adding uncertainty to species distinction using this call type. The following protocol was employed to aid in distinguishing upsweeps from right and bowhead whales: (1) association with conspecific calls; (2) amplitude modulation of the sweep, which is more common in bowhead whale (Clark and Johnson 1984); (3) variability of vocalizations within a bout, as bowhead vocalizations often include more than one call type within a bout (Clark and Johnson 1984, Blackwell *et al.* 2007) and NPRW produce sequences of solely upcalls in sets of 3–50 (>5 s apart; McDonald and Moore 2002); (4) spacing within call sequences, as bowhead sequences occur fairly regularly in 3–15 s intervals (Clark and Johnson 1984, Würsig and Clark 1993) and NPRW upcall production is often irregular (>5 s) with more time between bouts (3–60 + min; McDonald and Moore 2002); and (5) higher variability in frequency range of sweep and length of call for bowheads (80–400 Hz and 1–3 s;[2] Clark and Johnson 1984) compared with NPRW (80–160 Hz sweep and 1 s; McDonald and Moore 2002).

Similar to the upsweep, there are currently no protocols to distinguish right and bowhead whale gunshots. From data collected in the Chukchi and Beaufort seas as part of multiple projects spanning 1979–1988, Würsig and Clark (1993) described bowhead gunshots as short (<0.2 s) broadband sounds that were produced "on rare occasions." There has been no further published analysis since that paper. Formal analysis of gunshot call characteristics in known bowhead summering areas in the Chukchi and Beaufort seas from passive acoustic data is currently underway, and preliminary results support infrequent and sporadic rates of calling (<10/h, > 5 s apart).[3] In contrast, gunshot calls are the most frequently detected call type of both sexes of NPRW, with an overall call rate of 133 calls/h based on focal follow data (Crance *et al.* 2017). Moreover, NPRW males produce 'evenly patterned gunshot bouts' (0.5–5 s apart; Crance *et al.* 2017), supporting this characteristic as a distinguishing feature of NPRW gunshots. Nevertheless, given the limited knowledge of bowhead gunshots, gunshot calls from this data set were marked but not attributed to either species during manual analysis.

Gunshots were distinguished from seismic surveys (*i.e.*, airguns) visually, given that seismic surveys produce identical, repetitive impulsive sounds for numerous hours, while bouts of patterned gunshots varied in amplitude and ICI within and between bout patterns (Fig. 3b, Crance and Berchok 2016, Crance *et al.* 2017). Gunshot calls were differentiated from other biological impulsive sounds, *e.g.*, walrus "knocks" (Stirling *et al.* 1987), gray whale M1 calls (also referred to as "bongos"; Crane and Lashkari 1996), and sperm whale clicks (*Physeter microcephalus*; Weilgart and Whithead 1988), aurally (gunshots sound reverberant, walrus knocks sound hollow, M1 calls sound metallic, and sperm whale impulsive sounds are "clicky"), visually (ICI and spacing of bouts), and given the presence of conspecific sounds. Finally, gunshots were distinguished from flipper slaps/breaches visually given the punctuated presence of patterned bouts throughout the duration of the period with gunshot detections (Crance and Berchok 2016, Crance *et al.* 2017).

Regardless, there were times and locations when sounds could not be attributed to species with confidence; in these cases, the intervals were binned as "maybe" for all probable species and were consequently excluded from analysis. A conservative approach was used in positively binning intervals to potential species given the

[2]Unpublished data provided by Stephanie Grassia, NOAA, Alaska Fisheries Science Center, Marine Mammal Lab (formerly MML); e-mail: stephanie.grassia@noaa.gov.

[3]See footnote 2 above.

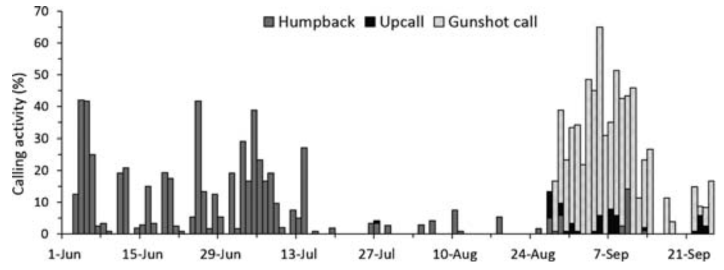

Figure 4. Stacked bar graph of calling activity (*i.e.*, the percentage of analysis intervals (225 s) with acoustic detections) for humpback whales (dark gray), right whale upcalls (black), and gunshot calls (light gray hatched); BS1 station, 1 June–25 September 2016 (sampling ended on 25 September 2016). Bowhead whale social calls and song were not detected.

present paucity of right whales and the potential implications of positive identification. As stated previously, only "yes" intervals are presented here.

Due to the low number of detections, individual NPRW calls were also counted to compare hourly call detection rates (calls/h) between the two call types using a nonparametric Kruskal-Wallis test (package *stats*). Only fully sampled hours with calls were included in hourly call detection rate comparisons. Average call detection rates were calculated for each call type using the total number of fully sampled hours with calls present (55 h gunshots; 16 h upcalls). It is important to emphasize that the call detection rates reported here are relative measures of NPRW calling rates, because neither the period of recording when right whales were present nor the number of whales is known. Daily numbers of the two call types were also determined. These data were adjusted for the staggered duty cycle using the following equation: daily number calls = daily total number calls/number hours sampled per day. All statistical analyses were conducted in the statistical program R (R Core Team 2015).

Out of the 1,779 d with recordings (2010–2016), NPRW upcalls ($n = 139$ total calls) were detected on 14 d spanning 27 July to 24 September 2016, and gunshot calls ($n = 15{,}575$ total calls) were detected for 24 d from 18 August to 25 September 2016, before recording ended at 02:20 on 25 September 2016 (Fig. 4). Daily calling activity was highest for upcalls on 27 August (8%; Fig. 4), but the most upcalls occurred on 7 September (six sampling-adjusted calls, Fig. 5). In contrast, the highest gunshot calling activity (59%; Fig. 4) and most gunshot calls (450 sampling-adjusted calls; Fig. 5) occurred on 5 September.

For both call types, the majority of days with calls occurred in September (9/14 d for upcalls; 20/24 d for gunshots; Fig. 4). Gunshot calls occurred on 12 of the 14 days with upcalls present (86% of days with upcalls; Fig. 4 and 5). For each day with both call types present, the calling activity and the total number of calls was higher for gunshots than upcalls (Fig. 4 and 5). Also, the average call detection rate (mean ± SE calls/h [minimum–maximum]) was significantly higher ($KW_1 = 11.84$, $P < 0.001$) for gunshot calls (209.5 ± 36.3 calls/h [1–1,273]) than for upcalls (5.8 ± 1.5 calls/h [1–20]; Fig. 5).

For humpback whale calls in summer 2016 (1 June–25 September), the majority of days with calling (43/53 d) occurred in June and July (Fig. 4). Humpback whale calling overlapped with the NPRW upcalls for only two days (14% of days with upcalls) and overlapped with gunshot calls for only five days (21% of days with

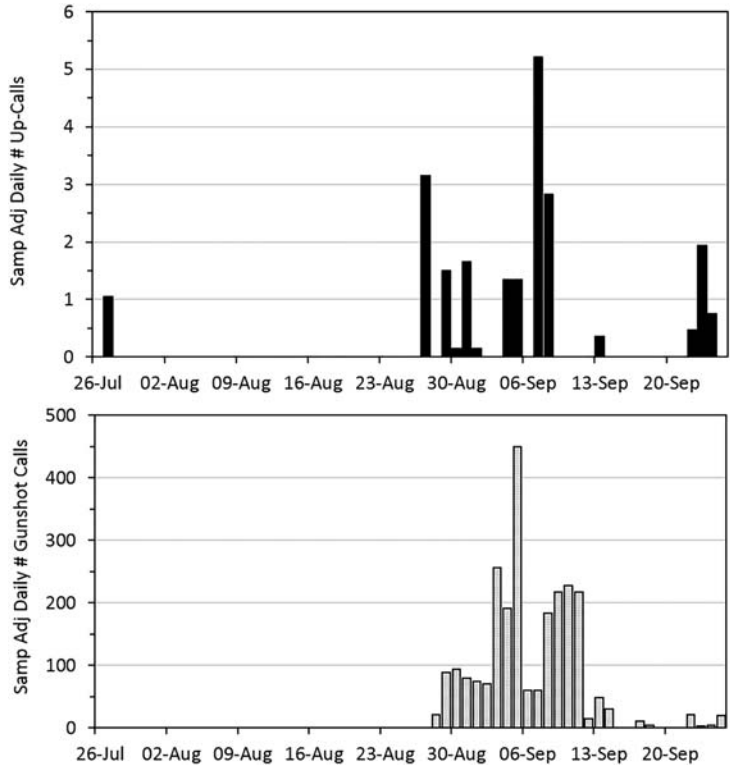

Figure 5. Sampling-adjusted daily number of right whale upcalls (top; black) and gunshot calls (bottom; light gray hatched); 26 July–25 September 2016. Sampling adjusted daily number of calls = daily total number calls/number hours sampled per day. Note the difference in *y*-axis scale.

gunshot calls). Further, all definitive humpback whale calls from July to September were stereotyped humpback whale grunts (Fig. 3c; Thompson *et al*. 1986). For bowhead whales, no social calls or song were recorded in summer 2016 (1 June–25 September).

We believe we have correctly classified the calls reported here to species. The upcall characteristics observed in this data set are consistent with previous acoustic studies of NPRWs. All identified NPRW upcalls were spaced $\geq$5 s apart and occurred in widely-spaced sets of low number (Fig. 3a, 5) with call detection rates consistent with previous NPRW studies (McDonald and Moore 2002, Munger *et al*. 2008, Crance *et al*. 2017). In addition, all identified upcalls appeared in association with only gunshot calls. Further, the hourly call rates reported here for both upcalls (5.8 calls/h) and gunshot calls (209.5 calls/h) are similar to those previously reported for NPRW in their critical habitat in the southeastern Bering Sea (upcall 4.3 calls/h; gunshots 228 calls/h; Crance *et al*. 2017). While formal analysis of patterning of gunshot bouts was out of the scope of this project, the analyst noted that the bulk of gunshots occurred in patterned bouts with consistent ICI within the bout (0.5–5 s; Fig. 3b), and all single gunshots occurred in the vicinity ($\pm$30 s) of gunshot bouts. The ICI and pattern of these bouts were consistent with focal follows of NPRWs in the southeastern

Bering Sea from the same time of year (July–August 2008, 2009; Crance and Berchok 2016, Crance *et al*. 2017). Furthermore, the small ICI (often 0.5 s), variance in amplitude within bouts, and punctuated presence of patterned bouts throughout the study support that these impulsive sounds are not slaps, breaches, or seismic surveys. Seismic surveys did not occur in U.S. waters west of Utqiaġvik[4] and were not heard at this station in summer 2016.

We do not believe the gunshot calls reported here were produced by bowhead whales. As stated previously, Würsig and Clark (1993) reported from projects spanning the 1980s that gunshots were produced by bowheads "on rare occasions." Since that time, a wealth of additional acoustic data focused on the acoustic repertoire of bowhead whales have been collected (*e.g*., Blackwell *et al*. 2007, Delarue *et al*. 2009, Moore *et al*. 2010, Stafford *et al*. 2008). All data published thus far have continued to support the belief that bowhead gunshot calling is rare, and there has been no support for attribution of persistent regular gunshot bouts to bowhead whales. Moreover, as stated previously, preliminary results of acoustic data from known bowhead summering grounds in the Chukchi and Beaufort seas suggest a much lower and more sporadic rate of gunshot calling compared with NPRW.[5] Additionally, the northern Bering Sea is currently considered a core-use zone of bowhead whale only during winter months (Citta *et al*. 2015). A handful of bowhead whales were reportedly captured in the northern Bering Sea from June to August during the historical whaling era (1847–1915; Bockstoce *et al*. 2005); however, species identification of these catches may be uncertain. More importantly, the ecological characteristics of the Arctic and Subarctic were much different during that time compared with the present (*e.g*., minimum ice extent extended into the Bering Sea throughout summer; Walsh *et al*. 2017), which undoubtedly influenced where and when bowheads could travel throughout the Arctic. Furthermore, despite visual (Ljunglad *et al*. 1986; Friday *et al*. 2012, 2013; Clarke *et al*. 2013), hunting (Noongwook *et al*. 2007), and tagging efforts (Citta *et al*. 2015, 2017), bowhead whales have not been documented in summer near St. Matthew Island since the historical whaling era. Altogether, these data support our conclusion that the observed upcalls and gunshots reported here were from NPRW.

Detection range, or the maximum distance from a recorder that a calling animal or signal can be detected by an analyst, depends on several factors, including the source level of the signal, the depth of the calling individual, ambient noise levels, and the sound speed profile of the water column and seafloor. The average underwater detection range of baleen whale calls was estimated at 10–30 km for this study area (Smith 2001);[6] this propagation range is in agreement with localization results from another acoustic study of NPRW in the Bering Sea conducted under similar water column profiles (Baumgartner *et al*. 2013) and from other species in the Arctic (Blackwell *et al*. 2007). However, previous propagation modeling in the southeastern Bering Sea suggests that NPRW upcalls in this region can propagate over distances of up to 100 km (Wiggins *et al*. 2004, Munger *et al*. 2011). While a comparable study of gunshots has not been completed, gunshots of congeneric North Atlantic right whales (*Eubalaena glacialis*) are 30 dB louder than upcall sources levels (Parks and Tyack 2005), suggesting an even farther range of detection.

[4]https://pcts.nmfs.noaa.gov/pcts-web/homepage.pcts.

[5]See footnote 2 above.

[6]The Monterey-Miami Parabolic Equation was used to model propagation losses (http://oalib.hlsresearch.com/PE/MMPE/mmpeintro.html).

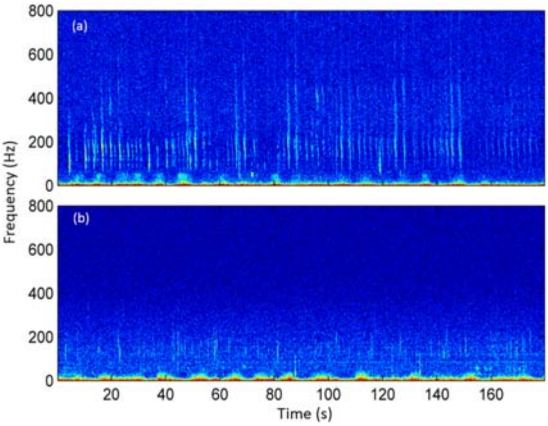

Figure 6. (a) Spectrogram of gunshot calls from station BS1, 10 September 2016 (07:10:20–07:13:20). (b) Spectrogram of unidentified 50–200 Hz impulsive sounds from station BS2, 10 September 2016 (09:10:00–09:13:00); Both spectrograms have an FFT length of 8,192, a 95% overlap, and Hamming window, and were downsampled to 1.6 kHz.

Therefore, intervals with NPRW calls from this recorder (BS1) were compared with intervals from additional passive acoustic recorders on subsurface moorings on the Bering Shelf (M2, BS3, M4, BS2, M5, M8, and NS1; Fig. 1) to explore whether the calls reported here were potentially propagated calls from a more southern location. All recorders from the 2015 deployment were AURALS that were analyzed using the same duty cycle (80 on every 300), but were not all time synchronized.

Four of the five stations south of BS1 preceded sampling at our station by 3 h (M2; ~668 km from BS1), 2 h (BS3; ~572 km), 3 h (M4; ~438 km), and 2 h (BS2; ~282 km), respectively (Fig. 1), resulting in no time-synched intervals for comparison. However, when impulsive sounds including gunshots were detected both at BS1 and BS2 (morning of 9 and 10 September 2016; Fig. 6), received levels were markedly higher at BS1 (Fig. 6a), supporting that the calls were produced closer to BS1. Figure 6 compares the gunshot bouts heard at BS1 (Fig. 6a) with 50–200 Hz impulsive sounds detected at BS2 that could be a faint gunshot bout (Fig. 6b). The final station south of BS1 (M5; ~189 km; Fig. 1) lagged BS1 by 60 min, resulting in partial sampling overlap (20 min of every 80 min sampling period). Eleven total intervals had right whale detections at both locations: 2/11 had a mismatch in call type (*i.e.*, solely upcalls at one location and solely gunshots at the other), 1/11 included solely upcalls at both locations, and 8/11 included solely gunshots at both locations. For each of the intervals with the same call type (9/11), the ICI, number of calls, and received levels varied between the two locations (*e.g.*, Fig. 7), supporting the belief that these calls were likely produced by different individuals. Moreover, the southeastern Bering shelf is assumed to be a relatively noisy environment during summer and fall months given the high vessel traffic from commercial fisheries and shipping (Nuka Research 2016); this would decrease the detection distance of calls, adding further unlikelihood that calls heard at BS1 were produced hundreds of km away. Finally, the recorders northwest (M8; ~189 km) and northeast (NS1; ~330 km; Fig. 1) of BS1 were time-synched with BS1 and did not have any right whale detections on any interval. Altogether, these data support the belief that the calls observed in this data set occurred in the general vicinity of BS1 in the northern

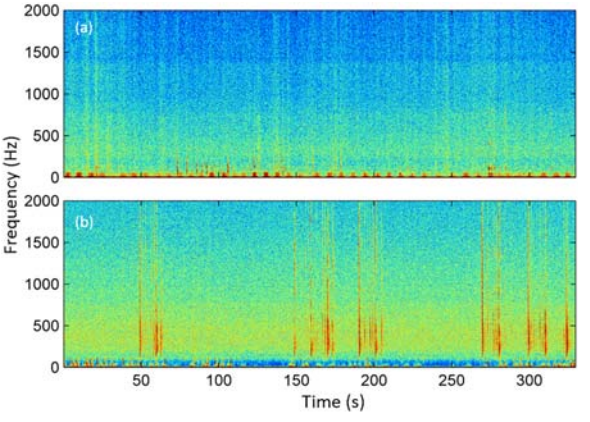

Figure 7. Time-synched spectrograms of gunshot calls from (a) station BS1 and (b) station M5, 7 September 2016 (23:00:00–23:05:30). Both spectrograms have an FFT length of 8,192, a 95% overlap, and Hamming window, and were downsampled to 1.6 kHz.

Bering Sea. Consequently, these data represent the most northerly acoustic detection of NPRWs, and supports historical distribution data from commercial whaling records that have recorded NPRWs in the northern Bering Sea during summer months.

The limited spatial scope of these data makes it difficult to interpret these findings. It is unclear at this time why NPRW only recently and briefly were detected in the passive acoustic recordings from the northern Bering Sea. The degree to which the presence of NPRW in this region is linked to changing climatic conditions needs to be explored given the present paucity of individuals in this population and the relatively rapid rate of climatic change in the Arctic (Comiso *et al*. 2014). While the number of individual NPRW and their behavior while in this region is unknown, the patterned gunshot bouts punctuated throughout the study suggest that at least one male was present (Crance *et al*. 2017). Further, these data support current findings that the gunshot call is the most frequently detected call type of NPRW (Crance *et al*. 2017). Altogether, these results warrant an expansion of acoustic monitoring for NPRW in the central and northern Bering Sea given that these data suggest that the current right whale critical habitat on the southeastern Bering shelf may no longer encompass the main summering range of this population. This is particularly important in light of the likely increase in transpolar ship traffic resulting from Arctic ice retreat, and the concomitant increase in the potential for ship strikes, notably at choke points such as the Bering Strait region.

Acknowledgments

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