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An unknown nocturnal call type in the Mariana Archipelago

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Abstract: In spring/summer of 2018 and 2021, the Pacific Islands Fisheries Science Center Cetacean Research Program deployed drifting acoustic recorders in the U.S. Exclusive Economic Zones surrounding the Mariana Archipelago. Manual assessments revealed a low-frequency (median 473–554 Hz), short-duration (median 0.596 s), stereotypic tonal nocturnal call throughout the Mariana Archipelago. Based on time of year, spatiotemporal patterns, clear division among calls (i.e., no chorusing), comparisons with known vocalizations of whales, turtles, and fish, and presence of Bryde's whale calls, and because the call has not been detected elsewhere, we hypothesize this 500-Hz pulsed call is produced by Bryde's whales (*Balaenoptera brydei*).

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1. Introduction

In the western Pacific Ocean sits a chain of 15 islands known as the Mariana Archipelago stretching 890 km from north to south. These islands are composed of two U.S. jurisdictions (the territory of Guam and the Commonwealth of the Northern Mariana Islands) and surrounded by extensive open waters with underwater boundaries of the Western Marina Ridge and Mariana Trench (Hill *et al.*, 2020b). The region encompasses numerous biogeographic habitats, which attract a diverse assemblage of fish, turtles, and marine mammals. There are at least 427 reef fish species in the northern islands alone (Pacific Islands Fisheries Science Center, 2010); 17 federally managed bottomfish species and 33 federally managed large pelagic species (DoN, 2005); five species of sea turtle (DoN, 2005, 2007); and an estimated 32 marine mammal species (DoN, 2005, 2007).

Despite comprising the U.S. Exclusive Economic Zones (EEZs) of Guam and the Northern Mariana Islands, where there is growing commercial and military interest, few data have been collected on cetacean presence in the region prior to 2007 (Mobley, 2007; Fulling *et al.*, 2011). In 2010, the Pacific Island Fisheries Science Center (PIFSC) began conducting visual and acoustic surveys to assess cetacean populations within the Mariana Archipelago and to evaluate potential exposure to U.S. Navy operations and other human-caused stressors.

Because visual surveys for cetaceans in the region can be difficult due to weather conditions, cost, and vessel access, passive acoustic monitoring (PAM) has provided additional opportunities to detect cetaceans year-round and when conditions are not ideal for visual surveys. PIFSC has deployed a number of PAM systems, including long-term moored hydrophones, towed arrays, and drifting buoys, which provide a year-round assessment of the cetaceans present in the region.

PIFSC's visual surveys have identified 14 cetacean species, and acoustic surveys have identified five cetacean species (Hill *et al.*, 2020b). Baleen whales visually or acoustically detected in the area include blue (*Balaenoptera musculus*), fin (*B. physalus*), humpback (*Megaptera novaeangliae*), sei (*B. borealis*), Bryde's (*B. brydei*), and minke whales (*B. acutorostrata*) (Širović *et al.*, 2013; Oleson *et al.*, 2015, Hill *et al.*, 2020b).

Here, we report on a new 500-Hz pulsed call type discovered while visually assessing acoustic data from PIFSC summer acoustic surveys across multiple years throughout the Mariana Archipelago, which we hypothesize is produced by Bryde's whales.

2. Methods

2.1 Data collection

The PIFSC Cetacean Research Program conducted the Mariana Archipelago Cetacean Survey (MACS) in the spring/summer months of 2018 and 2021 (Hill *et al.*, 2020b; Yano *et al.*, 2022). In both years, drifting acoustic spar buoy recorders

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(DASBRs) were deployed/retrieved from the NOAA R/V *Oscar Elton Sette*. In 2018, the study area included the waters between the islands and the West Mariana Ridge, from Guam to Pagan. In 2021, the study area consisted of the whole U.S. EEZ surrounding the Mariana Archipelago (Fig. 1 and Table 1). In both years, deployment locations were chosen to representatively survey the study area while minimizing the impacts to daytime survey operations. The DASBRs were retrieved when the ship was in the general vicinity of the instrument after conducting other survey efforts.

Each PIFSC DASBR consisted of a surface buoy with 150 m of line attached to an anchor creating a vertical array platform. The acoustic recording package attached at the bottom of the DASBR was a SoundTrap ST4300-HF (Ocean Instruments, Auckland, New Zealand) with two hydrophones (HTI-92 and HTI-96; High Tech, Inc., Long Beach, MS) spaced 10 m apart. For more detailed information and schematics, see McCullough *et al.* (2021).

2.2 Call detection and annotation

Each 2-min acoustic data file was decimated to 9.6 kHz using the "decimate" function in MATLAB's Signal Processing Toolbox. The 2-min files were scanned manually in Raven Pro (version 1.6.2; Cornell Lab of Ornithology, 2022) (hereafter "Raven") for the presence of the unknown call type. Each 2-min spectrogram was viewed from 0 to 1 650 Hz frequency range with the brightness set at 48 and the contrast set at 55. Any call, regardless of quality, was initially annotated. A secondary manual assessment of each 2-min file containing calls was conducted to identify files that likely had single callers based on the consistency in timing and frequency range of the calls [Fig. 2(B) and Mm. 1]. For this secondary assessment, files with less than two calls, files with overlapping calls from multiple animals [Fig. 2(B) and Mm. 2], or files where background noise masked any calls were not included.

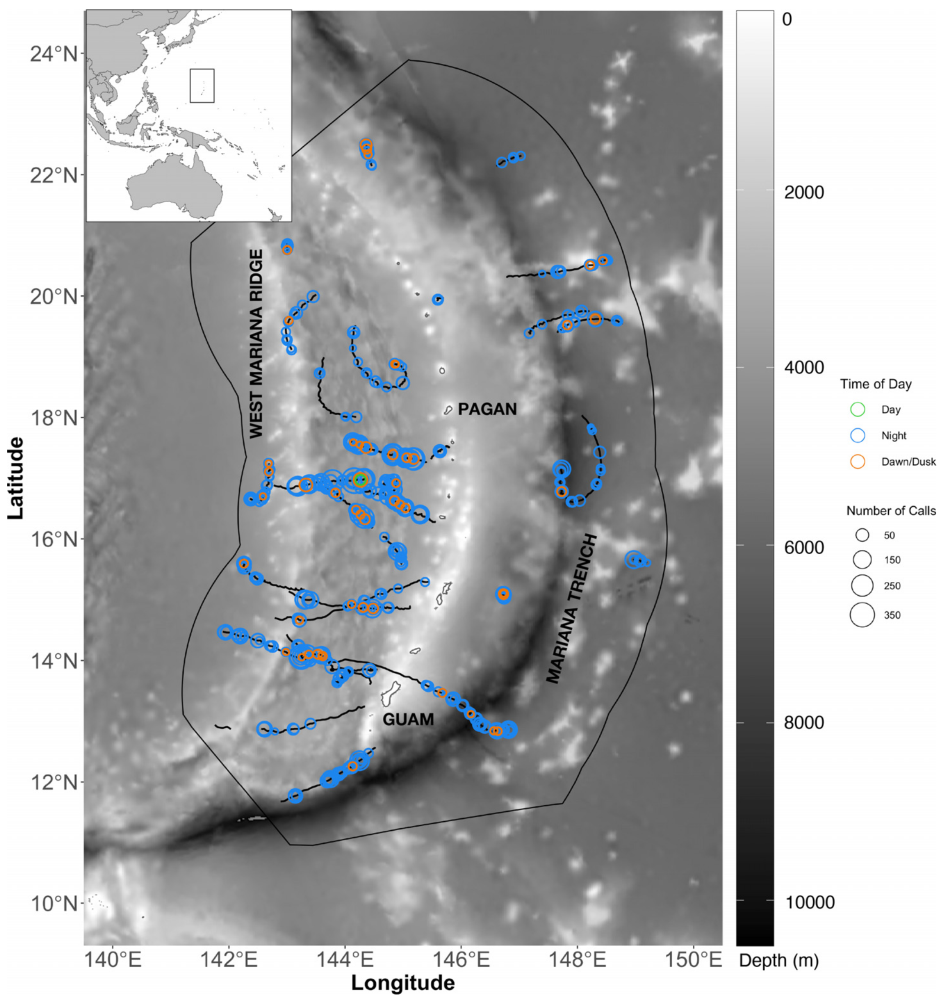

Fig. 1. Map of DASBRs drift tracks (depicted as black lines). Bathymetry is depicted in gray scale below, ranging from 0 to just over 10 000 m. Call detections are colored by time of day (day as green circles, dawn/dusk as orange circles, and night as blue circles). The number of calls paired to closest Global Positioning System (GPS) location is indicated by size of circle. Black box in the inset indicates region within the broader global region.

Table 1. Deployment and retrieval locations and dates of DASBRs during the 2018 and 2021 MACSs.

	Deployment			Retrieval			
ID	Latitude	Longitude	Time (UTC)	Latitude	Longitude	Time (UTC)	Duration (h:mm:ss)
DS1	13.60	144.43	7/09/2018 08:13:06	14.43	142.99	7/20/2018 08:43:10	264:41:59
DS2	14.90	145.13	7/09/2018 18:10:54	15.14	143.03	7/20/2018 20:49:14	266:49:30
DS3	16.29	145.54	7/11/2018 12:14:40	16.86	144.15	7/24/2018 00:26:27	275:25:38
DS4	17.26	145.40	7/12/2018 14:34:54	17.63	144.09	7/24/2018 05:58:33	279:50:49
DS5	16.98	144.38	7/14/2018 16:12:47	16.88	142.77	7/22/2018 20:50:37	208:14:27
DS6	16.17	144.47	7/15/2018 06:47:55	16.89	143.65	7/23/2018 20:48:10	206:11:07
DS7	13.24	144.36	7/18/2018 09:12:23	12.88	142.55	7/27/2018 02:33:13	209:32:21
DS8	15.58	144.98	7/21/2018 09:04:31	16.04	144.65	7/25/2018 19:37:05	107:06:16
DS1	13.85	144.56	5/03/2021 08:47:28	14.67	143.67	5/28/2021 12:00:43	285:19:09
DS2	15.31	145.45	5/04/2021 01:03:44	14.71	142.78	5/14/2021 06:42:29	246:06:16
DS3	17.31	145.47	5/06/2021 08:43:05	17.52	145.79	5/11/2021 06:41:27	118:40:15
DS4	19.53	144.18	5/08/2021 19:56:40	18.87	144.86	5/25/2021 12:47:02	389:03:37
DS5	16.64	144.78	5/11/2021 20:04:47	16.78	144.82	5/25/2021 06:52:10	335:14:40
DS6	15.17	143.31	5/12/2021 10:20:31	15.71	142.24	5/26/2021 21:32:12	347:22:16
DS7	16.66	142.38	5/16/2021 10:24:46	17.24	142.68	5/26/2021 10:31:17	240:41:07
DS8	18.99	143.64	5/17/2021 09:45:45	18.01	144.20	5/25/2021 10:46:17	193:14:18
DS9	20.03	143.50	5/18/2021 10:53:11	19.11	143.08	5/24/2021 11:41:55	145:02:08
DS10	22.14	144.47	5/19/2021 10:09:51	22.49	144.36	5/23/2021 10:34:47	96:57:31
DS11	20.71	143.01	5/20/2021 19:47:17	20.88	142.99	5/23/2021 23:08:58	75:45:53
DS12	12.88	142.04	5/27/2021 19:39:07	12.94	141.76	5/29/2021 08:21:22	36:53:12
DS13	12.57	144.52	6/15/2021 11:26:47	11.67	142.89	6/24/2021 11:35:57	216:28:06
DS14	12.85	146.84	6/17/2021 11:04:46	14.48	141.88	7/11/2021 20:11:07	585:24:22
DS15	15.67	148.97	6/19/2021 12:30:20	15.61	149.21	6/21/2021 11:11:33	47:01:31
DS16	15.07	146.74	6/20/2021 09:59:11	15.05	146.74	6/26/2021 8:46:34	142:57:04
DS17	17.15	147.73	6/27/2021 09:53:15	18.07	148.05	7/08/2021 08:33:12	262:58:42
DS18	19.39	147.65	6/29/2021 05:03:29	19.55	148.78	7/07/2021 06:54:30	196:27:36
DS19	19.39	147.15	6/29/2021 12:01:39	19.76	148.22	7/07/2021 02:56:37	183:13:38
DS20	20.31	146.77	6/29/2021 19:46:49	20.59	148.52	7/06/2021 18:51:00	167:13:43
DS21	22.31	147.04	6/30/2021 15:16:53	22.15	146.59	7/03/2021 03:23:02	60:17:49
DS22	19.92	145.57	7/04/2021 02:32:48	19.98	145.73	7/05/2021 11:06:00	32:42:43

Mm. 1. Audio file of likely single animal calling. This is a file of type "wav" (2.3 MB).

Mm. 2. Audio file of likely multiple animals engaged in calling. This is a file of type "wav" (2.3 MB).

2.3 Call characterization

Raven was used to extract a number of call metrics including duration (s), low frequency (Hz), high frequency (Hz), center frequency (Hz), peak frequency (Hz), delta frequency (Hz), and signal-to-noise ratio (SNR; dB). Raven uses a "quick" estimation method, a National Institute of Standards and Technology (NIST) SNR algorithm that compares a signal (the 85th percentile) to noise (the 15th percentile) of a root mean square (rms) power histogram computed over the entire file. The SNR was used to create a cutoff so that only relatively high-quality calls were characterized. To ensure robust call characterizations, only those above a 10% SNR were retained. Inter-call intervals (ICIs) were calculated for each 2-min wav file containing calls (including files with likely multiple animals) and also for the subset of files identified in the secondary manual assessment as containing likely single-calling animals. Histograms of both assessments were created in R (version 4.2.0; R Core Team, 2021) using the "ggplot2" package (version 3.3.6; Wickham, 2016) using ETOPO1 bathymetry from the "marmap" package (version 1.0.6; Pante and Simon-Bouhet, 2013).

2.4 Ancillary information

The buoy attached to each drift contained an Iridium satellite tracker (NAL 9602-AB; NAL Research, Manassas, VA) that provided GPS location at programmed time intervals (typically every 2 h). GPS locations greater than 2 h were linearly interpolated using the "sula" package (version 1.0.1; Lerma 2021). Each call was matched to the closest drift GPS position

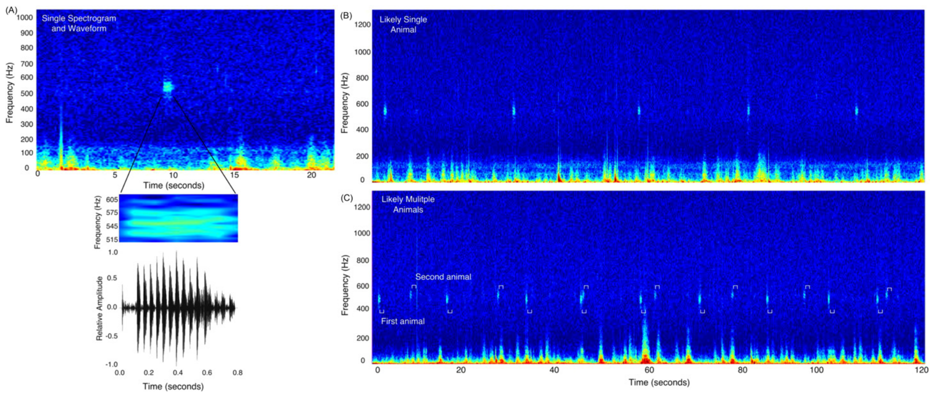

Fig. 2. (A) Spectrogram (shown zoomed out and zoomed in) and waveform of single 500-Hz pulsed call detected on drifting acoustic spar buoy recorders. (B) Example of likely single animal calling based on consistency (e.g., inter-call interval) and similarity of call characteristics (e.g., min, max, and delta frequency). (C) Example of likely multiple animals engaged in calling based on the differences in consistency and similarity of call characteristics between the two calling animals.

using a rolling join based on nearest datetime with the "data.table" package (version 1.14.2; Dowle and Srinivasan, 2021). Time of day was assigned based on the time of each call using the "maptools" package (version 1.1-4; Bivand and Lewin-Kon, 2021). "Day" and "night" were assigned to calls based on the timing of sunrise and sunset, respectively. "Dawn" and "dusk" were assigned to calls based on the angle of the sun above or below the horizon. We used nautical dawn and dusk (above and below 12°) and combined dawn and dusk into one classification for simplicity of analyses. All numerical data manipulation, plotting, and analyses were conducted in R.

3. Results

3.1 Call detection and annotation summary

There were 1800 h of acoustic data collected in 2018 and 4405 h of acoustic data collected in 2021. A total of 17 921 500-Hz pulsed calls were detected in 2018 and 2021. Of those, 11 439 were detected in 2018, and 6482 were detected in 2021. Calls were detected on every drift except one in 2021, which was the shortest deployment of all the drifts recording for <8 h of total duty-cycled data (spanning a 36-h period). After applying the SNR cutoff, 16 116 calls were retained for call metric extraction (10 710 from 2018 and 5406 from 2021). The secondary manual assessment to annotate likely single-calling animals identified 333 2-min files and 1567 calls.

3.2 Call description

The pulsed call is a low-frequency, short duration, stereotypic, tonal call with median frequencies between 473 and 554 Hz [Fig. 2(A) and Table 2]. The ICI histogram of all 2-min wav files containing calls (including files with likely multiple calling animals) displayed a bi-modal distribution with two peaks: one at 9 s and one at 22 s [Fig. 3(A) in color]. The slight peak at 0–1 s was due to animals calling at or near the same time as one another. The ICI histogram from the subset of files identified in the secondary manual assessment as containing likely single-calling animals [Fig. 3(A) in gray] revealed a strong cutoff at 9 s and broader ICI peak ranging from 18 to 31 s.

Table 2. Pulsed call metric summary for each project (MACS 2018 and MACS 2021) and all calls combined. Metrics include median [10th, 90th percentiles] duration of call (s), low frequency (Hz), high frequency (Hz), center frequency (Hz), peak frequency (Hz), delta frequency (Hz), and signal-to-noise ratio (dB).

Project	Duration (s)	Low frequency (Hz)	High frequency (Hz)	Center frequency (Hz)	Peak frequency (Hz)	Delta frequency (Hz)	Signal-to-noise ratio (dB)
MACS 2018	0.564	476	557	511	511	80.8	14.3
($n = 10\,710$)	[0.430, 0.703]	[440, 516]	[523, 601]	[480, 553]	[476, 553]	[63.6, 103]	[12.1, 17.4]
MACS 2021	0.675	467	549	506	502	80.4	13.2
($n = 5406$)	[0.525, 0.837]	[434, 505]	[511, 589]	[471, 544]	[469, 544]	[64.1, 101]	[11.6, 15.8]
Overall	0.596	473	554	509	506	80.8	13.9
($n = 16\,116$)	[0.453, 0.764]	[438, 513]	[519, 597]	[476, 548]	[473, 551]	[63.9, 102]	[11.9, 16.9]

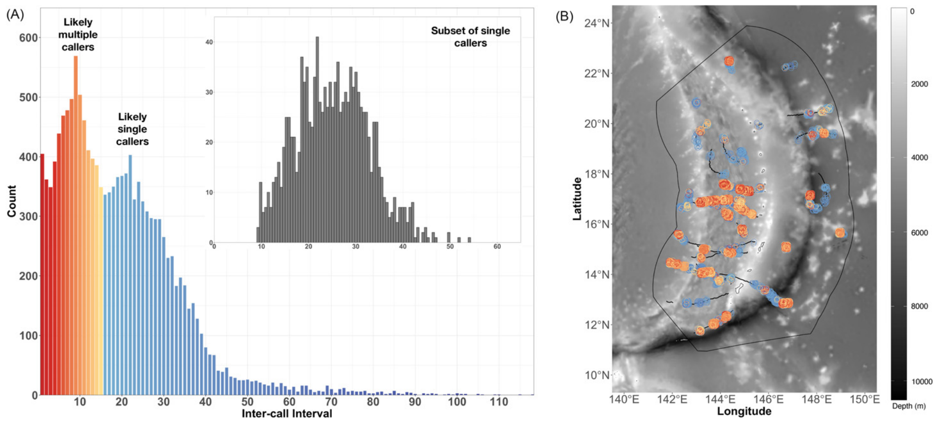

Fig. 3. (A) Histogram of ICIs for all 2-min wav files containing pulsed calls (including files with likely multiple calling animals) colored by natural break in bi-modal distribution. A gradient of red to yellow represents ICIs <15 s, and a gradient of light to dark blue indicates ICIs >15 s. Shown is a histogram of ICIs from the subset of files identified in the secondary manual assessment as containing likely single-calling animals in the top right corner (gray bars). (B) Map of calls colored by ICIs [same ICI colors as in Fig. 3(A)]. Drift tracks are depicted as black lines. Bathymetry is depicted in gray scale below ranging from 0 to just over 10 000 m.

3.3 Temporal patterns

Calls were detected across all months of the DASBR deployments in 2018 (July only) and 2021 (May–July). Roughly 11.7% ($n = 2\,100$) of calls occurred in May, 17.6% ($n = 3\,160$) occurred in June, and 70.6% ($n = 12\,661$) occurred in July. More calls were detected in 2018 (64%, $n = 11\,439$) compared to 2021 (36%, $n = 6\,482$). Recording effort was consistent across all hours of the day. Nearly all of the calls—15 748 (97.7%)—occurred during the nighttime (Figs. 1 and 4). The nighttime calls peaked at 20:00 local time ($n = 3\,491$; 19.5%), followed by 21:00 ($n = 3\,003$; 16.8%). 353 calls (2.2%) occurred during dawn and dusk, while 15 calls (<0.1%) occurred during the day (immediately after dawn). All early daytime calls occurred on one day during a new moon.

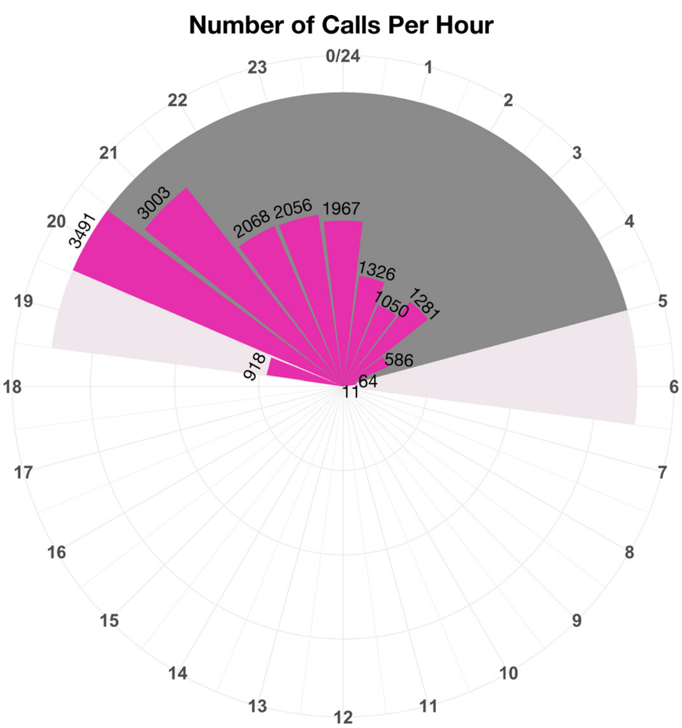

Fig. 4. (A) Polar plot displaying number of calls per hour (dark pink bars). Total number of calls is indicated on top of each bar. Light gray indicates dawn/dusk, and dark gray indicates nighttime.

3.4 Spatial patterns

The pulsed calls were detected throughout the U.S. EEZ around the Mariana Archipelago [Figs. 1 and 3(B)]. There was no relationship between call occurrence and bathymetry. The bathymetry in the regions where the calls were detected ranged from 951 to 9676 m with a median bathymetry of 3851 m [confidence interval (CI) 3056–5403 m]. Calls spanned mesopelagic to bathypelagic habitats, predominantly over abyssal and hadal zones, whose geomorphic features include submarine canyons, basins, slopes, troughs, trenches, ridges, spreading ridges, rift valleys, and seamounts.

4. Discussion

The call appears to be solely nocturnal. Ninety-eight percent of calls occurred during the nighttime, with a small number during dawn/dusk and even fewer during the day. The daytime calls occurred once during a new moon when the morning sky would have been darker than usual. The dawn/dusk and day calls had lower ICIs (60% were <15 s). These calls were spatially associated with low ICI call bouts [Fig. 3(B)], suggesting that the rare dawn/dusk and daytime calls only occur when multiple animals are around.

During periods when there was likely only a single caller present [e.g., Fig. 2(B) and Mm. 1], the calls were consistent in ICI and frequency characteristics. When there were likely multiple callers present [e.g., Fig. 2(C) and Mm. 2], individuals could be detected based on the characteristics of their calls, which were similar but distinct from other callers. In some recordings, at least four individuals could be identified. The calls of multiple callers continued in the presence of increased signal-to-noise ratio during storm events. Without confirmation of the species and information about the individuals producing the pulsed calls, we cannot yet hypothesize the nature of the calls (e.g., contact call, reproductive-related, etc.). It is possible single-calling individuals may be broadcasting their presence or trying to locate individuals from a distance in the nighttime, which could result in multiple animals calling.

The call could hypothetically belong to a species of odontocete, mysticete, sea turtle, or fish. The low-frequency, stereotypic nature of the call suggests that it is unlikely to be an odontocete. The call does not resemble the only recorded underwater vocalization of any sea turtle (*Chelonia mydas*; Charrier *et al.*, 2022). The calls span many habitats and geomorphological regions, suggesting it is not a soniferous fish species, which are more typically associated with nearshore kelp (e.g., Butler *et al.*, 2021) or reef (e.g., McWilliam *et al.*, 2017) habitats. Although the frequency range falls within those capable of fish, the calls never developed into chorusing, which would be more indicative of fish behavior (e.g., Cato, 1978). Baleen whales remain the likely culprit.

Baleen whales produce vocalization in both day and nighttime. However, some whales increase certain call types at night, likely related to mating, territory defense, foraging, sensing the environment, or a combination of these functions (Stafford and Moore, 2005; Wiggins *et al.*, 2005; Munger *et al.*, 2008). Calls were detected May–July with the majority occurring in July. Although acoustic data have not been evaluated outside of these months for this call type, the temporal occurrence can be used to rule out certain migratory species described below.

The Mariana Archipelago is a wintering area for western North Pacific humpback whales (Hill *et al.*, 2020a) from December to April, and they are not present during summer months. Sei whales are likely to be feeding in subpolar higher latitudes in the summer (Horwood, 2009), and the call does not match any known calls, especially calls attributed to sei whales in the Navy's Mariana Islands Range Complex (Rankin and Barlow, 2007; Norris, 2012). Fin and blue whales are rare in the region (Oleson *et al.*, 2015), and fin whales are not likely to be present at all in the summer (Hill *et al.*, 2020b). Additionally, the call is dissimilar to any globally known fin whale (Širović *et al.*, 2013; Archer *et al.*, 2019) or blue whale calls (McDonald *et al.*, 2006; Širović and Oleson, 2022). Minke whales are not as migratory in the western North Pacific (Horwood, 1990), so it is possible they are present in the Mariana Islands in summer months. However, minke whales are rare (Hill *et al.*, 2020b), and the call is unlike any known minke whale calls (Rankin and Barlow, 2005; Risch *et al.*, 2019).

The calls sometimes co-occurred with the biotwang (Allen *et al.*, 2022) and croak-like calls attributed to Bryde's whales (Edds, 1993). Bryde's whales are also likely present year-round in the region (Hill *et al.*, 2020b; Tepp *et al.*, 2021). Additionally, there were also more visual sightings of Bryde's whales in 2018, which coincided with an increased number of pulsed calls. Thus, we hypothesize that the calls belong to Bryde's whale.

The call was not similar to any other calls described for eastern Pacific Bryde's whales (e.g., Heimlich *et al.*, 2005; Oleson *et al.*, 2003). This suggests the call is regional to the Mariana Archipelago. A review of High-frequency Acoustic Recording Packages (HARP) data from Saipan, Pagan, Tinian, and Palmyra (visually scanning 12- or 24-h long term spectral averages at 2 kHz) only detected the call in one deployment in Saipan on May 31, 2017, during the nighttime (18:30–6:00 local time). This provides further evidence of both a nocturnal call and a call type specific to this particular region.

Given the stereotypic nature of the call, the next step is to develop a call detector that can be used to assess the longer-duration HARP data more thoroughly as well as other DASBR deployments in the Mariana Islands and also around Hawaii. Acoustic tagging or triangulation may also identify the source of the call.

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