An Acoustic Survey in the Main Hawaiian Islands Using Drifting Recorders

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Executive Summary

During the 2017 Hawaiian Islands Cetacean and Ecosystem Assessment Survey (HICEAS), 19 drifting hydrophone recorders were deployed around the main Hawaiian Islands with the goal of improving detection of beaked whales and *Kogia*. These Drifting Acoustic Spar Buoy Recorders (DASBRs) contained a two-element vertical hydrophone array at 150 m depth, sampling at 288 kHz for 2 of every 10 min. Deployment locations were planned to cover a 50 nmi minimum convex polygon around the main Hawaiian Islands (MHI Stratum). In actuality, DASBRs drifted significantly within the MHI Stratum and up to 200 nmi beyond. Overall, the DASBRs collected data over a 96-day period and over 6,354 km of drifting track. Using the Click Detector Module within PAMGuard (version 2.00.11), cetacean echolocation pulses within 2-min periods were classified to species based on peak frequency and other pulse characteristics. We found frequency modulated (FM) pulses characteristic of Longman's, Cuvier's, Blainville's, and Cross Seamount beaked whales (BWC) in 928 of the 2-min files, spread along the drift track of each DASBR. Additionally, two types of *Kogia* spp. echolocation clicks were detected with peak frequencies of 116 kHz and 123 kHz. To further improve detections of *Kogia* spp. echolocation clicks, custom MATLAB subroutines were used to re-analyze the recordings in greater detail resulting in 60 2-min detections versus the original 13 detected with these PAMGuard classifiers. Detections of sperm whales (in 2,809 2-min files) and echolocation from unidentified odontocetes (in 3,939 2-min files) were also identified. Acoustic detections of beaked whales and *Kogia* spp. were much more numerous than those from the towed array efforts during HICEAS 2017 and will enhance understanding of the distribution of these species in the main Hawaiian Islands.

Introduction

Passive acoustic monitoring for cetaceans during abundance surveys has become a valued component of the study of cryptic species that have long dive times and/or very limited surface behavior (Henry et al. 2020; Keating et al. 2018; Yano et al. 2018). Several cetacean species can be identified based on their acoustic features alone, making them good candidates for autonomous passive acoustic studies. This is especially true for deep-diving species, including sperm whales (Backus and Schevill 1966) and most beaked whale species (Baumann-Pickering et al. 2013, 2014), while *Kogia* spp. can be identified to the genus level (Marten 2000; Merkens et al. 2018).

Of the echolocation signals beaked whales produce, their frequency-modulated (FM) pulse is identifiable to species level classification (Baumann-Pickering et al. 2013, 2014). To date there have been four species of beaked whales acoustically detected in the Hawaiian Islands. These include Cuvier's beaked whale (*Ziphius cavirostris*), Blainville's beaked whale (*Mesoplodon densirostris*), Longman's beaked whale (*Indopacetus pacificus*), and "BWC." BWC, known as the Cross Seamount beaked whale, is an unidentified beaked whale FM pulse that is thought be produced by the ginkgo-toothed beaked whale (*Mesoplodon ginkgodens*) based on size and stranding records for the region (Baumann-Pickering et al. 2014; McDonald et al. 2009).

While towed hydrophone arrays have been used for ship-based acoustic monitoring during cetacean surveys for many decades, their near-surface location and high levels of flow noise limit detection for some species, including deep-divers. In contrast, Drifting Acoustic Spar Buoy Recorders (DASBRs) developed at the Southwest Fisheries Science Center (SWFSC) (Griffiths and Barlow 2015, 2016) have hydrophones placed deeper in the water column, lack continuous ship and flow noise, and monitor a broad frequency range. These free-floating autonomous recording units can record species ranging from baleen whales to dolphins and detect animals that might behaviorally avoid a large survey vessel. We deployed 19 DASBRs during the Hawaiian Islands Cetacean and Ecosystem Assessment Survey (HICEAS) in 2017 (Yano et al. 2018). The DASBRs were configured to optimize detection and localization of deep-diving species such as beaked whales and *Kogia* spp. (dwarf and pygmy sperm whales).

Methods

Data Collection

The Pacific Islands Fisheries Science Center (PIFSC) and SWFSC collaborated to conduct the Hawaiian Islands Cetacean and Ecosystem Assessment Survey (HICEAS) from July 6th to December 1st, 2017, aboard NOAA Ships *Oscar Elton Sette* and *Rueben Lasker* (Yano et al. 2018). DASBRs were deployed in the portion of the survey conducted in main Hawaiian Islands waters during the first three months of the survey effort.

DASBRs used for deployment during HICEAS were based on a design deployed during the SWFSC's Passive Acoustics Survey of Cetacean Abundance Levels (PASCAL) (Keating et al. 2018; Figure 1) and modified to increase stability while drifting. Modifications consisted of an expanded diameter spar buoy, use of an NAL Research Iridium transmitter (www.nalresearch.com) (Yano et al. 2018), relocation of the dampener plate to the base of the bungee cord, additional subsurface float, 50 m extension of ¼" nylon main line, and increased anchor weight. The vertical array of two hydrophones spaced 10 m apart consisted of either two HTI-96-min hydrophones or an HTI-92-WB/96-min combination with the HTI-92-WB being closer to the ocean surface (High Tech, Inc., Long Beach, MS). Acoustic recordings were collected on a SoundTrap ST4300 (Ocean Instruments, Auckland, NZ) or a SM3M recorder (Wildlife Acoustics, Maynard, MA). The ST4300s were duty cycled to record 2 out of every 10 minutes, at a sampling rate of 288 kHz, and SM3Ms continuously recorded at a 256 kHz sampling rate.

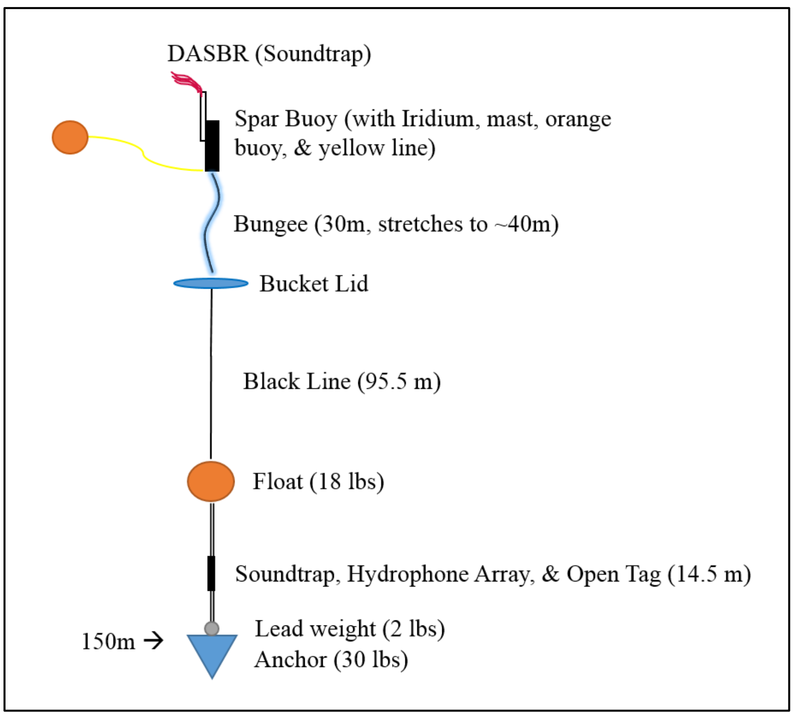

Figure 1: Drifting Acoustic Spar Buoy Recorder (DASBR) schematic.

Detection and Classification

Echolocation signals from beaked whales, *Kogia* spp., sperm whales, and unidentified odontocetes were identified within the acoustic data using the click detector module (IIR Butterworth 2 kHz high pass filter) within PAMGuard software v. 2.00.11c (Gillespie et al. 2009) with custom specifications based on peak frequency (Keating and Barlow 2013). Spectral and temporal characteristics of the echolocation signals were used to manually classify the signals as *Kogia* spp., sperm whale, or the individual beaked whale species (Backus and Schevill 1966; Baumann-Pickering et al. 2013, 2014; Keating et al. 2016, Marten 2000; Merkens et al. 2018). To further improve detections of *Kogia* spp. echolocation clicks, custom MATLAB functions were used to analyze the recordings in greater detail. Echolocation signals from beaked whales and *Kogia* spp. were aggregated into "acoustic encounters" to avoid oversampling for encounter duration analysis (McCullough et al. Submitted). Acoustic encounters were the combination of adjacent 2-min data periods with gaps in detections of less than 15 minutes. Due to the duty cycled data collection, it is not possible to examine the specific start and stop time of each acoustic encounter as echolocation signals may have begun or ended during a period with no recording, resulting in acoustic encounter duration lasting 0–11 additional minutes.

Results

Data Collection

Nineteen DASBRs were deployed within the main Hawaiian Island (MHI) Stratum portion of the HICEAS survey effort; six were lost at sea due to equipment failure, transmission failure, or loss of data recorder. The 13 recovered DASBR units traveled a total of 6,354 km over a 96-day period (19-day average) and cumulatively collected 6,017 hours (251 days) of acoustic data (Table 1, Figure 2). DASBRs drifted significantly within the MHI Stratum and up to 200 nmi beyond. All of the recovered units contained the ST4300 recording packages; all the SM3M recorders were lost. In addition, all but one of the DASBR datasets used in analysis used the HTI-92/96 hydrophone combination. DASBR Station 4 (DS4) recorded with two HTI-96 hydrophones.

Table 1. DASBR deployment and retrieval locations.

	DEPLOYMENT			RETRIEVAL			
ID	**LAT**	**LON**	**Time (UTC)**	**LAT**	**LON**	**Time (UTC)**	**Duration (h:mm:ss)**
DS0	21.29	−160.33	7/07/2017 12:26:09	--	--	--	--
DS1	20.52	−158.87	7/08/2017 15:46:19	--	--	--	--
DS2	20.65	−157.77	7/09/2017 04:18:27	--	--	--	--
DS3	19.56	−156.62	7/12/2017 12:23:02	20.87	−160.54	7/29/2017 14:27:30	410:04:28
DS4	19.82	−154.56	7/14/2017 20:58:37	20.83	−154.86	8/01/2017 07:11:59	418:13:22
DS5	20.98	−155.84	7/15/2017 09:38:55	--	--	--	--
DS6	21.89	−157.07	7/15/2017 23:24:30	23.85	−158.65	8/11/2017 08:52:17	532:33:20
DS7	21.99	−158.83	7/17/2017 05:35:23	21.13	−161.55	7/29/2017 07:39:22	290:03:59
DS8	20.97	−158.10	8/08/2017 19:37:09	21.99	−165.03	9/24/2017 07:22:25	522:26:53
DS9	20.23	−156.82	8/09/2017 06:02:03	18.19	−158.50	9/01/2017 12:48:19	558:36:16
DS10	20.20	−155.15	8/09/2017 16:34:15	19.98	−155.04	8/27/2017 07:06:08	422:31:53
DS11	21.61	−157.08	8/10/2017 09:07:01	24.43	−156.99	8/30/2017 16:21:18	487:14:17
DS12	22.12	−158.37	8/10/2017 21:27:09	25.26	−156.88	8/30/2017 08:21:25	466:54:16
DS13	21.60	−159.79	8/11/2017 20:40:00	20.51	−164.90	9/23/2017 15:25:47	--
DS14	20.89	−155.84	9/02/2017 07:22:17	20.53	−154.08	9/13/2017 07:19:32	263:57:15
DS15	20.83	−157.16	9/03/2017 16:07:42	17.73	-158.47	10/08/2017 10:00:11	550:36:35
DS16	21.11	−157.65	9/11/2017 14:44:42	--	--	--	--
DS17	21.37	−157.41	9/11/2017 17:39:20	21.11	−157.95	10/09/2017 07:12:14	554:49:22
DS18	22.27	−159.77	9/12/2017 19:13:10	22.67	−160.56	10/07/2017 08:29:36	539:11:20

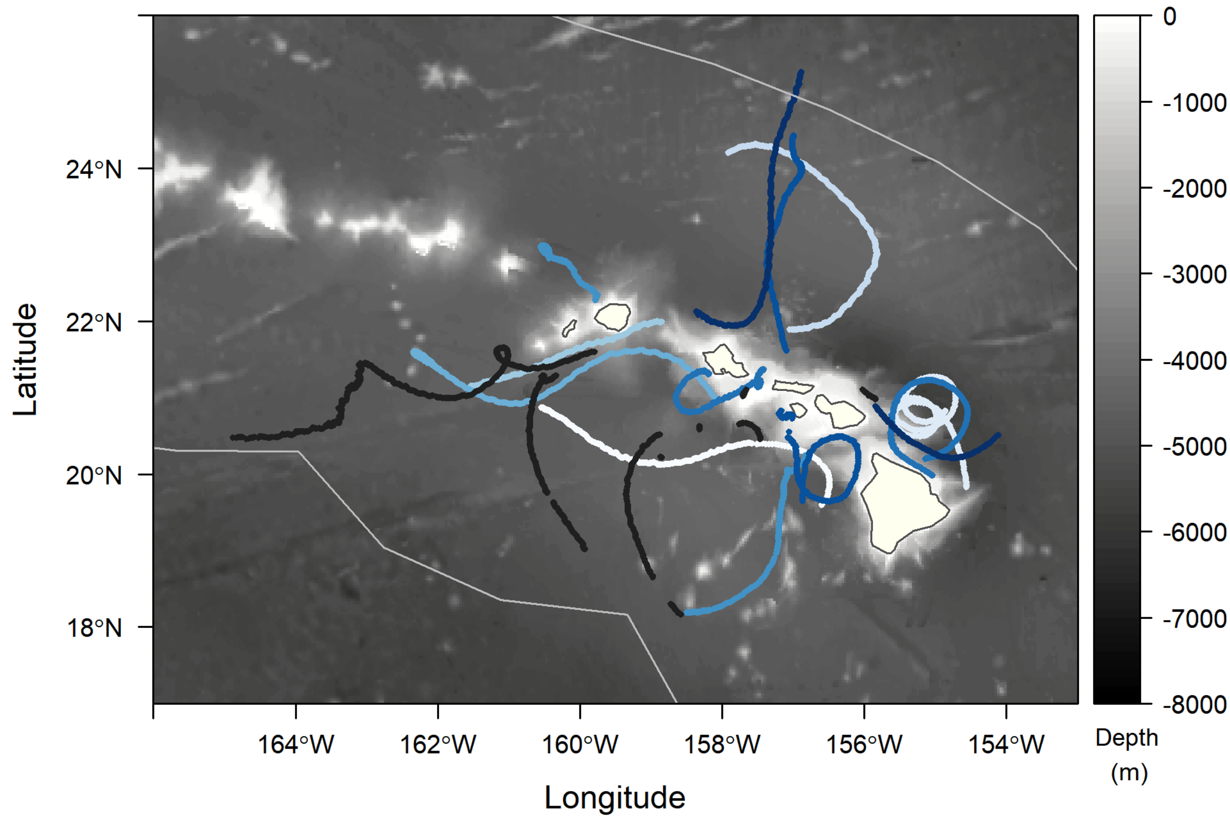

Figure 2. Bathymetric map of the main Hawaiian Islands with DASBR tracks in various shades of blue to show individual drifts. Black tracklines are for those recording units that were not retrieved. Gray lines indicate the boundary of the Hawaii Exclusive Economic Zone. Bathymetry pulled from R-package 'marmap' (Pante and Simon-Bouhet 2013; R Core Team 2020).

Detection and Classification

Detections of echolocation signals from odontocetes were present in 7,736 of the 36,317 2-min recording files (21%; Table 2). Beaked whale and *Kogia* spp. detections were further aggregated across consecutive 2-min acoustic files into acoustic encounters. Detections of sperm whales and unidentified odontocetes have not been aggregated into acoustic encounters as doing so requires integration of additional information about species behavior.

Table 2. Acoustic detections of cetaceans. Counts consist of the number of 2-min files with detection of a given species. The number of acoustic encounters represents the aggregated 2-min files that were binned together to represent dive-cycles. Median encounter duration is provided with 10th and 90th percentiles in parentheses. Sperm whales and unidentified odontocetes were only identified as present/absent in the 2-min files with no further analyses.

SPECIES		COUNTS		
Scientific Name	Common Name	2-min Files	Acoustic Encounters	Encounter Duration (min)
Mesoplodon densirostris	Blainville's beaked whale	518	289	1.95 (0.09, 21.74)
Ziphius cavirostris	Cuvier's beaked whale	201	126	1.55 (0.05, 20.23)
Indopacetus pacificus	Longman's beaked whale	121	43	11.53 (0.30, 31.98)
--	BWC	84	55	1.85 (0.02, 19.71)
Kogia spp.	Dwarf & pygmy sperm whale	60	42	1.49 (0.05, 11.86)
--	Unknown beaked whale	4	4	1.58 (0.53, 1.82)
Physeter macrocephalus	Sperm whale	2,809	--	--
--	Unidentified odontocete	3,939	--	--

Beaked Whales

Of the 2-min recording files, 3% (928) contained acoustic detections of one of the four species of beaked whales (Blainville's, Cuvier's, Longmans, BWC) (Table 2, Figures 3–7). There were four detections of frequency modulate (FM) pulses, with insufficient signal quality to differentiate between Blainville's or Cuvier's beaked whales. Beaked whales were detected on all DASBR drifts. Most acoustic encounters spanned more than one 2-min recording period, resulting in 516 encounters of beaked whales; 80% were classified as Blainville's or Cuvier's.

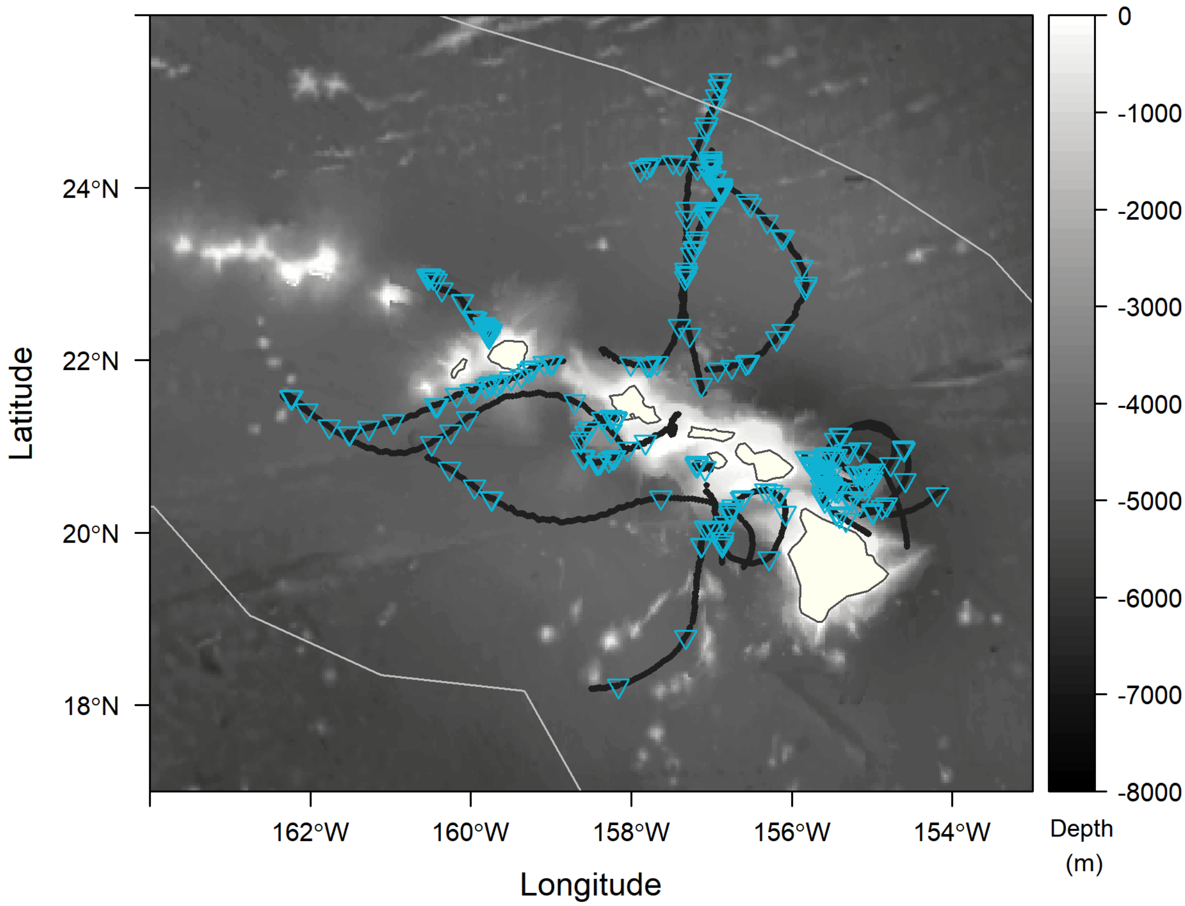

Figure 3. Locations of Blainville's beaked whale acoustic detections (2-min files) shown as blue downward triangles. DASBR tracks are shown as bold black lines. Gray lines indicate the boundary of the Hawaii Exclusive Economic Zone.

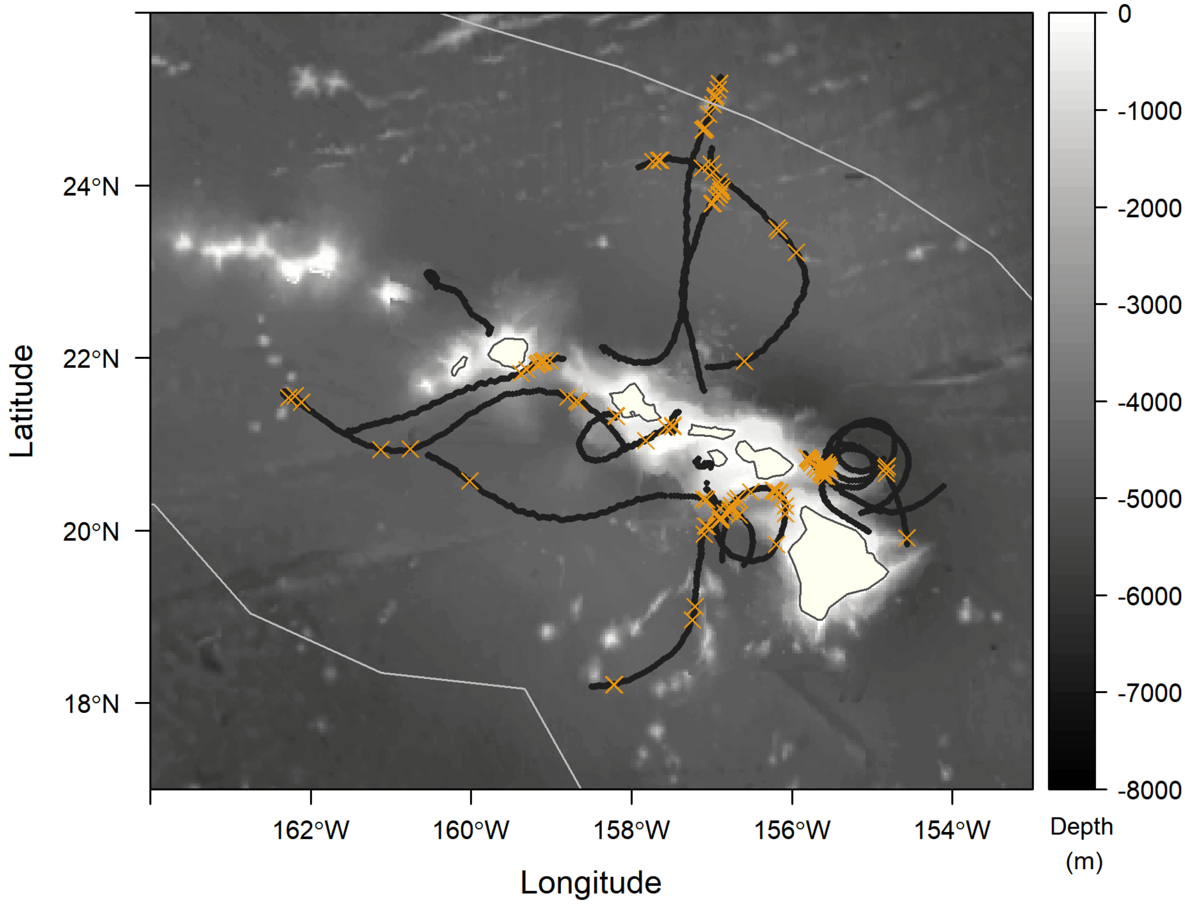

Figure 4. Locations of Cuvier's beaked whale acoustic detections (2-min files) shown as orange "x". DASBR tracks are shown as bold black lines. Gray lines indicate the boundary of the Hawaii Exclusive Economic Zone.

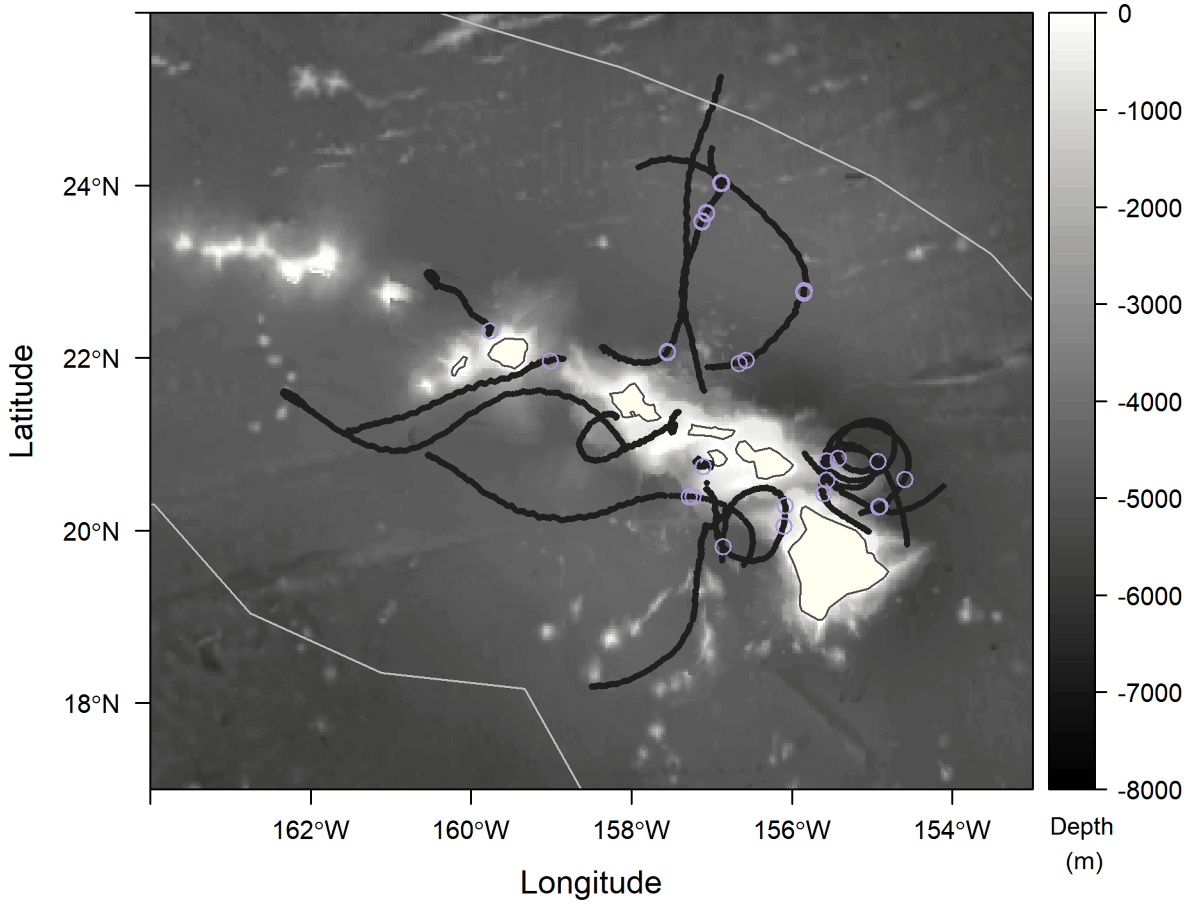

Figure 5. Locations of Longman's beaked whale acoustic detections (2-min files) shown as purple circles. DASBR tracks are shown as bold black lines. Gray lines indicate the boundary of the Hawaii Exclusive Economic Zone.

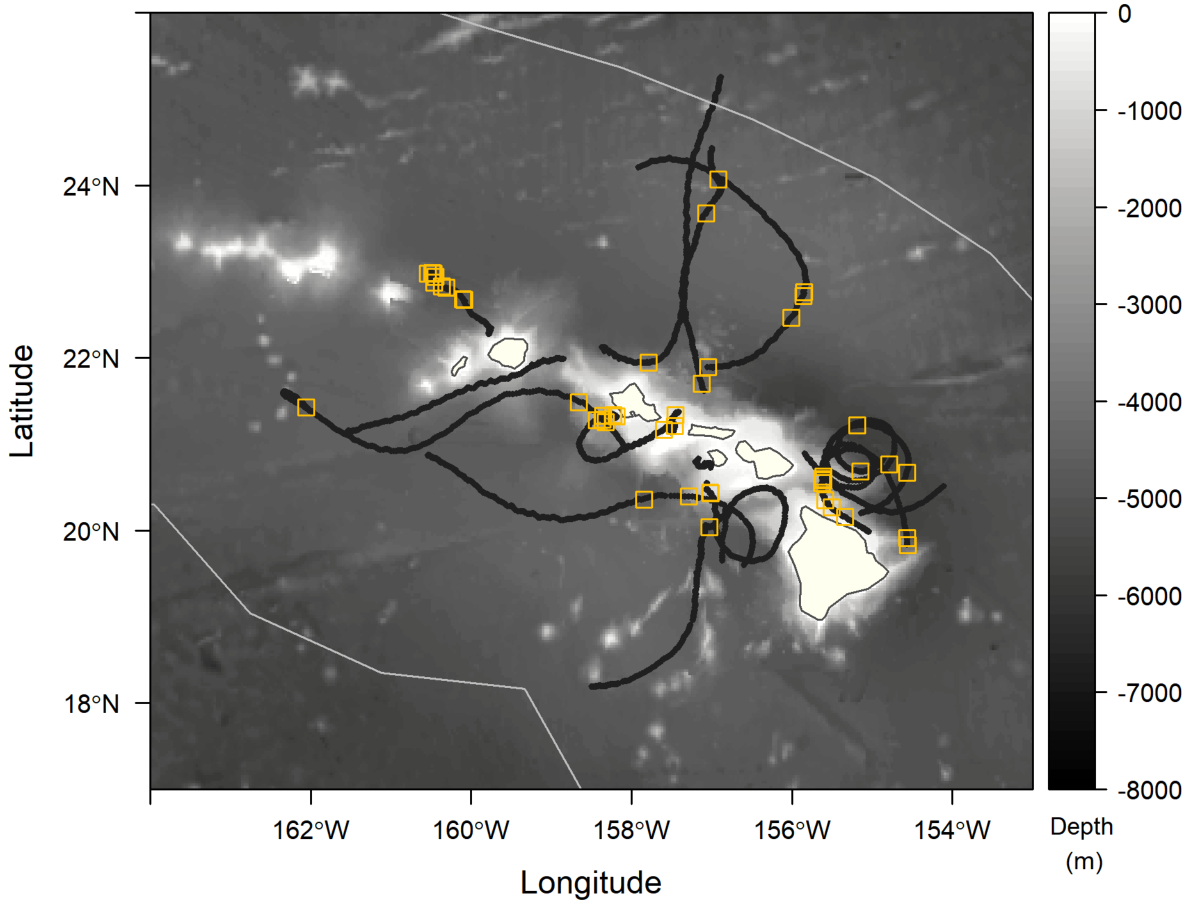

Figure 6. Locations of BWC beaked whale acoustic detections (2-min files) shown as yellow squares. DASBR tracks are shown as bold black lines. Gray lines indicate the boundary of the Hawaii Exclusive Economic Zone.

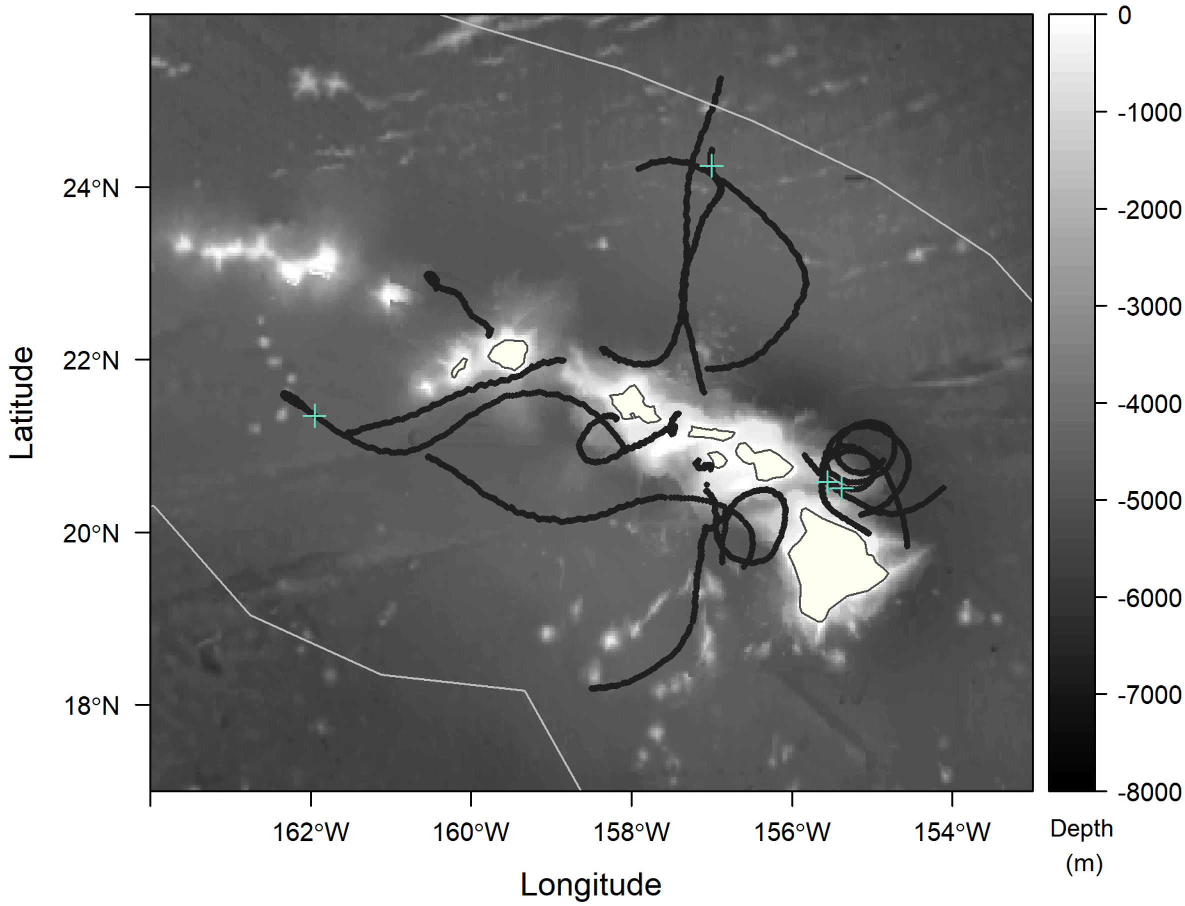

Figure 7. Locations of unknown beaked whale acoustic detections (2-min files) shown as teal crosses. DASBR tracks are shown as bold black lines. Gray lines indicate the boundary of the Hawaii Exclusive Economic Zone.

Acoustic detections of beaked whales varied based on the time of day. Blainville's and Cuvier's beaked whales were detected at all hours of day and night, with a slight increase in the detection rate of Blainville's beaked whales during the day (Figure 8). Detections of BWC and Longman's beaked whales appear to have a daily pattern to their occurrence, with no detections of Longman's beaked whales during the afternoon (Figure 8D), and most detections of BWC during the night. Previous studies have noted a strong nocturnal pattern in the detection of BWC (McDonald et al. 2009), though our data indicate continued echolocation activity into the morning hours during some drift tracks (Figure 8C).

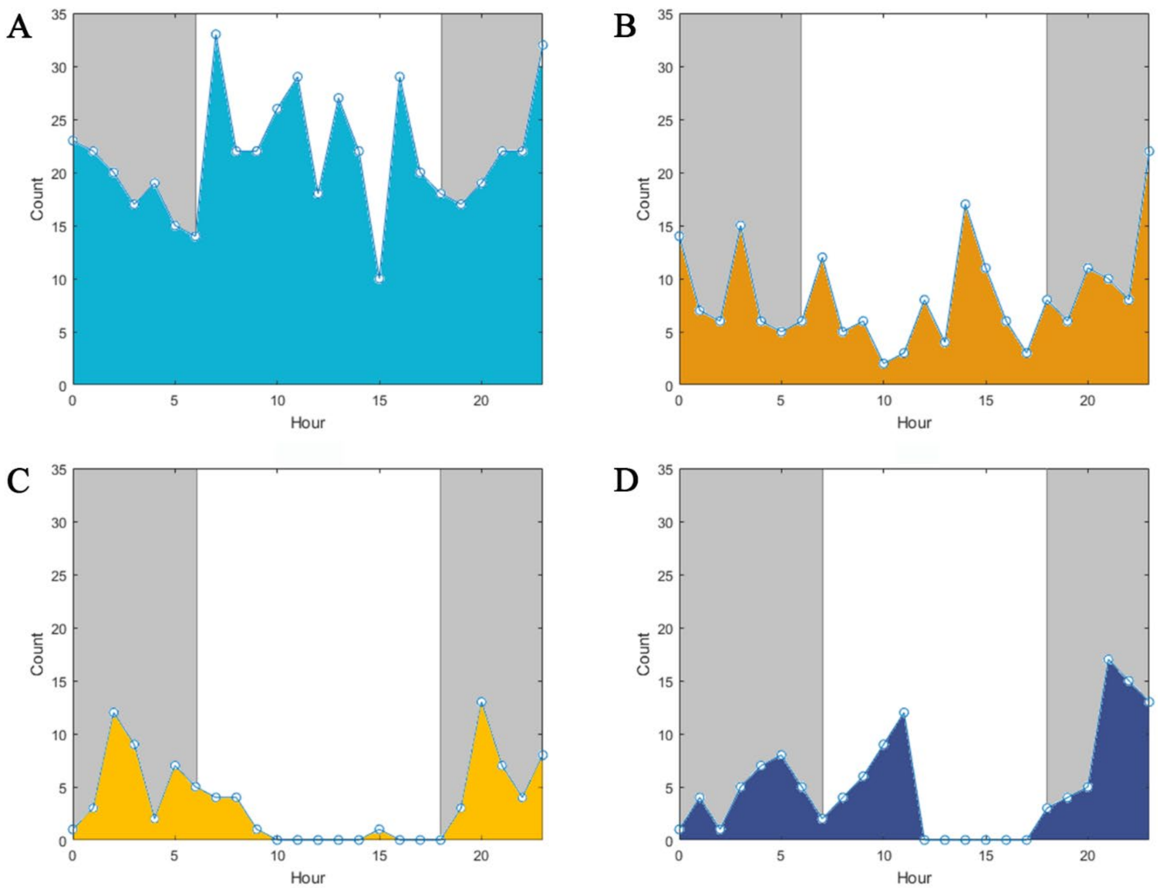

Figure 8. Detections of beaked whales plotted in Hawaiian Standard Time by the hour (A = Blainville's; B = Cuvier's; C = BWC; D = Longman's). Light gray shading represents night.

Detailed assessment of Blainville's beaked whale detections revealed variability in character of their FM pulses (Figure 9). All acoustic encounters with Blainville's beaked whales had a peak frequency at 32 kHz (Figure 9A), though 22% (64) of encounters had either additional frequency peaks (Figure 9B) or included energy into higher frequencies (Figure 9C).

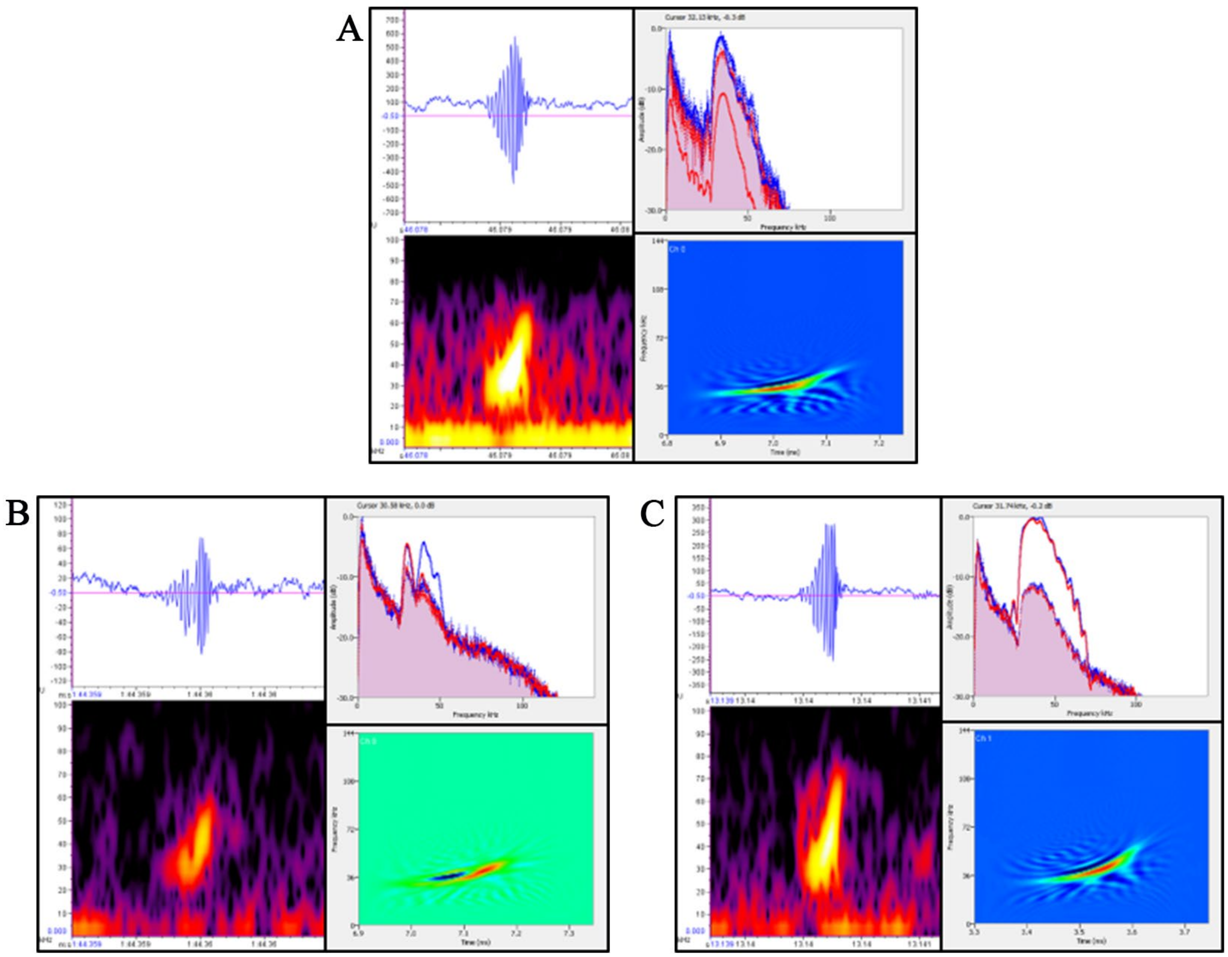

Figure 9. Examples of frequency modulated (FM) pulses from Blainville's beaked whales (A = standard 32 kHz FM pulse; B = FM pulse with multiple peaks in frequency; C = FM pulse with additional dynamic range into higher frequencies). Each example contains four images of the FM pulse (top left = waveform; top right = spectrum; bottom left = spectrogram; bottom right = Wigner plot).

Kogia spp.

Eleven of the thirteen DASBR drifts and less than one percent of the 2-min recording files (60) contained acoustic detections of *Kogia* spp. (dwarf and pygmy sperm whales) (Table 2, Figure 10). *Kogia* spp. clicks cannot presently be classified to species and they are grouped as *Kogia* spp. for this analysis. We did detect two types of *Kogia* spp. echolocation clicks with peak frequencies of 116 kHz and 123 kHz but have not yet ascertained the relevance between the two peaks. Encounters contained one or the other peak frequency, but not both. Acoustic encounters on 18 occasions spanned more than one 2-min recording period, resulting in 42 encounters of *Kogia* spp. Median duration of acoustic encounters for *Kogia* spp. was 1.5 minutes, but two encounters lasted for more than 30 minutes.

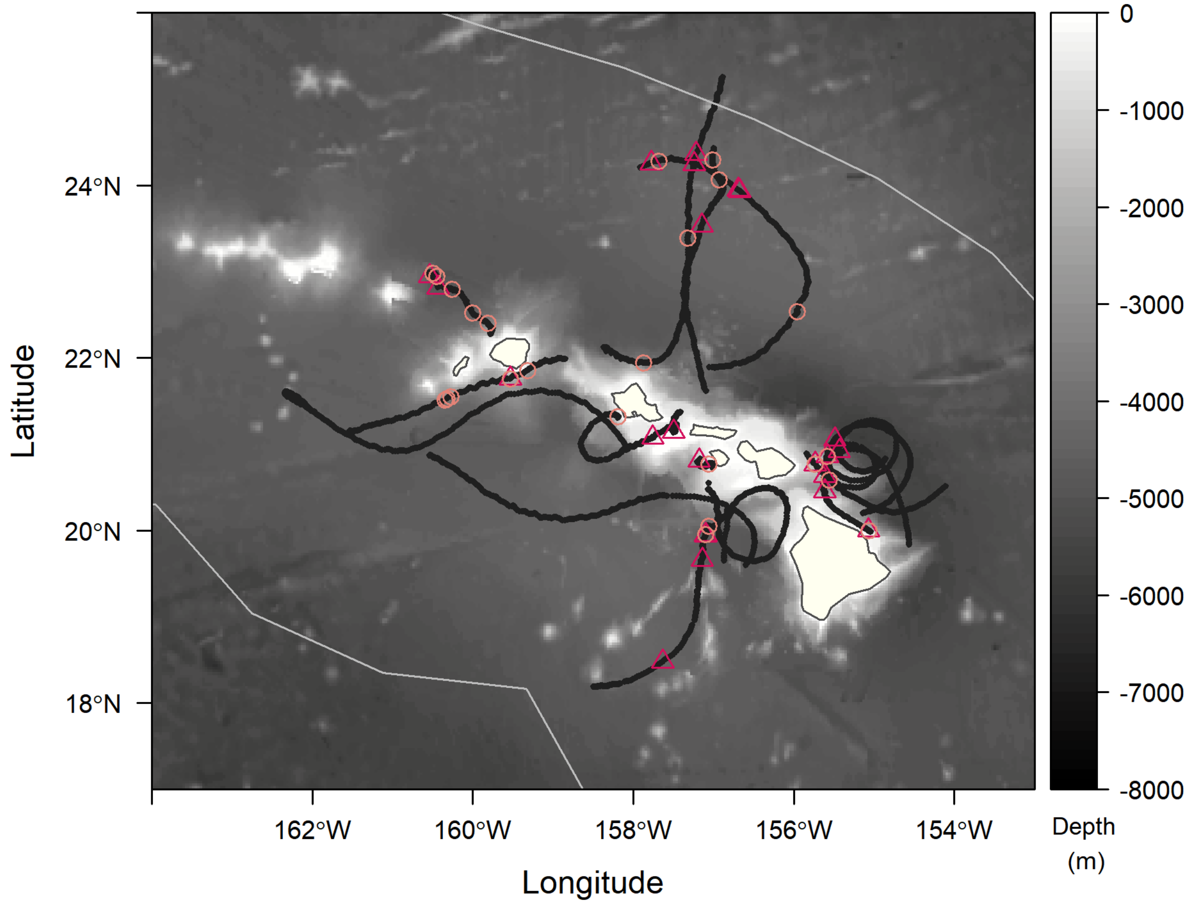

Figure 10. Locations of *Kogia* spp. (dwarf/pygmy sperm whales) acoustic detections (2-min files) shown as peach circles and pink upward triangles (116 kHz and 123 kHz peak frequencies, respectively). DASBR tracks are shown as bold black lines. Gray lines indicate the boundary of the Hawaii Exclusive Economic Zone.

Sperm Whales

All DASBR tracks included detections of sperm whales, including 8% (2,809) of the 2-min files (Table 2). These detections indicate the presence of this species in nearshore and offshore waters around the main Hawaiian Islands (Figure 11).

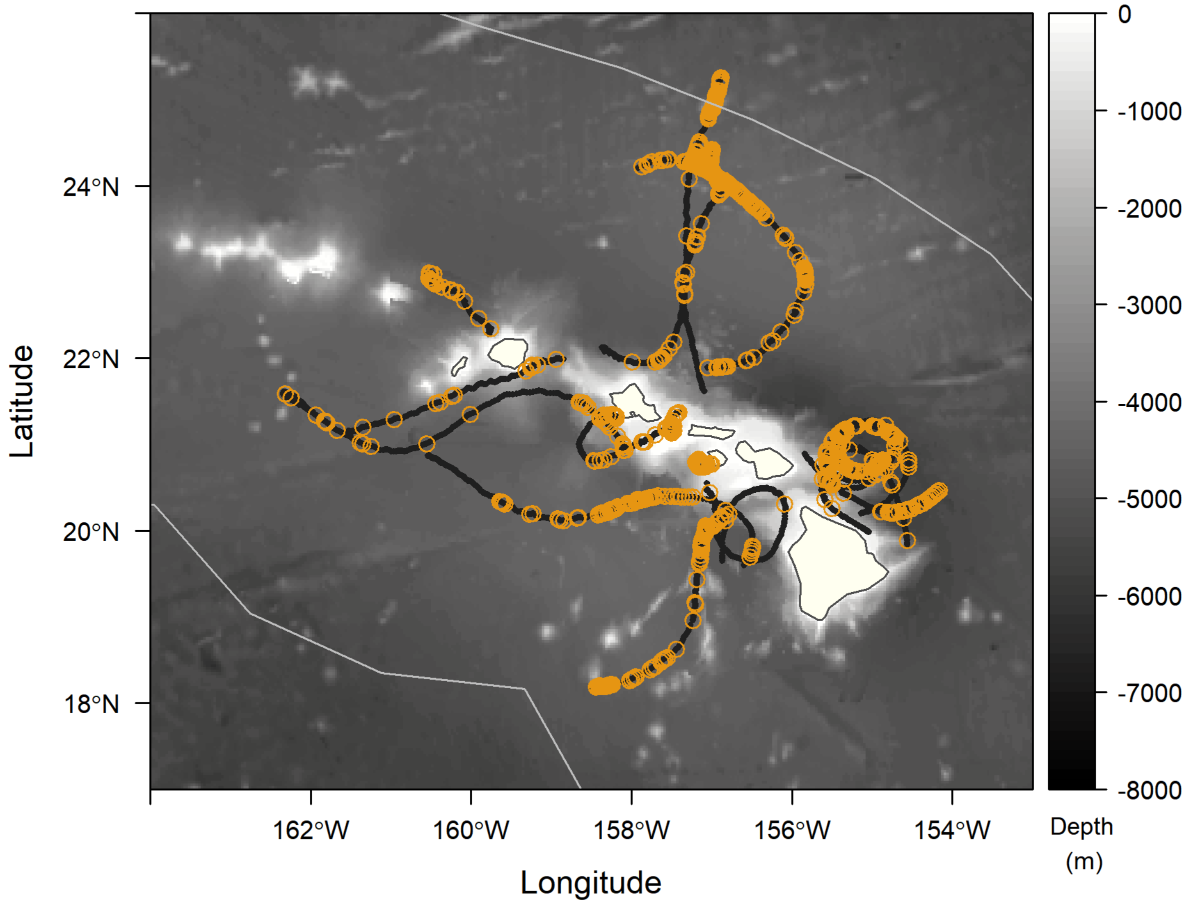

Figure 11. Locations of acoustic detections (2-min files) of sperm whales shown as orange circles. DASBR tracks are shown as bold black lines. Gray lines indicate the boundary of the Hawaii Exclusive Economic Zone.

Unidentified Odontocetes

Echolocation clicks from unidentified odontocetes were detected on all DASBR drifts and in 11% (3,939) of 2-min files (Table 2). These detections indicate the presence of unidentified odontocetes throughout nearshore and offshore waters around the main Hawaiian Islands without large gaps along DASBR tracks (Figure 12).

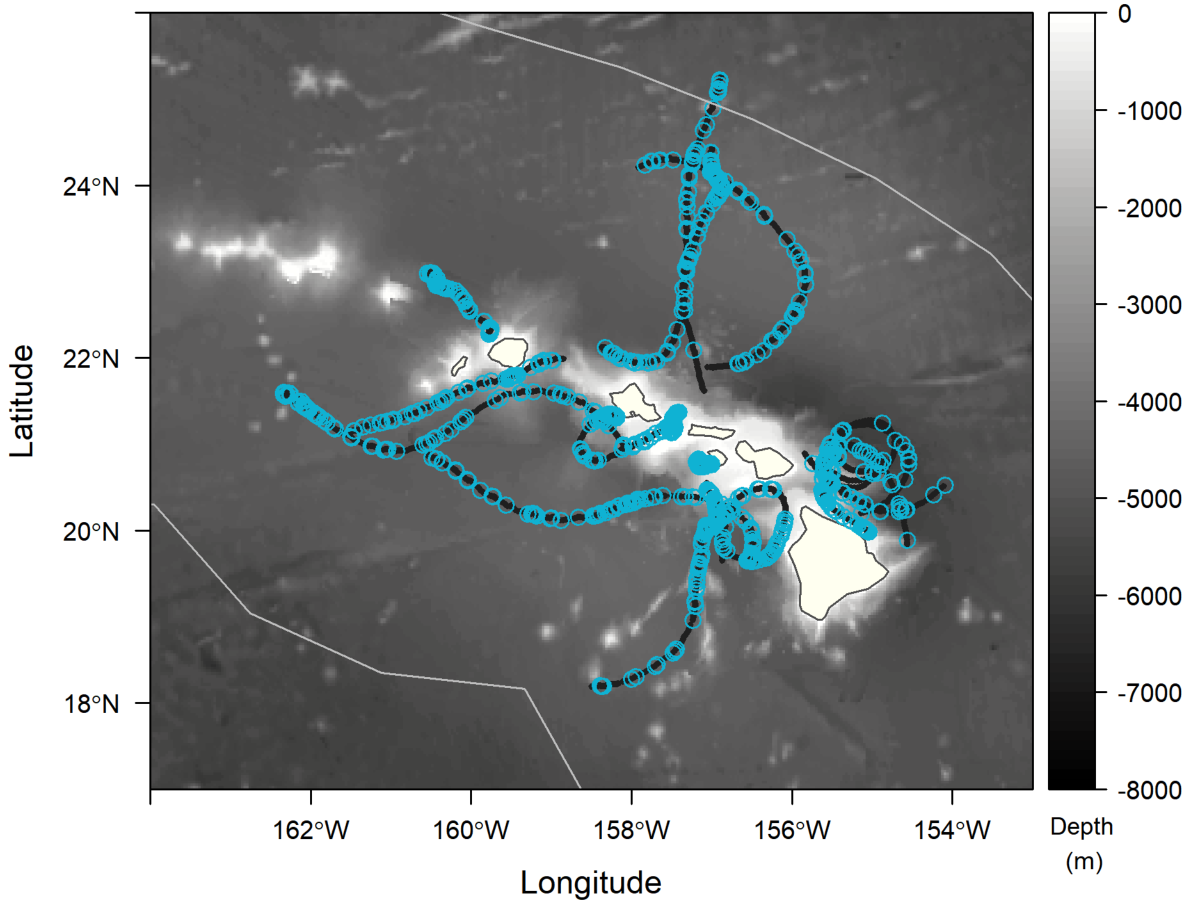

Figure 12. Locations of acoustic detections (2-min files) of echolocation clicks from unidentified odontocetes shown as blue circles. DASBR tracks are shown as bold black lines. Gray lines indicate the boundary of the Hawaii Exclusive Economic Zone.

Discussion

The HICEAS 2017 survey was the first comprehensive cetacean assessment survey in Hawaiian waters to use DASBRs to examine the occurrence and distribution of deep-divers and other cetacean species. The unique platform provides passive acoustic occurrence and location data free from the limitations of towed array datasets, including ship and flow noise, and puts acoustic sensors at depths closer to the subject species where detection rates for deep-divers may be more frequent. The substantial numbers of beaked whale detections on all DASBR drift tracks demonstrates the value of deploying these sensors to assess their distribution in the region.

Further analysis of data from DASBRs collected during HICEAS 2017 has the potential to contribute to examinations of species presence, habitat usage, and abundance estimation for a variety of other cetacean species as well. Detections of sperm whales may be further examined to better understand click rates, dive cycles, depth in the water column, and range from the DASBR. A variety of automated routines further incorporating detections of whistles and burst pulses may help further sort detections of unidentified odontocetes to species, providing an opportunity for similar work with other priority species, including false killer whales (*Pseudorca crassidens*). To date there has been no effort to detect and classify calls of baleen whales on these DASBR recordings. Detections of baleen whales during the summer when humpback whales are not present could help our understanding of how other species of baleen whales use the main Hawaiian Islands.

Acoustic encounters of beaked whales and *Kogia* spp. can be similarly compared to oceanographic covariates as described by McCullough et al. (Submitted). This would provide insight to habitat features in the main Hawaiian Islands that increase the presence of beaked whales and *Kogia* spp. Once other species have been identified, the same habitat analysis could be conducted as well.

Density and abundance estimations of deep-diving species from drifting recorders have been the goal from the outset of these deployments. Barlow et al. (2021 and Submitted) establishes the framework to use acoustic encounters of beaked whales for population density in a small-scale experiment and identify a snapshot length for encounters. Barlow et al. (In review) applies those methods to estimate Cuvier's beaked whale density and abundance for a large region (U.S. West Coast). The data collected in the Hawaiian Islands are comparable to those from the U.S. West Coast; therefore, the same density and abundance analyses can be applied.

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Literature Cited

Backus RH, Schevill WE. 1966. Physeter clicks. In: Norris KS, editor. Whales, dolphins and porpoises. Berkeley: University of California Press. p. 510–527.

Barlow J, Fregosi S, Thomas L, Harris D, Griffiths ET. 2021. Acoustic detection range and population density of Cuvier's beaked whales estimated from near-surface hydrophones. J Acoust Soc Am. 149(1):111–125.

Barlow J, Moore JE, McCullough JLK, Griffiths ET. (*In Review*). Acoustic-based estimates of Cuvier's beaked whale (*Ziphius cavirostris*) density and abundance along the U.S. West Coast from drifting hydrophone recorders.

Barlow J, Trickey JS, Schorr GS, Rankin S, Moore JE. (*Submitted*). Recommend snapshot length for acoustic point-transect surveys of intermittently available beaked whales.

Baumann-Pickering S, McDonald MA, Simonis AE, Solsona Berga A, Merkens KP, Oleson EM, Roch MA, Wiggins SM, Rankin S, Yack TM, Hildebrand JA. 2013. Species-specific beaked whale echolocation signals. J Acoust Soc Am. 134(3):2293–2301.

Baumann-Pickering S, Roch MA, Brownell RL, Jr., Simonis AE, McDonald MA, Solsona-Berga A, Oleson EM, Wiggins SM, Hildebrand JA. 2014. Spatio-temporal patterns of beaked whale echolocation signals in the North Pacific. PLoS one. 9(1):e86072.

Gillespie D, Mellinger DK, Gordon J, McLaren D, Redmond P, McHugh R, Trinder P, Deng XY, Thode A. 2009. PAMGuard: Semiautomated, open source software for real-time acoustic detection and localization of cetaceans. J Acoust Soc Am. 125(4):2547–2547.

Griffiths ET, Barlow J. 2015. Equipment performance report for the Drifting Acoustic Spar Buoy Recorder (DASBR). NOAA Tech Memo. NMFS-SWFSC-543:1-41.

Griffiths ET, Barlow J. 2016. Cetacean acoustic detections from free-floating vertical hydrophone arrays in the southern California Current. J Acoust Soc Am. 140(5):EL399–EL404.

Henry A, Moore JE, Barlow J, Calambokidis J, Ballance LT, Rojas-Bracho L, Urbán Ramirez J. 2020. Report on the California Current Ecosystem Survey (CCES): Cetacean and seabird data collection efforts, June 26–December 4, 2018. NOAA Tech Memo. NOAA-TM-NMFS-SWFSC-636:1-38.

Keating JL, Barlow J. 2013. Summary of PAMGuard beaked whale click detectors and classifiers used during the 2012 southern California behavioral response study. NOAA Tech Memo. NMFS-SWFSC-517:1-17.

Keating JL, Barlow J, Griffiths ET, Moore JE. 2018. Passive acoustics survey of cetacean abundance levels (pascal-2016) final report. US Department of the Interior, Bureau of Ocean Energy Management. OCS_Study_BOEM_2018-025:1–29.

Keating JL, Barlow J, Rankin S. 2016. Shifts in frequency-modulated pulses recorded during an encounter with Blainville's beaked whales (*Mesoplodon densirostris*). J Acoust Soc Am. 140(2):EL166-EL171.

Marten K. 2000. Ultrasonic analysis of pygmy sperm whale (*Kogia breviceps*) and Hubbs' beaked whale (*Mesoplodon carlhubbsi*) clicks. Aquat. Mamm. 26(1):45–48.

McCullough JLK, Wren JLK, Oleson EM, Allen AN, Siders ZA, Norris ES. 2021. An acoustic survey of beaked whales and *Kogia* spp. in the Mariana Archipelago using drifting recorders. (Submitted).

McDonald MA, Hildebrand JA, Wiggins SM, Johnston DW, Polovina JJ. 2009. An acoustic survey of beaked whales at Cross Seamount near Hawaii. J Acoust Soc Am. 125(2):624–627.

Merkens K, Mann D, Janik VM, Claridge D, Hill M, Oleson E. 2018. Clicks of dwarf sperm whales (*Kogia sima*). Mar. Mamm. Sci. 34(4):963-978.

Pante E, Simon-Bouhet B. 2013. Marmap: A package for importing, plotting and analyzing bathymetric and topographic data in r. PLoS one. 8(9):e73051.

R Core Team. 2020. R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing.

Yano KM, Oleson EM, Keating JL, Ballance LT, Hill MC, Bradford AL, Allen AN, Joyce TW, Moore JE, Henry A. 2018. Cetacean and seabird data collected during the Hawaiian Islands Cetacean and Ecosystem Assessment Survey (HICEAS), July–December 2017. NOAA Tech Memo. NMFS-PIFSC-72:1-110.