PASSIVE ACOUSTIC SURVEY OF DEEP-DIVING ODONTOCETES IN THE CALIFORNIA CURRENT ECOSYSTEM 2018: FINAL REPORT

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Cover Photos (top to bottom):
Cuvier's beaked whales (*Ziphius cavirostris*), credit: NOAA, A. Simonis
Sperm whale (*Physeter macrocephalus*), credit: NOAA, P. Olson
Dwarf sperm whale (*Kogia sima*), credit: NOAA, J. Barlow

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1 Introduction

The 2018 California Current Ecosystem Survey (CCES) was a multidisciplinary survey of the marine ecosystem from southern British Columbia, Canada to northern Baja California, Mexico. This survey was a collaboration between the Southwest Fisheries Science Center's (SWFSC) Fishery Resource Division (FRD) and Marine Mammal and Turtle Division (MMTD). CCES 2018 was conducted from 26 June to 4 December 2018 aboard the NOAA ship *Reuben Lasker*. The survey included oceanographic measurements, use of multi-frequency echosounders, surface trawls, vertically and obliquely integrating net tows, continuous underway fish egg sampling, visual line-transect surveys for marine mammals, photographic capture-recapture studies of marine mammals, strip transect surveys for seabirds, and passive acoustic surveys of marine mammals using Drifting Acoustic Spar Buoy Recorders (DASBRs). MMTD and FRD worked jointly aboard the vessel during Legs 1 through 4 (OMAO Project No. RL-18-03) when the vessel surveyed off the coasts of Vancouver Island and the US West Coast. MMTD conducted operations alone during Legs 5 through 7 (OMAO Project No. RL-19-01) when the vessel surveyed off the US West Coast and Mexico. Preliminary results from the oceanographic, fisheries, and krill investigations by FRD are presented in Stierhoff et al., (2019). Preliminary results from the visual surveys for marine mammals and seabirds by MMTD are presented in Henry et al., (in press). In this report we present the preliminary results of the passive acoustic monitoring efforts using DASBRs.

DASBRs were first used in a broad-scale Passive Acoustics Survey of Cetacean Abundance Levels (PASCAL) in the California Current during 2016, (Keating et al., 2018). They are free-floating acoustic recording instruments that include two hydrophones (configured as a vertical hydrophone array) and a digital recorder. DASBRs are tracked with two satellite geo-locators in a spar buoy at the surface, and the archival recorders must be recovered to download acoustic data. In that earlier study, DASBRs were deployed 30 times for a total of 421 recording days. Acoustic recordings were analyzed to detect echolocation signals from beaked whales, sperm whales (*Physeter macrocephalus*), and dwarf and pygmy sperm whales (*Kogia* spp.). In 2016, the most common beaked whale echolocation pulses were from Cuvier's beaked whale (*Ziphius cavirostris*), Baird's beaked whale (*Berardius bairdii*), Stejneger's beaked whale (*Mesoplodon stejnegeri*), and two unidentified species of beaked whales whose echolocation pulses were referred to as BW43 and BW39V. In a subsequent paper describing it, the name for the BW39V signal type was revised to BW37V (Griffiths et al., 2019). Keating et al., (2018) mapped the DASBR drifts from the 2016 cetacean survey along the U.S. West Coast, including the distributions of echolocation detection events of each identified species or signal type. Analysis of narrow-band high frequency (NBHF) signals from Dall's porpoise (*Phocoenoides dalli*), and presumed dwarf and pygmy sperm whales detected during the 2016 survey were presented by Griffiths et al., (2020).

Here we present analyses of the DASBR deployments from the CCES 2018 project. We provide information on the times and locations of drift deployments and retrievals. Each drift is also illustrated on maps of the study area. We present analyses of cetacean echolocation detections from DASBR recordings including those from beaked whales, sperm whales, and NBHF species. As in the previous 2016 study, beaked whale detections were dominated by Cuvier's beaked whale. All the beaked whale species detected in 2016 were also detected in this 2018 study, plus the addition of a signal, designated BWC that had been previously detected in the central and western Pacific, but not previously in the eastern Pacific. Sperm whales and NBHF species were detected throughout the study area.

CCES 2018 was the second survey conducted under the Pacific Marine Assessment Program for Protected Species (PacMAPPS), supported by the National Oceanographic and Atmospheric Administration (NOAA), the US Navy, and the Bureau of Ocean Energy Management (BOEM). This study conducts annual cetacean and ecosystem surveys throughout the North Pacific and generates data products used by all three agencies to meet regulatory requirements pertaining to protected species. Funding is provided in part by the US Department of the Interior, BOEM, Environmental Studies Program, Washington, DC through Interagency Agreement (IAA) M17PG00025 with NOAA/National Marine Fisheries Southwest Fisheries Science Center, and the US Department of Navy US Pacific Fleet through IAA N00070-18-MP-4C560. This report has been technically reviewed by BOEM, US Navy, and NOAA/NMFS, and has been approved for publication. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the opinions or policies of the US government, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

2 Methods

2.1 Drifting Acoustic Spar Buoy Recorders

Acoustic recordings were collected from DASBRs deployed at 22 predetermined locations distributed approximately uniformly throughout the California Current study area, offshore of the continental shelf (Figure 1). Each DASBR includes a pair of hydrophones, vertically separated by approximately 5-10 m, with the midpoint positioned approximately 100-150 m below the surface (Figure 2). Acoustic recordings were collected on one of two types of instruments, including the SoundTrap ST4300 (Ocean Acoustics, Auckland, New Zealand) and the Song Meter SM3M (Wildlife Acoustics, Maynard, MA) (Table 1). The hydrophones and recorder were attached to a line below a surface spar buoy and terminated at depth with an anchor, which maintained the vertical orientation of the hydrophones in the water column (Figure 2). Some of the deployments also had a ½” elastic “bungee” line in parallel with the ¼” nylon line to reduce the effect of wave action on recording data quality.

The sampling rate and duty cycle varied across all deployments (Table 1), however all acoustic recordings were collected with a minimum sampling rate of 256 kHz and used a 2-minute file size. All devices recorded stereo signals from two hydrophones. The hydrophone sensor types, sensitivities, and other relevant settings are shown in Table 2.

A pressure and 3D accelerometer logger (Loggerhead Computers OpenTag) or a temperature and depth recorder (Lotek Archival Tag LAT-1400) was included in all deployments except drift 16, (Table 1) to measure hydrophone depth and (for the former) array tilt. All SoundTrap ST4300 recorders were also set to record 3D accelerometry. Array depth is critical for estimating the range to vocalizing animals. Array tilt is also critical for estimating range when the array is not vertical in the water column (Barlow and Griffiths 2017).

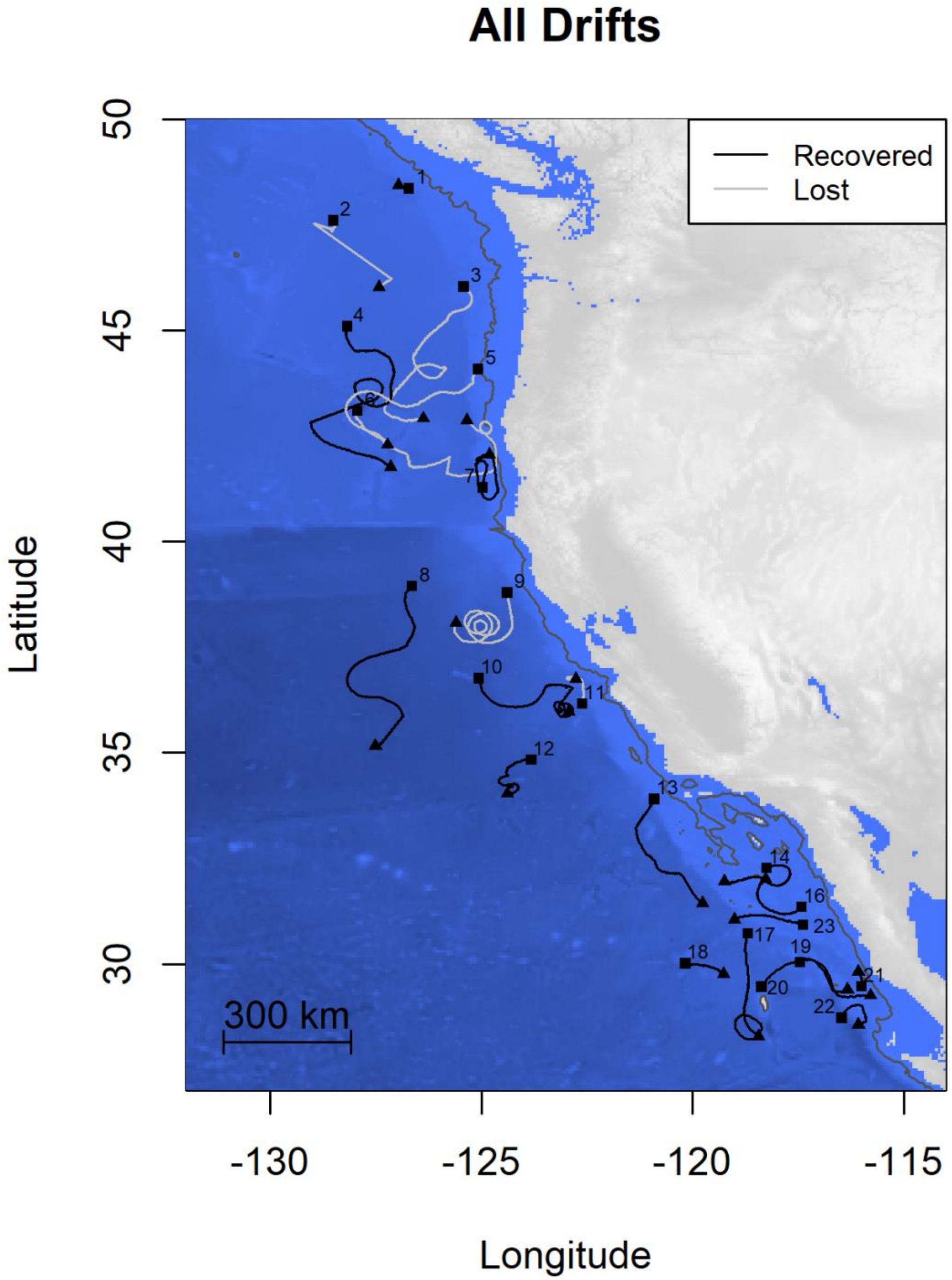

Figure 1. Locations of DASBR deployments (black squares), retrievals or last known location (black triangles), and buoy drifts (recovered = black lines, lost = gray lines). Darker gray line indicates the 500 m isobath.

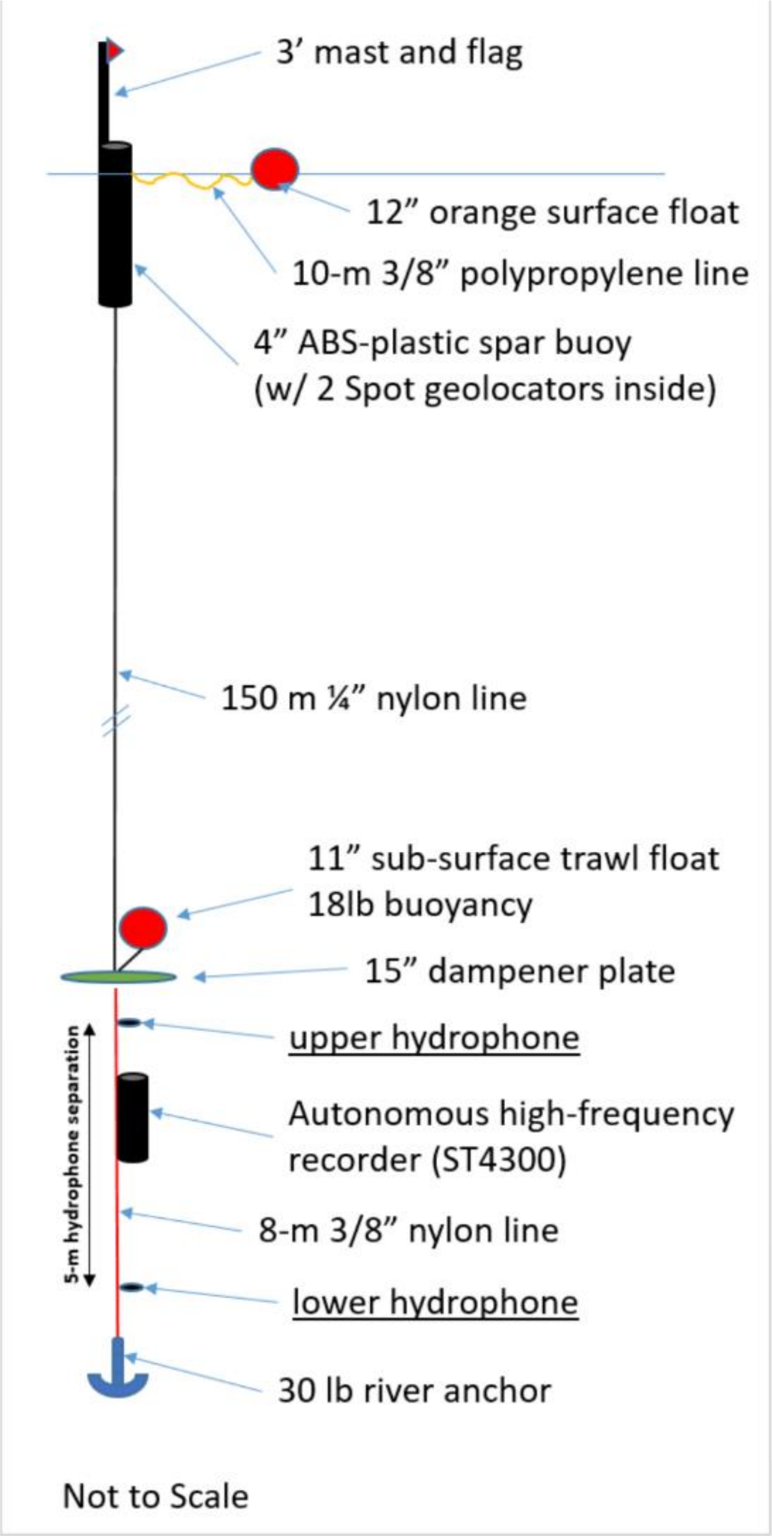

Figure 2. Schematic of DASBR. Note, the SM3M deployments used only 100m of ¼” nylon line, with a 10-m hydrophone separation. See Table 2 for details on configuration of each DASBR.

Table 1. Deployment details for each DASBR deployment during CCES 2018. Seven DASBRs could not be found and data was lost (drifts 1, 2, 3, 5, 6, 9, 11). Acoustic recorder types included ST=SoundTrap, SM3M = Song Meter 3 Marine, with each instrument serial number given. Two types of depth recorders were used: LAT= Lotek Archival Tag LAT1400 and OT= Loggerhead OpenTag.

Cruise Leg	DASBR Drift	Deployment Position	Recovery Position	Recorder Type and ID	Sample Rate (kHz)	Hydrophone Array Label	Duty Cycle On/Off (mins)	Depth Recorder	SPOT Labels
1	1	48. 3440 N, 126. 7029 W	N/A	ST4300 L-256	288	A	2/18	LAT-1	AB, AC
1	2	47. 5919 N, 128. 5120 W	N/A	SM3M #1	256	1	2/2 for 20d, then 2/18	OT-4	H, V
2	3A	46. 2560 N, 125. 3746 W	N/A	ST4300 M-256	288	B	2/18	LAT-2	N, O
2	3B	46. 0893 N, 125. 3746 W	45. 6098 N, 125. 2710 W	ST4300 J-128	288	I	2/18	LAT-12	G, AI
2	3C	45. 6098 N, 125. 2710 W	N/A	ST4300 J-128	288	I	2/18	LAT-12	G, AI
2	4	45. 0834 N, 128. 2082 W	41. 7569 N, 127. 1545 W	SM3M #3	256	3	2/2 for 20d, then 2/18	OT-6	E, K
2	5	44. 0938 N, 125. 0046 W	N/A	ST4300 N-256	288	11	2/18	LAT-3	L, M
2	6	43. 0957 N, 127. 9195 W	N/A	ST4300 D-128	288	C	2/18	LAT-4	P, Q
2	7	41. 2604 N, 125. 0157 W	42. 0400 N, 124. 4850 W	ST4300 O-256	288	12	2/18	LAT-5	R, S
3	8	38. 9485 N, 126. 6449 W	34. 3774 N, 128. 3174 W	ST4300 F-128	288	D	2/18	LAT-6	T, U
3	9	38. 7919 N, 124. 3891 W	N/A	ST4300 P-256	288	13	2/18	LAT-7	I, J
3	10	36. 7607 N, 125. 0584 W	35. 9671 N, 122. 9397 W	ST4300 Q-256	576	E	2/18	LAT-8	Z, AA
3	11	36. 1534 N, 122. 6094 W	N/A	ST4300 E-128	288	F	2/18	LAT-9	AJ, AK
3	12	34. 8303 N, 123. 8146 W	34. 0316 N, 124. 3911 W	ST4300 G-128	288	G	2/18	LAT-10	C, D
4	13	33. 8980 N, 120. 9078 W	31. 4444 N, 119. 7754 W	ST4300 I-128	288	H	2/18	LAT-11	X, Y
5	14	32. 2688 N, 118. 2563 W	31. 9507 N, 119. 2481 W	ST4300 O-256	576	J	2/18	LAT-5	A, B
6	16	31. 3534 N, 117. 4199 W	32. 1253 N, 118. 0337 W	ST4300 K-128	576	12	2/8	none	R, S
6	17	30. 7250 N, 118. 6933 W	28. 2857 N, 118. 4385 W	SM3M #3	256	3	2/2	OT-6	E, K
6	18	30. 0108 N, 120. 1815 W	29. 5059 N, 118. 8216 W	ST4300 Q-256	576	E	2/4	LAT-8	Z, AA
6	19	30. 0477 N, 117. 4605 W	28. 4041 N, 115. 5497 W	ST4300 F-128	576	D	2/8	LAT-6	T, U
6	20	29. 4590 N, 118. 3930 W	29. 3920 N, 116. 3355 W	ST4300 I-128	576	G	2/8	LAT-11	X, Y
6	21	29. 4677 N, 116. 0120	29. 8233 N, 116. 0796 W	ST4300 O-256	576	J	2/4	LAT-5	A, B
6	22	28. 7247 N, 116. 4778 W	28. 2846 N, 116. 6829 W	ST4300 G-128	576	H	2/8	LAT-10	C, D
7	23	30. 9285 N, 117. 3812 W	31. 0542 N, 119. 0123 W	ST4300 O-256	576	J	2/3	LAT-5	A, B

Table 2. Sensor and pre-amp characteristics for each recovered DASBR array (corresponding to the hydrophone array numbers in Table 1).

		Hydrophone				Array Characteristics		Soundtrap		Wildlife Acoustics Board	
Hydrophone Array	Element #	Hydrophone Type	Serial Number	Hydrophone Sensitivity	High-pass Filter (Hz)	Line Type	Hydrophone separation (m)	Gain (dB)	High-pass Filter (Hz)	Gain (dB)	High-pass Filter (Hz)
3	0	HTI-92-WB	856073	-154. 8	20	nylon	9. 1	n/a	n/a	12	2
	1	HTI-96-min	856040	-164. 7	20			n/a	n/a	12	2
12	0	HTI-92-WB	856049	-154. 5	20	nylon	9. 9	High	OFF	n/a	n/a
	1	HTI-96-min	856068	-165. 1	20			High	OFF	n/a	n/a
D	0	HTI-92-WB	856095	-155. 2	20	nylon/poly	4. 88	High	OFF	n/a	n/a
	1	HTI-96-min	856041	164. 5	20			High	OFF	n/a	n/a
E	0	HTI-92-WB	856096	-155. 6	20	nylon/poly	4. 89	High	OFF	n/a	n/a
	1	HTI-96-min	856044	-164. 7	20			High	OFF	n/a	n/a
G	0	HTI-92-WB	856097	-155. 2	20	nylon/poly	4. 82	High	OFF	n/a	n/a
	1	HTI-96-min	856017	-181. 4	100			High	OFF	n/a	n/a
H	0	HTI-92-WB	856051	-154. 7	20	nylon	4. 7	High	OFF	n/a	n/a
	1	HTI-96-min	856067	-164. 9	20			High	OFF	n/a	n/a
J	0	HTI-92-WB	856048	-155. 6	20	Falmat cable	5. 03	High	OFF	n/a	n/a
	1	HTI-96-min	856059	-165. 0	20			High	OFF	n/a	n/a

2.2 Analyses of Acoustic Survey Data to Detect Deep-Diving Whales

Acoustic data recorded by DASBRs were examined using a semi-automated approach to find echolocation pulses from beaked whales, sperm whales, and species that produce NBHF pulses. The NBHF species in our study area include *Kogia* (dwarf and pygmy sperm whales), Dall's porpoise, and harbor porpoise (Barlow 2016; Kyhn et al., 2013; Madsen et al., 2005; Merkens et al., 2018; Griffiths et al., 2020). Our approach generally follows that used by Keating et al. (2018). All DASBRs used a 2-minute recording time with varying duty cycles among deployments based on the expected battery life and duration of the deployment (Table 1). An acoustic detection event is defined as the presence of three or more echolocation clicks from a given species group within a 2-minute recording file.

2.2.1 Identification of Beaked Whales and Sperm Whales

Echolocation pulses were automatically detected using the Click Detector module in PAMGuard software (version 2.00.16e Beta) (Gillespie et al., 2008). A 1st order IIR Butterworth high-pass filter with a corner frequency of 80 kHz was used to flatten (or whiten) the ocean ambient noise spectrum (which is normally dominated by lower frequencies) which helps identify the true peak frequency of faint pulses. Prior to click detection and classification, a digital high-pass pre-filter was used (4th order Butterworth with a 10 kHz corner frequency) to prevent false-triggering on low-frequency sounds. Click detection for these species was based only on signals from the upper, more sensitive hydrophone (HTI-92-WB) using a 12 dB signal-to-noise ratio (SNR) threshold. Echolocation pulses were classified into categories based on peak frequency, and pulses in each category were color-coded with different symbol shapes for viewing in the PAMGuard Viewer click detector window (using a system similar to that described by Keating and Barlow 2013). The peak frequency categories for the click classification were 2-15, 15-30, 30-50, 50-80 and >80 kHz. Within the 30-50 kHz peak frequency category (the typical category for most beaked whale pulses), pulses were further classified based on the presence of a frequency sweep characteristic of beaked whale pulses (Baumann-Pickering et al., 2013; Keating and Barlow 2013). The initial PAMGuard processing also automatically estimated the vertical angle at which echolocation pulses were received using the time-difference-of-arrival of signals at the two elements of the vertical hydrophone array.

After the initial click detection and classification in PAMGuard, the Matched Template Classifier module was used to re-classify clicks based on idealized waveforms from six recognized categories of beaked whales found in the study area (Cuvier's, Baird's, and Stejneger's beaked whales, BW43, BW70, (Baumann-Pickering et al., 2013), and BW37V (Griffiths et al., 2019)). Relatively high thresholds (0.06 for Cuvier's beaked whale and 0.15 for all others) were used with the Matched Template Classifier to minimize the rate of false positive detections of beaked whales, so relatively few clicks were reclassified with this secondary classification method. All clicks above the Matched Template Classifier threshold were displayed in the same color and shape in the PAMGuard Viewer click detection window.

Analysts (AES and JST) used the click detector window with a Bearing-Time display in PAMGuard Viewer to distinguish echolocation pulses of beaked whales and sperm whales from the much greater number of clicks detected from other sources (primarily dolphins). This click detector window displays all detected clicks as symbols in a plot with time on the x-axis and bearing angle on the y-axis. Potential signals were initially identified based on the shape and color of the displayed symbols (corresponding to the peak frequency or Matched Template classification schemes described above). Additional contextual information that contributed to species recognition included bearing angles (the direct-path signals from beaked whales and sperm whales are typically received from depths below the hydrophones and bearing angles are relatively constant over a 2-minute recording period) and pulse repetition rate. Once potential echolocation signals were identified, the analyst could click on the symbol representing a pulse and display its waveform, frequency spectrum, and Wigner plot of frequency versus time (which typically shows a frequency upsweep for beaked whales). After probable beaked whale and sperm whale clicks were identified, all similar clicks within a 2-minute recording were grouped as an event within PAMGuard Viewer.

Initial screening of the data indicated that at times, sperm whale click trains were detected continuously over many hours, creating an enormous analysis challenge. The detection range for sperm whale clicks has been reported as out to 37 km on towed hydrophone arrays (Barlow and Taylor 2005), the low self-noise of DASBRs may result in an even greater detection range. Due to limited available time for data analysis in this study, sperm whale events were only recorded if the direct-path signal arrived from below the hydrophone array at an angle greater than 20° declination relative to horizontal. This eliminated the majority of distant sperm whale signals, which are received at horizontal angles of 0 to -10°, and greatly reduced the time that would have been required to mark all clicks within sperm whale events. Accordingly, the effective survey area was also reduced, which will be accounted for in future density estimates.

During an initial training period, both analysts independently identified beaked whale and sperm whale events for the same DASBR drift (#23) and compared results. Subsequently, a single analyst examined all other drifts. Beaked whale and sperm whale acoustic events were identified by AES in drifts 4-16 and by JST for drifts 17-23. When events were identified, the analyst also recorded an initial species classification based on an identification guide for beaked whale echolocation pulses, utilizing inter-click intervals, with spectral and Wigner characteristics of pulses as seen in PAMGuard (Appendix A). After the initial species classifications were made by a single analyst, the PAMGuard database was stripped of species identification information and then reviewed by the second analyst to independently label species classifications.

After both analysts (JST & AES) independently made their initial species classifications for all beaked whale events (including categories of “unidentified beaked whale” and “possible beaked whale”), all discrepancies were reviewed. Each analyst independently reviewed the subset of discrepancies to determine whether, based on additional scrutiny, they would change their species classification. If the discrepancy remained, events were re-examined in PAMGuard Viewer during a joint session with a third experienced analyst (JB) to reach unanimous approval of all three analysts. If any analyst felt that the species-classification could not be determined with certainty, the event would be re-labeled with the highest level of certainty based on the consensus of all analysts (for example "unidentified beaked whale").

2.2.2 Identification of NBHF pulses from *Kogia* and porpoise species

NBHF pulses were initially identified by each analyst while scanning the data for beaked and sperm whale events. Subsequently, all recordings from SoundTrap ST4300 recorders were re-analyzed using specialized PAMGuard settings that were optimized for NBHF pulses. These PAMGuard settings were different from those used by Keating et al., (2018) in their analyses of NBHF pulses from the 2016 PASCAL project. The SM3M recordings (sampled at 256 kHz) did not have adequate bandwidth to cover all NBHF pulses and were not analyzed for NBHF pulses. To eliminate low-frequency noise, the acoustic data was filtered with a 6th order IIR Butterworth high-pass filter with a corner frequency of 100 kHz. Preliminary analyses indicated that some NBHF signals were only received on one hydrophone; therefore, signals from both hydrophones were included while searching for NBHF signals, using a click detector with a 12 dB SNR threshold. Echolocation pulses with peak frequencies outside of the range of 100-144 kHz were discarded, leaving a reduced set of detections, which could be more efficiently reviewed in PAMGuard Viewer. Analyst JST identified distinct NBHF events based on pulses with a narrow peak frequency above 100 kHz and a Wigner plot showing a relatively long duration signal at a relatively constant frequency. Because NBHF signals were frequently received on only one hydrophone, which prevented an accurate bearing calculation, the Amplitude-Time display was substituted for the usual Bearing-Time display when reviewing clicks in PAMGuard viewer.

3 Results

3.1 DASBR survey effort

High-quality acoustic data was obtained from 15 of 23 deployments, resulting in 1,910 cumulative hours of recordings (Table 3). Of these, 14 DASBRs were recovered at sea by the *Lasker*. One drift (#7) grounded off Brookings, Oregon and was recovered by a small boat launched locally. For recovered deployments, the distance traveled by individual drifts ranged from 46 to 961 km, with an average distance traveled of 370 km (Table 3). Acoustic recordings on the SM3M recorder (Drifts 4 and 17) had a higher level of instrument noise than the ST4300 recorders, particularly within the frequency range of 55-70 kHz. In general, beaked whales were harder to detect and to identify in the SM3M recordings due to the instrument noise. In future analyses of detection probability, separate analysis of SM3M recordings may be prudent.

Seven drifts were not recovered due to a loss of geolocation information (lost drifts included: 1, 2, 3, 5, 6, 9, and 11; Table 1; Figure 1). The reasons for these losses are unclear, but each DASBR had two SPOT geolocation devices and the pattern of signal loss provides some clues, which are discussed further in section 4.4. The SPOT geolocation transmissions from Drift 1 stopped abruptly after 2 days on one SPOT and after 6 days on the other. Transmissions from Drift 2 became very intermittent on both SPOTs after the second day but continued to be received occasionally for another 93 days. Drift 3 was problematic for several reasons. Initially (Drift 3a) the mast was entangled with the floating line which prevented the spar buoy from floating vertically. During a retrieval attempt, the line became entangled in the ship's propeller and the recorder and hydrophones were lost. A second deployment (Drift 3b) with different instruments also resulted in an entanglement of the mast in the floating line. This DASBR was recovered a few days later and was deployed a third time (Drift 3c). Transmissions from this last deployment stopped abruptly after 8 days on one SPOT and after 58 days on the other. Transmissions from Drift 5 became intermittent after 15 days on one SPOT (but continued to be received occasionally for another 14 days) and stopped abruptly after 79 days on the other SPOT. Transmissions from Drift 6 stopped abruptly after 3 days on one SPOT and after 13 days on the other. Transmissions from Drifts 9 and 11 stopped abruptly on both SPOTs on the same day. The last transmissions from Drifts 2 and 5 were just 2-3 days prior to their scheduled pickup dates; attempts were made to search for these lost DASBRs using the 25X binoculars on the ship, but search conditions were poor and they were not found. An AIS ship track coincided closely with the sudden loss of Drift 9 and thus a ship strike is strongly suspected. Because four of the five most northern deployments were lost, acoustic survey effort is skewed towards the southern portion of the study area.

3.2 Beaked whale detections

Six distinct beaked whale signals were detected, including those from Cuvier's, Baird's, and Stejneger's beaked whales, as well as the BW43, BW37V, and BWC signal types. There were no detections of Blainville's beaked whales or BW70 signals. The numbers of detections of each signal type are shown in Table 4.

After reviewing the species classifications made by each analyst, there was agreement on 90% of species classifications for two-minute files containing beaked whale clicks, and all remaining discrepancies were resolved during the cooperative analyst review (Table 5). Most discrepancies (115/134) were the result of one analyst initially using a more conservative classification (e.g., “beaked whale”, “possible beaked whale”), which was later reclassified to the species level by both analysts. Many of these reclassifications were based on the context of having detections with clear species identification before and after the two-minute file with nondescript characteristics. Eight two-minute files were classified to a more general level than initial analyst decisions, resulting in detections of Cuvier’s (n=7) and Baird’s (n=1) beaked whales to be labeled as “possible beaked whales”. These files often contained low amplitude clicks, with long duration waveforms and consistent inter-click intervals, but undistinguishable spectral features.

Cuvier’s beaked whales were the most frequently detected beaked whale, with detections in 925 two-minute files across 14 drifts throughout the California Current (Figure 3). Baird’s beaked whales were detected in 31 two-minute files across 5 drifts, with 97 % (n=30) occurring in the southern California Current and 3% (n=1) in the northern California Current, offshore of Oregon (Figure 4). Stejneger’s beaked whales were detected in 42 two-minute files in one drift (#4) in the northern, offshore area of the California Current (Figure 4). The BW37V signal type was detected in 66 two-minute files across 2 drifts, with 98% (n=65) occurring on drift 4 in the northern, offshore region of the California Current, and 2% (n=1) in the offshore, central California Current (Figure 5). The BW43 signal type was detected in 135 two-minute files across 10 drifts, all of which occurred in the central and southern California Current (Figure 5). The BWC signal type was detected in 6 two-minute files across two different drifts (17 and 18) offshore of Baja California (Figure 5). All unidentified and possible beaked whale detections are shown in Figures 6 and 7, respectively. The diversity of beaked whale acoustic events per drift is shown in Figure 8 (drifts 4, 7, 8 and 10), Figure 9 (drifts 12-16), Figure 10 (drifts 17-20), and Figure 11 (drifts 21-23).

Table 3. Deployment and retrieval dates (UTC time zone), total deployment duration in days, number of 2-minute recording files, cumulative recording durations, and distance traveled. Differences in total deployment durations and cumulative recording durations are due to duty cycle schedules and/or expiration of memory/battery.

DASBR Drift	Deployment Date/Time (UTC)	Recovery Date/Time (UTC)	Deployment Duration (days)	# 2-min files	Cumulative Recording Duration (hh:mm)	Cumulative Recording Duration (days)	Distance Traveled (km)
4	7/25/2018 03:30	10/13/2018 00:36	79.9	11161	372:02	15.5	961
7	8/5/2018 14:48	10/22/2018 09:00	77.8	4187	139:34	5.8	446
8	8/16/2018 02:34	10/10/2018 16:53	55.6	3311	110:22	4.6	634
10	8/22/2018 02:11	10/22/2018 00:21	60.9	4385	146:10	6.1	664
12	8/30/2018 02:34	10/6/2018 17:08	37.6	2687	89:34	3.7	339
13	9/11/2018 20:35	10/23/2018 14:34	41.7	3004	100:08	4.2	420
14	10/5/2018 05:46	11/1/2018 16:55	27.5	1977	65:54	2.7	329
16	10/30/2018 14:33	11/21/2018 04:18	21.6	2356	78:32	3.3	206
17	10/31/2018 00:02	11/24/2018 04:31	24.2	8707	290:14	12.1	497
18	10/31/2018 09:58	11/23/2018 18:41	23.4	3879	129:18	5.4	145
19	11/1/2018 02:11	11/27/2018 14:20	26.5	2513	83:46	3.5	253
20	11/5/2018 14:04	11/22/2018 19:21	17.2	2479	82:38	3.4	300
21	11/6/2018 03:43	11/11/2018 09:29	5.2	1257	41:54	1.7	46
22	11/7/2018 14:04	11/27/2018 04:55	19.3	2333	77:46	3.2	145
23	11/22/2018 08:10	12/3/2018 00:25	10.7	3075	102:30	4.3	174
	TOTAL		**529.4**	**57311**	**1910:22**	**79.6**	**5559**

3.3 Sperm whale detections

Sperm whales were detected across 11 drifts throughout the California current using the restricted definition for an acoustic event (clicks must be received at angles greater than 20° declination relative to horizontal) (Figure 12). Sperm whale acoustic encounters were detected in 1736 two-minute files, and often occurred across several consecutive hours (Table 4).

3.4 NBHF detections

NBHF clicks were detected in 136 two-minute files across 11 drifts throughout the California Current (Figure 13). To investigate the variation in NBHF click types, the mean center frequency at -3dB was calculated for all clicks within each encounter. Considering the expected distribution of NBHF species along with the distribution of center frequencies in the study area, five general categories of NBHF clicks emerged, including: “<110 kHz”, “114-124 kHz”, “125-129 kHz”, 130-139 kHz”, and “140+ kHz” (Figure 9). There were only one or two click types detected on most drifts; however, all NBHF click types, except for “<110 kHz”, occurred on drift 7 (Figure 14).

Table 4. Total number of detections for each species and signal type in two-minute recording files for the full CCES DASBR dataset. The proportion of detections reflects the number of detections for each species relative to the total number of detections for all species (n=3,176).

Species Code	Scientific Name	Common Name	Total Detections	Proportion of detections
BW	*Ziphiid* whale	Unidentified beaked whale	9	0.2%
?BW	NA	Possible beaked whale	90	2.8%
ZC	*Ziphius cavirostris*	Cuvier's beaked whale	925	29.1%
BB	*Berardius bairdii*	Baird's beaked whale	31	1.0%
MS	*Mesoplodon stejnegeri*	Stejneger's beaked whale	41	1.3%
BW43	BW43	43 kHz peak frequency (possibly Perrin's beaked whale)	136	4.3%
BW37V	BW37V	37 kHz valley frequency (possibly Hubbs' beaked whale)	66	2.1%
BWC	BWC	Cross Seamount beaked whale (possibly gingko-toothed beaked whale)	6	0.2%
PM	*Physeter macrocephalus*	Sperm whale	1736	54.7%
NBHF	NBHF	Narrow band high frequency	136	4.3%

Table 5. Confusion matrix of initial and final classifications of two-minute files containing confirmed or possible beaked whale echolocation clicks. Initial classifications were based on a single analyst's review; final classifications were achieved by a consensus of up to three analysts (see text). Species codes are defined in Table 4.

	Final								
Initial	ZC	BB	MS	BW37V	BW43	BWC	BW70	BW	?BW
ZC	869	0	0	0	0	0	0	0	7
BB	2	12	0	0	0	0	0	0	1
MS	0	0	34	0	0	0	0	0	0
BW37V	0	0	0	53	0	0	0	0	0
BW43	0	0	0	0	114	0	0	0	0
BWC	0	0	0	0	0	6	0	0	0
BW70	0	0	0	0	0	0	0	1	0
BW	20	0	0	0	16	0	0	4	3
?BW	34	19	7	13	6	0	0	5	79

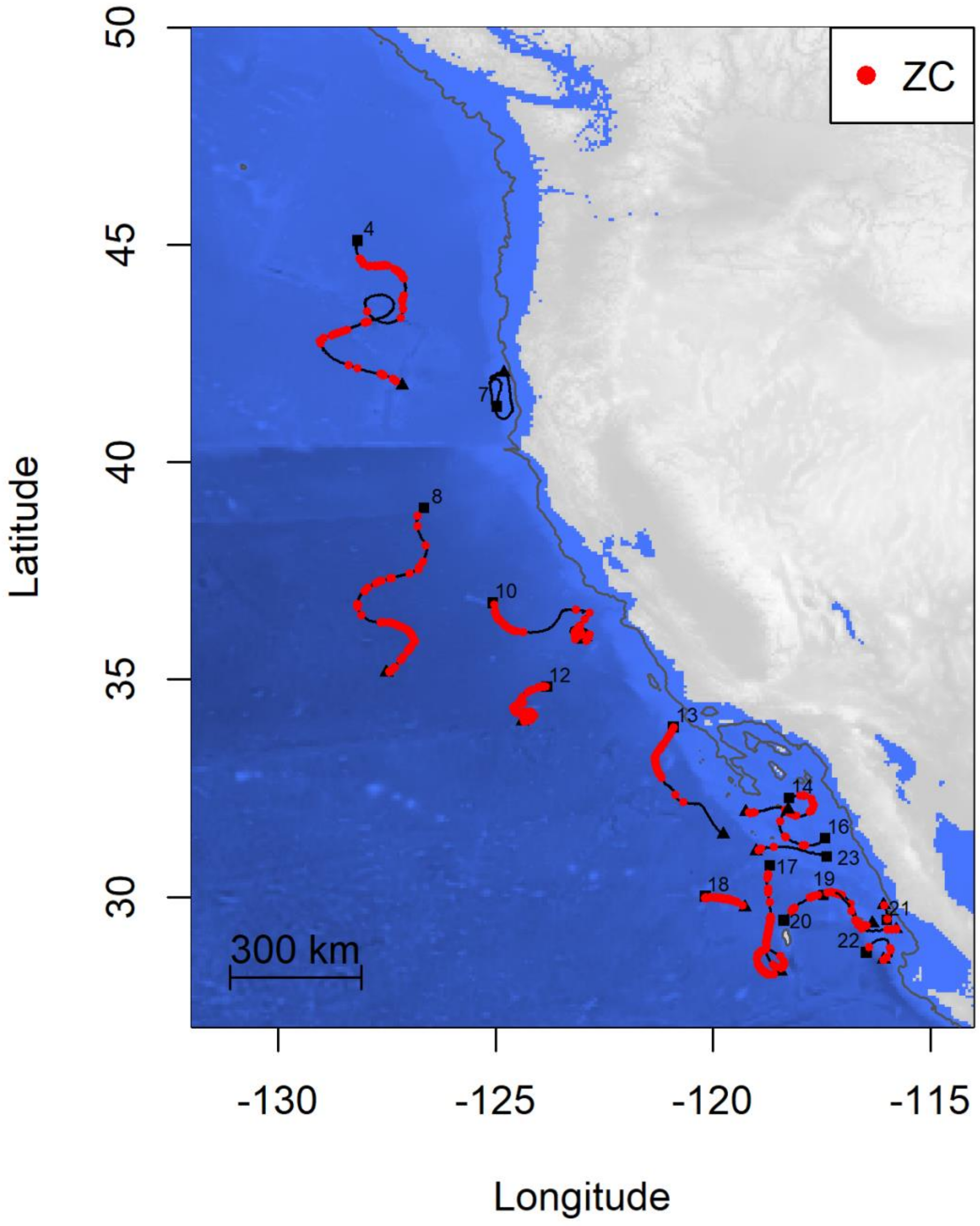

Figure 3. Acoustic detections of Cuvier's beaked whale (ZC) along recovered DASBR drifts. Black squares and triangles show drift origin and recovery locations, respectively. Gray line indicates the 500 m isobath.

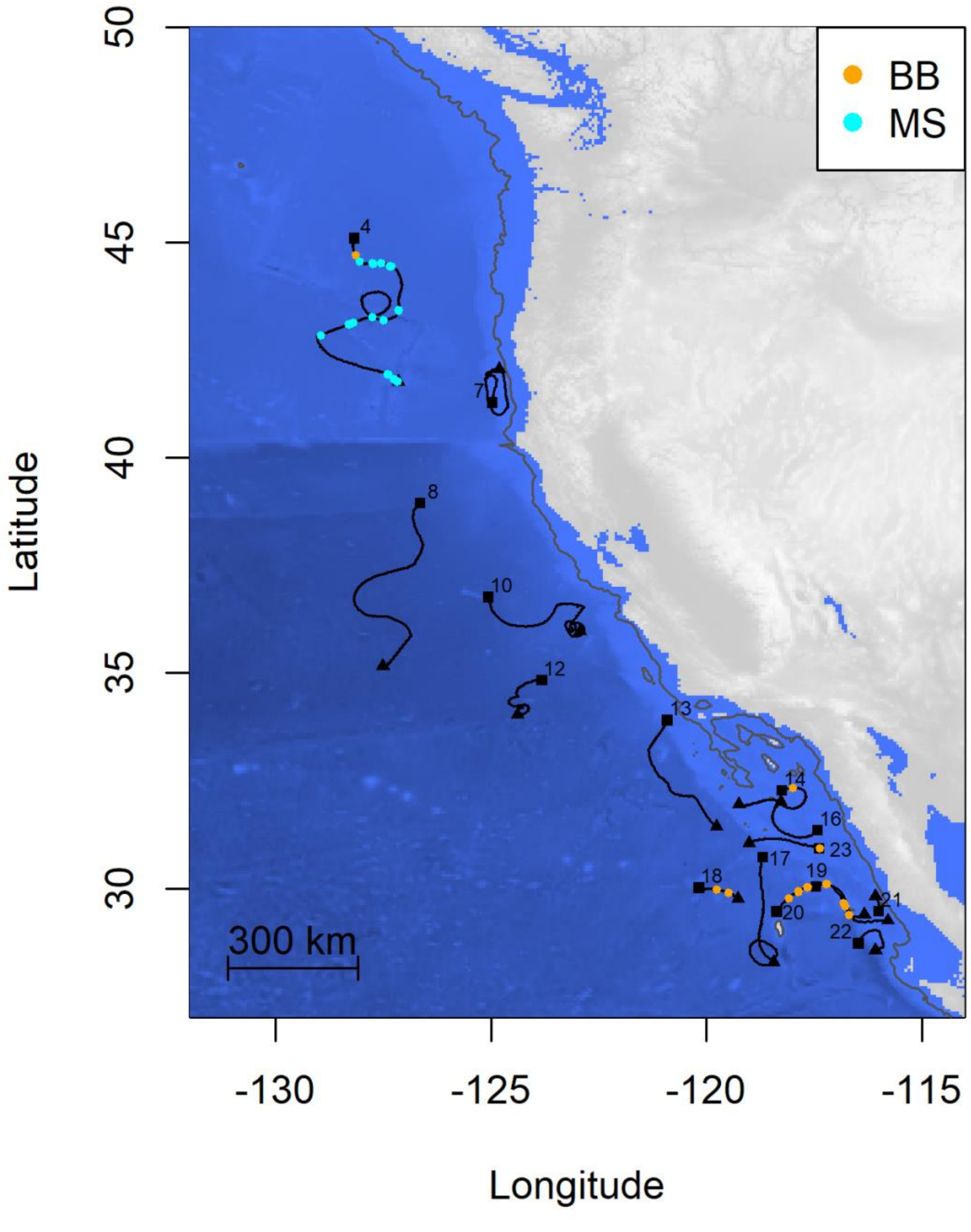

Figure 4. Acoustic detections of Baird's (BB) and Stejneger's (MS) beaked whales along recovered DASBR drifts. Black squares and triangles show drift origin and recovery locations, respectively. Gray line indicates the 500 m isobath.

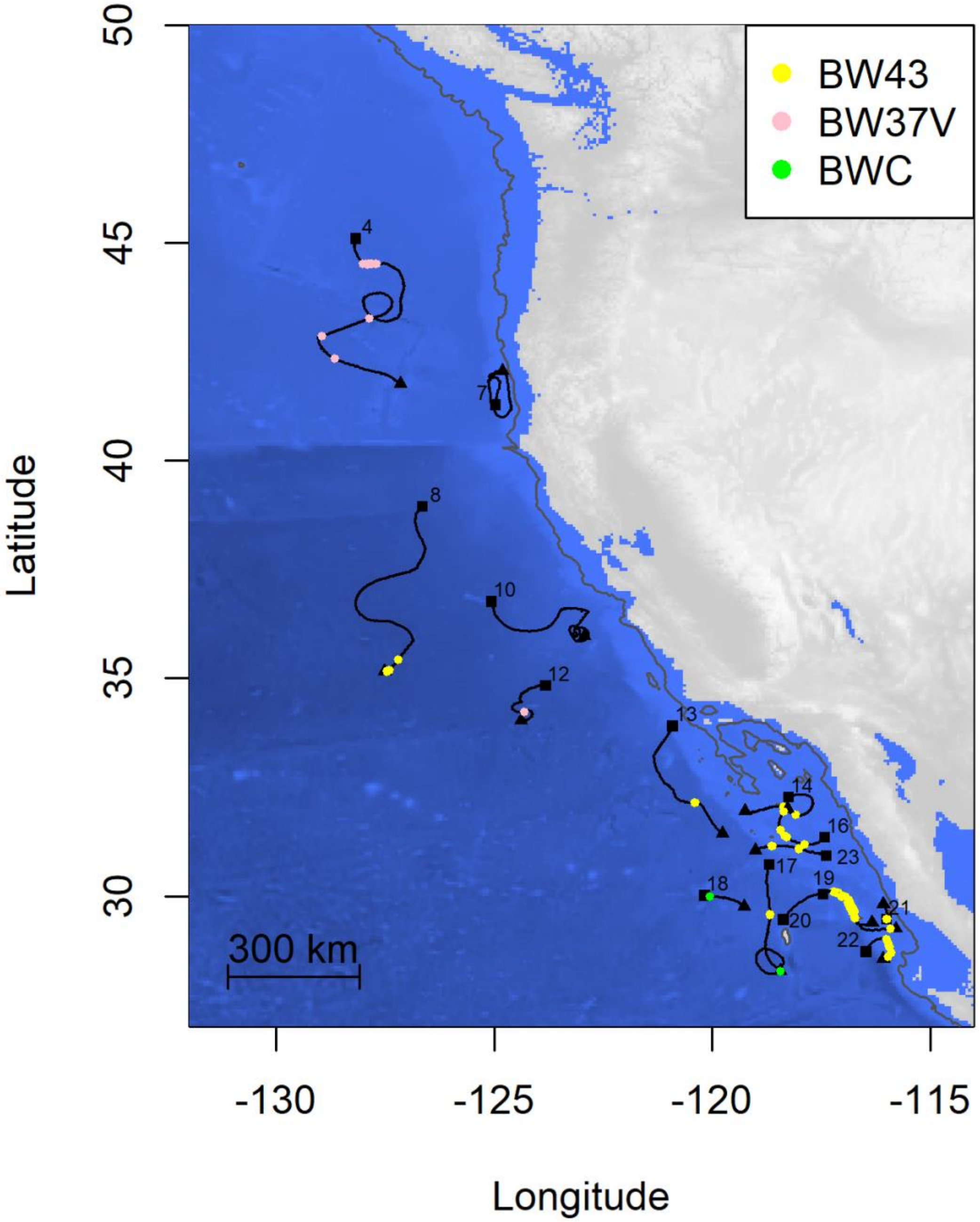

Figure 5. Acoustic detections of BW43, BW37V, and BWC beaked whale signals along recovered DASBR drifts. Black squares and triangles show drift origin and recovery locations, respectively. Gray line indicates the 500 m isobath.

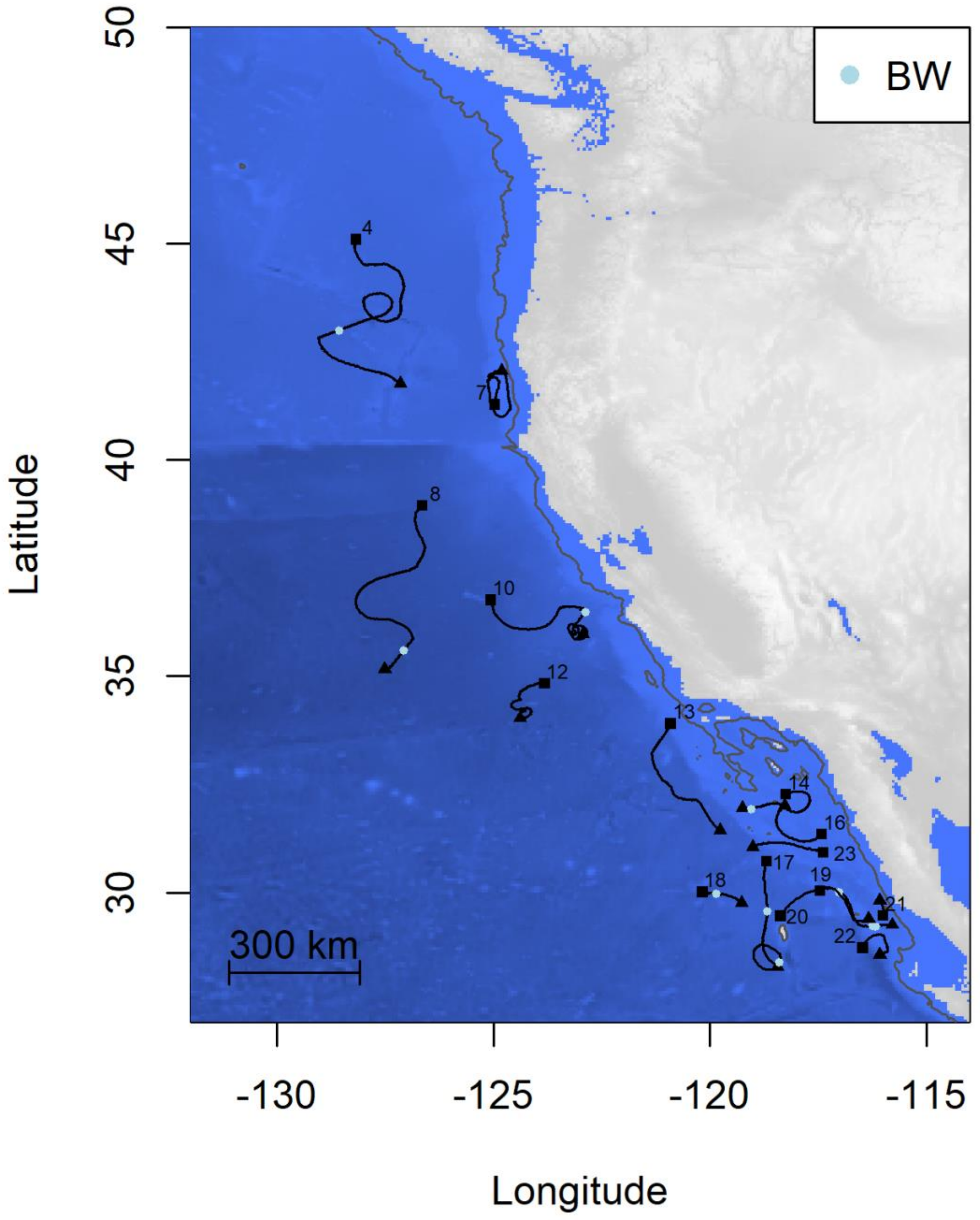

Figure 6. Acoustic detections of unidentified species of beaked whales along recovered DASBR drifts. Black squares and triangles show drift origin and recovery locations, respectively. Gray line indicates the 500 m isobath.

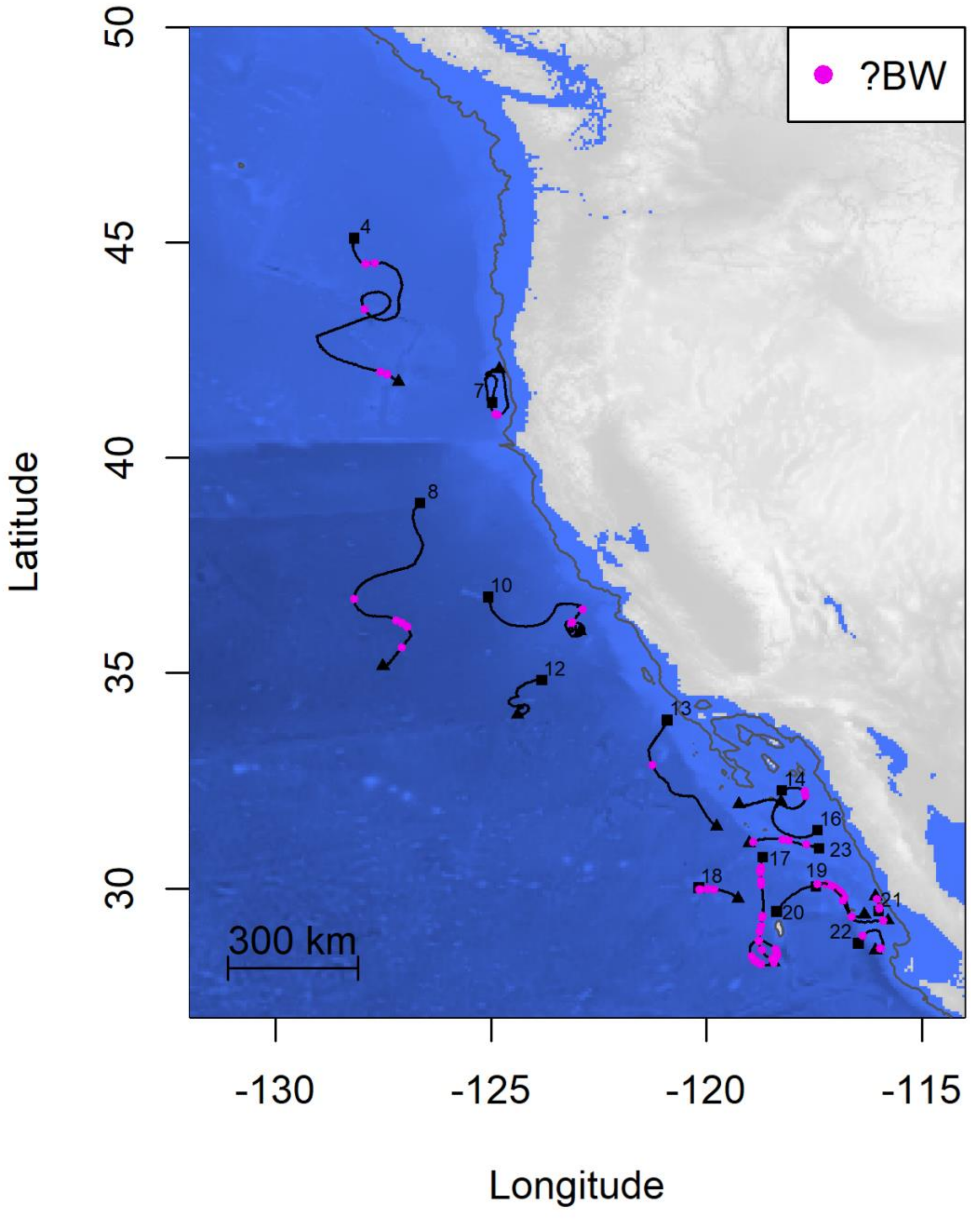

Figure 7. Acoustic detections of possible beaked whale signals along recovered DASBR drifts. Black squares and triangles show drift origin and recovery locations, respectively. Gray line indicates the 500 m isobath.

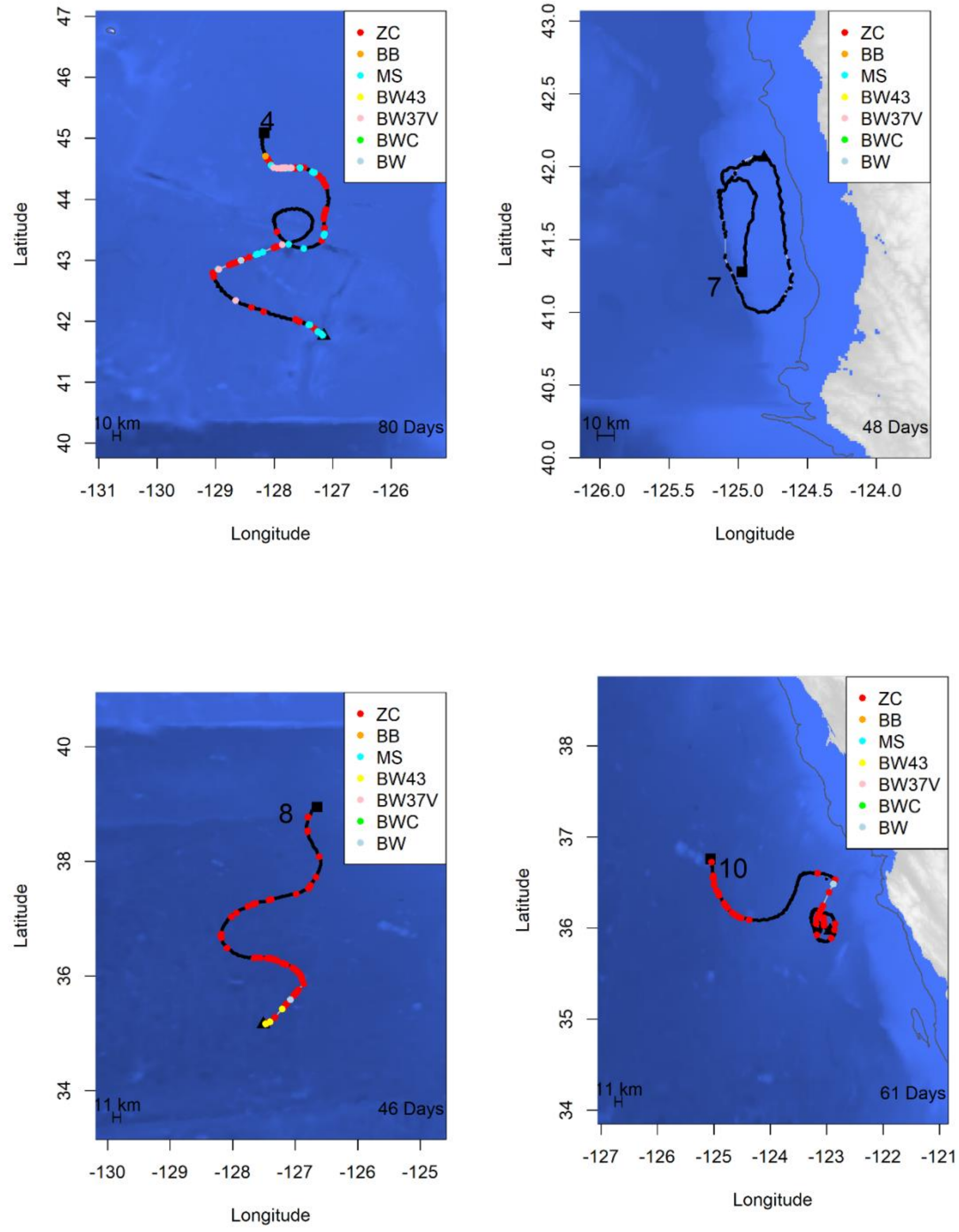

Figure 8. Acoustic detections of distinct beaked whale signals along the track of DASBR drifts 4, 7, 8, and 10. Deployment duration is shown in the lower right corner. Black squares and triangles show drift origin and recovery locations, respectively. Gray line indicates the 500 m isobath. Note: NBHF and Pm detections shown in separate figures.

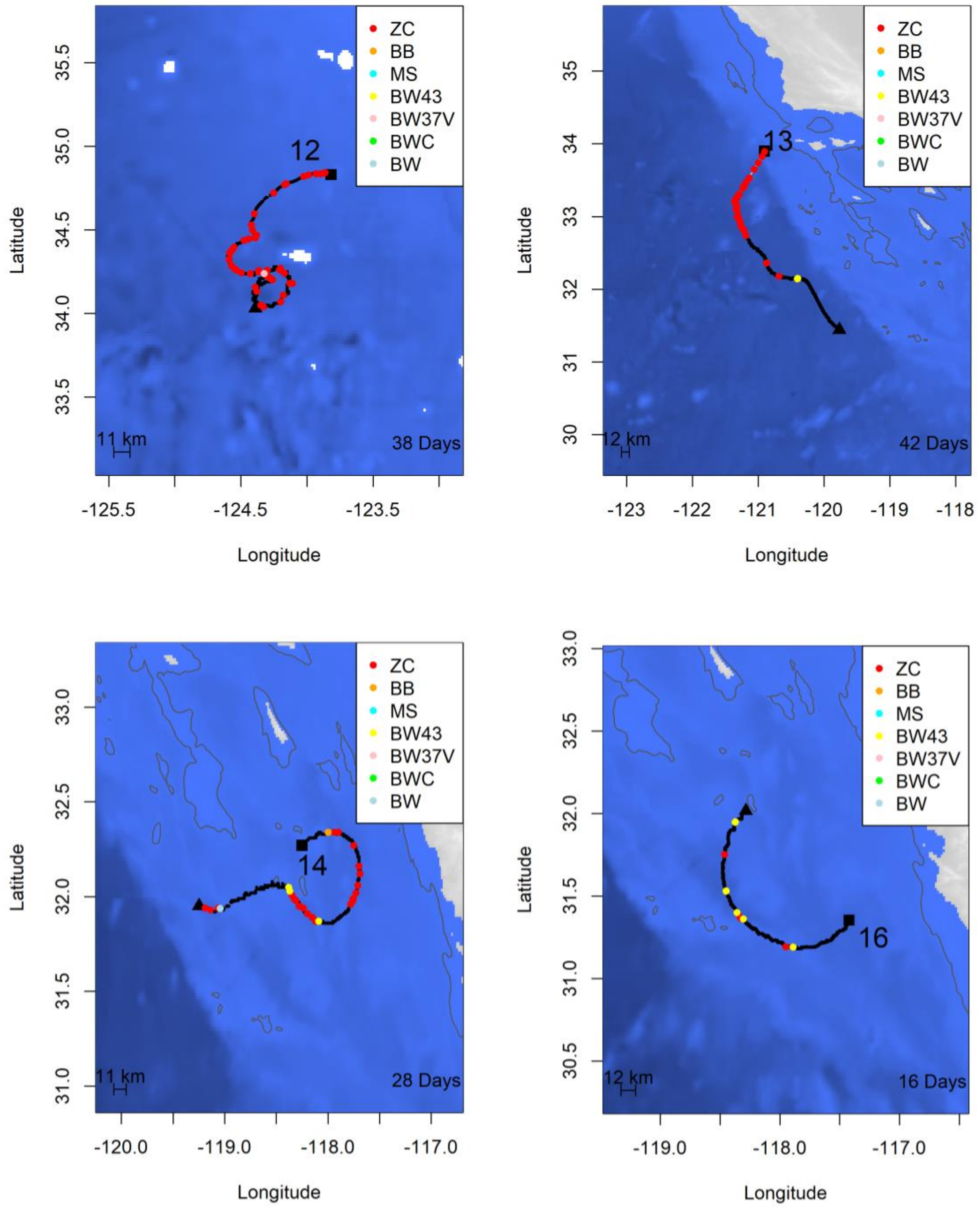

Figure 9. Acoustic detections of distinct beaked whale signals along the track of DASBR drifts 12, 13, 14, and 16. Deployment duration is shown in the lower right corner. Black squares and triangles show drift origin and recovery locations, respectively. Gray line indicates the 500 m isobath. Note: NBHF and Pm detections shown in separate figures

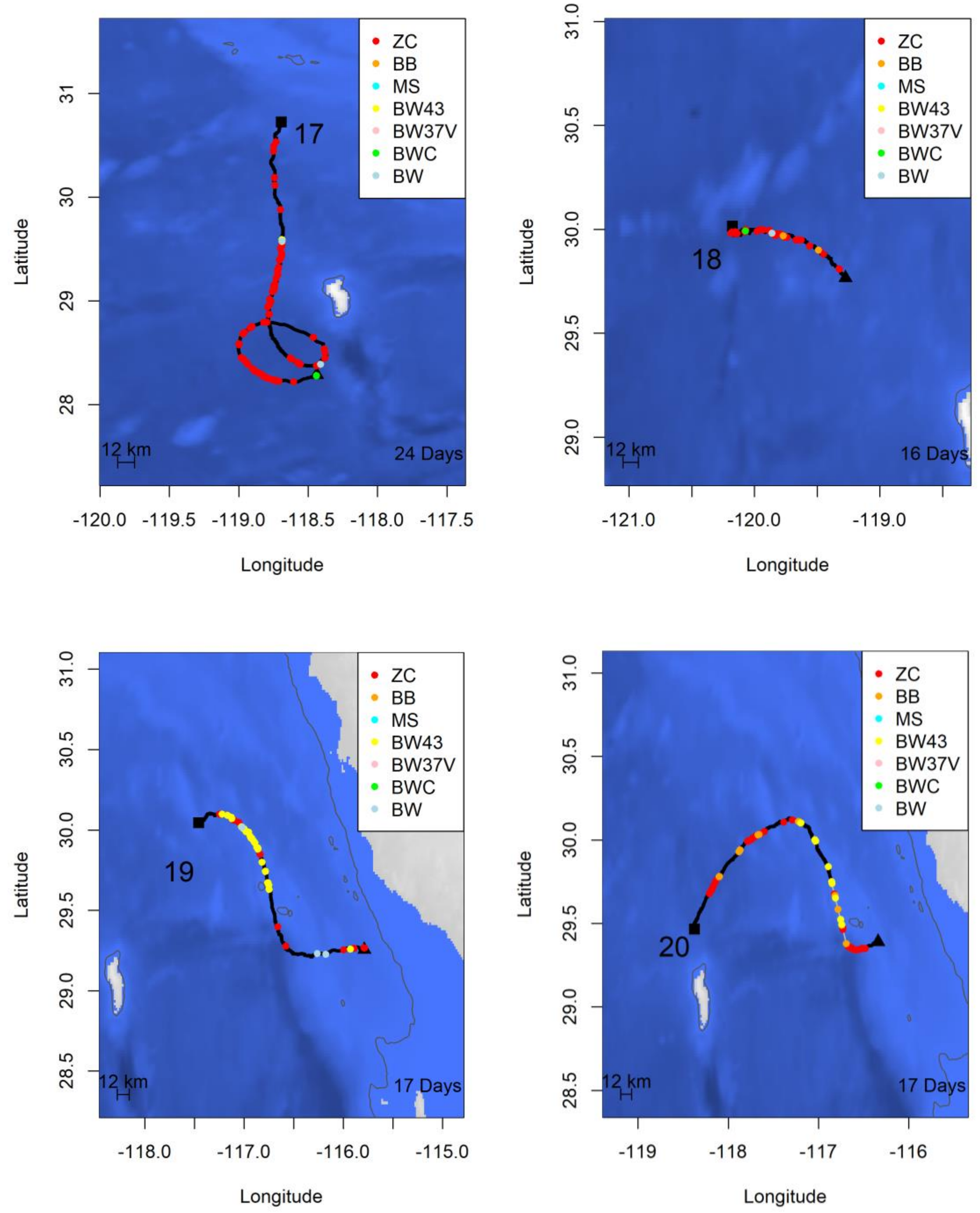

Figure 10. Acoustic detections of distinct beaked whale signals along the track of DASBR drifts 17, 18, 19, and 20. Deployment duration is shown in the lower right corner. Black squares and triangles show drift origin and recovery locations, respectively. Gray line indicates the 500 m isobath. Note: NBHF and Pm detections shown in separate figures.

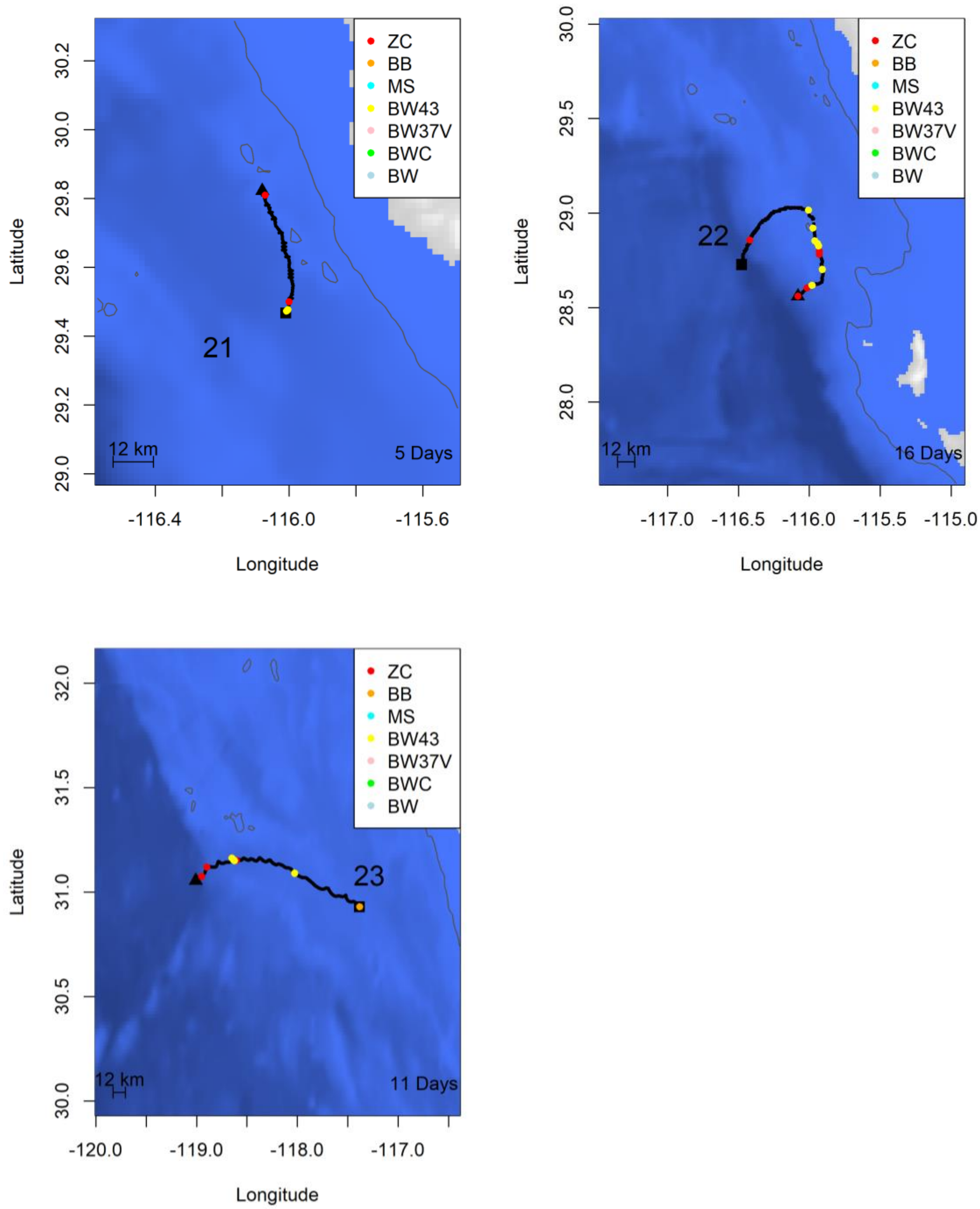

Figure 11. Acoustic detections of distinct beaked whale signals along the track of DASBR drifts 21, 22, and 23. Deployment duration is shown in the lower right corner. Black squares and triangles show drift origin and recovery locations, respectively. Gray line indicates the 500 m isobath. Note: NBHF and Pm detections shown in separate figures.

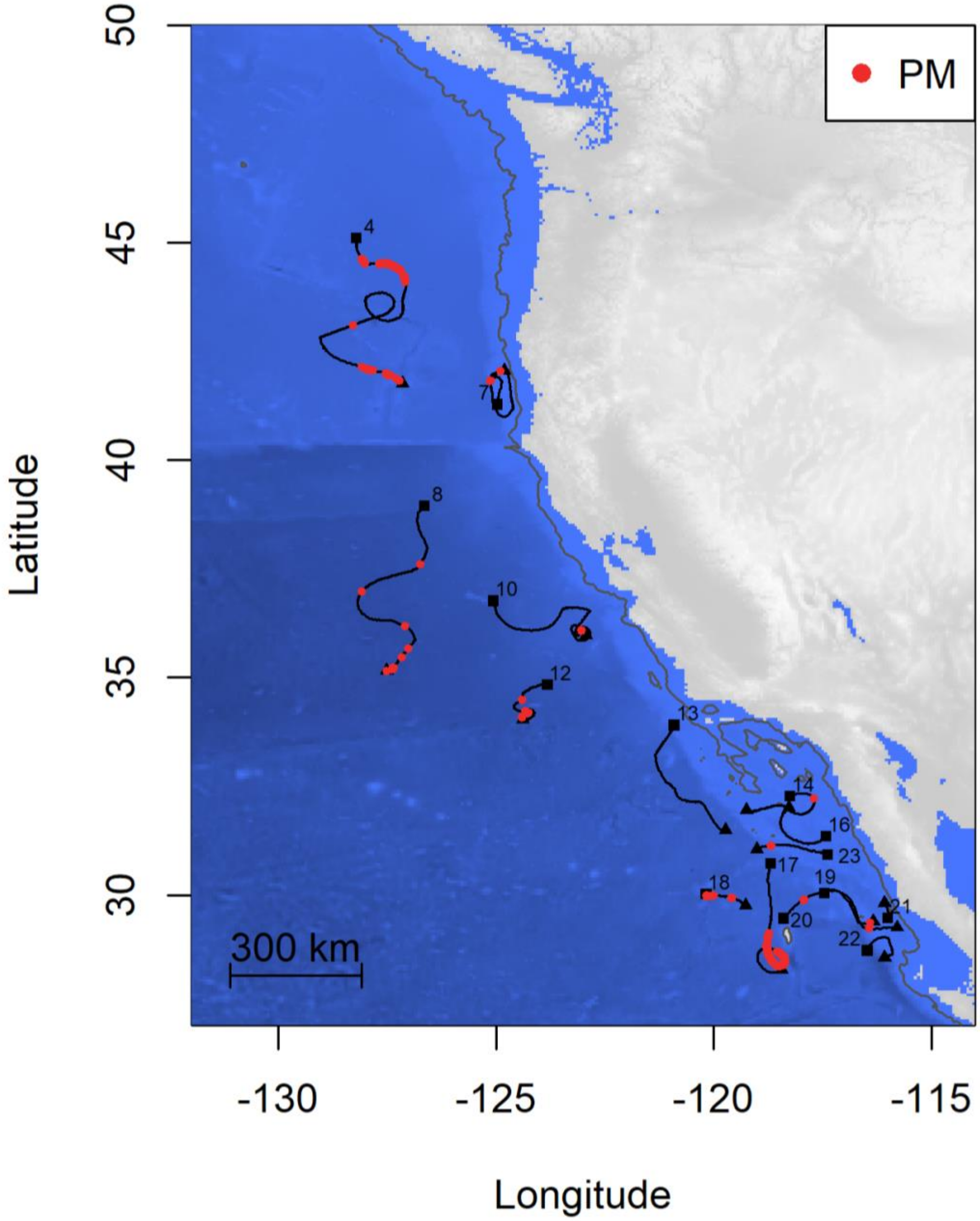

Figure 12. Acoustic detections of sperm whale (PM) echolocation clicks along recovered DASBR drifts. Black squares and triangles show drift origin and recovery locations, respectively. Gray line indicates the 500 m isobath. Sperm whale events are only plotted and included in analysis if the direct-path signal arrived from below the hydrophone array at a declination angle greater than 20° from horizontal.

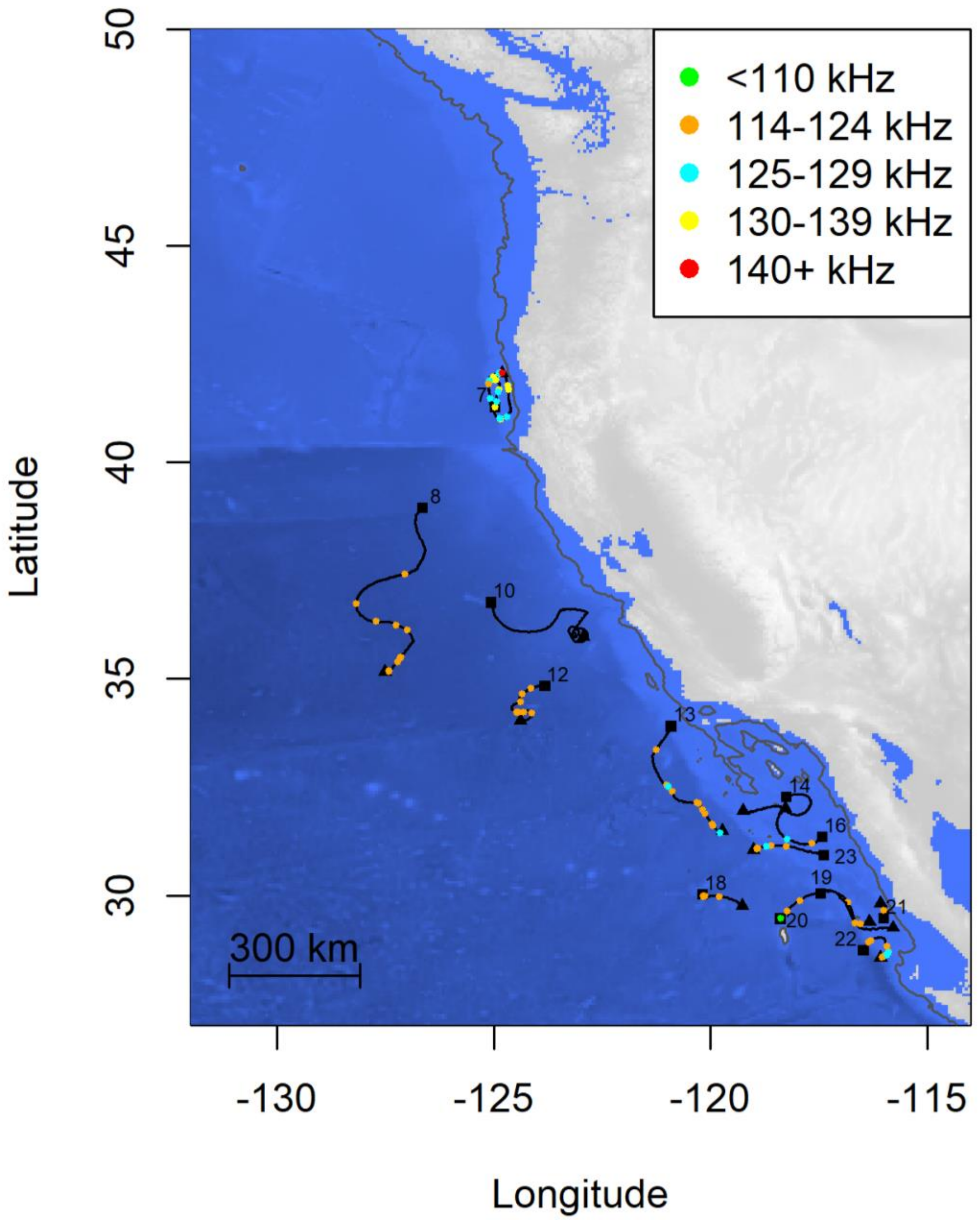

Figure 13. Acoustic detections of NBHF echolocation clicks along recovered DASBR drifts. Black squares and triangles show drift origin and recovery locations, respectively. Acoustic events are color-coded by their mean center frequency

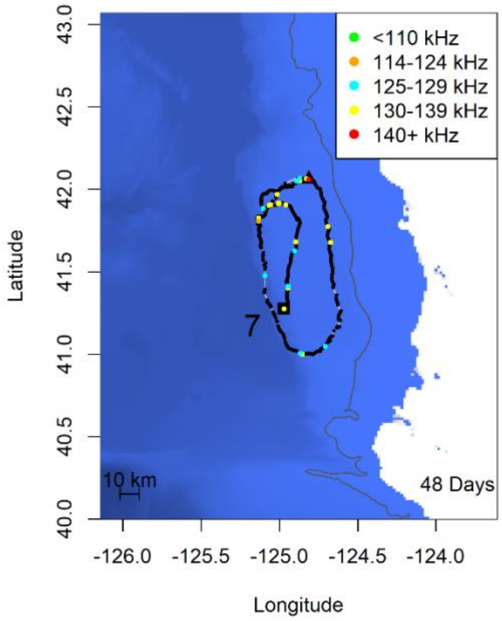

Figure 14. Acoustic detections of distinct NBHF signals along the track of DASBR drift 7. Deployment duration is shown in the lower right corner. Black squares and triangles show drift origin and recovery locations, respectively. Acoustic events are color-coded by their mean center frequency

4 Discussion

The acoustic recordings collected from 15 drifting DASBRs along the US West Coast between Jul 25 and Dec 3, 2018 indicate the presence of 6 distinct beaked whale signals, sperm whales, and multiple types of NBHF signals attributed to harbor and Dall's porpoises, as well as dwarf and pygmy sperm whales. The DASBRs provided an effective means of surveying deep-diving odontocetes, which are otherwise particularly challenging to survey with visual methods. The results of this project provide useful data products to estimate the density of beaked whales throughout the California Current, although additional analyses will be required to similarly estimate the densities of sperm whales and individual NBHF species. Overall, this survey effort and analysis provide further support for the use of drifting buoys to acoustically monitor cetaceans in pelagic environments.

4.1 Beaked whales

The use of the Matched Template Classifier in PAMGuard was particularly helpful to identify beaked whale clicks among detections of delphinid echolocation and noise. There was high agreement among analysts in the classification of species-specific beaked whale signals, which provides confidence in the use of this dataset as a ground-truth to develop more automated routines for beaked whale classification.

Positive sea surface temperature (SST) anomalies during 2018 may have contributed to a northward shift in the range of some cold-temperate species (Stejneger's and BW37V beaked whales), and the first BWC detections in the southern California Current may also have been the result of a northward shift of this warm-temperate to tropical species. Further discussion of the distribution and abundance of each species and unique signal type is discussed below.

4.1.1 Cuvier's beaked whale

Cuvier's beaked whales continue to be the most commonly detected beaked whale throughout the extent of our study area in the California Current between August and December 2018. Cuvier's beaked whales were detected in a greater fraction of the sound files in our study (1.6%) than in the 2016 study (0.8%, Keating et al., 2018). Anomalously warm conditions were present during the 2018 study, particularly in southern California and Baja California (Cheng et al., 2019; Lonhart et al., 2019; Thompson et al., 2019), however the distribution of Cuvier's beaked whales did not seem to appreciably shift compared to previous survey years. Previous DASBR surveys did not cover the area off Baja California, but our study shows that Cuvier's beaked whales are the most common species there too.

4.1.2 Baird's beaked whale

Compared to the 2016 PASCAL survey in which Baird's beaked whale detections were distributed throughout the California Current, in 2018 there were fewer acoustic encounters of Baird's beaked whales occurring over a smaller area. In both surveys, the highest densities of detections in the southern California Current were found on drifts that were closer to the shelf break. This matches the distribution of Baird's beaked whale sightings on previous SWFSC surveys (Figure 10 in Hamilton et al., 2009). After publication of Keating et al., (2018), some of the Baird's beaked whale events were re-classified as unidentified or Cuvier's beaked whales (Barlow, pers. comm.). Near-bottom Cuvier's beaked whales may have been misclassified as Baird's beaked whales in that report because the effect of bottom reflections on signal characteristics was not understood. Prior to any concerted study of Baird's beaked whales from the 2016 PASCAL survey and this survey, a careful review of all Baird's beaked whale detections from both surveys is needed to ensure consistent classification.

Baumann-Pickering et al., (2014) reported Baird’s beaked whales as the second most encountered beaked whale species in southern California, which is inconsistent with our observations. Considering the four distinct beaked whale signals that we observed in southern California in 2018, Baird’s beaked whale was the third-most encountered species (n=31) after Cuvier’s (n=925) and BW43 (n=136), with only BWC signals occurring less frequently. The vast majority of Baird’s beaked whale detections (96 of 116) reported from Southern California in Baumann-Pickering et al., (2014) occurred from one location during Mar-May 2009, whereas the CCES 2018 survey occurred during July through December 2018. In addition to dissimilar seasonal coverage, the geographical areas surveyed by PASCAL and CCES predominantly cover offshore areas whereas the Baumann-Pickering et al., (2013) study examined nearshore and island associated areas. The disparate temporal and geographical coverage among these studies may explain the different detection rates of Baird’s beaked whales.

4.1.3 Stejneger’s beaked whale

In 2018, all detections of Stejneger’s beaked whale occurred in the northern California current, which reflects the expected cold-temperate distribution observed in other studies (Mead 1989; Baumann-Pickering et al., 2014; Keating et al., 2018). In 2016, acoustic detections of Stejneger’s beaked whale occurred offshore Washington (the northern extent of the study area), to Point Conception in the south (Keating et al., 2018); however, in 2018 detections only occurred in the northern California Current, offshore of Oregon. Sea surface temperature anomalies (relative to 1982-2010 monthly means) in the central and northern California Current may be influencing the distribution of Stejneger’s beaked whales, as low SST anomalies were present in August 2016 and high SST anomalies were present in August 2018 (Cheng et al., 2019; Lonhart et al., 2019; Thompson et al., 2019).

4.1.4 BW37V

Detections of the BW37V signal type primarily occurred in the northern, offshore region of the California Current, although one detection occurred offshore of central California (Figure 5). Results from the 2016 PASCAL survey showed a similar distribution of BW37V (referred to as “BW39V” in Keating et al., 2018) acoustic encounters extending from the Oregon-Washington border to Point Conception in the south. The lack of detections in southern California in 2018 may be attributed to anomalously warm summer SST conditions (Thompson et al., 2019). Griffiths et al., (2019) hypothesized that the BW37V signal was produced by Hubb’s beaked whales (*Mesoplodon carlhubbsi*), which are considered a cold-temperate species, with a known distribution extending from southern California through Washington along the US west coast (Yamada et al., 2012; Mead, Walker and Houck 1982). The distribution of BW37V encounters from the 2016 and 2018 surveys is consistent with the expected distribution for Hubb's beaked whales.

4.1.5 BW43

A high density area of 'BW43' echolocation clicks was identified offshore of the coast of Baja California, potentially indicating a previously undescribed preferred habitat for the beaked whale that produces the BW43 signal. Results from the 2016 PASCAL survey also indicate a southern distribution for this signal in the California Current, although the BW43 encounters were restricted to further offshore waters in 2016 compared to 2018. Baumann-Pickering et al., (2013) proposed the hypothesis that the BW43 signal type is made by Perrin's beaked whale (*Mesoplodon perrini*). Our observations are generally consistent with this hypothesis but would extend the known range of this species south to approximately 29° N (Pitman et al., 2009; Brownell et al., 2012).

4.1.6 BWC

The BWC signal type was first documented at Cross Seamount near Hawaii (McDonald et al., 2009), resulting in its designation as the "Cross Seamount beaked whale" or "BWC", and it has since been detected throughout the central and western tropical Pacific. However, it has never been detected as far east as the locations included in our study (Baumann-Pickering et al., 2014). Record high sea surface temperatures during summer 2018 in southern California and northern Baja California may have facilitated the influx of this species (Thompson et al., 2019). It is also possible that BWC has historically gone undetected due to infrequent monitoring, and the overall low detectability of the BWC's high frequency, low source level and broad bandwidth echolocation signal (Baumann-Pickering et al., 2013). Although the origin of this signal type remains unknown, Baumann-Pickering et al., (2014) proposed that BWC signals are produced by the gingko-toothed beaked whale (*Mesoplodon gingkodens*). The locations of the BWC encounters in the CCES DASBR datasets support this hypothesis, as they fall within the presumed distribution of gingko-toothed beaked whales (Jefferson et al., 2015) based on the stranding record.

Unlike most other beaked whale species described to date, a strong diel cycle has been documented for the BWC signal (McDonald et al., 2009), with most acoustic activity occurring at nighttime. All BWC detections in the CCES dataset support this nocturnal foraging strategy. It is also believed that the species producing the BWC signal forages at relatively shallow depths compared to most other beaked whale species (Baumann-Pickering et al., 2014), and our observations support this hypothesis as well. The bearing angles were above horizontal, suggesting that the whales were foraging at the depth of the hydrophones (100-150 m depth) and shallower.

4.2 Sperm whales

In contrast to the short duration encounters of beaked whale and NBHF signals, sperm whale acoustic detections were nearly continuous in some areas. Barlow and Taylor (2005) reported that sperm whale clicks can be detected at ranges of 37 km on towed hydrophone arrays. The low self-noise of DASBRs may result in an even greater detection range; however, the local environment (temperature profile, bathymetry, and ambient noise) will also strongly influence the propagation of sperm whale clicks. Given the long range of sperm whale detectability, it is possible that multiple groups of sperm whales were simultaneously detected when the DASBRs drifted through high-density areas. The multi-path arrivals of some sperm whale signals may be useful to estimate the range to the source (Thode 2005), which could in turn be used to distinguish multiple sperm whale groups. Further analytical effort will be needed to distinguish multiple groups and estimate sperm whale detection rates before this data can be used to estimate density.

4.3 NBHF click types

There are four species in the California Current known to produce NBHF signals, including harbor and Dall's porpoises, dwarf and pygmy sperm whales. Although the NBHF signals exhibit many similar spectral and temporal characteristics (narrow bandwidth, high frequency content, long duration), the variation in the mean center frequency of NBHF encounters suggests that center frequency may be a useful feature to distinguish NBHF species (Griffiths et al., *submitted*).

The "140+ kHz" click type occurred in the nearshore section of drift 7 in the northern California Current, corresponding to the only habitat likely suitable for harbor porpoises (depths <200 m). All of the "130-139 kHz" click type detections also occurred on drift 7, although in deeper areas of the drift. The geographic restriction of the "130-139 kHz" encounters to the northern, offshore region of the California Current corresponds with the known distribution of Dall's porpoise. The majority of the "114-124 kHz" encounters occurred in the central and southern California Current. The abundance of detections offshore of the California Current suggest these clicks from *Kogia* spp. The intermediate "125-129 kHz" click type was detected throughout the extent of the study area, and likely represents acoustic encounters from both *Kogia* spp. and Dall's porpoise. Lastly, there were 7 detections of the "<110 kHz" click type, all of which occurred along drift 20 in the southern California Current, near the island of Guadalupe offshore of Baja California. The source of these clicks is still unknown, as the restricted range and unusual spectral features of this click type do not correspond to any click types described for odontocetes in this region.

4.4 DASBR Loss

This survey experienced a much greater DASBR loss rate (7 of 22 deployments) than the 2016 PASCAL survey (which lost none, Keating et al., 2018). Only three DASBRs would have been lost (# 1, 6 and 11) if the deployments in 2018 were as short as in 2016 (less than 24 days), so longer deployments are associated with increased risk of loss. For the two cases when both satellite transmitters stopped at the same time, a ship strike is likely. In the cases when loss was preceded by a long period of very intermittent transmissions, the spar buoy mast may have been entangled in the lines so that transmitters were submerged most of the time. This condition was also seen during the deployment of drift 3 and on several recovered DASBRs. Losses on future DASBR surveys may be reduced by 1) shorter deployments (<30 days), 2) addition of a radar reflector to warn ships thereby reduce the likelihood of hitting DASBRs, and 3) a DASBR redesign that prevents the mast entanglement seen in 2018.

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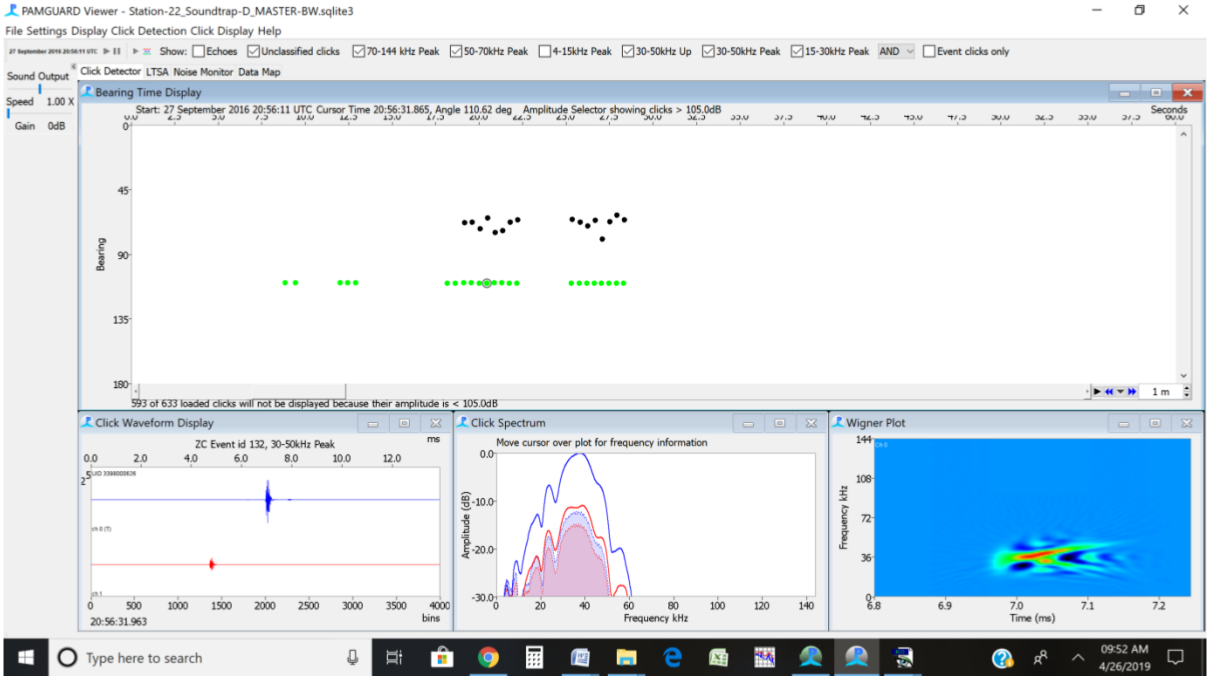
7 Appendix A: Beaked Whale Pulse Species Identification Guide

ZC: *Ziphius cavirostris*, Cuvier's beaked whale

Ziphius template (gray). Strong null at about 27 kHz, with peaks at 32-40 kHz, 22-24 kHz and ~18 kHz. Upsweep usually evident. Wigner plots shows a "kickstand" (downsweep appearing after the upsweep). Sometimes this kickstand can just appear as a dot. At great range, the 18 and 22 kHz peaks may be higher than the 32-40 kHz peak and the Wigner can just show the downsweep. IPI= 0. 3-0. 5 sec, PPS= 2-3. (IPI= inter-pulse interval, PPS= pulses per sec)



PAMGUARD Viewer - Station-22_Soundtrap-D_MASTER-BW.sqlite3

Show: ☐Echoes ☑Unclassified clicks ☑70-144 kHz Peak ☑50-70kHz Peak ☐4-15kHz Peak ☑30-50kHz Up ☑30-50kHz Peak ☑15-30kHz Peak AND ☐Event clicks only

Speed 1.00 X

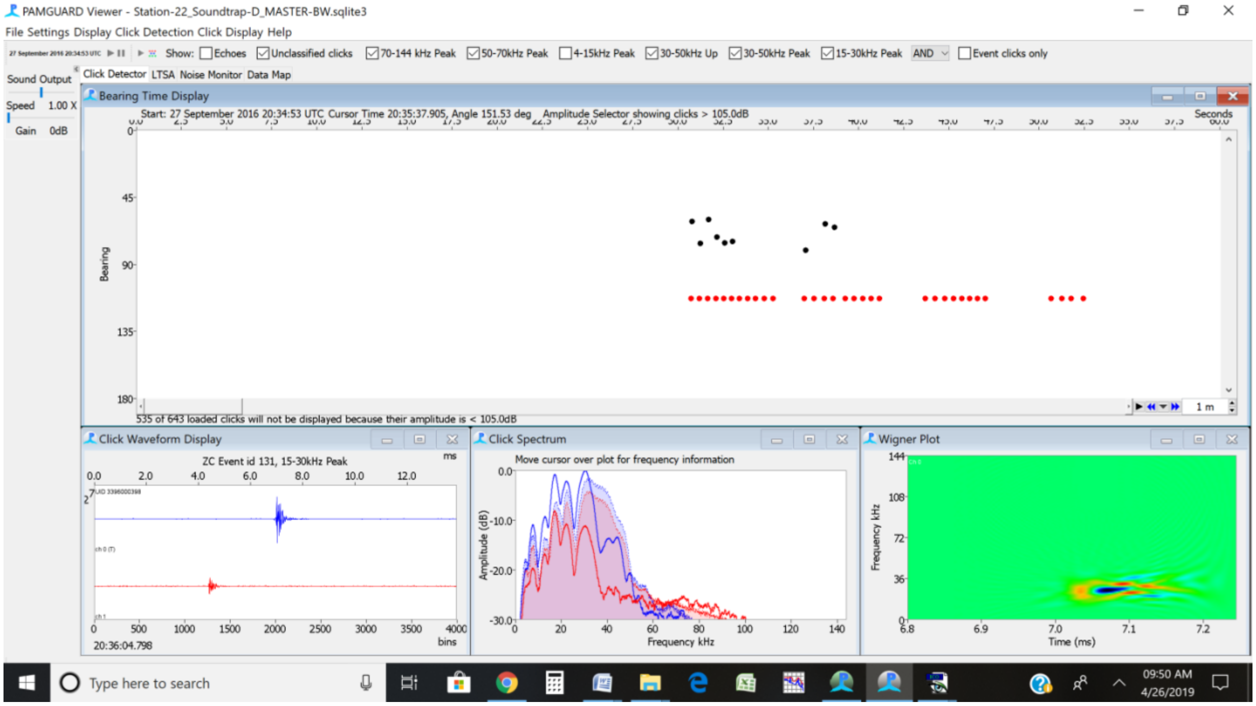
Gain 0dB

Start: 27 September 2016 20:56:11 UTC Cursor Time 20:56:31.865, Angle 110.62 deg Amplitude Selector showing clicks > 105.0dB

593 of 633 loaded clicks will not be displayed because their amplitude is < 105.0dB

ZC Event id 132, 30-50kHz Peak

Move cursor over plot for frequency information



PAMGUARD Viewer - Station-22_Soundtrap-D_MASTER-BW.sqlite3

Show: ☐Echoes ☑Unclassified clicks ☑70-144 kHz Peak ☑50-70kHz Peak ☐4-15kHz Peak ☑30-50kHz Up ☑30-50kHz Peak ☑15-30kHz Peak AND ☐Event clicks only

Speed 1.00 X

Gain 0dB

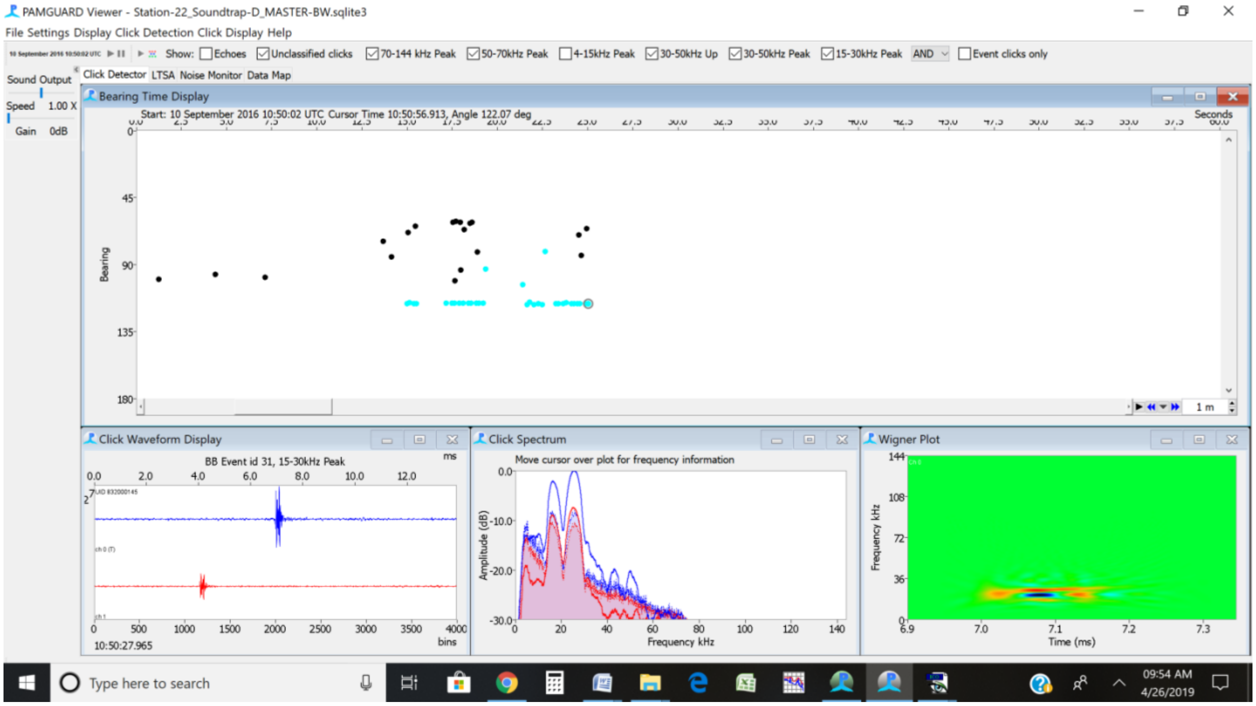
Start: 27 September 2016 20:34:53 UTC Cursor Time 20:35:37.905, Angle 151.53 deg Amplitude Selector showing clicks > 105.0dB

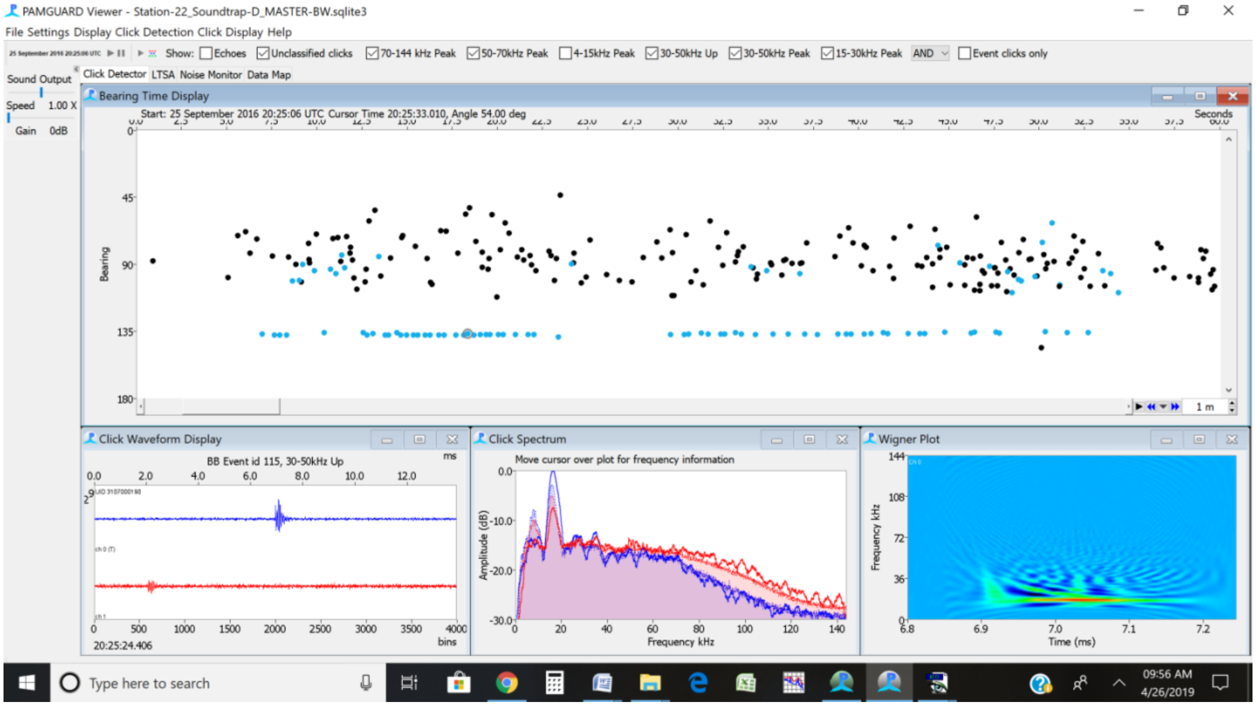
535 of 643 loaded clicks will not be displayed because their amplitude is < 105.0dB

ZC Event id 131, 15-30kHz Peak

Move cursor over plot for frequency information

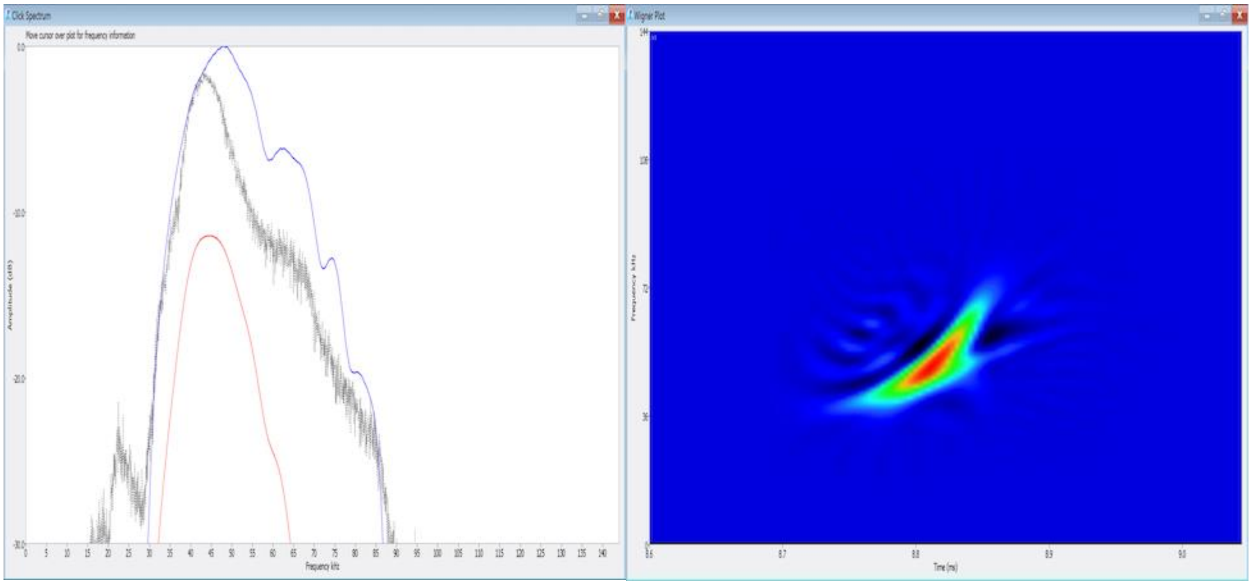
BB: *Berardius bairdii,* Baird's beaked whale. Low frequency click, often with multiple peaks. Upsweep is sometimes present, but pulses will look pretty flat on this scale. Peaks are expected at 15-16 kHz, 25-26 kHz, and, sometimes, 9 kHz and 35-45 kHz. Can produce dolphin-like clicks as well as these longer pulses. Clicks can come from above the hydrophone. IPI= 0. 20-0. 25 sec, PPS= 4-5.



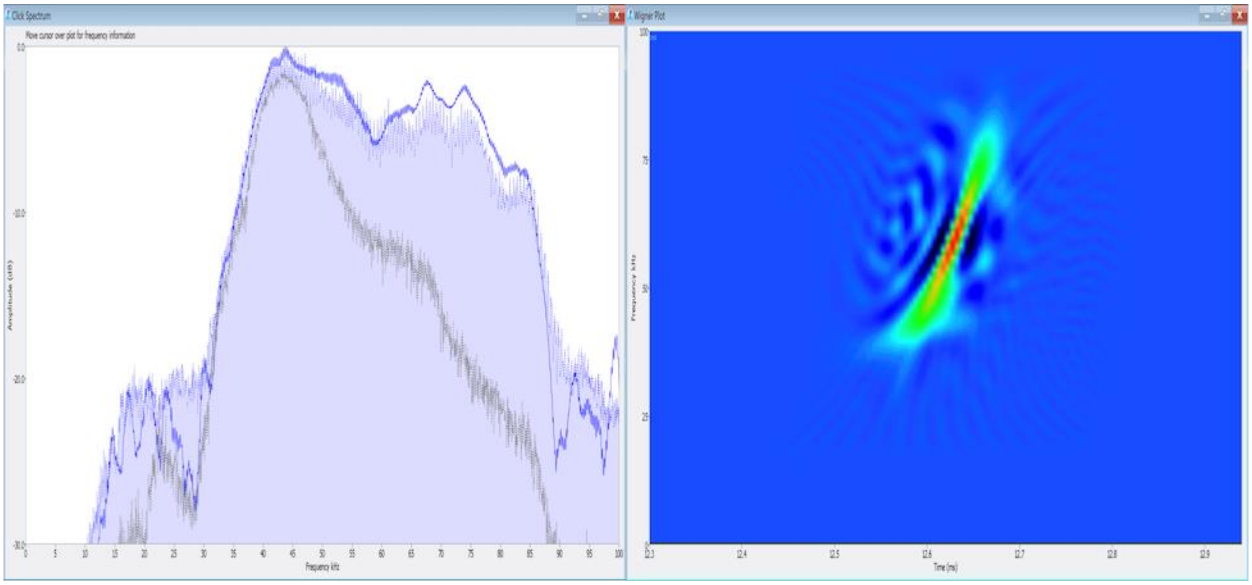


BW43: Possibly Perrin's beaked whale

BW43 (gray template)- Peak frequency at 43 kHz. Some higher peaks may be evident if the animal is close. The left limb declines less steeply than with BW46. Wigner is "crescent moon" shaped and lower limb, if present is strongly upswept. IPI= ~0. 22; PPS= 4-5.

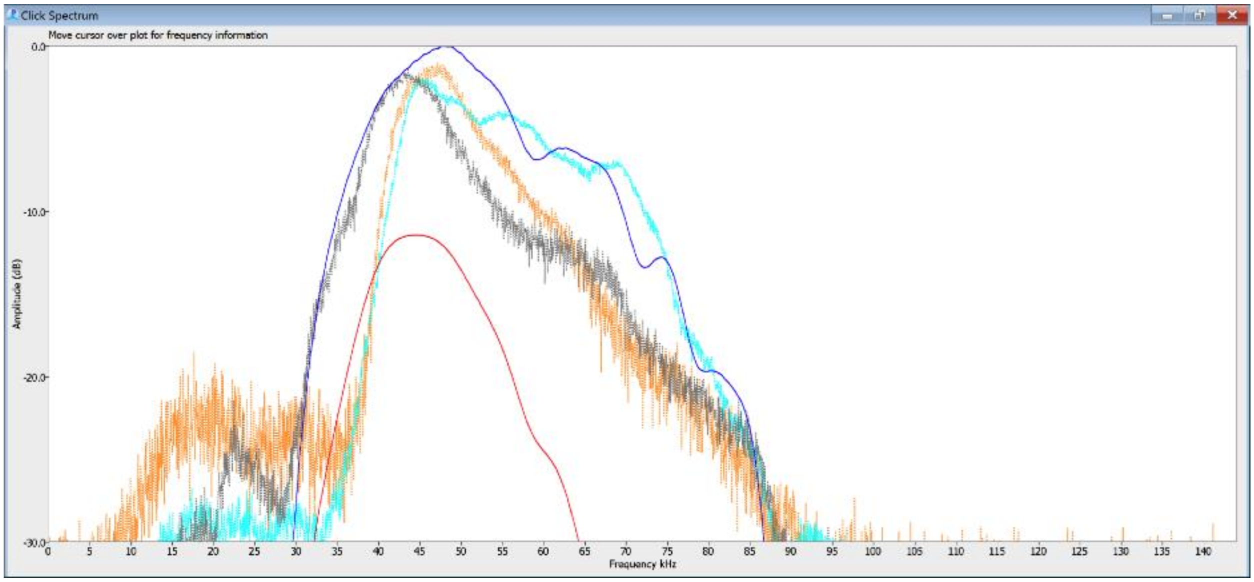


BW43 template (gray) and BW43 click from Baumann and Pickering (blue, pers. comm.). Peak and slope to the left of peak match well. Slope to the right of peak is much broader, perhaps reflecting proximity or hydrophone differences. Differences in Wigner plots are likely due to scaling differences.
[Source: SOCAL41N_DL29_110122_175230. x_0000. wav]

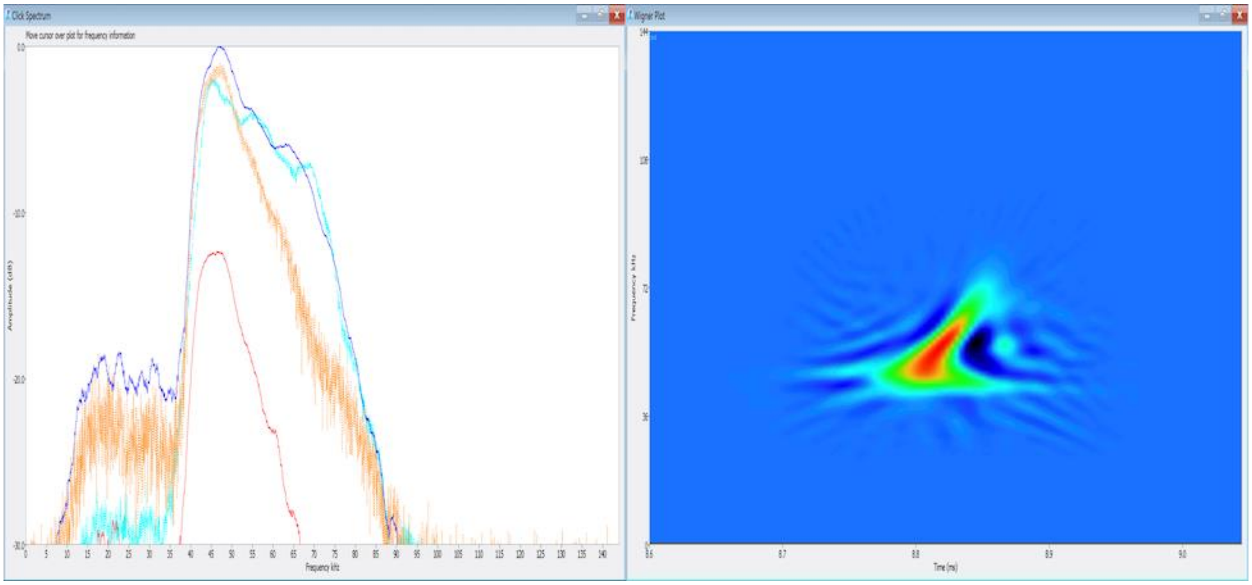


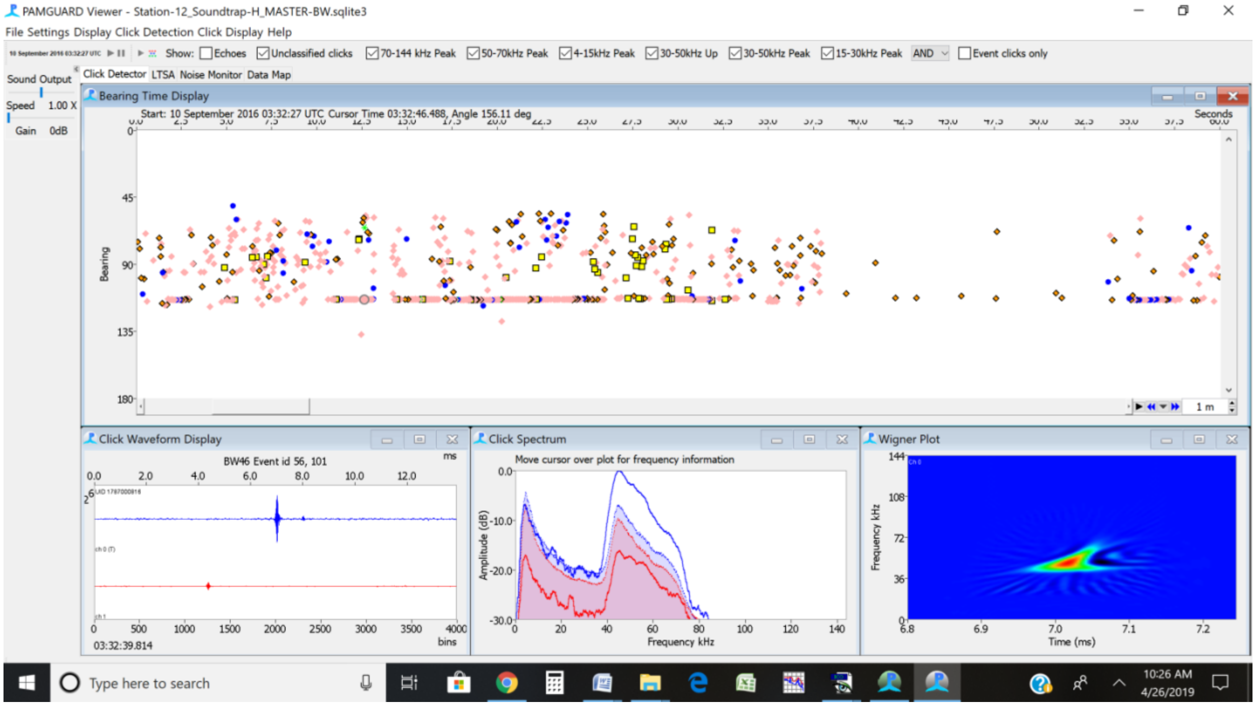
MS: *Mesoplodon stejnegeri,* Stejneger's beaked whale

Peak at about 46kHz (cyan and tan) shown on top of BW43 (gray). Notice how left slope in frequency spectrum declines more steeply than BW43, even when the peaks are similar (dark blue). The right slope is more variable for both types, but is less steep than the left slope. IPI= 0. 09; PPS= 10-11.



Frequency has very steeply declining slope to the left of peak. Right slope declines less steeply and may show higher peaks. Wigner shows "sorting cap". The lower branch of the Wigner (if present) is nearly horizontal. Peak varies between 44-48 kHz.





☐ Echoes ☑ Unclassified clicks ☑ 70-144 kHz Peak ☑ 50-70kHz Peak ☑ 4-15kHz Peak ☑ 30-50kHz Up ☑ 30-50kHz Peak ☑ 15-30kHz Peak AND ☐ Event clicks only

Sound Output

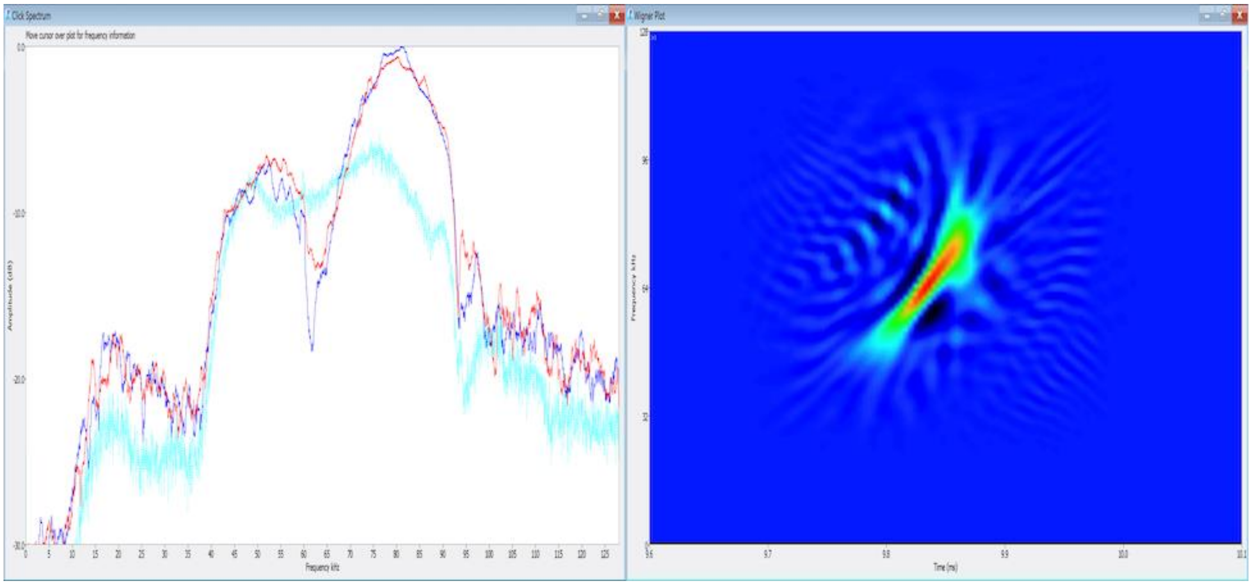
Speed 1.00 X

Gain 0dB

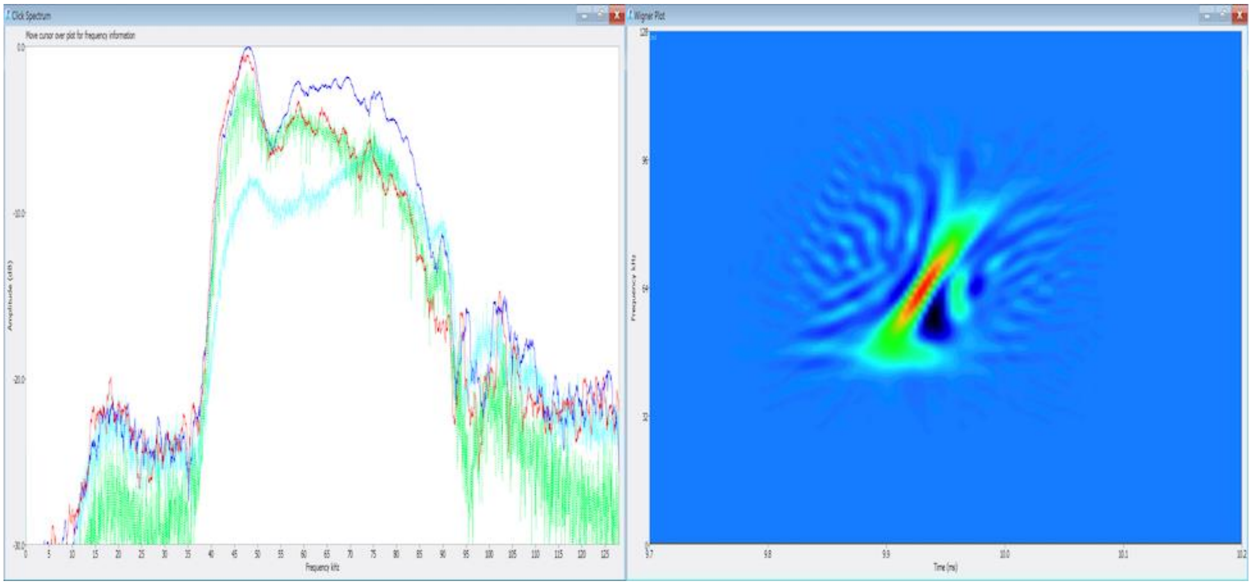
Start: 10 September 2016 03:32:27 UTC Cursor Time 03:32:46.488, Angle 156.11 deg

MS: Stejneger's beaked whale (continued)

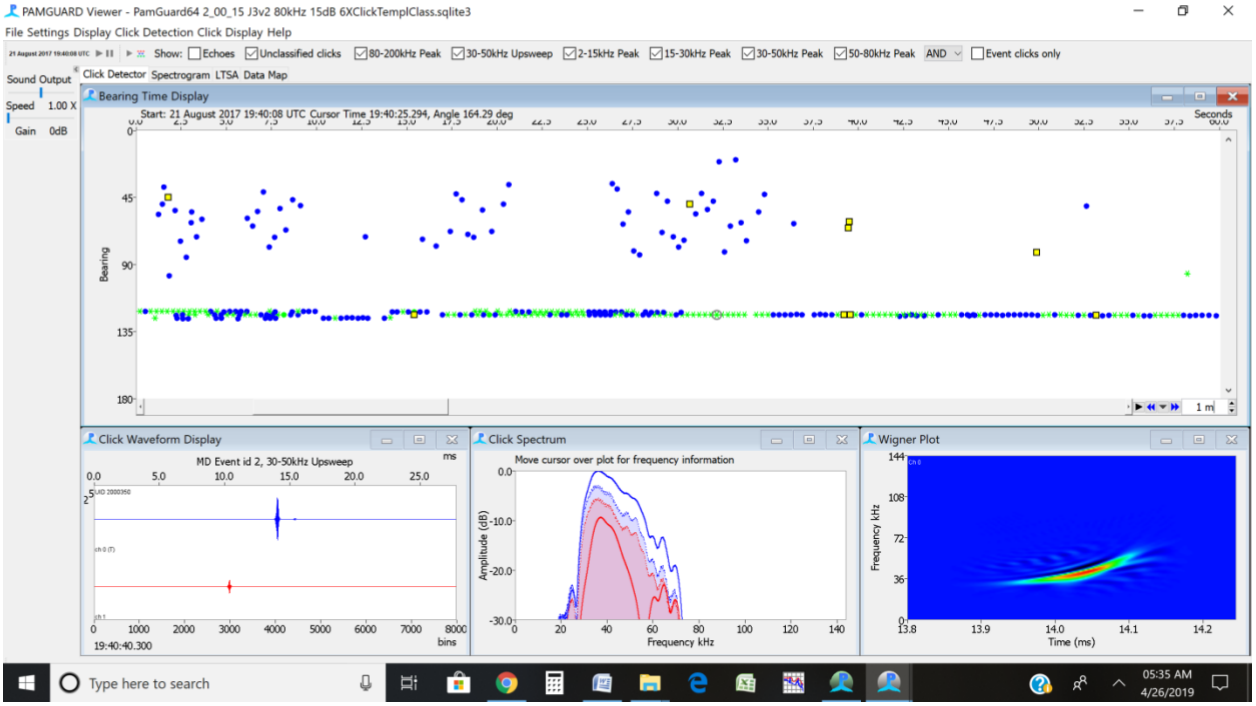
Some pulses show very strong higher peak at about 75 kHz in addition to a distinct lower peak at about 50 kHz. Some signals (presumable closer or more on-axis) show a strong peak at 80 kHz, a second peak at 52 kHz, and a strong null at about 62 kHz. These may appear in the same event as 44-48kHz pulses (see above). No evidence of "sorting hat" in Wigner.



Again two peaks (green, same group as above). In this case, the lower peak is loudest. Inconspicuous "sorting hat" look to wigner.

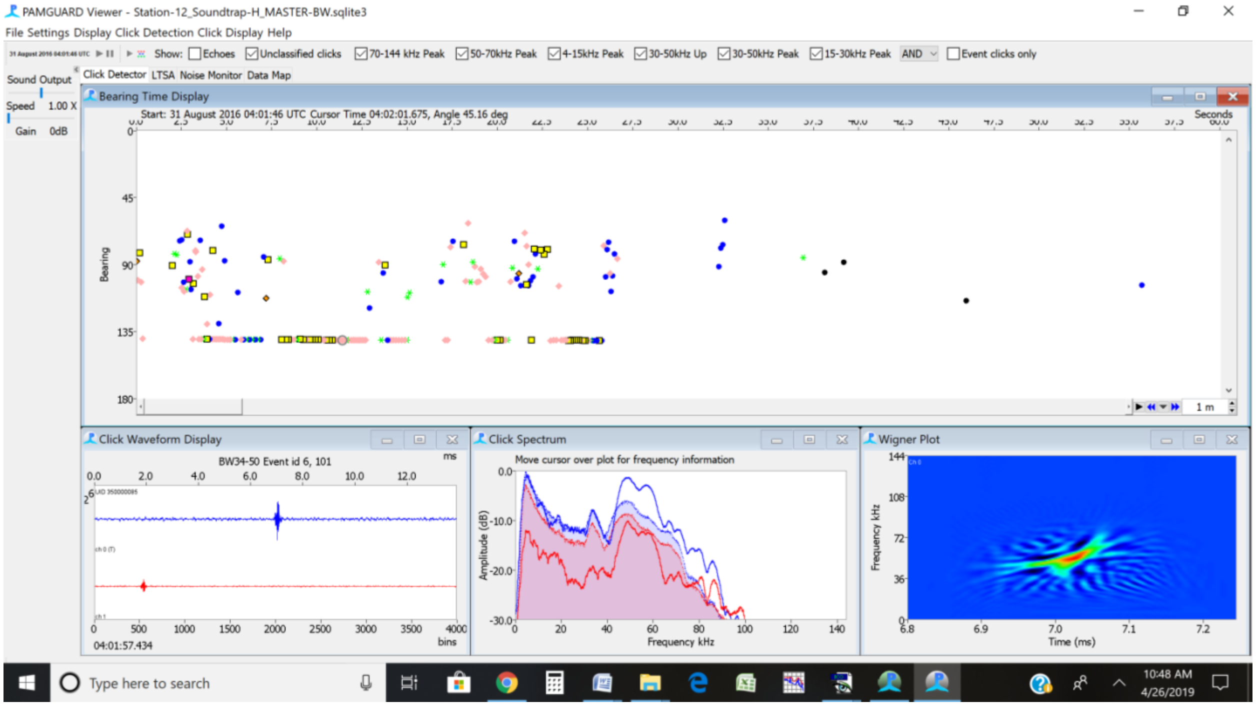


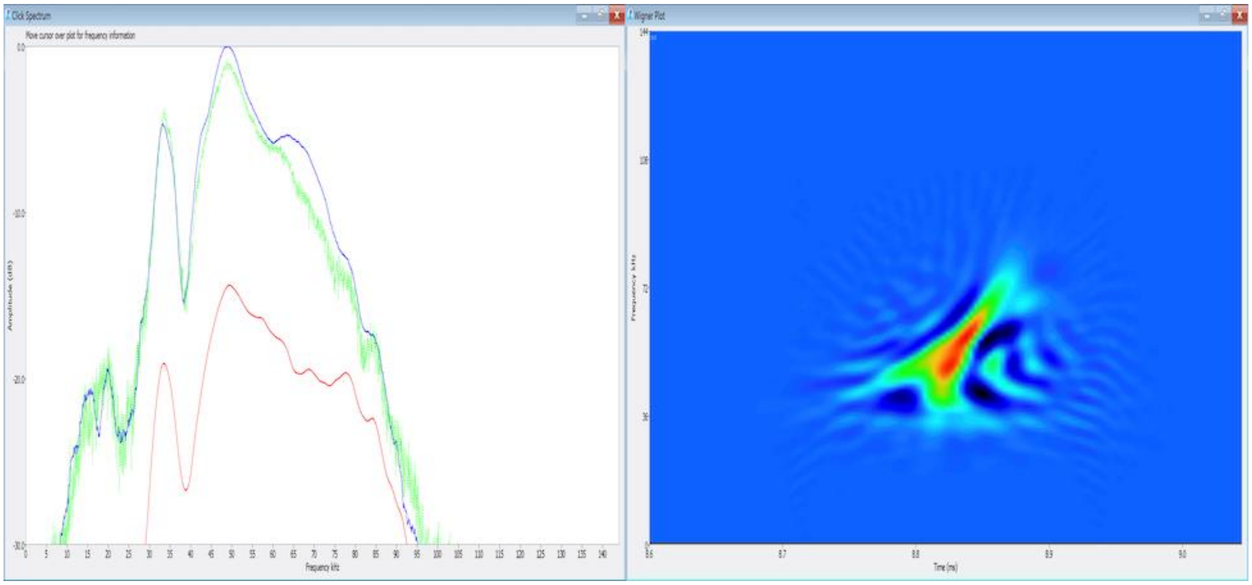
MD: *Mesoplodon densirostris*, Blainville’s beaked whale. Peak frequency is ~36kHz (similar to Ziphius) but with a very steep decline in amplitudes at lower frequencies (left of the peak). This very clear one shows a secondary peak at 25 kHz, but that is 20dB below the peak and is not likely to be seen in a lower SNR signal. Wigner plot is slightly concave upward, with no sign of “kickstand”. IPI= 0. 25-0. 33; PPS=3-4.



BW37V: Likely Hubb’s beaked whale

BW37V template (green) shows two distinct peaks at about 34 kHz and 50 kHz, with a strong null (valley) at 37 kHz. IPI= 0. 125-0. 166; PPS= 6-8.

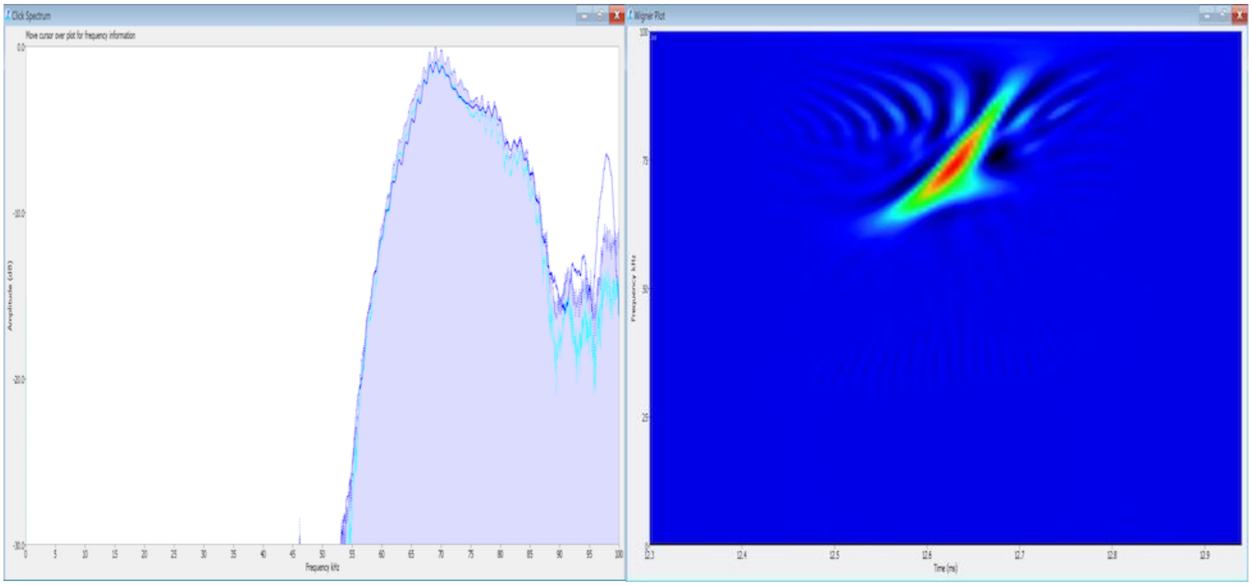




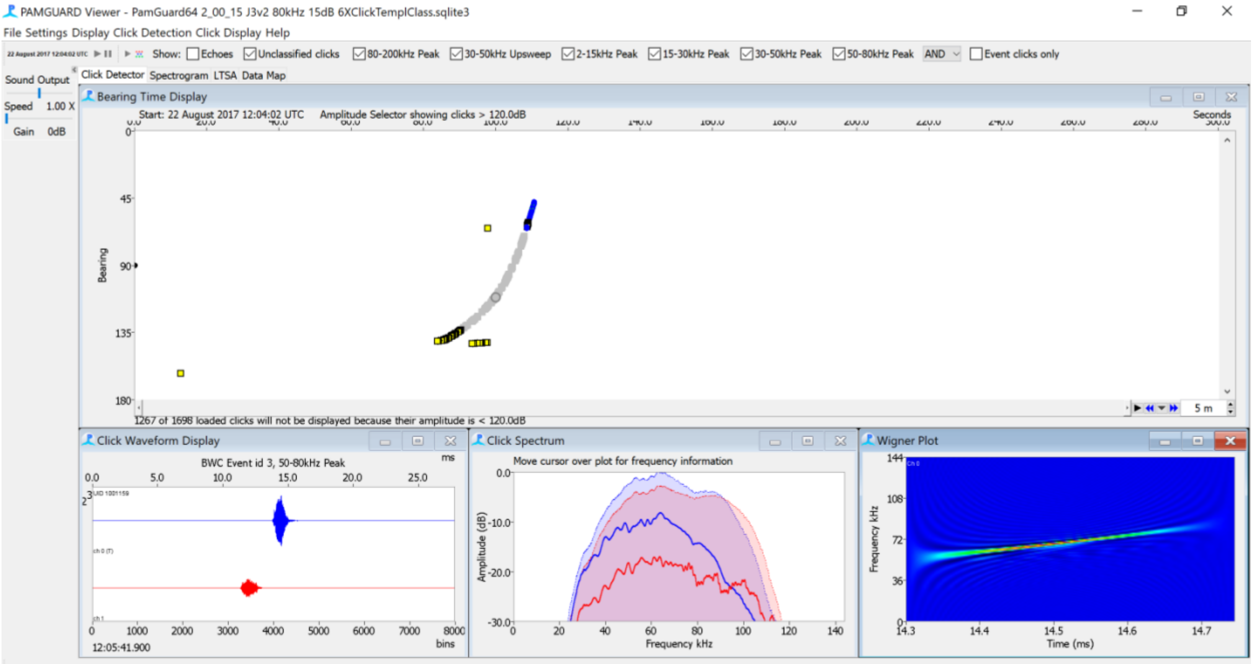
BW70: probably Pygmy beaked whale, *Mesoplodon peruvianus*

BW70 template (cyan) shows a peak at 70 kHz. Slope to the left of the peak is steeper than to the right. Upsweep in the Wigner plot. IPI= 0. 12; PPS= 8.

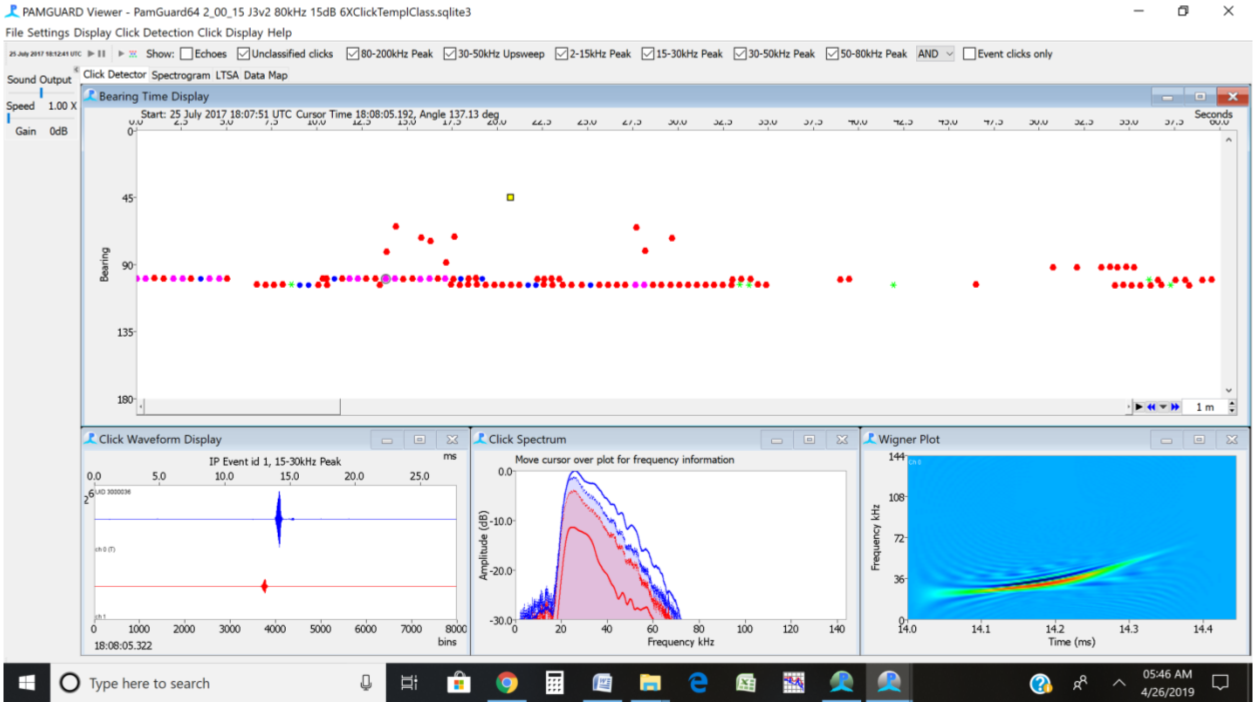
[Source is SIO, Baumann & Pickering pers. comm., GofCA4A4_051217_234230. x_1114. wav]



BWC- Cross Seamount beaked whale. Very long click with very long frequency sweep and a peak frequency of about 60-65 kHz. Signals may come from above the hydrophones. IPI= 0. 127; PPS= 8.

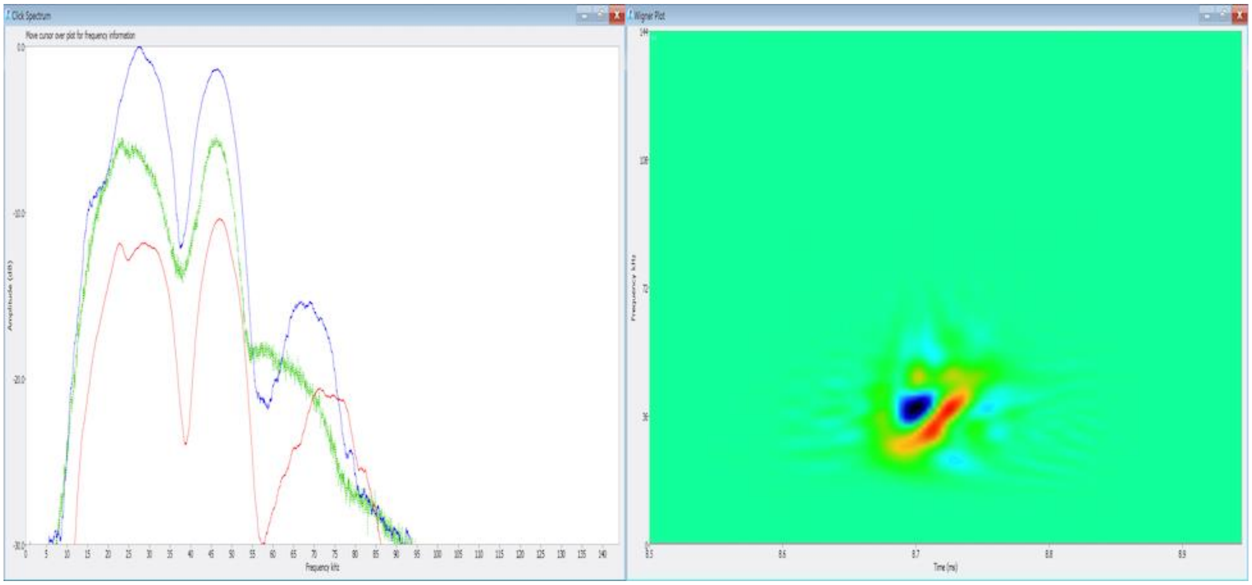


IP: *Indopacetus pacificus*, Longman’s beaked whale. Pulses are low-frequency, with peak at ~26 kHz. IPI= 0. 27-0. 40s; PPS= 3-4.

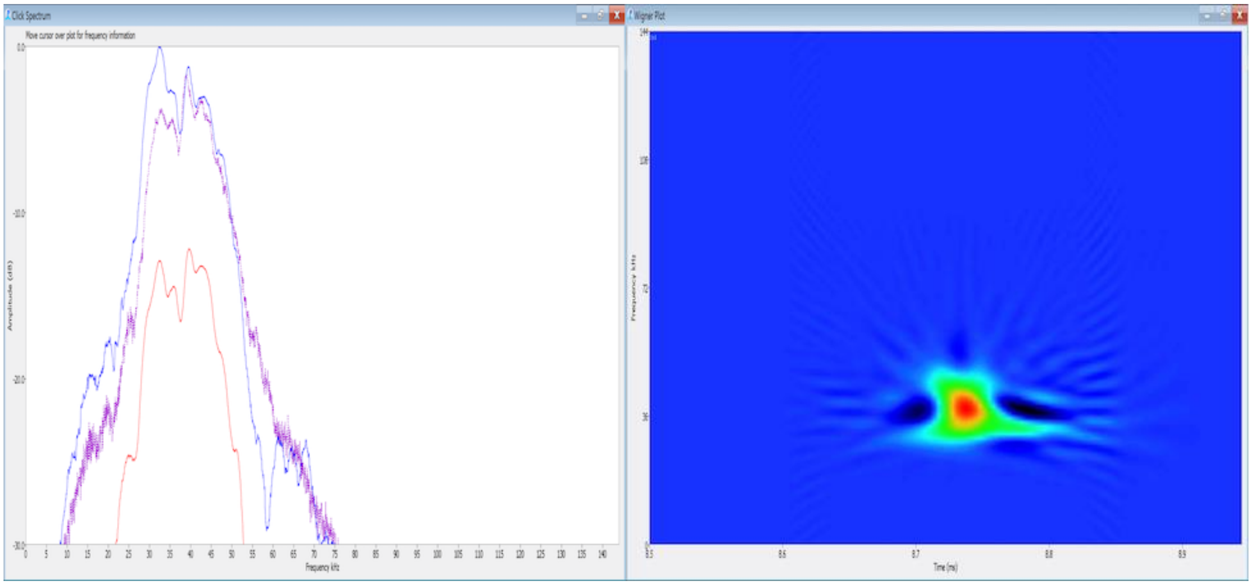


Miscellaneous other signals that looked like beaked whales

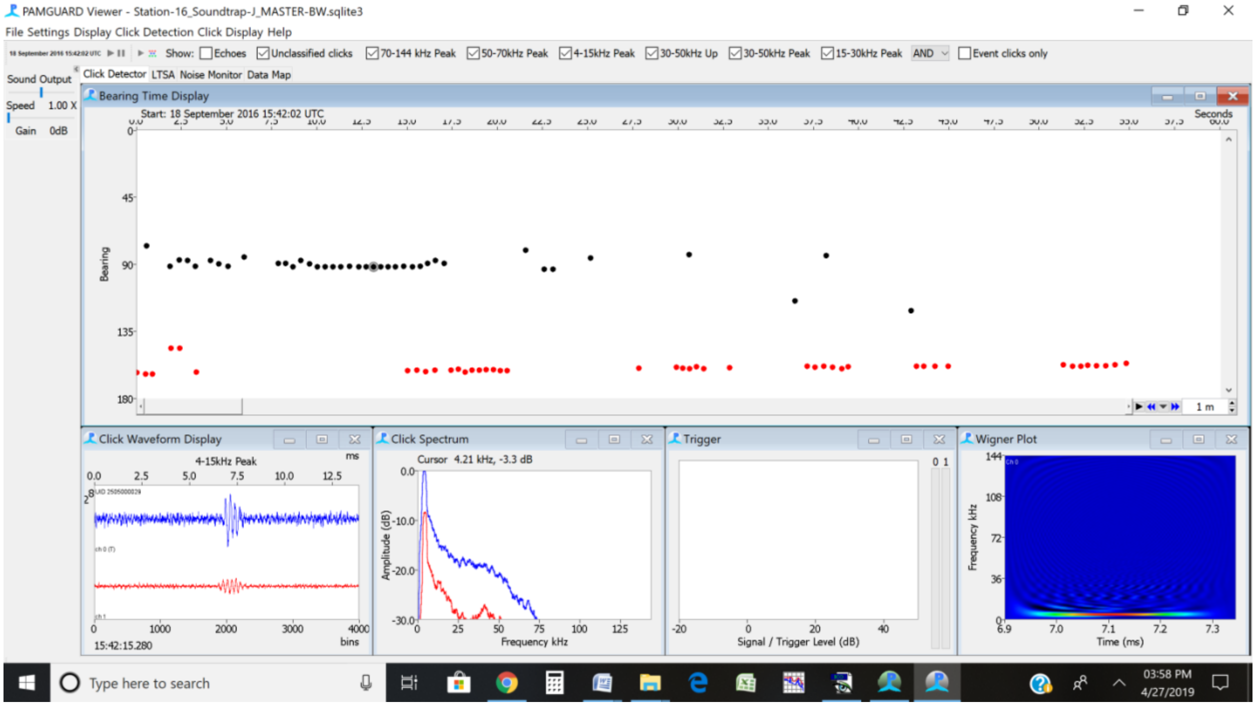
BW26-47 template (dark green). Was above hydrophone. May be alternate part of the beam pattern of a BW46. Wigners were variable and odd looking. Some were almost circular. Need to look for others.



BW38 template (lavender). Maybe M. densirostris, but no evidence of an upsweep and signal was relatively short.



PM: *Physeter macrocephalus*, sperm whale. Low-frequency click, typically < 12 kHz peak. IPI= 0. 4-1. 0, PPS=1-2.



Show: ☐ Echoes ☑ Unclassified clicks ☑ 70-144 kHz Peak ☑ 50-70kHz Peak ☑ 4-15kHz Peak ☑ 30-50kHz Up ☑ 30-50kHz Peak ☑ 15-30kHz Peak AND ☐ Event clicks only

Speed 1.00 X

Gain 0dB

Start: 18 September 2016 15:42:02 UTC

Cursor 4.21 kHz, -3.3 dB