Passive Acoustics Survey of Cetacean Abundance Levels (PASCAL-2016) Final Report

**US Department of the Interior
Bureau of Ocean Energy Management
Pacific OCS Region**

BOEM
BUREAU OF OCEAN ENERGY MANAGEMENT

Passive Acoustics Survey of Cetacean Abundance Levels (PASCAL-2016) Final Report

June 2018

Authors:
Jennifer L. Keating[1,2], Jay Barlow[3], Emily T. Griffiths[4], Jeffrey E. Moore[3]

Prepared under Interagency Agreement M16PG00011
By
[1] Pacific Islands Fisheries Science Center, National Marine Fisheries Service
  National Oceanic and Atmospheric Administration
  1845 Wasp Boulevard
  Honolulu, HI 96818
[2] Joint Institute for Marine and Atmospheric Research
  University of Hawaii
  1000 Pope Road
  Honolulu, HI 96822
[3] Marine Mammal and Turtle Division
  Southwest Fisheries Science Center, National Marine Fisheries Service
  National Oceanic and Atmospheric Administration
  8901 La Jolla Shores Drive
  La Jolla, CA 92037
[4] Ocean Associates Inc.
  4007 N Abingdon Street
  Arlington, VA 22207

US Department of the Interior
Bureau of Ocean Energy Management
Pacific OCS Region

BOEM
BUREAU OF OCEAN ENERGY MANAGEMENT

DISCLAIMER

This study was funded, in part, by the US Department of the Interior, Bureau of Ocean Energy Management (BOEM), Environmental Studies Program, Washington, DC, through Interagency Agreement Number M16PG00011 with the US Department of Commerce, National Oceanic and Atmospheric Administration (NOAA). This report has been technically reviewed by BOEM, and it 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.

REPORT AVAILABILITY

To download a PDF file of this report, go to the US Department of the Interior, Bureau of Ocean Energy Management Data and Information Systems webpage (https://www.boem.gov/Environmental-Studies-EnvData/), click on the link for the Environmental Studies Program Information System (ESPIS), and search on 2018-025.

CITATION

ABOUT THE COVER

Blainville's beaked whale. Photo Credit: Barbara Taylor (NOAA/SWFSC)

ACKNOWLEDGMENTS

Contents

List of Figures

List of Tables

List of Abbreviations and Acronyms

BOEM	Bureau of Ocean Energy Management
CA	California
DASBR	Drifting Acoustic Spar Buoy Recorder
DC	District of Columbia
DOI	US Department of the Interior
ESPIS	Environmental Studies Program Information System
HI	Hawaii
kHz	kilohertz
m	meter
min	minute(s)
NBHF	narrow-band high-frequency
NOAA	National Oceanic and Atmospheric Administration
nmi	nautical mile
OCS	Outer Continental Shelf
PASCAL	Passive Acoustics Survey of Cetacean Abundance Levels
PDF	Portable Document Format
SIO	Scripps Institution of Oceanography
SWFSC	Southwest Fisheries Science Center
US	United States
VA	Virginia

1 Introduction

The National Marine Fisheries Service Southwest Fisheries Science Center (SWFSC) conducted a dedicated acoustic survey for cetaceans throughout the California Current off the U.S. West Coast in August and September 2016. The survey, Passive Acoustics Survey of Cetacean Abundance Levels (PASCAL), was conducted from the NOAA R/V *Bell M. Shimada* (hereafter *Shimada*). The *Shimada* is quieter vessel than the older survey vessels used in previous large scale cetacean and ecosystem assessment surveys allowing for improved acoustic data collection.

Focal study species were beaked whales (family *Ziphiidae*), sperm whales (*Physeter macrocephalus*), and dwarf and pygmy sperm whales (genus *Kogia*). These species are difficult to survey visually due to their cryptic behavior. Consequently, population abundance estimates from visual line-transect data, collected during past large-scale cetacean assessment surveys, have poor precision. *Mesoplodon* beaked whale visual encounter rates have typically been so low during visual surveys that their abundance was assessed as a clade. Following recent advancements in acoustic sensing technology (Griffiths and Barlow 2015; 2016), the primary objective for PASCAL was to conduct a large scale acoustic survey to obtain improved data for estimating population size for these species throughout the California Current study area off the U.S. West Coast.

A secondary objective of this study was to improve our ability to identify acoustic calls to the species level. For example, many beaked whale detections are identifiable to the genus level (e.g., *Mesoplodon*), but we lack paired visual sighting confirmation to allow species-specific *Mesoplodon* calls to be identified to the correct species in most cases. Once calls are identified to the species level, we may be able to provide species-specific density estimates in the California Current for the first time.

A third objective materialized during the PASCAL effort. We conducted a pilot experiment southwest of Point Conception, using paired deployments of acoustic instruments over seamounts and in nearby areas off the seamounts. We aimed to explore the hypothesis that beaked whale occurrence is associated with these topographic seafloor features.

The survey was divided into three legs: Leg 1 (August 19–23), Leg 2 (August 23–September 7), and Leg 3 (September 11– September 30). The legs were led by Shannon Rankin, Jeff Moore, and Jay Barlow, respectively (all from SWFSC). During the initial transit leg (from the *Shimada's* home port in Newport, Oregon, to San Diego, California), during which scientist Rankin deployed 5 Drifting Acoustic Spar Buoy Recorders (DASBRs). Scientific crew on Legs 2 and 3 consisted of the cruise leader, a lead acoustician and acoustic technician, two dedicated visual observers, and two visiting scientists to assist with various operations (see Acknowledgments).

2 Methods

2.1 DASBR Survey Effort

2.1.1 Abundance Estimation

The primary data collection instrument were Drifting Acoustic Spar Buoy Recorders (DASBRs), deployed at 20 pre-determined locations distributed approximately uniformly throughout the California Current study area offshore of the continental shelf (Figure 1). Each DASBR (Figure 2) includes a pair of hydrophones, vertically separated by 10 m, with the midpoint positioned at approximately 100 m depth.

Acoustic signals received by the hydrophones were recorded on one of three types of situ data recorders (Table 1). The hydrophones and recorder were attached to a line that originated from a vertical spar buoy at the surface and terminated at depth with an anchor (to maintain verticality and positional stability of the hydrophones in the water column). A 30-m elastic cord at the top of the line helped isolate the hydrophones from wave motion.

The three types of recording devices used in the DASBRs had different battery and memory capabilities and different maximum sampling rates. Duty cycles were selected to match the capabilities and expected deployment durations for each instrument. Eleven Soundtrap ST4300 recorder were set to record for 2 min out of every 10 min at 288 kHz sampling rate. Four Wildlife Acoustics SM2+Bat recorders were set to record for 2 min out of every 4 min at a 192 kHz sampling rate. Four Wildlife Acoustics SM3M recorders were set to record continuously, with each hour consisting of 29 2 min files at a 256 kHz sampling rate followed by one 2 min file at 96 kHz sampling rate (for cleaner ocean noise measurements). All devices recorded stereo signals from two hydrophones. Hydrophone types, sensitivities and other relevant settings are given in Table 2.

A pressure and 3-D accelerometer logger (Loggerhead Computers Open Tag) was included in some deployments to measure hydrophone depth and array tilt (Table 1). Array depth is critical for estimating range to the vocalizing animals, and array tilt is critical because different (and less precise) methods are required for range estimation if the array is not vertical in the water column (Barlow and Griffiths 2017). Hydrophone depth for SM2+Bat recorders was logged using a separate pressure sensor using the SM2's 12-bit data logger.

An additional single-channel acoustic recorder (Soundtrap 300HF, hereafter ST300HF) was included for some deployments. At station 9, an experiment was conducted to determine whether the automated click detection algorithm in a ST300HF can reliably detect beaked whale clicks and their surface reflections. An ST300HF with an external battery pack was attached between the two other hydrophones and was set to record continuously at 48 kHz and to record click events at 576 kHz. If successful, click detection algorithms could reduce data storage requirements and allow collection of more continuous data for a longer period of time. At stations 26 and 29, another experiment was conducted with an ST300HF recording continuously at 288 kHz at a depth of 150 m below the bottom of the array. These data will be used to determine whether surface reflections that are recorded at 100 m depth are also detectable at 250 m depth.

A total of 21 DASBR deployments were of the primary acoustic survey design for estimating population size of the target species (Figure 1). Five DASBRs were deployed during Leg 1 and 16 during Leg 2. One of the DASBRs deployed on Leg 1 (Station 4) did not drift as expected and thus was did not sample a variety of habitats. It was retrieved at the end of Leg 2 and another DASBR was re-deployed to replace it at a nearby location (Station 21). Collectively, these 21 primary DASBRs were at sea for a total of 373 days. Individual DASBRS were at sea from 11 to 23 days (Table 3) and drifted up to 200 nmi during the deployment period. In total, there were 388 days of total recording effort including the ad-hoc seamount study.

Figure 1. Locations of DASBR deployments (red dots), retrievals (black dots), buoy drifts (red lines), and Leg 3 ship tracklines during the PASCAL cruise. Inset shows the drifts of buoys deployed in the seamount study area (outlined box).

Figure 2. Schematic of DASBRs deployed on the PASCAL cruise (those labeled B-1 to B-16 in Table 1). DASBRs (W-1 to W-4) are illustrated in Griffiths and Barlow (2015). Subsurface floats were added above the upper hydrophone based on type of autonomous high-frequency recorder (ST3400: 1.9 and 3.5 lbs.; SM3M: 3.5 lbs. of floatation).

Table 1. Location and date for 30 DASBR deployments during PASCAL. Also included are the type of recorder and its serial number, the type and number of depth recorder (if present), the array number, the SPOT geo-locator letters, recording notes, and (for seamount deployments) the name of the seamount. Hydrophone specifications for each numbered array are given in Table 2. (OT = Open Tag; SM2+ = SoundMeter)

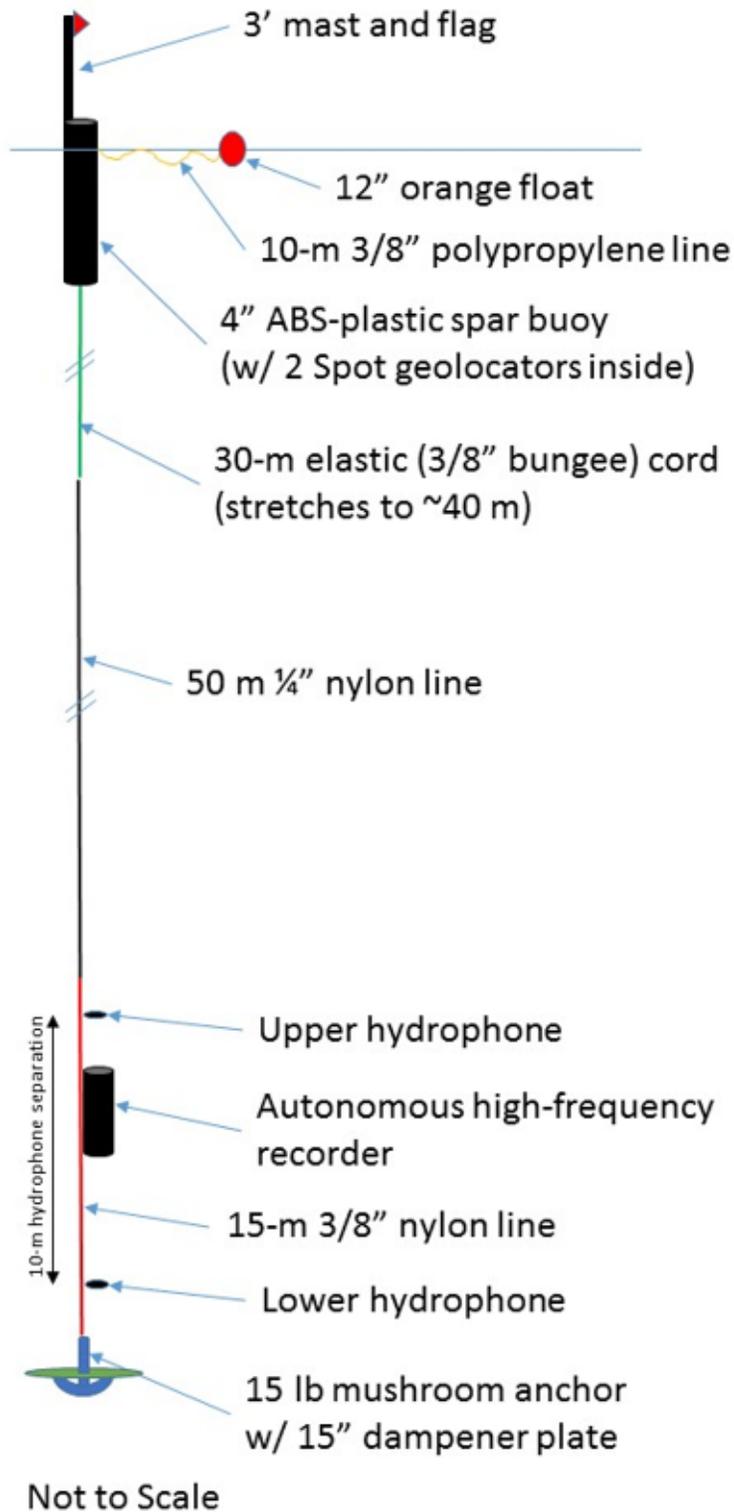| Leg	DASBR Station	Latitude	Longitude	Deployment Date	DASBR #	DASBR Recorder Type and ID	Depth Recorder	HP Array Number	SPOTs	Sea Mount
1	1	44 21.157 N	125 18.395 W	8/19/2016	B-5	Soundtrap 4300 #A	-	5	F, G	
1	2	41 29.393 N	125 21.816 W	8/20/2016	B-6	Soundtrap 4300 #B	OT-1	6	P, Q	
1	3	38 34.397 N	124 21.784 W	8/21/2016	B-7	Soundtrap 4300 #C	-	7	R, S	
1	4	36 20.753 N	122 56.912 W	8/22/2016	B-8	Soundtrap 4300 #D	-	8	T, U	
1	5	34 12.600 N	121 25.900 W	8/22/2016	B-9	Soundtrap 4300 #E	OT-3	9	X, Y	
2	6	32 11.669 N	119 54.746 W	8/24/2016	B-10	Soundtrap 4300 #F	-	10	Z, AA	
2	7	31 22.159 N	123 42.453 W	8/25/2016	B-1	SM3M #1	-	1	Gen-C, A	
2	8	33 45.879 N	125 54.937 W	8/25/2016	W-1	SM2+Bat #1	OT-4; SM2+	GDA-1	H, I	
2	9	36 32.461 N	127 34.300 W	8/26/2016	B-11	Soundtrap 4300 #G + ST300 #1	-	11	AB, AC	
2	10	39 14.831 N	129 11.593 W	8/27/2016	B-2	SM3M #2	OT-5	2	C, V	
2	11	42 14.267 N	129 50.924 W	8/28/2016	W-2	SM2+Bat #2	SM2+	GDA-2	J, K	
2	12	45 15.778 N	129 46.784 W	8/29/2016	B-12	Soundtrap 4300 #H	-	12	AD, AE	
2	13	46 13.748 N	127 36.370 W	8/29/2016	B-3	SM3M #3	OT-6	3	Gen-D, D	
2	14	47 06.472 N	125 36.307 W	8/30/2016	W-3	SM2+Bat #3	SM2+	GDA-3	L, M	
2	15	43 40.924 N	127 44.650 W	8/31/2016	B-13	Soundtrap 4300 #I	-	13	AF, AG	
2	16	40 48.712 N	127 32.230 W	9/01/2016	B-14	Soundtrap 4300 #J	OT-7	14	AH, AI	
2	17	38 31.146 N	126 38.408 W	9/01/2016	B-16	SM3M #4	-	4	Gen-A, B	
2	18	35 50.512 N	124 54.905 W	9/03/2016	W-4	SM2+Bat #4	SM2+	GDA-4	N, O	
2	19	33 12.924 N	123 09.332 W	9/04/2016	B-15	Soundtrap 4300 #K	-	15	AJ, AK	
2	20	33 08.555 N	118 59.592 W	9/05/2016	B-6	Soundtrap 4300 #B	OT-1[2]	6	P, Q	
2	21	35 17.509 N	122 14.690 W	9/03/2016	B-8	Soundtrap 4300 #A[2]	-	8	T, U	
2	22	33 03.371 N	120 59.337 W	9/04/2016	B-5	Soundtrap 4300 #D[2]	OT-3[2]	9	F, G	San Juan
3	23	33 00.036 N	121 00.084 W	9/23/2016	B-7	Soundtrap 4300 #E[2]	OT-4[2]	14	R, S	San Juan
3	24	33 04.796 N	120 59.061 W	9/23/2016	B-9	Soundtrap 4300 #F[2] + ST300-Jason	OT-5[2]	5	X, Y	San Juan
3	25	33 08.118 N	121 03.683 W	9/23/2016	B-10	Soundtrap 4300 #G[2]	-	10	Z, AA	San Juan
3	26	34 21.022 N	121 04.704 W	9/24/2016	B-11	Soundtrap 4300 #H[2] + ST300 #1	OT-6[2]	11	AB, AC	Rodriguez
3	27	34 03.445 N	121 02.951 W	9/24/2016	B-12	Soundtrap 4300 #I[2]	-	12	AD, AE	Rodriguez
3	28	33 58.436 N	120 59.134 W	9/24/2016	B-13	Soundtrap 4300 #J[2]	OT-7[2]	13	AF, AG	Rodriguez
3	29	34 03.074 N	121 03.074 W	9/25/2016	B-11	Soundtrap 4300 #H[2] + ST300 #1	OT-6[2]	11	AB, AC	Rodriguez
3	30	34 02.120 N	121 04.675 W	9/25/2016	B-12	Soundtrap 4300 #I[2]	-	12	AD, AE	Rodriguez

Table 2. Sensor and pre-amp characteristics for each DASBR array. DASBR array # corresponds to hydrophone array numbers given in Table 1.

DASBR Array #	Element #	Hydrophone Type	Serial Number	Hydrophone Sensitivity (dB re: 1V/uPa)	High-pass Filter (Hz)	Gain (dB)	High-pass Filter (Hz)	Gain (dB)	High-pass Filter (Hz)	Gain (dB)	High-pass Filter (Hz)
		HYDROPHONE				PRE-AMP		WILDLIFE ACOUSTICS BOARD		SOUNDTRAP	
GDA-1	0	HTI-92-WB	856028	-158.8	100	14	159	0	3	n/a	n/a
GDA-1	1	HTI-96-min	856025	-181.6	100	34	159	0	180	n/a	n/a
GDA-2	0	HTI-96-min	856019	-181.4	100	34	159	0	3	n/a	n/a
GDA-2	1	HTI-96-min	856023	-181.6	100	34	159	0	180	n/a	n/a
GDA-3	0	HTI-96-min	856027	-181.0	100	34	159	0	3	n/a	n/a
GDA-3	1	HTI-96-min	856022	-181.6	100	34	159	0	180	n/a	n/a
GDA-4	0	HTI-96-min	856026	-181.1	100	34	159	0	3	n/a	n/a
GDA-4	1	HTI-96-min	n/a	~ -161.0	10	14	159	0	180	n/a	n/a
1	0	HTI-96-min	856045	-164.7	20	n/a	n/a	12	2	n/a	n/a
1	1	HTI-96-min	856042	-164.6	20	n/a	n/a	12	2	n/a	n/a
2	0	HTI-92-WB	856046	-165.2	20	n/a	n/a	12	2	n/a	n/a
2	1	HTI-96-min	856039	-165.2	20	n/a	n/a	12	2	n/a	n/a
3	0	HTI-96-min	856044	-164.7	20	n/a	n/a	12	2	n/a	n/a
3	1	HTI-96-min	856040	-164.7	20	n/a	n/a	12	2	n/a	n/a
4	0	HTI-96-min	856041	-164.5	20	n/a	n/a	12	2	n/a	n/a
4	1	HTI-96-min	856043	-164.7	20	n/a	n/a	12	2	n/a	n/a
5	0	HTI-92-WB	856052	-154.7	20	n/a	n/a	n/a	n/a	High	OFF
5	1	HTI-96-min	856063	-164.8	20	n/a	n/a	n/a	n/a	High	OFF
6	0	HTI-96-min	856061	-165.4	20	n/a	n/a	n/a	n/a	High	OFF
6	1	HTI-96-min	856056	-164.8	20	n/a	n/a	n/a	n/a	High	OFF
7	0	HTI-92-WB	856051	-154.7	20	n/a	n/a	n/a	n/a	High	OFF
7	1	HTI-96-min	856067	-164.9	20	n/a	n/a	n/a	n/a	High	OFF
8	0	HTI-96-min	856060	-165.0	20	n/a	n/a	n/a	n/a	High	OFF
8	1	HTI-96-min	856058	-165.2	20	n/a	n/a	n/a	n/a	High	OFF
9	0	HTI-92-WB	856048	-155.6	20	n/a	n/a	n/a	n/a	High	OFF
9	1	HTI-96-min	856059	-165.0	20	n/a	n/a	n/a	n/a	High	OFF
10	0	HTI-92-WB	856053	-154.7	20	n/a	n/a	n/a	n/a	High	OFF
10	1	HTI-96-min	856064	-165.0	20	n/a	n/a	n/a	n/a	High	OFF
11	0	HTI-92-WB	856050	-154.5	20	n/a	n/a	n/a	n/a	High	OFF
11	1	HTI-96-min	856065	-164.9	20	n/a	n/a	n/a	n/a	High	OFF
12	0	HTI-92-WB	856049	-154.5	20	n/a	n/a	n/a	n/a	High	OFF
12	1	HTI-96-min	856068	-165.1	20	n/a	n/a	n/a	n/a	High	OFF
13	0	HTI-92-WB	856055	-155.1	20	n/a	n/a	n/a	n/a	High	OFF
13	1	HTI-96-min	856066	-165.2	20	n/a	n/a	n/a	n/a	High	OFF
14	0	HTI-92-WB	856054	-154.6	20	n/a	n/a	n/a	n/a	High	OFF
14	1	HTI-96-min	856057	-165.2	20	n/a	n/a	n/a	n/a	High	OFF
15	0	HTI-92-WB	856047	-154.6	20	n/a	n/a	n/a	n/a	High	OFF
15	1	HTI-96-min	856062	-164.7	20	n/a	n/a	n/a	n/a	High	OFF
ST300-1	0	Soundtrap	201883689	-172.1	n/a	n/a	n/a	n/a	n/a	High	OFF
ST300-Jason	0	Soundtrap	1678299174	-172.4	n/a	n/a	n/a	n/a	n/a	High	OFF

Table 3. Deployment and retrieval dates, total deployment duration, and total recording time for DASBRs deployed during PASCAL. Differences in total deployment duration and recording duration are due to expiration of memory/battery or a hardware/software malfunction.

Station #	Deployment Data/Time	Retrieve Date/Time	Deployment Duration (hh:mm:ss)	Deployment Duration (Days)	Recording Duration (hh:mm:ss)
1	08/19/2016 17:14:13	08/31/2016 15:04:41	285:50:28	11.9	276:17:54
2	08/21/2016 06:43:25	09/01/2016 02:19:50	259:36:25	10.8	259:36:25
3	08/21/2016 10:41:47	09/02/2016 16:30:42	293:48:55	12.2	287:25:29
4	08/22/2016 00:34:38	09/03/2016 19:11:44	306:37:06	12.8	299:57:56
5	08/22/2016 15:05:24	09/04/2016 22:51:13	319:45:49	13.3	313:38:34
6	08/24/2016 13:00:00	09/12/2016 12:53:21	455:53:21	19.0	127:27:26
7	08/25/2016 09:31:29	09/13/2016 09:29:54	455:58:25	19.0	414:08:37
8	08/26/2016 04:56:14	09/14/2016 11:39:54	462:43:40	19.3	453:47:46
9	08/27/2016 00:30:47	09/15/2016 13:04:56	468:34:09	19.5	468:34:09
10	08/27/2016 17:45:53	09/16/2016 04:22:18	466:36:25	19.4	466:36:25
11	08/28/2016 12:47:37	09/17/2016 04:18:38	471:31:01	19.6	471:31:01
12	08/29/2016 09:10:25	09/17/2016 19:55:07	466:44:42	19.4	466:44:42
13	08/29/2016 20:51:57	09/18/2016 04:00:12	463:08:15	19.3	404:32:09
14	08/30/2016 07:51:05	09/18/2016 16:08:10	464:17:05	19.3	464:17:05
15	08/31/2016 07:11:05	09/16/2016 20:27:05	397:16:00	16.6	110:36:38
16	09/01/2016 13:20:15	09/20/2016 23:57:07	466:36:52	19.4	460:21:47
17	09/02/2016 03:55:42	09/21/2016 23:11:20	475:15:38	19.8	475:15:38
18	09/03/2016 05:34:44	09/22/2016 11:48:22	462:13:38	19.3	462:13:38
19	09/04/2016 11:49:02	09/23/2016 06:59:23	451:10:21	18.8	451:10:21
20	09/06/2016 01:35:28	09/29/2016 05:07:18	555:31:50	23.1	555:31:50
21	09/04/2016 00:05:17	09/25/2016 10:03:07	513:57:50	21.4	513:57:50
22	09/05/2016 06:45:44	09/28/2016 17:04:08	562:18:24	23.4	562:18:24
23	09/24/2016 01:37:36	09/28/2016 00:54:00	95:16:24	4.0	95:16:24
24	09/24/2016 02:30:18	09/28/2016 01:51:21	95:21:03	4.0	95:21:03
25	09/24/2016 04:08:38	09/28/2016 02:38:48	94:30:10	3.9	94:30:10
26	09/24/2016 15:16:01	09/26/2016 04:19:07	37:03:06	1.5	37:03:06
27	09/24/2016 15:49:32	09/26/2016 03:52:20	36:02:48	1.5	36:02:48
28	09/24/2016 16:40:10	09/29/2016 02:57:31	106:17:21	4.4	99:24:28
29	09/26/2016 05:40:28	09/28/2016 14:16:43	56:36:15	2.4	49:55:04
30	09/26/2016 06:07:42	09/28/2016 15:12:32	57:04:50	2.4	50:14:13
TOTAL			10103:38:16	421.0	9323:49:00

2.1.2   Ad hoc Seamount Experiment

No significant time was lost on the cruise due to weather or mechanical problems, which allowed additional time in the schedule for a focused study of beaked whales on and near seamounts. Beaked whale are commonly believed to be concentrated on such bathymetric features. To evaluate this hypothesis, nine DASBRs were re-deployed on or near San Juan Seamount and Rodriguez Seamount (Deployments 22-30 at the ends of Legs 2 and 3) (see Inset in Figure 1). All DASBR deployments are detailed in Table 1.

2.2 Towed acoustic array effort

During transits between DASBR deployments and retrievals, we towed a hydrophone array to (a) collect information to estimate the depth distribution of beaked whales, a parameter required to estimate the horizontal range to a detected beaked whale from the DASBR (for density estimation) and (b) provide visual confirmation of the species identification associated with different beaked whale call types within the genus *Mesoplodon*. Due to time and personnel constraints, hydrophone arrays were not towed during Leg 1.

On most days during PASCAL, we towed two different hydrophone arrays, mainly during daylight hours. At the beginning of Leg 2, a 4-element spatial array was towed. This prototype designed by Proteus Technologies allowed better localization capabilities but was determined to be too noisy. It was replaced by a series of two 2-element oil-filled linear hydrophone arrays (IL15s and EA15e) separated by 20 m from 8/31/2016 to 9/14/2016. The array depth sensor was not working in that configuration, so only array EA15e was used for the remainder of the cruise. The hydrophone spacing for both linear arrays was 1.0 m. All arrays were towed approximately 300 m behind the ship. The arrays were not towed during rough seas and during some nights.

2.3 Analyses of acoustic survey data

Acoustic data collection by DASBRs were reviewed to assess the occurrence of beaked whales and other deep-diving cetaceans. The standard file duration for all recorders was two minutes, regardless of duty cycle, such that we define an acoustic detection event as the presence of a species within a 2 min sound file. Because the characteristics of a single echolocation click can be misleading, we only consider acoustic detections with at least three echolocation clicks.

Acoustic technicians used PAMGuard software (version 1.15.03) to review all recordings and identify signals from beaked whales, sperm whales, and dwarf and pygmy sperm whales (*Kogia* spp.). Initially, PAMGuard software was used to automatically detect all odontocete echolocation clicks, to classify them into general categories based on peak frequencies and the presence or absence of frequency upsweeps, and to estimate the vertical angle from which the signals were received using the time-difference-of-arrival of the signals on the two hydrophones. The click classification settings are described by Keating and Barlow (2013). Two analysts (JLK and ETG) independently used PAMGuard Viewer Mode to review the initial classifications and to identify acoustic detection events of beaked whales, narrow-band high-frequency (NBHF) cetaceans (likely Dall's porpoise and *Kogia* spp.), and sperm whales. Independently identified beaked whale events were then reviewed by three analysts (JLK, ETG, and JPB) who reached a consensus determination of species category (Cuvier's beaked whale, Baird's beaked whale, and likely *Mesoplodon* species). Sperm whale and NBHF cetaceans were not reviewed further.

A second classification system for *Mesoplodon* species was developed after reviewing all the likely *Mesoplodon* acoustic detections and comparing signals to published descriptions of *Mesoplodon* echolocation pulses. This *Mesoplodon* classification scheme includes Stejneger's beaked whale, Blainville's beaked whale, BW70 (likely pygmy beaked whale), and BW43 (likely Perrin's beaked whales) from descriptions by Baumann-Pickering et al. (2013). To this, we added BW39V (likely Hubb's beaked whales) from a unique beaked whale signal recorded in this study (Griffiths et al. submitted). The classification scheme is formulated as a dichotomous key and includes Cuvier's and Baird's beaked whales in addition to these *Mesoplodon* species (Griffiths et al. in prep 1.). All final species classifications were made by unanimous agreement among all three analysts. In cases of disagreement or uncertainty, the final classification was "unidentified beaked whale".

2.4   Visual observations and biopsy sampling of marine mammals

The main objectives of visual operations were to opportunistically sight and identify target species matched to concurrent acoustic towed array detections, and to opportunistically detect cetacean groups (target species and others) of interest for biopsy sampling. In good weather conditions (e.g., Beaufort state 0 – 2), a pair of observers searched visually for marine mammals using a combination of naked eye, hand-held binoculars, and through 25x150 "big-eye" binoculars mounted on the flying bridge of the *Shimada*. In poorer conditions, and on most days, a single observer was usually on watch during daylight hours. We did not adhere to a systematic visual survey design or observation protocol, as the cruise was not designed for this purpose.

3   Results

3.1   DASBR survey effort

High-quality acoustic data was obtained for 28 of the 30 deployments (Table 1), resulting in 110,767 2 min sound files collected during PASCAL. One deployment (Station 14) appears to have failed completely due to excessive noise from one of the hydrophones or pre-amplifiers. Another deployment (Station 8) was noisy below 20 kHz, but data quality for beaked whales and *Kogia* was not affected. In addition, two deployments of the ST4300 recorders ended prematurely due to a bug in their firmware that resulted in continuous (rather than duty cycled) recording.

Analysis of DASBRs revealed 1011 detections of beaked whales in 2-min files (Table 4, Figure 3 - Figure 8). No Blainville's beaked whales or likely pygmy beaked whales (BW70) were detected. NBHF and sperm whale detections were annotated within the dataset, but have not yet been verified (Table 4 and Figure 9 and Figure 10).

To date, our analysis efforts have focused on Cuvier's beaked whales. The vast majority (89%) of Cuvier's beaked whale acoustic detections were identified independently by both analysts. Detections of this species were concentrated in more southern and offshore waters and were rare in the nearer-shore deployments north of San Francisco Bay (Figure 3). Echolocation pulses from Cuvier's beaked whales were found in 0.8% of the collected 2 min files.

Table 4. Summary of beaked whale and narrow-band high-frequency (NBHF) detections in 2-min files through the PASCAL DASBR dataset.

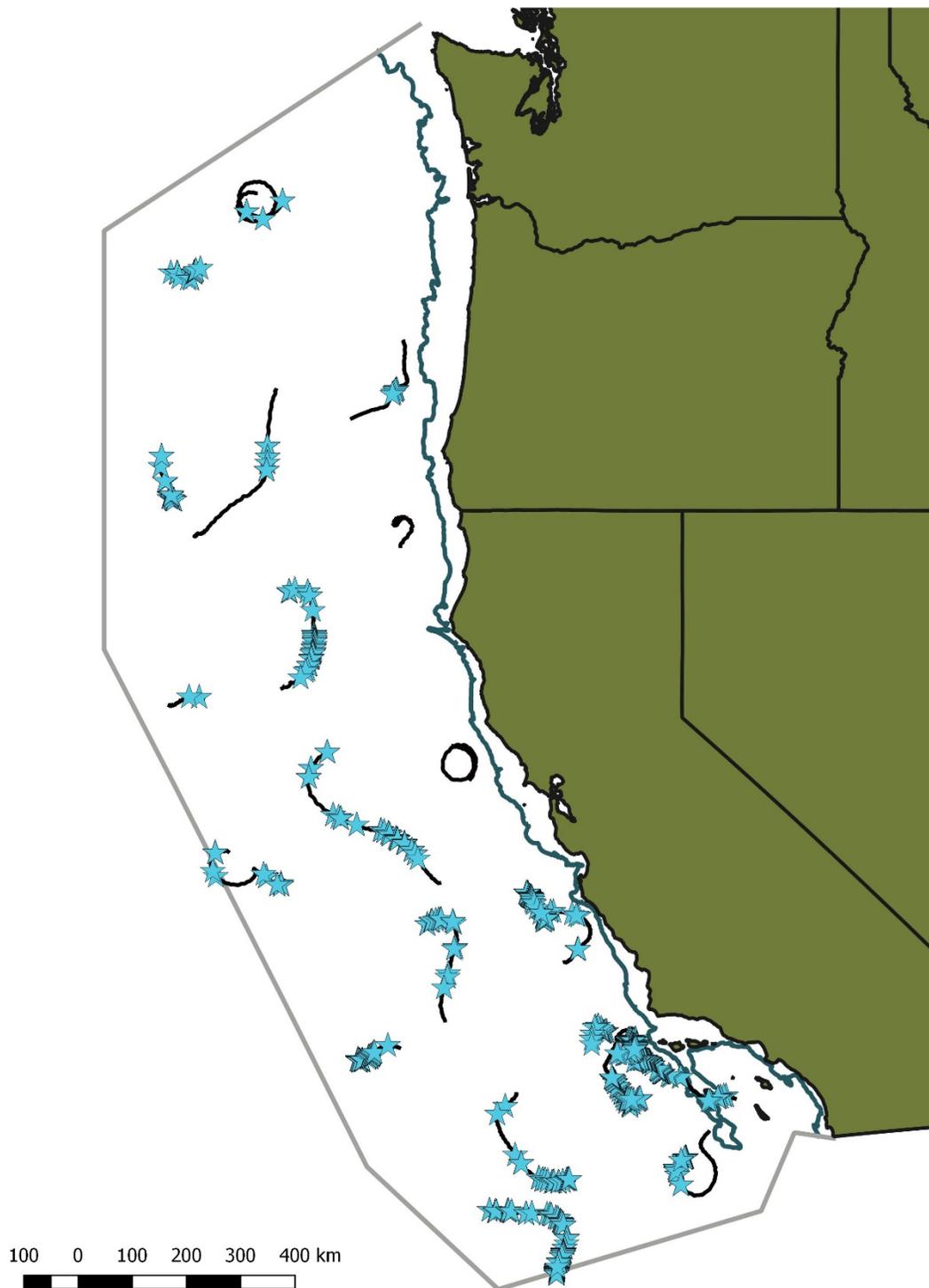| Species Code	Scientific Name	Common Name	Total Detections
049	*Ziphiid whale*	Unidentified beaked whale	83
061	*Ziphius cavirostris*	Cuvier's beaked whale	727
063	*Berardius bairdii*	Baird's beaked whale	90
081	*Mesoplodon stejnegeri*	Stejneger's beaked whale	53
n/a	*BW43*	Beaked whale 43 peak frequency	38
n/a	*BW39V*	Beaked whale 39 peak frequency variation	20
n/a	*NBHF*	Narrow band high frequency	112

Figure 3. Cuvier's beaked whale detections in 2-min files, spread along the drift track of each DASBR. The gray line denotes the boundary of the study area and the dark green line denotes the 500-m isobath.
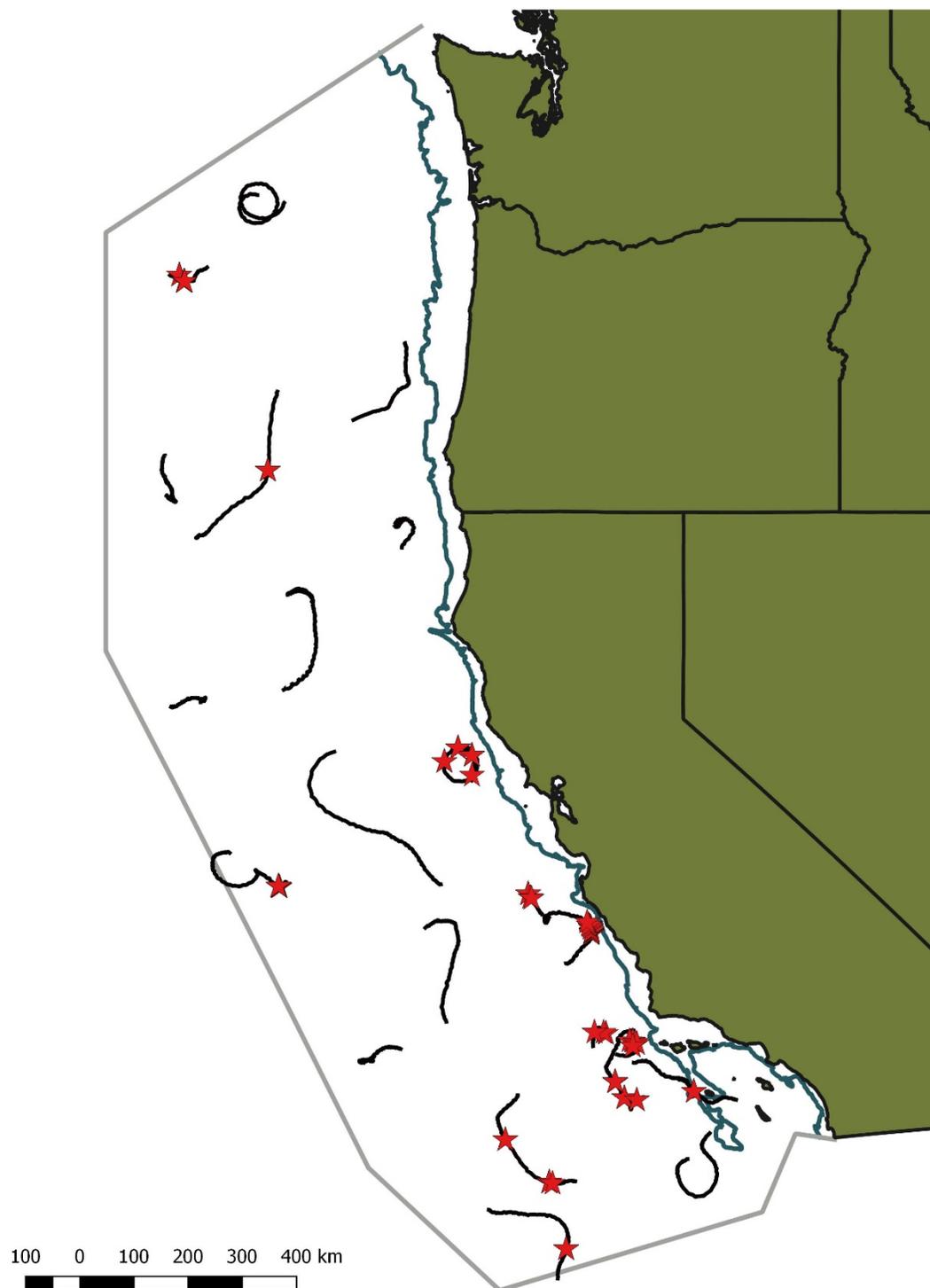
Figure 4. Baird's beaked whale detections in 2-min files, spread along the drift track of each DASBR. The gray line denotes the boundary of the study area and the dark green line denotes the 500-m isobath.

Figure 5. BW43 beaked whale detections in 2-min files, spread along the drift track of each DASBR. The gray line denotes the boundary of the study area and the dark green line denotes the 500-m isobath.

Figure 6. Stejneger's beaked whale detections in 2-min files, spread along the drift track of each DASBR. The gray line denotes the boundary of the study area and the dark green line denotes the 500-m isobath.
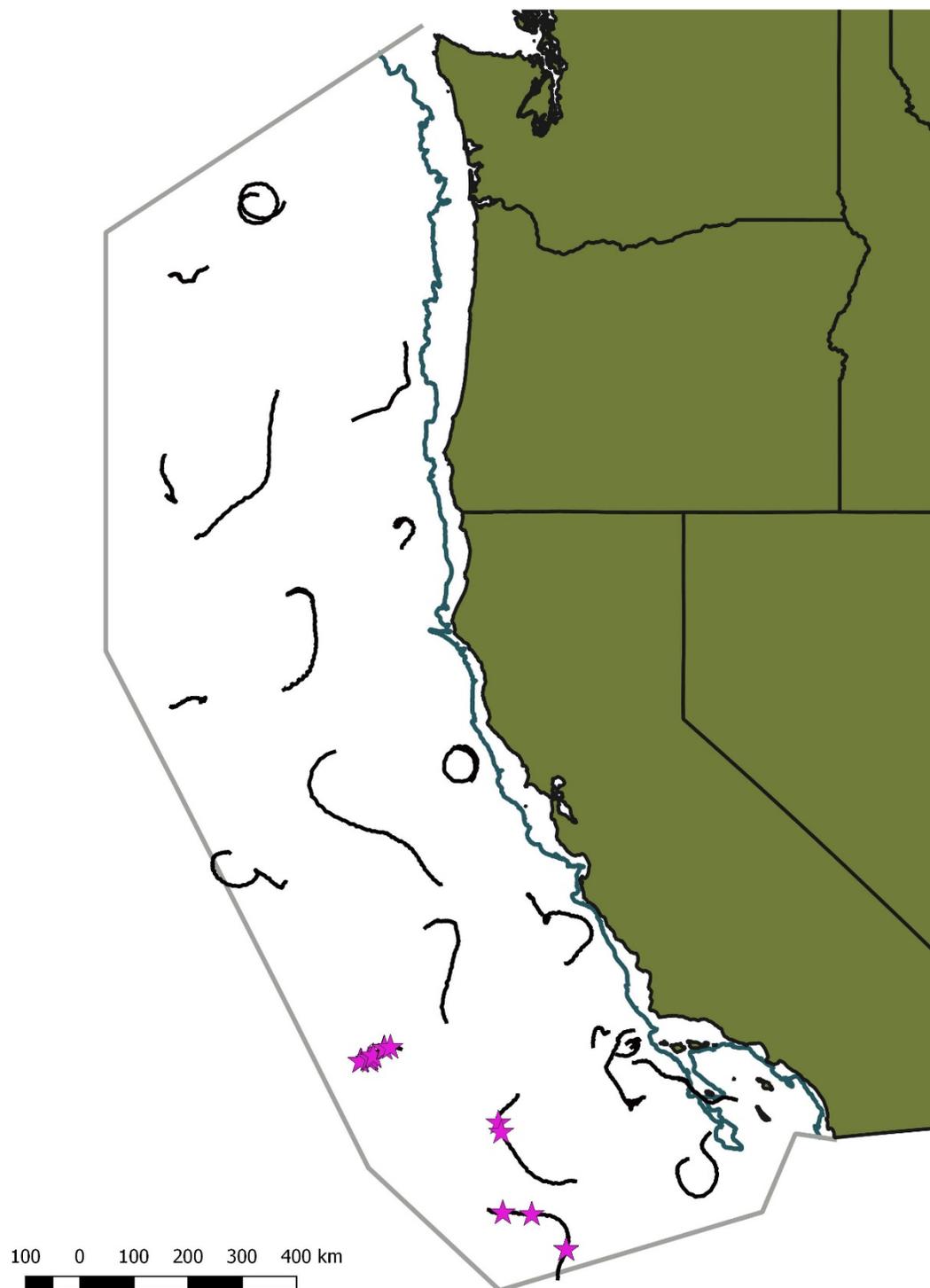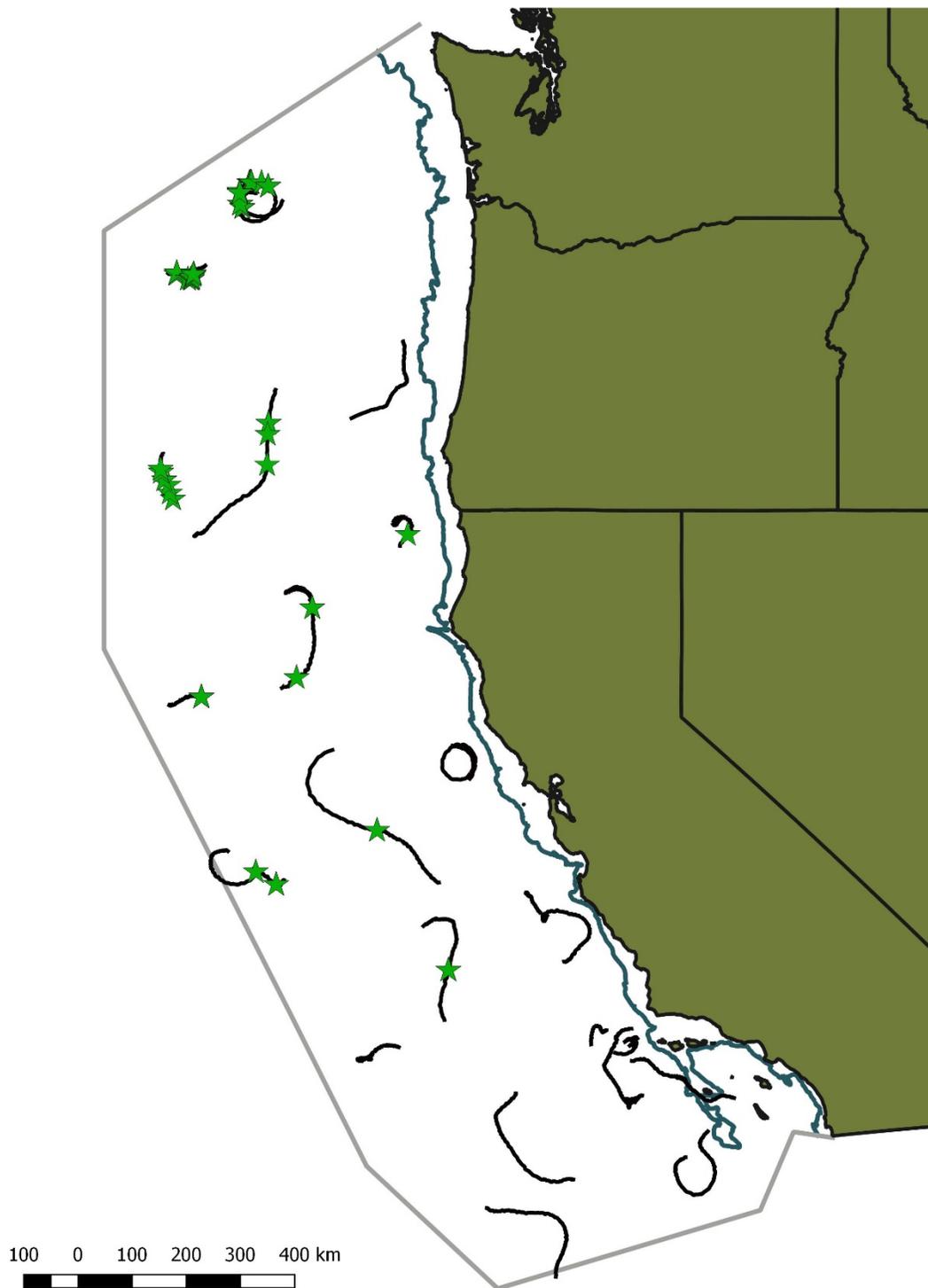
Figure 7. BW39V beaked whale detections in 2-min files, spread along the drift track of each DASBR. The gray line denotes the boundary of the study area and the dark green line denotes the 500-m isobath.

Figure 8. Unknown beaked whale detections in 2-min files, spread along the drift track of each DASBR. The gray line denotes the boundary of the study area and the dark green line denotes the 500-m isobath.

Figure 9. Narrow-band high-frequency (NBHF) detections in 2-min files, spread along the drift track of DASBRs with ST4300 recorders. The gray line denotes the boundary of the study area and the dark green line denotes the 500-m isobath.

Figure 10. Sperm whale detections in 2-min files, spread along the drift track of each DASBR. The gray line denotes the boundary of the study area and the dark green line denotes the 500-m isobath.
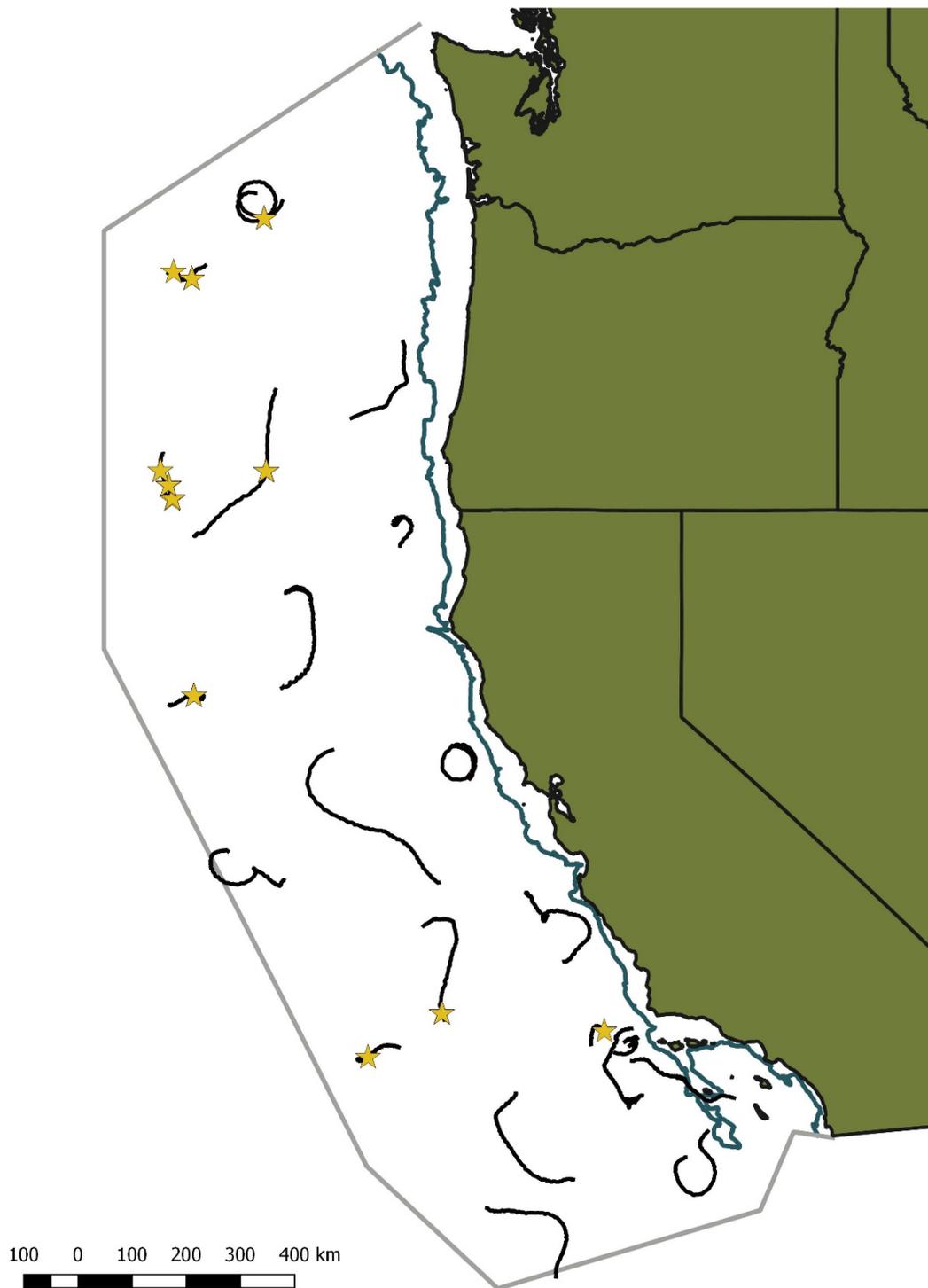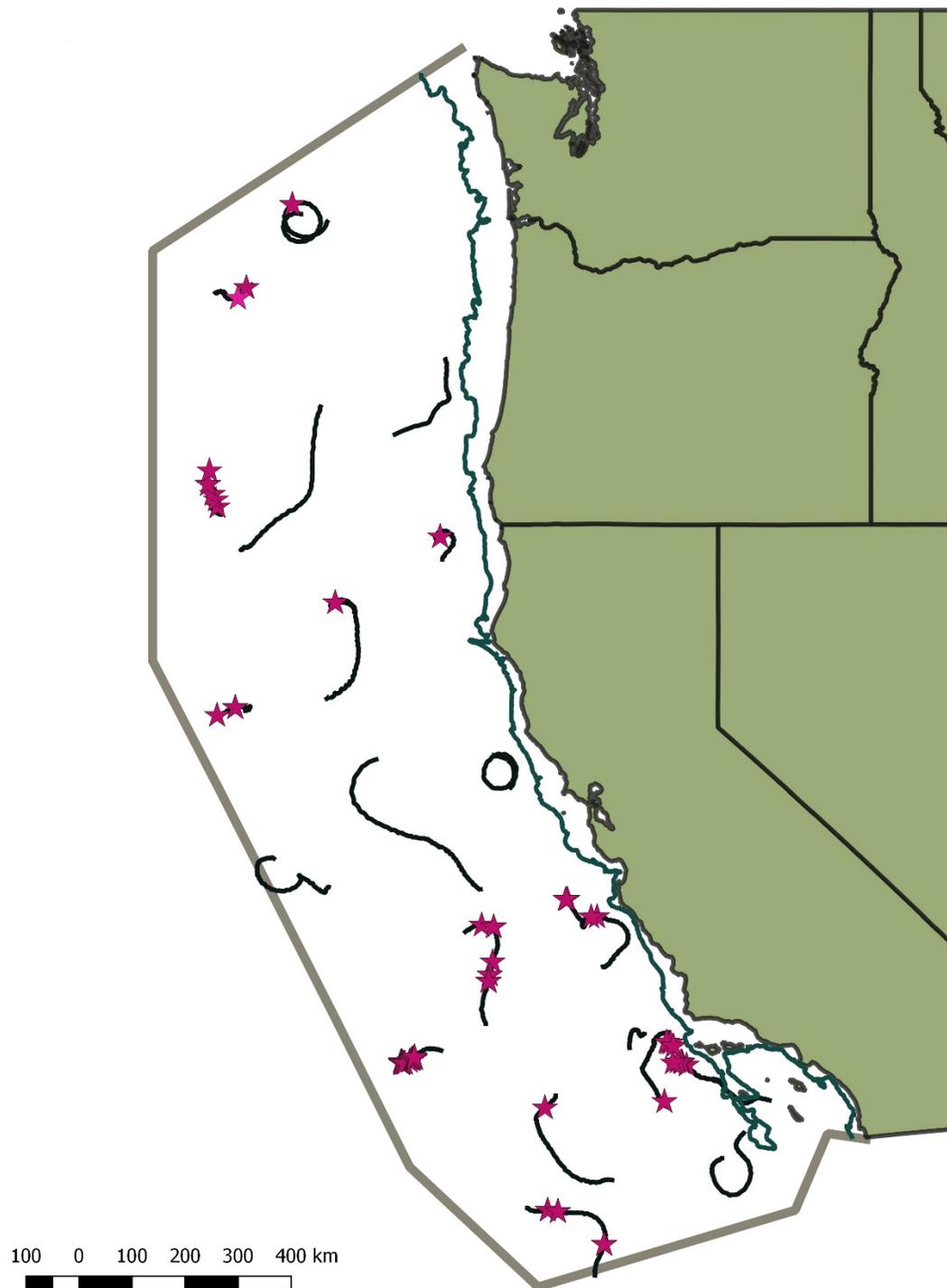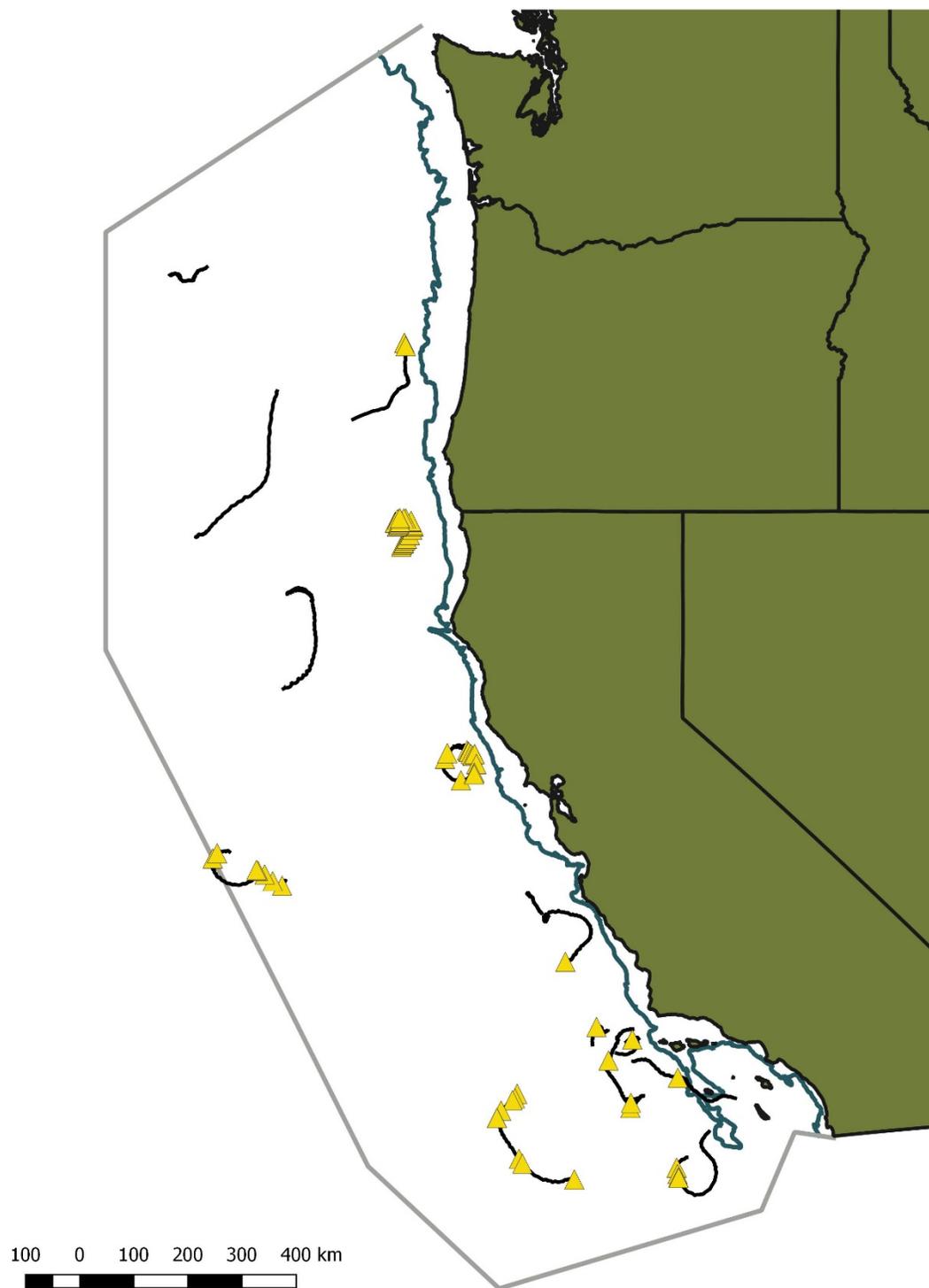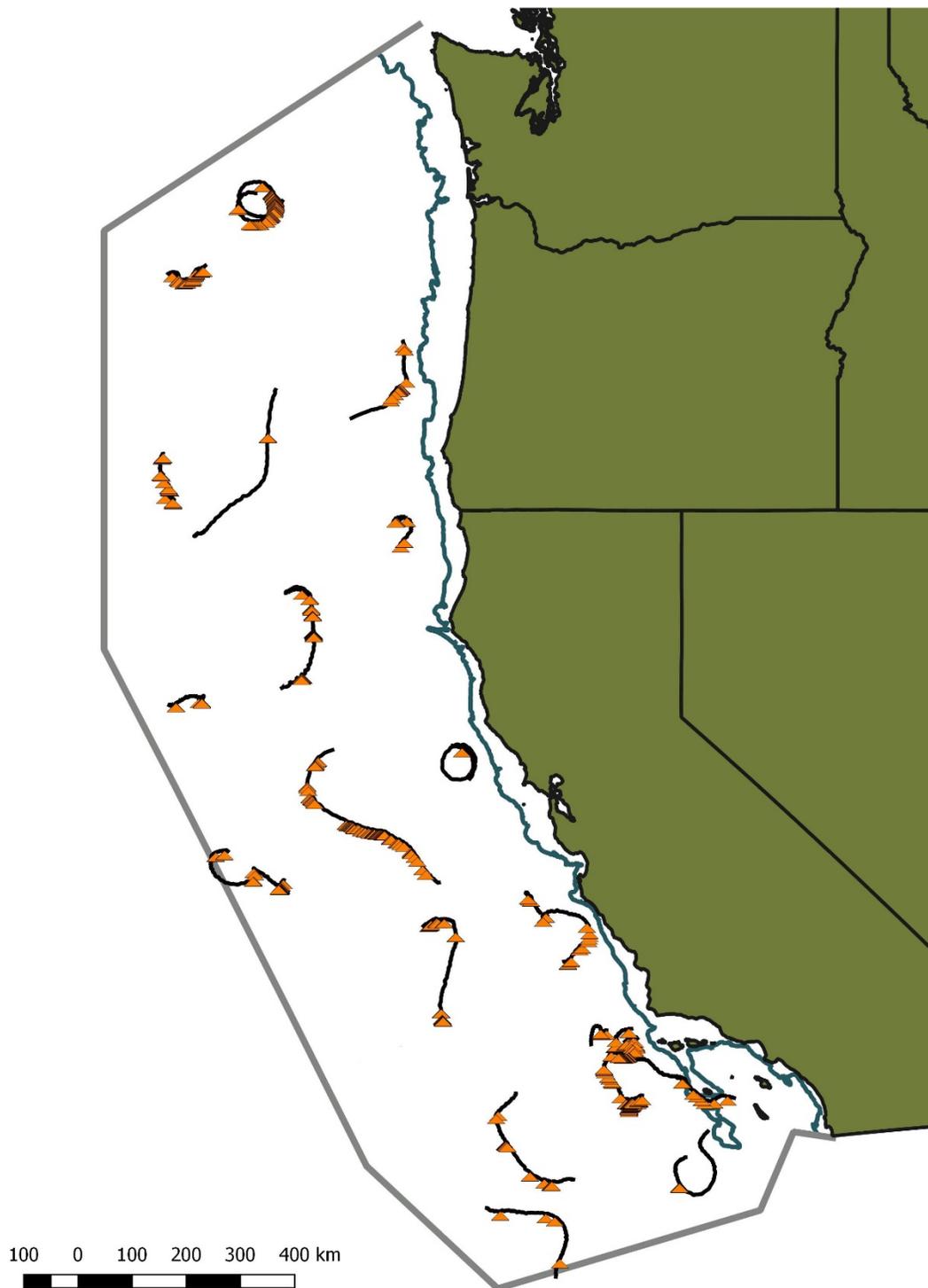
3.2 Towed acoustic array effort

Overall, there were 88 acoustic detections during daytime effort of which 33 had visual confirmation of species (Figure 11). Beaked whales were detected with the towed array 15 times from the following species: unidentified beaked whale (*Ziphiid whale*), unidentified Mesoplodon (*Mesoplodon sp.*), Blainville's beaked whale (*Mesoplodon densirostris*), Cuvier's beaked whale (*Ziphius cavirostris*), and Baird's beaked whale (*Berardius bairdii*).
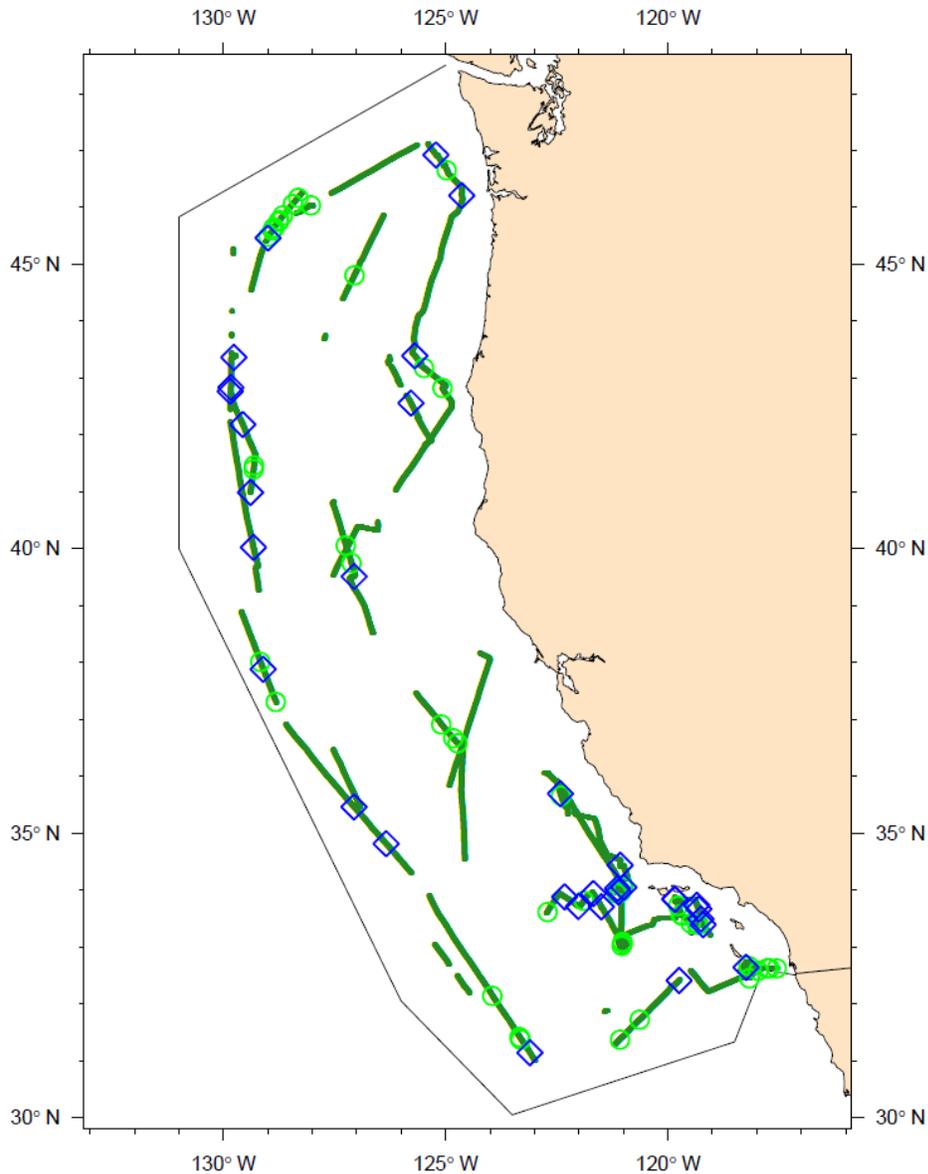

Figure 11. Real-time acoustic monitoring effort (dark green lines) and acoustic detections made in the study area (black outline) during PASCAL. Concurrent sightings and acoustic detections are shown as blue diamonds. Acoustic detections without a concurrent visual sighting are shown as green circles.

3.3 Visual observations and biopsy sampling of marine mammals

The visual team functioned using a reduced version of the observation protocol due to the smaller research party on board the *Shimada*. These efforts produced 135 sighted groups, of which 9 were beaked whales. (Table 5). Unfortunately, none of the sighted beaked whales were species that had an unmatched acoustic signature. Six biopsy samples were collected via crossbow dart from the bow of the *Shimada*: one from short-beaked common dolphin (*Delphinus delphis*) and five from Pacific white-sided dolphins (*Lagenorhynchus obliquidens*).

Table 5. The number of marine mammal groups sighted during PASCAL.

Species Code	Scientific Name	Common Name	Total Sightings
005	*Delphinus sp.*	Unidentified common dolphin	10
013	*Stenella coeruleoalba*	Striped dolphin	9
017	*Delphinus delphis*	Short-beaked common dolphin	23
018	*Tursiops truncatus*	Bottlenose dolphin	2
021	*Grampus griseus*	Risso's dolphin	2
022	*Lagenorhynchus obliquidens*	Pacific white-sided dolphin	2
027	*Lissodelphis borealis*	Northern right whale dolphin	1
044	*Phocoenoides dalli*	Dall's porpoise	11
046	*Physeter macrocephalus*	Sperm whale	5
049	*Ziphiid whale*	Unidentified beaked whale	1
051	*Mesoplodon sp.*	Unidentified Mesoplodon	2
061	*Ziphius cavirostris*	Cuvier's beaked whale	4
063	*Berardius bairdii*	Baird's beaked whale	2
070	*Balaenoptera sp.*	Unidentified rorqual	3
071	*Balaenoptera acutorostrata*	Common minke whale	6
074	*Balaenoptera physalus*	Fin whale	4
075	*Balaenoptera musculus*	Blue whale	20
076	*Megaptera novaeangliae*	Humpback whale	5
077	*Unidentified dolphin*	Unidentified dolphin	10
078	*Unidentified small whale*	Unidentified small whale	1
079	*Unidentified large whale*	Unidentified large whale	4
080	*Kogia sp.*	Unidentified Kogia - dwarf or pygmy sperm whale	1
096	*Unidentified cetacean*	Unidentified cetacean	5
097	*Unidentified object*	Unidentified object	2
TOTAL			**135**

4   Discussion

This report is intended to be technical summary and brief synopsis of the preliminary results of the 2016 PASCAL survey. Analysis of beaked whale detections is ongoing. A manuscript on methods and results for acoustic abundance estimation for Cuvier's beaked whales is in preparation and is anticipated to be ready for submission to a journal in summer 2018. Abundance estimation for *Mesoplodon* beaked whales and Baird's beaked whale requires additional information on depth distributions for these species.

The PASCAL effort revealed that DASBRs are a highly effective tool for examining beaked whale occurrence, distribution, and abundance. This funding is supported through comparison of the number of acoustic detections on DASBRs during PASCAL versus the number of beaked whale visual detections obtained during previous SWFSC sighting surveys in the same study area (seven surveys from 1991 to 2014, Barlow 2016). The total number of sightings for Cuvier's beaked whales, Baird's beaked whales, and *Mesoplodon* beaked whales from all seven surveys are 63, 27, and 38, respectively. Although the acoustic detections on DASBRs are not all independent as some clearly represent multiple detections during a single dive, the magnitude of the overall detection rate on DASBRs for these species is much greater (727, 90, and 111, respectively). We anticipate the high detection rate on DASBRs will provide much more precise estimates of beaked whale abundance than has been previously possible. The acoustic data collection on DASBRs has also provided the ability to acoustically discriminate individual beaked whale species from each other based on the echolocation signal characteristics. During all seven previous visual surveys in this region, only a handful of *Mesoplodon* sightings have been identified to species, and these cases comprised of just two species (one sighting of Hubb's beaked whale and two sightings of Blainville's beaked whale). Stejneger's beaked whale were detected 53 times on the DASBRs, though have not been visually observed in the study area during prior survey efforts. Although additional progress is needed to identify the source of three presumed *Mesoplodon* echolocation signals (BW43, BW70, and BW39V), the DASBR data provide information on the distribution and abundance of these call types before their species identity is known.

Acoustic recordings from the pilot experiment southwest of Point Conception, looking at beaked whale occurrence associated with topographic seafloor features, were included the total number of beaked whale detections. It has yet to be determined if there was an increase in beaked whale detections over seamounts.

Additional information is needed to interpret the NBHF echolocation clicks that were detected during this study. In deep pelagic waters of the California Current, these clicks are only likely to be produced by Dall's porpoise and dwarf and pygmy sperm whales (*Kogia* sp.). A clustering analysis is ongoing to examine which characteristics best describe the differences in NBHF clicks from these three species (Griffiths et al. in prep 2.). There have been only seven visual sightings of *Kogia* during prior sighting surveys, compared to 112 NBHF acoustic detections on DASBRs during PASCAL.

Sperm whale acoustic detections differed substantially from beaked whale detections. Most beaked whale detections occurred as discrete events which lasted less than an hour and appeared to correspond to a deep foraging dive by an individual or synchronized group of beaked whales within 4 km distance (based on theoretical detection distances; Zimmer 2008). In contrast, sperm whale acoustic detections were nearly continuous in some areas. Barlow and Taylor (2005) found that some sperm whale clicks can be detected at ranges of 37 km on towed hydrophones. The DASBRs have lower self-noise and are likely to be able to detect sperm whales at even greater range. In high density areas, the DASBRs were likely receiving echolocation clicks from multiple groups of sperm whales. The long-range detection of sperm whale clicks is likely to vary with ocean sound propagation conditions. A meaningful interpretation of our sperm whale detections clearly requires additional analysis. Many of our sperm whale detections showed

multi-path sound propagation whereby the same echolocation clicks arrives at a hydrophone multiple times due to sound refraction and reflection. These multi-paths signals can be used to estimate the range to the source (Thode 2005). This method can be used to distinguish between multiple sperm whale groups based on their range and may allow us to select only those clicks that are within a range that can be detected by all DASBRs to allow better comparability in detection rates. Analyses of these sperm whale detections is ongoing.

5   References

Barlow, J. 2016. Cetacean abundance in the California Current estimated from ship-based line-transect surveys in 1991-2014. NOAA SWFSC Admin R. LJ-16-01:1-63.

Barlow J, Griffiths ET. 2017. Precision and bias in estimating detection distances for beaked whale echolocation clicks using a two-element vertical hydrophone array. J Acoust Soc Am. 141(6):4388-4397.

Barlow J, Taylor BL. 2005. Estimates of sperm whale abundance in the northeastern temperate Pacific from a combined acoustic and visual survey. Mar Mammal Sci. 21(3):429-445.

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: 2293–2301.

Gillespie D, Mellinger, D. K., Gordon J, McLaren D, Redmond P, McHugh R, Tinder P, Deng XY., Thode A. 2008. PAMGUARD: Semiautomated, open source software for real-time acoustic detection and localisation of cetaceans. J Acoust Soc Am. 30:54-62.

Griffiths ET, Barlow J. 2015. Equipment performance report for the drifting acoustic spar buoy recorder (DASBR). NOAA Tech Memo. NOAA-TM-NMFS-SWFSC-543:1-36.

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):EL399-404.

Griffiths ET, Barlow J, Keating JL. (*In prep 1*). Dichotomous Identification Key: Beaked whale echolocation pulses.

Griffiths ET, Barlow J, Rankin S, Archer E, Keating JL, Keen E, Moore JE. (*In prep 2*). Detection and classification of narrow banded high frequency echolocation clicks from drifting recorders.

Griffiths ET, Keating JL, Barlow J, Moore JE. (*Submitted*). Description of possible species-specific echolocation pulses of Hubb's beaked whale in the California Current. Mar Mammal Sci.

Keating JL, Barlow J. 2013. Click detectors and classifiers used during the 2012 southern California behavioral response study. NOAA Tech Memo NOAA-TM-NMFS-SWFSC-517:1-14.

Thode A. 2005. Three-dimensional passive acoustic tracking of sperm whales (*Physeter macrocephalus*) in ray-refracting environments. J Acoust Soc Am. 118(6):3575-3584.

Zimmer WM., Harwood J, Tyack PL, Johnson MP, Madsen PT. 2008. Passive acoustic detection of deep diving beaked whales. J Acoust Soc Am. 124:2823–2832.

Department of the Interior (DOI)

The Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors the Nation's trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.

Bureau of Ocean Energy Management (BOEM)

The mission of the Bureau of Ocean Energy Management is to manage development of U.S. Outer Continental Shelf energy and mineral resources in an environmentally and economically responsible way.

BOEM Environmental Studies Program

The mission of the Environmental Studies Program is to provide the information needed to predict, assess, and manage impacts from offshore energy and marine mineral exploration, development, and production activities on human, marine, and coastal environments. The proposal, selection, research, review, collaboration, production, and dissemination of each of BOEM's Environmental Studies follows the DOI Code of Scientific and Scholarly Conduct, in support of a culture of scientific and professional integrity, as set out in the DOI Departmental Manual (305 DM 3).