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Cetacean acoustic detections from free-floating vertical hydrophone arrays in the southern California Current

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Abstract: Drifting acoustic recorders were deployed in the southern California Current during Fall 2014. Two hydrophones configured as a 2-m vertical array at 100 m depth recorded using a 192 kHz sample rate on a 10% duty cycle (2 min/20 min). Beaked whales were detected in 33 of 8618 two-minute recordings. Sperm whales were detected in 185 recordings, and dolphins in 2291 recordings. Many beaked whales detected were over an abyssal plain and not associated with slope or seamount features. Results show the feasibility of using free-floating recording systems to detect a variety of cetacean species over periods of several months.

[CFM]
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1. Introduction

Recently, passive acoustic methods have been used to estimate abundance, population density, and distribution for a variety of cetacean species (Marques *et al.*, 2013; Mellinger *et al.*, 2007; Zimmer, 2011). Acoustic survey methods have an advantage over the more commonly used visual survey methods in being able to detect animals in inclement weather, at night, and when they are submerged (Mellinger *et al.*, 2007; Zimmer, 2011). Currently, there are three commonly used approaches for acoustic surveys of cetaceans: towed hydrophone arrays, autonomous recorders in undersea gliders, and seafloor hydrophones (either autonomous or hard-wired to shore).

Each approach has different advantages and drawbacks. Towed hydrophone surveys allow broad geographic coverage, visual species confirmation (during daylight hours), and real-time detection and tracking of target species (Melinger *et al.*, 2007). Gliders are quiet, oscillating between the surface and great depths, and can also cover broad geographic areas (Wiggins *et al.*, 2010). However, these methods can be prohibitively expensive, and towed survey recordings are frequently marred with ship and flow noise (Mellinger *et al.*, 2007). Hard-wired hydrophones can be used as permanent listening stations (McDonald *et al.*, 1995), and autonomous bottom-mounted recorders can be deployed in remote locations for long-term data collection to study seasonal patterns in distributions (Mellinger *et al.*, 2007; Van Parijs *et al.*, 2009). Though individual units are less costly, detection range typically cannot be estimated from single bottom recorders which limits their use in estimating cetacean density (Harris *et al.*, 2013). Bottom hydrophones are fixed in space and broad spatial coverage requires many instruments with economical deployments restricted to shelf and slope waters (Mellinger *et al.*, 2007; Van Parijs *et al.*, 2009).

Here we present results from a pilot survey using an alternative approach: a free-drifting autonomous recorder with a vertical hydrophone array. The Drifting Acoustic Spar Buoy Recorder (DASBR) is free-floating, autonomous recorder developed at the Southwest Fisheries Science Center (SWFSC). These instruments can be inexpensively deployed over a broad geographic area and can collect data for several months as they drift passively with the currents. Here, we present odontocete detection results (beaked whales, sperm whales and a combined category of all dolphins) from the first multi-month deployment of several DASBRs in the California Current during the Fall of 2014.

2. Methods

2.1 DASBR construction and deployment

DASBRs were designed to be assembled using inexpensive, off-the-shelf components. Construction details are provided by Griffiths and Barlow (2015). For this study, two

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Table 1. DASBR deployment dates and times, deployment and retrieval locations (in decimal degrees), and deployment and recording durations (days, H:M:S). Recording duration was limited by battery power. DASBR D was never recovered. (N/A indicates not available.)

Deployment	Deploy Start Time GMT	Deploy North Latitude	Deploy West Longitude	Deployment Length	Recording Length	Retrieval North Latitude	Retrieval West Longitude
A	8/8/2014 13:58:53	34.956	126.687	83 days, 1:10:20	42 days, 18:40:00	34.761	127.453
B	8/2011/2014 2:09:46	40.37	126.301	49 days, 12:41:42	42 days, 02:00:00	39.449	128.611
C	10/12/2014 21:09:47	34.887	121.512	38 days, 18:00:33	37 days, 18:20:00	36.017	121.92
D	10/13/2014 14:17:52	34.015	121.811	N/A	N/A	N/A	N/A
E	10/24/2014 1:04:43	32.847	118.866	39 days, 13:45:50	39 days, 07:00:00	33.48	119.754

High Tech Inc. (Long Beach, MS).[1] HTI-96-min hydrophones with two meter vertical separation were suspended on a 100 m Cat5e conducting cable. Housed within a spar buoy, a Wildlife Acoustics SM2+Bat board recorded signals from these hydrophones as stereo 16-bit WAV files at a 192 kHz sample rate. To conserve battery power and memory, a 10% duty cycle was used to record 2 min at 20-min intervals. The hydrophone depth (nominally ~90 m) was recorded using an analog pressure sensor and a 12-bit A/D converter on the SM2+ board. Locations were recorded using a GPS receiver with an SM2+ daughter board. Elastic cables (10–16 m) were attached to the conducting cable to decouple the hydrophones from surface waves. Two low-cost Spot satellite locators were used to track the DASBRs: one enclosed within the spar buoy and one mounted ~1 m above the water's surface on a highly visible buoy tethered to the DASBR by a 5-m line. Each satellite locator provided at least one location per day which facilitated recovery of the instrument and associated data. DASBRs were deployed during a combined visual and acoustic survey of cetaceans in California Current in Fall 2014 and were recovered by ship later in the survey.

2.2 Data processing

Recordings were analyzed to determine the presence of echo-location clicks from three types of cetaceans: beaked whales, sperm whales, and dolphins. Echo-location clicks were automatically detected using an energy detector within PAMGuard software (version 1.13.00, Gillespie *et al.*, 2008) with a signal to noise ratio (SNR) threshold of 12 dB. Detected clicks were classified into peak-frequency categories using the PAMGuard click classification module. The parameters for automated odontocete click categorization are based on taxonomic differences described by Keating and Barlow (2013). Vertical bearing angles to the source of each click were automatically estimated in PAMGuard using the time difference of arrivals for signals received on the two hydrophones.

Click detections were reviewed manually in PAMGuard Viewer by the lead author (E.T.G.) and cetacean clicks were classified as being from beaked whales, sperm whales, or dolphins. The analyst classified clicks into these general categories based on peak frequency, the signal's waveform, evidence of an upsweep in a Wigner plot, inter-click interval (ICI), the vertical bearing angle, and, for sperm whales, the timbre and rhythm of the clicks (listening to playbacks). Beaked whale clicks were sub-categorized based characteristics outlined by Baumann-Pickering *et al.* (2013). Not all beaked whale click types have been identified to species, and we used the nomenclature outlined by Bauman-Pickering for click types that could not be identified to species (including her BW40, BW43, and BW70 designations). To determine the final beaked whale species classification, four experienced analysts reviewed all beaked whale candidates using the same criteria. If the analysts could not agree, the encounter was classified as an unidentified beaked whale.

Mapped locations of beaked and sperm whale detections were superimposed on bathymetric profiles from the ETOPO1 database (Pante and Simon-Bouhet, 2013).

3. Results

Five DASBRs (A–E) were deployed off the Californian coast for 37–83 days (Table 1). Signals from both satellite locators on DASBR D were lost within the first 48 h of the deployment, and the unit was not recovered. DASBR deployments A, B, C, and E were

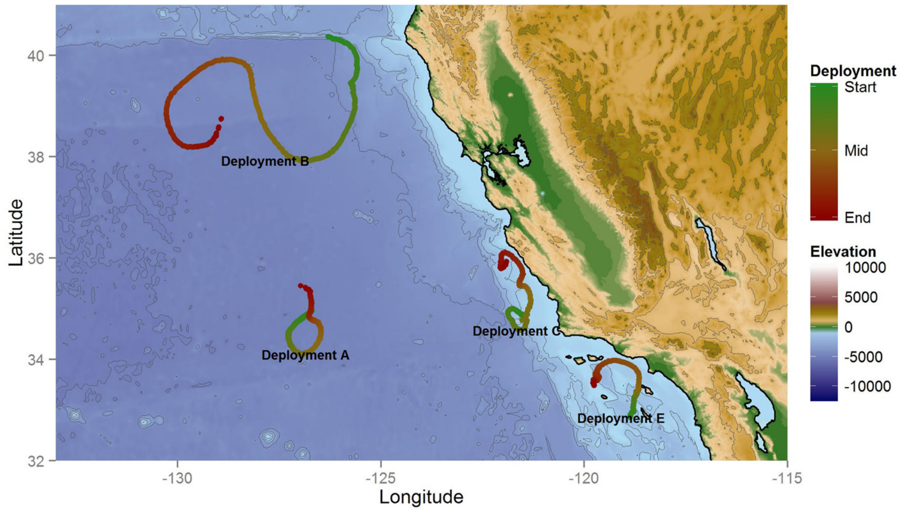

Fig. 1. (Color online) Drift trajectories of the four recovered DASBRs off the Californian coast. Each deployment start is denoted by green, which fades into red where the unit was retrieved. Isobaths are at 500 m intervals and west longitudes are negative.

successfully retrieved, and their drift trajectories are plotted in Fig. 1. Average drift speeds were 0.56, 1.31, 0.62, and 0.61 km day^{-1} (for A, B, C, and E, respectively). The hydrophone array was damaged during deployment B and produced no useable data. Our acoustic results are limited to DASBR deployments A, C, and E.

An acoustic event is considered to be the presence of an identified cetacean within a 2-minute recording, regardless of the number of clicks received. The 8618 total recordings included 33 beaked whale events, 185 sperm whale events, and 2291 dolphin events (Table 2). Many of the sperm whale and dolphin events were associated with events in the previous or subsequent recording, and thus events cannot be considered independent. Only six of the beaked whale events followed beaked whale events within the adjacent 20 min. Most sperm whale events were recorded during deployment A, which had a mean water depth of 4733 m (Fig. 2). Sperm whales were occasional detected during deployment C (mean depth of 1162 m), but were not recorded during deployment E (mean depth of 849 m). Dolphins were detected heavily on all three deployments, with slightly more events recorded along the coast (Fig. 2).

All 33 of the beaked whale events were in waters deeper than 500 m (Fig. 3). Cuvier's beaked whales (*Ziphius cavirostris*) were detected more frequently (N = 19) than all four of the other recognizable beaked whale types combined. Deployment A included the highest diversity of beaked whale types including Cuvier's beaked whale (N = 8), BW40 (N = 1), BW43 (N = 2), BW70 (N = 2), and an unidentified beaked whale (N = 1). Cuvier's beaked whale was the only beaked whale species detected during deployment C (N = 5). Deployment E included Cuvier's beaked whales (N = 6), Baird's beaked whale (*Berardius bairdii*) (N = 4) and unidentified beaked whales (N = 4). All of the beaked whale signals arrived from below 90 m, the depth the hydrophones were deployed at, except the BW70 signals which arrived from above.

4. Discussion

The DASBR deployments were in three distinctive habitats. Deployment A was ~480 km from the closest point of land over an abyssal plain (>4 km depth). Both deployments C and E passed within 40 km of the coast, but the former was along the open, steep shelf coastline of Big Sur and the latter was in the Southern California

Table 2. Number of two-minute recordings with detections of beaked whale, sperm whale, and dolphin echolocation clicks for each DASBR deployment and for all deployment locations pooled. Values in parentheses indicate percentage of recordings with presence of the given category of cetacean. Total number of sound files in all deployments = 8618; in A = 3036; in C = 2741; and in E = 2851.

	All Locations	Deployment A	Deployment C	Deployment E
Beaked Whales	33 (0.38%)	14 (0.46%)	5 (0.18%)	14 (0.49%)
Sperm Whales	185 (2.1%)	142 (4.7%)	43 (1.6%)	0 (0%)
Dolphin Activity	2291 (26.6%)	187 (6.2%)	732 (26.7%)	1372 (48.1%)

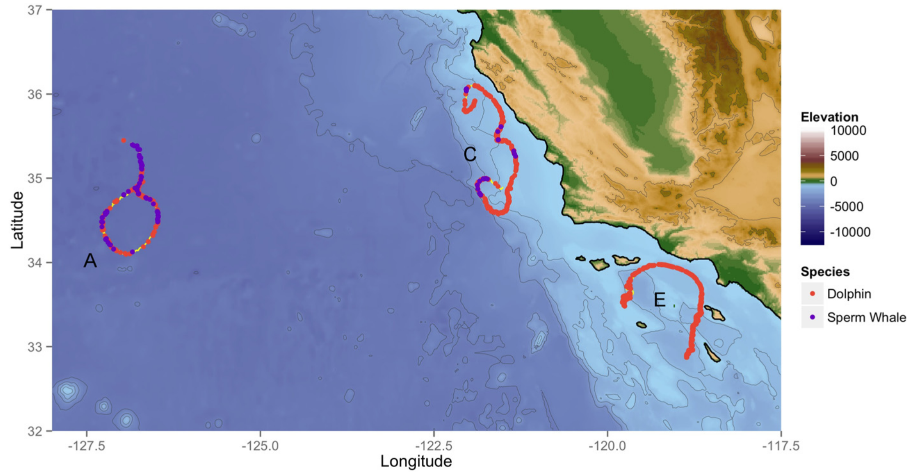

Fig. 2. (Color online) Dolphin (orange) and sperm whale (purple) events detected on deployments A, C and E. Isobaths are at 500 m intervals and west longitudes are negative.

Bight protected by an archipelago and underwater ridges. Unsurprisingly, dolphins were present more often in coastal and shelf waters than offshore. Although many species of dolphin utilize deep water habitat, dolphin densities in the California Current are higher close to shore (Forney *et al.*, 2012). All beaked whales and most sperm whales events were recorded in deeper waters or over steep slopes, matching what is known of their distributions and habitat preferences (Forney *et al.*, 2012). Deployment A had the highest diversity of cetaceans, including dolphins, sperm whales, and at least four recognizable beaked whale click types. Our most commonly detected beaked whale species was Cuvier's beaked whale, which is also the most commonly seen beaked whale in California offshore waters (MacLeod *et al.*, 2006; Forney *et al.*, 2012). Baumann-Pickering *et al.* (2014) suggested that the BW70 click type may be the pygmy beaked whale, BW43 may be Perrin's beaked whale, and BW40 may be Hubb's beaked whale. If our BW70 events are pygmy beaked whales, these records are well north of the presumed range of this species (MacLeod *et al.*, 2006); however, strandings of this species have occurred in California. Our BW43 falls within the distribution of Perrin's beaked whale that has been inferred from strandings and other acoustic detections (MacLeod *et al.*, 2006; Baumann-Pickering *et al.*, 2014). Likewise, our

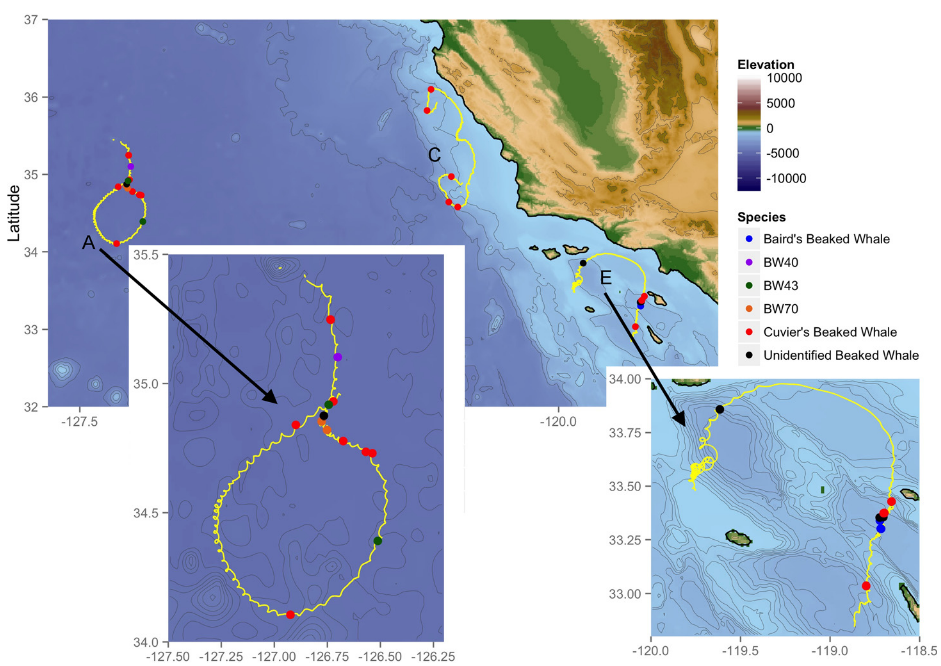

Fig. 3. (Color online) Beaked whale detections on deployments A, C, and E. Left inset of deployment A shows locations where four distinct beaked whale detections. Right inset of deployment E shows where three distinct beaked whale detections. Isobaths are at 500 m intervals and west longitudes are negative.

BW40 click events are within the temperate, offshore habitat of Hubb's beaked whale (MacLeod *et al.*, 2006).

Our data clearly show that beaked whales are more present than previously considered over abyssal plains in waters greater than 4 km deep (Fig. 3). This counters a common misperception that beaked whales are primarily found over slope waters, in deep basins, or over seamounts (Baumann-Pickering *et al.*, 2014). Higher density of certain species of beaked whales may be found in these potentially preferred habitats, and we had a relatively high detection rate for beaked whales at the north end of the Catalina Basin (Fig. 3). However, abyssal plains may be, overall, a more important habitat than previously thought for beaked whales given that the average depth of the ocean is >4 km. Our acoustic result agrees with visual cetacean surveys in the Pacific Ocean that also show the vast majority of Cuvier's beaked whale sightings over abyssal plains (Hamilton *et al.*, 2009). Prior to this study, virtually all of long-term acoustic studies of beaked whales have been in slope waters and deep basins or on seamounts. Our results highlight the value of drifting recording systems in making long-term measurements in deep, abyssal waters.

Clearly there are limits on what can be inferred from a pilot study of this sort; however, we have shown that autonomously recording vertical hydrophones can be deployed and successfully retrieved after periods of several months. They can collect valuable data on the seasonal and geographic distribution of a wide variety of cetaceans. The high SNR of the recordings allow differentiation of beaked whale species. The vertical array allows estimation of vertical bearing angles which are a key feature in searching for beaked whale clicks in a cacophony of dolphin clicks. It may be possible to couple these vertical bearing angles with multipath signals (e.g., from surface reflection) to estimate both range to and depth of vocalizing animals (Thode, 2004). If detection range can be estimated, then distance estimation methods can be used to estimate the density and abundance of some species.

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[1]Mention of brand names does not imply an endorsement by NOAA or the U.S. Government.

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