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PASSIVE ACOUSTIC BEAKED WHALE MONITORING SURVEY OF THE CHANNEL ISLANDS, CALIFORNIA

Tina M. Yack, Jay Barlow, John Calambokidis, Lisa Ballance,
Robert Pitman, and Megan McKenna

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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Passive Acoustic Beaked Whale Monitoring Survey of the Channel Islands, off the coast of southern California

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I. INTRODUCTION

Beaked whales (family Ziphiidae) are a poorly understood group of cetaceans, known for their deep diving capabilities. Recently, interest in beaked whales has increased due in part to well publicized stranding events associated with military sonar exercises (Johnson et al., 2004). Mass strandings of beaked whales were first linked to Naval sonar exercises in the Canary Islands (Simonds and Lopez-Jurado, 1991). Pathological examinations of the heads of stranded whales following naval maneuvers in the Bahamas (Balcomb and Claridge 2001) and the Canary Islands (Jepson *et al.* 2003) confirmed the existence of lesions. Although the exact causal factors resulting in these stranding events remains unclear, it has been hypothesized that an acoustically induced, maladaptive behavioral flight response that elicits long bouts of shallow dives above lung compression depth could result in gas bubble formation and ultimately stranding (Cox et al. 2006; Falcone et al., 2009).

Beaked whales spend the majority of their time at depth and are relatively inconspicuous at the surface of the water. As such, they are difficult to detect using standard visual survey methods. Visual surveys are further constrained by poor weather and light conditions. This has resulted in difficulty in gathering basic abundance and distribution information about these animals in the field. The lack of information regarding abundance and distribution of beaked whale species impedes the ability of researchers to accurately characterize and define beaked whale habitat. This in turn limits the researchers capacity to effectively inform policy makers and resource managers about conservation, management and mitigation measures for these species.

Beaked whales produce directional ultrasonic biosonar in the form of clicks to echolocate their pelagic and bentho-pelagic prey (Johnson et al. 2006). Recent research on Blainville's (*Mesoplodon densirostris*) and Cuvier's (*Ziphius cavirostris*) beaked whales has shown that stereotyped frequency-modulated (FM) clicks are produced continuously when the animals are foraging at 400 – 1200 m depth

(Madsen et al. 2005; Tyack et al. 2006; Johnson et al. 2004 /2006; Zimmer et al. 2005). Clicking starts at approximately 400 m on the descent as they presumably begin foraging. Although it appears that multiple species of beaked whales produce a similar click profile, specific spectral characteristics of the clicks vary from species to species (Table 1). The unique characteristics of beaked whale echolocation behavior combined with the general elusiveness of these species to visual observers provide an opportunity for passive acoustic monitoring (PAM) to play an important role in research, mitigation, and conservation efforts for this species.

The Southern California Bight is comprised of deep slope waters that would be expected to provide good foraging habitat for beaked whales. While a population of beaked whales has been consistently observed offshore of San Clemente Island (Falcone et al. 2009), there have been few sightings of beaked whales in the vicinity of the other Channel Islands (Hamilton et al. 2009). The purpose of this survey was (1) to field-test automated beaked whale acoustic detection algorithms, and (2) to determine if beaked whales were present in other regions of the Channel Islands with similar bathymetric features to those of San Clemente Island.

II. MATERIALS AND METHODS

A. Acoustic

The 49 foot sailing vessel *Nauti Buoys* was used as a research platform to survey a region of the Southern California Bight south of Santa Cruz Island from 18 to 25 August, 2009. A three-element hydrophone array was towed approximately 100 m behind the vessel. The hydrophone array consisted of an oil-filled streamer section containing three high-frequency hydrophone elements and pre-amplifiers. Each hydrophone consisted of a spherical ceramic element connected to a 40dB preamplifier. The combined hydrophone and preamplifier sensitivity was approximately -165 dB re 1 V/μ Pa and a flat

(+/1 XX dB) from 1.5 kHz to 150 kHz. With the exception of the overnight transit to and from the Channel Islands survey area, during which acoustic monitoring and recordings were made, acoustic and visual effort took place only during daylight hours.

Analog acoustic signals were passed through a signal conditioning (Magrec), which provided outputs for each channel and high pass filtering, signal gain adjustments, and outputs for each channel. The signal was high-pass filtered at 2 kHz and digitized at a 384 kHz sample rate using a National Instruments 6251 USB data acquisition board connected to a 12 v fanless computer. This system was used to continuously record acoustic data to computer hard disks using Logger 2000 data-acquisition and recording software (www.ifaw.org/sotw). Electrical power was limited on the research vessel, so the acoustic system was designed to run efficiently from 12 V-DC batteries (AGM deep cycle 92 Ah). The computer system included, a 6-inch Xenarc LCD monitor, Garmin GPS, and USB powered external hard drives, all of which were powered from the 12 V-DC battery power.

Rainbow Click (Gillespie and Leaper, 1996) was used for auto-detection and classification of beaked whale echolocation signals. Rainbow Click is designed to save the waveform and spectrum of clicks, which can then be further examined by post-processing and reviewing to verify classification. At sea, a bio-acoustic technician continually monitored aurally and visually incoming acoustic signals from two array hydrophones using the Rainbow Click display and stereo headphones. The waveform, spectrum, bearing display, and inter-click interval were the main signal characteristics used to identify probable beaked whale clicks in real time. Beaked whale detections were further categorized into three subjective categories: 1) possible, 3) probable, and 3) definite, based on a number of criteria by an experienced bio-acoustic technician. Clicks classified as beaked whale using Rainbow Click's automated classifier (based on waveform and spectral characteristics) were designated as 'possible' detections. Clicks classified as beaked whale using both Rainbow Click's automated classification and with an experienced bio-acoustic technician who examined and verified that the inter-click-interval was typical (0.2 – 0.5s) (Madsen et al., 2005; Johnson et al., 2006) of a beaked whale were designated as ‘probable’ detections. Clicks acoustically designated as probable with a confirmed visual sighting of a beaked whale, were designated as definite encounters (except in one instance where very intense and clear beaked whale clicks without a visual sighting were detected). The designations presented in this report are preliminary, and thorough analysis of the data may identify false detections.

Bearing angles to beaked whale clicks were calculated by Rainbow Click software using target motion analysis to estimate the location of animals.

B. Visual

A team of three scientists rotated between visual observation and recorder positions from the *Nauti-Buoys*. Observers typically used handheld 7x50 binoculars to scan the horizon from 0-90 degrees of the ship’s heading from one side of the vessel or scanned by naked eye. Two additional scientists surveyed for marine mammals from an inflatable rigid hull inflatable boat (RHIB, ~5.5 m) that operated in the close proximity of the sailboat during daylight hours. All marine mammal sightings were entered into a form and later onto computer-based spreadsheets. Photo identification and biopsy samples were collected opportunistically as conditions allowed.

III. RESULTS

The sailing vessel Nauti Buoys surveyed 950 km of trackline in the Southern California Bight from 18 to25 August, 2009 (Figure 1). The depth of the hydrophone array was dependent on the survey speed (Figure 2) and the mode of propulsion (sailing vs. motorized). The typical survey speed was 4 knots, resulting in a hydrophone depth of approximately 4.5 meters.

During this time there was approximately 88 hours of recording effort. During approximately 70 hours of acoustic monitoring effort (i.e. when a bio-acoustic technician was monitoring the signals) there were 42 separate acoustic *encounters* that were classified as beaked whales. Of these, eight were classified as possible, 31 were classified as probable, and three were classified as definite (Figure 1). The majority of these detections occurred in clusters within three distinct regions (A-1, A-2 and B-1)_ (Figure 3).

Region A-1 is located south and west of Santa Cruz Island. The detections in this region were clustered along the 1000 to 1600 meter isobaths. This region is comprised of a deep central basin with steep slopes on all sides.

Region A-2 is located to the east of Santa Barbara Island and northwest of Catalina Island. This area is comprised of steep-sloped bathymetry to the northeast and northwest and deep open water to the south. The Cuvier's beaked whale sighting occurred in the northeast part of this area.

Region B-1 is located south of Catalina Island and 23 km offshore of Oceanside, CA. The habitat is characterized by a deep-water basin with areas of steep contour and shallow sea-mounts. This region is a promising future research area given its relatively close proximity to shore and ease of access from Oceanside Harbor.

During the survey, there was approximately 66 hours of visual survey effort during which 54 sightings of cetaceans were made from the *Nuati Buoys* survey platform. The highest number of sightings were of unidentified common dolphin species (*Delphinus* spp.) (16), followed by long-beaked common dolphin (*Delphinus capensis*) (13), Risso's dolphin (*Grampus griseus*) (10), bottlenose dolphin (*Tursiops truncatus*) (6), and unidentified delphinids (4). Single sightings were made for the following species: Cuvier's beaked whale (*Ziphius cavirostris*), blue whale (*Balaenoptera musculus*), fin whale (*Balaenoptera physalus*), minke whale (*Balaenoptera acutorostrata*), and an unidentified small whale.

There was one simultaneous acoustic and visual encounter with a group of three Cuvier's beaked whales that will be described in greater detail. The acoustics team had decided to survey the area where the encounter occurred based on prior acoustic beaked whale detection events during two previous transects through the area. The survey vessel departed anchorage at Santa Barbara Island at approximately 7:30 a.m. on August 23rd in Beaufort 0 conditions. At 8:58 a.m. a beaked whale sighting occurred at a distance of approximately two nautical miles and a bearing of five degrees starboard of the survey vessel. The encounter lasted approximately four hours. During the encounter there were six dives resulting in seven surfacing events. Biopsy samples were obtained from two of the animals. There were five short dives (<30 min) and two long dives (>45 min). Echolocation clicks were detected during the two long dives; an example of a click series is shown in Figure 4. These data were analyzed during post-processing. During the first long dive, echolocation clicks were detected over a period of 17 minutes and 10 seconds. A total of 711 clicks were detected on recordings made from the towed array. There were 49 bouts of clicking (> 2 clicks) detected during this period. The average inter-click-interval (ICI) was 0.4 seconds. During the second long dive, echolocation clicks were detected over a period of 17 minutes and 48 seconds. A total of 881 clicks were detected on the towed array. During the detection period there were 71 bouts of clicking. The average ICI was again 0.4 seconds.

IV. DISCUSSION

A. Acoustic

The towed array and 12-v computer operating system proved to be very effective for acoustic detection of beaked whales from a small vessel platform. The automated detection system performed well at detecting and discriminating beaked whale clicks from noise and clicks of other species when jointly monitored by an acoustic technician. The high quality recordings made on this survey provide a means of testing and improving detection and classification algorithms for future surveys. Future work will include refining detection algorithms and implementing an audible alarm signal for classified clicks. This would allow a listener to distinguish click patterns of beaked whales quite easily by ear if alarm tones are within the audio range and match the rate of clicking. This report presents preliminary data that will be verified using a newly parameterized beaked whale classifier in PAMGUARD Beta 1.08 software once algorithm testing is complete.

The distribution of probable and definite beaked whale clicks appears to be concentrated in three main areas (Figure 3). These areas all encompass deep-water habitat with steeply sloped bathymetry. We recommend that future work further explore the identified regions.

Localization of signals during the beaked whale encounters proved difficult. Bearing angles were calculated using target motion analysis methods in Rainbow Click. Bearing angles for beaked whale clicks typically ranged from 60-120 degrees. The lack of variation in bearing angles suggests that these are not true angles but rather slant angles comprised primarily of a depth component, but not calculated accurately. In order to obtain true slant angles and localize animals in three dimensions, one solution would be to use detected surface echoes as signals from a virtual hydrophone and use the time of arrival differences between the two real hydrophones and the virtual hydrophone to obtain a 3-D localization of the animal. Future analysis of these data will include identification and detection of surface echoes if present and use of this information to obtain three dimensional localizations. The ability to localize animals in three dimensions will greatly increase our understanding of beaked whale dive behavior and habitat use on a large scale.

Recording data using the 12 v computer system provided high S/N recordings that were free of the electrical noise interference typical of most ship surveys. We recommend this type of system for future vessel based surveys. However, the Xenarc LCD monitor was not as successful. The screen was too small for adequate real time monitoring and it often malfunctioned. For future surveys we suggest testing other larger 12 v monitors.

B. Visual

Visual efforts were secondary to the primary objectives of this survey. Visual observation was restricted by low observation height and vessel movement, resulting in minimized detection distance for animals. However, during Beaufort 0-1 conditions a beaked whale sighting did occur, and it is likely that during optimal conditions beaked whales could be reliably detected from this platform. The success for sighting beaked whales was improved dramatically by the acoustic team's efforts in guiding the vessel to an area where there were previously high numbers of acoustic probable beaked whale detections. Future surveys should continue to incorporate complementary acoustic/ visual efforts as a means for providing matches between sounds and confirmed species.

V. CONCLUSIONS

The Channel Islands beaked whale survey successfully accomplished the main goals to field-test automated acoustic detection algorithms for detecting beaked whales and to identify beaked whale presence in regions of the Channel Islands with habitat similar to that of San Clemente Island, an area where a beaked whale population is consistently detected acoustically using a bottom mounted array and sighted. These results will allow future research on beaked whale ecology and behavior to be conducted in this area which is located outside of the San Clemente navy range, an area which is more difficult to access and typically has poor weather for beaked whale surveys. Additionally, this survey showed that combined visual and acoustic methods can effectively identify previously unidentified beaked whale habitat.

VI. ACKNOWLEDGEMENTS

This research was conducted using Rainbow Click software, developed by the International Fund for Animal Welfare (IFAW) to promote benign and non-invasive research. This work would not have been possible without the assistance and software support of Douglas Gillespie and Jonathon Gordan. We would also like to thank Barb Taylor for planning and field support. Funding was provided by the U.S. Navy (N45).

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VIII. TABLES

Table I. Click characteristics of five species of beaked whales (Johnson et al. 2006, Gillespie et al. 2009, Johnson et. al. 2004, Dawson et al. 1998, Yack et al. 2010 *unpub*.).

Beaked Whale Species	*Mesoplodon densirostris* (Blainville's)	*Ziphius cavirostris* (Cuvier's)	*Mesoplodon europaeus* (Gervais')	*Berardius bairdii* (Baird's)
Frequency Range	26-51 kHz	26-51 kHz	30-50 kHz	5-100 kHz
Center Frequencies	30-40 kHz	30-45 kHz	-	10-75 kHz
Duration (mean)	250-270 µs	175-200 µs	200 µs	157 - 205 µs
Estimated Click Rate	-	0.407 clicks/sec	-	-
Inter-Click-Interval (ICI)	0.2 – 0.4 secs	0.4 secs	0.2 – 0.4 secs	-
Cutoff depth for click (descent, ascent)	400m, 720m	475m, 850m	-	-
Avg number buzzes per foraging dive	23	27	-	-
Buzz frequency	25-80 kHz and above	-	-	-

Table II. Beaked whale click classification parameter for Rainbow Click, including: energy band detector ranges, peak frequency ranges, click length, and bearing and amplitude filters.

ENERGY BAND DETECTOR

	Test Band		Control Band	
Frequency Range (kHz)	25	50	12	22
Click Energy Range (dB re 1 µPa)	0	500	0	500

Minimum energy difference between test & exclusion bands: 3.0 dB

PEAK FREQUENCY RANGE

	Search Range		Peak Frequency Range	
Frequency Range (kHz)	20	95	32	45
Click Energy Range (dB re 1 µPa)	0	500	0	500

CLICK LENGTH

	Measure click length over:	Click Length Range (µs)	
Frequency Range (kHz)	50% of total energy	0.2	0.5

IX. FIGURES

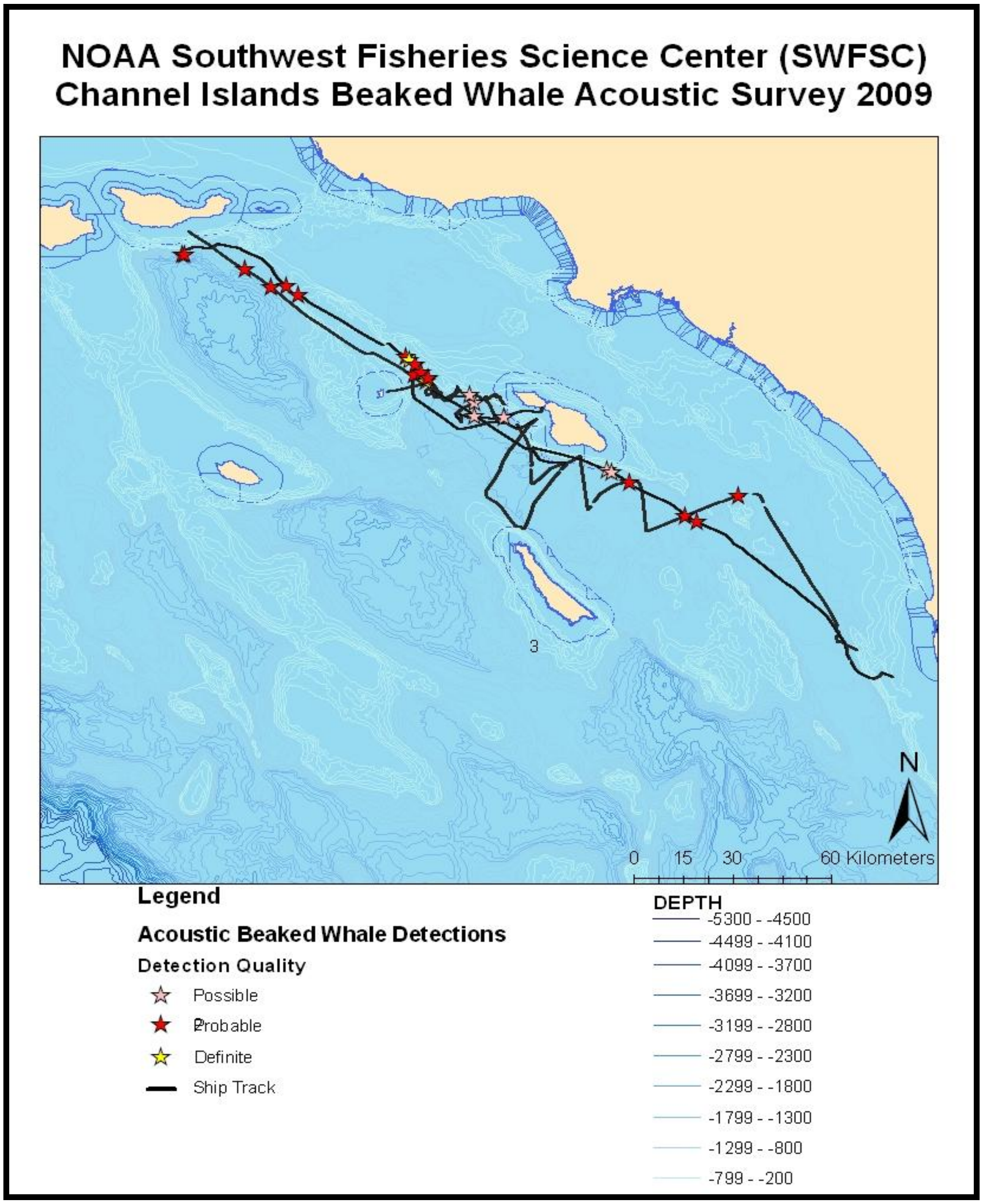

Figure 1. Map of Acoustic Beaked Whale Detections. The map shows every acoustic beaked whale detection along the ship trackline (black) classified by quality; possible (pink star), probable (red star), and definite (yellow star).

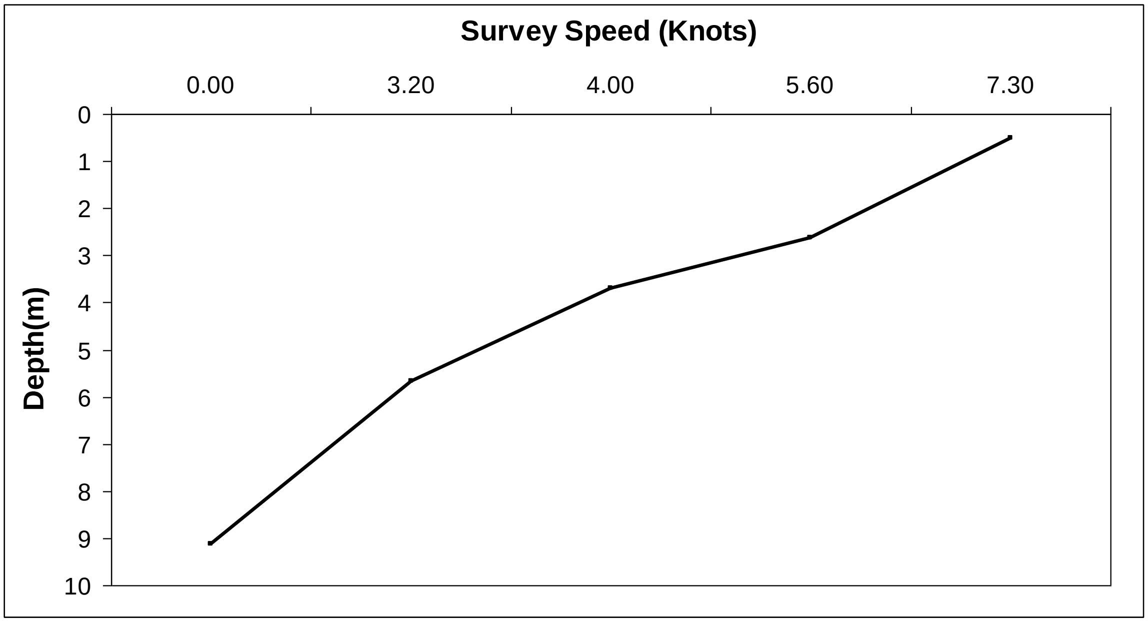

Figure 2. Array depth profile. This figure shows the array depth in meters at various survey speeds (knots).

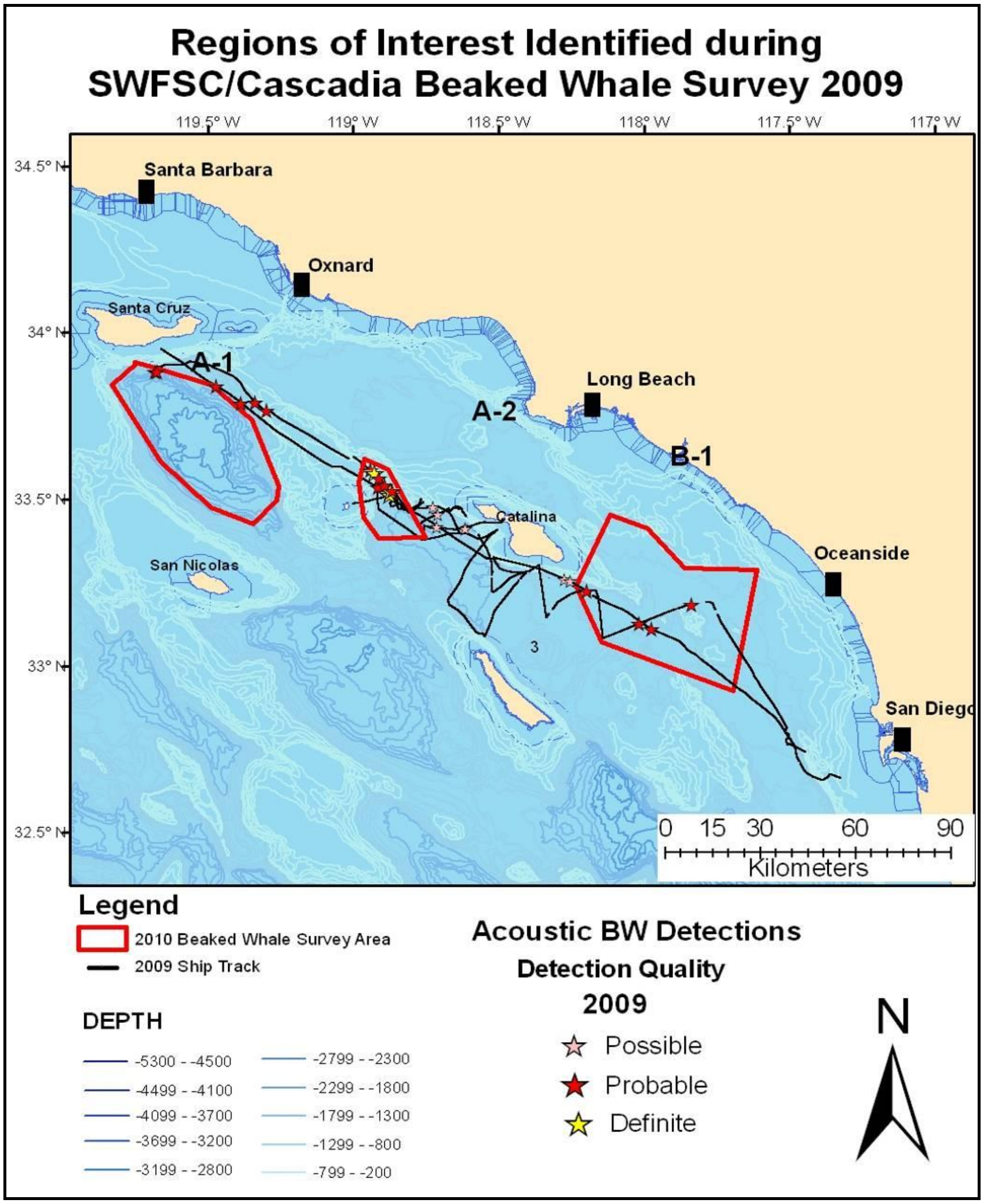

Figure 3. Map of Acoustic Beaked Whale Detections in Distinct Regions. The map shows every acoustic beaked whale detection along the ship trackline (black) classified by quality; possible (pink star), probable (red star), and definite (yellow star) within three distinct regions (A-1, A-2, and B-1).

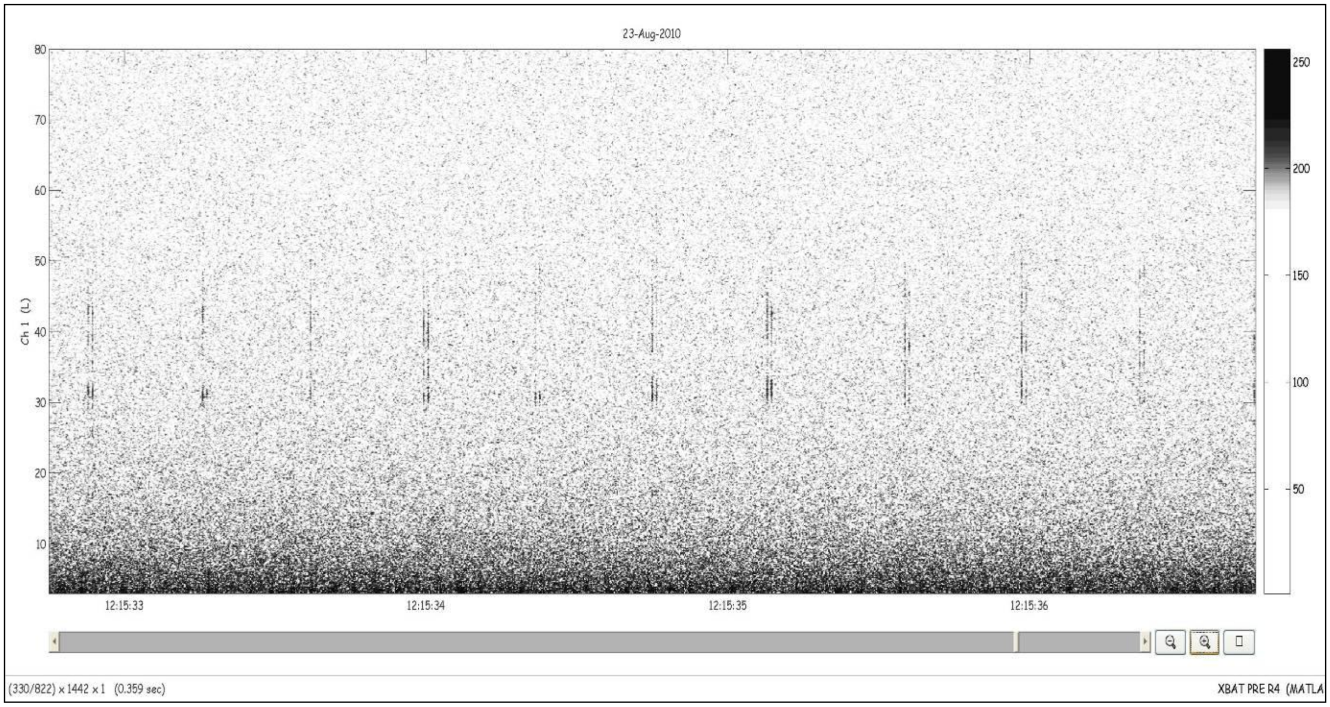

Figure 4. Spectrogram of Cuvier's beaked whale (*Ziphius cavirostris)* echolocation clicks. The figure shows a series of 11 echolocation clicks with time along the x-axis and frequency along the y-axis.

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