Beaked Whale Presence, Habitat, and Sound Production in the North Pacific

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LONG-TERM GOALS

The goal of this project is to understand beaked whale distribution, density and habitat, and improve capabilities for classification of these species from passive acoustic data. By studying beaked whale presence, habitat and sound production in the North Pacific, the Navy will be better prepared to conduct environmental impact assessments in this region of significant training activity. In addition, fundamental information will be gained on beaked whale foraging ecology.

OBJECTIVES

Our objective is to construct a density estimate and distribution map of beaked whale presence in the southern California region, based on long-term passive acoustic monitoring data. Our primary effort focuses on Cuvier's beaked whales, whose acoustics are well known, but whose density and distribution are not. Another focus is on the other beaked whale species in the North Pacific, whose acoustic signatures have not been well characterized. We aim to improve understanding of the acoustic characteristics of these species, to allow for study of their populations using passive acoustic monitoring. Better knowledge of beaked whale distribution and abundance is expected to lead to better understanding of the niche habitats of each beaked whale species, allowing use of environmental correlates to interpret distribution maps.

APPROACH

Passive acoustic monitoring provides an alternative to conventional sighting surveys for assessing beaked whale populations. With Navy support, we have been conducting long-term passive acoustic monitoring with High-frequency Acoustic Recording Packages (HARPs) in the southern California region for the past six years. These data reveal ample acoustic signatures from beaked whales, characterized by a frequency swept echolocation pulse. At least nine species of beaked whale are known to occur in southern California waters, mostly based on stranded animals (Mitchell 1968, Dalebout et al. 2007). The most abundant beaked whale species off southern California is Cuvier's as evidenced by fishery bycatch, visual sighting surveys, and acoustic monitoring data. Other beaked whales expected to be present include: Baird's, Blainville's, Ginkgo-toothed, Perrin's, Hubb's, Pygmy, Stejneger's and Longman's.

Steep bathymetric slope and intermediate water depth (~ 1000 m) are the two parameters most often positively correlated to beaked whale abundance, although data often are limited and sometimes contradictory (MacLeod and Zuur 2005, Moulins et al. 2007, Ferguson et al. 2006). Cuvier's beaked whales most commonly feed on squid at depths ranging from 700 to 1900 m (Tyack et al. 2006b), although fish can be the primary prey in some geographic areas (Nishiwaki and Oguro 1972). The squid species vary geographically (Santos et al. 2001), with no apparent prey preference for muscular versus ammoniacal species. The preferred food niche of Cuvier's is larger prey than that of the next most common beaked whale, Blainville's (*Mesoplodon densirostris*), with maximum prey size being about 4 kg (MacLeod et al. 2003). There appears to be no distinct calving season (Heyning 1989), and limited data suggest Cuvier's beaked whales do not migrate as stranding rates and commercial harvest rates are similar year around (Mitchell 1968, Nishiwaki and Oguro 1972).

Cuvier's beaked whales produce frequency modulated echolocation pulses with mean inter-pulse intervals of 0.4 s and durations of about 200 µs. These upswept pulses have center frequencies at 42 kHz and -10 dB bandwidths of 22 kHz (Zimmer et al. 2005). The echolocation pulse of Cuvier's beaked whale are distinct from those of other beaked whale species, allowing them to be used for quantitative assessment of population distribution and density.

Our approach for Cuvier's beaked whale population estimation is a cue count method. The basic unit for analysis is one foraging dive for either a group of beaked whales or a single beaked whale. Due to the highly directional nature of beaked whale echolocation, we expect to detect the echolocation sounds intermittently, depending on animal orientation. We estimate the number of echolocating animals in the group using the acoustic data, by counting the approximate number of overlaying sequences in the timeseries, looking for amplitude changes and corresponding inter-pulse intervals, and thereby derive an estimate for group size. At each site, we determine the average number of foraging dives per day. The overall density of Cuvier's beaked whales in the southern California study area is then estimated by calculating the number of animals within the detection radius of each monitoring site, and then dividing by the effective monitoring area (Zimmer et al. 2008). The expected number of dives per day when animals are within the detection range of the instrument is obtained from published tag data (Baird et al. 2006, Tyack et al. 2006a). We further examine the setting of each site to better understand how to extend beaked whale habitat to the larger southern California region.

WORK COMPLETED

Data from 12 sites collected in the southern California region between 2006 and 2009 were analyzed. Based on their acoustic characteristics, the detections of Cuvier's beaked whales were separated from echolocation associated with other species of beaked whales. There were 265 encounters with high amplitude signals that were analyzed for group size. Individuals from these nearby groups were counted from their consistent inter pulse intervals and slowly varying amplitudes. The detection of beaked whale signals was assumed to be constant between study sites; an effective detection range of 3.1 km was used based on Zimmer et al. (2008), adjusted for differences in detected signal-to-noise.

RESULTS

Figure 1 shows the sites for our study and Table 1 gives the beaked whale density results by site. Since no directional information is associated with these detections, we consider the entire bathymetric range within the 3.1 km detection range.

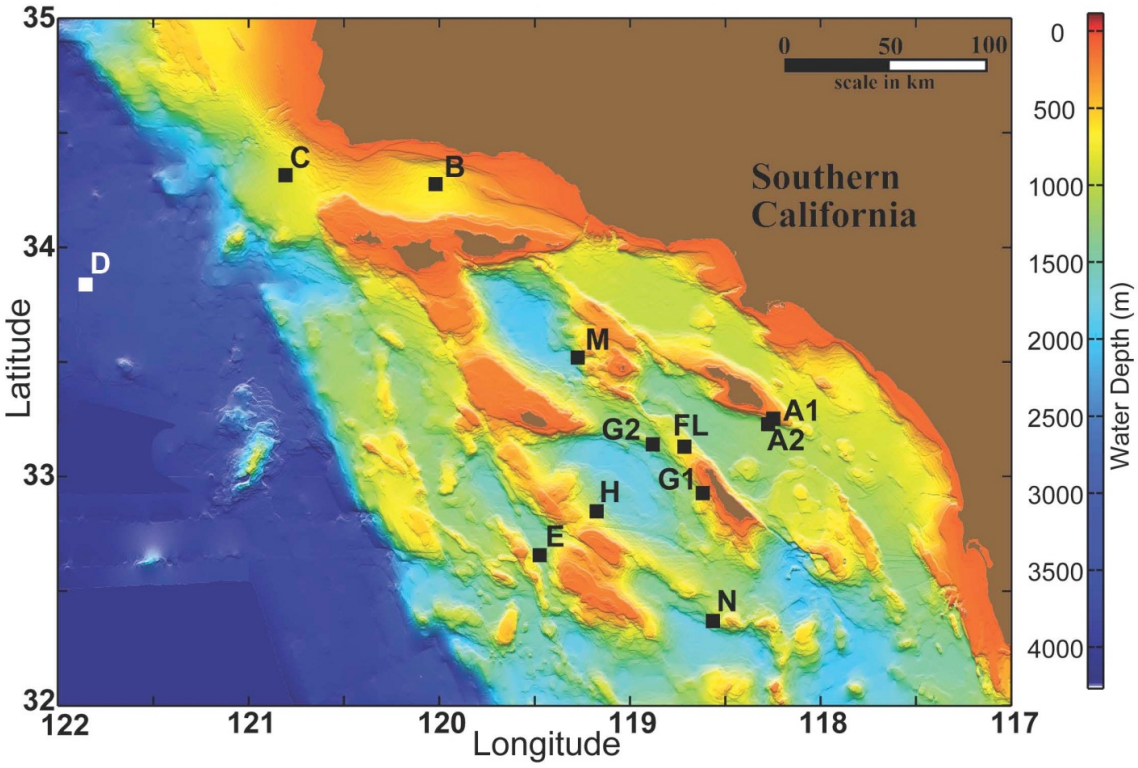

Figure 1. Study sites in the Southern California Bight.

Table 1. Density of Cuvier's beaked whales in the Southern California Bight. Figure 1 shows site locations.

Site	Water Depth (m) midpoint & (3.1 km radius)	Days of data	Total # dives	Average dives/day	Density #/1000 km^2
A1	238 (170-1042)	24	0	0	0
A2	1120 (401-1131)	162	22	0.1	1
B	580 (555-591)	54	0	0	0
C	760 (755-788)	84	0	0	0
D	3500 (3486-3514)	138	32	0.3	4
E	1288 (1231-1322)	478	2185	4.8	58
FL	622 (585-746)	31	0	0	0
G1	460 (105-889)	100	0	0	0
G2	1130 (1039-1244)	51	112	2.2	26
H	1015 (750-1112)	406	861	2.1	25
M	895 (565-1502)	109	96	0.9	11
N	1370 (900-1450)	163	399	2.4	29

Table 1 shows that bathymetric depth is clearly a key parameter for Cuvier's beaked whale foraging. Their distribution also may be controlled by prey distributions, related to oceanographic parameters such as oxygen level, for either fish or squid prey. Squid distributions are considered to positively correlate with low oxygen levels to avoid fish predators, fish being less tolerant of low oxygen levels (Gilly 2006). It is expected that distributions of the squid that are the Cuvier's beaked whale prey in this region, are controlled by oceanographic parameters (Pierce et al. 2008).

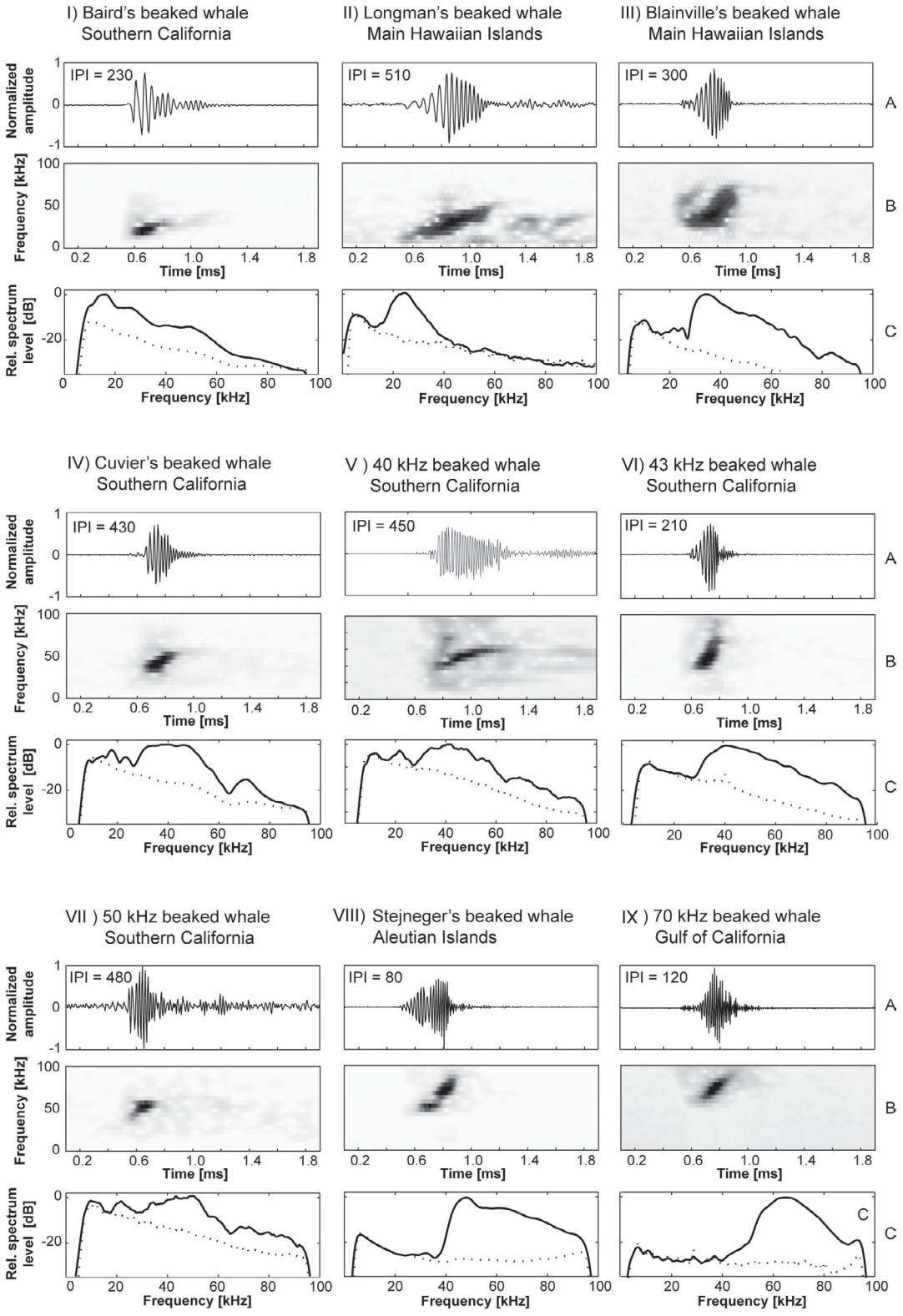

Figure 2. Beaked whale signals known to occur in the Pacific Ocean basin.

Beaked whale echolocation signals are frequency-modulated (FM) upsweep pulses that appear to be species specific (Johnson et al. 2004, Zimmer et al. 2005, McDonald et al. 2009, Baumann-Pickering et al. 2010). To develop an understanding about habitat preference, geographic distribution and abundance of all beaked whale species, we compare FM pulses of known and unknown origin from the Pacific Ocean (Aleutian Islands, southern California, Gulf of California, Pacific Islands). Currently, we are able to identify FM pulses made by Baird's, Blainville's, Cuvier's, Longman's and Stejneger's beaked whales (Dawson et al. 1998, Zimmer et al. 2005, Johnson et al. 2006, Rankin et al. 2011, Baumann-Pickering et al. in press) as well as other distinct signals of unknown origin (Figure 3). All of these signals are distinguishable by their spectral and temporal features. In addition to their spectral shape, we compared their peak frequency, center frequency, bandwidth, duration and inter-pulse interval, all of which are relevant to signal discrimination. Four of these signals from unknown species occur in the Gulf of California and offshore of southern California (Figure 2 V, VI, VII, IX). They could represent Hubb's, Perrin's, Ginkgo-toothed and Pygmy beaked whale. Additionally, two signals from unidentified species have been recorded and described for the Pacific Island region (McDonald et al. 2009, Baumann-Pickering et al. 2010). Comparison of known species at various locations suggests that despite inter-regional differences, their signal characteristics allow discrimination to species level. Evaluating the geospatial distribution, habitat preference and temporal occurrence patterns for unidentified species, and comparing those to sighting information may be useful for additional species acoustic identification. Additional detailed analysis of echolocation behavior may give insight into reasons for this strong acoustic species separation, potentially due to niche separation.

IMPACT/APPLICATIONS

The ability to conduct marine mammal population estimates and habitat assessments using acoustic monitoring provides a complimentary means for study of marine mammal populations. This is particularly important in the context of monitoring naval training ranges, and the potential impact of range activities on marine mammal populations and beaked whales in particular.

RELATED PROJECTS

Project title: Southern California Marine Mammal Studies; Sponsor: CNO N45 and the Naval Postgraduate School; Support from this project allowed for the development of HARP instrumentation and collection of the acoustic data processed for beaked whales with ONR support during N000140910489.

Project title: SBIR Topic N07-024 Marine Mammal Acoustics; awarded to Sonalysts; Sponsor: NavAir PMA264; Support from this project has allowed analysis of sonar exposure levels for Cuvier's beaked whales and their impact on foraging.

REFERENCES

Baird, R. W., D. L. Webster, D. J. McSweeney, A. D. Ligon, G. S. Schorr, and J. Barlow. 2006. Diving behaviour of Cuvier's (Ziphius cavirostris) and Blainville's (Mesoplodon densirostris) beaked whales in Hawai 'i. Canadian Journal of Zoology **84**:1120-1128.

Baumann-Pickering, S., S. M. Wiggins, E. H. Roth, M. A. Roch, H. U. Schnitzler, and J. A. Hildebrand. 2010. Echolocation signals of a beaked whale at Palmyra Atoll. Journal of the Acoustical Society of America **127**:3790-3799.

Dalebout, M. L., C. Scott Baker, D. Steel, K. M. Robertson, S. J. Chivers, W. F. Perrin, J. G. Mead, R. V. Grace, and T. David Schofield. 2007. A Divergent mtDNA Lineage Among Mesoplodon Beaked Whales: Molecular evidence for a new species in the tropical Pacific? Marine Mammal Science **23**:954-966.

Dawson, S., J. Barlow, and D. Ljungblad. 1998. Sounds recorded from Baird's beaked whales, *Berardius bairdii*. Marine Mammal Science 14:335–344.

Ferguson, M. C., J. Barlow, S. B. Reilly, and T. Gerrodette. 2006. Predicting Cuvier's (Ziphius cavirostris) and Mesoplodon beaked whale population density from habitat characteristics in the eastern tropical Pacific Ocean. Journal of Cetacean Research and Management **7**:287-299.

Gilly, W. F. 2006. Vertical and horizontal migrations by the jumbo squid *Dosidicus gigas* revealed by electronic tagging. Marine Ecology Progress Series **324**:1-17.

Heyning, J. E. 1989. Cuvier's Beaked whale – Ziphius cavirostris, G. Cuvier, 1823. Pages 289-308. *in* S. H. Ridgeway and R. Harrison, editors. Handbook of Marine Mammals. Academic Press Ltd, San Diego.

Johnson, M., P. T. Madsen, W. M. Zimmer, N. A. de Soto, and P. L. Tyack. 2004. Beaked whales echolocate on prey. Proc Biol Sci **271 Suppl 6**:S383-386.

Johnson, M., P. T. Madsen, W. M. X. Zimmer, N. Aguilar de Soto, and P. L. Tyack. 2006. Foraging Blainville's beaked whales (*Mesoplodon densirostris*) produce distinct click types matched to different phases of echolocation. Journal of Experimental Biology 209:5038-5050.

MacLeod, C. D., M. B. Santos, and G. J. Pierce. 2003. Review of data on diets of beaked whales: evidence of niche separation and geographic segregation. Journal of the Marine Biological Association of the United Kingdom **83**:651-665.

MacLeod, C. D. and A. F. Zuur. 2005. Habitat utilization by Blainville's beaked whales off Great Abaco, northern Bahamas, in relation to seabed topography. Marine Biology **147**:1-11.

McDonald, M. A., J. A. Hildebrand, S. M. Wiggins, D. W. Johnston, and J. J. Polovina. 2009. An acoustic survey of beaked whales at Cross Seamount near Hawaii. Journal of the Acoustical Society of America **125**:624-627.

Mitchell, E. 1968. Northeast Pacific stranding distribution and seasonality of Cuvier's beaked whale, Ziphius cavirostris. Canadian Journal of Zoology **46**:265-279.

Moulins, A., M. Rosso, B. Nani, and M. Würtz. 2007. Aspects of the distribution of Cuvier's beaked whale (Ziphius cavirostris) in relation to topographic features in the Pelagos Sanctuary (north-western Mediterranean Sea). J. Mar. Biol. Ass. U.K. Spec. Issue **87**:177-186

Nishiwaki, M. and N. Oguro. 1972. Catch of the Cuvier's Beaked whales off Japan in recent years. Scientific reports of the Whales Research Institute **24**:35-41.

Pierce, G., V. Valavanis, A. Guerra, P. Jereb, L. Orsi-Relini, J. Bellido, I. Katara, U. Piatkowski, J. Pereira, E. Balguerias, I. Sobrino, E. Lefkaditou, J. Wang, M. Santurtun, P. Boyle, L. Hastie, C. MacLeod, J. Smith, M. Viana, A. González, and A. Zuur. 2008. A review of cephalopod–environment interactions in European Seas. Hydrobiologia **612**:49-70.

Santos, M. B., G. J. Pierce, J. Herman, A. Lopez, A. Guerra, E. Mente, and M. R. Clarke. 2001. Feeding ecology of Cuvier's beaked whale (Ziphius cavirostris): a review with new information

on the diet of this species. Journal of the Marine Biological Association of the United Kingdom **81**:687-694.

Tyack, P. L., M. Johnson, N. A. Soto, A. Sturlese, and P. T. Madsen. 2006a. Extreme diving of beaked whales. J. Exp. Biol. **209**:4238-4253.

Tyack, P. L., M. P. Johnson, W. M. X. Zimmer, and P. T. Madsen. 2006b. Acoustic behavior of beaked whales, with implications for acoustic monitoring. Pages 1-6 *in* OCEANS 2006.

Zimmer, W., J. Harwood, P. Tyack, M. Johnson, and P. Madsen. 2008. Passive acoustic detection of deep-diving beaked whales. The Journal of the Acoustical Society of America **124**:2823.

Zimmer, W. M. X., M. P. Johnson, P. T. Madsen, and P. L. Tyack. 2005. Echolocation clicks of free-ranging Cuvier's beaked whales (*Ziphius cavirostris*). Journal of the Acoustical Society of America **117**:3919-3927.

PUBLICATIONS and PRESENTATIONS

Baumann-Pickering, S., M. A. McDonald, A. E. Simonis, S. M. Wiggins, and J. A. Hildebrand. Beaked whale-type echolocation signals in Southern California and Gulf of Mexico. Presented at the 2011 Southern California Marine Mammal Workshop in Newport, CA. January 21-22, 2011.

Baumann-Pickering, Simone, Anne E. Simonis, Mark A. McDonald, Erin M. Oleson, Shannon Rankin, Sean M. Wiggins, John A. Hildebrand. Comparison of beaked whale echolocation signals. 3rd Symposium on Acoustic Communication by Animals, 2011, Cornell University, Ithaca, NY.

Baumann-Pickering, S., Simonis, A. E., Wiggins, S. M., Brownell Jr., R. L., and Hildebrand, J. A. (accepted). Aleutian Islands beaked whale echolocation signals. *Mar. Mamm. Sci.*

Rankin, S., Baumann-Pickering, S., Yack, T., and Barlow, J. (2011). Description of sounds recorded from Longman's beaked whale, *Indopacetus pacificus*. *J. Acoust. Soc. Am.* 130, DOI: 10.1121/1.3646026