

# Temporal patterns in the acoustic signals of beaked whales at Cross Seamount

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**Seamounts may influence the distribution of marine mammals through a combination of increased ocean mixing, enhanced local productivity and greater prey availability. To study the effects of seamounts on the presence and acoustic behaviour of cetaceans, we deployed a high-frequency acoustic recording package on the summit of Cross Seamount during April through October 2005. The most frequently detected cetacean vocalizations were echolocation sounds similar to those produced by ziphiid and mesoplodont beaked whales together with buzz-type signals consistent with prey-capture attempts. Beaked whale signals occurred almost entirely at night throughout the six-month deployment. Measurements of prey presence with a Simrad EK-60 fisheries acoustics echo sounder indicate that Cross Seamount may enhance local productivity in near-surface waters. Concentrations of micronekton were aggregated over the seamount in near-surface waters at night, and dense concentrations of nekton were detected across the surface of the summit. Our results suggest that seamounts may provide enhanced foraging opportunities for beaked whales during the night through a combination of increased productivity, vertical migrations by micronekton and local retention of prey. Furthermore, the summit of the seamount may act as a barrier against which whales concentrate prey.**

**Keywords:** beaked whales; passive acoustic monitoring; seamounts; Pacific Ocean; fisheries acoustics

## 1. INTRODUCTION

Seamounts are prominent topographic features of all ocean basins and may play an important role in the growth, distribution and movements of marine organisms (Boehlert & Genin 1987; Hyrenbach *et al.* 2000). A query of Kitchingman & Lai's (2004) database of potential seamount locations worldwide (inferred from global bathymetric data) indicates that there may be as many as 4600 in the North Pacific. In comparison, a query of the Seamounts Online database reveals that only approximately 130 of these locations have species assemblage data available (Stocks 2005). Seamounts

can have profound effects on the local physical and biological environment. They can structure the velocity and vorticity of ocean currents and alter the vertical structure of water properties (e.g. Dower *et al.* 1992). These changes in the physical environment can alter local biological and ecological phenomena. For example, some seamounts exhibit increased primary productivity compared with non-seamount environments (Boehlert & Genin 1987; Dower *et al.* 1992). Enhanced secondary productivity is also found at seamount locations (e.g. Boehlert & Genin 1987; Dower & Mackas 1996), possibly resulting from increased primary productivity or through physical means of retention and biological aggregation. Benthic communities are often enriched at seamounts and depend on their depth and topography (Boehlert & Genin 1987). Finally, the seamounts are often frequented by larger consumers (Boehlert & Genin 1987; Dower & Perry 2001) and pelagic predators (e.g. Holland *et al.* 1999) that congregate at these locations to take advantage of an enhanced food web (Boehlert & Genin 1987). For example, tuna fitted with geolocation telemetry instruments in the central Pacific clearly use seamounts regularly (Holland *et al.* 1999), even when moving amongst them (Sibert *et al.* 2000). The effects of seamounts on seabird abundance and distribution have also been studied, illustrating that they provide enhanced foraging opportunities for diving seabirds (Haney *et al.* 1995).

The effects of seamounts on the distribution, abundance and behaviour of cetaceans remain largely unstudied. Acoustic studies have localized the calls of large baleen whales to the vicinity of the Emperor seamounts in the Pacific (Moore *et al.* 2002). Sperm whales have been sighted over seamounts in the Mediterranean Sea (Moullins & Wurtz 2005), and blue whales fitted with satellite telemetry packages off the west coast of the USA moved between undersea canyons and seamount regions (Lagerquist *et al.* 2000).

The purpose of the present study is to begin assessing the presence of cetaceans at Cross Seamount, a foraging site for pelagic fishes in the central Pacific Ocean using passive acoustic monitoring techniques. Developing an understanding of how seamounts are used by cetaceans will inform ongoing efforts to study the distribution and abundance of cetaceans in the Pacific Ocean.

## 2. MATERIAL AND METHODS

### (a) Study location

Cross Seamount is located at 18.7° N and 158.3° W in the central Pacific Ocean, approximately 290 km south of Oahu in the Hawaiian Islands. The summit is approximately 5 by 7 km across and ranges in depth between 450 and 350 m. The location of Cross Seamount is presented in figure 1a.

### (b) Passive acoustic monitoring

Passive acoustic monitoring was conducted at Cross Seamount between 26 April 2005 and 19 November 2005 using a high-frequency acoustic recording package (Wiggins & Hildebrand 2007). The instrument was deployed at 18.7221° N and 158.2538° W at 395 m depth and was programmed to record sound at a sample rate of 200 kHz. The instrument was programmed to record for 5 min periods separated by inactive intervals of 20 min.

### (c) Signal processing and detection

Automated detection of odontocete echolocation sweeps was performed using the spectrogram correlation method in the ISHMAEL software package (Mellinger 2001). A detector level was chosen so as to provide a low false alarm rate, while missing

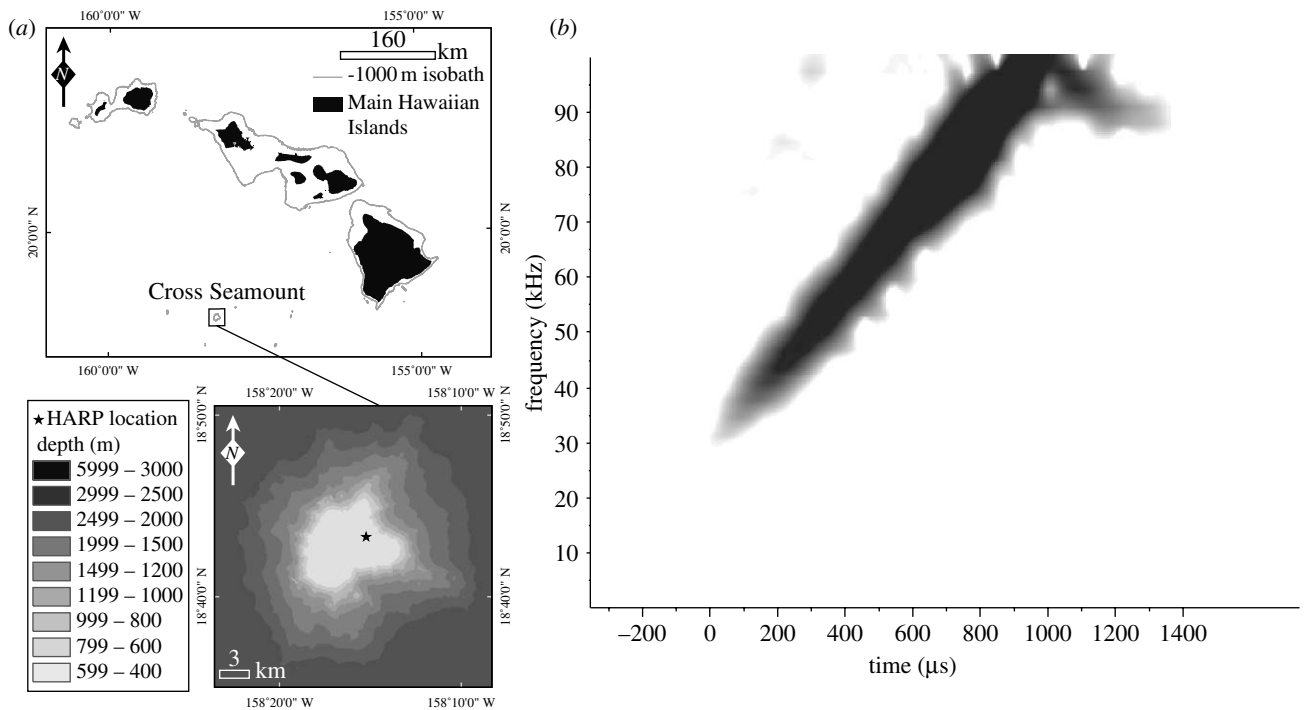


Figure 1. (a) Location of Cross Seamount and the HARP deployment during April through October 2006, along with (b) a spectrogram of a typical frequency modulated echolocation click detected during acoustic monitoring.

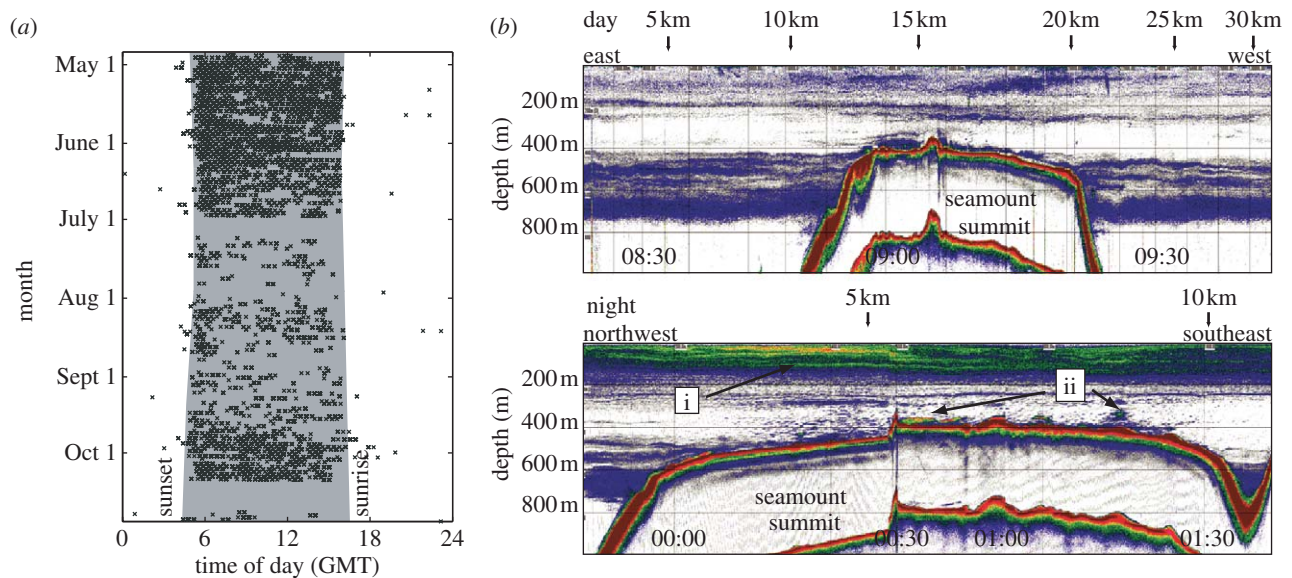


Figure 2. (a) Detection of beaked whale clicks, primarily at night, at Cross Seamount. Each X indicates a detection, and the grey region represents local night. (b) Day and night echogram snapshots illustrating the nocturnal enhancement of prey fields (i and ii) at Cross Seamount.

approximately 80% of the echolocation sounds. All detections were reviewed by viewing a spectrogram of the associated sound and the false detections eliminated. The relatively high percentage of echolocation sweeps missed by the detector is largely due to the effects of seafloor reflections when the echolocating animals were near the bottom. Calls occurring less than 0.25 s apart from one another were counted as a single detection. A typical detection as counted here contains approximately five echolocation sweeps.

#### (d) Prey field examples

The mean volume backscattering strength ( $S_v$ , in dB re  $1 \text{ m}^{-1}$ ) of sound scattering layer (SSL) prey fields at Cross Seamount was obtained using a Simrad EK60 split beam echo sounder (operating at 38 and 120 kHz frequencies) during a fisheries oceanography study in March 2005. Echograms ( $S_v$  maps) of prey fields were produced using Simrad ER60 (Simrad, Norway) software for a qualitative snapshot of prey densities at the seamount during night and day.

### 3. RESULTS

Visual examination of scrolling spectrograms from these data discovered that the most frequently detected cetacean signals were echolocation sweeps similar to those produced by Cuvier's beaked whales (*Ziphius cavirostris*) or Blainville's beaked whales (*Mesoplodon densirostris*) and a spectrogram correlation detector was designed to match these. A spectrogram of a representative click is provided in figure 1b. The number and timing of beaked whale echolocation events occurring during the six-month deployment is shown in figure 2a. Almost all detections occurred during the night.

Images of acoustic backscatter across the summit of the seamount are presented in figure 2b. Acoustic backscatter data indicate higher densities of organisms over the seamount and at its flanks relative to those in ambient water and show a prominent diel cycle due to vertical migratory behaviour of sound scattering organisms (figure 2b). Highest densities over the plateau were observed during the night-time, with a prominent SSL in the upper 200 m (figure 2b(i)) and dense patches of aggregations near the seafloor of the seamount (figure 2b(ii)). Trawl surveys of SSL layers in this region revealed squid and fishes (R. Domokos 2005, unpublished data), which are potential prey items for beaked whales.

#### 4. DISCUSSION

Few studies have assessed the influence of seamounts on the distribution and behaviour of cetaceans, and our study indicates that seamounts may be important features for beaked whales. The broadband echolocation signals of beaked whales are poorly known. Only two species of cetacean are known so far to use frequency-modulated echolocation signals, Cuvier's beaked whale (Zimmer *et al.* 2005) and Blainville's beaked whale (Johnson *et al.* 2004). The signals reported here have distinctly longer durations and greater frequency sweeps than either of these two previously reported signals (figure 1b). While not all beaked whales use frequency-swept echolocation signals (Dawson *et al.* 1998), it appears probable that all frequency swept cetacean signals are from beaked whales. It is unclear whether the echolocation signals reported here are from a species of beaked whale known to occur in this region—either a geographical variant of Cuvier's or Blainville's beaked whales—or from Longman's beaked whale (*Indopacetus pacificus*) or perhaps an undescribed beaked whale species (e.g. Dalebout *et al.* 2007). Feeding buzzes that were not frequency modulated were also occasionally associated with the echolocation signals described here, somewhat resembling those known to be associated with Cuvier's and Blainville's beaked whale echolocation sounds (Johnson *et al.* 2004).

Our acoustic monitoring reveals that beaked whales foraged at Cross Seamount during most nights. The detection range (based on seafloor reflections) for these signals appears to be less than 5 km, thus detected animals were at the seamount summit. Few beaked whale detections occurred during daylight hours, and several hypotheses may explain this pattern. It is possible that the whales were not present at Cross during the day or that the whales were present in the area but not echolocating. It is also possible that the whales were present, but diving past the summit of the seamount before echolocating at depth.

The prey field examples illustrate that Cross Seamount has effects on secondary productivity in the region, as greater densities of vertically migrating SSL micronekton are concentrated over the summit during the night compared with off-seamount locations. This example is strikingly similar to studies of SSL organisms at other seamounts. For example, Boehlert & Genin (1987) used an echo sounder to illustrate the

formation of dense patches of organisms over Southeast Hancock Seamount during the night. These prey concentrations may provide enhanced foraging opportunities for beaked whales at seamounts as they do for other species. For example, Grubbs *et al.* (2002) found that bigeye tuna (*Thunnus obesus*) caught at Cross Seamount have fuller stomachs (and more diverse prey items including a high percentage of cephalopods) than those caught in the open ocean and concluded that Cross provides a significant advantage for foraging bigeye. It is possible that dense concentrations of prey at Cross may reduce diving demands for beaked whales, allowing them to spend greater time foraging at depth. Several marine mammals use barriers to enhance their foraging abilities (Hain *et al.* 1982). In this case, the presence of the seamount summit may facilitate prey capture by providing a barrier against which whales concentrate prey.

The results of this preliminary acoustic monitoring study indicate that seamounts may be important foraging habitats for beaked whales in the tropical and sub-tropical North Pacific. We hypothesize that this may stem from the enhancement of local productivity by 'seamount effects', providing predictable patches of prey in an otherwise dilute and oligotrophic environment.

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- Boehlert, G. W. & Genin, A. 1987 A review of the effects of seamounts on biological processes. In *Seamounts, islands and atolls* (eds B. H. Keating, P. Fryer, R. Batiza & G. W. Boehlert). Geophysical Monograph Series, vol. 43, pp. 319–334. Washington, DC: American Geophysical Union.
- Dalebout, M. L., Baker, C. S., Steel, D., Robertson, K. M., Chivers, S. J., Perrin, W. F., Mead, J. G., Grace, R. V. & Schofield Jr, T. D. 2007 A divergent mtDNA lineage among *Mesoplodon* beaked whales: molecular evidence for a new species in the tropical Pacific? *Mar. Mamm. Sci.* **23**, 954–966. (doi:10.1111/j.1748-7692.2007.00143.x)
- Dawson, S., Barlow, J. & Ljungblad, D. 1998 Sounds recorded from Baird's beaked whale, *Berardius bairdii*. *Mar. Mamm. Sci.* **14**, 335–344. (doi:10.1111/j.1748-7692.1998.tb00724.x)
- Dower, J. F. & Mackas, D. L. 1996 "Seamount effects" in the zooplankton community near Cobb Seamount. *Deep Sea Res. I: Oceanogr. Res. Pap.* **43**, 837–858. (doi:10.1016/0967-0637(96)00040-4)
- Dower, J. F. & Perry, R. I. 2001 High abundance of larval rockfish over Cobb Seamount, an isolated seamount in the Northeast Pacific. *Fish. Oceanogr.* **10**, 268–274. (doi:10.1046/j.1365-2419.2001.00162.x)
- Dower, J., Freeland, H. & Juniper, K. 1992 A strong biological response to oceanic flow past Cobb Seamount. *Deep Sea Res.* **39**, 1139–1145. (doi:10.1016/0198-0149(92)90061-W)
- Grubbs, R. D., Holland, K. & Itano, D. 2002 Comparative trophic ecology of yellowfin and bigeye tuna associated



- with natural and man-made aggregation sites in Hawaiian waters. In *Fifteenth Meeting of the Standing Committee on Tuna and Billfish Secretariat of the Pacific Community, Oceanic Fisheries Programme, Secretariat of the Pacific Community, Honolulu, HI*.
- Hain, J. H. W., Carter, G. R., Kraus, S. D., Mayo, C. A. & Evans, H. E. 1982 Feeding behavior of the humpback whale, *Megaptera novaeangliae*, in the western North Atlantic. *Fish. Bull.* **80**, 259–268.
- Haney, J. C., Hauray, L. R., Mullineaux, L. S. & Fey, C. L. 1995 Sea-bird aggregation at a deep North Pacific seamount. *Mar. Biol. Berl.* **123**, 1–9. (doi:10.1007/BF00350317)
- Holland, K. N., Kleiber, P. & Kajiura, S. M. 1999 Different residence times of yellowfin tuna, *Thunnus albacares*, and bigeye tuna, *T. obesus*, found in mixed aggregations over a seamount. *Fish. Bull.* **97**, 392–395.
- Hyrenbach, K. D., Forney, K. A. & Dayton, P. K. 2000 Marine protected areas and ocean basin management. *Aquat. Conserv.* **10**, 437–458. (doi:10.1002/1099-0755(200011/12)10:6<437::AID-AQC425>3.0.CO;2-Q)
- Johnson, M. P., Madsen, P. T., Zimmer, W. M. X., Aguilar de Soto, N. & Tyack, P. L. 2004 Beaked whales echolocate on prey. *Proc. R. Soc. B* **271**, S383–S386. (doi:10.1098/rsbl.2004.0208)
- Kitchingman, A. & Lai, S. 2004 Inferences on potential seamount locations from mid-resolution bathymetric data. In *FCRR seamounts: biodiversity and fisheries*, vol. 12 (eds T. Morato & D. Pauly). Fisheries Centre Research Reports, pp. 7–12. Vancouver, Canada: University of British Columbia.
- Lagerquist, B. A., Stafford, K. M. & Mate, B. R. 2000 Dive characteristics of satellite-monitored blue whales (*Balaenoptera musculus*) off the central California coast. *Mar. Mamm. Sci.* **16**, 375–391. (doi:10.1111/j.1748-7692.2000.tb00931.x)
- Mellinger, D. K. 2001 *ISHMAEL 1.0 user's guide*. NOAA technical memorandum OAR-PMEL-120. 7600 Sand Point Way, NE, Seattle, WA: NOAA/PMEL.
- Moore, S. E., Watkins, W. A., Daher, M. A., Davies, J. R. & Dahlheim, M. E. 2002 Blue whale habitat associations in the Northwest Pacific: analysis of remotely-sensed data using a geographic information system. *Oceanography* **15**, 20–25.
- Moulins, A. & Wurtz, M. 2005 Occurrence of a herd of female sperm whales and their calves (*Physeter catodon*), off Monaco, in the Ligurian Sea. *J. Mar. Biol. Assoc. UK* **85**, 213–214. (doi:10.1017/S0025315405011094h)
- Sibert, J., Holland, K. & Itano, D. 2000 Exchange rates of yellowfin and bigeye tunas and fishery interaction between Cross Seamount and near-shore FADs in Hawaii. *Aquat. Living Resour.* **13**, 225–232. (doi:10.1016/S0990-7440(00)01057-3)
- Stocks, K. 2005 Seamounts. Online: an online information system for seamount biology. *World Wide Web electronic publication* San Diego Supercomputer Center, University of California San Diego, San Diego, CA. See <http://seamounts.sdsc.edu>.
- Wiggins, S. M. & Hildebrand, J. A. 2007 High-frequency acoustic recording package (HARP) for broad-band, long-term marine mammal monitoring. In *Symp. on Underwater Technology and Workshop on Scientific Use of Submarine Cables and Related Technologies*, pp. 551–557.
- Zimmer, W. M. X., Johnson, M. P., Madsen, P. T. & Tyack, P. 2005 Echolocation clicks of free-ranging Cuvier's beaked whales *Ziphius cavirostris*. *J. Acoust. Soc. Am.* **117**, 3919–3927. (doi:10.1121/1.1910225)