Impact of mid-frequency active sonar on Cuvier's beaked whale echolocation from long-term passive acoustic recordings

S Baumann-Pickering[1*], JS Trickey[1], CS Odekoven[2], CGM Paxton[2], A Širović[3], JA Hildebrand[1], L Thomas[2], SM Wiggins[1], MA Roch[4]

[1] Scripps Institution of Oceanography
[2] University of St. Andrews
[3] Texas A&M University Galveston
[4] San Diego State University

Abstract

Behavioral response studies of tagged cetaceans have documented an adverse reaction to mid-frequency active sonar (MFAS). We examined long-term, passive acoustic data for acoustic behavioral response of Cuvier's beaked whales (*Ziphius caviostris*) to sonar operations in southern California, an area of frequent naval activity.

Acoustic data were collected at one site from 2009 to 2015, resulting in 1982 days of acoustic effort. Cuvier's beaked whale echolocation clicks occurred 42% of all days and on average 8.5 minutes per day. There were >1 million sonar pings recorded with received levels ranging from 85 dBpp re: 1µPa up to recorder clipping level of 175 dBpp re: 1 µPa.

A comparison of click densities before, during and after sonar events using several time windows from 1 minute to 24 hours showed **significantly reduced click densities during and after the sonar events.**

The relationship between MFAS and the acoustic behavior of whales is complex and requires accounting for natural temporal and spatial variability in click densities which may be caused by e.g., variability in seasonality, habitat preference, and individual variability.

Generalized estimating equations (GEEs) were used to model relationships between click presence and temporal and sonar covariates (*italic*):

- *Year* showing **considerable inter-annual variability** possibly related to larger oceanographic cycles.
- *Julian day* describing seasonality with **highest presence in spring and lowest in late summer/early fall**.
- *Normalized minutes since sunrise* documented a **diel calling** pattern, with an **increase of echolocation behavior mid-day**; this behavior is likely site specific.
- *Sonar lag time;* the probability of **detecting beaked whales increased with increasing time since the last use of sonar up to about a week**, and then remained stable.
- *Proportion of sonar in 1 minute* is a measure of sonar duty cycle and **probability of detecting beaked whales decreased with higher proportions**.
- *Maximum peak-to-peak received level of sonar in one minute* (forced into the model) showed **declining probability of beaked whale detections with increasing recieved levels**

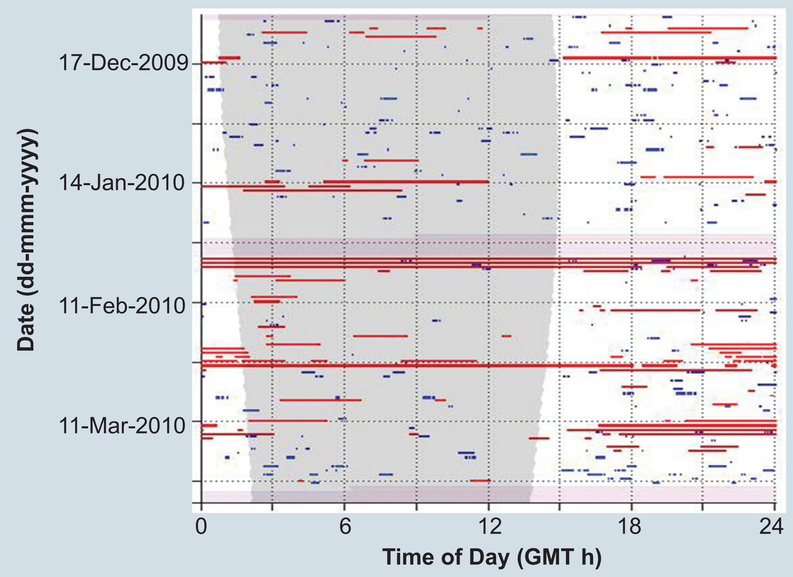
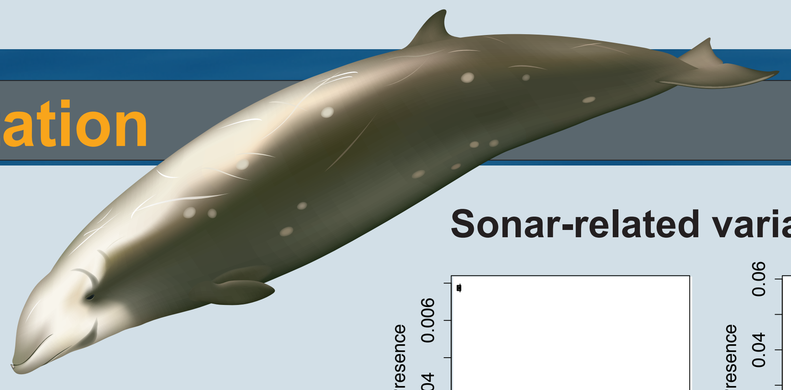
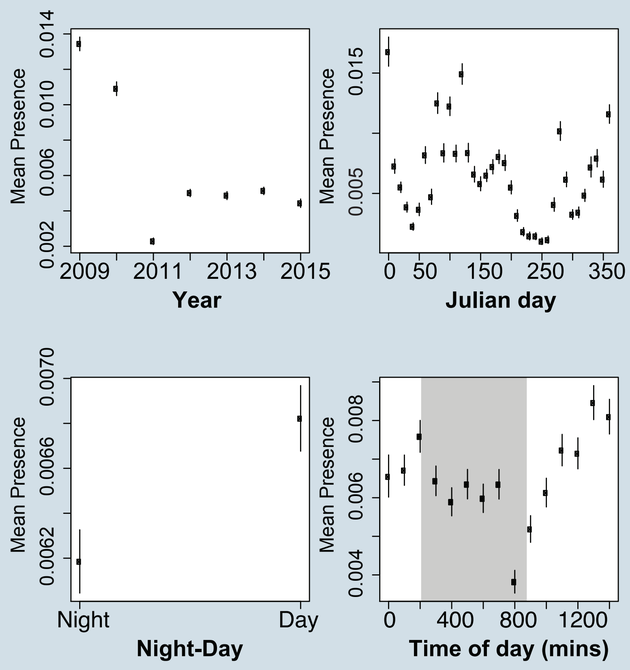


Figure 1. *Example time sequence showing sporadic short Cuvier's beaked whale echolocation click detections (blue) and longer duration MFAS detections (red). Nighttime in light grey. Light red shaded areas had no recording effort.*

Exploratory Data Visualization



Non-sonar variables



Sonar-related variables

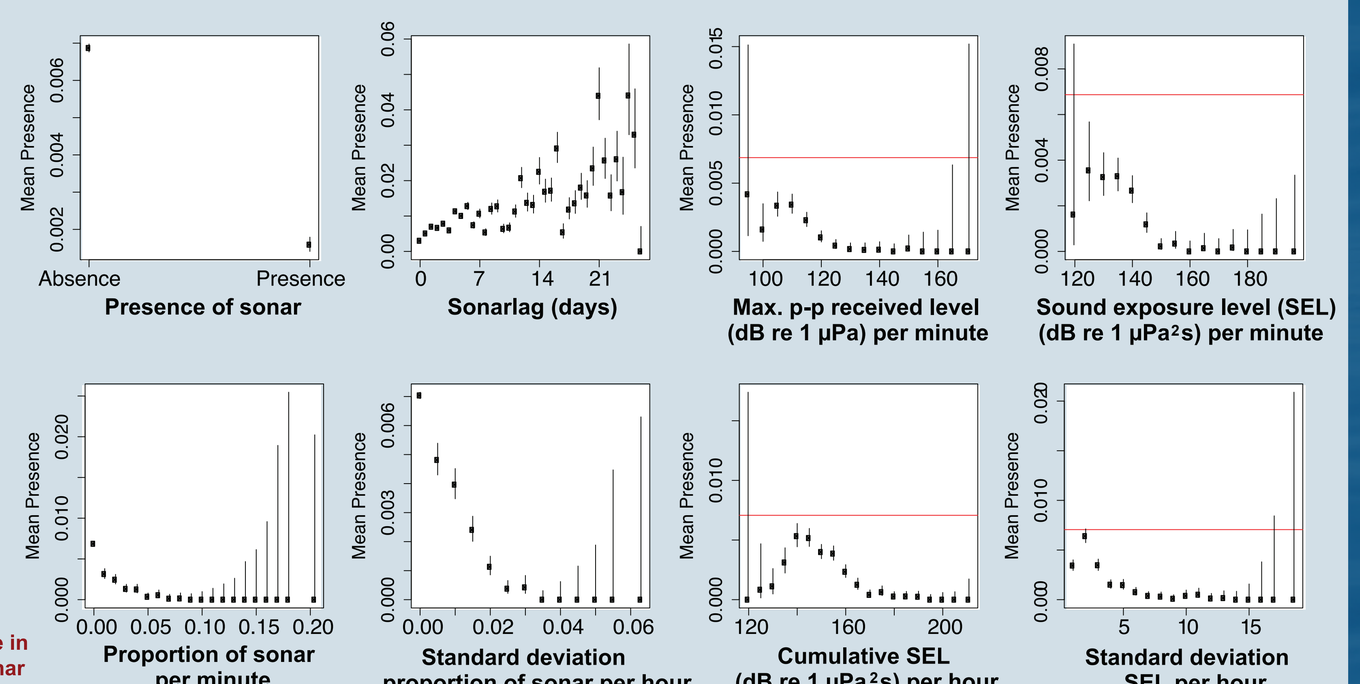


Figure 2. *Mean presence of Cuvier's beaked whales based presence or absence of echolocation clicks in one minute, in relation to temporal (non-sonar) and sonar-related variables.*

Before / During / After

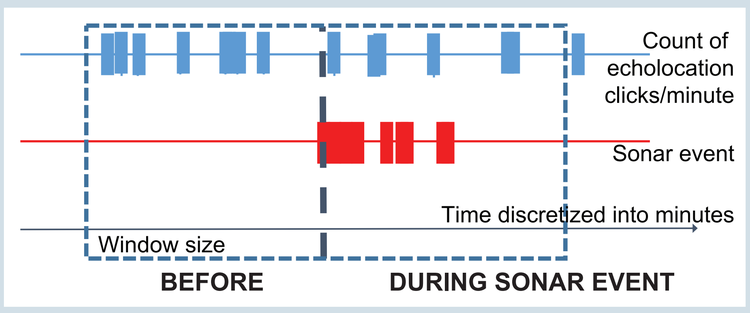


Figure 3. *Schematic of window size x before and during sonar event.*

Table 1. *Wilcoxon sign rank test showing significant differences between "before" and "during" and insignificant differences "during" and "after sonar event" of all window sizes.*

Window size	Wilcoxon sign rank	Window size	Wilcoxon sign rank
1hr conditional on presence before or during	df = 77, **P=0.001** Median before 0.092 Median during 0	1hr conditional on presence during or after	df = 59, **P=0.504** Median during 0.033 Median after 0.017
2hr conditional on presence before or during	df = 89, **P=0.012** Median before 0.042 Median during 0	2hr conditional on presence during or after	df = 93, **P=0.470** Median during 0.008 Median after 0.017
4hr conditional on presence before or during	df = 139, **P=0.004** Median before 0.013 Median during 0	4hr conditional on presence during or after	df = 124, **P=0.153** Median during 0.004 Median after 0.013
8hr conditional on presence before or during	df = 203, **P<0.001** Median before 0.010 Median during 0	8hr conditional on presence during or after	df = 168, **P=0.670** Median during 0.006 Median after 0.006
24hr conditional on presence before or during	df = 180, **P<0.001** Median before 0.010 Median during 0.002	24hr conditional on presence during or after	df = 171, **P=0.204** Median during 0.004 Median after 0.006

Generalized Estimation Equation (GEE) Model

Non-sonar variables

Sonar-related variables

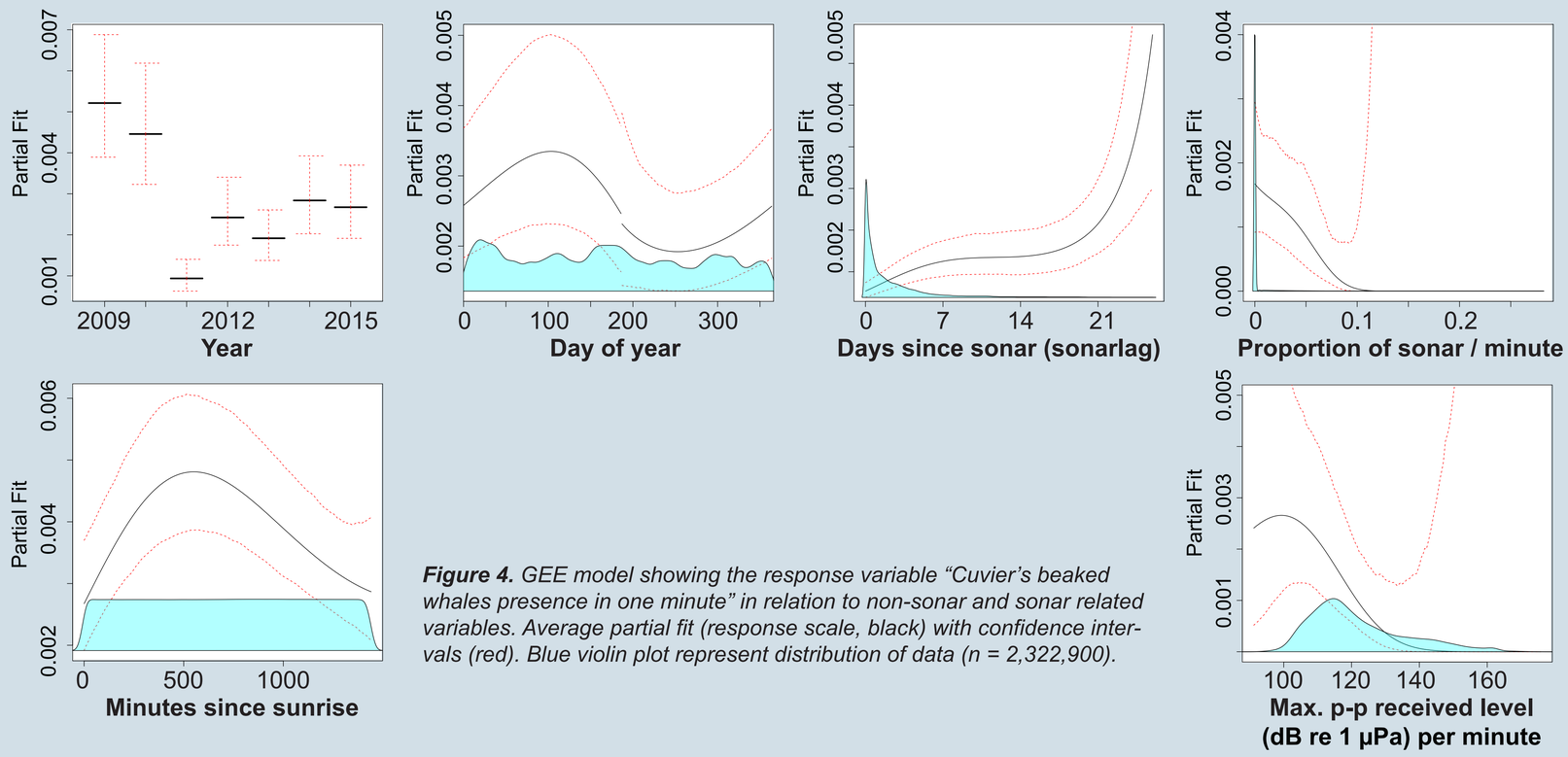


Figure 4. *GEE model showing the response variable "Cuvier's beaked whales presence in one minute" in relation to non-sonar and sonar related variables. Average partial fit (response scale, black) with confidence intervals (red). Blue violin plot represent distribution of data (n = 2,322,900).*

Future Goals

1) Implement propagation error; calculate uncertainty of sonar received level at the location of the whale (i.e., +/- 2-5 km)

2) Include additional species; currently no response for blue whale D calls; however, need to reduce detection range

Acknowledgements

Corresponding author
Simone Baumann-Pickering - sbaumann@ucsd.edu

Funding for this project was provided by US Pacific Fleet, C. Johnson
Funding for data collection and prior data analysis was provided by US Pacific Fleet, C.Johnson; US Office of Naval Research, M.Weise; US Navy Living Marine Resources, F. Stone and B. Gisiner; Naval Postgraduate School, C. Collins and J. Joseph. The authors thank staff of the Scripps Acoustic Ecology Lab and Scripps Whale Acoustics Lab for fieldwork, gear and analysis assistance.

Illustration: Uko Gorter, Photo: Jennifer S. Trickey-