1 Introduction

Beaked whales (family Ziphiidae) are a group of deep-diving cetaceans that rely on sound to forage, navigate, and communicate [@macleod_review_2006; @johnson_beaked_2004; @aguilar_de_soto_no_2012]. Multiple mass strandings of beaked whales have been associated with high-intensity anthropogenic sound sources. These acute events have motivated research into whether and how beaked whales respond to different types and intensities of anthropogenic noise [@cox_understanding_2006].

Anthropogenic sound can disrupt the patterned dive cycles of these animals [CITE e.g. Falcone, also Southall re syncrhronicity?], potentially leading to death [CITE Jepson] or to cumulative sublethal impacts [PCoD, CITE]. For example, research on Blainville's beaked whales *Mesoplodon densirostris* on a Navy range in the Bahamas has shown that animals may stop foraging and/or move away from sonar sources [@tyack_beaked_2011; @joyce_behavioral_2019].

Naval sonar can be broadcast from various platforms, including vessels, helicopters, buoys, submarines, and torpedoes [@harris_changes_2019; @us_department_of_the_navy_final_2018]. Most research has focused on the impacts of mid-frequency active (MFA) sonar broadcast from US Naval vessels, but has not been able to isolate the effect of associated training activity beyond MFA sonar. Separately, researchers have shown that, in the absence of MFA sonar, beaked whales may alter their behavior in response to vessel noise [@aguilar_soto_does_2006; @pirotta_vessel_2012].

There are different experimental and analytical ways of quantifying responses to sonar. Here, we focus on methods used for analysis of data from cabled hydrophone arrays.

For example, [@mccarthy_changes_2011] used separate generalized additive models (GAMs) for before/during/after, response was GVPs per 5 hr periods, explanatory vars were inner/outer and time. Hypotheses were evaluated using z-tests.

[@moretti_risk_2014] used a GAM to model the presence or absence of acoustic detections of groups of Blainville's beaked whales on the AUTEC range as a function of a smooth on MFA sonar received level. They then compared . . . probability of disturbance. They found that fograging dive behavior was reduced by 50% at 150 dbrms re 1μPa.

In the present study, our primary objective was to replicate this effort with the same species on a different US Navy training range in a different oceanic environment. Unlike AUTEC, which occurs in a deep isolated basin surrounded by steep slopes, the Pacific Missile Range Facility (PMRF) range occurs on the side of an ancient volcano, with a steep slope down to the deep ocean floor.

We wanted to compare the probability of response to similar US Navy training activity in the same species to determine whether environment changed the likelihood of response.

In addition, our secondary objective was to examine the cumulative effects of Naval training activity and MFA sonar while explicitly accounting for differences in underlying beaked whale presence. We wanted to isolate the effect of training activity from the effect of hull-mounted MFA sonar. To do this, we used a spatially referenced dataset of Blainville's beaked whale foraging dives recorded off the island of Kauai, Hawaii. Acoustic detections of Blainville's beaked whales were collected via a cabled hydrophone array at PMRF before and during six Naval training exercises. Previous work in this region has shown that Blainville's beaked whales are present year-round at this site, that they prefer certain slope habitats, and that acoustic detections decrease during multi-day training events [@henderson_occurrence_2016; @manzano-roth_impacts_2016].

Here, we . . .