Acoustic Ecology and Behavior of Minke Whales in the Hawaiian and Marianas Islands: Localization, Abundance Estimation, and Characterization of Minke Whale "Boings"

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1 Introduction

Balaenoptera acutorostrata (minke whale) is a small and elusive baleen whale that is rarely sighted in the tropical waters of the North Pacific Ocean. During winter and spring, complex sounds called "boings" are frequently detected around the Hawaiian Islands and other Pacific island regions (Norris et al. 2009; Thompson and Friedl 1982). Although boings were described over 45 years ago (Wenz 1964), they were not attributed to minke whales until very recently (Rankin and Barlow 2005). Sightings of *Balaenoptera acutorostrata* are uncommon in tropical and subtropical waters; however, boings are frequently detected around the Hawaiian Islands using seafloor hydrophones and from hydrophone arrays towed from research vessels. Even today, very little is known about acoustic behaviors and ecology of *Balaenoptera acutorostrata.* The long-term objective of this research effort is to improve our understanding of the acoustic ecology and behavior of *Balaenoptera acutorostrata* in their breeding habitat.

A primary goal of this study is to compare characteristics of boings recorded in the Hawaiian Islands (central North Pacific) to other regions in the central and western North Pacific (e.g., the Northern Mariana Islands). These results will be used to elucidate stock identities and population characteristics for *Balaenoptera acutorostrata* in the Pacific Islands. Another goal is to estimate the local abundance of calling *Balaenoptera acutorostrata* for our main study sites off the Hawaiian Island of Kaua'i and around the Marianas Islands. Finally, we are collecting information

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that is being used to assess the calling rates of *Balaenoptera acutorostrata*. This information is necessary to validate cue-counting methods that are being developed to estimate densities of *Balaenoptera acutorostrata* exclusively from their calls (Marques et al. 2009; Martin et al. 2009; Thomas et al. 2008).

2 Methods

To accomplish these objectives, we used several types of passive acoustic methods to record and analyze data from vocalizing *Balaenoptera acutorostrata*. We used an acoustically quiet, 25-m motor-sailing vessel equipped with 2- to 6-element towed hydrophone arrays (effective bandwidth: ~100 Hz to 48 kHz) to conduct localization experiments in 2009 and an acoustic-visual line-transect survey in 2010. Bioacousticians monitored and processed acoustic data in real time throughout on-effort periods using various software including Ishmael, PAMGUARD, and WhaletrackII. In 2010, AN/SSQ-53F DIFAR sonobuoys were also used. Localizations of individual *Balaenoptera acutorostrata* were estimated using target-motion analysis techniques when possible.

Acoustic data were simultaneously recorded from the Barking Sands Underwater Range Expansion (BSURE) test site seafloor hydrophone array that is part of the Navy's Pacific Missile Range Facility (PMRF) off the west coast of Kaua'i. This Navy test range encompasses a large (>2,000 km^2), deep-water area northwest of the island of Kaua'i and includes 17 bottom-mounted hydrophones (effective bandwidth: ~100 Hz to 18 kHz) that were used for this project. PMRF seafloor array data were postprocessed using two localization methods: time-of-arrival (TOA) hyperbolic localization methods (manual and automated) and a propagation model-based time-of-arrival (PMTOA) localization method (automated). For the first method, manual techniques were initially used to identify and associate boings from the same calling animal on multiple PMRF seafloor hydrophones. Once associations and accurate TOAs were obtained, 2-dimensional (2-D) localizations were performed using standard hyperbolic techniques. Sound speed profiles (SSPs) were obtained from expendable bathythermographs (XBTs) deployed each day off the research vessel. For the second method (PMTOA), the upper 760 m of SSPs were averaged from several XBT deployments, whereas for depths below 760 m, SSPs were estimated from historical data.

In 2009, efforts were focused on obtaining localizations from the towed hydrophone array to compare with and validate those obtained from the BSURE seafloor array. In 2010, efforts were focused on conducting an acoustic-visual line-transect survey of the BSURE range for estimating abundance and comparison to the seafloor hydrophone array dataset.

Finally, two additional sources of data were included in this study: 1) data collected using a bottom-mounted hydrophone located at the Station ALOHA Cabled Observatory (ACO) were analyzed to examine seasonal and diurnal variability and 2) data from an acoustic-visual line-transect survey conducted in winter/spring 2006 for a large region surrounding the Mariana Islands that will be analyzed to derive abundance estimates and assess population structure from boing signal characteristics.

3 Results

We have completed two winter/spring field seasons (2009 and 2010) and are in the process of analyzing the acoustic data and developing automated analysis methods. In 2009, a vessel-based localization effort was conducted inside the BSURE area for 21 days between 15 March and 28 April and resulted in ~850 km of survey effort. In 2010, line-transect surveys were conducted for 2.5 mo

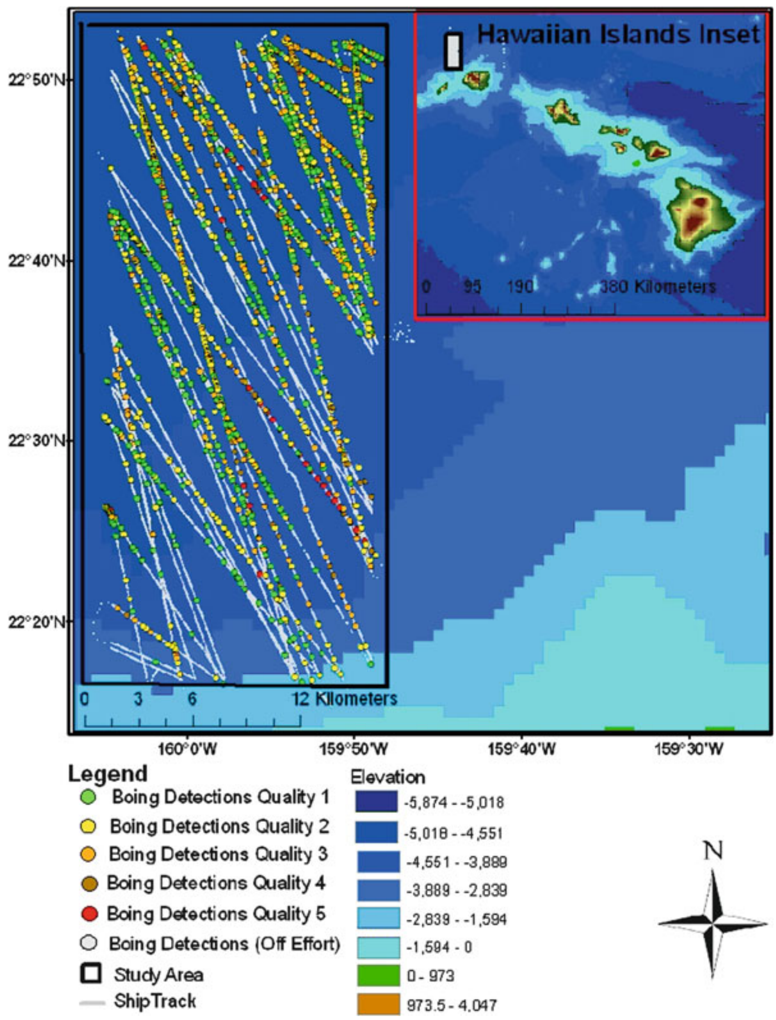

Fig. 1 Map of acoustic detections of minke whale boings made during 2010 vessel-based line-transect surveys of Kauai study area (~650 km^2). Locations of boings are plotted at location detected on ship track and do not necessarily indicate locations of calling animals

from 12 March to 11 April, resulting in 13 days and over 1,520 km of line-transect effort. Over 260 h of recordings were made for both field seasons.

In 2009, we obtained bearings for at least 777 boings that were manually detected using the towed array. Preliminary results from the just-completed 2010 field season indicate that at least 1,598 boings were detected manually, of which 1,198 bearings were obtained (Fig. 1). Over 50 localizations were made during the line-transect survey effort.

Automated detection and localization methods in PAMGUARD and Ishmael were attempted in real time during the 2010 surveys but were deemed too demanding on the available computer resources so they were discontinued after leg I. Therefore, the acoustic data are being postprocessed using automated and semiautomated techniques. These methods are expected to yield more detections and possibly localizations. The results of the automated detections and localizations will be reviewed and validated manually to ensure their reliability. Localizations obtained from the towed hydrophone array data will be compared with localizations collected from the BSURE seafloor hydrophone array. These automated methods will be used to assess localization estimates of animals and track movements and eventually to estimate the density and abundance of calling animals in the two main study areas using modified distance sampling analysis methods.

Assessment of localization accuracy is important to verify the assumptions of statistical methods being developed in a related effort called the density estimation of cetaceans from passive acoustic fixed sensors (DECAF) to estimate densities of calling animals from fixed hydrophones (Thomas et al. 2008). A case study was conducted from the BSURE seafloor hydrophone dataset containing over 6,000 boings automatically detected over a 6-h period in late April 2009. Comparisons of localizations from the two seafloor array methods described above indicated good agreement (mean difference = 142.7 m; range: 67-280 m).

Researchers on the survey vessel were able to acoustically detect, track, and sight the same individual that was being tracked from the seafloor array. The position of the sighted animal indicated relatively good accuracy (within a few hundred meters) of the positions obtained using the two seafloor localization techniques described earlier. Interestingly, the localizations determined from the towed array, although relatively precise, indicated biases based on the different algorithms used to plot the bearings from the towed hydrophone array to the calling animal. These errors were investigated further by manually plotting data. Results indicated that uncertainties in the true heading of the towed array can significantly affect localization error.

Based on the results of this case study, more fully automated techniques are being developed to facilitate the localization analysis. In addition, improvements were made to existing Matlab-based detectors used to detect boings for the automated localization algorithm. These automated methods were used to reduce processing time during the 2010 field effort.

One year of data collected at the ACO were analyzed (February 2007 to February 2008). These data showed that boings occurred seasonally from October to May, with little diurnal variation.

4 Discussion

Analyses of minke whale boings are underway to identify signal characteristics that might be useful for individual identification and as indicators of population structure. We have already found statistically significant differences in the pulse repetition rates of boings from Hawaiian waters compared with those recorded in the Mariana Islands in the western North Pacific. Interestingly, preliminary results from analysis of boings recorded on the seafloor hydrophone array (work conducted by S. Martin) indicate that there may be reliable signal characteristics that can be used for individual recognition. If so, these signal characteristics can be used to identify and track individuals using passive acoustic methods.

We are continuing to analyze data from both Hawai'i field seasons and the Marianas effort. Our immediate efforts are focused on obtaining density estimates for our two main study areas. We are also examining the effects of noise produced by our own vessel on the calling rates and acoustic behavior patterns of minke whales. It is important to assess any effects of vessel noise on calling rates in order to evaluate any biases in these data caused by our survey vessel and in future vessel-based surveys. The results of these investigations will provide important information about a species that is common in the subtropical waters of the North Pacific Ocean but about which there is little information regarding their ecology and behavior.

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