Obtaining Acoustic Cue Rate Estimates for some Mysticete Species using Existing Data

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LONG-TERM GOALS

The long-term goals of this research effort are to improve the Navy's passive underwater acoustic monitoring of marine mammal populations. A major focus in this project is on further enhancing the ability to estimate animal density (animals per unit area per unit time) obtained from raw detections of calls in underwater acoustic recordings. The efforts in this program also will support the Master's Thesis research of Roanne Manzano-Roth at the Naval Postgraduate School in Monterey.

OBJECTIVES

An emerging area of study in the field of marine mammal passive acoustics is the estimation of animal population densities from detections in passive acoustic data. In order to calculate animal density from passive acoustics, one must know the species-specific average cue rate, which is the average number of calls produced per animal per time. The cue rate can vary significantly by location and season, in addition to other factors. The objective of this proposed effort is to estimate average cue rates for several species of endangered mysticete whales on and near U.S. Navy ranges, using existing recordings from both the SCORE and PMRF hydrophone networks. One primary focus is to obtain cue rates for humpback whales (Megaptera novaeangliae) off the California coast and on the PMRF range. To our knowledge, no humpback whale cue rates have been calculated for these populations. Once a cue rate is estimated for the populations of humpback whales off the California coast, density estimates can be readily calculated using previously published results of environmentally calibrated call densities. Animal density estimates are of great interest to NAVFAC monitoring efforts. The PMRF range off the coast of Hawaii provides an opportunity to estimate cue rates for humpback whales on breeding grounds, in addition to average cue rates for other species of mysticete whales such as Bryde's whales (Balaenoptera brydei,). Cue rates of several other species of baleen whales off the California coast, including fin whales (Balaenoptera physalus), also can be estimated from existing data sets (e.g., the MNT/FET data set collected in 1999 by the ADS program) and so warrants additional study.

APPROACH

Because of their extensive spatial coverage in areas of direct relevance to the U.S. Navy, datasets from the SCORE and PMRF ranges provide a unique opportunity for passive acoustic monitoring. Extensive recordings from the PMRF range are already in-house, provided by Steve Martin at SSC Pacific. SCORE range data is obtainable through David Morreti at NUWC. In the original proposal for this project, we intended the SCORE range dataset to be a component of the analysis. Unfortunately only a few days of recordings from SCORE were provided to us, and so our efforts were focused on the PMRF range datasets.

Traditional methods of obtaining cue rates for vocally active species of whales involve using acoustic tags, or a visually tracking the whales as they pass over a network of hydrophones. The number of acoustic cues are than tallied for individual animals. Ideally, metrics such as the intercall interval, the proportion of time a whale is calling, and the number of animals that are vocally active out of the total population can be measured. The downside to these methods is that the effort is costly, and usually yields extremely small sample sizes (sometimes just 1 or 2 individuals). Additionally, harassment of the animal in placing tags or following the animals from ships can influence their behavior. Oftentimes the observations are limited to daytime hours and calm seas, which can bias observed cue rates.

Passive acoustic tracking using multiple hydrophones provides a relatively inexpensive means to measure the calling behavior of a large number of animals in a region. The process can be conducted completely passively without the animals knowledge in all sea states in both daytime and nighttime conditions. While metrics can only be collected for vocalizing animals (the number of silent animals cannot be derived from the acoustic datasets), the calling metrics and swim kinematics while vocally active can be analyzed in great detail. This additional information when combined with tag data or visual tracking data increases the certainty in the overall cue rate estimates dramatically when compared to just tagging or visually tracking alone.

The PMRF dataset contains a large number of humpback vocalizations, providing a challenging environment for estimating both cue rates and animal densities. Previous efforts resulted in ambiguous animal locations, and localization efforts were abandoned. However, new techniques using methods described in Helble et al., 2015(a) have allowed for unambiguous animal locations, even during periods of multiple calling animals. The same methods were also successfully used for Bryde's whales, fin whales, and minke whales. The localization techniques described in Helble et al., 2015(a) allow for an extremely low probability of false localization (less than 2%), which allows tracks from animals to be automatically assigned. However, it is not guaranteed that every vocalization from an animal will result in a recorded localization. To accomplish this task, additional software was written in this ONR funded program to ensure that nearly every call produced by a marine mammal on the PMRF range was counted (essential for determining animal cue rates). The techniques for doing so are partially described in Sect IIIB of Helble et al., 2015(a), and fully described in Sect. IIC of Helble et al., 2015(b).

Once every vocalization on an whale track is tabulated, trajectories are fitted to the tracks and swim kinematics are extracted as described in Sect. IID of Helble et al., 2015(b). The vocal behavior is then analyzed over many different animal behaviors, providing insight into the stability and variability of the cue rate.

WORK COMPLETED

This report marks the end of the one year funding effort and serves as the final report. To date, relevant cue rates have been calculated for Bryde's whales and humpback whales on the Navy's PMRF range, and the software developed in this program will allow for many more species to be readily added in the future. Three total publications are expected from this project, one publication is in print and the other two are in preparation and expected to be submitted no later than November 2015. The publications are:

Helble, T. A., G. R. Ierley, G. L. D'Spain, S.W. Martin (2015a). "Automated acoustic localization and call association for vocalizing humpback whales on the Navy's Pacific Missile Range Facility, J. Acoust. Soc. Am. 137(11), 11-21.

Helble, T. A., S.W. Martin (2015b). "Swim track kinematics and calling behavior attributed to Bryde's whales on the Navy's Pacific Missile Range Facility, J. Acoust. Soc. Am. In Prep.

Helble, T. A., S.W. Martin, E. Henderson (2015c). "Swim track kinematics and calling behavior of humpback whales on the Navy's Pacific Missile Range Facility, J. Acoust. Soc. Am. In Prep.

RESULTS

The detailed vocal behavior for 17 Bryde's whale tracks is described in Helble et al., 2015(b) and is provided with this report. This publication will be the first time the Bryde's calls have been described around the Hawaiian islands and are notably different than those described in other publications. The 17 tracks analyzed can be seen in Figure 1 below. The intercall interval for each for each of the tracks can be seen in Figure 2 below, with the mean, median, and 10^{th} and 90^{th} percentile intercall intervals noted. The mean and median for all aggregated intercall intervals was 363 s and 290 s respectively.

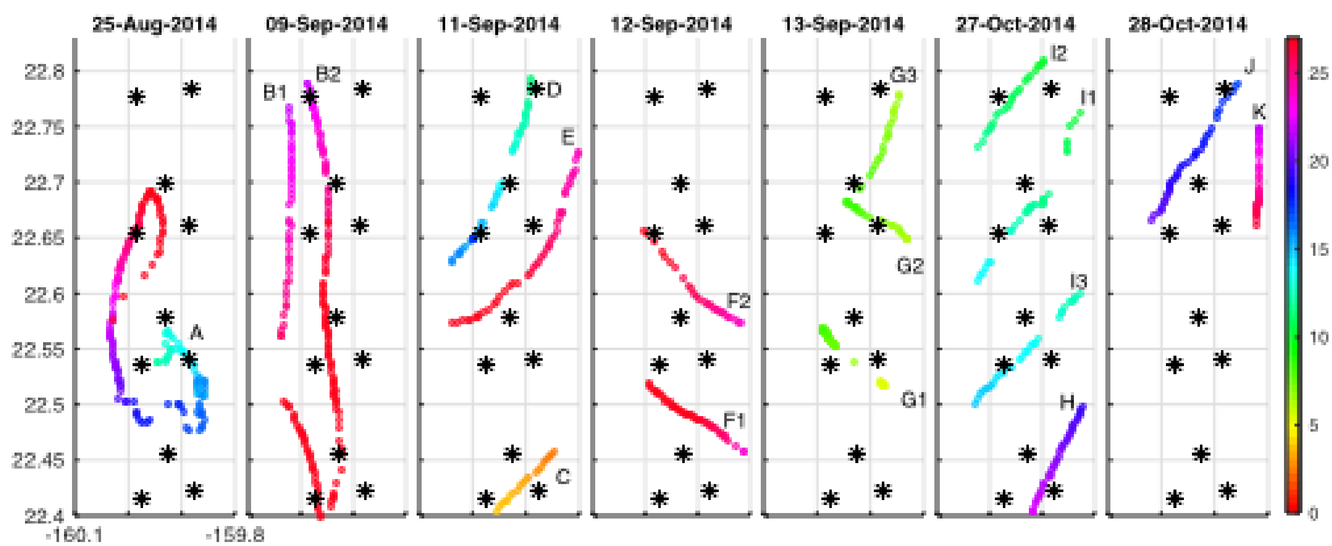

Figure 1 – Bryde's whale tracks formed from TDOA acoustic localizations on the Navy's PMRF range. Individual tracks are labeled A-K, tracks with the same letter represent tracks that occurred at the same time. The shading represents elapsed time since midnight local time.

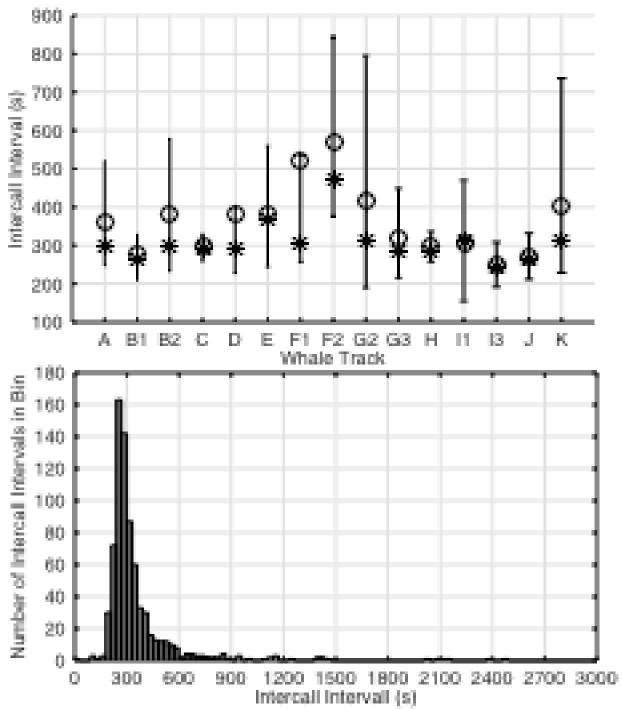

Figure 2 – Intercall interval for each of the Bryde's tracks (upper plot) showing the mean (circle), median (asterisk). The error bars represent the 10th and 90th percentile intercall interval for the track. The histogram (lower plot) shows the aggregated intercall intervals for all 746 calls, the tallest bin is between 240 and 270 seconds, with 163 calls.

All Bryde's vocalizations were the same call type, and had more consistent ICI's than those reported in other regions. The consistent calling, combined with long vocal bouts (the whales almost always vocalized over the entire observable array) makes the Hawaiian population a candidate for acoustic density estimation. The percentage of the population that currently vocalizes is unknown, as is percentage of time an individual animal spends vocalizing. However, once these numbers are established, the intercall interval and track kinematics provided here will allow for density estimate calculations. In the meantime, the information provided from this study allows one to calculate *minimum density estimates*, which is the minimum number of animals that must exist assuming all animals vocalize continuously in the region. This number can be helpful for understanding the likely number of animals present when multiple hydrophone arrays are not available, opening up the possibility of gleaning more information from single hydrophone sensors in the region.

The detailed vocal behavior for 81 humpback whale tracks will be described in Helble et al., 2015(c), currently in preparation. A subset of these tracks are shown in Figure 3 below, organized by the month in which they occur. The corresponding intercall intervals are shown in Figure 4 below. A total of 16,196 vocalizations were logged for the 16 tracks shown, with a mean intercall interval of 22.45 seconds, and a median of 10.5 seconds. The intercall interval that occurs most frequently is between 9 and 10 seconds. The humpback whales produce song while transiting across the range, and the spacing between individual vocalizations, or units, occurs roughly every 10 seconds. However, the mean ICI is higher because the humpbacks take occasional break in the song, presumably to breath or rest. Several different behaviors were noted on the range: travel, drift dive, meander, and combinations of those three. For example, track D3 was a meander track (several thousand localized localizations), while track A3 is a drift dive (patches of dives, each containing a song phrase). Overall, the mean ICIs were fairly consistent across behaviors.

It is known that mature males produce song, but percentage of time these males are vocally active is unknown. Once this is established (either through tagging or visual surveys), then the intercall interval information from this study can be used for density estimates. Internal funding from SSC-PAC is funding Dr. Elizabeth Henderson to tag a few humpback whales on the PMRF range. The calling information from the acoustic study in Helble et al., 2015(c) will be essential for establishing cue rate information for the offshore population of humpback whales in the region, since the sample size of tagged animals will be relatively small.

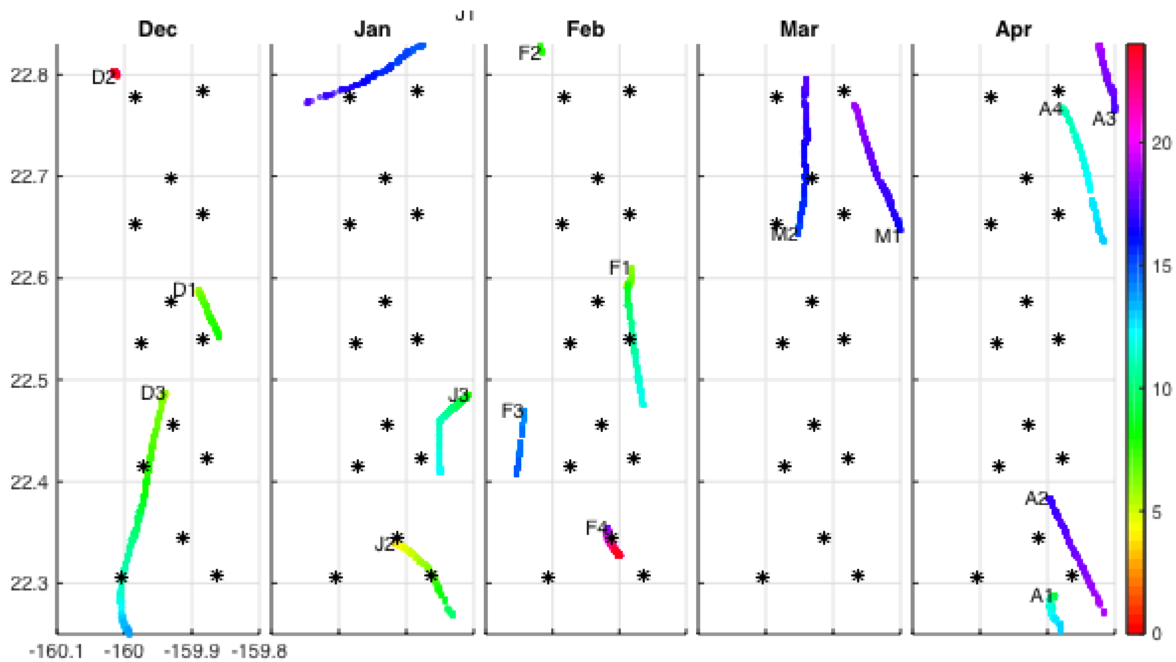

Figure 2 – 16 humpback tracks on the PMRF range, organized by the month in which they occur. The color represents the hours into the day since midnight on the day the track occurred.

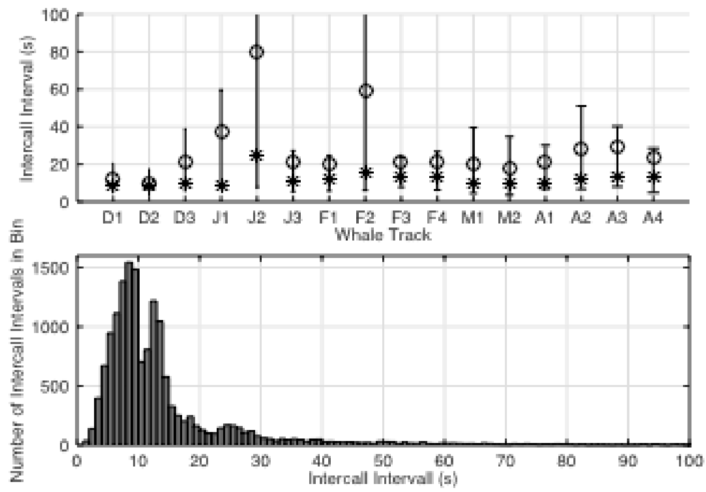

Figure 3 – Intercall interval for each of the humpback tracks (upper plot) showing the mean (circle), median (asterisk). The error bars represent the 10th and 90th percentile intercall interval for the track. The histogram (lower plot) shows the aggregated intercall intervals for all 16,196 calls, the tallest bin is between 9 and 10 seconds, with over 1500 ICIs.

IMPACT/APPLICATIONS

Passive underwater acoustic monitoring of marine mammal sounds is the Navy's primary method for characterizing the presence, distribution, and number of marine mammal species in a wide variety of environments, particularly those associated with Navy training ranges. Marine mammal population density estimates are particularly important in regions of Navy activities, or potential activities, in order to properly evaluate their potential impact under federal environmental legislation. Understanding, and improving, this passive acoustic monitoring capability will decrease the environmental risk of Navy training exercises and other activities. Both the southern California Bight region and the area west of Kauai are areas of operational/training interest to the Navy. In addition, since these research efforts involve a student in the field of marine bioacoustics, as part of their thesis research, this project will help provide the Navy with the future generation of highly trained ocean bioacousticians aware of both Navy needs and environmental issues.

RELATED PROJECTS

The efforts in this project was heavily leveraged with other programs. First, efforts in our Living Marine Resources project titled "Improving the Navy's Automated Methods for Passive Underwater Acoustic Monitoring of Marine Mammals" are focused on modifying the GPL processor for detecting a wide variety of marine mammal calls recorded by Navy range monitoring systems (the range hydrophones at the SCORE and PMRF ranges, and John Hildbrand's HARP packages in southern California), and environmentally calibrating the resulting detected call counts in the HARP data. Results from Gerald D'Spain's ONR Code 322-MMB project "Improving the Navy's Passive Underwater Acoustic Monitoring of Marine Mammal Populations" will be used to improve environmentally calibrated call density estimates. Steve Martin's ongoing project with PAC FLEET has supplied archival data from the PMRF Range hydrophones and will be helping, in coordination with Dave Moretti at NUWC, with data collection from the SCORE Range hydrophones. Finally, algorithms developed in the “Glider-Based Passive Acoustic Monitoring Techniques in the Southern California Region”, Code 322-MMB, including the GPL detector, are being used in this program to automatically scan the data for marine mammal calls of interest.

REFERENCES

Helble, T. A., G. R. Ierley, G. L. D’Spain, S.W. Martin (2015a). “Automated acoustic localization and call association for vocalizing humpback whales on the Navy's Pacific Missile Range Facility, J. Acoust. Soc. Am. 137(11), 11-21.

Helble, T. A., G. R. Ierley, G. L. D’Spain, M. A. Roch, and J. A. Hildebrand (2012). “A generalized power-law detection algorithm for humpback whale vocalizations,” J. Acoust. Soc. Am. 131(4), 2682-2699.

Lombard, E. (1911). "Le signe de l'élévation de la voix," Annales des Maladies de L’Oreille et du Larynx 37 (2), pp. 101–109.

Marques, T. A., L. Thomas, J. Ward, N. DiMarzio, and P. L. Tyack (2009). “Estimating cetacean population density using fixed passive acoustic sensors: An example with Blainville’s beaked whales,” J. Acoust. Soc. Am. 125(4), 1982-1994.

Moore, S.E., W.A. Watkins, M.A. Daher, J.R. Davies and M.E. Dahlheim (2002)”. Blue whale habitat associations in the Pacific: Analysis of remotely-sensed data using a Geographic Information System. Oceanography, 15(3):19-25.

PUBLICATIONS

Helble, T.A., S.W. Martin (2015). “Cue rate and track kinematics of calling Bryde's whales (Balaenoptera brydei) transiting through the U.S. Pacific Missile Range Facility (PRMF),” MMS Conference, San Francisco, CA, 15 Dec.

Helble, T.A., G.R. Ierley, S.W. Martin (2015). “3-D localization and swim track kinematics of humpback whales on the Navy’s Pacific Missile Range Facility,” DCLDE Workshop, San Diego, CA, 14 July.

D’Spain, G. L., T. A. Helble, J. A. Hildebrand, and M. Roch (2013). “(Near) Optimal signal processing approaches and environmental calibration of passive acoustic monitoring results,” DCLDE Workshop, St. Andrews, Scotland, 12 June.

Helble, T. A., G. L. D’Spain, J. A. Hildebrand, G. S. Campbell, R. Campbell, and K. D. Heaney (2013a). “Site specific probability of passive acoustic detection of humpback whale calls from single fixed hydrophones,” J. Acoust. Soc. Am. 134(3), Pt. 2, 2556-2570.

Helble, T. A., G. L. D’Spain, G. S. Campbell, and J. A. Hildebrand (2013b). “Calibrating passive acoustic monitoring: Correcting humpback whale call detections for site-specific and time-dependent environmental characteristics,” JASA Exp. Lett. 134(5), EL400-406.

Helble, T. A., G. L. D’Spain, G. R. Ierley, J. A. Hildebrand, M. Roch, G. S. Campbell, R. Campbell, and K. D. Heaney (2013c). “Calibrating call counts from single fixed sensors,” DCLDE Workshop, St. Andrews, Scotland, 14 June.

Helble, T. A., G. L. D'Spain, G. S. Campbell, J. A. Hildebrand, and L. Thomas (2014a). "Environmentally calibrated humpback whale vocalization activity at Sur Ridge and in the Santa Barbara Channel from 2008-2009," Endang. Spec. Res., 46 pgs plus 6 figs, submitted.

Helble, T. A., G. R. Ierley, G. L. D'Spain, and S. W. Martin (2014b). "Automated acoustic localization and call association for humpback whales on the Navy's Pacific Missile Range Facility," accepted for J. Acoust. Soc. Am., Nov, 2014, 11 pgs plus 9 figs.

Helble, T. A., G. R. Ierley, G. L. D'Spain, and S. W. Martin, Automated Acoustic Localization of humpback whale calls on the Navy's Pacific Missile Range Facility, ASA Providence, RI, May 9 2014.

Helble, T. A., G. R. Ierley, G. L. D'Spain, and S. W. Martin, Acoustic detection localization and 3D tracking of vocalizing humpback whales on the Navy's Pacific Missile Range Facility, ASA Invited Talk, ASA, Indianapolis, IN. Oct 26, 2014.