REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
29-09-2014

2. REPORT TYPE
Monitoring report

3. DATES COVERED *(From - To)*
1 Jan 2013 - 31 Dec 2014

4. TITLE AND SUBTITLE
Minke whales respond to US Navy training in Hawaiian waters

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Stephen W. Martin
Cameron R. Martin
Brian Matsuyama
E. Elizabeth Henderson

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Marine Mammal Foundation 2240 Shelter Island Drive Suite 200 San Diego, CA
SPAWAR Systems Center Pacific 53366 Front Street, San Diego, CA

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Commander, U.S.Pacific Fleet 250 Makalapa Dr. Pearl Harbor, HI

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Minke whales (Balaenoptera acutorostrata) were acoustically detected and localized, via their boing vocalizations, using recorded data from the US Navy's Pacific Missile Range Facility (PMRF) located off Kauai, Hawaii. All available recorded data (766 h) from 24 seafloor mounted hydrophones were processed to localize boing calling minke whales associated with US Navy training events which occurred in the month of February over three years (2011-2013). The average number of boing calling minke whale individuals present in 1 h observation intervals is converted to an estimated minimum density of calling minke whales in a study area of 3,780 km2. The data were categorized temporally as being before, during and after the Navy training events with the during times further categorized as phases A and phase B, and the latter being the only period with mid-frequency active sonar (MFAS) activity from Navy surface ships. Results indicate that the estimated minimum density of calling minke whales within each year are higher for the 'before' data compared to the 'phase B' data ($p < 0.001$ for all three years). However, preliminary analysis of the Feb 2014 training event indicated that the proximity of surface ships to calling whales can result in cessation of calling even when no MFAS activity is occurring. The minimum densities of calling minke whales were different from year to year, with 2011 the highest. For 2011 the estimated minimum density of calling minke whales during the phase B period was 0.69 whales per 3,780 km2 (CI 0.27-1.8) which was depressed compared to the 2011 before period with 3.64 whales per 3,780 km2 (CI 3.31-4.01). A similar trend was observed for the 2012 data. Given only 5 h of data for the 2013 before period a robust estimation of minimum density is not provided for that period. Correction factors required for this estimated minimum density of calling minke whales to represent all minke whales (i.e. how many calling whales are present but not calling and the ratio of calling whales to the entire population [i.e. males vs. females and juveniles]) were not available and would result in higher density estimates. Thus this estimate may also be considered a minimum density for all minke whales for these periods of time in this study area.

15. SUBJECT TERMS
Monitoring, marine mammal, adaptive management review, Hawaii Range Complex

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT** UU	**18. NUMBER OF PAGES** 17	**19a. NAME OF RESPONSIBLE PERSON** Department of the Navy
a. REPORT Unclassified	**b. ABSTRACT** Unclassified	**c. THIS PAGE** Unclassified			**19b. TELEPONE NUMBER (*Include area code)*** 808-471-6391

Minke whales respond to US Navy training in Hawaiian waters

29 September 2014

Stephen W. Martin[1], Cameron R. Martin[1], Brian Matsuyama[2] and E. Elizabeth Henderson[1]
[1]National Marine Mammal Foundation, 2430 Shelter Island Drive Suite 200, San Diego, CA 92106
[2]SPAWAR Systems Center Pacific, 53560 Hull Street, San Diego, CA 92152-5001

Abstract:

Minke whales (*Balaenoptera acutorostrata*) were acoustically detected and localized, via their boing vocalizations, using recorded data from the US Navy's Pacific Missile Range Facility (PMRF) located off Kauai, Hawaii. All available recorded data (766 h) from 24 seafloor mounted hydrophones were processed to localize boing calling minke whales associated with US Navy training events which occurred in the month of February over three years (2011-2013). The average number of boing calling minke whale individuals present in 1 h observation intervals is converted to an estimated minimum density of calling minke whales in a study area of 3,780 km^2. The data were categorized temporally as being before, during and after the Navy training events with the during times further categorized as phases A and phase B, and the latter being the only period with mid-frequency active sonar (MFAS) activity from Navy surface ships. Results indicate that the estimated minimum density of calling minke whales within each year are higher for the 'before' data compared to the 'phase B' data ($p < 0.001$ for all three years). However, preliminary analysis of the Feb 2014 training event indicated that the proximity of surface ships to calling whales can result in cessation of calling even when no MFAS activity is occurring. The minimum densities of calling minke whales were different from year to year, with 2011 the highest. For 2011 the estimated minimum density of calling minke whales during the phase B period was 0.69 whales per 3,780 km^2 (CI 0.27-1.8) which was depressed compared to the 2011 before period with 3.64 whales per 3,780 km^2 (CI 3.31-4.01). A similar trend was observed for the 2012 data. Given only 5 h of data for the 2013 before period a robust estimation of minimum density is not provided for that period. Correction factors required for this estimated minimum density of calling minke whales to represent all minke whales (i.e. how many calling whales are present but not calling and the ratio of calling whales to the entire population [i.e. males vs. females and juveniles]) were not available and would result in higher density estimates. Thus this estimate may also be considered a minimum density for all minke whales for these periods of time in this study area.

INTRODUCTION

There has been concerted effort in understanding the role of active sonar in stranding of marine mammals since the multi-species stranding event in the Bahamas in 2000 (Evans, Hogarth, England, Livingstone and Johnson 2001). Much of the focus has been on beaked whale species as this stranding resulted in seven dead animals, six of which were beaked whales. This stranding was also unusual in that two minke whales stranded. One of the stranded minke whales spent over 24 h on the beach and was physically removed to deep water by a boat. The second stranded minke stayed in a shallow enclosed harbor for two days before being escorted to deep water by a boat. Neither minke were examined while in shallow water or on the beach and they were not reported to re-strand.

Various reports have shown behavioral responses (e.g., cessation of foraging clicks and changes in dive ascent rates) of beaked whales to mid-frequency active sonar (MFAS) activity at the US Navy's three test ranges: the Atlantic Undersea Test and Evaluation Center (AUTEC) in the Bahamas (McCarthy et al. 2011), the Southern California Offshore Range (SCORE) off California (DeRuiter et.al. 2013), and the Pacific Missile Range Facility (PMRF) in Hawaii (Manzano-Roth et.al. in process). The Behavioral

Response Study (BRS) conducted off southern California has also reported that blue whales (*Balaenoptera musculus*) respond to simulated MFAS by a cessation of deep feeding, increased swimming speeds, and directed travel away from the sound source (Goldbogen et.al. 2013). Fin whales (*Balaenoptera physalus*) have also shown changes in acoustic signal parameters resulting from shipping noise and seismic air gun activity (Castellote et al. 2012). However, there is the potential argument that some reported effects could partially be due to ship activity rather than solely from MFAS or air guns. Richardson et al. 1995 documented disturbance reactions of baleen whales to multiple disturbance sources including ships and boats. Watkins (1986) reported on four baleen species (minke, right, humpback and fin whales) reactions to boats in Cape Cod waters with a general finding that avoidance was especially strong when boats directly approach whales and that whales go silent when disturbed. Richardson et al. (1985) observed that when bowhead whales (*Balaena mysticetus*) were approached within 1-4 km by boats (e.g. seismic vessels, drill ships, and dredging vessels) that the surface/dive cycles became shorter and the whales swam away rapidly. Moore and Clarke (2002) reported on potential impact of multiple sources of human activity, including commercial shipping and whale watching boats on gray whales in the northeast Pacific. A study of minke whales on a feeding ground off Iceland (Christiansen et al. 2013) found a possible decrease in foraging behavior in the presence of whale watching craft. Minke whale behavior in Hawaiian waters is believed to be for breeding purposes, so sensitivity to boats may be different from that on feeding grounds.

Minke whales are a difficult species to sight due to their small size, low visibility blow, and short surfacing intervals which is compounded in Hawaiian waters in the winter/spring months due to generally higher sea states. However, the boing sound has been seasonally detected off Hawaii since the 1960s (Wenz 1964) and was suspected to be produced by a whale species (Thompson and Friedl 1982), but was only recently associated with minke whales (*Balaenoptera acutorostrata*) (Rankin and Barlow 2005). Given the seasonal and spatial overlap of boing calls with humpback whale (*Megaptera novaeangliae*) song, it is suspected that only sexually active males make boing vocalizations for breeding purposes, similar to the humpback whale (Payne and McVay 1971). The minke whale boing call is readily automatically detected (Mellinger et al. 2011) and localized (Martin et al. 2013) using recorded acoustic data from PMRF. Model-based localization methods have been applied to US Navy range hydrophone data for sperm whale (*Physeter macrocephalus*) clicks (Tiemann et al. 2006, Nosal 2012) and more recently for humpback whales (Helble et al. submitted). A model-based localization method was utilized here to investigate minke whale boing vocalization behavior relative to US Navy training activities conducted during the month of February over three years (2011-2013).

This study included times of US Navy training activities which involve multiple vessels (various sized surface ships and undersea vessels) and aircraft (both fixed and rotary wing) that participated in, and supported the training activity. Acoustic data has been recorded before, during and after specific US Navy training events in February since 2011. Utilizing these recorded acoustic data from the PMRF underwater range hydrophones, individual minke whales were automatically detected and localized based upon their boing calls. The number of individual boing calling minke whales in the study area was quantified on hourly intervals for available recorded data before, during, and after these training events. The average number of boing calling minke whales in 1 h observation intervals also provides a minimum estimated density of minke whales in the study area for the periods of time for which recorded data were available.

METHODS

Study Area

The study area of 3,780 km^2 was 54 km in the east-west direction and 70 km in the north-south direction. The study area is approximately centered on the offshore hydrophones where US Navy training has occurred off of the island of Kauai, Hawaii, but has been extended to the east and west of the hydrophones by approximately 20 km. The study area was not extended significantly to the north beyond the hydrophone range (localization accuracy concerns) nor to the south due to different characteristics in the southernmost six hydrophones (e.g. ambient noise fields, shallower bathymetry and different spectral responses). Figure 1 depicts the study area highlighted in light red superimposed on a nautical chart of the area, along with approximate locations of the 24 hydrophones used for analysis.

Automated Acoustic Detection, Classification, and Localization

The same types of training events occurred during the month of February in 2011, 2012, and 2013, where each training event consisted of multiple days of various activities conducted in two distinct phases. Phase A involved training without naval surface ships equipped with MFAS participating, while phase B involved surface ships conducting MFAS training (e.g. AN/SQS-56 and AN/SQS-53C). The time periods analyzed herein were segmented and labeled relative to the training activity as: before, phase A, phase B, and after. The February 2013 training event had a weekend period between the two phases of training which was labeled “between”. Thirty-one bottom-mounted range hydrophones were recorded; of those, 24 had suitable bandwidth for detection of minke boing calls which have peak frequencies around 1400 Hz as observed by a bottom-mounted hydrophone (Thompson and Friedl 1982). In late August of 2012 an additional 31 hydrophones were added, bringing the total number of hydrophones recorded suitable for minke boing analysis up to 47. For compatibility with the earlier years, this study utilized the same 24 hydrophones for the February 2013 data. However, an additional analysis was conducted for February 2013 to compare the localizations from the 47 hydrophones with the subset of 24 hydrophones which were recorded in the prior years. The additional hydrophones were expected to increase both the accuracy of minke whale localizations farther from the range and the number of localized individuals farther from the hydrophone array.

Automated methods of detection, classification, and localization of minke whale boing vocalizations have been developed and previously applied to US Navy hydrophone data from PMRF (Mellinger et al. 2011, Martin et al. 2013). The minke boing is complex, with multiple spectral components from around 100 Hz to over 10 kHz (figure 2 in Martin et al. 2013). For bottom mounted hydrophones located in deep (>1 km) water such as at PMRF, the last detectable component of the minke boing at distances over 30 km is typically detected in the 1350 to 1440 Hz band (Mellinger et al. 2011). The peak frequency in this band, termed the dominant spectral component (DSC) with sub-Hz frequency bin width has been shown to be a feature to help isolate individuals (Martin et al. 2013). An improvement to the boing detector was also made to better detect the onset of the call, which improved the accuracy of the automatic detection start time and in turn improved the localization accuracy. Automatic minke boing detections were required to exceed the background noise level estimate in the detection band for at least 0.8 s. Previous localizations of boing-vocalizing minke whales were performed using two-dimensional hyperbolic methods and times of arrival with four hydrophones required in the solution (Martin et al. 2013). While this previous localization method worked well for animals located within the hydrophone array, model-based localization was added to improve localization farther from the hydrophone array.

The model-based localization utilized is similar to other methods previously reported (Tiemann et al. 2006, Nosal 2012). Model-based methods compare measured time differences of arrival (TDOA) across multiple hydrophones with arrival times based upon modeled TDOAs from potential source locations.

Measured TDOAs have typically been based upon cross correlation of signals received from spatially separated hydrophones. Here, the measured arrival times were based upon the automatic detection start times. The time difference of arrival between two hydrophones, i and j ($TDOA_{ij}\ or\ \Delta T_{ij}$) is defined as $T_i - T_j$ where T_i is the measured presumed first detected arrival of a single call and T_j is the measured arrival of the call at the j^{th} hydrophone. The weighted least squares (*LS*) between measured ($\Delta T_{ij,measured}$) and modeled ($\Delta T_{ij,modeled}$) TDOAs as defined by equation 1 were minimized utilizing a spatial grid search method where *i* represents the hydrophone with the first detected arrival of a single call and *j* represents hydrophones with subsequent arrivals of the call to the maximum of N hydrophones using equation 1.

$$Equation\ 1) \qquad LS = \sqrt{\sum_{j=2}^{N} W_{Tj,modeled} \frac{\left(\Delta T_{ij,measured} - \Delta T_{ij,modeled}\right)^2}{N}}$$

The weighting function $W_{Tj,modeled}$ weighs the contributions to the *LS* s according to their order in the time of arrival with the later arrivals weighted less than earlier arrivals and normalized such that $\sum_{j=2}^{N} W_{Tj,modeled} = N$. Using these results, a new search grid was established with reduced spacing centered at the cell location possessing the lowest *LS* value. This process was repeated for a maximum of 16 iterations with every iteration resulting in finer and finer grid resolution if *LS* thresholds were achieved. If the final candidate location meets threshold criteria, the localization was kept; otherwise the localization was discarded and a new set of detection times were loaded into the algorithm. Animal depth was assumed to be at or near the surface and the actual hydrophone depths were utilized with an assumption of iso-velocity water, computed as the average over the historical sound velocity profile for the area and time (newer methods take into account non-iso-velocity water assumptions).

The threshold criteria for an accepted localization involved multiple requirements. The first stage of the localization process computed a tentative solution which required the DSC frequencies of the first four detections to be within 3.5 Hz of one another to reduce the search space down from all possible detections. This was justified as a single call would ideally be detected with the same frequency as received on different hydrophones; however for various reasons (e.g. propagation effects and complexities of the amplitude modulated constant frequency portion of the boing call) the precise frequency can vary a small amount. Measured TDOAs from other hydrophones were later included into the localization solution using a smaller initial start grid centered at the four TDOA location. *LS* grid iterations continued and the threshold criteria were again applied. Known singularities exist when the *LS* minimization process encounters local minima; however, these can be reduced by further requiring a minimum threshold requirement on the number of TDOA detections used in the final localization. When processing the 24 recorded hydrophones, it was not unusual to have over a dozen hydrophones included in the localization solution for a single boing vocalization.

All potential localization solutions also required that the weighted *LS* could not exceed 0.5 s and individual TDOA differences from measured to modeled did not exceed 0.25 s. These parameters are user configurable and affect performance; the above values are rather loose in terms of localization accuracy, however they resulted in providing more call localizations from an individual which improved the call interval analysis. By tightening both of these two timing parameters to 0.075 s the localization precision increases, however fewer calls are localized.

Four spatially collocated and frequency coherent call localizations were utilized as a threshold for declaring the presence of an individual minke whale. The four calls must have occurred within the span of an hour and be within a few hundred meters of one another. The DSC frequency deviation of the four calls also had to be within 5 Hz of one another. Spurious localizations were often characterized as isolated in space from true localizations. Spatial/temporal review of automatic localizations helped visualize individual animal movements over time. A temporal window of 1 h was utilized to review the minke boing localizations and estimate the number of individual minke whales present in the study area. At the end of a 1 h period the number of localized individuals in the preceding hour was logged.

Figure 1 shows four individual minke whales represented by the yellow X symbols for the period 1100 to 1200 GMT on 11 February 2012. The analyst would determine the number of localizations in the previous hour using features such as the time and distance between localizations, DSC frequency of calls, number of hydrophones in each solution, and the least squares of the localization solution. For the four animal locations shown in figure 1 the north-west and south-east animals had ten localizations each while the south-west individual had seven localizations and the north-east animal had eleven. The repeated localization times for each animal fit the 5 to 6 min typical boing call interval for minke whales. Currently, suitable data does not exist to ground truth the minke whale locations to determine the accuracies of the automated localizations or the probability of correct localization. This would require either acoustically tagged animals, towing a source that emitted simulated minke whale boing calls, or potentially a Monte Carlo simulation such as done in Helble et al. 2014 (submitted).

Density Estimation

Density estimation of localized sperm whales was described in Ward et al. (2012) with two major assumptions: a) assuming that all periods of whale presence were identified, and b) all individuals vocalizing within the study area were included. In Ward et al. (2012) sub-sampling of the data was done to count whales with *k* samples periods over the available data period with the estimated average density of sperm whales given as shown in equation 2 where *n* is the number of individuals counted over their *k* 10 min sample periods, *A* is the study area (in km), p_p is the proportion of the total time monitored (in min) and $\hat{p}_v$ is the estimated proportion of time an individual whale vocalizes at least once in their 10 min sample intervals.

$$Equation\ 2) \qquad \hat{D} = \frac{n\, p_p}{A\, k\, \hat{p}_v}$$

In Ward et al. (2012) *n/k* was the mean number of whales detected over the *k* sample periods. Here we did not sub-sample the available data but utilized the measured numbers of whales in each 1 h of available data, therefore our mean number of whales localized in all available data was equivalent to *n/k*. In addition, for this study p_p was 1.0 as all available data is utilized.

An estimation of minke whale density not only requires $\hat{p}_v$ in the denominator of equation 2, but also the ratio of boing calling minke whales to all minke whales (i.e. the proportion of males to females and juveniles in this area). Given there were no current estimates for these two parameters, they were both set to 1.0 to represent a minimum average density of minke whales based on the observed mean number of boing calling minke whales present in any hour. For this study we also assumed that all vocalizing individuals in the study area were counted (probability of correctly localizing calling individuals=1.0) and that the probability of a false positive (declaring an individual present when actually not was =0). With these assumptions we can therefore provide an estimated minimum average density of minke whales for our study area (*A*) and time periods as simply

$$Equation\ 3) \qquad \hat{D}_{min} = \frac{\hat{n}}{A}$$

where $\hat{n}$ is the mean number of localized whales counted. Here we use 1 h intervals for measurement of animal counts.

The assumption of correctly counting all calling individuals with no false positives was not unrealistic given the methods utilized and the one h observation intervals. The typical minke whale boing rate is a call produced every 5-6 min; however when two calling animals are in close proximity the call rate increases to calls produced approximately every 0.5 minutes (Rankin and Barlow 2005, Thompson and Friedl 1982). Minke whales producing boing vocalizations at their typical rates would result in production of 10 to 12 boings in a 1 h observation interval if continuously calling. This increases the probability of localizing whales as multiple opportunities are given with only four localizations in the same area required. In addition, the chance of at least four incorrect localizations occurring in the 1 h observation interval, all within a few hundred meters of one another, with features of the DSC frequencies being within 3.5 Hz of each other, and the call intervals matching known minke boing rates was observed to be extremely low. Observation intervals shorter than 1 h resulted in less than perfect localization with potential false localizations, and intervals over a couple of hours resulted in duplicate counting of individual animals that stop and resume calling. The accuracy of the whale localizations have not been quantified and likely decreases with increasing distance from the hydrophones. Due to consistent analysis across temporal periods and use of the same hydrophones and processing algorithms, localization accuracy is believed to vary from +/- a few dozen meters within the hydrophone array to +/- a few hundred meters towards the outer boundaries of the study area.

Given the assumptions above, the variance of the density estimate is a function of $\hat{n}$ and the coefficient of variation determined as the standard error (i.e. standard deviation of n divided by the square root of the number of samples) divided by the estimate ($\hat{n}$) (Buckland et al. 2001). The 95% confidence intervals of the density are estimated assuming a lognormal distribution for the density estimate and a normal approximation to the distribution of log (density).

The average noise levels in the detection band utilized for automated minke boing detection (approximately 1300 Hz to 1450 Hz) is also of interest to ensure that the reduction of detections are not due to an increased noise level from the training activity (e.g. surface ship radiated noise and MFAS transmissions masking the calls). Data indicate that the increased noise level is small compared to the signal to noise ratios for boing calls detected on the PMRF range.

RESULTS

Seven hundred sixty-six hours of recorded acoustic data from 24 bottom-mounted hydrophones were collected before, during, and after the February 2011-2013 training events. Table 1 summarizes the number of hours of available data for each period of time (i.e. before, phase A, between phases, phase B and after) along with the mean ($\hat{n}$) and 95% confidence intervals (CI) of the minimum density estimates for these periods of time for the 3,780 km^2 study area for the month of Februrary for the three years. As equation 3 indicates, $\hat{n}$ is the minimum average density of minke whales in this study area over these time periods. Rather than sub-sampling from the 766 total h of available recorded data (255 h in 2011, 298 h in 2012 and 213 h in 2013) all 766 h of data were analyzed for the number of individually acoustically localized minke whales present in each hour. Although the estimated densities are different from year to year, the trend of the phase B densities being depressed compared to other periods hold. The 2013 phase B confidence intervals are large due to the mean estimate being close to zero at only 0.06. The 2011 after period also shows the highest estimated density for all periods.

Figure 2 provides time sequence plots of the number of localized boing calling minke whales in 1 h observation intervals (n) in the study area for all available recorded data with the different periods of time indicated for each year. Gaps seen between data values in Figure 2 indicate periods of time that recorded acoustic data were not available. Note that there was a weekend separating the two phases of the training only in 2013. Also note that in 2013 there was very little data (5 h) available before the training began and a gap of about six days from the end of phase B of the training event to the available after data. There is also a gap greater than two days between two available portions of the before data in 2012. There was a high amount of variability in the numbers of animals localized in the 1 h periods, as demonstrated in Figure 2. The number of localized minke whales present decreased over the years for the data analyzed, with a maximum of nine individuals localized in one observation period in the 2011 after data. The number of localized minke whales during phase B periods decreased relative to the other periods within the same year with the unique situation of no minke whales localized for 2.5 days after the start of phase B in 2013 (although numbers in 2013 are lower compared to the prior years).

To gain insight into the distributions of the number of acoustically localized minke whales present in 1 h observation intervals, histograms were generated for all periods of time (Figure 3). These histograms provide the number (min 0 max 9) of acoustically localized minke whales (n) that were present in the 1 h observation intervals with the number of total hours available (N) shown in the upper right of each histogram. As mentioned above, the phase B data for 2013 had very low detections of minke whales; 62 of the available 67 hours (93%) had no localizations. In addition, in 2013 the other periods of time (phase A, between and after) have a maximum of only one minke whale localized in the study area for the majority of the available hours. In 2011, there was a peak of four minke whales present for 28 of the available 64 h (44%) for the before period compared to the before period for 2012 with a peak of two whales for 34 of the available 94 h (36%). A comparison of the before period data with the phase B period data shows a trend of a reduced number of whales in phase B.

The number of localized minke whales in 1 h observation intervals was tested for normality using the Shipiro-Wilks normality test. The before periods for 2011 and 2012 data tested highly significant as non-normal ($p<0.001$). The Mann-Whitney / Wilcoxon rank-sum test was therefore selected, given its ability to deal with non-normal distributions as well as the significant number of ties in the ranking process, to test if the means of any two distributions are the same.

The Mann-Whitney tests indicated that for the comparisons within periods across years (e.g. before to before, phase A to phase A, etc.) only the comparison of 2011 phase B and 2012 phase B had the same means ($p=0.77$); all other comparisons across years were significantly different (p values ranged from 0.044 to less than 0.001). Given the higher number of animals present in 2011 compared to 2012, this suggests the possible involvement of another factor which made the 2011 phase B similar to the 2012 phase B, as the 2011 phase B mean would otherwise be expected to be higher. The before periods represent the best estimate at baseline data, however the before periods had different means ($p<0.05$) across all paired year comparisons (i.e. 2011 to 2012, 2011 to 2013 and 2012 to 2013). The small sample size of the before data for 2013 (five hours) should be considered when interpreting tests involving that data. The fact that before periods over different years had different means suggests that the densities of calling animals in our baseline was different from year to year, and therefore interannual differences may factor into the differences observed across all sampling periods.

The Mann-Whitney tests of the 10 paired combinations involving phase B distributions *within* years (i.e. 3 paired tests in 2011, 3 paired tests in 2012 and 4 paried tests in 2013 due to the additional between period of time) the means all test as highly significantly different ($p<0.001$) . Phase B periods were the only periods of time with MFAS activity from naval surface ships and also the only period when the mean number of animals in the study area was less than one per hour. This indicates that the phase B training activity impacts the number of localized minke whales, resulting in fewer calls as compared to the other time periods .

The Mann-Whitney paired tests involving phase A counts *within* years had mixed results compared with other periods of time (e.g. phase A to before, phase A to after). Phase A to before periods within each year all had statistically significant different means ($p<0.05$), as did the 2013 phase A to between period comparison ($p=0.05$). However, the phase A to after periods had means that were not siginificanlty different for 2012 and 2013 ($p=0.709$ and $p=0.18$ respectively). Thus, impacts of phase A training on minke calling behavior was not as clear as the phase B impacts and requires further study.

The results from the localizations in 2013 which utilized the 47 available hydrophones were similar to results using only the subset of 24 hydrophones for compatiability with 2011 and 2012 comparisons. As expected there were a few more localized animals at longer distances from the hydrophones. The Mann-Whitney test comparing the 47 to 24 hydrophone localizations across periods had means that were not significantly different across all periods. The sole exception to this was the after period ($p=0.0106$), when the larger number of hydrophones resulted in a higher mean number of animals per 1 h periods (1.95 compared to 1.41).

DISCUSSION

The use of estimated densities of calling minke whales based upon individual minke whale localizations to investigate minke whale density and potential responses to Navy surface ship training activity is a new development in the science of acoustic detection, classification, and localization. This method is favored as much of the anlaysis, including localizations, was automated and it is not unreasonable to perform the analysis for all available data rather than sub-sampling the available data. The amount of minke whale calling (and resultant localizations) were shown to be reduced by the phase B training activities (surface ship training with MFAS) when compared with the available before period data.

North Pacific minke whales migrate from high latitudes where they feed to low latitudes presumably for breeding . Due to low avaialbility and detectability biases, there are not minke density estimates currently available for the Hawaii area. However, the average density for minke whales from a vessel based visual survey on summer feeding grounds in the Aleutian Islands and Alaskan waters reported by Zerbini et al. (2006) was 60 whales per 10,000 km^2. Keeping in mind the different behavioral states (breeding vs. feeding grounds) but lack of any density estimates for minke in Hawaiian waters we compare our density estimate here to Zerbini's for a crude sanity check. The minimum density estimated here averaged over 2011 and 2012 was about 3.2 animals for this study area of 3,780 km^2, which is about seven times fewer animals than one would expect if the Zerbini estimate is reduced to a similar size study area (i.e. 22.7 whales per 3,780 km^2). However, given that these density estimates were only counting sexually mature males and were not corrected for proportion of time a calling whale is vocally active, they may actually be comparable numbers. For example, the assumption could be made that males are one-third of the population on breeding grounds, with females and calves/juveniles making up the other two-thirds. In addition, based on one observed boing call bout duration of 6 h and an inter-bout interval of 4 h, male minke whales could spend approximately 60% of their time calling at PMRF. Using those rough assumptions, the minimum density estimate would increase from 3.2 animals to 16 animals per 3,780 km^2, falling closer to what one would estimate based upon Zerbini et al. (2006).

Since baleen whales do not rely on echolocaiton clicks when foraging like odontocete whales, baleen whale calling behavior is not easily predictable and is dependant on the whale's behavioral state. Thus, while the measured numbers of localized minke whales vary from year to year it is not certain if the densities are varying at this rate or it may be different behavioral states with different calling behavior. Minke boing calling behavior is also density dependant since when two animals are relatively close to one another, call rates increase by a factor of over 10 (Thompson and Friedl 1982). This was occassionally observed in PMRF data with one of the animals typically ceasing to call after an increased call bout session with another calling whale. This behavior has also been observed in humpback whales, with singers joining or being joined by other males (Darling et al. 2006; Tyack 1981). However, in contrast to the behavior observed in calling minke whales, the singers typically join with non-singing males, rather than with another singing male. Individual minke whales have also been observed to cease calling for varying amounts of time before continuing calling. Thus, the proportion of time, on average, that a boing calling minke whale actually vocalizes is complex and potentially expensive to obtain (e.g. successfully attaching medium-term acoustic tags on multiple animals with multi-day attachment durations). Studies of humpback whale singer-to-overall population ratios have also been shown to vary from year to year but currently no similar data exists for minke whales wintering in Hawaiian waters.

The situation for February 2013 phase B was distinctive in that there were no localized minke whales for the majority of phase B; however, this year also had the lowest number of localized minke whales present compared to the other years. A unique situation was observed for the onset of this phase B activity. A minke whale that was nearly constantly vocalizing within the study area over the preceeding day was 14.9 km away and about 30 deg off of the ship's bow when the first, single MFAS ping in phase B was transmitted. The minke showed no apparent change in vocalization behavior after this single transmission. However, the minke ceased vocalizing approximately 15 min later when the ship changed course and began repeated transmissions with the whales location 9.2 km away and about 3 deg off the ship's bow. Several minutes later the ship passed near the last localized position of the now silent minke whale.

In contrast, a ship-whale encounter reported for February 2011 (Martin and Kok 2011) from a 1.5 h test case analysis for 16 February 2011 had a ship approximately 16.6 km from a boing calling minke whale, with the animal about 90 deg off the bow, when it began transmitting MFAS. In this case the minke continued vocalizing while the ship opened in range relative to the whale. Although the initial distances between the MFAS source ships and the localized minke whales were similar in these two examples (16 February 2011 and 19 February 2013), one instance had the ship moving away from the whale with no cessation of vocalizing, while the other instance had the ship appraoching the whale with a cessation of vocalizing. From analysis of only the 1.5 h test case in 2011 one might suspect there are not major impacts to boing calling minke whales from MFAStraining, however analysis of the 766 h reported herin, over three years and three training events, indicate an overall reduction in boing calling and localizations during the phase B time periods of the training events.

While phase B does involve periods of MFAS activity one should keep in mind the presence of the naval surface ships conducting manuevers in the area at speeds on the order of 18 km/hr. A boing calling minke whale was also observed to cease calling when a surface ship was headed towards it but not transmitting MFAS in the February 2014 training event (not included in this analysis). In this ship-whale encounter (18 February 2014) two surface ships were training on the PMRF range at the start of phase B of the training event (again after a weekend gap) but not transmitting MFAS. At 0720 GMT one of the ships transiting northerly on the range was 9.4 km from an individual localized minke whale that was 11 deg off its bow (i.e. closing geometry) when the whale ceased vocalizing. This indicates that the ship's heading and speed relative to the whale's position (and potentially the size of the ship) should be considered as a factor in cessassion of calling, rather than assuming that the MFAS trainingis the sole cause for the cessation of calling. Ship speed and heading relative to nearby whales will be obtained in future studies to gain more insight into this as well as estimated received levels on localized whales when MFAS is present. This has implications for other controlled studies such as the southern California BRS (e.g. DeRuiter et al. 2013, Goldbogen et al. 2013) and the 3S study (Miller et al. 2012).

This study presents conflicting evidence to whether the phase A part of the training event had an impact on boing-calling minke whales. This effect is less pronounced relative to the comparison between baseline/before data and the phase B data for 2011 and 2012. It is unclear what activity in phase A could be responsible for reducing minke calling behavior, but it could be related to surface range support craft movement (which are smaller than the vessels present during phase B), undersea vessel activity, or aircraft presense (both fixed and rotary wing) which occur both in phase A and phase B. The presence of both aircraft and boats have been shown to negatively affect baleen whales (e.g. Christiansen et al. 2013, Moore and Clarke 2002, Richardson et al. 1985). It could also be that the normal variation in the number of acoustically localized minke whales in 1 h observation intervals requires more hours of data than what is available for this study to fully represent the true variability of calling behavior when training is not occuring. Additional analyses of available data in other months that minke whales are present in Hawaii are planned to obtain better baseline information. Future data collection efforts will also focus on obtaining more data for before and after periods in attempt to better understand the impacts of US Navy MFAS training on whale behavior.

The use of standard statistical tests to compare the number of localized boing calling minkes violated some of the tests' assumptions. While the Mann-Whitney test is non-parametric and robust to matches in rankings, it does make assumptions that the data are independent and the variances similar. The independence assumption is of concern; if a minke whale is present in the study area at hour N, it is often also present and counted for other hours (e.g. N+1, N+2, …) for several hours or more in many cases. This could be handled by only counting the onset of boing bouts from an individual or by employing methods for dealing with the dependence of the observations (such as utilizing the autocorrelation of the observations). This is an area appropriate for future research. In spite of this concern, the number of localized minke whales were measured for all available data and the means and distributions of the before data were obviously different from that for the phase B periods.

CONCLUSIONS

The use of widely spaced, bottom-mounted hydrophone arrays to detect, classify, and localize marine mammals and assess behavioral responses to US Navy training activity, is a powerful tool and is planned to be pursued for other whale species (e.g. humpback, fin, sei, and Bryde's whales) using available PMRF data. The large number of hydrophones on US Navy ranges provides unique opportunities to not only detect, classify, and provide presense information, but to also localize individual whales in the area. This conceptually simplifies density estimation for vocalizing whales to a census type measurement which can be considered a lower bound of whale density. Tracks of localized individuals can also be generated automatically which further reduces manual analysis when analyzing recorded data for the numbers of whales present and also allows a true snapshot-type density analysis. These types of analyses are not typically possible with towed hydrophones or a handful of seafloor autonomous data recorders, and localizing individuals over relatively large areas and over long time periods is not possible for most species with directional and attenuating higher frequency vocalizations. In addition, the cost for analysis of the range hydrophone data is low given the large quantity of existing data and relatively low cost to record additional data in the future. This favors use of the US Navy range hydrophones for monitoring marine mammals on (and near) the US Navy range rather than conducting separate types of acoustic data collections requiring deployment of autonomous recorders or towing of hydrohones from ships.

In addition to providing minimum density estimates for minke whales, this analysis also documented a behavioral response of the estimated densities of calling whales related to US Navy training in the area. Previous studies of beaked whales with tags attached provide evidence that beaked whales depart an area during MFAS activity and later return (Tyack et al. 2011, DeRyuter et al. 2013). No similar data currently exists for minke whales, therefore it is not known if minke whales leave the area or simply cease calling. Finally, the one documented case of cessation of calling in response to a ship movement toward a minke whale indicates that cessation of calling may be attributable to more than just the presence of MFAS.

ACKNOWLEGEMENTS

The support of personnel at PMRF in obtaining recordings of acoustic data is invaluable as without the acoustic data this type of analysis would not be possible. Financial support for this analysis and supporting research was provided by Commander Pacific Fleet, (Julie Rivers), the Office of Naval Research (Dr. M. Weise) and the Test Resource Management Center's Test and Evaluation/Science & Technology Program through the U.S. Army Program Executive Office for Simulation, Training and Instrumentation under contract W900KK-13-C-0019. Any opinions, findings and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of others.

REFERENCES

Buckland, S., D. R. Anderson, K. P. Burnhanm, J. L. Laake, D. L. Borchers and L. Thomas. (2001). Introduction to distance sampling. Oxford University Press, Oxford, U.K.

Castellote, M., Clark, C.W., and Lammers, M.O. (2012). Acoustic and behavioral changes by fin whales (Balaenoptera physalus) in response to shipping and air gun noise. Biological Conservation. Vol. 147, issue 1, pp. 115-122.

Christiansen, F., Rasmussen, and M., Lusseau, D. (2013). Whale watching disrupts feeding activities of minke whales on a feeding ground. Mar. Ecol. Prog. Ser. 478, 239-251.

Darling, James D., Meagan E. Jones, and Charles P. Nicklin. (2006). Humpback whale songs: Do they organize males during the breeding season? *Behaviour* 143, 1051-1102.

DeRuiter, S.L., B.L. Southall, J. Calambokidis, W.M.X. Zimmer, D. Sadykova, E.A. Falcone, A.S. Friedlaender, J.E. Joseph,D. Moretti, G.S. Schorr, L. Thomas, and P.L. Tyack. (2013). First direct measurements of behavioral responses by Cuvier's beaked whales to mid-frequency active (MFA) sonar. Biology Letters, vol. 9 no. 4.

Evans, D.L., Hogarth, W.T, England, G.R., Livingston, S.M. and Johnson, H.T. (2001). Joint Interim Report Bahamas marine mammal stranding event of 15-16 March 2000.

Goldbogen, J.A., B.L. Southall, S.L. DeRuiter, J. Calambokidis, A.S. Friedlaender, E.L. Hazen, E.A. Falcone, G.S. Schorr, A., Douglas, D.J. Moretti, C. Kyburg, M.F. McKenna, P.L.Tyack.(2013). Blue whales respond to simulated mid-frequency military sonar. Proc. Roy. Soc. B., vol. 280, no. 1765.

Helble, T.A., Ierley, G., D'Spain, G.,L. and Martin, S.W. (submitted). Automated acoustic localization and call association for humpback whales on the Navy's Pacific Missile Range Facility.

Manzano-Roth, R.A., Martin, S.W., Matsuyama, B. and Henderson, E.E. (in process). Impacts of a U.S. Navy training event on beaked whale dives in Hawaiian waters.

Martin, S.W., Marques, T.A., Thomas, L., Morrissey, R.P., Jarivs, S., DiMarzio, N., Moretti, D. and Mellinger, D.K. (2013). Estimating minke whale (*Balaenoptera acutorostrata*) boing sound density using passive acoustic sensors. Mar. Mam. Sci. 29(1): 142-158.

Martin, S.W. and Kok, T. (2011). Report on Analysis for Marine Mammals Before, During and After the Feb 2011 Submarine Commanders Course training exercise, dated 08 September 2011.

McCarthy, E., Moretti, D., Thomas, L., DiMarzio, N., Morrissey, R., Jarvis, S., Ward, J., Izzi, A., and Dilley, A. (2011). Changes in spatial and temporal distribution and vocal behavior of Blainville's beaked whales (Mesoplodon densirostrius) during multiship exercises with mid-frequency sonar. Mar. Mamm. Sci. 27(3), 206-226.

Mellinger, D.K., Martin, S.W., Morrissey, R.P., Thomas, L. and Yosco, J.J. (2011). A method for detecting whistles, moans, and other frequency contour sounds. J. Acoust. Soc. Am. 129(6), 4055-4061.

Miller, PJO, Kvadsheim, P.H., Lam, F-P.A., Wensvenn, P.J., Antunes, Rl, Alves, A.C., Visser, F., Kleivane, L., Tyack, P.L. and Sivle, L.D. (2012). The Severity of Behavioral Changes Observed During Experimental Exposures of Killer (Orcinus orca), Long-Finned Pilot (Globicephala melas), and Sperm (Physeter macrocephalus) Whales to Naval Sonar. Aquatic Mammals. 38,4, p. 362-401.

Moore, S.E. and J.T. Clarke. (2002). Potential impact of offshore human activities on gray whales (*Eschrichtius robustus*), J. Cetacean Res. Manage 4(1):19-25.

Payne, R.S. and McVay, S. (1971). Songs of humpback whales. Science 173(3997), 585-597.

Rankin, S. and Barlow, J. (2005). Source of the North Pacific "boing" sound attributed to minke whales. J. Acoust. Soc. Am. 118(5), 3346-3351.

Richardson, W.J., Fraker, M.A., Würsig, B., Wells, R.S. (1985). Behaviour of bowhead whales (Balaena mysticetus) summering in the Beaufort Sea: Reactions to industrial activities. Biological Conservation 32, 195-230.

Richardson, W.J., C.R. Greene, Jr., C.I. Malme, and D.H. Thomson. (1995). Marine Mammals and Noise. Acadmenic Press , San Diego, CA.

Thompson, P.O. and Friedl, W.A. (1982). A long term study of low frequency sounds from several species of whales off Oahu, Hawaii. Cetology 45, 1-19.

Tiemann, C.O., Thode, A.M., Straley, J., O'Connell, V., Folkert, K. (2006). Three-dimensional localization of sperm whales using a single hydrophone. J. Acoust. Soc. Am. 120(4), 2355-2365

Tyack, P.L. (1981). Interactions between singing Hawaiian humpback whales and conspecifics nearby. *Behavioral Ecology and Sociobiology* 8.2: 105-116.

Tyack, P.L., Zimmer, W.M.X., Moretti, D., Southall, B.L., Claridge, D.E., Durban, J.W., Clark, C.W., D'Amico, A., DiMarzio, N., Jarvis, S., McCarthy, E., Morrissey, R., Ward, J. and Boyd, I.L. (2011). Beaked whales respond to simulated and actual Navy sonar. PLoS ONE 6(3), 1-15.

Watkins, W.A. (1986) Whale reactions to human activities in cape cod waters. Mar. Mam. Sci. Vol 2, Issue 4, pp 251-262

Ward, J.A., Thomas, L., Jarvis, S., DiMarzio, N., Moretti, D., Marques, T.A., Dunn, C. and Claridge, D. (2012). Passive acoustic density estimation of sperm whales in the tonge of the ocean, Bahamas. Mar. Mamm. Sci. 28(4), 444-455.

Wenz, G.M. (1964). Curious noises and the sonic environment in the ocean. Pages 101-119 in W.N.Tavolga, ed. Marine bioacoustics. Volume 1. Pergarmon, New York, NY.

Zerbini, A. N., J. M. Waite, J. L Laake and P. R. Wade. (2006). Abundance, trends and distribution of baleen whales off Western Alaska and the central Aleutian Islands. Deep-Sea Research I 53:1772–1790.

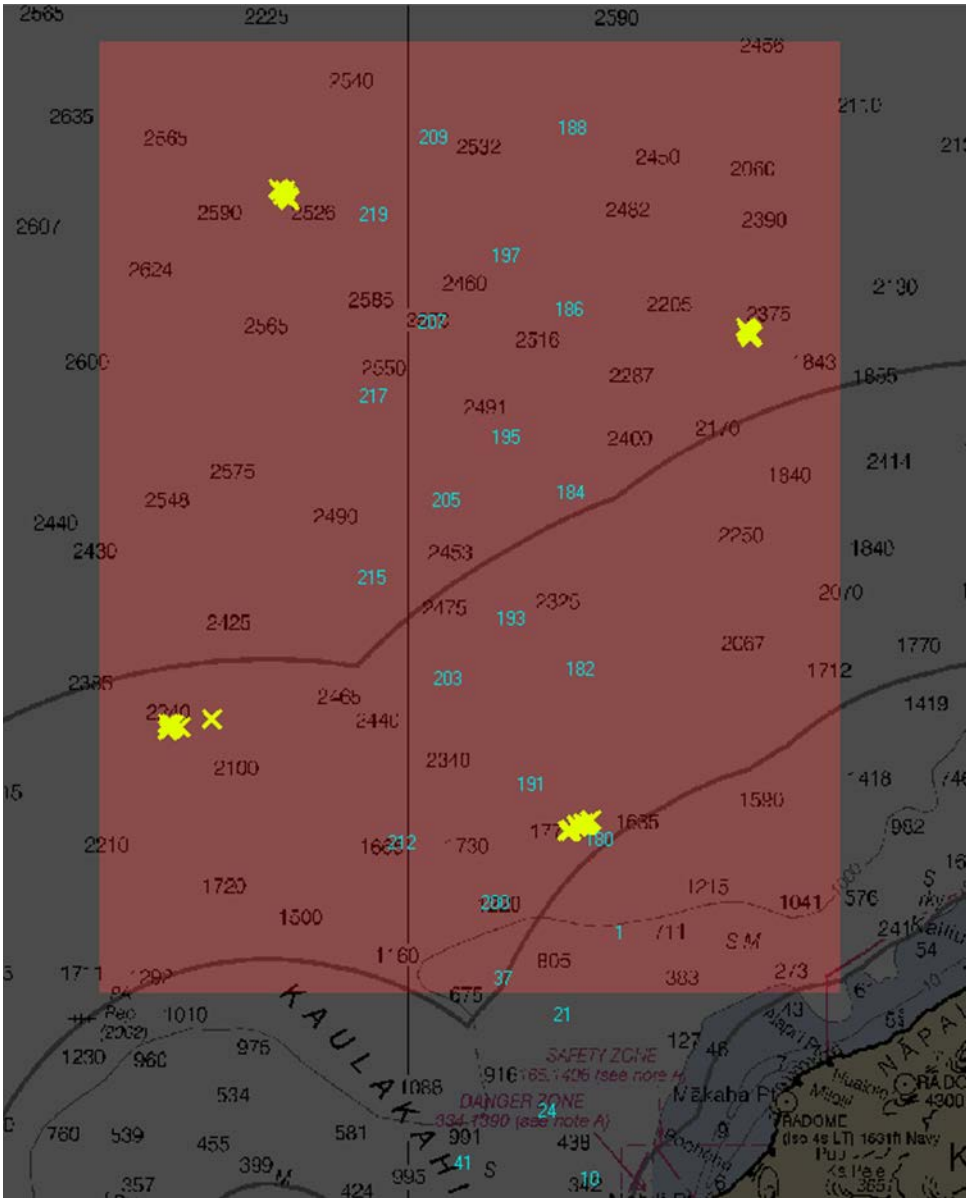

Figure 1. Display showing a chart view of the region with the 3,780 km^2 study area indicated in red. The Napali coast of the Island of Kauai is located in lower right. Blue numbers represent approximate locations of the 24 range hydrophones utilized in the analysis. Yellow X symbols indicate localizations of four minke whales (each containing from 7 to 11 separate localizations) for the 1 h period ending at 12:00 GMT on 11 February 2012.

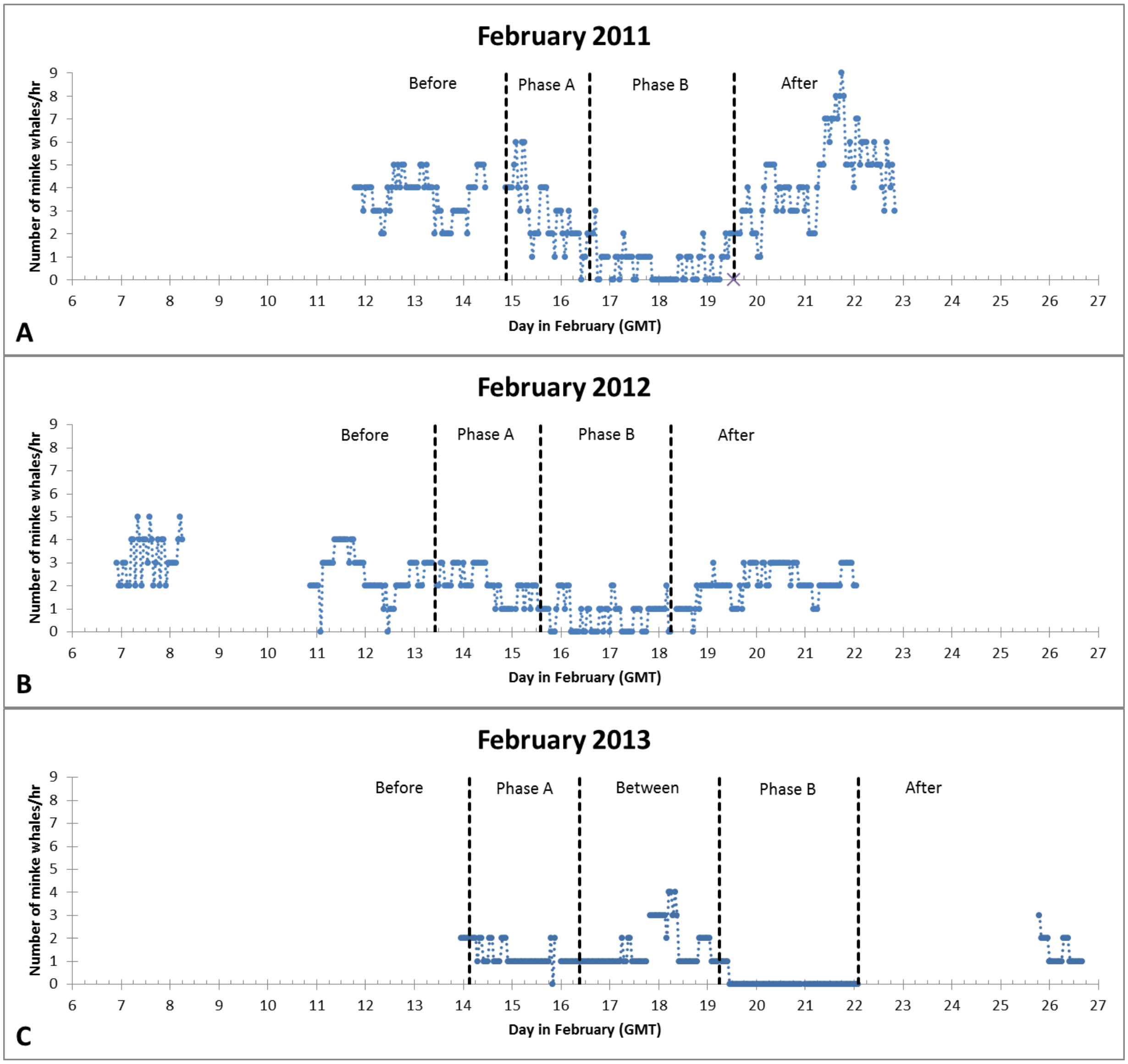

Figure 2. Number of minke whales acoustically localized in the study area in 1 h bins for February 2011 (A), 2012 (B), and 2013 (C). Labels on each figure represent the periods of time associated with the US Navy training activity (before, phase A, between, phase B and after). Blank periods indicate recorded data is not available.

		Before	**Phase A**	**Between**	**Phase B**	**After**
Feb 2011	N (# 1 h periods)	65	42	NA	70	78
	min density of minke whales per 3,780 km^2: $\hat{n}$ (CI)	3.64 (3.31-4.01)	2.81 (2.31-3.42)	NA	0.69 (0.27-1.8)	4.44 (4.04-4.88)
Feb 2012	N (# 1 h periods)	94	51	NA	64	89
	min density of minke whales per 3,780 km^2: $\hat{n}$ (CI)	2.77 (2.41-3.18)	2.04 (1.65-2.52)	NA	0.70 (0.28-1.76)	2.08 (1.73-2.5)
Feb 2013	N (# 1 h periods)	5	52	67	67	22
	min density of minke whales per 3,780 km^2: $\hat{n}$ (CI)	NA	1.21 (0.84-1.75)	1.58 (1.14-2.19)	0.06 (0.001-4.63)	1.409 (0.93-2.12)

Table 1. Estimated densities of calling minke whales with 95% confidence intervals and number of hours of effort in the study area of 3,780 km^2 offshore of Kauai, Hawaii by year for the months of February during the

various periods of time relative to the SCC training event.

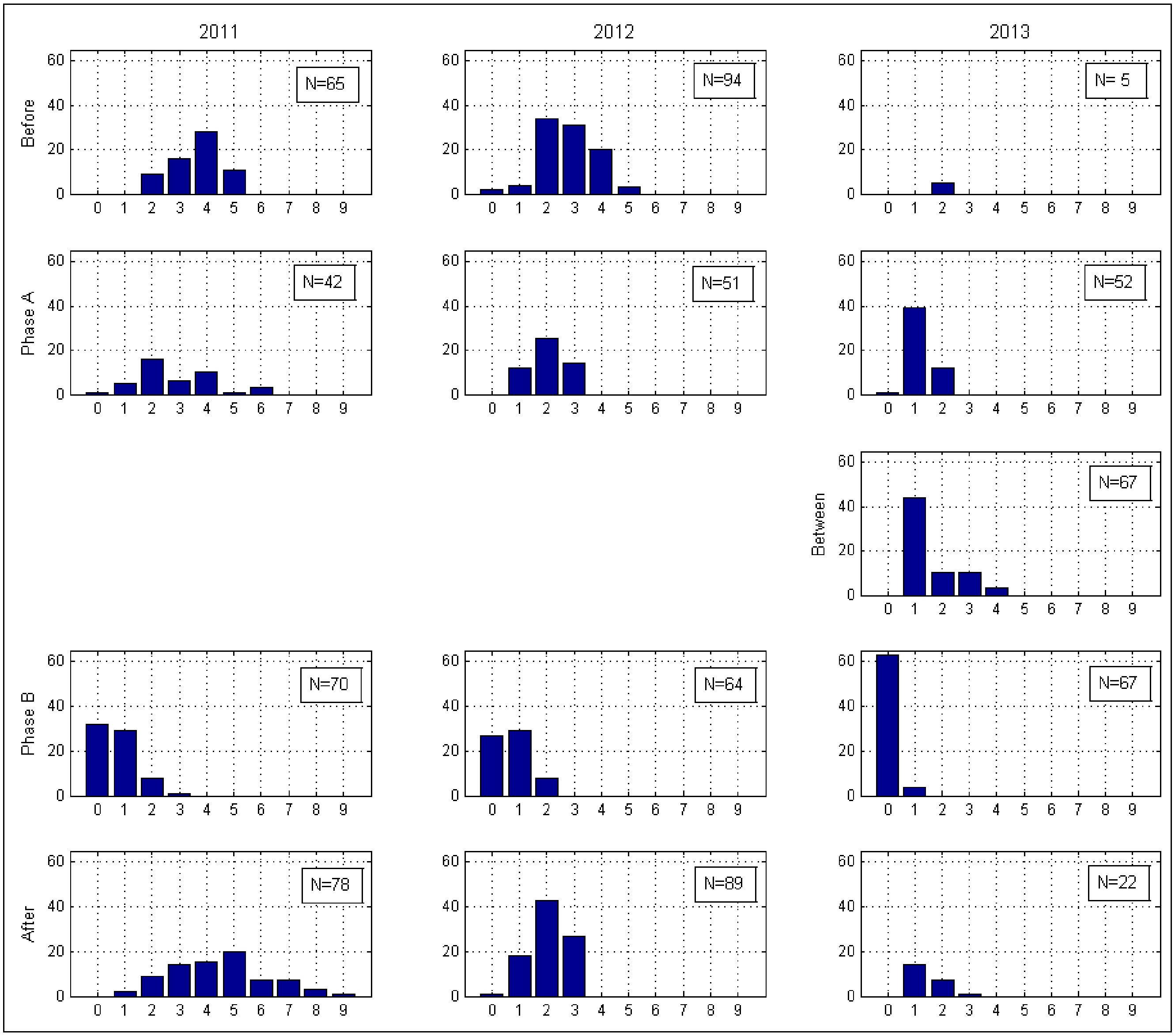

Figure 3. Historgrams of the numbers of individual minke whales localized (min 0 to max 9) in 1 h observation intervals by year and periods of time relative to training (i.e. before, phase A, between, phase B, after). Plots have same scales for easy comparison of shapes of the distributions with the number of hours (N) insert in upper right of each histogram. Before periods represent a nominal baseline for 2011 (65 h) and 2012 (94 h) while 2013 has only 5 h of data which is not useful for a baseline. Phase B distributions show clear shifts to the left showing fewer numbers of minke whales localized in 1 h observation intervals.