APPENDIX J Report on passive acoustic analysis for marine mammals before and after the Submarine Commanders Course training exercise at PMRF Feb 16-19, 2010

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Executive Summary:

This report provides passive acoustic evidence of the presence of beaked and minke whales on the Pacific Missile Range Facility (PMRF) instrumented acoustic range (BSURE and BARSTUR) before and after the Feb 2010 Submarine Commanders Course training event (SCC). The effort focuses on these species utilizing automated species passive acoustic detection and classification algorithms. Manual verification of selected automatic detections was performed to confirm presence of the species under investigation. Results indicate presence of beaked whales (BW), suspected to be Blainville's and Cuvier's (*Mesoplodon densirostris and Ziphius cavirostris* respectively) and minke whales (*Balaenoptera acutorostrata*) before and after the SCC on the PMRF range. While data does show a lower number for the POST versus the PRE periods, it is not clear if the differences are due to the exercise or normal variations.

Introduction:

Passive acoustic monitoring (PAM) for marine mammal species is a technology undergoing rapid change, with significant progress in areas of detection, classification and density estimation for various species. Density estimation is a pivotal area as it is defined as the number of animals per unit area. Understanding the normal variation of the densities for marine mammal species that frequent US Navy ranges is important to understanding potential impacts due to US Navy exercises. Without this baseline information, both short and longer term impacts from sonar operations can be difficult to determine and acoustic density estimation techniques are a promising tool to aid in this understanding.

Recent progress in acoustic density estimation of vocalizing marine mammal species includes demonstrated methods for estimating Blainville's beaked whale species density (Marques et al. 2009) at the Atlantic Undersea Test and Evaluation Center (AUTEC), located in the Bahamas. This method utilized cue counting (beaked whale echolocation clicks were the cues) and relied on data from acoustic tags attached to whales for obtaining other required parameters such as the probability of detection as a function of distance, and the foraging echolocation click cue rate. Both cue counting and dive counting methods for Blainville's beaked whale density estimation has also recently been reported for data collected before, during, and after a mid-frequency sonar exercise at AUTEC (Moretti et al., 2010).

Passive acoustic data from the Pacific Missile Range Facility (PMRF) has been utilized in demonstrating techniques to study the density of minke whales by virtue of their boing vocalization. These studies use data collected in the winter and early spring in 2006 and 2007 (Marques et al., 2010 and Martin et al., in preparation). The methods also utilized cue (minke boing vocalization) counting methods, but did not require tagging of animals to arrive at the probability of detection as a function of distance. Spatially explicit capture-recapture methods were applied to the acoustic cues to derive the probability of detection function.

Application of these density estimation methods referenced above currently require significant manual verification effort, which is beyond the scope of this study. However, advances are being made to reduce the amount of manual effort involved, and it is feasible that in the not too distant future, density estimate capability for some species will be possible with relatively low effort in terms of cost and time.

This report provides results of an analysis of acoustic data before and after the SCC operation at PMRF conducted 16-19 Feb 2010. The analysis is focused on beaked whales and minke whales using automation tools recently developed for these species. These species are also ideally suited for acoustic study due to the difficulty in visually sighting them in Hawaii in the winter and early spring due both to availability bias (animals spending limited time at the surface), and difficulty detecting the species (small blows, limited body out of water when at surface, rough sea state). There are other species detectable in the passive acoustic data, such as humpback whales via their song, and sperm whales via their echolocation clicks. Vocalizations from other species of marine mammals are also present in the acoustic data (e.g. whistles and echolocation clicks from undetermined species). Significant efforts have not been directed at these other species in the area to date for a variety of reasons (e.g. humpbacks are too distant from the sensors for distance sampling density estimations, and reliably detecting the smaller Odontoceti species acoustically is not as advanced as it is for the species involved in this study).

Methods:

Acoustic data collection

A personal computer based data acquisition system was installed at PMRF in 2002 for the express purpose of collecting raw passive acoustic data from the 24 broadband hydrophones at PMRF (many other hydrophones are available but most are high pass filtered and not suitable for studies at frequencies below ~10 KHz). The data collection system records the hydrophones continuously, saving data as files representing 10 min of data with no gaps between the end of one file, and the start of the following file. The system was modified in 2006 to increase the sample rate to 96 kHz and again in 2007 to record 7 additional high pass filtered hydrophones, both modifications done explicitly in order to improve the probability of detecting beaked whale echolocation clicks. Figure 1 shows a Google earth map of the approximate location of the hydrophones utilized in this analysis. The fifteen farthest offshore hydrophones (i.e. those labeled with numbers from 44 to 60) were utilized for minke whale analysis, while the remainder of the hydrophones shown were utilized for beaked whale analysis. The current data collection system was limited to 31 hydrophones of data: the additional seven were selected for depths where beaked whales are often found, and compliment the broadband hydrophones spatial coverage, albeit in two areas only. The depths of the hydrophones utilized for the minke analysis range between 3.5 km to 4.8 km, while the depth of the hydrophones used for the beaked whale analysis ranged from 600m to over 1.8km. Calibration data is currently not available for the hydrophones utilized in the analysis, so amplitudes are relative vice absolute.

The data set for this analysis consisted of a total of 126.1 hr for the 28 hydrophones shown in figure 1 for the following periods: PRE SCC 80.8 hr starting at 14:59 HST on 12 Feb 2010 and concluding at 23:40 15 Feb 2010; and POST SCC 45.3 hr of data collected after the SCC training event and between 03:04 HST 20 Feb 2010 and 00:20 on 22 Feb 2010.

The hydrophone spacing is such that one can NOT guarantee detecting beaked whale dives on the range given expected maximum detection ranges of 4km to 6km (Zimmer et al., 2005; Marques et al., 2009, respectively). On the other hand, if minke whale boing vocalizations are of sufficient level (e.g. on the order of 150dB re: μ Pa) for animals in the BSURE instrumented range area, it is assumed that the sound will be detected by bottom mounted hydrophones.

Acoustic data automated processing Beaked Whale

Both Blainville's and Cuvier's beaked whales have been sighted at the PMRF underwater range area by Dr. J. Mobley during various aerial surveys conducted from 2002 through the present. These species echolocation clicks have been identified in publications (e.g. Zimmer et al., 2005; Johnson et al., 2006). A hallmark of these clicks are that they exhibit a frequency upsweep characteristic in their approximately 0.3 millisecond duration, which makes them distinct from many other species clicks that do not show appreciable frequency sweep. The dive behavior for these two species near the big Island of Hawaii has also been documented (Baird et al., 2006). It is estimated that the acoustic detection of dive vocal time (time an animal emits foraging clicks during a dive) can range from as low as 10 min to as high as 40 min when utilizing 10 min binned data, as in this study. Also, the time between dive vocal periods (from one dive to another) can range from 2 hr to over 3.5 hr. Data from Cross Seamount, located in near Hawaiian waters, (McDonald et al., 2009) shows some clicks on the order of 1 ms in duration that also exhibit frequency upsweep covering a very broad band (potentially band limited by the recordings limitation of 192 kHz sample rate). The inter-click-intervals from Cross Seamount data also show much shorter periods than those reported for both Cuvier's and Blainville's.

An automated beaked whale echolocation click detector (Martin, 2008) implemented in Matlab (Mathworks Inc., Natick, MA USA) processes recorded data for clicks that exhibit frequency modulation characteristics within 0.5 ms decision intervals. The detector purposely does not make a distinction between clicks from Cuvier's or Blainville's beaked whales; in fact, it was designed to be generic in detecting clicks with frequency upsweep as so little is known of beaked whale echolocation clicks for the majority of the species. In a check of the generality of the beaked whale click detector, the Cross Seamount click data was obtained and re-sampled to simulate originating from a PMRF sensor (first order approximation by bandwidth limitation and re-sampling at 96 kHz). Processing 5 min of the modified Cross Seamount data (file Apr09_06_12_39_28.wav) resulted in 636 click detections of which 81 were classified as being from BW which is qualitatively consistent with McDonald et al. 2009.

The automated beaked whale detector reports the time of detection, hydrophone designation per detection, along with several of the features utilized in the decision. Plots are automatically generated for each hydrophone's detections over the analysis time using 10 min non-overlapping windows. These plots are reviewed to find areas where there are reported beaked whale echolocation clicks that correlate with reported dive vocal periods. The dive vocal period is represented by calls grouped between 1, and up to 4, contiguous data points (representing 10 to 40 min time periods) with no beaked whale click calls reported before, or after, these detections. This is done to isolate potential areas of actual beaked whale clicks based upon reported dive vocal intervals for further investigation. Each of the potential beaked whale call periods (potential dive vocal periods, or dives) identified in this manner are then manually investigated using adobe audition plots of the time series and spectrogram. Numbers of manually validated beaked whale echolocation clicks and validated dive vocal periods are tallied. One validated dive vocal period can have very few validated clicks (when the animal is at long distances from the hydrophones with low probability of detection) to hundreds of clicks if the animal is in close proximity to a hydrophone. Summary plots for each hydrophone's manually validated beaked whale detections (in 10 min periods) are generated. A count is tallied of each valid dive vocal period, with at least 10 clicks present in the 10 min period over the 13 hydrophones utilized in the analysis, and normalized by the number of hr analyzed, to arrive at an average beaked whale dive vocal period per hr. This period, and the average number of validated beaked whale clicks detected per hr, then serve as single numbers to compare the before and after exercise activity in terms of beaked whale activity. The final 45.3 hr of the PRE exercise data is also reported separately in order to equalize the POST analysis efforts.

When dive vocal intervals also exhibit longer duration patterns of repeating from 2 hr to 3.5 hr the longer duration patterns then match known characteristics of Blainville's and Cuvier's inter-dive vocal periods, which reinforces the hypothesis that the clicks detected are from beaked whales. However, due to the sparse spacing of the hydrophones in this study relative to the expected detection distance for the beaked whale clicks, not all dives are expected to be detected. Inter-detection-interval histograms are also plotted for data with manually validated beaked whale dive vocal periods to compare with beaked whale inter-foraging click-interval values expected from the literature.

Acoustic data automated processing Minke whale

A Matlab based implementation (Morrissey et al. 2009) minke boing detector based upon a generic Ishmael tonal detector (Mellinger et al 2010) was modified and employed for detecting minke boing vocalizations for the fifteen hydrophones in the analysis. This detector is based upon frequency peak detection and tracking over time in the 1350Hz to 1440Hz spectral band. The raw data corresponding to 0.68 sec before the detection (pre-trigger from detection reported time), for 2.73 sec is processed to generate a spectrum with 0.73 Hz bin resolution which captures the majority of energy in a boing. The frequency of the bin with the maximum amplitude is reported as the boings dominant signal component (DSC) in this band. The maximum relative amplitude, in dB, is reported for each boing, as well as the peak signal to average level over the detection band (a value obtained automatically from detection data serving as a proxy for a signal to noise level but not requiring manual validation of noise segments).

The modified Matlab boing detector operates at a different operating point from the previous Matlab and Ishamel versions which have been characterized. Effort is underway to characterize this detectors probability of detection (P_d)vs. distance at this operating point, along with its probability of false positive (P_{fa}). The unmodified Matlab detector was previously characterized as having a 0.79 P_d with a 0.2 P_{fa}. The detector employed for this automated analysis is very similar but has slightly different parameter set.

The dominant (or peak) frequency of the signal in the detection band is an important feature which not only helps associate the same boing as received on the spatially separated sensors, but also may help identify individual whales. This frequency feature has been previously found to be stable for what is believed to be one individual over a several hour period (N=55, mean freq=1384.4 Hz, se=1.55Hz).

Automated detection of boings is the first stage of automatic processing and results in all automated detections being logged. The next step of automated processing automatically removes redundant reports of the same boing on individual hydrophones due to effects such as multipath arrivals and detector segmentation of single boings into multiple boing reports. This step is necessary in utilizing spatially explicit capture recapture processing for boing density estimation. The effect is a reduction in the overall boing detection counts. An automatic association of boing reports across all hydrophones to correspond with a single boing emitted in the water is then performed. An optional manual process utilizing experienced human operators verifies all detections and associations – the result of which is termed "validated associations". A localization process is currently under investigation using associated boings (manually validated or not). The localization process limits the signal to higher levels (eg. above a threshold of 65dB relative), thereby reducing detections from weak or distant sources. A requirement of having four detections representing both north-south lines of hydrophones is currently utilized. The localization process also integrates localization results over time such that locations with actual vocalizing whales will reinforce, while erroneous localizations (from various error sources) will not reinforce over time. This last process takes advantage of the fact that a minke whale producing boing bouts tends to emit calls repeatedly over several hours.

Automated boing detections are binned into one hr, non-overlapping, periods for each hydrophone. The boing count per hour data are then averaged over the 15 hydrophones and plotted vs. time as mean boings per hour over the PRE and POST SCC periods. The mean and standard deviation of the boing rate per hour was also calculated for each hydrophone

RESULTS

All 126.1 hr of data available for the PRE and POST SCC periods has been automatically processed for the 13 hydrophones used in the beaked whale analysis and 15 hydrophones utilized in the minke analysis.

Beaked whale

Figure 2 provides an example of an automatically detected and manually verified single beaked whale echolocation click, the frequency sweep is evident in both the time series and the spectrogram. Although no attempt was made to differentiate Blainville's clicks from Cuvier's clicks in the manual validation process it was noted that some click envelopes have more of a Gaussian shape and are suspected of being from Blainville's whale, while other clicks had distinctive envelopes that were more rectangular during the onset, these clicks are suspected of being from Cuvier's whales. Similar characteristics have been observed in published figures (Zimmer 2005, Moretti 2010).

Figure 3 provides sample plots of numbers of beaked whale automatically detected clicks in 10 min temporal segments vs time for three separate hydrophones for part of the PRE SCC period. The two upper traces show characteristics which fit with beaked whale vocal behavior and inter-dive intervals. The lower trace provides an example of automatic detections, between approximately 1000 and 1500 on Feb 14 which were not manually validated due to not meeting the criteria for being called dive vocal periods. While there are four areas which do have counts of 10 or more detections in the lower trace, the detections do not go to zero between them. It is possible that beaked whale clicks are present among other odontoceti species and incorrectly rejected using this logic, which would result in an under-estimate of the number of beaked whale echolocation clicks and dive vocal periods.

Figure 4 provides a sample time series plot of 4.5 sec of data from a period validated as beaked whale dive vocal activity. This figure shows inter-click-intervals (ICI's) consistent with published data for beaked whales (Tyack 2006), as well as, potential head scanning evidenced by the varying peak levels of individual clicks in the click train. Figure 5 shows a sample histogram of inter-detection-intervals for ten min of data with validated beaked whale clicks. The histogram shows a peak at 0.29 sec with a range of about 0.22 to 0.32 sec for occurrences greater than 15. Figures 4 and 5 illustrate examples of temporal inter detection, or click, intervals which are consistent with values reported in the literature reinforcing the hypothesis that the validated dive vocal periods do represent foraging dives from beaked whales.

Figure 6 shows a plot of the number of manually validated BW dive vocal periods, or dives, for the PRE SCC 80.8 hr period from 12 Feb 15:00 to 15 Feb 23:50 for the 13 hydrophones used in the beaked whale study. A threshold of 10 clicks is applied and all remaining continuous 10 to 40 minute periods (1 to 4 data points) are summed to represent dive vocal periods, which is 21 in the PRE SCC period of 80.8 hr. Hydrophone # 37 is seen to account for 10, of the 21 total dive vocal periods (or BW dives) detected, however only 3 of these occurred in the last 45.3 hr of the PRE SCC timeframe. Note that for the last 45.3 hr of the PRE period, the number of dive vocal periods detected is 14. In some instances, such as at 15 Feb 15:40 for sensors # 1 and # 133 in figure 6, two dive vocal periods are counted. This could actually be from the dive of a single group of beaked whales, as the two phones are slightly less than 3 km from one another and could potentially detect individuals from the same group during a group dive. Figure 7 shows a similar plot for the post SCC 45.3 hour period which is slightly greater than half of the PRE SCC total period with a total of 14 dive vocal periods.

	PRE SCC total	PRE SCC first 45.3 hrs	PRE SCC last 45.33 hrs	POST SCC 45.3 hrs
Total time analyzed (hrs)	80.83	45.3	45.3	45.3
Validated BW dive vocal periods	21	8	14	14
Validated BW dive vocal periods/hr	0.260	0.177	0.31	0.31
BW clicks detected in val. dives	10,098	3,839	6,643	2,356
BW clicks detected clicks per hr	125.7	84.7	146.6	52.0
BW clicks detected per dive	459	474.5	479.9	168.3

Table 1 – Summary of manually validated automatic beaked whale echolocation click detections and dive vocal periods as defined in text for 13 hydrophones over periods analyzed.

Table 1 summarizes the PRE and POST SCC manually validated dive vocal periods, dive vocal periods per hour, and numbers of clicks detected in valid dive vocal periods (total, per hr and per dive). The table shows the PRE SCC period in three ways, the total 80.8 hrs, and the first, and last, 45.3 hr periods in order to equal the POST SCC effort time. By dividing the PRE SCC period in this manner, there is an overlap of some 10 hr of data. Two dives in the first 45.3 hrs of the PRE SCC period had over 1,000 detected clicks in each dive, two dives in the second 45.3 hrs of the PRE SCC period account for over 2,500 detected clicks, while the largest number of clicks detected in any

POST SCC dive was 699, with the second highest count being 168. This shows the variability possible when the hydrophones do not provide full spatial coverage: the number of dives detected, dive vocal periods, and clicks per dive, and are highly dependant upon the distance from the sensors to the vocalizing whales. The data do show reduced BW click counts, counts per hour, and clicks per dive vocal period for the POST as compared to the PRE periods.

The main purpose of this analysis is to show, with a high degree of certainty, that beaked whales are indeed present at PMRF before, and after this exercise in Feb 2010.

Minke whale

Figure 8 shows a typical minke whale boing time series and spectrogram as received on PMRF bottom hydrophones. Higher frequency components are present, but not shown. The detector detects only in the frequency band of 1350 Hz to 1440 Hz. Figure 9 shows an example of 16.7 hr of data from the POST SCC period, of a histogram of the detections dominant frequencies (one value per detection). The histogram shows an overall bimodal distribution, and fine details suggest multiple individual animals within each major frequency region.

PRE SCC Mean Boing Rate per Hr

Phone	Mean	Std Dev
44	39.91	26.73
45	55.14	38.33
46	59.88	42.21
47	75.80	44.40
48	86.1	46.42
49	86.85	50.19
50	91.92	43.79
51	88.16	42.04
53	24.99	24.02
54	56.57	35.80
55	61.12	40.65
56	68.30	36.44
57	67.24	40.64
58	88.71	51.77
60	91.85	43.32

Average of means: 69.50

POST SCC Mean Boing Rate per Hr

Phone	Mean	Std Dev
44	46.62	22.74
45	57.53	24.57
46	72.31	31.27
47	99.89	41.19
48	92.53	39.76
49	93.73	39.61
50	97.56	38.24
51	100.78	43.38
53	28.42	14.88
54	66.24	32.77
55	72.53	36.31
56	85.47	42.23
57	83.73	42.30
58	108.96	50.46
60	96.38	42.71

Average of means: 80.18

Table 2 – Summary of automatic minke boing detection count, mean and standard deviation, for 15 hydrophones over the PRE (left column) and POST SCC periods (right column).

Automatic boing detections from the 15 hydrophones totaled 83,614 boings in the PRE period and 54,316 boings in the POST period. Figure 10 shows the PRE SCC minke whale automatic boing detections per hour averaged over all 15 sensors for the 80.8 hr. This is for the raw boing detections without additional processing (i.e. multipath, and segmentation, removal; associations; manual verification; and localization). The data shows a great deal of variability over time, with a strong peak of 200 mean boings per hour at 10:00 on 13 Feb and lowest values around 03:00 on 15 Feb (around 20 mean boings per hour). Figure 11 shows a similar plot for the POST SCC, which starts at lower values (~20) and whose peak is around 143 mean boings per hr. Table 2 provides the means, and standard deviations, of the boing detections per hr across hydrophones for each of the PRE and POST periods, along with the average of the means across hydrophones.

Figure 12 shows a plot of the mean boing rate per hr for each of the 15 hydrophones utilized over the PRE and POST full hour periods, which corresponds to the means shown in table 2.

Early results for automatically localizing minke whales boing source locations suggests the number of individual vocalizing minke whales in the area at any time, and potential tracking of individual animals over time. Samples of these early localization results are shown in figure 13 showing automatic localization results for two time periods during the PRE SCC separated by 4 hrs 49 min in time. Evidence of three individual whales are seen in the left panel and four in the right panel from the later time period.

Discussion and Conclusions:

This analysis illustrates the type information possible using automated passive acoustic detection and classification processing for marine mammals from the US Navy instrumented range hydrophones. The analysis focused on minke whales and beaked whales using existing automation tools. These species are good candidates for passive acoustic monitoring due to the difficulty of visual sighting them, as witnessed in the low number of these species sighted in the area given appreciable effort from both US Navy personnel (lookouts) and trained observers both on surface and aerial platforms.

This analysis shows, with good confidence, that there were beaked whales, and minke whales, present in the area before, and after, the SCC training exercise. No data was recorded during the actual operation, so nothing can be said for that period. Furthermore, as the normal variations in the number presented here are unknown, it is not possible to say with any confidence if the numbers convey any statistical significance related to effects of the SCC exercise. If one were to have recorded data during the SCC training event, one may have seen statistically significant changes. The limited number of hydrophones utilized in the beaked whale study under-samples the area spatially and can not guarantee detecting a group of diving beaked whales, this hinders detailed analysis for this species. However, it is possible to process large numbers (dozens to hundreds) of range hydrophones in order to ensure detecting groups of diving beaked whales over large areas of the instrumented range.

The number of beaked whale clicks (table 1: det in val. dives, det per hr, and det per dive) indicate lower numbers for the POST SCC period over all three PRE SCC periods shown. The number of beaked whale clicks detected is highly dependant upon how close to the hydrophones the beaked whale group is when diving. The number of detected dives a better metric, and shows how normal variation can impact the results. While the number of beaked whale dives (dive vocal periods validated) in the POST period is the same as that for the last 45.3 hrs of the PRE SCC, it is lower than the first 45.3 hrs of the PRE SCC. This highlights the need to better understand normal variations of beaked whale dives before arriving at conclusions based solely on PRE and POST analysis relative to the exercise between the time periods.

In FY11, the Naval Undersea Warfare Center (D. Moretti and R. Morrissey) will be installing a Marine Mammal Monitoring on Navy Ranges (M3R) system at PMRF. This will allow a more thorough investigation for beaked whales using dozens more hydrophones and potentially guaranteeing detection of beaked whale group dives in large areas of the instrumented range, such as has been done both at AUTEC and SCORE. Dive counting has been shown (Moretti et al. 2010) to have lower variance in density estimation for Blainville's beaked whales at AUTEC. There are additional benefits to using dive counting, such as it alleviates the need to manually validate all click detections, one only has to validate some detections in a dive. However to obtain density, the group sizes need to be known. Baird (Baird et al. 2006) has published group sizes for Blainville's and Cuvier's species off the Kona coast, employing Kona coast data would make more sense at PMRF than the group size estimates for other areas such as the Bahamas, southern California and the Canary Islands.

It appears that once it is known what to look for acoustically for specific marine mammal species, we discover they are present in larger numbers, even on US Navy ranges, than previously known. The data from AUTEC suggests that Blainville's beaked whales regularly use the area to forage, and either go quiet, or leave the area, when mid frequency sonar exercises occur, and that they either return, or resume vocalizing, after the operation has completed. It is uncertain which species of beaked whales are represented in this analysis (suspect both Blainville's and Cuvier's species due to some frequency content and signal envelope differences). Without having data for the SCC exercise, one can only speculate as to the impact of the exercise on beaked whale dive vocal behavior at PMRF. For beaked whale analysis, having more sensor data is clearly desirable for a more complete analysis. Efforts at the southern California offshore range (SCORE) may have parallels with PMRF relative to Cuvier's species. We have very little knowledge of the many other species of beaked whale and their associated acoustics, some of which may be present at PMRF.

This study shows the presence of boing vocalizing minke whales for both the PRE and POST SCC periods in terms of the automatic minke boing detections per hour using 15 hydrophones. While there is some evidence of potentially suppressed boing rates (i.e. the first 10 hr of the POST SCC period where rates steadily rise from a low initial value), a similar situation existed in the final portion of the PRE SCC period (~04:00 to 14:00 15 Feb). The large variations in boing rates observed in both the PRE and POST SCC periods needs to be better understood before arriving at conclusions relative to effects of the exercise. The use of the localization tool suggests the peak in boing rate at 11:00 13 Feb (PRE SCC) could be the result of boing rates much more rapid than normally observed when two minke are in close proximity to one another. The boing rate by hydrophone (figure 12) also shows large variations with indication of a depth relationship given that hydrophones 44 and 53 are the shallowest in the boing analysis. The use of fine resolution frequency content of the boing detection shows promise in helping isolate individuals. Density estimation of the minke boing density is possible; however the cue rate for converting to vocalizing minke whales is currently unknown. The FY9-10 ONR effort (Norris et al.) may provide insight into the boing rate for PMRF utilizing an acoustic surface line transect study in conjunction with analysis of the PMRF hydrophones for the same time period. The amount of manual effort involved in estimating minke boing density using existing techniques is currently beyond the scope of this effort, however less manually intensive methods to perform acoustic density estimation for minke whales (potentially applicable to other species) are under investigation which could developing a baseline for minke whale (boing) density over several years using currently available PMRF data.

The effort to automate localizations of the automatic boing associated detections is showing promise. This effort is capitalizing off the fact that boing vocalizing minke whales typically are producing fairly regular boing rate bouts for multiple hours by integrating boing localizations over time. When estimated animal locations cluster in space and time, it is reasonable to believe an animal is in that area producing the boings that are being detected, associated and localized. Incorrect localizations occur for a variety of reasons: false positive detections, erroneous associations, and boing detection time errors relative to actual boing start times. However, incorrect localizations typically do not reoccur in space and time, and are observed as outliers when observed over multiple hours. This automatic localization effort is exciting as it can reduce Terabytes of multiple days of raw acoustic data, to a few hours of processed products, all done automatically with minimal labor effort involved. An analyst then only needs to manually review for localizing minke whales present on the range by viewing the processed products, and can potentially simply count vocalizing minke whales.

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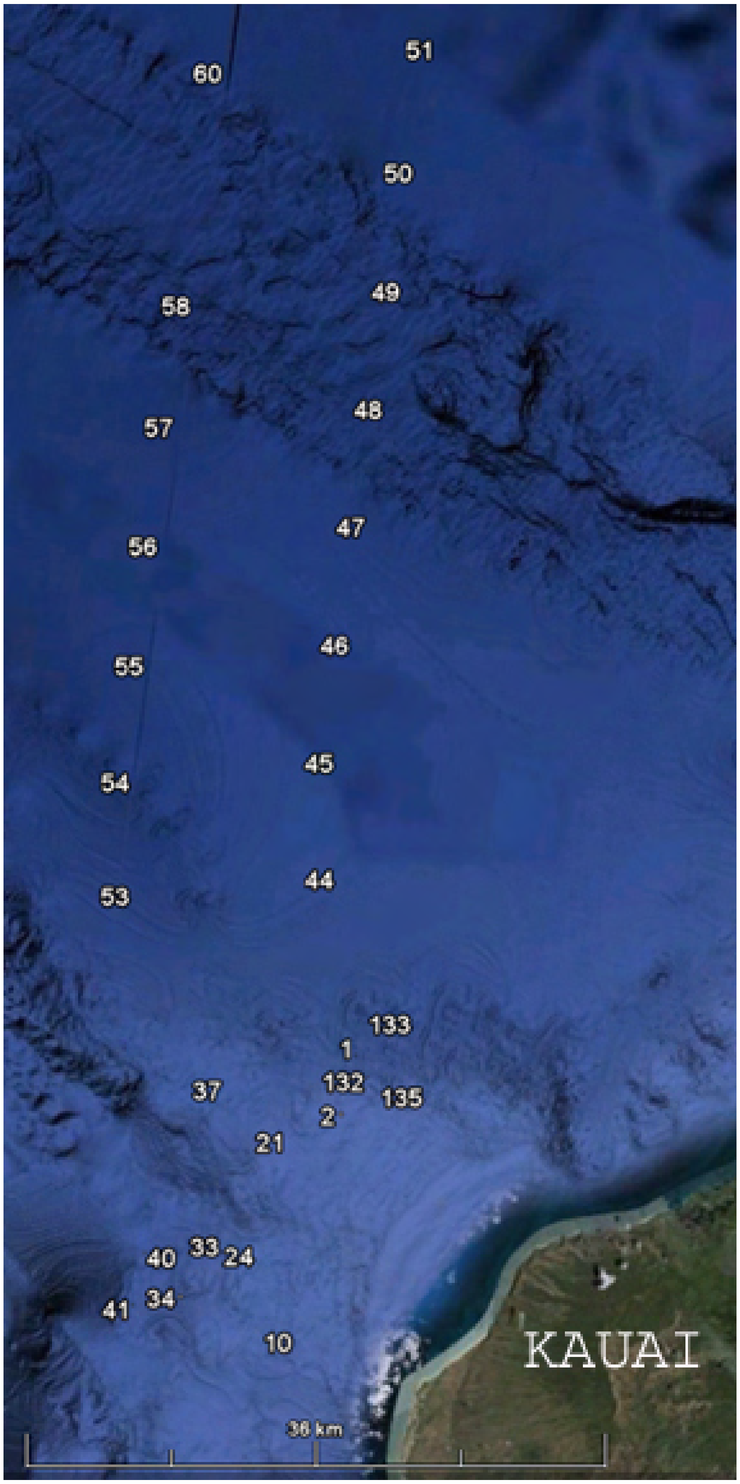

Figure 1 – Approximate location of hydrophones utilized in Pre, and Post, SCC acoustic analysis (true north up). Fifteen hydrophones (44-51 and 53-60) utilized for minke whale boing analysis. The thirteen other phones shown are utilized for beaked whale echolocation analysis.

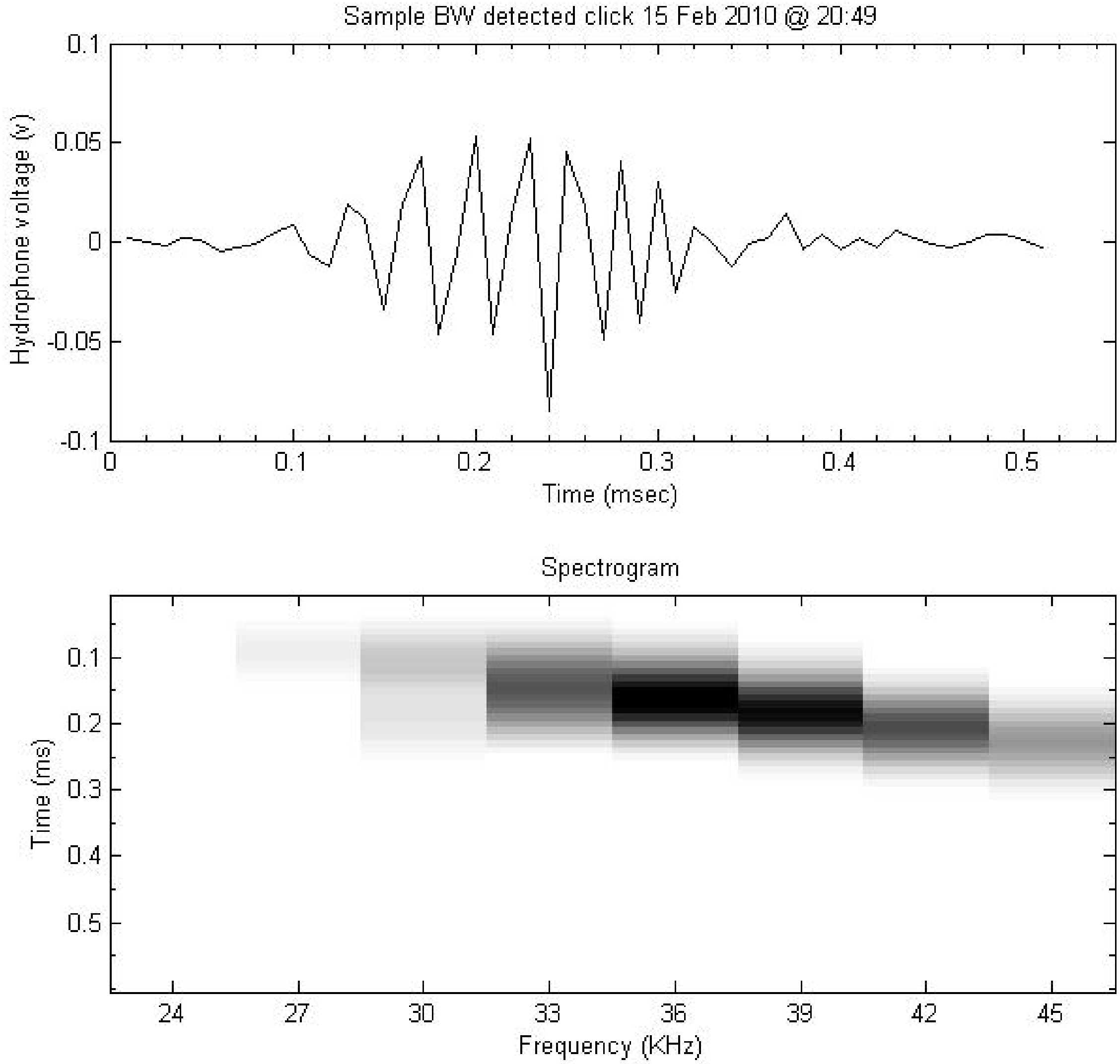

Figure 2 – Sample automatically detected beaked whale foraging click from hydrophone #1 on 15 Feb 2010 @ 20:49. Spectrogram parameters 96 kHz sample rate, 32 point FFT, slip one sample (overlap 31 samples of 32). No appreciable energy below 24 kHz. This sample reflects characteristics similar to those for Blainville's, and Cuvier's, beaked whale foraging clicks. The frequency up sweep is evident in both the time series, and more easily in the spectrogram.

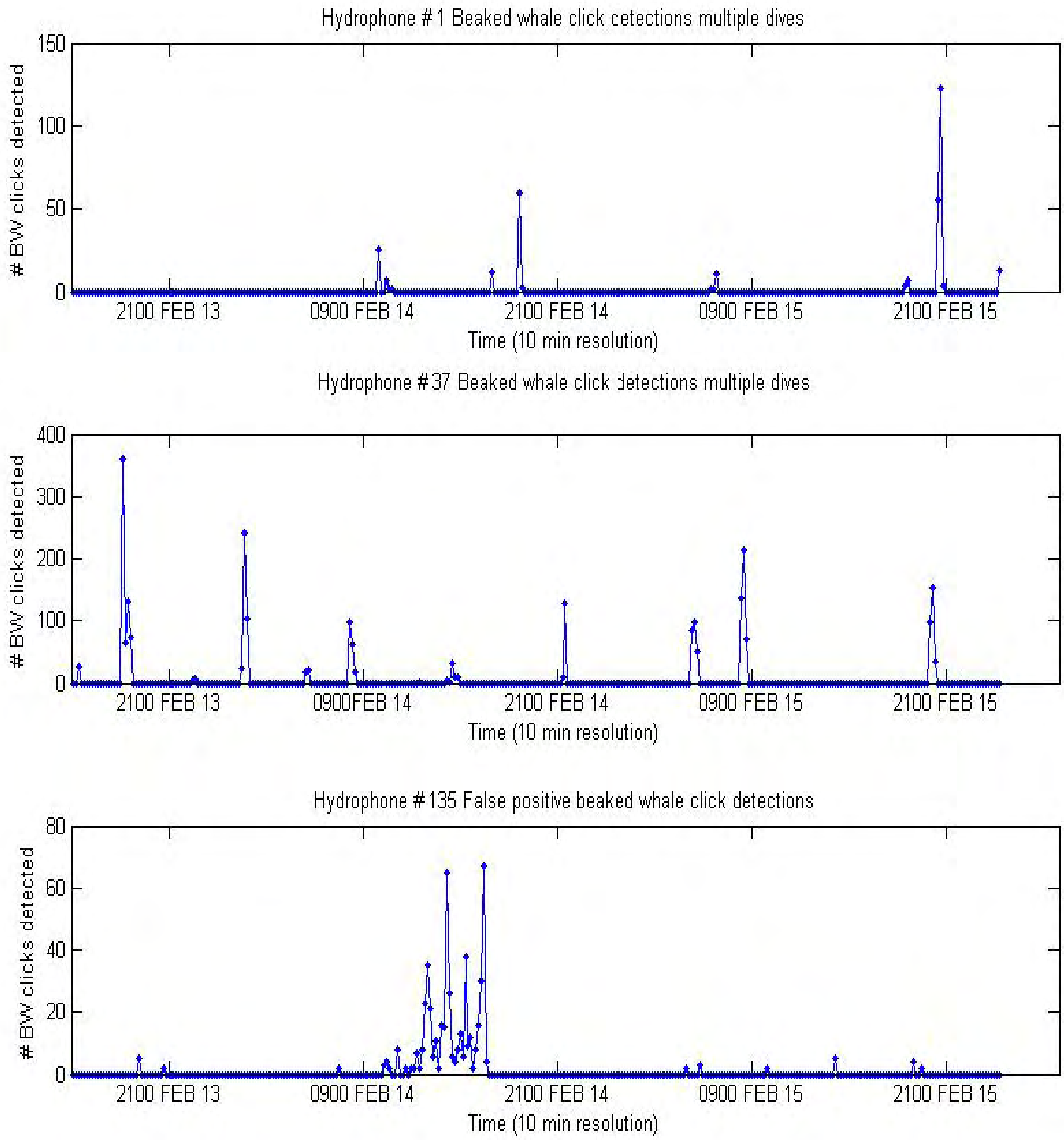

Figure 3 - Outputs of automatic beaked whale echolocation click detector during a portion of the PRE SCC period for three hydrophones. Top: phone # 1 showing two strong indicators for beaked whale dives (counts > 50 just before 2100 Feb 14 and at 2100 Feb 15), with multiple other suspect dives with lower total click counts. Middle: phone # 37 showing strong indication of multiple beaked whale foraging dive echolocation behavior with 20 to 30 min of foraging echolocation behavior throughout the period. Lower: false positive detections of beaked whale clicks – the temporal patterns are distinctly different from beaked whale foraging.

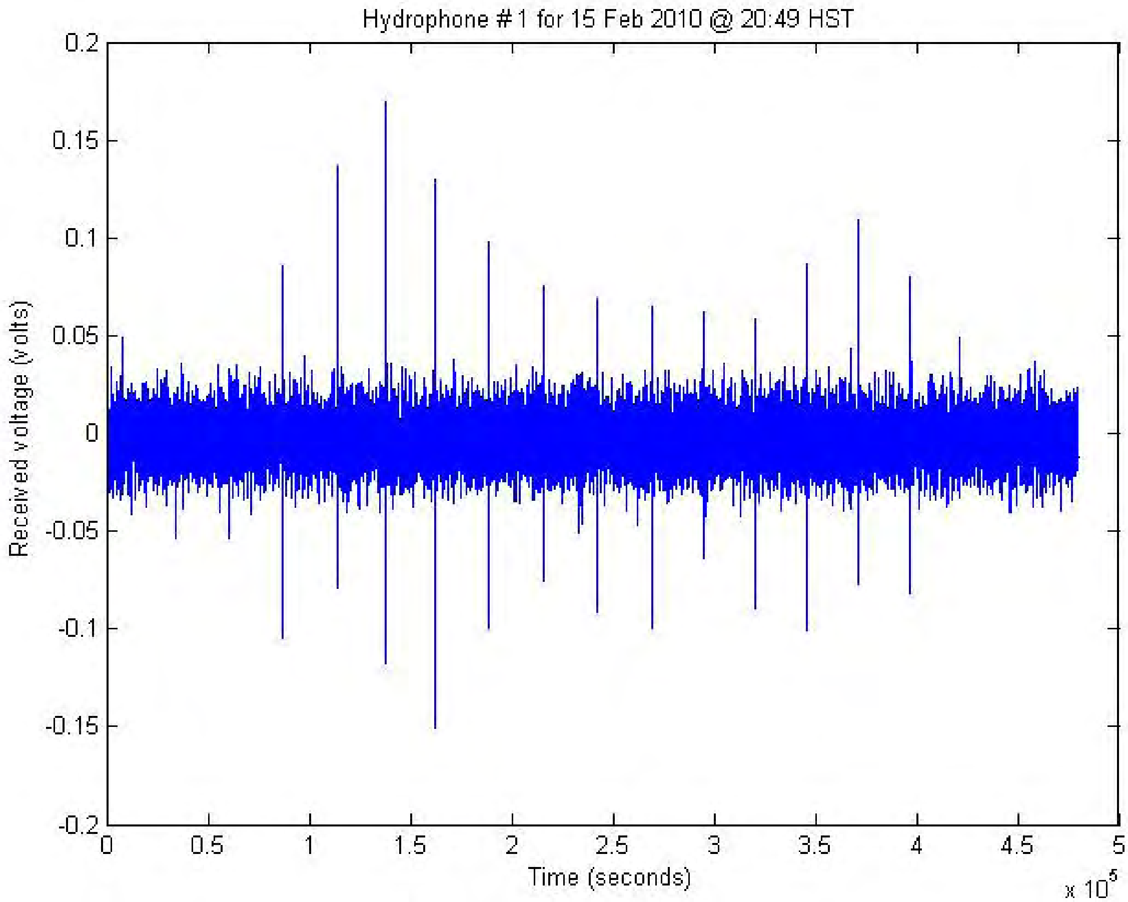

Figure 4 – Beaked whale clicks received on hydrophone # 1 on 15 Feb 2010 at 20:49 HST. Head scan motion apparent in click amplitudes. Inter-detection-intervals for this 10 min period have the peak intervals slightly under 0.3 sec.

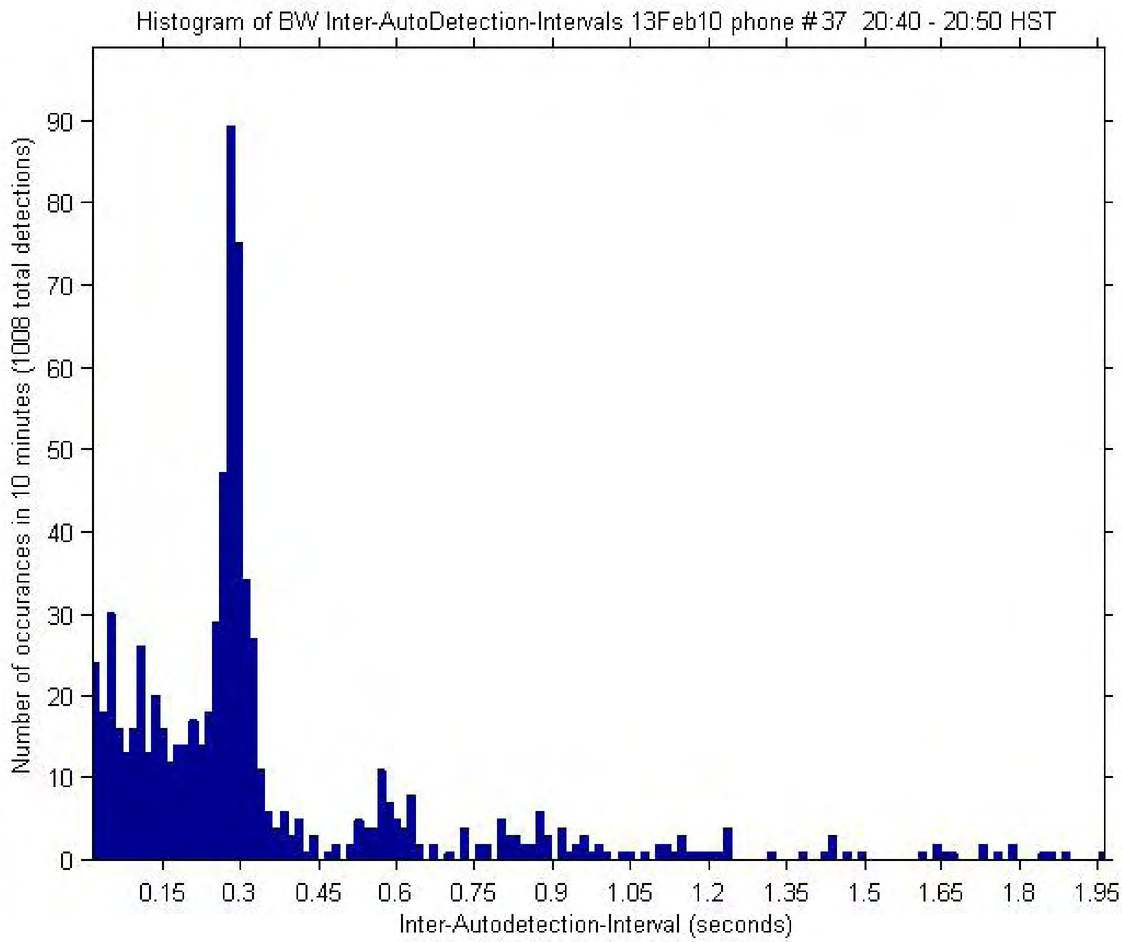

Figure 5 - Histogram of hydrophone # 37 inter-detection-intervals for 13 Feb 2010 between 20:40 and 20:50 HST, which corresponds to the data shown figure 3: middle trace for the first strong peak with > 300 BW clicks detected. The peak is at approximately 0.3 sec inter-detection-interval which is in the range of published information for beaked whales.

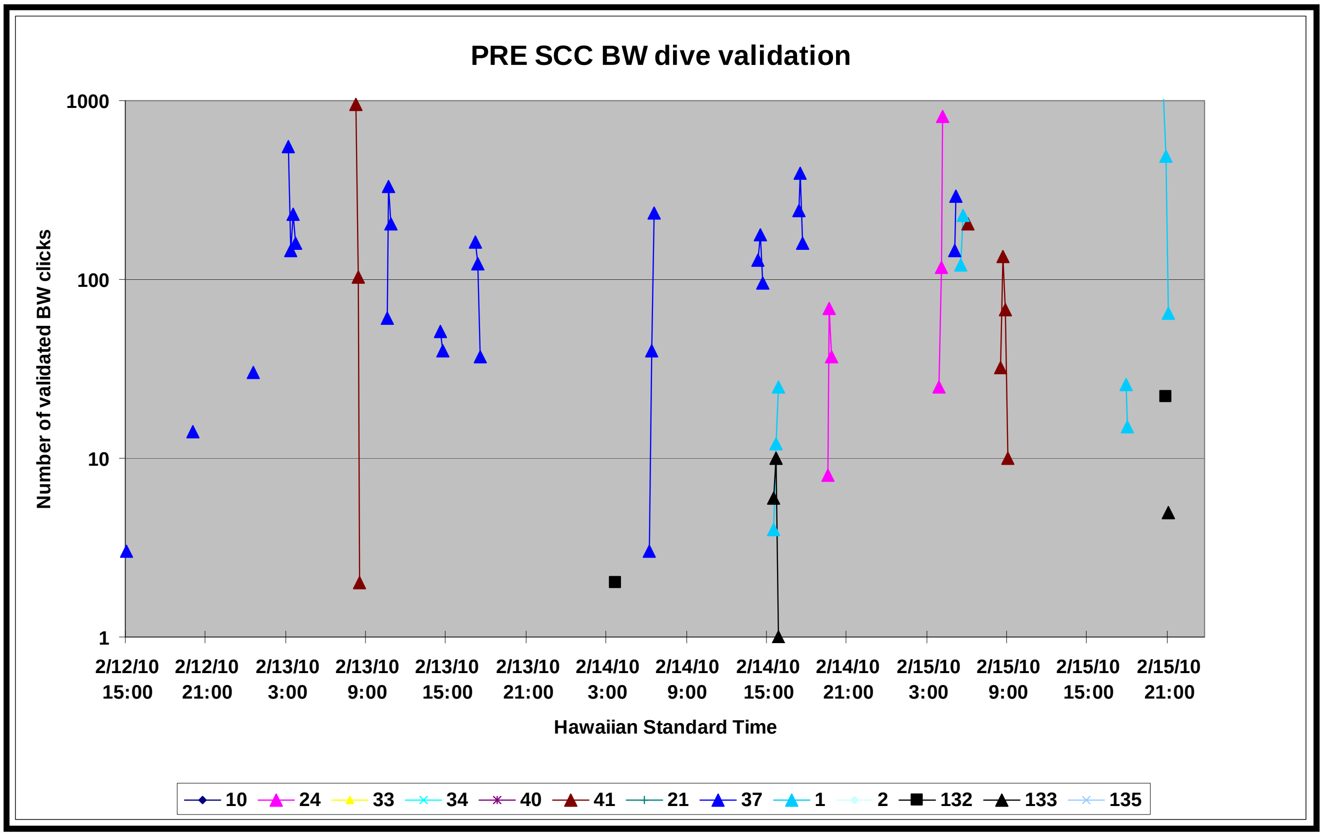

Figure 6 – Pre SCC operation beaked whale manually validated automated click detections per 10 minute period throughout the 80.8 hr period. Twenty one 'dives' with > 9 clicks in 10 min periods are observed.

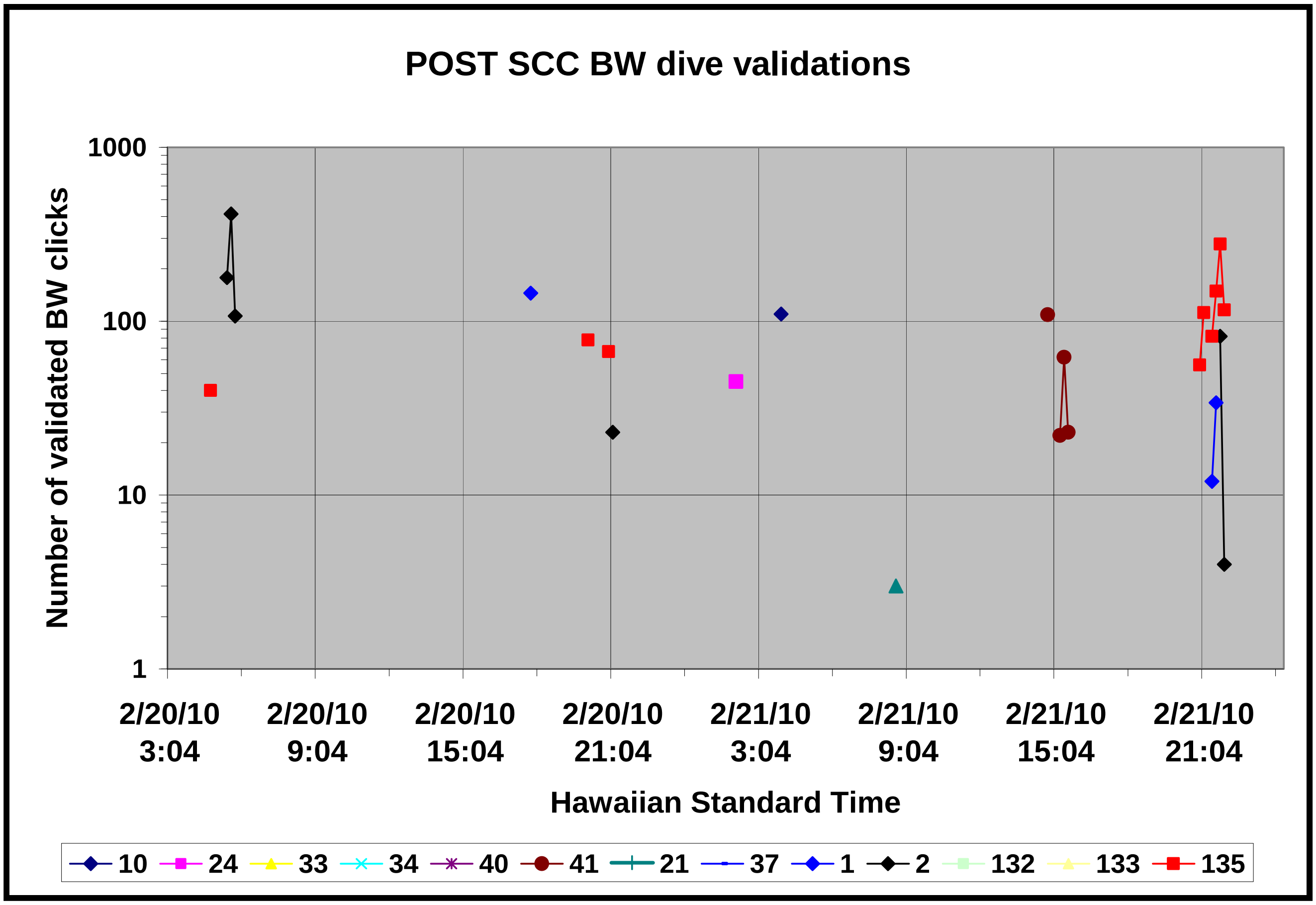

Figure 7 - Post SCC beaked whale dive manual validations. The number of 'dives', as defined in the text, is eleven in this case. Hydrophones 1, 2 and 135 are fairly close together and what is counted as four dives after 21:00 on 21 Feb could actually be fewer dives.

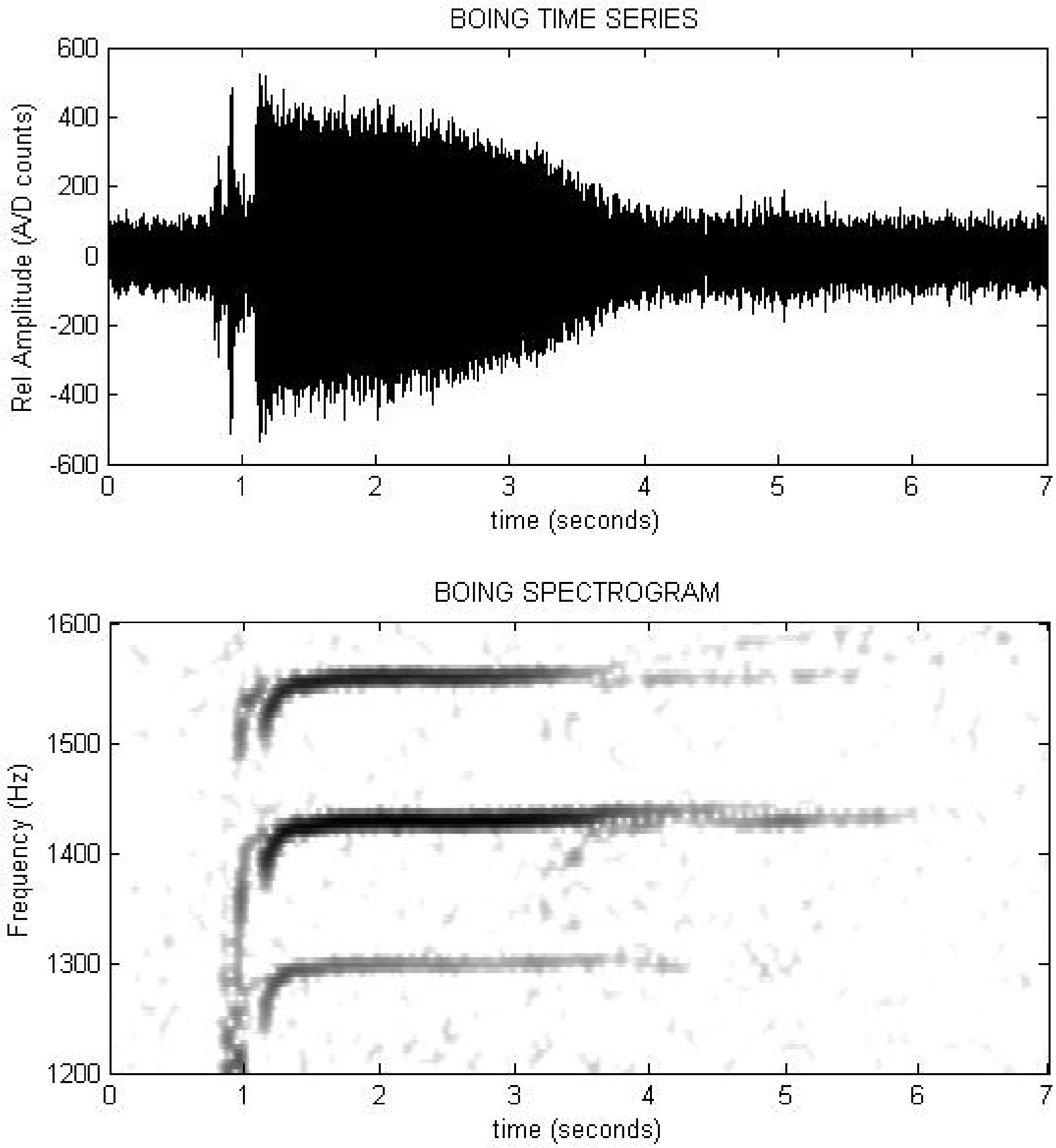

Figure 8 - Minke whale boing vocalization time series and spectrogram between 1200 Hz and 1600Hz.

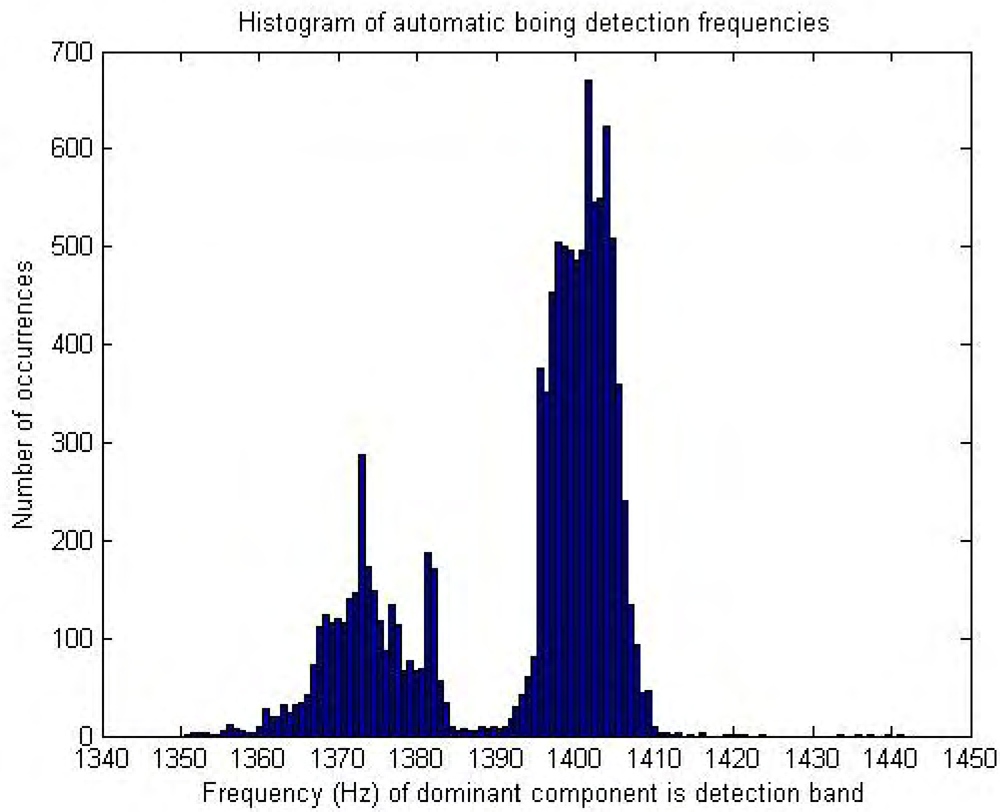

Figure 9 – Histogram of the dominant frequencies of each automatically detected boing over the detection band of 1350 Hz to 1440 Hz. POST SCC 16.7 hour period from 20 Feb 19:44 to 21 Feb 03:22. Data suggests multiple animals present.

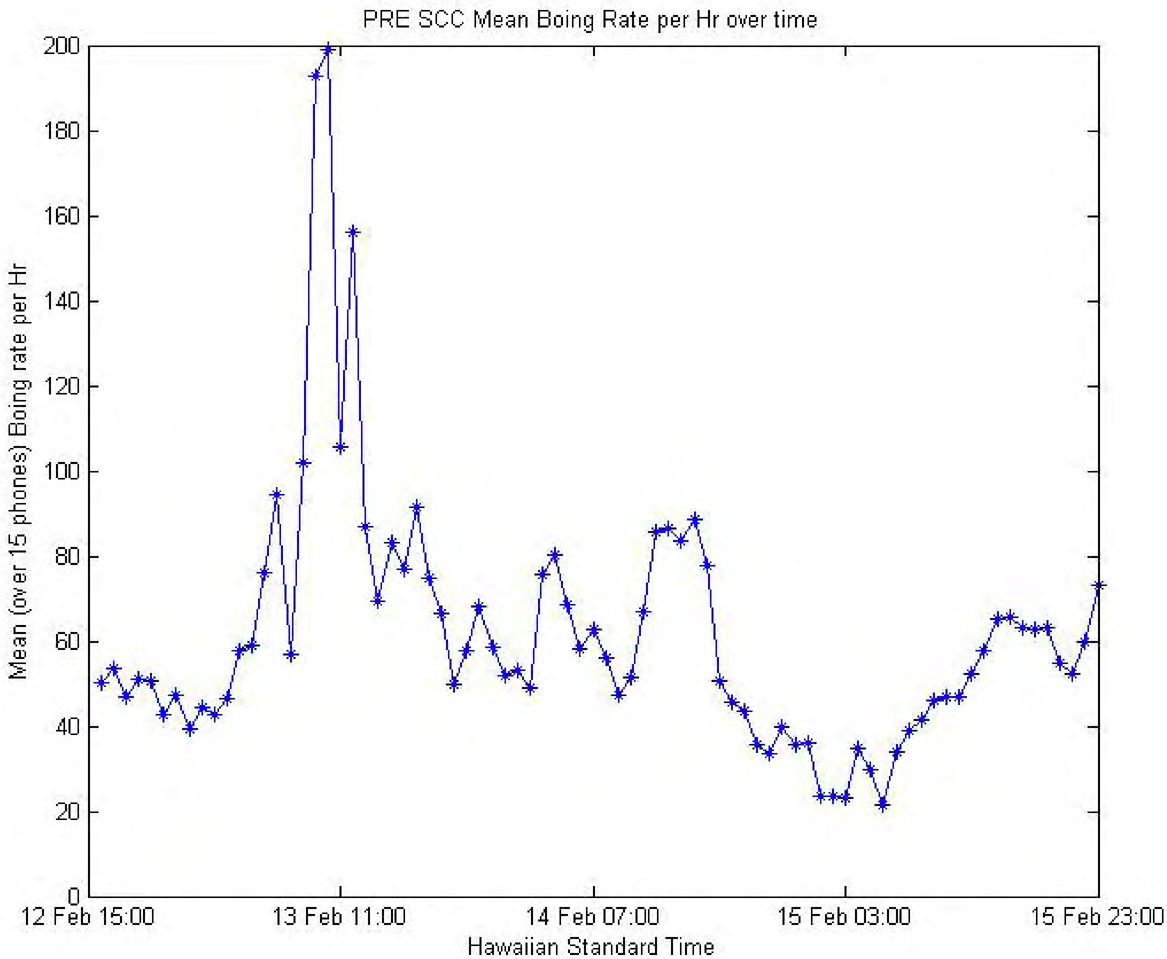

Figure 10 - Pre SCC mean automatic minke boing detections per hr for all 15 hydrophones. Note the high degree of variability. The peak just before 11:00 13 Feb is believed due to having multiple minke whales on the range and emitting boings approx every 5 to 6 min.

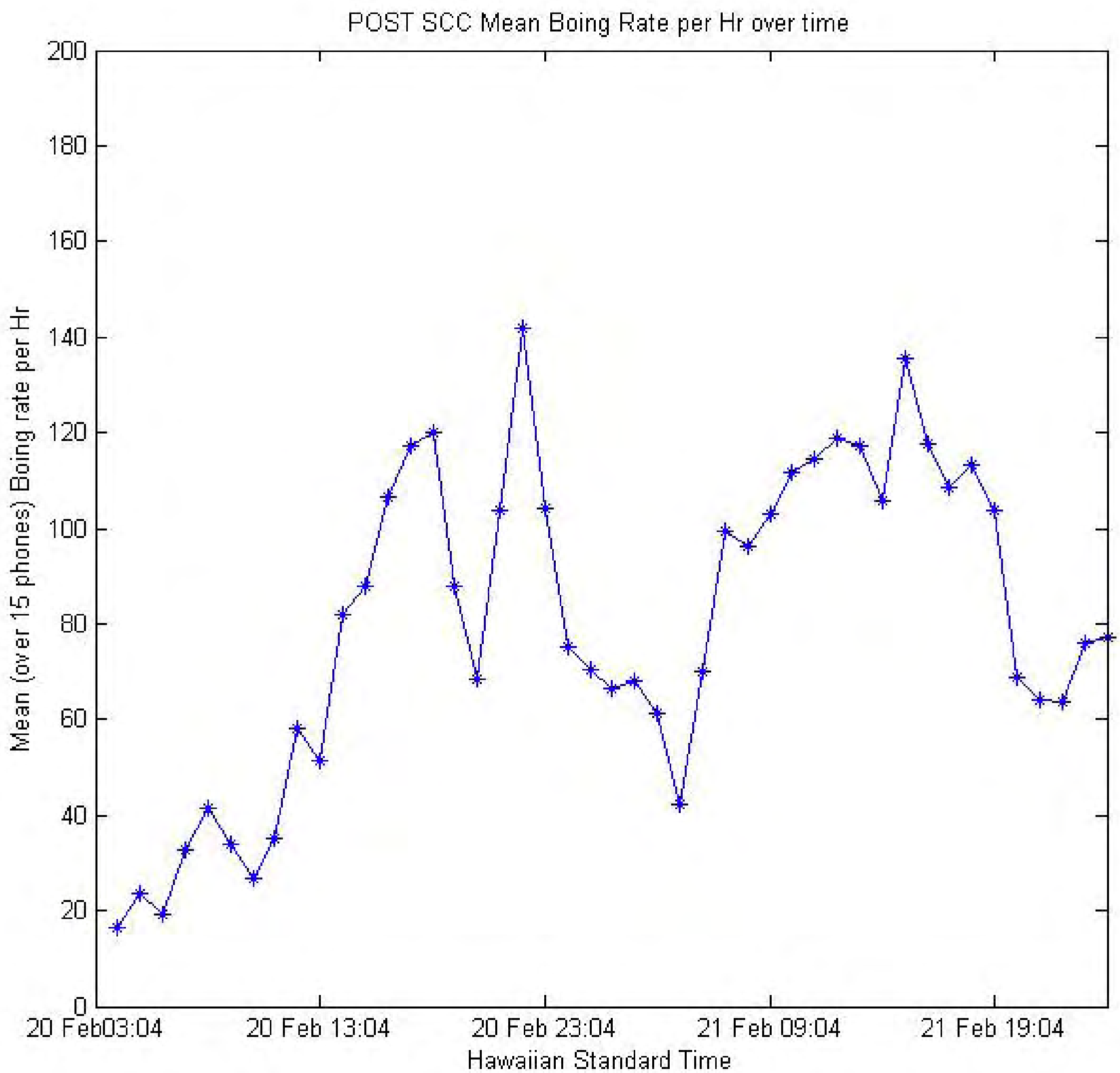

Figure 11 - Post SCC mean automatic minke boing detections per hour for all 15 hydrophones. The peak just at approx. 22:00 on 20 Feb is potentially due to TWO minke whales being in close proximity (within a couple of km of one another) and emitting boings at rates more rapid than typically observed (one every 30 sec vice one every 5 to 6 min).

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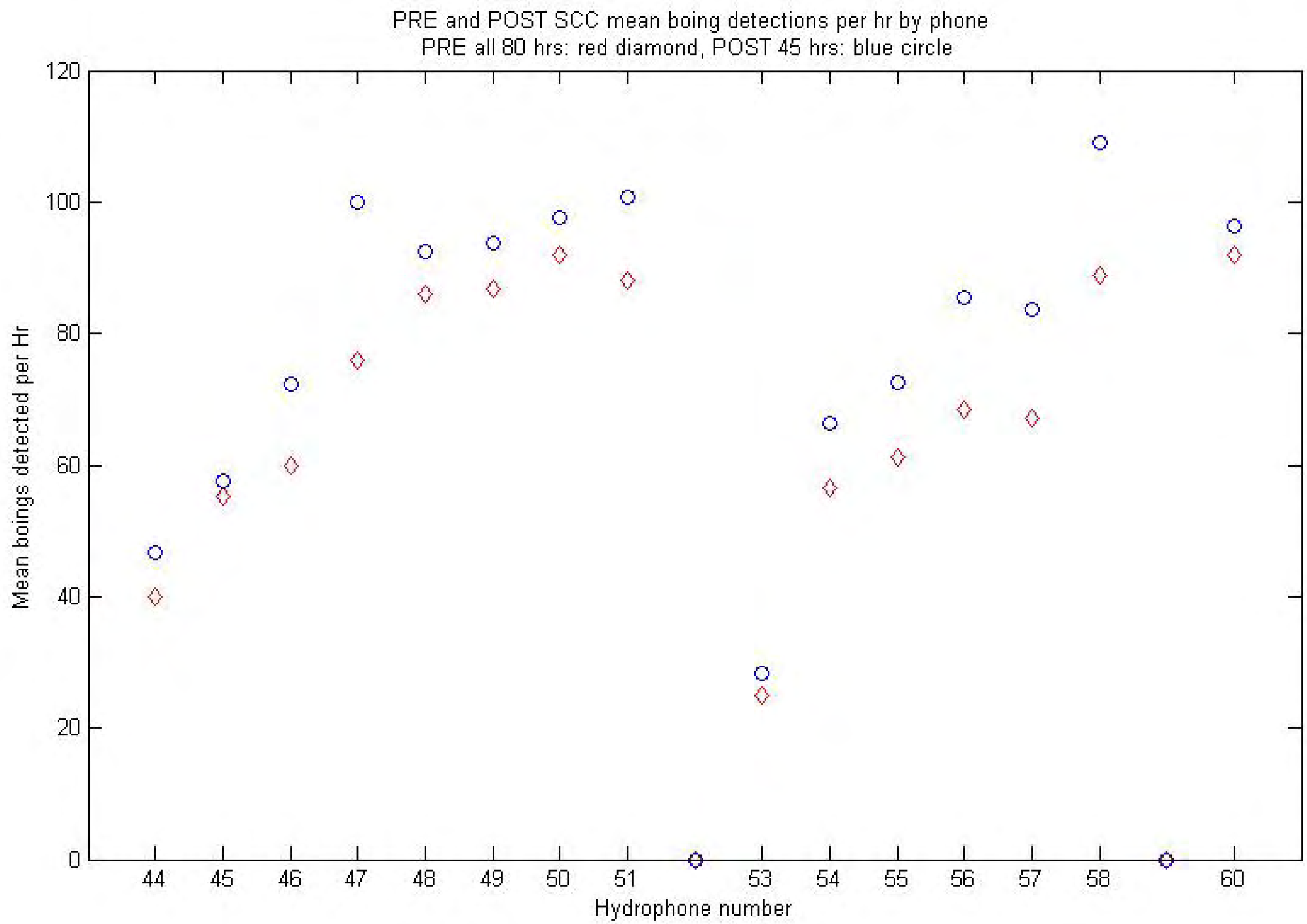

Figure 12 - PRE, and POST SCC automatic minke mean boing detections per hour by phone. All 80 hrs of PRE (red diamonds) shown along with the POST 45 hr (blue circles). The data corresponds to the means shown in table 2, note the standard deviations are on the order of one half of the means.

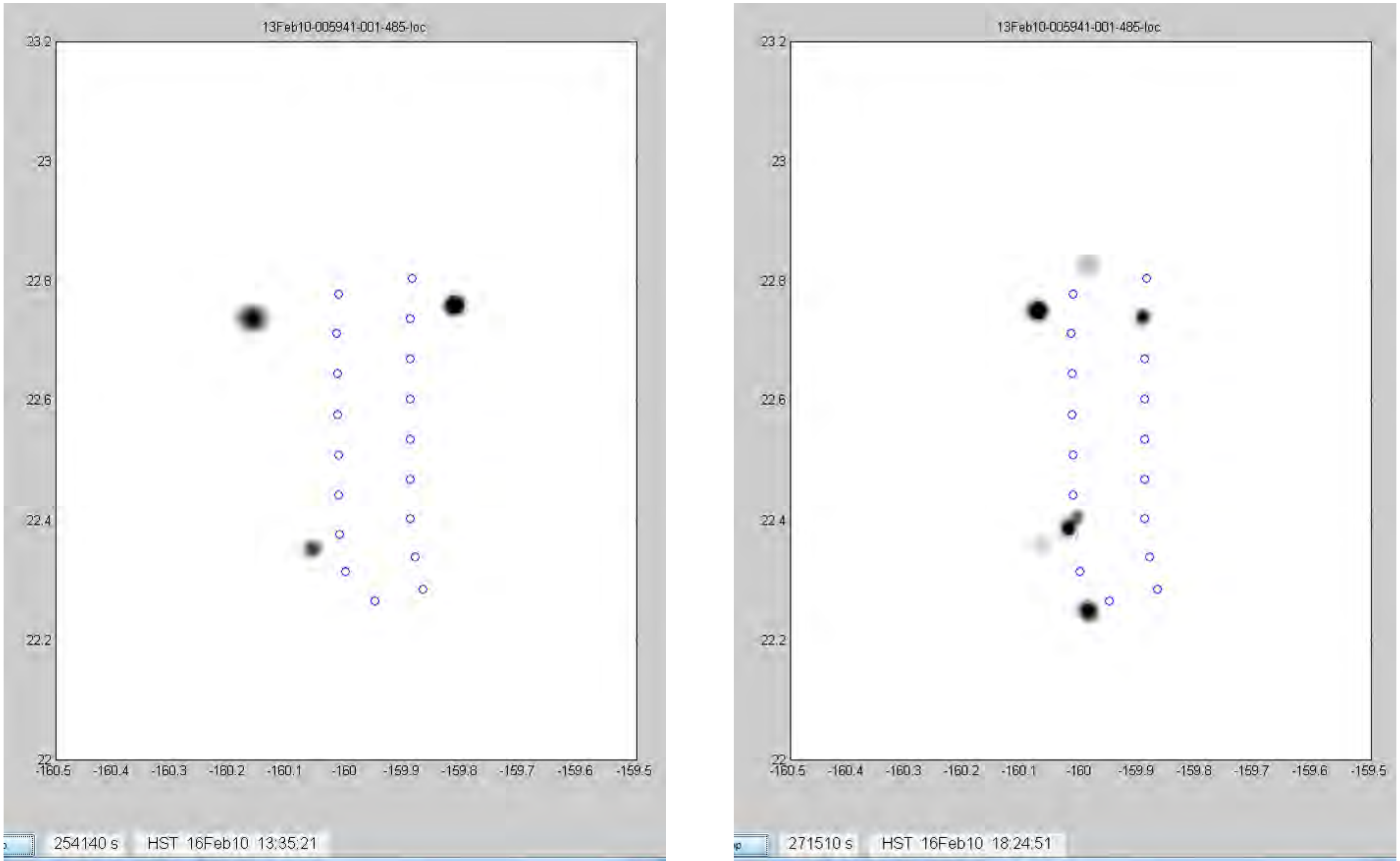

Figure 13 – Two segments of PRE SCC data automatically localized (no manual validations) showing suspected minke whale individuals. Left side: three minke whales at 13:35 HST 15 Feb 2010 (matlab error shows julian date on plots). Right side shows auto localizations 4 hrs and 50 min later. Right panel shows apparent movement of the three minke whales (seen on left panel) towards the hydrophones (blue circles) and a forth individual showing up on south portion of range. Weaker grey circle areas suspect to be erroneous localizations.