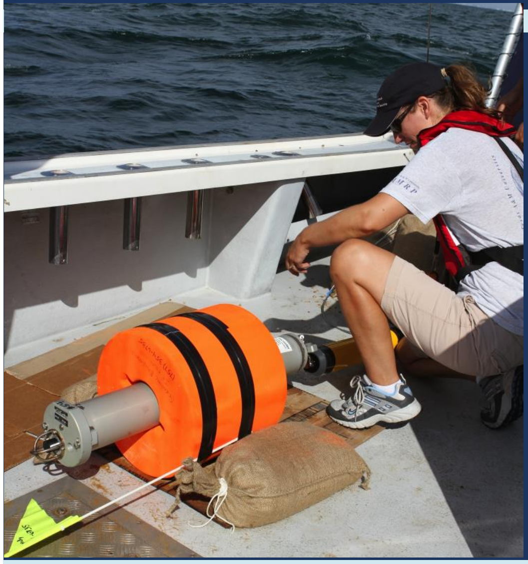
Final

Acoustic Monitoring of Dolphin Occurrence and Activity in the VACAPES MINEX W-50 Range 2012 – 2014: Preliminary Results

Submitted to:

Naval Facilities Engineering Command Atlantic under Contract No. N62470-10-D-3011, Task Orders 03 and 43, issued to HDR, Inc.



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23 March 2015

Suggested Citation:

Lammers, M.O., M. Howe, L. Munger, and E. Nosal. 2015. *Acoustic Monitoring of Dolphin Occurrence and Activity in the Virginia Capes MINEX W-50 Range 2012 – 2014: Preliminary Results. Final Report.* Prepared for U.S. Fleet Forces Command. Submitted to Naval Facilities Engineering Command Atlantic, Norfolk, Virginia, under Contract No. N62470-10-3011, Task Orders 03 and 43, issued to HDR Inc., Virginia Beach, Virginia. 23 March 2015.

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Ecological Acoustic Recorders. Photos courtesy of D. Engelhaupt and Marc Lammers (left to right).

This project is funded by US Fleet Forces Command and managed by Naval Facilities Engineering Command Atlantic as part of the US Navy's marine species monitoring program.

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Acronyms and Abbreviations

EAR	ecological acoustic recorder
khz	kilohertz
km	kilometer(s)
m	meter(s)
MINEX	mine neutralization exercise
U.S.	United States
UNDET	underwater detonation
VACAPES	Virginia Capes

Executive Summary

Mine neutralization exercise (MINEX) activities that utilize underwater detonations (UNDET) have the potential to injure or kill marine mammals occurring in close proximity. To better understand the impact of MINEX training on marine mammals, an effort was begun in August 2012 to monitor odontocete activity at the Virginia Capes Range Complex MINEX site using passive acoustic methods as part of the United States Navy's Integrated Comprehensive Monitoring Program. The initial objectives of the project were to establish the daily and seasonal patterns of occurrence of dolphins in the Virginia Capes W-50 MINEX training area, to detect explosions related to MINEX activities, and to determine whether dolphins in the area show evidence of a response to MINEX events. Between 2012 and 2013, two Ecological Acoustic Recorders (EARs) programmed to achieve continuous monitoring were deployed and refurbished approximately every 2 months. The data were analyzed manually for the daily presence/absence of dolphins, and their acoustic activity was quantified in detail for the period prior, during, and after MINEX training events, which can occur on the range multiple times per month. The initial results indicated that dolphins are present daily in or near the MINEX range, but have either reduced acoustic activity or diminished occurrence between December and February. The data also revealed that dolphins exhibit a short-term acoustic response immediately following an UNDET event. Acoustic activity increases briefly and then declines substantially during the hours following an UNDET. This response appears to persist during the day following the exercise. The duration of the response until normal behavior is re-established is not yet known.

A second phase of the project began in September 2013 to determine whether the responses observed represent a shift in acoustic behavior or a spatial redistribution of animals. Alternating 2-month deployments in 2013 and 2014 consisted of two different EAR array configurations. In the first configuration, four EARs were arranged in a linear coastal array at distances of 1 kilometer (km), 3 km, 6 km, and 12 km from the primary MINEX training site in order to examine whether or not animals are redistributing along the coast or offshore in response to training events. In the second configuration, EARs were arranged in a localization array in an effort to establish the distances that animals occur from MINEX training activities.

The data from the second year of work have generally confirmed the findings previously reported (Lammers et al, 2014). Seasonally, there appears to be a consistent period of 1–3 months of low occurrence or reduced acoustic activity centered on February. Dolphin occurrence within some other months of the year also varied from year to year, demonstrating some natural inter-annual variability in the occurrence of dolphins in the area around the 'epicenter' of MINEX training.

The sample sizes analyzed from the linear coastal EAR arrays are still too small to draw any firm conclusions, but the data examined to date do not suggest that dolphins follow a consistent pattern of re-distribution away from the epicenter after a MINEX training event. There is some evidence that dolphins may be more acoustically active or abundant 3 km from the epicenter during the early morning hours of the day after an exercise, but this trend may or may not hold as data from additional deployments are collected and/or analyzed.

Two localization EAR array deployments have yielded data suitable for localizing dolphins. The time-alignment of recordings from the array was made possible by adding a pinger to one of the EAR moorings during the second localization array deployment. Algorithms for localizing dolphin signals have been developed and successfully applied to a subset of data.

1. Introduction

The United States (U.S.) Navy is required to comply with Federal laws designed to protect marine species, including the Endangered Species Act and the Marine Mammal Protection Act. As part of the regulatory process, the U.S. Navy must monitor and report on certain activities that have the potential to injure or kill marine mammals, such as sonar and underwater detonations (UNDETs). The U.S. Navy's Integrated Comprehensive Monitoring Program was established in 2009 as a planning tool to focus the U.S. Navy's monitoring priorities pursuant to Endangered Species Act and Marine Mammal Protection Act requirements. Two of the principal monitoring goals identified in the ICMP are:

A. To increase understanding of how many marine mammals are likely to be exposed to stimuli (e.g., sonar and underwater detonations) associated with adverse impacts, such as behavioral harassment and hearing threshold shifts (temporary or permanent).

B. To increase understanding of how marine mammals respond (behaviorally or physiologically) to sonar, underwater detonations, or other stimuli at specific received levels that result in the anticipated take of individual animals.

In order to help meet these goals for the Virginia Capes (VACAPES) W-50 mine neutralization exercise (MINEX) training range (**Figure 1**), a long-term passive acoustic monitoring study was begun in August 2012, in conjunction with a separate vessel-based visual survey study, to document the spatial and temporal occurrence of cetaceans in the W-50 area, as well as adjacent coastal waters, and to examine their behavioral responses to UNDETs. To this end, the objectives of the first year of the study (August 2012–July 2013) were to:

1. Detail the daily and seasonal occurrence of resident bottlenose dolphins (*Tursiops truncatus*) near the primary location of MINEX activities.
2. Detect UNDETs associated with training events.
3. Quantify the acoustic activity of dolphins in response to UNDETs.

During the second year of the study (August 2013–July 2014), these objectives were expanded to also address the following questions:

4. At what distance from the explosion site is an acoustic response observable?
5. Do dolphins show evidence of re-distribution as a result of MINEX activities?
6. At what distance from MINEX explosions do dolphins occur?

Here we present the methods employed in the study and report on the results from the first 2 years of monitoring. We discuss the implications of the initial findings and describe current data-collection efforts to meet the research objectives for 2014–2015.

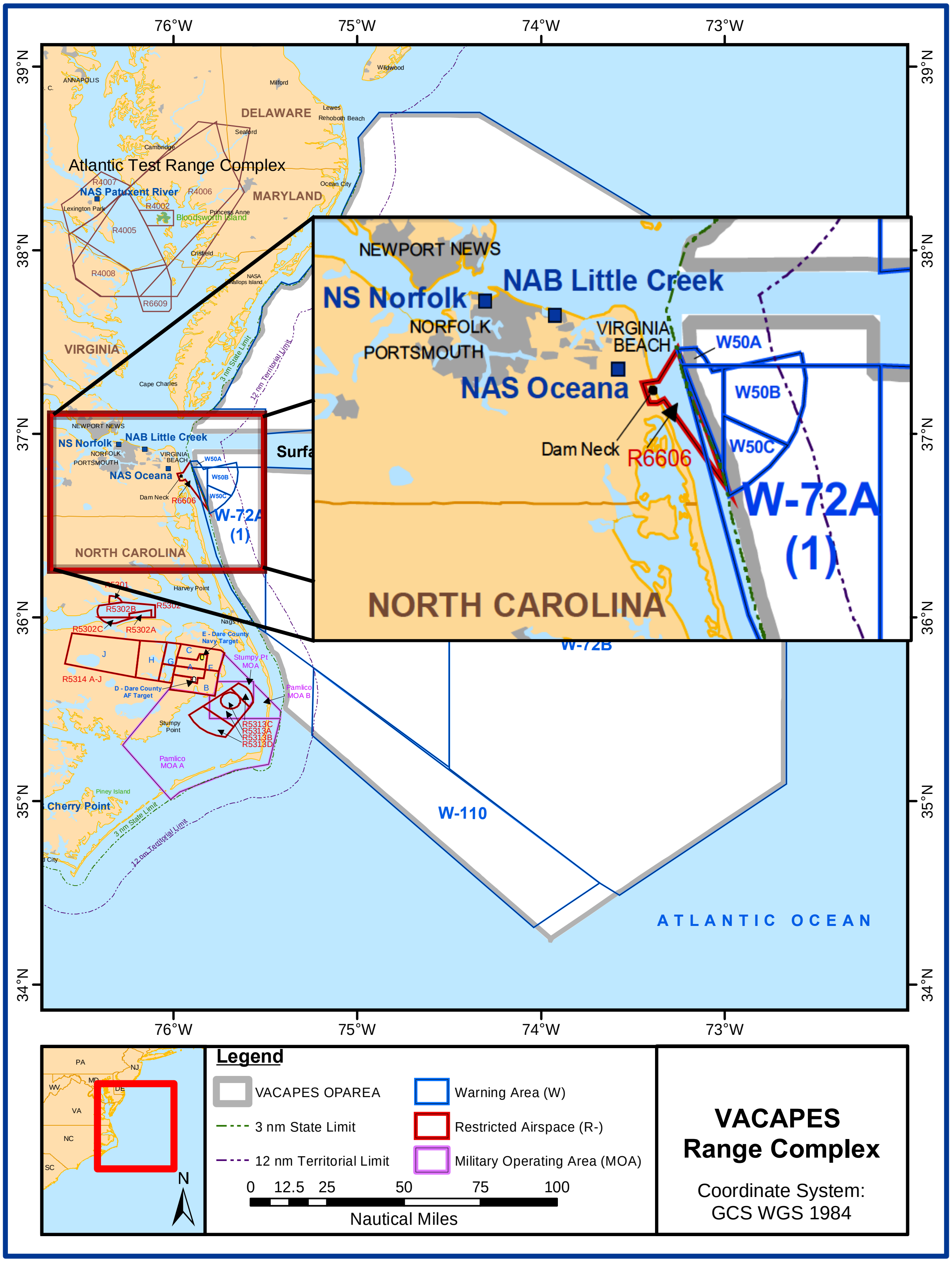

Figure 1. Map of the VACAPES Range Complex displaying an expanded view of the W-50 MINEX training range.

2. Methods

2.1 2012–2013 EAR Monitoring

Passive acoustic monitoring was initiated in the MINEX W-50 training area on 15 August 2012, using bottom-moored Ecological Acoustic Recorders (EARs) (**Figure 2**). The EAR is a microprocessor-based autonomous recorder that samples the ambient sound field on a programmable duty cycle (Lammers et al. 2008). Four EARs were programmed to sample at a rate of 50 kilohertz (kHz) for 180 seconds (3 minutes) every 360 seconds (6 minutes), providing a recording bandwidth of ~25 kHz at a 50 percent duty cycle (**Appendix A**). This bandwidth is sufficient to detect signals (whistles and the low-frequency end of clicks) from bottlenose dolphins and other delphinid species potentially occurring in the area, which produce signals at frequencies below 25 kHz. Harbor porpoise (*Phocoena phocoena*) clicks, with center and peak frequencies of 130—140 kHz (Goodson and Sturtivant 1996), are above the recording range of these EARs.

The EARs were paired and co-located approximately 1 kilometer (km) apart, and their recording periods were offset so that one unit was recording while the other was off. As a result, one of the paired units was always 'on' in order to detect any nearby explosions. Two of the paired EARs (units A and B) were placed in 13-meter (m) and 14-m water depths (respectively) approximately 1 km from a site that was considered to be the 'epicenter' of MINEX training activity. This is a search field location where the majority (~95 percent) of MINEX detonations were expected to occur each year. The other two EARs (units C and D) were deployed in 15-m and 16-m water depths (respectively) approximately 5 km to the south-southeast of EARs A and B near another mine search field area. The recording parameters and deployment specifics are presented in **Appendix A**.

Of the four EARs initially deployed in August 2012, two EARs were lost due to a malfunction in the anchoring system. As a result, monitoring at sites C and D was discontinued. For all subsequent deployments, the EARs were recovered, refurbished, and re-deployed by staff from HDR approximately every 2 months, or as weather conditions and logistics allowed.

An experienced acoustic technician manually scanned recordings from sites A and B for the presence of MINEX explosion events, and from site B only for dolphin signals, using the Matlab™ program Triton (Wiggins 2003) and/or the program CoolEdit™(Syntrillium, Inc). Recordings containing dolphin whistles, echolocation clicks, or burst pulses were considered a 'detection' of dolphins in the area. For periods when explosions were detected on either EAR, a detailed assessment was made of the dolphin acoustic activity on unit B the day before, during, and after each explosion. An acoustic activity index, representing the sum of the index values for the various sounds detected (**Table 1**), was assigned for each 3-minute recording to quantify acoustic activity. Activity indices were then used to statistically compare the acoustic activity of dolphins during the minutes, hours, and day before, day of, and day after UNDETs. In addition, an analyst manually counted whistles in the 30-second periods before and after each UNDET. In addition to quantifying dolphin acoustic activity during periods associated with MINEX exercises, dolphin presence/absence was quantified on a recording-by-recording (file-by-file) basis at site B for the entire deployment period.

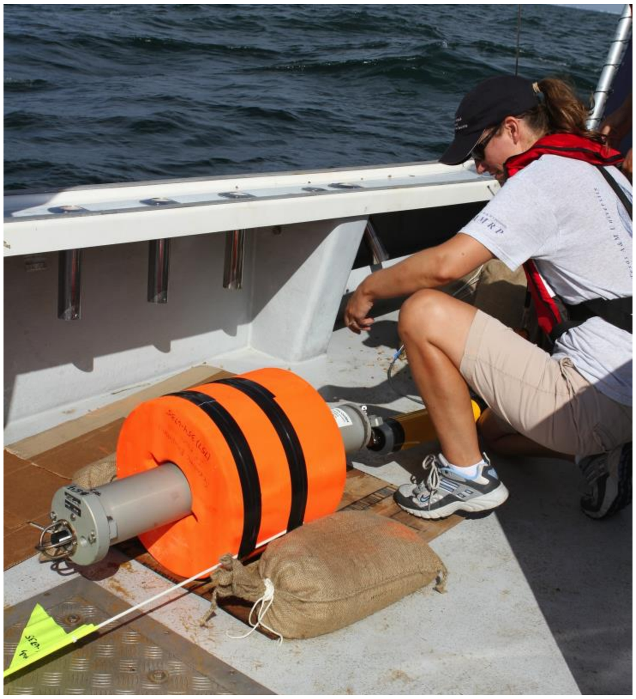

Figure 2. Images of an EAR prior to deployment and while deployed.

Table 1. Index values used to quantify dolphin acoustic activity for each 3-minute recording made the day before, during, and after detected explosions, based on the abundance of dolphin whistles, burst pulses (BP) and echolocation.

Acoustic category	**Index value**
1-20 whistles	1
BP only <10	1
Echolocation only <2 clicks/sec	1
21-40 whistles	1.5
Echolocation only >2 clicks/sec	1.5
BP only >10	1.5
Echolocation & BP <10	1.5
1-20 whistles & echolocation or BP	2
>41 whistles	2.5
Echolocation & BP >10	2.5
1-20 whistles, echolocation & BP	3
21-40 whistles & echolocation or BP	3
21-40 whistles, echolocation & BP	3.5
>41 whistles & echolocation or BP	3.5
>41 whistles, echolocation & BP	4

2.2 2013—2014 EAR Monitoring

Beginning in September of 2013, EAR deployments were modified to address questions 4, 5, and 6 in the introduction (**Section 1**). Two EARs were added to replace the units that were lost in 2012, and the deployment configurations were modified. To address questions 4 and 5, the four EARs were placed in a 'linear coastal array' configuration, with the units spaced at distances of 1 km (site B), 3 km (sites H & K), 6 km (sites F, I & L) and 12 km (G, J & M) from the primary MINEX epicenter. The EARs at 1 km and 3 km were programmed at offsetting duty cycles in order to ensure the capture of all UNDETS, as in the previous year. Site B was maintained as the 1-km location for this and all subsequent linear coastal array deployments to ensure the continuation of the data time-series obtained during the previous year. The data obtained from linear coastal array deployments were used to examine the acoustic activity of dolphins at the four locations during the days before, during, and after MINEX training events to determine the range at which an acoustic response by dolphins is observed. Data from the four coastal locations were also used to assess whether or not there is a re-distribution of animals following MINEX training activities. The linear coastal array was shifted to the south, east and north during alternating EAR redeployments (**Figure 3, Appendix A**).

Question 6 is being addressed by placing the EARs in a localization array configuration during alternating deployments, with the units separated by approximately 150 m (**Figure 4**). This array configuration is being used to localize dolphins during periods of MINEX training using time-of-arrival differences of dolphin signals recorded on the four EAR units. A Trimble high-accuracy global positioning system is used to precisely record EAR deployment locations. The four EAR units are programmed to record simultaneously at a 50 percent duty cycle, allowing them to record the same dolphin signals and explosions. However, in order to accurately localize signals during post-processing, the EAR recordings must be precisely time-aligned. This time-alignment of the EAR clocks was originally going to be accomplished by using the acoustic waveform of the UNDET signal as a synchronization pulse originating from a known location. However, after the first localization array deployment in November 2013, it was determined that the waveform would not be a reliable signal for this purpose. As a result, an ARS-100 pinger (RJE International, Inc.) was co-deployed with one of the moorings in the subsequent localization array deployment. The pinger produces a short series of five 1-second tonal frequency sweeps (4–7 kHz) once every 30 minutes. The known location of the pinger is used to calculate the time-delay between EARs in order to align the recordings. Upon recovery, and once the EAR clocks have been time-aligned, dolphin signals recorded during the day of UNDETs are localized using time-of-arrival differences. This data collection and data analysis effort is currently in progress. The information obtained will be used to determine the approximate distance animals occurred from the explosion site and compare the spatial distribution of dolphins immediately prior to and following an UNDET.

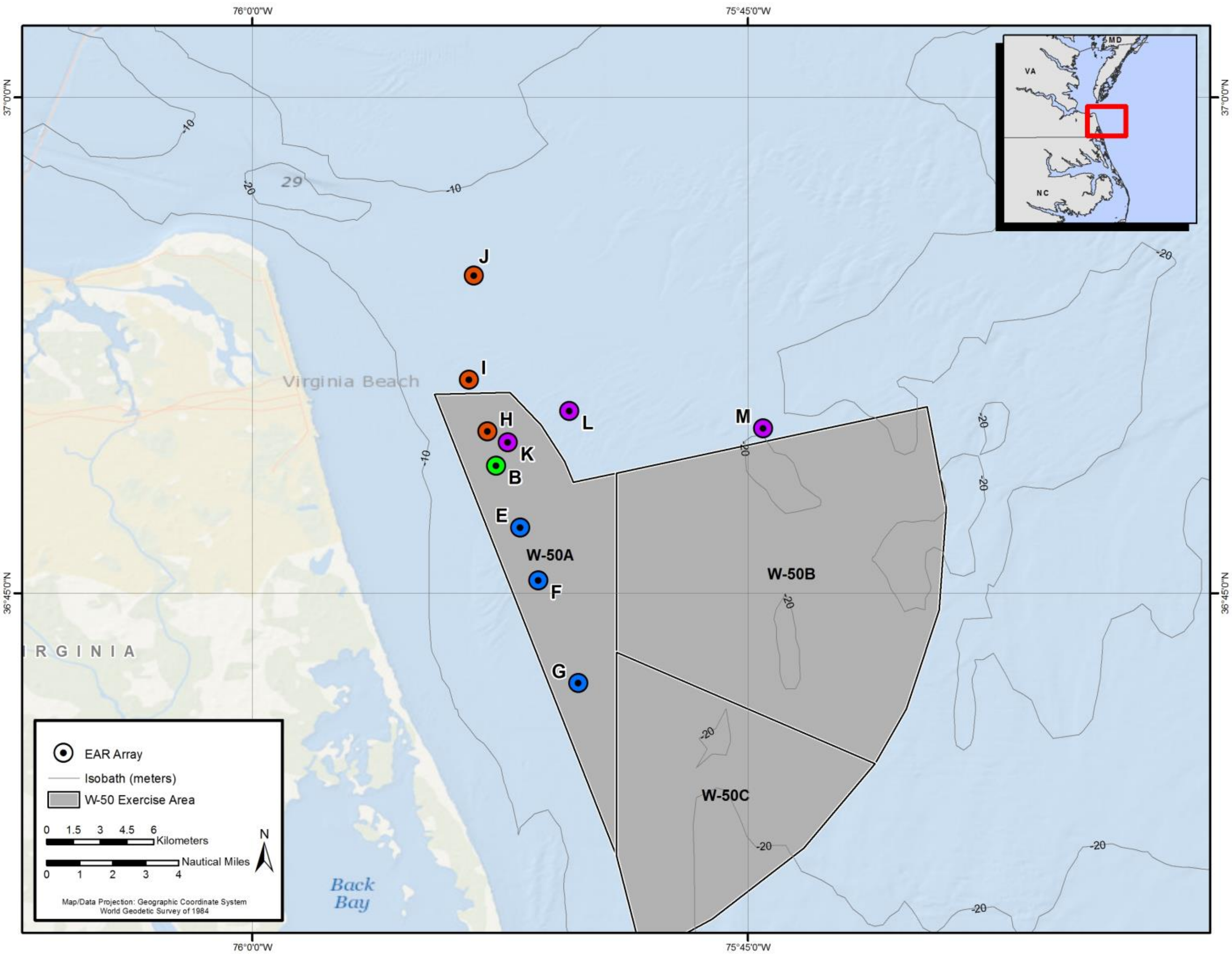

Figure 3. Spatial configuration of three linear coastal EAR arrays deployed during the second year of the project. Site B remained constant and north is shown as red (B–H–I–J), east as purple (B–K–L–M), and south as blue (B–E–F–G).

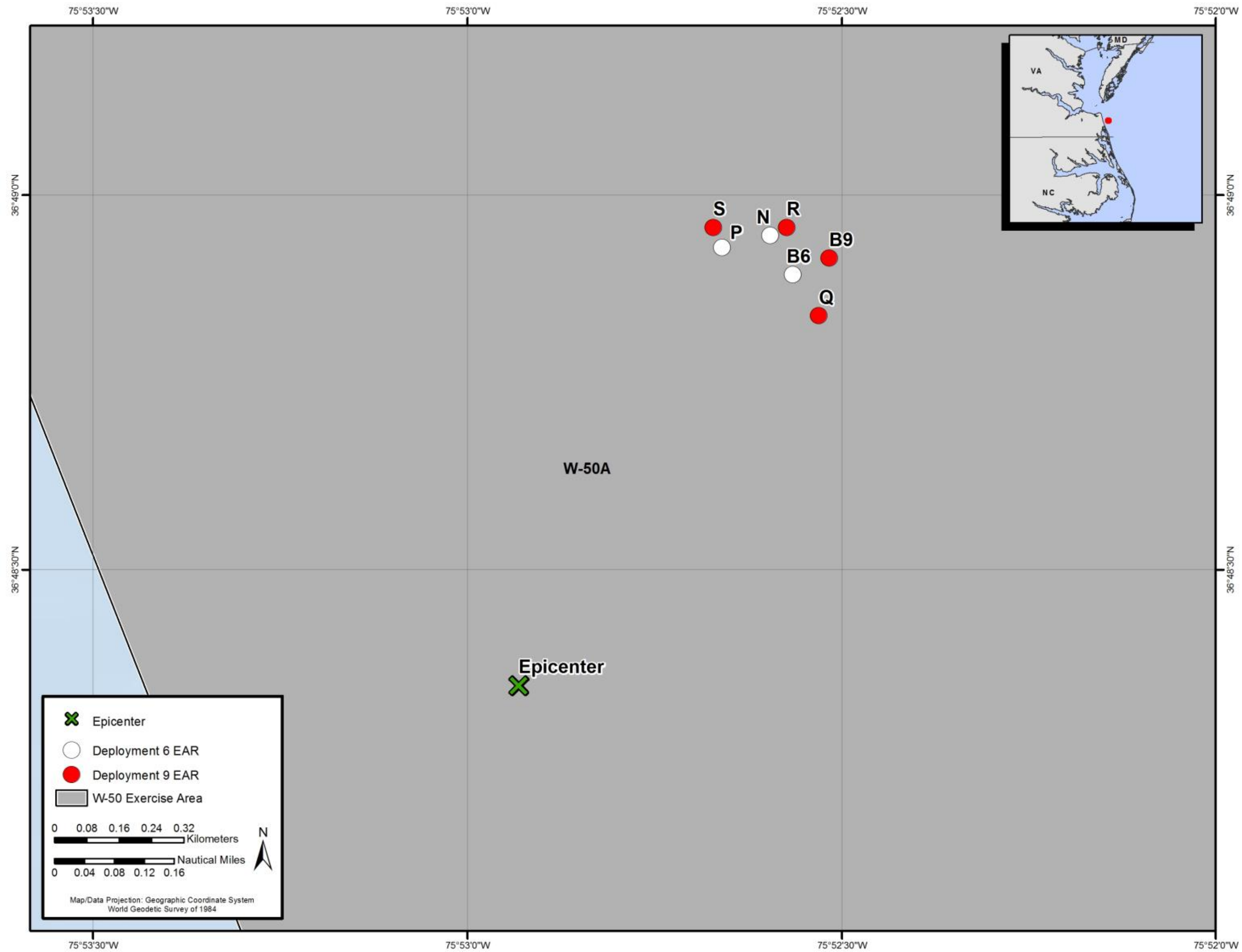

Figure 4. Spatial configuration of the two localization EAR arrays relative to the location of the epicenter of MINEX training activities. The white markers represent deployment 6 and the red markers represent deployment 9.

3. Results

3.1 Work Completed to Date

HDR staff performed twelve deployments and eleven recoveries since the beginning of the project on 15 August 2012 (**Appendix A**). Three instruments have been lost during this time. However, 19 out of 26 EAR deployments (18 out of 22 after the initial deployments) were successful and produced high-quality data. In total, 344,510 3-minute recordings have been made, totaling 17,225 hours of data.

3.1.1 EAR deployments at Site B

In total, 128,471 recordings representing 6,423 hours of data have been made at site B since the beginning of the study. All deployments except #7 successfully obtained data from this location. The hard disk drive from deployment #7 malfunctioned, preventing recovery of the on-board data. For deployment #7, data from EAR K were used instead as a proxy of dolphin activity near the epicenter of MINEX training. The data from site B (and K) have been analyzed through 28 July 2014, by manually examining individual recordings for the presence/absence of dolphin signals and UNDETs. In total, 27 UNDETs were recorded at this location.

3.1.2 Linear coastal array EAR deployments

The initial linear coastal array was deployed towards the south of the epicenter on 21 September 2013, and was retrieved on 11 November 2013. However, only three of the units were successfully retrieved. The EAR located 6 km from the MINEX training area (unit F) did not respond to commands from the surface transponder used to communicate with the acoustic release and was therefore presumed lost. The most likely explanation is that it was moved or picked up by a fishing trawler. The lost EAR was replaced with a new unit, and on 16 February 2014, four EARs were redeployed in an eastern orientation. They were recovered on 27 April 2014. The north-oriented array was deployed on 19 May 2014, and retrieved on 6 August 2014.

The data obtained from the first three linear coastal array deployments were examined to determine the acoustic activity of dolphins at the EAR locations during the days before, during, and after MINEX training events to determine the range at which an acoustic response by dolphins could be observed. Data from unit B continued to be analyzed for the presence of dolphin signals to maintain consistency with the data time series, with recordings containing dolphin whistles, echolocation clicks, or burst pulses considered a ‘detection’ of dolphins in the area. Data from the four coastal locations for each linear array were also used to determine whether or not there was a re-distribution of animals following MINEX training activities. The acoustic activity index was averaged by EAR location and pooled by the distance from the epicenter of training exercises for the days before, during and after an UNDET event. This allowed an examination of animal presence at each distance from the epicenter following MINEX events irrespective of the direction of the linear array.

3.1.3 Localization array EAR deployments

The first localization array was deployed on 16 November 2013, and retrieved on 23 January 2014. The data from this deployment were evaluated for the feasibility of using the UNDET impulse to time-align the recordings on the three EARs. Upon closer examination of the waveform properties, it was observed that there were inconsistencies in the low-frequency precursor to the pulse that were likely due to propagation effects that could not be resolved (**Figure 5**). As a result, this method for time-aligning the recordings was abandoned.

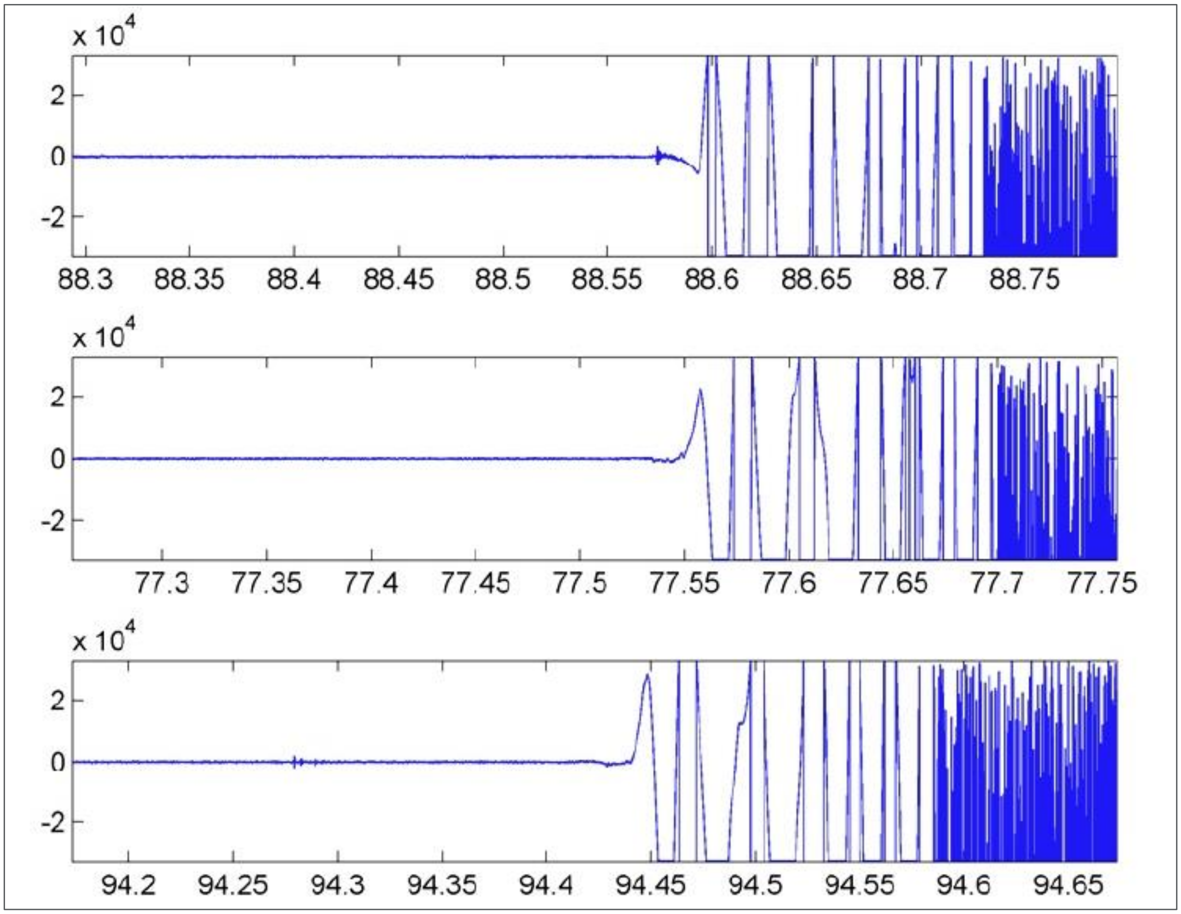

Figure 5. Zoomed-in view of low frequency precursor to the UNDET impulse on the three EARs. Note the phase inconsistency between the top panel and the two lower panels. The Y-axis represents 16 bit analog-to-digital sample values; the X-axis shows the time from the beginning of the recording at each EAR in seconds.

The second localization array deployment was made between 16 August 2014 and 7 November 2014, with the pinger at the EAR B mooring. EARs B and Q recorded successfully during the entire deployment. EAR R recorded for 10 days and then unexpectedly stopped. EAR S recorded during the entire deployment, but the resulting data were contaminated by electronic noise, most likely due to instrument malfunction.

To time-align the recordings on the three EARs that yielded high-quality data, a ‘pinger template’ was created using a 0.5-second linear chirp from 4 kHz to 7 kHz. The pinger template was cross-correlated with the recorded pings on each EAR to give pinger arrival times at each phone. These actual ping arrival times were compared to the expected ping arrival times modeled using the known EAR positions and sound speed, and EAR timing was corrected accordingly (**Figure 6**).

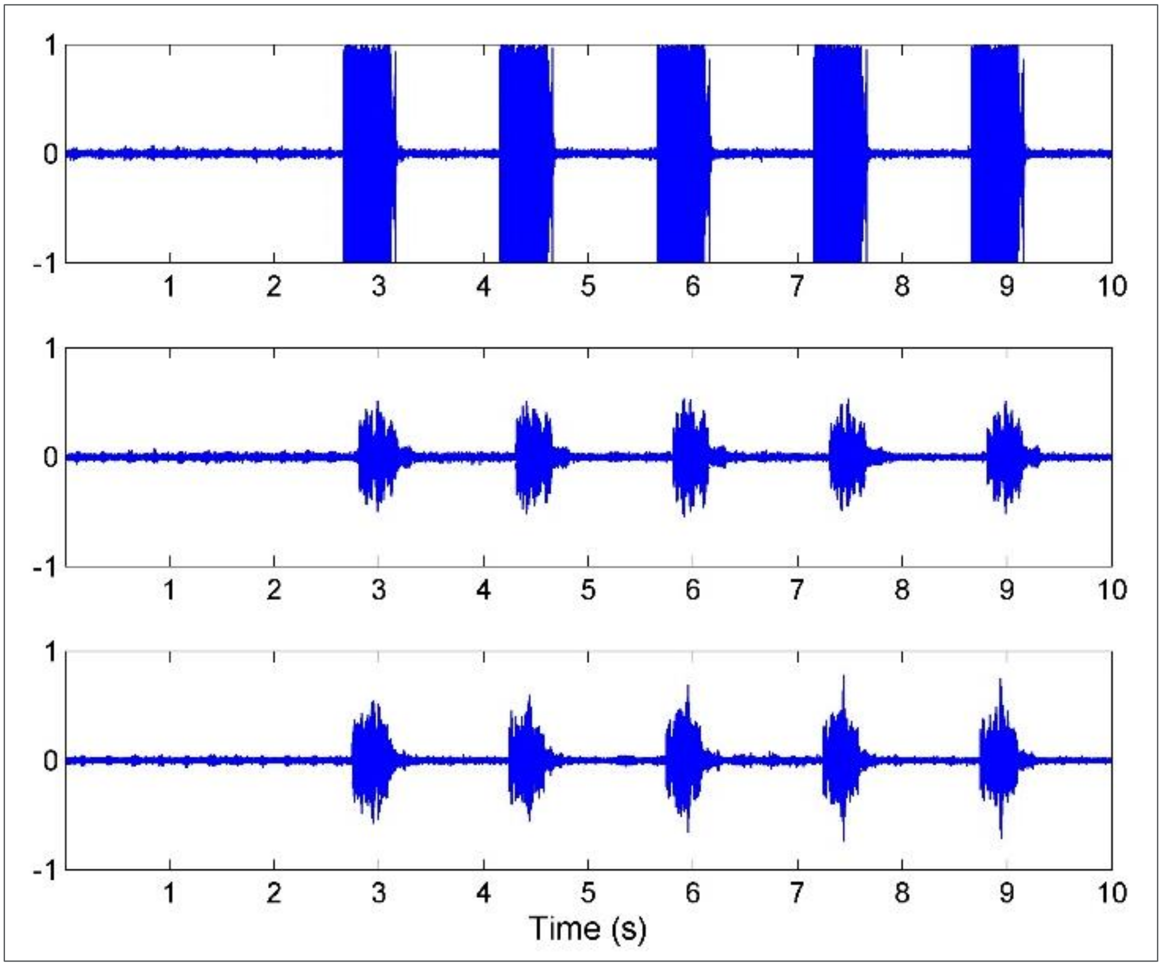

Figure 6. Example of the time-aligned pinger source signal as it was received at EAR B (top), Q (middle), and R (bottom). Y-axis values represent volts.

Once the EARs were time-aligned, each recording was band-pass filtered between 5 and 10 kHz (the band with most dolphin whistle energy for these recordings). Recordings were then divided into overlapping 1-second segments (50 percent overlap). Segments were cross-correlated for each receiver pair, and a threshold function was used to flag 'sound present' segments. Time-differences of arrival between hydrophone pairs for "sound present" segments were estimated by picking the peak in the cross-correlation function for each hydrophone pair. Finally, the estimated time-differences of arrival were fed into a hyperbolic localization algorithm to produce position estimates for each sound (**Figure 7**).

3.2 Temporal Presence of Dolphins in MINEX W-50

The analysis of recordings from site B for the presence/absence of dolphin signals has been completed for the period from 15 August 2012 to 28 July 2014, totaling 530 days of recordings. The findings reveal that dolphins are present daily in or near the MINEX range, with detections (as defined in **Section 2.1**) made on 97 percent of recording days (**Figure 8**). The species identity cannot be confirmed without the use of classification algorithms (not planned under the present contract), but it is assumed that the majority of detections are from bottlenose dolphins (*Tursiops truncatus*), given the presence of a resident population in the area (Barco et al. 1999).

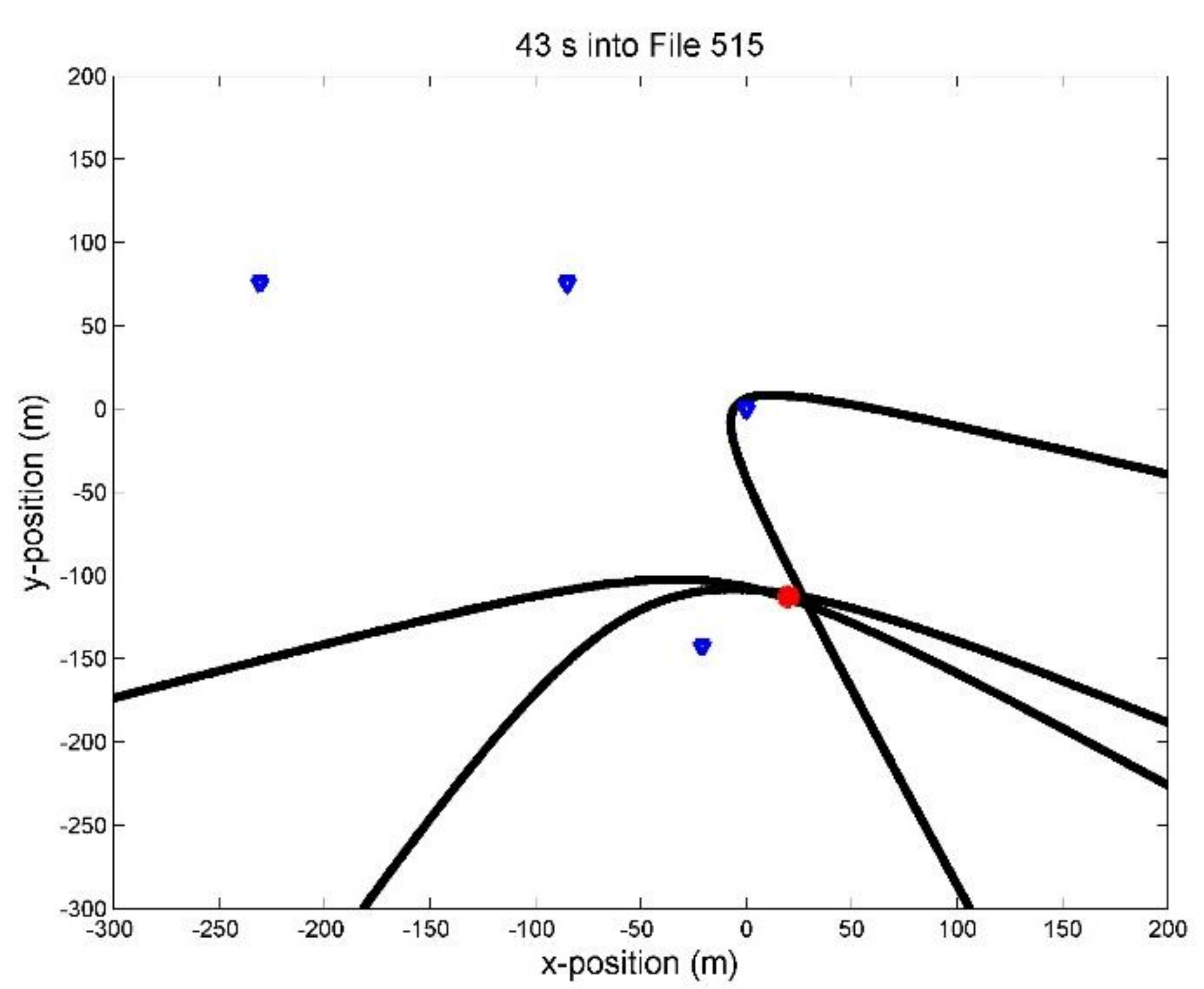

Figure 7. Example of a localized dolphin whistle. The blue marks indicate the positions of the four EARs. The red dot is the position of the signaling dolphin inferred by the convergence of the three hyperbolae.

During the first year of monitoring between August 2012 and July 2013, significant variation was observed in the mean number of daily detections each month (**Figure 9**; One-way ANOVA, DF = 11, F = 28.9, $p < 0.001$), with the lowest overall activity observed between December and February. No data are available for the month of November 2012 because the EAR was not deployed due to weather and logistical constraints. During the second year of monitoring from August 2013 to July 2014, there were again significant differences between months, with February repeating as the month with the fewest number of daily detections. However, there was more variability overall, with reduced numbers of daily detections during the months of August, September, November, and March. Comparing the differences between months from year to year, there were significantly fewer daily detections in August 2013 (Mann-Whitney U test, U = 254, $p = 0.003$), September 2013 (U = 75.5, $p = 0.02$) and March 2014 (U = 394, $p = 0.001$) than the corresponding month the previous year. Conversely, there were significantly more daily detections in December 2013 (U = 394, $p < 0.001$) and January 2014 (U = 685, $p < 0.001$) than the corresponding month the previous year.

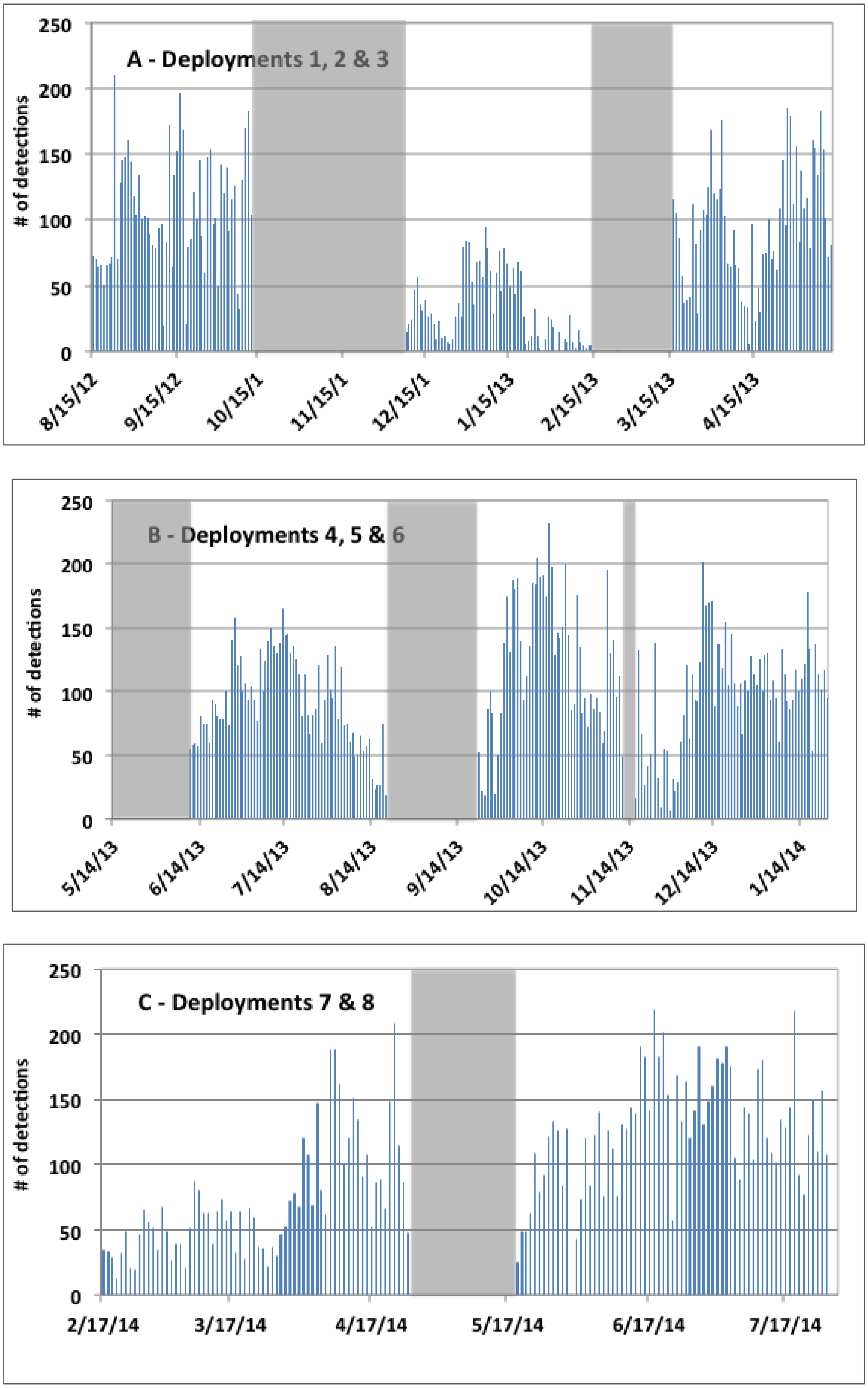

Figure 8. Daily numbers of dolphin detections near the epicenter of UNDET activity in MINEX W-50 between 15 August 2012 and 28 July 2014 for deployments 1–8. All detections are from site B, except during deployment 7 (16 February–27 April 2014), which came from site K. Greyed areas represent periods when the EAR was not deployed or recording.

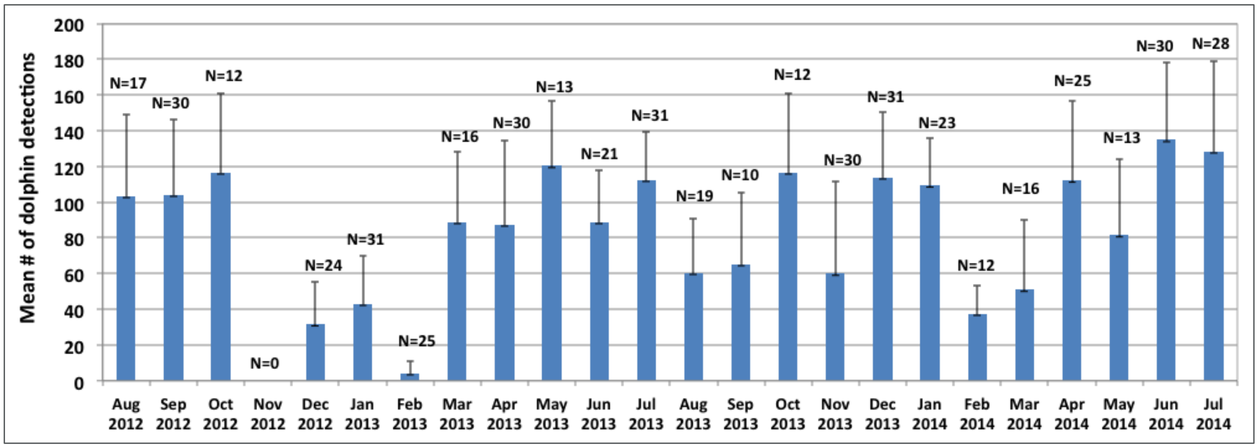

Figure 9. Mean number of daily dolphin detections at EAR site B by month. Error bars represent one standard deviation. 'N' values give the number of days that were monitored during each month. No data were collected in November 2012.

3.3 Dolphin Acoustic Response to Explosions

In total, 46 explosions were detected in the data analyzed between 15 August 2012 and 28 July 2014 (**Table 2**). Dolphin acoustic activity was quantified and compared on progressively longer time scales (i.e., seconds, minutes, hours, and days) relative to each explosion. Detailed manual whistle counts were completed in the 30-second before and after periods for data through 30 July 2013; all other time scales (minutes through days) were characterized using acoustic activity indices (**Section 2.1.**, **Table 1**) through 28 July 2014. **Figure 10** shows the mean number of whistles counted during the 30 seconds immediately preceding and following an UNDET. There were significantly more whistles recorded immediately after an UNDET (Mann-Whitney U-test, $n = 16$, $p = 0.02$), reflecting a short-term increase in whistle production by the animals. In **Figure 11**, the mean acoustic indices are presented for the 3-minute recordings before, during, and after an UNDET. The mean index was greater for the 3-minute recordings containing the UNDET than for the recordings before and after the UNDET; however, this difference was not significant (Kruskal-Wallis test, $N = 45$, $H = 1.5698$, $p = 0.47$). Comparing the mean acoustic indices within the hours before and after an UNDET, a significant decrease in dolphin acoustic signaling was seen during the 2 hours following the event compared to the hour prior to it (One-way ANOVA, $DF = 2$, $F = 9.2$, $p < 0.001$) (**Figure 12**).

The hourly sum of acoustic activity of dolphins the day prior, the day of, and the day after MINEX training events is shown in **Figure 13**. During the day prior to an event, dolphins were most active during mid-day (11:00–12:00), late afternoon (15:00), and nighttime hours (19:00–04:00). On the day of MINEX training and the following day, the daytime peak in activity was reduced or absent, although the nighttime peak persisted. The difference between the day before and the day of the exercise was significant for the three hourly periods between 10:00 and 12:59 (Kruskall-Wallis test, $p < 0.05$). In addition, comparing the day before an exercise with the following day also yielded a significant difference, with less overall activity on the day after the training event for the two hourly periods between 11:00 and 12:59 (Kruskall-Wallis test, $p < 0.05$). Interestingly, the nighttime peak in activity persisted following MINEX training events, suggesting that the animals in the area resumed normal activity during these hours.

Table 2. Explosions detected during deployments 1–8, including the site at which it was detected, the date and time of the explosion, and whether dolphin signals were observed in the same recording (Y = yes, N = no).

Deployment	EAR	Explosion Date & Time	Dolphins present?
1	B	9/5/12 12:21	Y
1	B	9/5/12 16:51	Y
1	B	9/5/12 17:27	Y
1	B	9/11/12 11:03	N
1	B	9/11/12 11:09	Y
1	B	9/11/12 16:09	Y
1	B	9/12/12 10:15	Y
1	B	9/17/12 11:09	N
1	B	9/28/12 15:33	Y
1	B	10/4/12 12:39	Y
2	B	12/10/12 15:09	N
2	A	12/10/12 19:09	N
2	B	1/12/13 19:09	Y
3	B	3/29/13 12:45	Y
3	B	4/3/13 12:53	Y
4	B	6/11/13 13:10	N
4	A	6/19/13 11:20	Y
4	B	7/30/13 12:57	N
4	B	7/31/13 14:33	Y
5	G	10/25/13 11:58	N
6	B	11/22/13 10:31	N
6	B	11/22/13 11:24	N
6	B	11/22/13 11:37	N
6	B	11/22/13 14:32	N
6	B	12/11/13 11:02	N
6	B	12/11/13 12:25	N
7	K	3/9/14 13:51	Y
7	K	3/9/14 14:35	Y
7	K	4/9/14 12:28	Y
7	K	4/9/14 15:33	N
7	K	4/24/14 14:46	Y
8	B	5/20/14 16:20	Y
8	B	5/20/14 18:20	Y
8	B	6/6/14 10:38	Y
8	B	6/6/14 11:44	N
8	B	7/15/14 11:25	Y
8	B	7/18/14 14:38	Y
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8	H	5/21/14 17:27	Y
8	H	5/21/14 17:57	Y
8	H	5/30/14 13:51	Y
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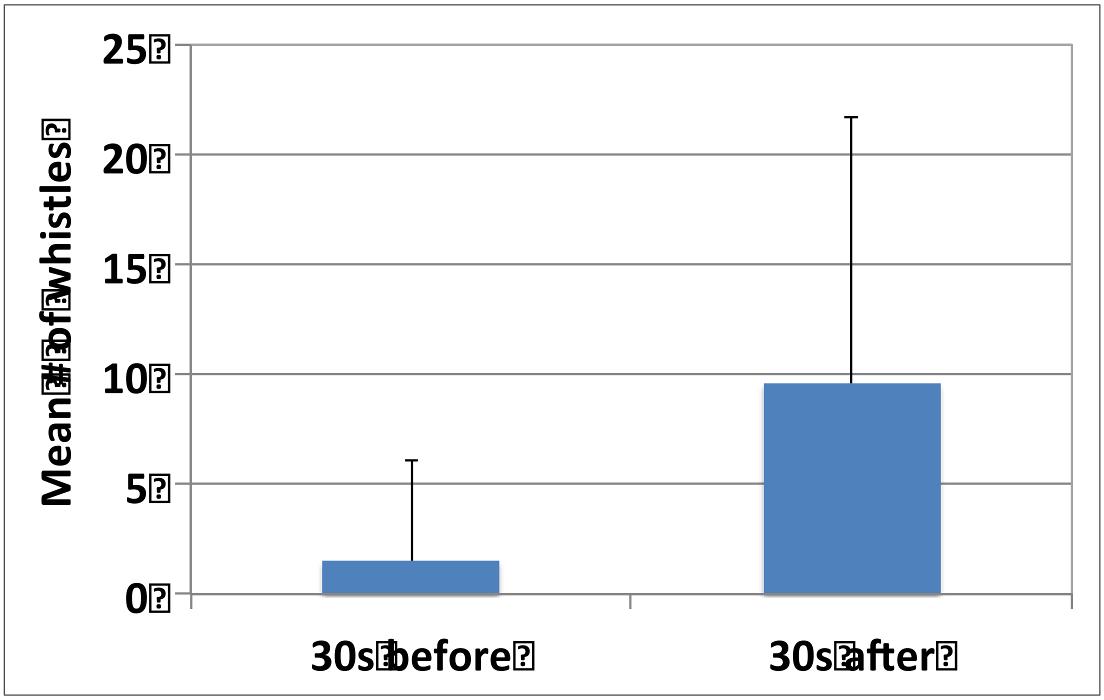

Figure 10. Whistle production observed in the 30 seconds before and after explosions (N = 16). Error bars represent one standard deviation.

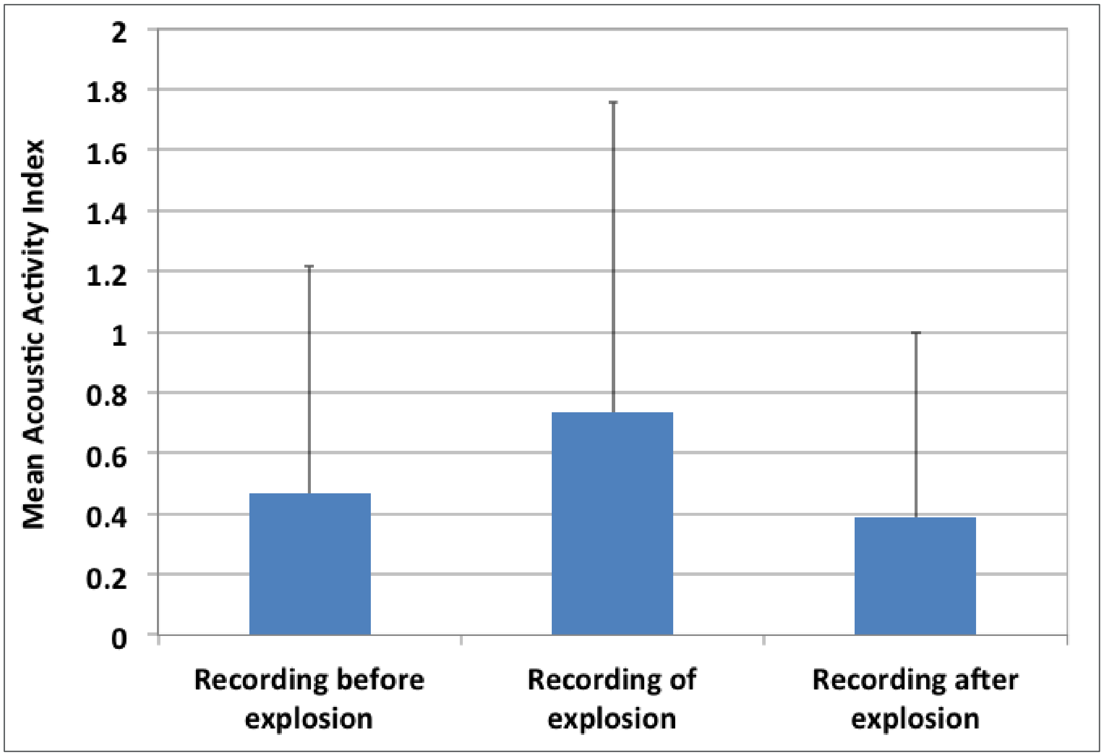

Figure 11. Dolphin acoustic activity observed in the 3-minute recording blocks before, during, and after an explosion (N = 45). Error bars represent one standard deviation.

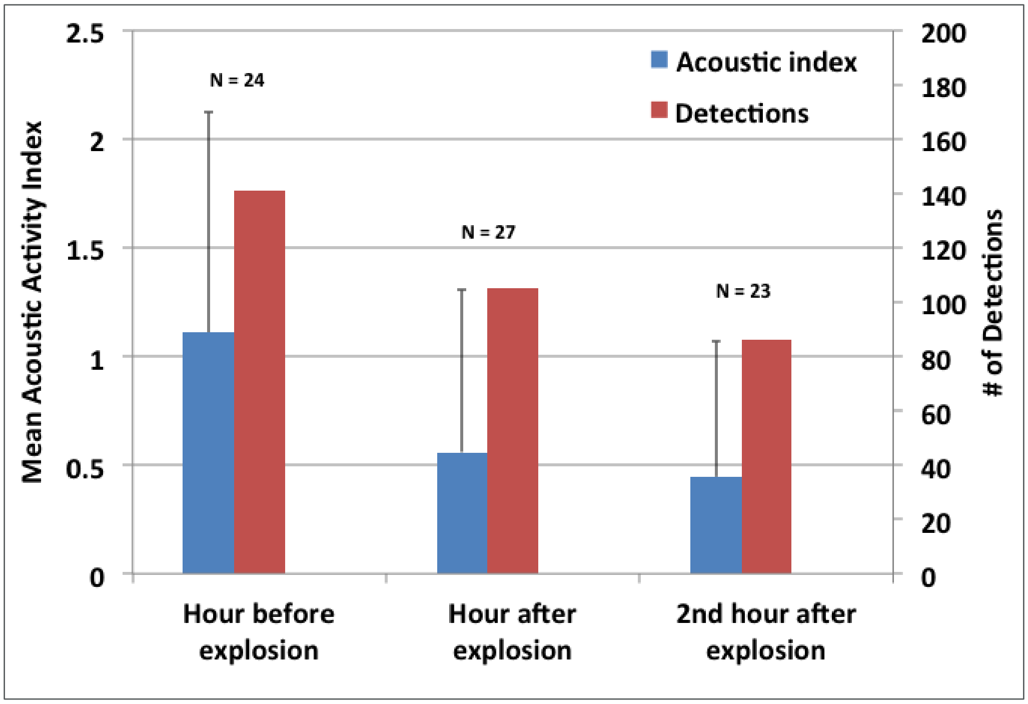

Figure 12. Dolphin acoustic activity observed in the hour before and the first and second hours after an UNDET. The different sample sizes reflect the fact that several UNDETs occurred within minutes or hours of each other and therefore were either treated as a single event or did not have baseline and/or post-UNDET data. Error bars represent one standard deviation.

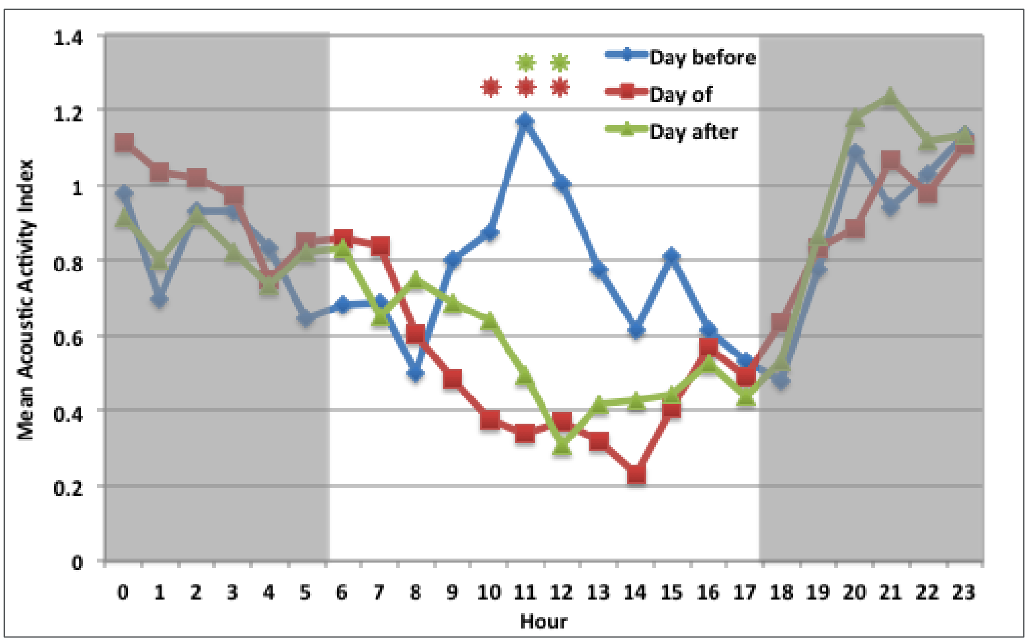

Figure 13. The hourly dolphin acoustic activity observed over the 24-hour period of the days before (N = 18), the days of (N = 22), and the days after (N =18) a MINEX training event at site B. Red stars indicate a significant difference (Kruskall-Wallis test, $p < 0.05$) between the day before and the day of the event. Green stars indicate a significant difference (Kruskall-Wallis test, $p < 0.05$) between the day before and the day after the event. Shaded periods represent twilight/nighttime hours.

However, this also suggests that the decreased activity observed during daylight hours of the following day might represent avoidance of the area.

Figure 14 presents the 24-hour dolphin acoustic activity observed on the linear coast array EARs as a function of the distance from the epicenter of MINEX training for the days before, the days of, and the days after a MINEX training event. For the pooled 3-km data, a significant difference was noted in the acoustic activity between the day before and the day after a MINEX event in the 04:00 time bin (Mann-Whitney U test, $N = 7$, $p = 0.015$). In addition, the difference was just above the $p < 0.05$ level for the 07:00 ($p = 0.084$) and 08:00 ($p = 0.084$) time bins. No inference was attempted on the pooled data from the 6-km sites because of the small sample size ($N = 3$ MINEX events) due to instrument problems at this site during two deployments. For the pooled data from 12 km that comprised seven MINEX events, no statistically significant differences were found between any time bins.

3.4 Summary of Localization Work

The effort expended to date on the localization work has been primarily focused on array deployments and the development of the time-alignment and localization algorithms. The results obtained to date are promising. The integration of the pinger with the EAR array is working well for time-aligning EAR recordings. Attempts to localize dolphin signals are also yielding positive results. **Figure 15** shows a sequence of whistles occurring on recording 515 on EARs B, Q, and R of deployment 9. Analysis of this file using the localization algorithm resulted in about 250 sound position estimates—most were dolphin whistles, some were synchronization pings, and several were likely errors resulting from noise (**Figure 16**).

4. Discussion of Findings and Future Work

After overcoming some initial complications related to the logistics of mooring EARs in the shallow waters off Virginia Beach, this monitoring project continues to yield high-quality information about the occurrence of odontocetes in the MINEX W-50 training area and the behavioral response of dolphins to UNDETs. The data show that dolphins are present in the training area nearly every day. Seasonally, there appears to be a consistent period of low occurrence or reduced acoustic activity centered on the February timeframe. This finding is consistent with seasonal trends in bottlenose dolphin abundance off Virginia Beach reported by Barco et al. 1999 and Engelhaupt et al. 2014. Year to year, differences were observed between a few of the same months, suggesting some inter-annual variability of the occurrence of dolphins in the area immediately around the epicenter. These findings suggest dolphins are periodically exposed to noise from UNDETs, although it is not clear yet at what range. The current effort aimed at localizing animals using the EAR array should yield answers regarding this question.

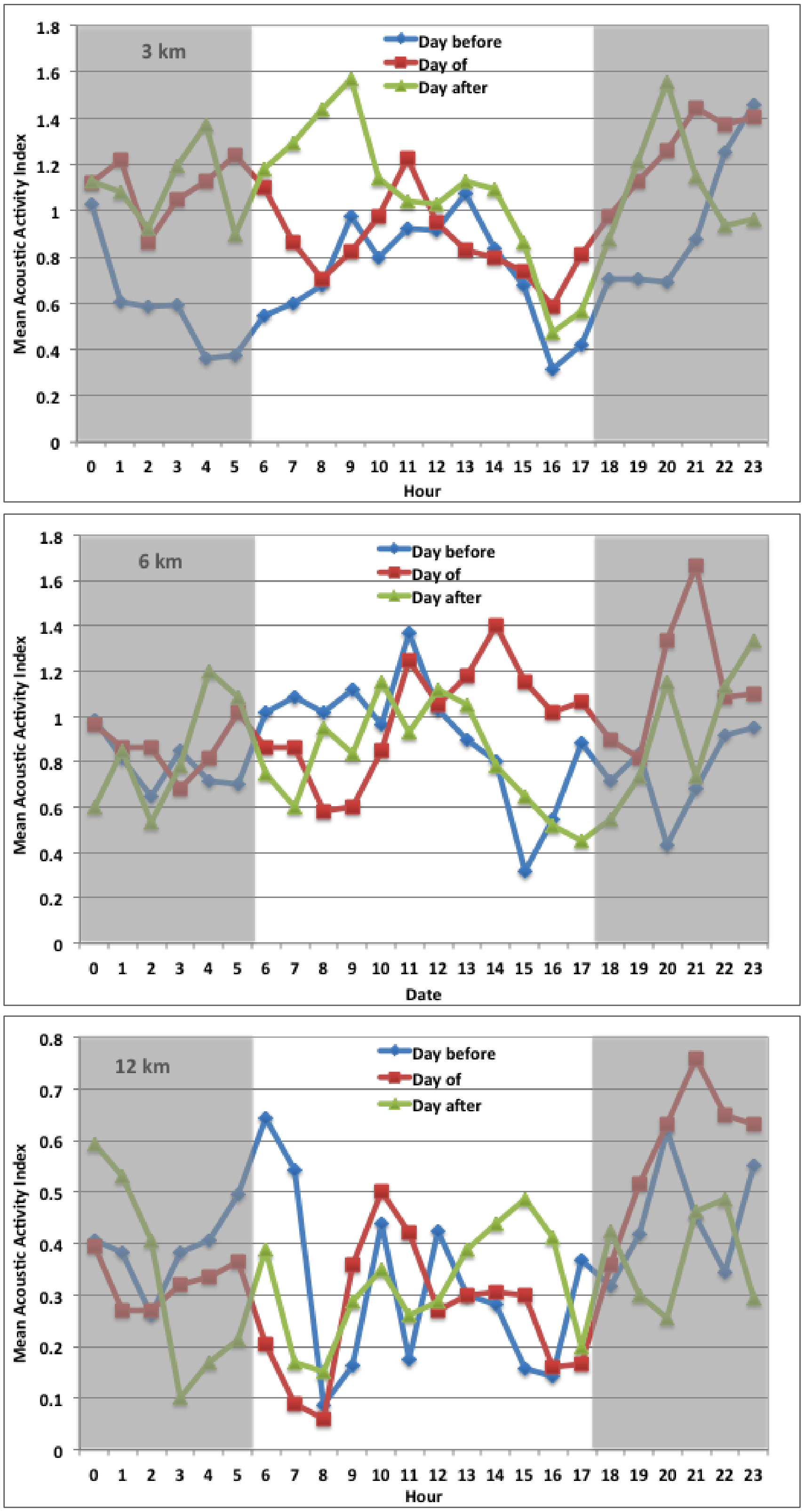

Figure 14. The hourly dolphin acoustic activity observed over the 24-hour period of the days before, the days of and the days after a MINEX training event pooled across sites 3 km (N = 7), 6 km (N = 3) and 12 km (N = 8) from the epicenter of training activities, regardless of directional orientation of array.

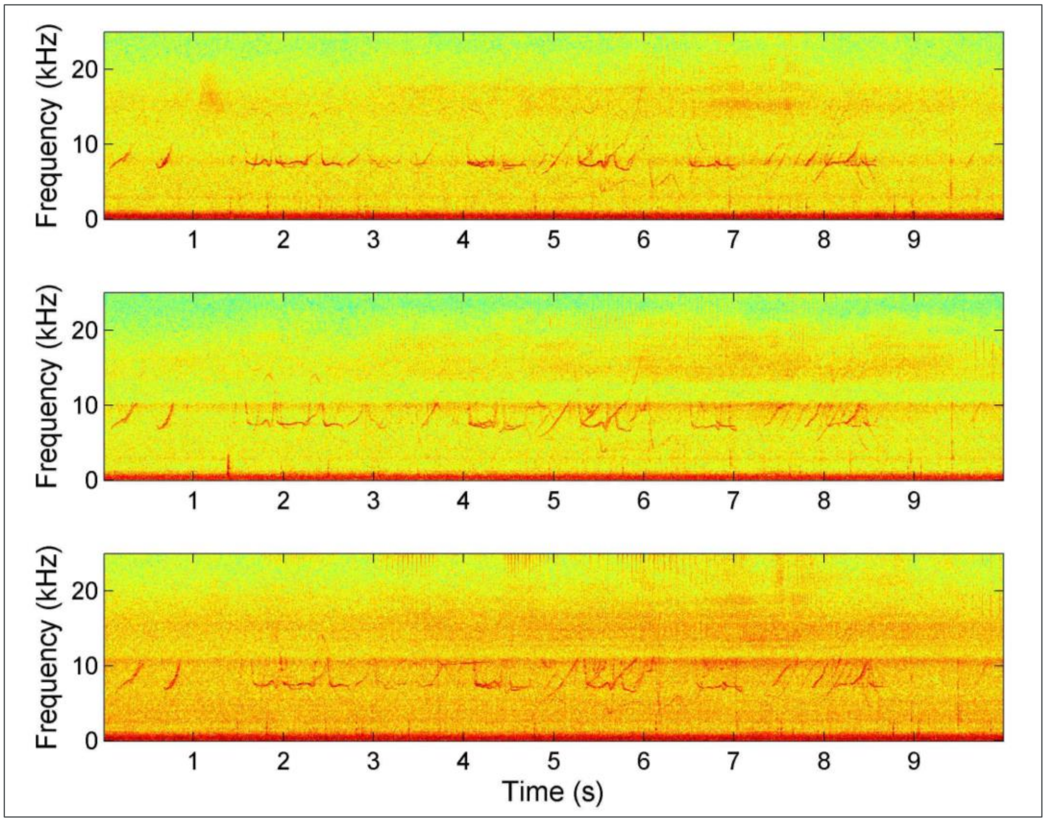

Figure 15. Spectrogram of a time-aligned sequence of whistles occurring on recording 515 of the three EARs for deployment 9.

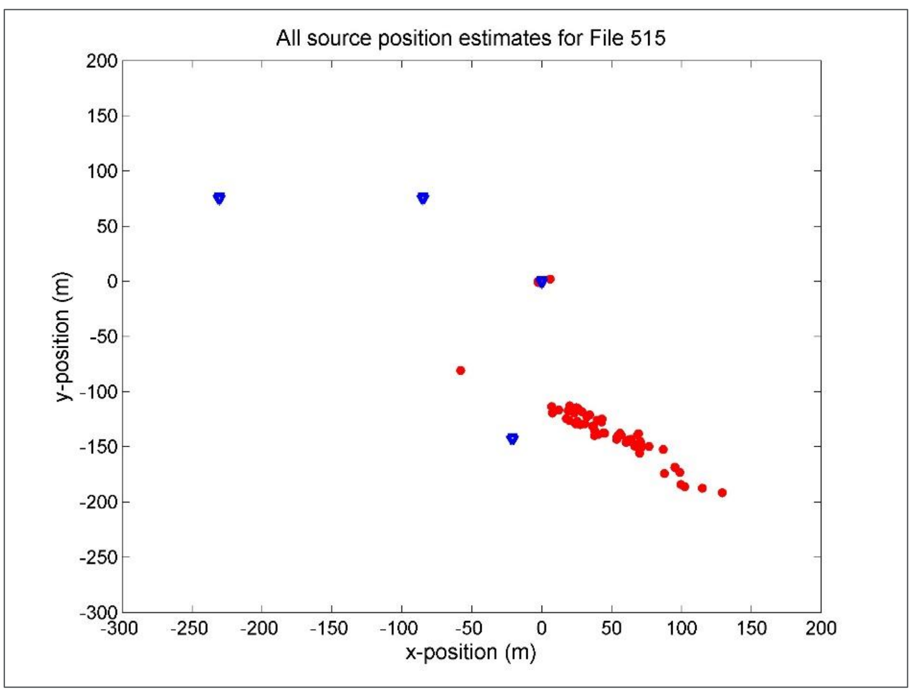

Figure 16. Localizations of dolphin whistles from recording 515. The blue marks indicate the position of the EARs and the red circles indicate localization of all source positions, including whistles, pings, and potential errors.

Based on 2 years of monitoring data, there is evidence that dolphins respond behaviorally to MINEX training events. Following an explosion, there is an immediate short-term acoustic response characterized by increased rates of whistling. Whistles are believed to function as cohesion calls (Janik and Slater 1998), and this response may indicate that the animals were surprised or startled by the explosion and acted to re-establish or reinforce social cohesion. After the immediate response, acoustic activity decreases during the following hours. It is still not clear whether this represents a suppression of acoustic activity by the animals, individuals moving away from the area, or both. In captive animals, stressful events can lead to periods of reduced or no acoustic activity lasting hours or even days (Sidorova et al. 1990, Castellote and Fossa 2006). It is not known whether free-ranging animals respond similarly. However, the data produced by the coastal EAR array deployments are beginning to shed some light on this question. The sample sizes are still too small to draw any clear conclusions, but the data examined to date do not suggest that dolphins follow a consistent pattern of re-distribution away from the epicenter after a MINEX training event. There is some suggestion that dolphins may be more acoustically active or abundant 3 km from the epicenter during the early morning hours of the day after an exercise, but this trend may or may not hold as data from additional deployments are collected and/or analyzed.

The localization array deployments are now yielding useful data. The addition of the pinger to the EAR mooring has made time-alignment of the EAR recordings possible. The algorithms developed to localize signaling dolphins are also showing promise, although ground-truthing efforts will need to be conducted during the final two localization-array deployments planned for later this year. Two other coastal-array deployments are also planned. These will hopefully add additional sample points for the analyses presented here and also allow a more detailed examination of the occurrence of dolphins in relation to specific cardinal distances from the epicenter (i.e., north, south, and east).

5. Acknowledgements

We are very grateful to Amy Engelhaupt, Jessica Aschettino, and Dan Engelhaupt at HDR for their invaluable role in the deployment, recovery, and refurbishing of EARs and also in overall project management. At OSI, Maegan Kraus and Mattie Cifuentes contributed greatly to the analysis of the data and preparation of this report. We thank US Fleet Forces Command and Joel Bell at NAVFAC Atlantic for support of this project.

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Appendix A

EAR Deployment Details

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Table A-1. Recording parameters of the MINEX EARs.

Sampling Rate	50 kHz
Recording Time (duration)	180 s (3 min)
Recording Period (how often)	360 s (6 min)
Anti-Aliasing Filter	90%
Hydrophone Sensitivity	Approx. -193 dB re 1μPa
Clock	Local Time
Disk Space	320 GB maximum
Energy Detection	Disabled

Table A-2. EAR deployment/recovery information and outcomes.

EAR Deployment	EAR Configuration	Deployment Date(s)	Recovery Date(s)	EAR Sites	EAR ID #s Deployed	EARs Recovered	# of Recordings on EAR B	# of Explosions Detected
1	Two paired EARs	8/15/12	10/15/12	A,B,C,D	27,54,61,63	61,63	14296	10
2	Paired EARs	12/7/12	3/3 & 3/15/13	A,B	61,63	61,63	16594	3
3	Paired EARs	3/15/13	5/31/13	A,B	61,63	61,63	16400	2
4	Paired EARs	5/31 & 6/9/13	8/19/13	A,B	61,63	61,63	17051	4
5	Coastal array	9/20/13	11/11/13	B,E,F,G	2,4,61,63	2,61,63	12633	1
6	Localization array	11/16/13	1/23/14	B,N,P	2,61,63	2,61,63	16808	4
7	Coastal array	2/16/14	4/27/14	B,K,L,M	2,61,63,797	2,61,63,797	16293 (EAR K)	5
8	Coastal array	5/18/14	8/3/14	B,I,H,J	2,61,63,797	2,61,63,797	17153	15
9	Localization array	8/15/14	10/27/14	B,Q,R,S	2,61,63,797	2,61,63,797	17536	N/A
10	Coastal array	11/9/14	1/23/15	B,E,F,G	2,61,63,797	2,61,63,797	N/A	N/A

Table A-3. EAR deployment coordinates by deployment site (A through S) and deployment number (1–10). For any given site, only the deployment numbers where an EAR was deployed at that site are included.

EAR site	Deployment	Latitude	Longitude
A	1	36 48.914'N	75 53.199'W
A	2	36 48.887'N	75 53.163'W
A	3	36 48.962'N	75 53.224'W
A	4	36 49.023'N	75 53.154'W
B	1	36 48.904'N	75 52.525'W
B	2	36 48.850'N	75 52.465'W
B	3	36 49.9144'N	75 52.4851'W
B	4	36 48.922'N	75 52.600'W
B	5	36 48.858'N	75 52.620'W
B	6	36 48.894'N	75 52.566'W
B	7	36 48.838'N	75 52.529'W
B	8	36 48.820'N	75 52.537'W
B	9	36 49.053'N	75 53.147'W
B	10	36 48.892' N	75 52.511'W
C	1	36 46.570'N	75 49.684'W
D	1	36 46.564'N	75 48.994'W
E	5	36 46.985'N	75 51.890'W
E	10	36 46.930' N	75 51.795'W
F	5	36 45.388'N	75 51.336'W
F	10	36 45.381'N	75 51.279'W
G	5	36 42.271'N	75 50.124'W
G	10	36 42.258' N	75 50.129'W
H	8	36 49.900'N	75 52.881'W
I	8	36 51.468'N	75 53.436'W
J	8	36 54.621'N	75 53.292'W
K	7	36 49.563'N	75 52.256'W
L	7	36 50.513'N	75 50.395'W
M	7	36 49.993'N	75 44.528'W
N	6	36 48.946'N	75 52.596'W
P	6	36 48.930'N	74 52.660'W
Q	9	36 48.93'N	74 52.500'W
R	9	36 48.85'N	75 52.417'W
S	9	36 48.833'N	75 52.55'W

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