Acoustic Monitoring of Dolphin Occurrence and Activity in the Virginia Capes

W-50 MINEX Range 2012-2013: Preliminary Results

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EXECUTIVE SUMMARY

Mine neutralization exercise (MINEX) activities involving underwater detonations have the potential to injure or kill marine mammals occurring in the same area. To better understand the impact of MINEX training on marine mammals, effort began in August 2012 to monitor odontocete activity at the Virginia Capes Range Complex MINEX site using passive acoustic methods as part of the Navy's Integrated Comprehensive Monitoring Program. The initial objectives of the project were to establish the daily and seasonal patterns of occurrence of bottlenose dolphins (*Tursiops truncatus*) in the training area, to detect detonations related to MINEX activities, and to determine whether dolphins in the area show evidence of a response to MINEX events. 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 to, during, and after MINEX training events, which can occur in the range multiple times per month. The results indicate 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 reveal that dolphins exhibit a short-term response immediately following an underwater detonation event. Acoustic activity increases briefly and then declines substantially during the hours following an event. This response persists during the day following the exercise. The duration of the response until normal behavior is re-established is not yet known.

It is not clear yet whether the responses observed represent a shift in acoustic behavior or a spatial redistribution of animals. To address these issues, a second phase to the project began in September 2013 and is ongoing as of this report. Alternating 2-month deployments in 2013 and 2014 consist of two different EAR array configurations. In the first configuration, four EARs are arranged in a linear coastal array at distances of 1 kilometer (km), 3 km, 5 km, and 10 km from the primary MINEX training area in order to examine whether animals are redistributing along the coast or offshore in response to training events. In the second configuration, EARs are arranged in a localization array to determine the distances that animals occur from MINEX training activities. This information will be useful to better understand the nature of behavioral responses and will inform any future efforts to establish sound exposure levels. Other open questions still to be addressed include the duration of the response exhibited by dolphins to MINEX training events, and whether the magnitude/duration of the responses is tied to factors such as the time of year, weather, the size of the explosive charges used, or other factors yet to be considered.

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Acronyms and Abbreviations

EAR	Ecological Acoustic Recorder
ESA	Endangered Species Act
ICMP	Integrated Comprehensive Monitoring Program
khz	kilohertz
km	kilometer(s)
MINEX	mine warfare exercise
MMPA	Marine Mammal Protection Act
PAM	passive acoustic monitoring
UNDET	underwater detonation
U.S.	United States

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1. INTRODUCTION

The U.S. Navy is required to comply with Federal laws designed to protect marine species, including the Endangered Species Act (ESA) and the Marine Mammal Protection Act (MMPA). As part of the regulatory process, the Navy must monitor and report on certain activities that have the potential to harass, injure or kill marine mammals, such as sonar and underwater detonations. The Navy's Integrated Comprehensive Monitoring Program (ICMP) was created in December 2009 as a planning tool to focus the Navy's monitoring priorities pursuant to ESA and MMPA 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 warfare exercise (MINEX) training range (**Figure 1**), a long-term passive acoustic monitoring (PAM) study began in August 2012, in conjunction with a separate vessel-based visual survey project, to document the temporal occurrence of odontocete cetaceans in the area and to examine their behavioral responses to underwater detonations (UNDETs). The objectives of the first year of the PAM study (August 2012–July 2013) were to:

1. Detail the daily and seasonal occurrence of bottlenose dolphins (*Tursiops truncatus*) near the primary location of MINEX activities.
2. Detect underwater detonations associated with MINEX 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 UNDET site is an acoustic response detectable?
5. Do dolphins show evidence of re-distribution as a result of MINEX activities?
6. At what distance do dolphins occur from UNDETS?

Here we present the methods employed in the PAM study and report on the preliminary results from the first year of monitoring. We discuss the implications of the initial findings and provide recommendations for continued monitoring work. We also describe current data-collection efforts to meet the research objectives for 2013–2014.

2. METHODS

A. 2012–2013 EAR Monitoring

Passive acoustic monitoring was initiated in the W-50 training area on 15 August 2012, using bottom-moored Ecological Acoustic Recorders (EARs) (Fig. 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 ~25 kHz of Nyquist bandwidth recording at a 50 percent duty cycle. 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 that 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 UNDETs. 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 activity (**Figure 3**). 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. Recording parameters and deployment specifics are presented in Appendix A.

Of the four EARs that were initially deployed in August 2012, only one (site B) was successfully retrieved 2 months later. The EAR from site A was recovered on a beach in North Carolina in November 2012 but the hard drive was damaged and the data were unusable. The EARs from sites C and D were not recovered. The loss of the three EARs was likely due to a malfunction in the EAR anchoring system. Based on recommendations from State officials of the Commonwealth of Virginia, four burlap sandbags were initially used as expendable anchors for the EARs and their acoustic releases. We believe these disintegrated prematurely as a result of heavy bio-fouling, causing the EARs and attached acoustic releases to drift away from their deployment locations. As a result of the loss of the two instruments, monitoring at sites C and D was discontinued. For all subsequent deployments, the EARs were anchored using the combination of a 34-kilogram concrete block and three synthetic sandbags. The EARs were recovered, refurbished, and re-deployed by staff from HDR, Inc. approximately every 2 months, or as weather conditions and logistics allowed.

Inspection of the data revealed that the acoustic environment at sites A and B is characterized by broadband noise, predominantly from surface-breaking waves and vessel traffic. The high noise environment is not ideal for the use of automated signal-detection algorithms, which would result in a high false alarm rate. Consequently, recordings were visually analyzed using the Matlab™ program Triton (Wiggins 2003) and/or the program CoolEdit™. An experienced acoustic technician manually scanned recordings from sites A and B for the presence of UNDET events. Given the proximity of sites A and B, it was decided that inspecting only one EAR unit for bottlenose dolphin signals would be sufficient to reveal temporal trends in occurrence and activity. Therefore, data from unit B were analyzed for the presence of both UNDETS and dolphin acoustic activity, while the data from unit A were examined only for the presence of UNDETs. Recordings containing dolphin whistles, echolocation clicks, or burst pulses were considered a 'detection' of dolphins in the area. For periods when UNDETs 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 event. An acoustic activity index (**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 the UNDET(s).

B. 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 southerly oriented 'linear coastal array' configuration (Fig. 4), with the units spaced at distances of 1 km (unit B), 3 km (unit E), 5 km (unit F) and 10 km (site G) 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 liner coastal array deployments will be 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 will also be used to assess whether there is a re-distribution of animals following MINEX training activities. The linear coastal array will be shifted to the east and to the north during subsequent alternating EAR redeployments (**Figure 4**). The initial coastal array deployed on 21 September was recovered on 11 November 2013. However, only three of the units were successfully retrieved. The EAR located 5 km from MINEX training area (unit F) did not respond to commands from the surface transponder used to communicate with the acoustic release and was 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 for the next linear coastal array deployment in January 2014.

Question 6 will be addressed by placing the four EARs in a localization array configuration during alternating deployments, with the units separated by approximately 100 m (**Figure 5**). This array configuration will be used to localize dolphins during periods of MINEX training using time-of-arrival differences of dolphin signals recorded on the four EARs. The time clocks on individual EARs will be calibrated to ensure localization accuracy using two techniques. The first technique will use explosion events recorded on the four EARs as a synchronization pulse to time-align the clocks on the individual EARs. The U.S. Navy will provide the exact locations of UNDETs and these will be used to calculate the time delay between EAR clocks. The second synchronization approach will be implemented multiple times over the course of each deployment. A series of 12-kHz pings will be emitted from a drifting vessel at exact known locations and times using the acoustic-release transponder. The recorded pings will be then be used to time-align the EAR clocks based on the known locations of the transmitting vessel and each EAR.

A Trimble high-accuracy GPS will be used to precisely record EAR deployment locations as well as the locations of the drifting vessel during clock calibration exercises. The four EAR units will be programmed to record simultaneously at a 50 percent duty cycle, allowing them to record the same dolphin signals and explosions. Upon recovery, and once the EAR clocks have been time-aligned, dolphin signals recorded three days before through three days after UNDETS will be localized using time-of-arrival differences. This information will then be used to determine the approximate distance of animals from the UNDET site and to compare the spatial distribution of dolphins during the days prior to and following an explosion. The first localization array was deployed on 16 November 2013 and recovered in late January 2014.

3. RESULTS

A. Work completed to date

HDR staff members have performed six EAR deployments and five EAR recoveries since the beginning of the project on 15 August 2012 (**Appendix A**). Three instruments have been lost during this time and one was recovered with unusable data. However, 10 out of 14 EAR deployments (9 out of 10 after the initial deployments) were successful and produced high-quality data. A total of 143,964 3-minute recordings has been made, totaling nearly 7,200 hours of acoustic data. Of these, 76,974 recordings representing 3,849 hours of data have been made at site B. The data from sites A and B have been analyzed through 19 August and 31 July 2013, respectively.

The coastal array deployed on 21 September 2013 was the first of six scheduled deployments for the 2013–2014 data collection period. Three of the instruments were recovered on 11 November 2013; these data have yet to be analyzed. One of the EARs was not recovered and is presumed lost. The first localization array using the remaining three instruments was deployed on 16 November. Clock synchronization exercises using the 12-kHz transponder signal were conducted three times during the first localization array deployment: on 16 November 2013, 28 December 2013, and 9 January 2014.

B. Temporal Presence of Dolphins

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 31 July 2013, totaling 308 days of recordings. Preliminary findings reveal that dolphins are present daily in or near the MINEX range, with detections made on 98 percent of recording days (**Figure 6**). The species identity cannot be verified without the application of classification algorithms, but it is reasonable to assume the majority of detections are from bottlenose dolphins based on small vessel visual surveys. Significantly fewer detections were made during the period between December and February (**Figure 7**; One-way ANOVA with Tukey's test, $p<0.001$), with the lowest overall activity observed in February. No data are available for the month of November 2012 because the EAR was not deployed due to weather and logistical constraints.

C. Dolphin Acoustic Response to Explosions

A total of 19 UNDETS were detected in the data analyzed from the recording period between 15 August 2012 and 19 August 2013 (**Table 2**). Dolphin acoustic activity was quantified for the days before, during, and after UNDETS for 17 events. Two UNDETs on 11 September 2012 occurred within 5 minutes of each other. These are treated as a single event for the analyses presented here. The acoustic activities associated with the UNDETS on 30 and 31 July 2013 are still being analyzed, and are therefore not included here. Dolphin activity was quantified and compared on progressively longer time scales (seconds, minutes, hours, days) relative to each explosion. **Figure 8** 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, $n=16$, $p=0.02$). This pattern is also shown in **Figure 9**, where the mean acoustic indices are presented for the recordings before, during, and after an UNDET. The mean index was significantly greater for the recordings containing the UNDET than for the recordings before and after (One-way ANOVA, $n=16$, $p=0.05$).

The acoustic activity of dolphins during the hour before, hour immediately following, and the subsequent 2 hours following an UNDET is shown in **Figure 10**. There was significant variability among the four periods (One-way ANOVA, DF=3, F=6.24, p<0.001), with the highest activity occurring during the hour of the explosion, followed by a decrease in activity during the subsequent two hours.

The hourly sum of acoustic activity of dolphins the day prior, the day of, and the day after MINEX training UNDETs (N=16) are shown in **Figure 11**. During the day prior to an event, dolphins were most active during mid-day (11:00–12:00), late afternoon (15:00), and evening hours (19:00–23:00). On the day of MINEX training and the following day, the daytime peak in activity was reduced or disappeared, although the evening peak persisted. The difference between the three days was significant (One-way ANOVA, DF=2, F =9.7, p<0.001). In addition, comparing the day of an exercise with the following day also yielded a significant difference, with less overall activity on the day after the training event (T-test, T=2.08, p=0.043). **Figure 11** also shows the timing of the 17 UNDETs that were recorded and used for the analyses. Thirteen of the seventeen UNDETs took place between 10:00 and 16:00, which corresponds with the hours of reduced dolphin activity observed during MINEX training days and the following day. Interestingly, the nighttime peak in activity persisted following MINEX training events, suggesting that the animals in the area resumed normal activity during these hours. However, this also suggests that the decreased activity observed the following day might represent avoidance of the area. It is presently not clear yet how much time elapses following a MINEX training event before dolphin acoustic activity returns to pre-event levels. However, additional analysis will be performed to address this question in the future.

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 is yielding high-quality information about the occurrence of odontocetes in the W-50 MINEX training range and the behavioral response of dolphins to underwater detonations. The data show that dolphins are present in the training area nearly every day. Between December and February, dolphins were either fewer in numbers or behaved differently acoustically (e.g. vocalized less); present passive acoustic methods cannot differentiate between the two possibilities. Otherwise, acoustic activity during the rest of the year was variable day-to-day, but approximately equivalent between months. These findings demonstrate that dolphins are periodically exposed to noise from MINEX underwater detonations, although it is not clear yet at what distances or received levels. The current effort aimed at localizing animals using the EAR array should yield some answers regarding the question of range, but establishing received levels would require a separate effort using propagation models.

It does appear that dolphins respond behaviorally to MINEX training events. There is an immediate short-term acoustic behavioral response following an UNDET characterized by increased rates of whistling. This is not surprising considering that whistles are believed to function as cohesion calls (Janik and Slater 1998) and would therefore be expected if the animals were surprised or startled by the UNDET. After the immediate response, acoustic activity decreases during the following hours. However, it is presently 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. The data produced by both the coastal EAR array deployments and the localization EAR array may shed light on this question. The former method will examine whether a spatial re-distribution of animals along the coast occurs following a MINEX training exercise, while the localization array will examine whether the range of animals changes before and after explosions. If animals do not show evidence of redistribution and/or their range remains constant, then it may be reasonable to assume that dolphins are changing their acoustic behavior, not their spatial distribution.

Other questions requiring attention include the duration of the response exhibited by dolphins to MINEX training events, and whether the magnitude of responses is tied to factors such as the time of year, weather, the size of the explosive charges used, or other factors. Quantitative analysis of the acoustic signaling occurring during additional days following MINEX training events will help address the question of response duration. Examining factors that might co-vary with the dolphins’ response will likely require a larger sample size of monitored training events under varied conditions than is presently available. Additional data collection beyond the currently scheduled 2-year period may be necessary to obtain sufficient statistical power to draw robust conclusions.

5. REFERENCES

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Sidorova, I. E., Markov, V. I., and Ostrovskaya, V. M. (1990).Signalization of the bottlenose dolphin during adaptation to different stressors. In: Sensory Abilities of Cetaceans. J. Thomas and R. Kastelein, Eds. Plenum Press, New York. Pp. 623-634.

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6. FIGURES

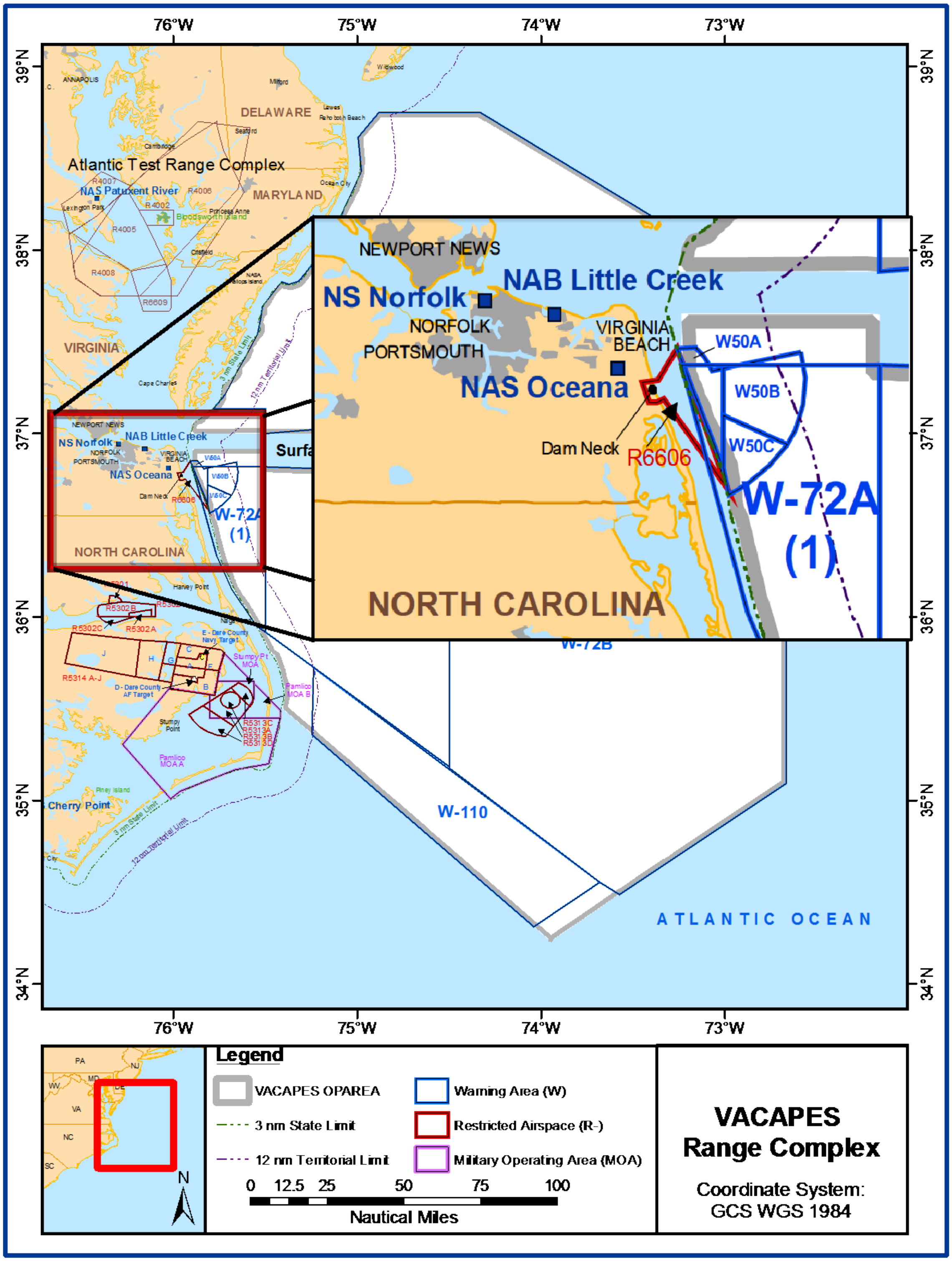

Figure 1. Map of the Virginia Capes (VACAPES) Range Complex displaying an expanded view of the W-50 MINEX training range.

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

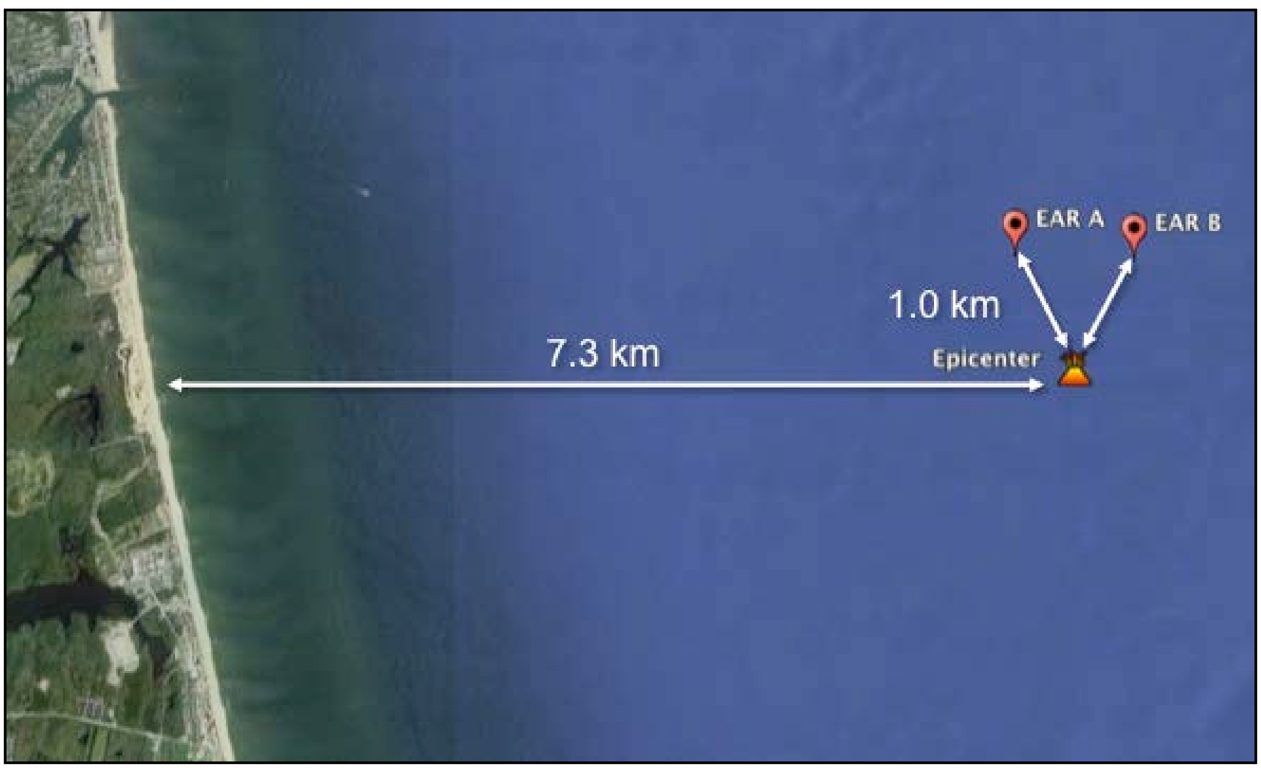

Figure 3. Configuration and spacing of EARs A and B in relation to the Virginia coastline and the 'epicenter' of MINEX activity.

Figure 4. Spatial configuration of three linear coastal EAR arrays (north, east and south) that will be used during the second year of the project. Only one 4-EAR (including EAR B each time) linear array will be deployed at any given time.

Figure 5. Spatial configuration of the localization EAR arrays that will be used during the second year of the project.

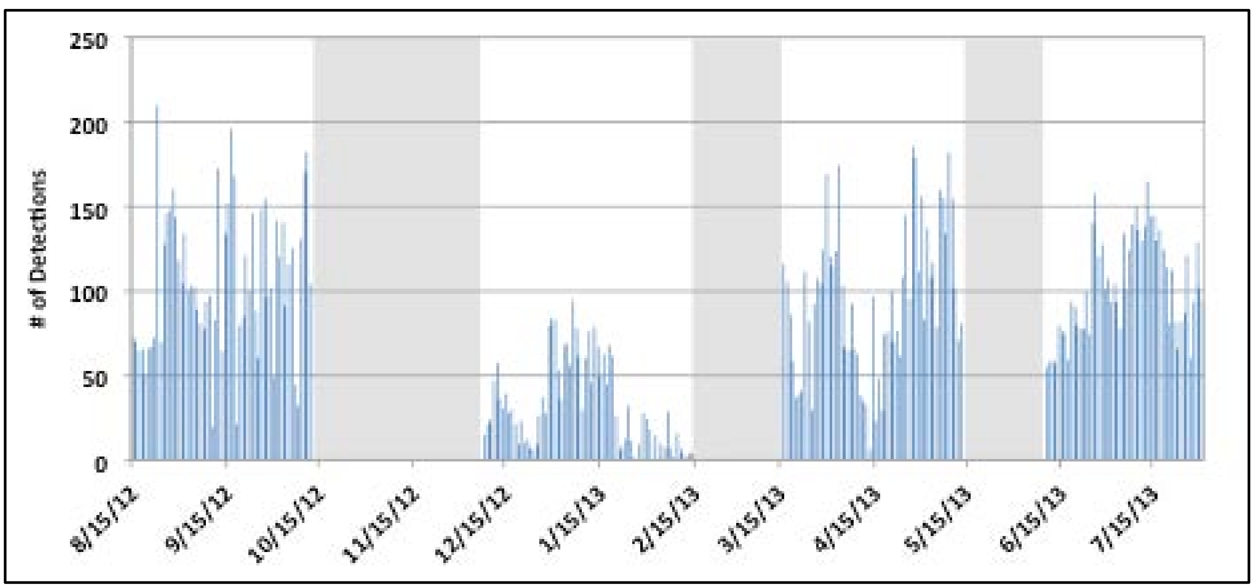

Figure 6. Daily numbers of dolphin detections at EAR site B between 15 August 2012 and 31 July 2013. Grayed areas represent periods when the EAR was not deployed or was not recording due to battery failure.

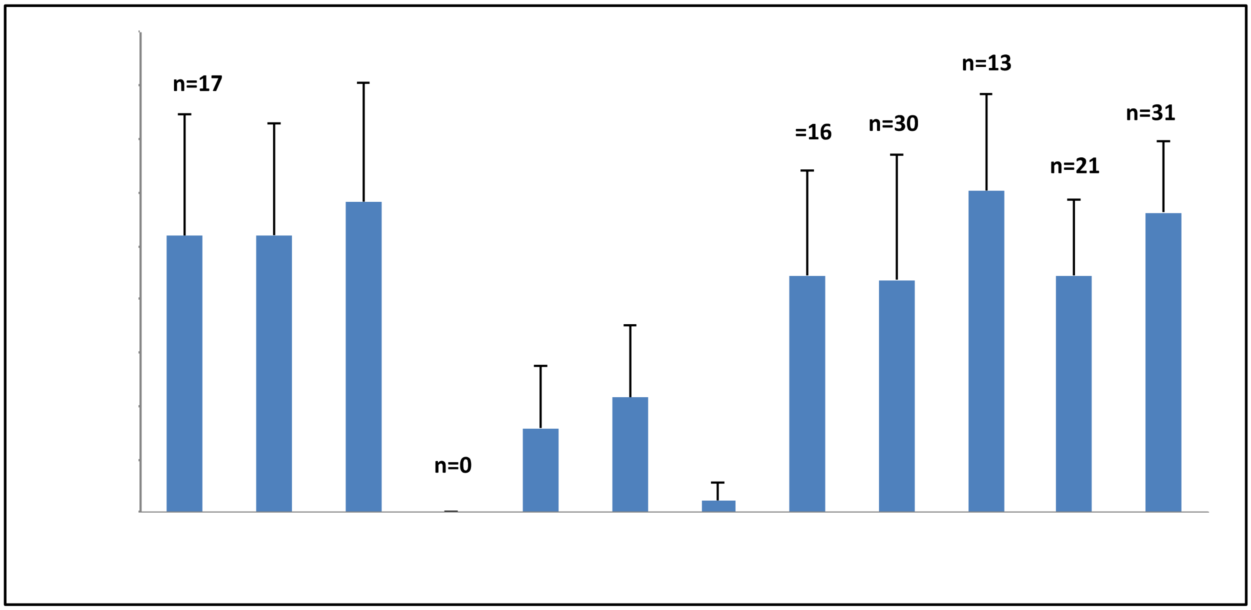

Figure 7. Mean numbers of daily dolphin detections at EAR site B by month. Error bars represent one standard deviation. The 'n' values give the number of days that were monitored during each month. No data were collected in November 2012.

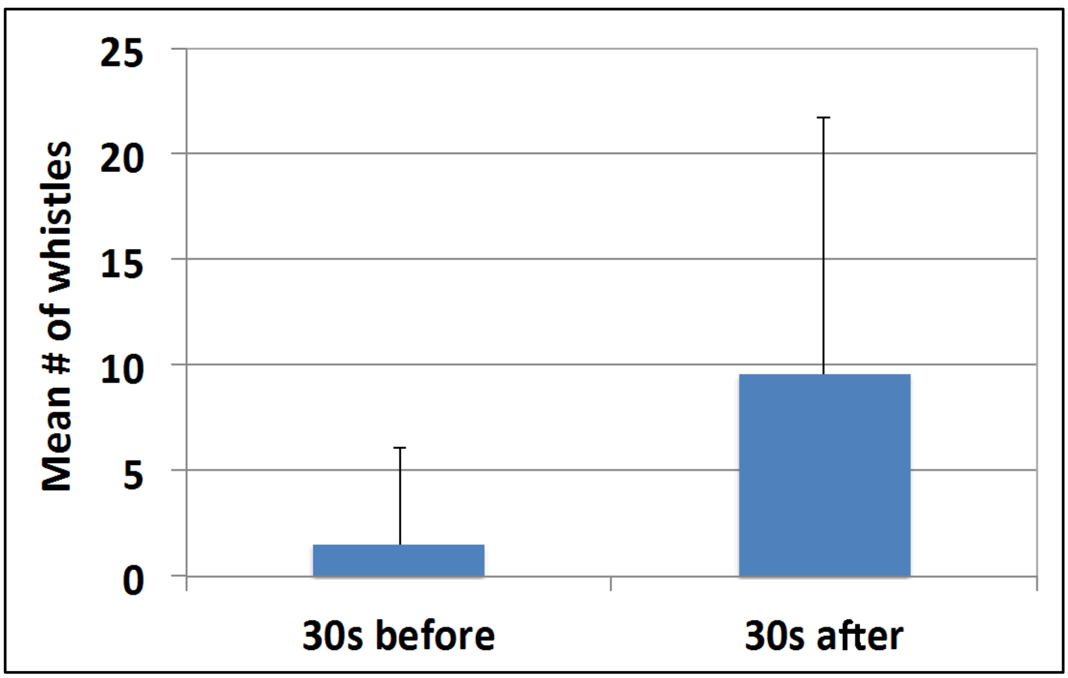

Figure 8. Whistle production observed 30 seconds before and after explosions (N=16). Error bars represent one standard deviation.

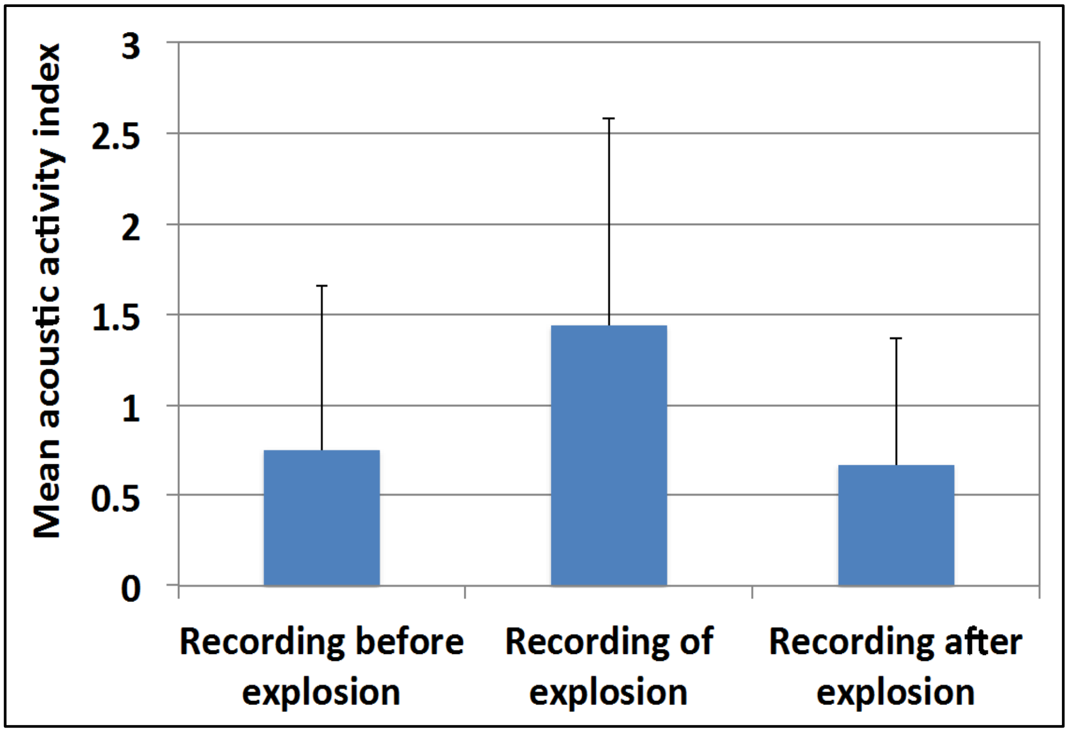

Figure 9. Dolphin acoustic activity observed in the 3-minute recording before, during, and after an explosion (N=16). Error bars represent one standard deviation.

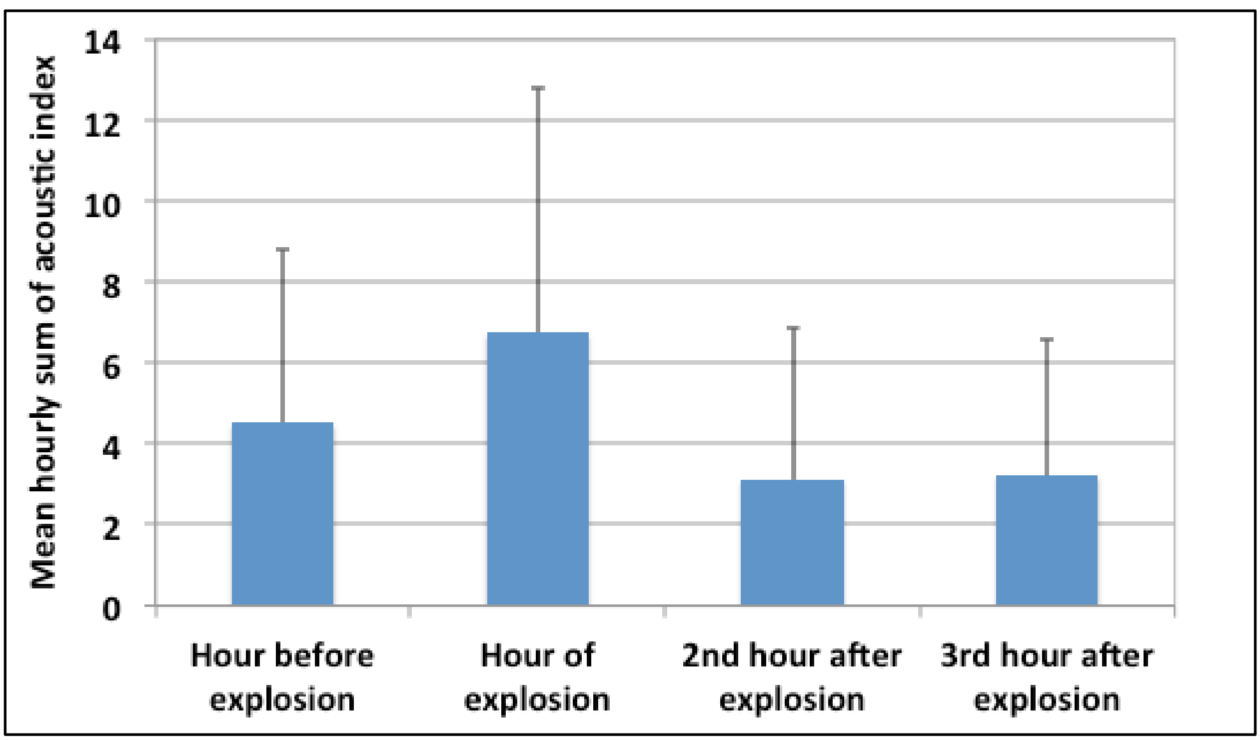

Figure 10. Dolphin acoustic activity observed in the hour before, immediately following, and the second and third hours after an explosion (N=16). Error bars represent one standard deviation.

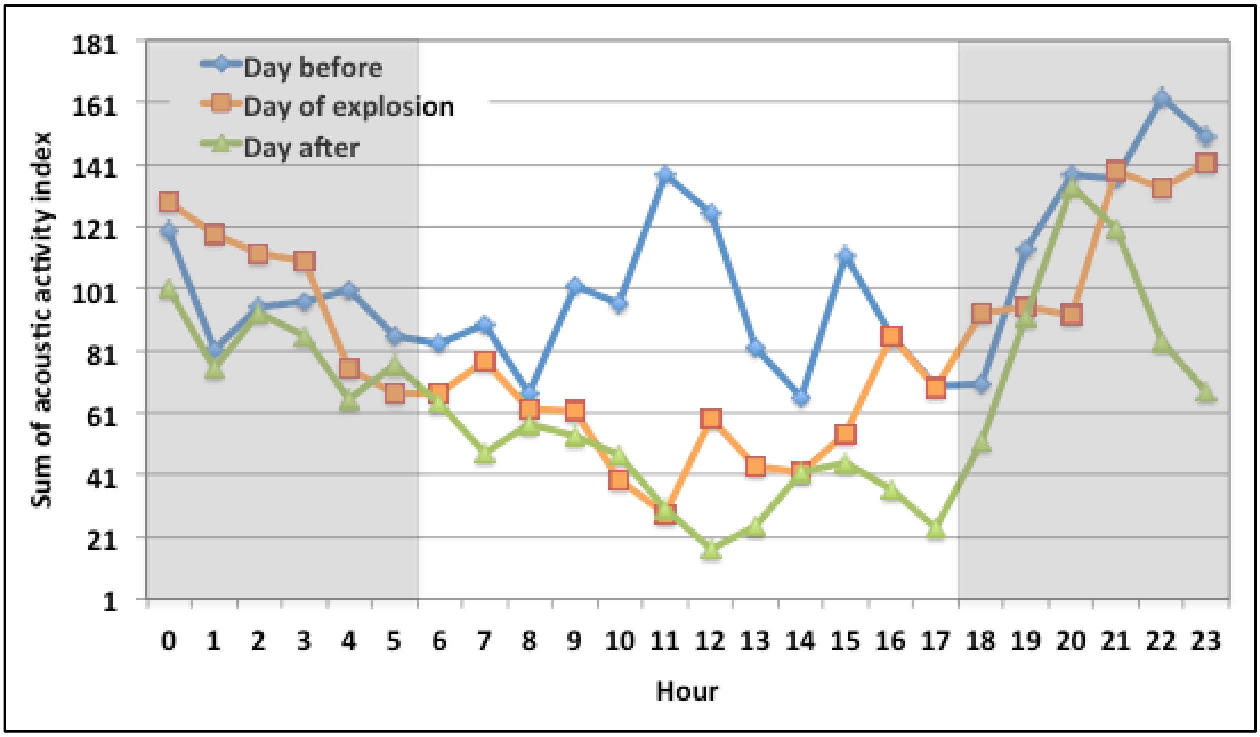

Figure 11. Hourly dolphin acoustic activity observed over the 24-hour period of the days before, the days of, and the days after MINEX training events (N=16). Shaded periods represent twilight/nighttime hours. Daytime acoustic activity is suppressed following training events but returns to normal in the evenings.

7. TABLES

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

Acoustic Category	Index Value
1-20 whistles	1
BP only > 10	1
Sonar only > 2 clicks/sec	1
21-40 whistles	1.5
Sonar only <2 clicks/sec	1.5
BP only > 10	1.5
Sonar & BP < 10	1.5
1-20 whistles & sonar or BP	2
> 41 whistles	2.5
Sonar & BP > 10	2.5
1-20 whistles, sonar & BP	3
21-40 whistles & sonar or BP	3
21-40 whistles, sonar & BP	3.5
> 41 whistles & sonar or BP	3.5
> 41 whistles, sonar & BP	4

Table 2. UNDETs detected during deployments 1–4, including the recording number, the date and time of the UNDET and whether dolphin signals were observed in the same recording (Y = yes, N = no).

Deployment	EAR	Recording #	Explosion Date & Time	Dolphins Present?
1	B	5163	9/5/12 12:21	Y
1	B	5208	9/5/12 16:51	Y
1	B	5214	9/5/12 17:27	Y
1	B	6590	9/11/12 11:03	N
1	B	6591	9/11/12 11:09	Y
1	B	6641	9/11/12 16:09	Y
1	B	6822	9/11/12 10:15	Y
1	B	8031	9/17/12 11:09	N
1	B	10715	9/28/12 15:33	Y
1	B	12126	10/4/12 12:39	Y
2	B	631	12/10/12 15:09	N
2	A	633	12/10/12 19:09	N
2	B	8591	1/12/13 19:09	Y
3	B	3247	3/29/13 12:45	Y
3	B	4448	4/3/13 12:53	Y
4	B	371	6/11/13 13:10	N
4	A	4433	6/19/13 11:20	Y
4	B	12129	7/30/13 12:57	N
4	B	12385	7/31/13 14:33	Y

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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

EAR Deployment	EAR Config	Deployment Date(s)	Recovery Date(s)	EAR Sites	EAR ID #s Deployed	EAR Recovered	# of Recordings on EAR B	# of Explosions Detected
1	2 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	2
5	Costal array	9/20/13	11/11/13	B,E,F,G	2,4,61,63	2,61,63	12633	N/A
6	Localization array	11/16/13	N/A	B,N,P	2,61,63	N/A	N/A	N/A

Table A-3: EAR deployment locations by deployment number

EAR Deployment	EAR Site Coordinates								
	A	B	C	D	E	F	G	N	P
1	36 48.914'N 75 53.119'W	36 48.904'N 75 52.119'W	36 46.570'N 75 49.684'W	36 46.564'N 75 48.994'W	--	--	--	--	--
2	36 48.887'N 75 53.163'W	36 48.850'N 75 52.465'W	--	--	--	--	--	--	--
3	36 48.962'N 75 53.224'W	36 49.9144'N 75 52.4851'W	--	--	--	--	--	--	--
4	36 49.012'N 75 53.154'W	36 48.922'N 75 52.600'W	--	--	--	--	--	--	--
5	--	36 48.858'N 75 52.620'W	--	--	36 46.985'N 75 51.890'W	36 45.388'N 75 51.336'W	36 42.271'N 75 50.124'W	--	--
6	--	36 48.894'N 75 52.566'W	--	--	--	--	--	36 48.946'N 75 52.596'W	36 48.930'N 74 52.660'W

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