Marine Mammal Monitoring on Navy Ranges (M3R) Passive Acoustic Monitoring on the Atlantic Undersea Test and Evaluation Center (AUTEC) and Undersea Shallow Water Training Range (USWTR)

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Table of Acronyms

1.	AUTEC	Atlantic Undersea Test and Evaluation Center
2.	ATO	Authority to Operate
3.	BMMRO	Bahamas Marine Mammal Research Organization
4.	DIACAP	Defense Information Assurance Certification and Accreditation Process
5.	DICASS	Directional Command Activated Sonobuoy System
6.	FA	False Alarm Rate
7.	FN	False Negatives
8.	FP	False Positives
9.	FFT	Fast Fourier Transform
10.	FVT	Feature vector testing
11.	FY	Fiscal Year
12.	GAM	Generalized Additive Model
13.	GVP	Group Vocal Period
14.	I/A	Information Assurance
15.	M3R	Marine Mammal Monitoring on Navy Ranges
16.	MFAS	Mid-Frequency Active Sonar
17.	NAEMO	Navy Acoustic Effects Model
18.	NMFS	Northeast Fisheries Science Center
19.	PMRF	Pacific Missile Range Facility
20.	PCoD	Population Consequences of Disturbance
21.	PD	Probability of Detection
22.	RL	Receiver Level
23.	RMS	Root-Mean Squared
24.	SCORE	Southern California Offshore Range
25.	USFF	United States Fleet Forces
26.	USWTR	Undersea Warfare Training Range

1. Executive Summary

In FY16, the following tasks were completed by Marine Mammal Monitoring on Navy Ranges (M3R) at the Atlantic Undersea Test and Evaluation Center (AUTEC) in the Tongue of the Ocean off Andros Island in the Bahamas and the Undersea Warfare Training Range (USWTR) currently under development off Jacksonville Florida.

1. Blainville's beaked whale (*Mesoplodon densirostris*, *Md*) detection statistics (probability of detection (PD) and false alarm rate (FA)) for M3R's Auto-Grouper program were derived and correction factors were calculated from beaked whale detections at AUTEC (Moretti and Fothergill, in preparation). Archived data were analyzed and the correction factors applied to derive a defensible initial *Md* abundance estimate.

2. An analysis of sighting data was completed by the Bahamas Marine Mammal Research Organization (Claridge, 2017). An update to the demographic analysis as presented by Claridge 2015 was completed. These data, in particular a comparison of the ratio of dependent calves to adult females, were provided and are being used to inform the Population Consequences of Disturbance (PCoD) model for *Md* at AUTEC.

3. An initial analysis of the behavioral risk functions for lower transmit level small-sources, including dipping sonar and DICASS sonobuoys, was initiated using AUTEC data. The functions calculate the probability of a behavioral disturbance (dive start disruption) as a function of mid-frequency active sonar (MFAS), root-mean squared (rms) receive level (RLrms). Initial analysis suggests that the behavioral risk function presented in Moretti et al., 2014 shifts approximately 10 dB re 1 µPa lower for sources smaller than hull mounted systems such as dipping sonar and DICASS sonobuoys.

4. An M3R signal processor was installed on the three-node evaluation array installed in August 2016 as part of the USWTR development. The processor is collecting both high and low frequency archives that will allow the initial evaluation of species vocalizations present on the range, including North Atlantic right whales (*Eubalaena glacialis*)

5. The Information Assurance (I/A) package for AUTEC was completed, submitted to NAVSEA Echelon II, and approved under the Department of Defense Information Assurance Certification and Accreditation Process (DIACAP). The Authority to Operate (ATO) at AUTEC was granted in December 2016.

2. 2016 Goals

In 2016 the programs were to

1. Develop and validate semi-automated tools to extract necessary data from M3R detection archives to support long-term estimates of *Md* abundance.

2. Demonstrate the above tools to produce a defensible AUTEC *Md* density estimate

3. Analyze mark-recapture data collected for *Md* at AUTEC (2005- 2016) to compare reproductive success and social structure to a separate *Md* population at Abaco

4. Analyze single ship, dipping helicopter, and DICASS sonobuoy events for potential variations in the *Md* behavioral risk function.

5. Design, build, test, and install a M3R signal processor to begin collecting detection data on the three-node USWTR prototype array

6. Complete the necessary I/A package and obtain the formal ATO at AUTEC

3. Validation of semi-automated tools

Blainville's beaked whale detection data were obtained from M3R archives collected at AUTEC [1]. The AUTEC undersea acoustic range is located off Andros Island in a deep-ocean canyon known as the Tongue of the Ocean or TOTO. The TOTO ends in a circular canyon known as the cul-de-sac. Animals must enter and leave the TOTO from the North. All data archives were collected from the 92 AUTEC hydrophones located approximately at the TOTO mid-point.

Initial abundance (N) estimates based on *Md* dive starts, as described by Moretti et al., 2010, assumed a probability of detection of one (PD=1), and a false alarm rate of zero (FA=0) as given in Equation 1 below [2]. The number of dives (s) was obtained from M3R detection archives over a known time period (T). The dive rate (d) was obtained from tags placed on selected animals.

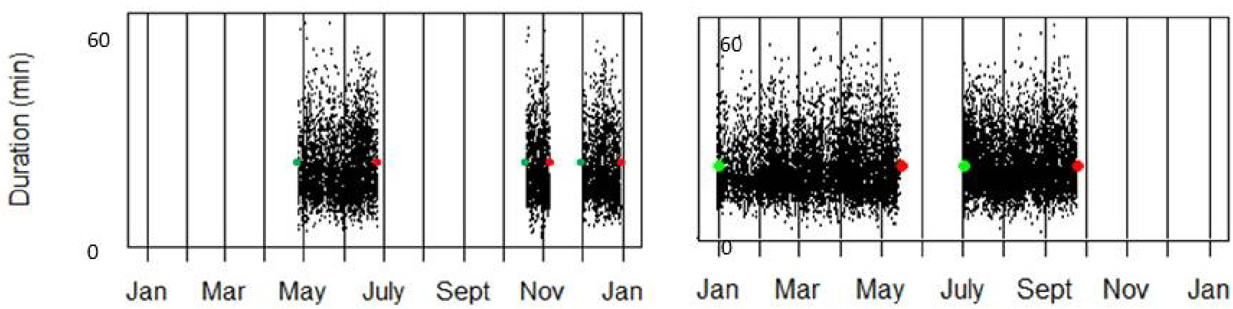

Figure 1. 2011 and 2012 data periods indicated by the dive duration for each detected *Md* dive. The period start (green) and stop (red) are indicated by the respective dots.

The Moretti et al., 2010 assumptions of PD=1 and FA=0 were reasonable for manually extracted and verified data (Equation 1), but not for *Md* group data automatically extracted [2].

$$\boldsymbol{N = \frac{sg}{dT}} \qquad \text{Equation 1}$$

N = number of animals
s = total number of dive starts
g = average group size
d = dive rate (dives/unit time)
T = measurement period

To obtain a measure of PD, False Positives (PF), and False Negatives (FN), random 2 hour periods were chosen throughout the corresponding 2011 and 2012 M3R archives (Figure 1) and examined by an analyst. Dive starts were manually identified and compared to those automatically extracted (1). These data were used to calculate correction factors for False

Negatives (C_N) and False Positives (C_P) and a bootstrap process was used to estimate the corresponding coefficient of variance (CV) for each.

Table 1. Comparison of automatically and manually extracted dive starts used to calculate PD and FP.

AUTEC 2011-2012

Sample #	Total # Manual Dive Starts	Total # Auto Dive Starts	# Exact Matches	# Confused Matches			# Dive Starts Manual Only (FN)	# Dive Starts Auto Only (FP)
				# Manual Dive Starts	# Auto Dive Starts	Confused vs Auto		
1	6	6	6	0	0	0	0	0
2	1	3	1	0	0	0	0	2
3	6	4	3	2	1	1	2	0
4	5	5	5	0	0	0	0	0
5	4	3	3	0	0	0	1	0
6	6	6	4	1	2	1	1	1
7	6	7	4	1	2	1	1	2
8	8	8	7	0	0	0	1	1
9	2	3	1	1	2	1	0	1
10	8	5	4	3	1	1	3	0
11	5	6	4	0	0	0	1	2
12	10	10	9	0	0	0	1	1
13	5	5	5	0	0	0	0	0
14	7	7	5	1	2	1	1	1
15	4	5	3	1	2	1	0	1
16	7	7	7	0	0	0	0	0
17	6	9	4	2	4	2	0	3
18	5	5	5	0	0	0	0	0
19	0	3	0	0	0	0	0	3
20	5	3	2	0	0	0	3	1
21	2	1	1	0	0	0	1	0
22	9	9	9	0	0	0	0	0
23	8	7	6	2	1	1	1	0
24	5	5	5	0	0	0	0	0
25	7	5	5	0	0	0	2	0
26	7	9	5	2	4	2	0	2
27	6	8	4	2	4	2	0	2
28	5	4	4	0	0	0	1	0
29	7	7	7	0	0	0	0	0
30	5	4	4	0	0	0	1	0
31	1	1	1	0	0	0	0	0
32	5	6	5	0	0	0	0	1
33	6	5	5	0	0	0	1	0
34	5	4	3	0	0	0	2	1
35	7	6	4	1	2	1	2	1
36	8	12	5	2	4	2	1	5
37	8	8	6	1	2	1	1	1
38	4	9	4	0	0	0	0	5
39	4	3	2	0	0	0	2	1
40	7	7	6	0	0	0	1	1

Total	**222**	**230**	**173**	**22**	**33**	**18**	**31**	**39**

Based on this analysis, a PD of .861 and a FP of .17 were calculated (Table 2).

% PD	**% FN**	**% FP**
0.860	0.139	0.170

Table 2. Probability of Detection, False Negatives, and False Positives calculated from randomly selected 2 hr. data periods.

$$\boldsymbol{N = \frac{sgC_nC_p}{dT}}$$ Equation 2

False positive correction factor (C_P) = 1-FP=.83
False negative correction factor (C_n) = 1/PD=1.163

4. Blainville's beaked whale abundance

Corrected monthly abundance (Equation 2) was estimated for 2011 and 2012 data periods (Figure 2). The delta method was used to calculate the CV for each [2].

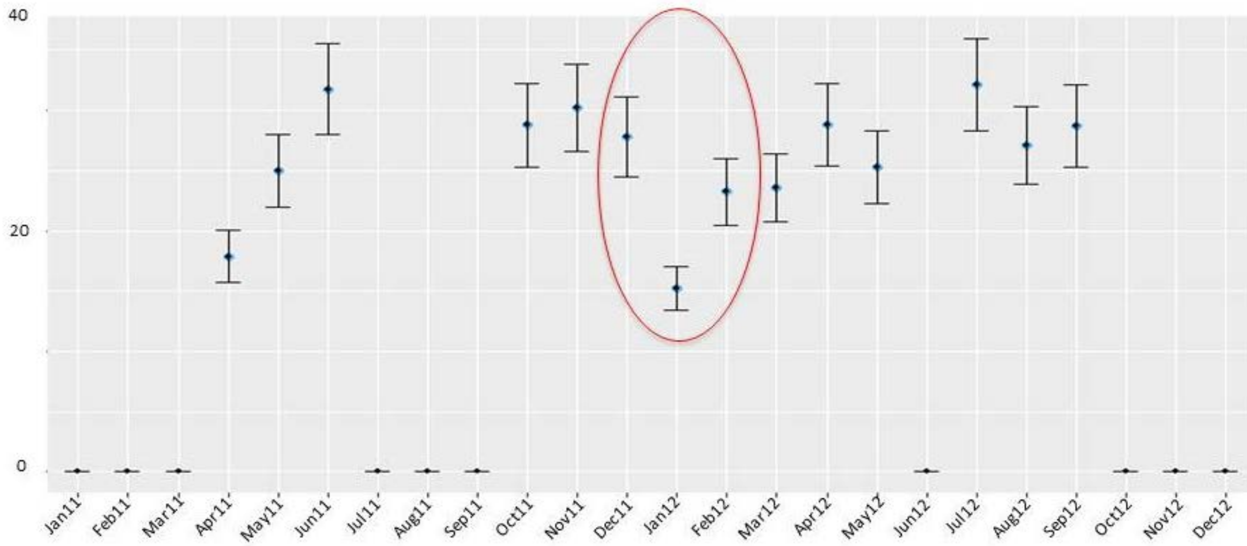

Figure 2. An estimate of the number of individual *Md* present (95% CI) per month derived from 2011 and 2012 detection archives corrected for PD and FA. Dip in monthly abundance indicated by the red ellipse.

The monthly estimate for January, 2012 appears to be low as compared to the surrounding months of December and February. The methods described allow examination of abundance on a finer scale to determine if such a monthly decline is supported by the data. Figure 3 provides the corrected abundance on a daily scale. A clear daily decline is evident.

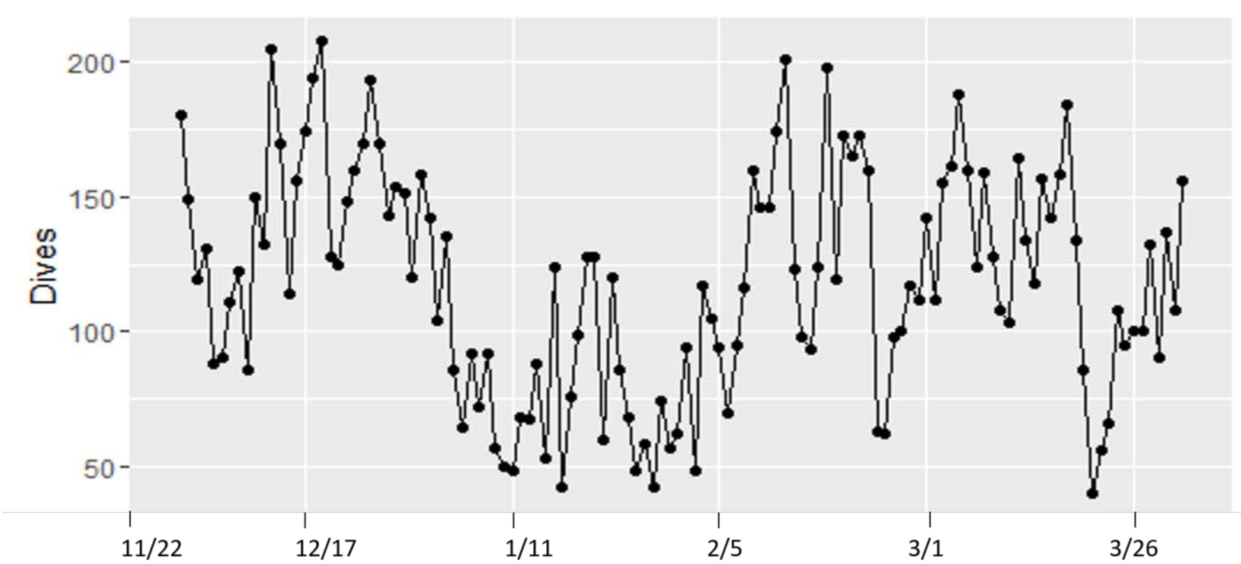

Figure 3. Daily abundance from 2 December, 2011 to 1 April, 2012
The described method provides a viable means of estimating short-term and long-term abundance. The correction factors derived are site-specific and depend on multiple factors, including system specific hardware and software, local bathymetry, propagation effects, and competing noise sources. Perhaps the single largest contributor to FA is the presence of

competing species vocalizations; however, at AUTEC, the density of other odontocete species is low. Species such as pantropical spotted dolphins are sometimes present, but generally detection of *Md* at AUTEC is straight forward. Detection is more difficult at SCORE and PMRF, where species density is higher and many odontocete species are found on the range.

5. Initial behavioral risk function evaluation of single ship, helicopter-deployed dipping sonar, and DICASS sonobuoy exercises

An initial *Md* risk function evaluation of single ship, dipping sonar (helicopter-deployed), and DICASS sonobuoy events was begun with funds provided by USFF and is on-going. Data from individual events of each type were isolated from the 2011 and 2012 AUTEC archive data. Only those isolated events that had a preceding time span of at least 72 hours free from MFAS operations were considered.

The method presented in Moretti et al., 2014 was applied [3] . Group vocal periods (GVPs), during which animals are echolocating at depth were detected [4]. Data were divided into 30 minute periods, the length of which is approximately the mean duration of a group vocal period (GVP) [2]. GVP start times within each 30 minute period were estimated from the initial clicking for a given *Md* group. The hydrophone with the highest number of clicks was designated the hydrophone closest to the group center. During operations, sonar pings were detected and for each ping a modified version of the Navy Acoustic Effects Model (NAEMO) was used to estimate the RL_{rms} on each hydrophone on the range. The maximum RL_{rms} for each hydrophone and 30 minute period was estimated. The probability of a dive start on a given hydrophone in a 30 minute period with no sonar ahead of an operation was calculated. For time periods during an operation, the probability of a dive start as a function of RL_{rms} was estimated via a generalized additive model (GAM). The probability of a dive start during an operation was compared to that calculated with the baseline to estimate the probability of dive disturbance as a function of RLrms (Figure 4).

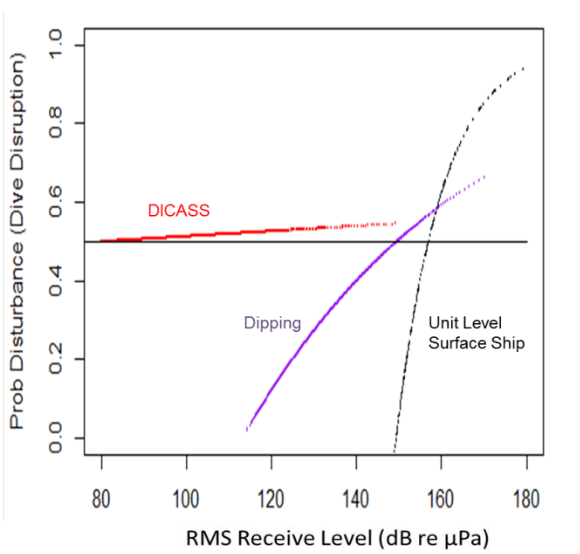

Figure 4. Preliminary probability of dive disruption for surface ship (black), dipping helo (purple) and DICASS sonobuoys (red) as a function of RL_{rms}.

These results are preliminary, but suggest that the reaction to sonar may be a function of both source level and distance from the source. For example, given their published source levels, at a RL_{rms} of 150 dB, a 53C would be at a distance of approximately 20,000 m, a helo with dipping sonar would be at a distance of approximately 2,000 m, while a DICASS sonobuoy would be at a distance of approximately 350 m.

These initial data are being expanded to additional years to increase the sample size and to address questions raised with the initial analysis.

6. Analysis of visual mark-recapture data

In 2015, the Bahamas Marine Mammal Research Organization expanded on the analysis completed by Claridge 2015 for mark-recapture data from 2005 -2010 to add data from 2011 to 2015. Both the abundance and age structure for *Md* populations were analyzed at AUTEC and at a comparative site off the southern tip of Abaco in the Northwest Providence Channel. While MFAS is routinely used at AUTEC, the Abaco site is generally free of MFAS. Social structure at both sites was also examined.

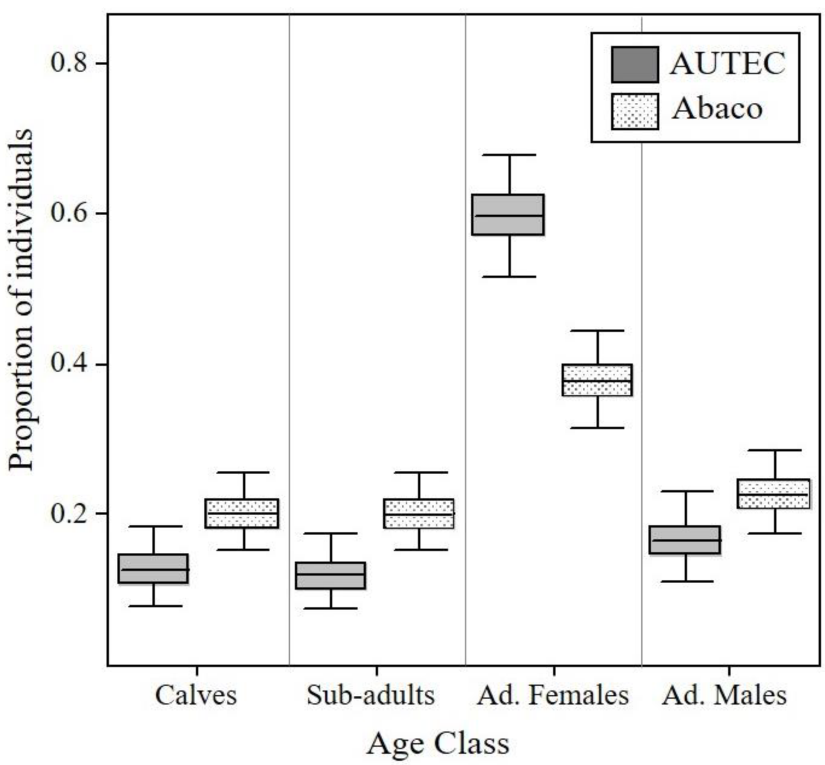

Figure 5. The average annual proportion of individuals within each age class at AUTEC and Abaco are presented as posterior medians (solid black line within bars), with 75% (grey bars) and 95% (vertical whiskers) showing the highest posterior density intervals. Extracted from

BMMRO Technical Report *Analysis to Compare Reproductive Success and Social Structure of Beaked Whales* [3].

Of particular note, the calf to adult female ratio at Abaco was estimated at 0.532 and at AUTEC 0.212 (Figure 4). This would suggest a longer inter-calf interval at AUTEC. A longer inter-calf interval at AUTEC suggests a reduced female fitness, which could be due to one or a combination of factors including prey density, cumulative MFAS displacement, biological factors affecting maternal health, increased calf mortality, etc.

Currently, Population Consequences of Disturbance models are under development [4]. These models will provide a tool to investigate the effect of cumulative disturbance on a population level. They assume that a reduction in calorie intake will be reflected along female lines and that a reduction in fitness will result in lower fetal and calf survival, leading to a decrease in the ratio of dependent calves to adult females.

For *Md*, the models estimate the calories lost due to dive disruption. Foraging dives are detected on the AUTEC hydrophones before an MFAS operation and the number of animals estimated using the dive start method described above. The number of dive starts is measured during the operation. The mean dives lost per individual are then estimated on a per operation basis. This estimate in turn is used to estimate calories lost and the effect of the loss on the dependent calf to adult female ratio. The data provided by visual mark-recapture methods are being used to inform the model. The study in the Bahamas provides a unique opportunity to study a MFAS exposed population and an undisturbed population separated by less than 100 km [5, 6].

7. Undersea Warfare Training Range (USWTR) signal processor

The Undersea Warfare Training Range (USWTR) is being developed for a 500 nmi^2 area on the continental shelf boundary approximately 50 nmi east of Jacksonville, Florida. The range will support Navy undersea testing and training. The Range area lays approximately 30 nmi east of the North Atlantic right whale (*Eubalaena glacialis*) critical habitat [7].

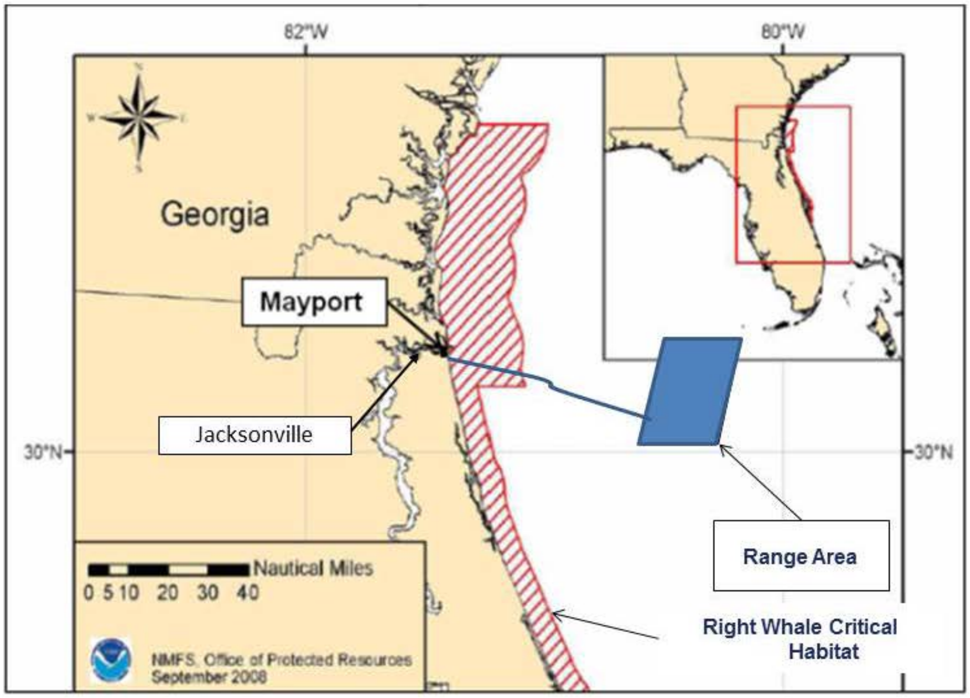

Figure 6. Undersea Warfare Training Range (USWTR) planned area of coverage (blue)

The range will consist of upwards of 300 bottom-mounted hydrophones with sufficient bandwidth to monitor both baleen and odontocete species, including beaked whales. In preparation for the full installation, a trunk cable and three-hydrophone array were installed in the summer of 2016. An initial M3R system was designed, built and tested in Newport, RI and installed on-site in the cable termination facility in Mayport, FL. The processor digitizes the analog array outputs and processes the hydrophones in real-time. The initial processor is being used to collect both high and low frequency detection data from the M3R FFT-based detector [1]. These data will be examined for species abundance with a focus on North Atlantic right whale up calls.

As right whales are not present on any of the existing ranges with M3R software implemented, a right whale detection algorithm will be necessary. Multiple right whale detection algorithms were reviewed for implementation at USWTR. These included: an ‘edge’ detector algorithm[8], a pitch tracking algorithm [9], and a multistage feature vector testing algorithm (FVT) [10]. These methods are similar in that they use smoothing algorithms on fast Fourier transformed data and amplitude thresholds to extract possible right whale calls.

The pitch tracking algorithm first picks out possible right whale calls from a spectrogram by using an amplitude threshold. A pitch tracking algorithm is then used which starts with forward pitch tracking then backwards pitch tracking to capture the entire upsweep. The cost between time steps is calculated based on the frequency jumps (the smaller the jump the lower the cost). The pitch tracking follows the path with the lowest cost. The pitch track ends when the gradient in cost drops below a threshold. Attributes such as average frequency, frequency variation, and time variation are extracted and quadratic discriminant analysis is used for classification.

The 'edge' detection algorithm uses an amplitude threshold to compare each FFT bin of the spectrogram to the background noise. This algorithm results in an outline of an upsweeping call that can then be measured to extract parameters such as duration, start frequency, minimum frequency, etc. A predetermined minimum duration, maximum duration, sweep frequency, and start frequency are used to filter possible calls before using multivariate discriminant analysis to classify the call.

The FVT algorithm specifically searches a spectrogram for the up call of a North Atlantic right whale. First, a pre-whitening algorithm is used on the spectrogram, then a set of features are selected to determine if the detected signals are up calls. The parameters that define these features could be better defined by a dataset of calls recorded on the USWTR range.

Before this set of features can be extracted from the spectrogram data the signals must be separated from the noise resulting in a distinct object to be used in feature extraction. A multilevel thresholding method is recommended to separate the call from any surrounding background noise. This allows quieter signals to come through while still allowing more dominant signals to be separated from louder background noise. An intensity threshold is used to remove unwanted clutter from the spectrogram.

After the separation algorithm, the spectrogram is treated as a binary set of data where the intensity of each pixel no longer plays a role. Now the features can be extracted from each object. Each feature extracted is compared to the features that have been selected earlier. Each feature is assigned a value. A zero is assigned if it falls within the acceptable bounds or, if this is not the case, a positive real number is assigned that is determined by the difference between the closest bound and the extracted feature squared and multiplied by a predetermined scalar. The values for all of the features for one possible signal are summed and if this is below a given threshold then it is accepted as an up call.

Additionally, discussions with NMFS Northeast Fisheries Science Center) were held for input on NMFS experience implementing these detectors on autonomous platforms. Based on the review and lessons learned from NMFS, a real-time detector based on Urazghildiiev et al., 2008 is being targeted for inclusion into the M3R system software build [8]. The next step is to validate the model in MATLAB. The code would need to be converted to C before being implemented at USWTR

8. Information assurance (IA), Authority to Operate (ATO)

The necessary M3R AUTEC Information Assurance (IA) package was submitted under DoD. Information Assurance Certification and Accreditation Process (DIACAP). In December, 2017 M3R obtained an authority to operate (ATO).

9. Works Cited

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