Marine Mammal Monitoring on Navy Ranges at AUTEC
2014 Summary Report

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Introduction

With funding from the Living Marine Resources Program and the Office of Naval Research, passive acoustic methods are being combined with visual observations and satellite telemetry to document the near and long-term effect of sonar on marine mammals. A Marine Mammal Monitoring on Navy Ranges (M3R) signal processor has been installed at the Atlantic Undersea Test and Evaluation Center (AUTEC) as a means of developing marine mammal passive acoustic systems and applying them to long-term monitoring of cetaceans in an area of frequent sonar use.

The AUTEC acoustic range is located in a deep ocean canyon known as the Tongue Of The Ocean (TOTO) which forms the southern branch of the Great Bahama Canyon among the islands of the Northern Bahamas. The range consists of an array of 91 widely-spaced, bottom-mounted hydrophones that are designed to track undersea vehicles. The range is being leveraged for a multi-disciplinary study of cetaceans that combines M3R passive acoustics, expert visual on-water observers collecting individual-based photo-identification data, and the deployment of satellite tags [1], [2], [3], some with depth sensors. This work is filling key data gaps to determine the effect of sonar on cetaceans and developing techniques for long-term range monitoring.

The M3R system is being used to monitor the AUTEC hydrophones for vocalizations using real-time passive acoustic tools developed by the program [4]. Trained at-sea visual observers are vectored to vocalizing animals isolated using the M3R system. By combining passive acoustics with visual observations, detected vocalizations are being associated with the species of origin. Significant progress has been made along these lines; however, uncertainty still remains with delphinid species vocalizations. The expert observers provide data on group composition and surface behavior and collect photo-identification data and biopsy samples for analysis. The satellite tags provide direct data on the movement and diving of animals around active sonar operations. To date, 51 satellite LIMPET tags have been successfully deployed on odontocetes that have used the AUTEC range and surrounding waters of TOTO (Table 1).

Table 1: Summary of satellite tag deployments in TOTO, including the AUTEC range. The number of tags with depth sensors is shown in parentheses.

Whale species	**Total # Tags** (# depth tags)	**Max Deployment** (days)	**Location Estimates**	**Dives** (>50 m)
Blainville's beaked *Mesoplodon densirostris*	6 (5)	28	721	665
Cuvier's beaked *Ziphius cavirostris*	4 (4)	19	200	239
Melon-headed *Peponocephala electra*	9 (2)	43	1079	65
Short-finned pilot *Globicephala macrorhychus*	15 (3)	42	3243	1580
Sperm *Physeter macrocephalus*	16 (5)	19	879	365
Rough-toothed dolphin *Steno bredanensis*	1 (0)	12	100	NA

<u>A focus on beaked whales</u>

Data collected by the program are being used to document the distribution and density of "sonar sensitive" Blainville's beaked whales (*Mesoplodon densirostris*), hereafter *Md*, along with a lesser number of both Cuvier's (*Ziphius cavirostris*) and Gervais' (*Mesoplodon europaeus*) beaked whales [5, 6]. Although AUTEC is the site of repeated sonar use, no mass strandings have been reported, despite what we now know to be a significant year-round beaked whale presence. Interestingly, AUTEC is located only 50 miles from the Northwest Providence Channel, the northern branch of the Great Bahama Canyon, and the site of the well-documented mass stranding in 2000 that has been associated with Navy MFA sonar [7, 8].

In an on-going series of tests, beaked whale vocalizations have been documented [9, 10, 11] and performance of passive acoustic tools have been characterized. These tests have made possible the development of methods to estimate the abundance and density of animals present on the AUTEC range. A *Md* density of 22.5 [6] to 24.75 [5]whales per 1,000 km^2 has been calculated.

In addition, beaked whales are being acoutically observed during multi-ship, MFA sonar operations and the reaction of animals is being documented through both the use of passive acoustics and satellite transmitter tags [12, 13]. Cessation of *Md* echolocation clicks and dispersion of vocalizations to the outer edge of the array suggests that *Md* move off range and away from the sonar. Four satellite tags deployed on *Md* ahead of a three-day MFA sonar operations (Submarine Commanders Courses, SCCs) documented responsive movements over tens of km to the western edge of TOTO, supporting inference from the passive acoustics (Figure 1).

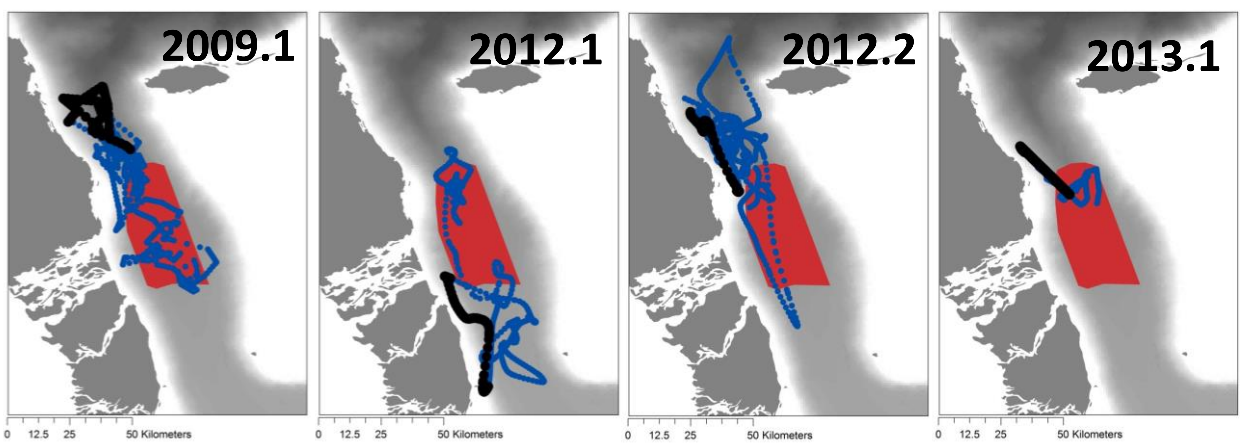

Figure 1. Md movement tracks of four animals (left to right) tagged on the AUTEC range (red) around MFA sonar operations, with estimated locations before and after exposure marked in blue and locations during exposure in black. Location estimates were calculated by fitting a continuous-time correlated random walk model [14] to locations derived from tag transmissions to the Argos satellite system (http://www.argos-system.org), smoothing across the estimated errors for the Argos locations.

FY14 Progress

Significant system improvements were completed in FY14. An improved Jarvis Support Vector Machine (SVMJ) classifier was added. The classifier includes a *Md* buzz classifier which may provide a means of evaluating foraging success. An improved user interface was added and the AIS link was reestablished.

In FY14 an *Md* risk function (**Error! Reference source not found.**) that maps the probability of behavioral disturbance to an RMS exposure level was completed based on M3R data and a paper was published [15]. Specifically, this models the probability of whales ceasing to produce detectable echolocation clicks (i.e., a cessation in foraging) as a function of exposure level. The model estimates a 0.5 probability of disturbance at ~150 dB, the function falls between the current 140 dB step function and the historical risk function with a 0.5 probability at 165 dB [15]. This suggests the current step function over-estimates the number of behavioral takes, while the historic function under-estimated the number. The function is described by a simple parametric equation.

$$F(-8.073 + .05407e^{2*RMS})$$

F(x) is the cumulative normal distribution function

Additionally, the risk function derivations used data obtained during a Submarine Commander's Course (SCC). Precise ship tracks and sonar ping times of emission derived from passive acoustic archives were combined with the Comprehensive Acoustic System Simulation (CASS), Gaussian Ray Bundle (GRAB) eigenray propagation model to estimate beaked whale received levels [16]. The model accounted for source type including beam pattern. Thus the calculated receive level is a function of ship movement and individual source characteristics. The exercise included multiple source types but was dominated by AN/SQS 53C surface ship sonar.

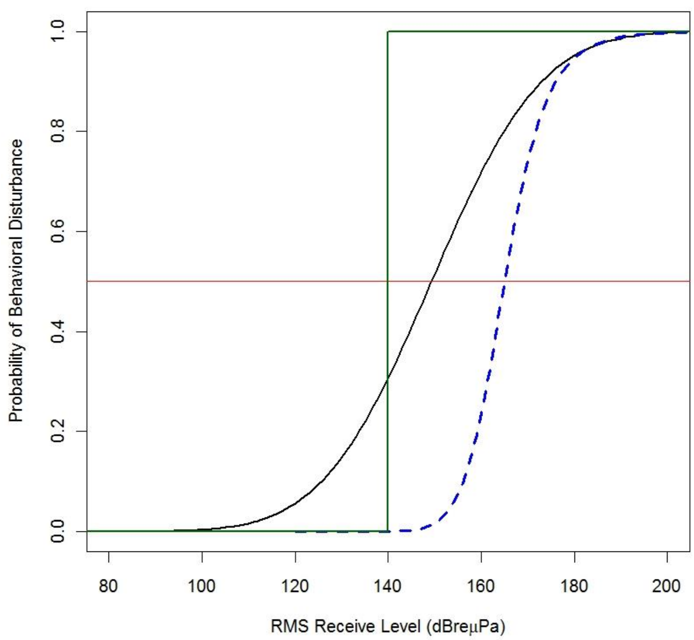

Figure 2. A comparison of risk functions relating the probability of disturbance (cessation of foraging using echolocation) to received level for beaked whales exposed to sonar signals. The current step function used by the U.S. Navy is shown by a green line and the historical function by a blue-dashed line. The empirical function developed in this paper is shown by a solid black line. A solid red line marks the 0.5 probability of disturbance.

In FY14, analysis of *Md* archives with data spanning over a year's duration was continued. Echolocating *Md* groups were isolated with and without active sonar present. These data included 53C and 56 surface ship sonar along with dipping helo sonar and DICASS sonobuoys. The results reinforce those reported in McCarthy et al., 2010 which suggested animals move to the periphery of the range during sonar operations (

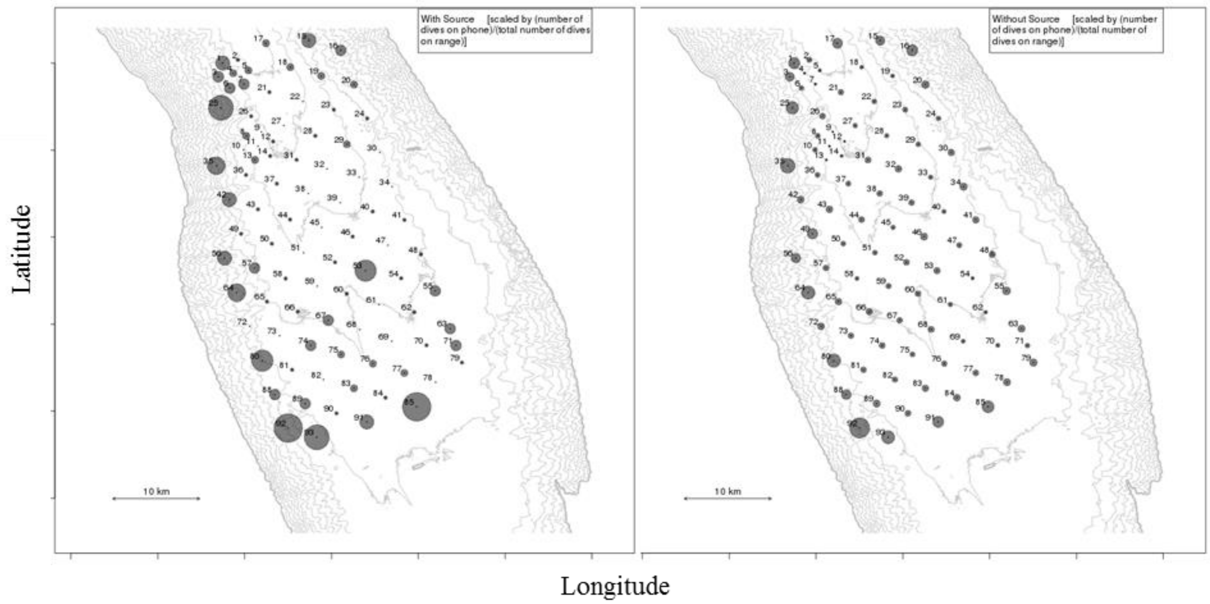

Figure 3).

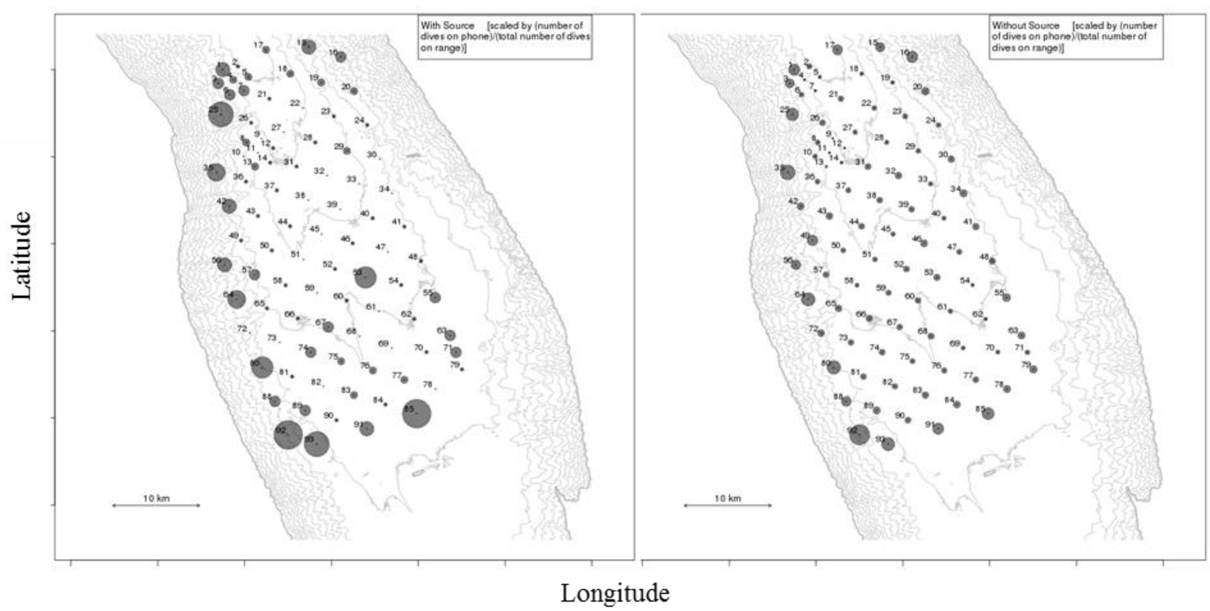

Figure 3. Distribution of Md dive starts (detected echolocations) with (left) and without (right) sonar present. Relative density is represented by the size of the circle, calculated by dividing the number of dive starts centered on the hydrophone by the total number of dive starts in the measurement period (~1 year).

A significant effort to quantify the performance of semi-automated analysis software was undertaken. The software first establishes click trains based on the detection reports from the various detector/classification algorithms. The click trains are then associated into beaked Group Vocal Periods (GVPs). The dive start time is provided as an output. The dive start is associated with a sonar receive level and these data are then used to derive the behavior risk function. From these data ancillary values such as vocal duration (Figure. 4) and Inter-Click Interval (ICI, Figure 5) were established.

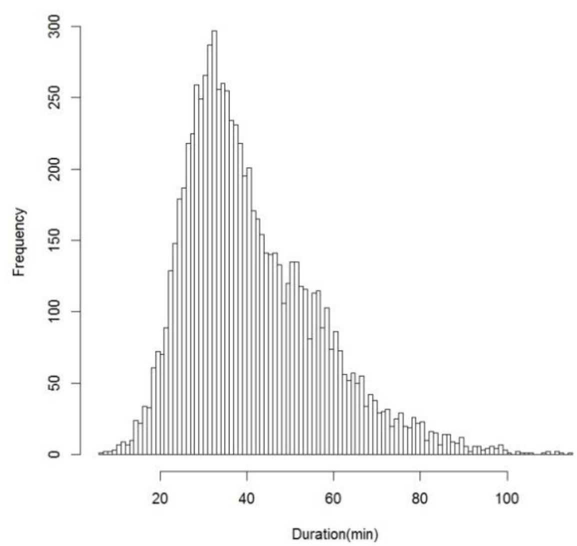

Figure. 4 Md group vocal period duration for all 2012 groups

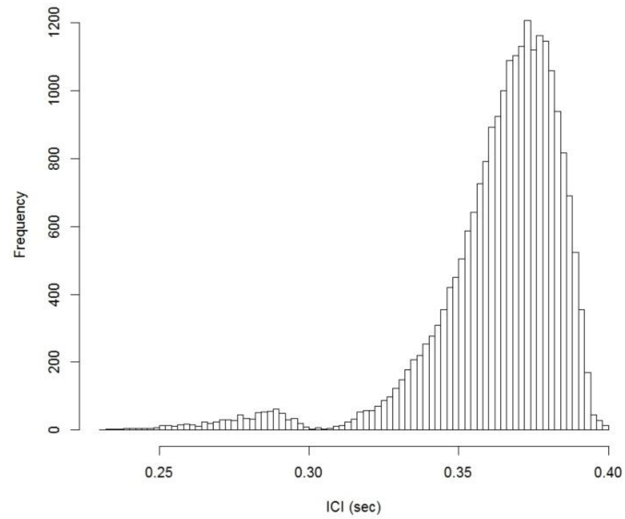

Figure 5. Inter-Click Interval (ICI) for all 2012 Md groups

These data are also being used to extend the empirical risk function to lower levels of exposure. Sonar type (dipping helo, DICASS, 53C etc.) along with stop and start times were manually detected in M3R archives. Ship tracks were obtained from AUTEC, and the sonar transmissions from the archives was associated with the correct ship. These data were used as input to the NAEMO model and the received level on a one-second basis on all AUTEC hydrophones was calculated. From these data, the *Md* exposure level was estimated (Figure 6). A Generalized Additive Model (GAM) is being fit to the data to examine the probability of disturbance to lower level sonar.

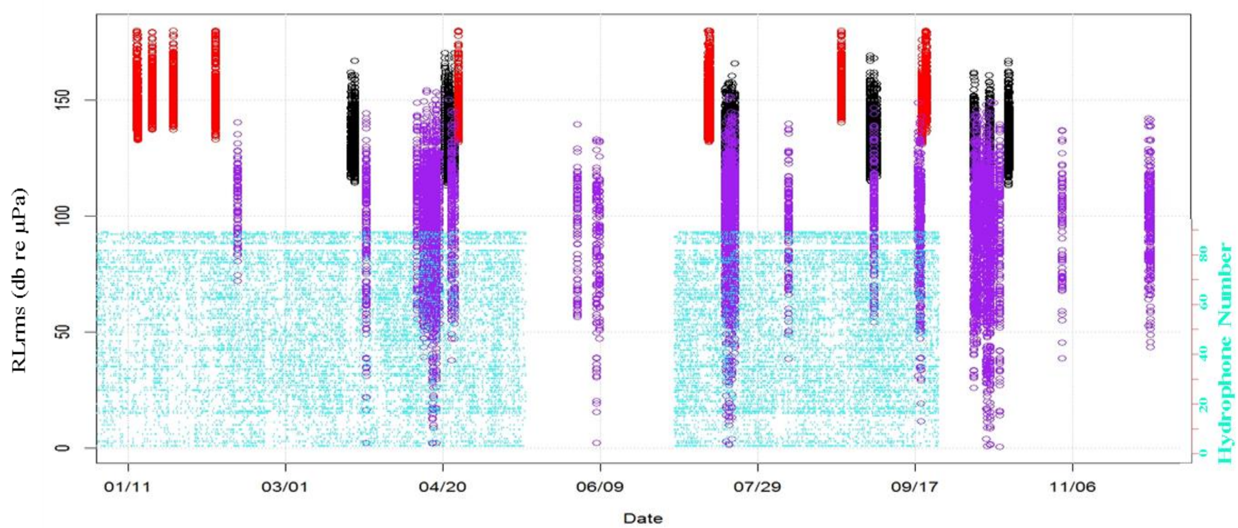

Figure 6. Md sonar receive levels for operations during 2012. The colors distinguish source type including 53C, 56, and dipping helo sonars (red, black, violet) respectively. The center hydrophone of each Md foraging dive is plotted in cyan to indicate periods with coincident passive acoustic data.

Prototype risk function for dipping helo sonars were derived and are being readied for publication. The dipping helo data suggest a 0.5 probability of behavioral disturbance a level ~10 dB lower than the function for surface ship sonar (~140 dB vs. ~150 dB). It is important to note the large source level difference between 53C sonar and dipping helo sonar. To obtain the same receive level with dipping helo as compared to 53C sonar requires the source to be significantly closer to the animal. Also, operation of dipping helo sonar requires the helo to hover and deploy the sonar. Transmission in an area starts abruptly and lasts for minutes unlike surface ship sonar which can last for hours. With 53C sonar, there will likely be a slow rise in level as the platform approaches an animal. Of equal importance, dipping helo sonar only lasts for minutes unlike surface ship sonar which can last for hours.

Data collected by the program were used to investigate the efficacy of the Navy Acoustic Effects Model (NAEMO). *Md* spatial and temporal distribution and density (

Table 2) based on dive counting from the 2009 SCC were used to inform the model. The number "takes" of all types (behavioral, level A, and level B) were calculated based on existing published data and with data derived from direct passive acoustic measurements. This was the first direct comparison of the model's performance to actual site-specific data.

Table 2.Summary of tests during a Submarine Commander's Course with corresponding abundance estimates. Periods of active sonar use are labeled Scenario 1, 3, 5 etc. No sonar was present in all other periods

Period	**Start Date**	**Time MFA Active**	**Duration (hrs)**	**Dive Starts**	**Abundance**	**CI**	
Pre-Test	13-May		19.58	106	34.72	34.72-44.08	
Scenario 1	14-May	10:47-19:56	9.15	30	21.02	15.34-26.70	Sonar active periods 17.05 (16.26-20.65)
Gap 1			4.35	14	20.64	15.07-26.21	
Scenaro 2	15-May	00:17-09:35	9.30	22	15.17	10.98-19.26	
Gap 2			2.62	8	19.58	14.30-24.86	
Scenario 3	15-May	12:12-21:02	9.83	18	11.74	8.57-14.91	
Gap 3			3.65	14	24.60	17.96-31.24	
Scenario 4	16-May	00:41-07:25	6.73	16	15.25	11.14-19.36	All Periods 17.046 (15.02-19.07)
Gap 4			6.62	12	11.62	8.12-14.76	
Scenario 5	16-May	14:02-21:57	7.92	14	11.34	8.29-14.39	

Period	Start Date	Time MFA Active	Duration (hrs)	Dive Starts	Abundance	CI
Gap 5			4.05	16	25.33	18.49-32.17
Scenario 6	17-May	02:00-10:44	8.73	21	15.43	11.27-19.59
Post-test			12.57	32	16.32	11.91-20.73

The sound field during the entire SCC was estimated using the standard NAEMO CASS/GRAB based algorithms and the root-mean squared (RMS) received level (RLrms) was calculated. The current behavioral take criteria (140 dB step function) were applied to estimate the number of takes. Initial runs resulted in double counting of groups resulting in an unreasonable number of takes. To mitigate this effect, an algorithm was developed to link successive groups. For each group vocal period (GVP), the maximum range to the next GVP was calculated based on published swim speeds and dive rates derived from tagged animals. Each GVP was compared to the next GVP based on time/distance criteria. If more than two GVPs matched the criteria, one was randomly linked to the GVP. A Monte Carlo simulation was run using these criteria and the number of takes for each Monte Carlo run was calculated. For the standard NAEMO run over the entire SCC with static animals and with abundance based on the standard database, 43.8 behavioral takes were predicted. With actual data combined with the movement model, 33 takes were predicted. However, correcting for the standard database density estimate using the pretest density derived with actual passive acoustic data using the dive start method [5] suggests the standard model overestimates the number of takes by roughly a factor of 10.

In Figure 7 Hours

, the data from 2011 and 2012 are combined to provide a count of *Md* clicks across the range on a monthly basis for an entire year. Figure 8 shows the distribution of animals across seasons, which provides insight into the *Md*'s use of the habitat and the extent, if any, of seasonal variation. From these *Md* group data, abundance estimates are being derived and methods developed to provide efficient long-term continuous measurements.

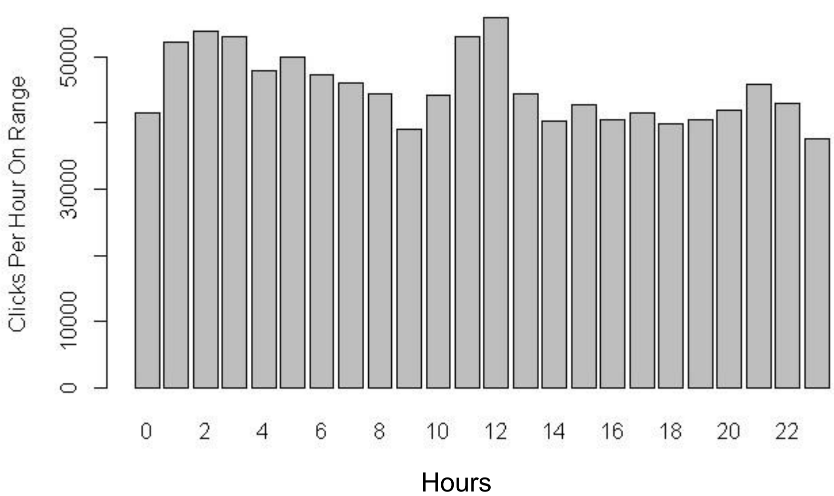

Figure 7. Mean click counts per hour over 24 hours derived from 14 months of data archived in 2011-2012 from all range hydrophones (local-time)

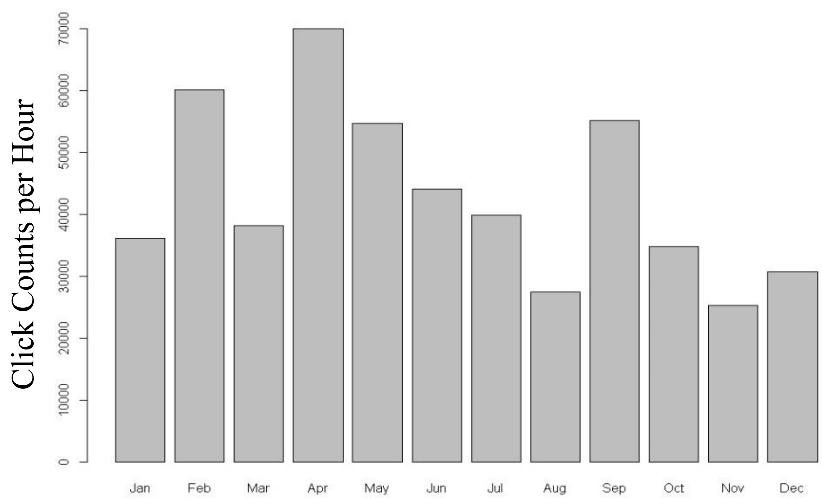

Figure 8. Distribution of mean click counts per hour across months.

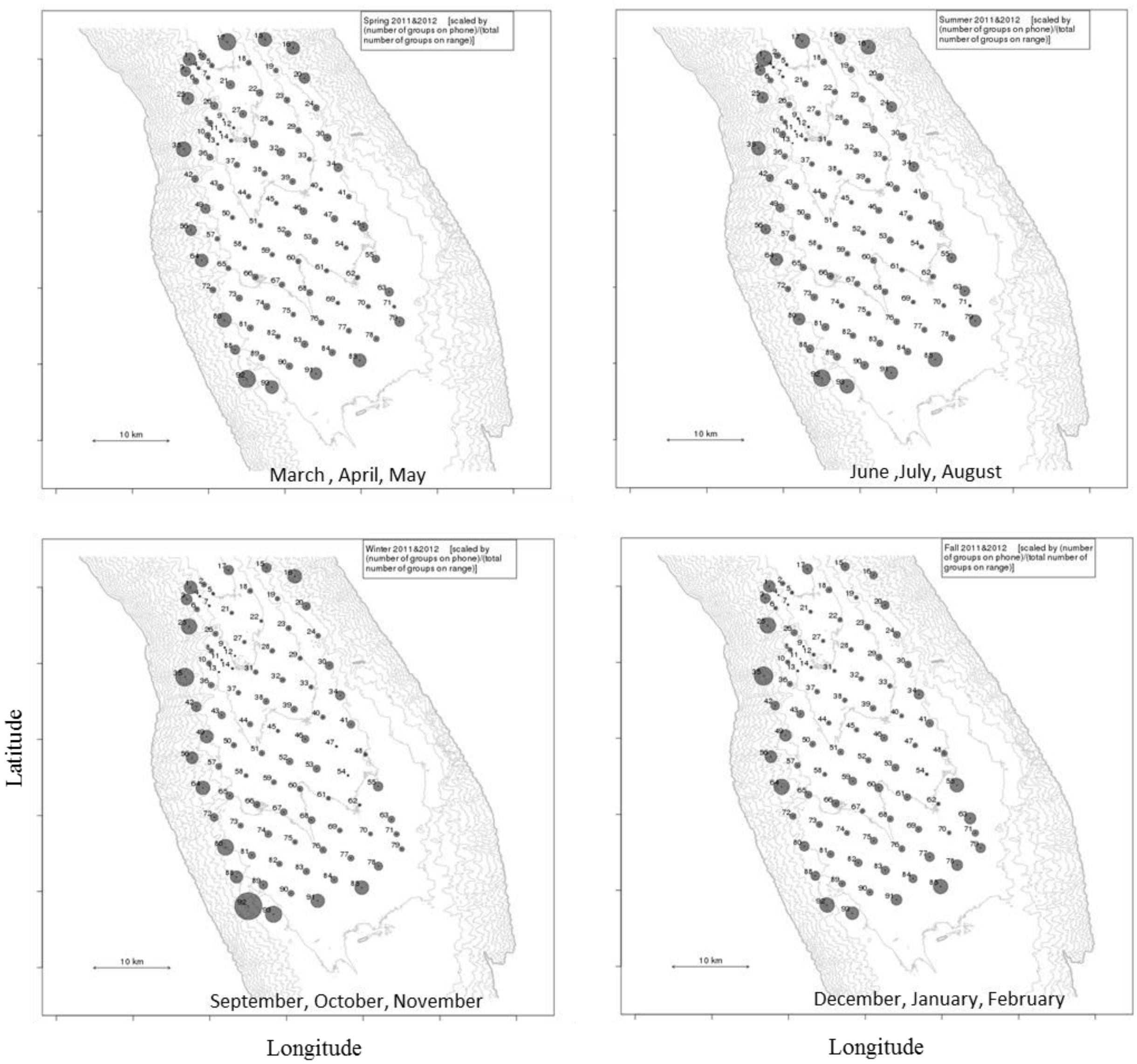

Figure 9. Md spring (upper left), summer (upper right), winter (lower left), and fall (upper right) seasonal distribution depicted by the size of the circle (hydrophone centered dive starts divided by the total number of dive starts).

In 2014 a tag was deployed on a Cuvier's beaked whale on the AUTEC range (Figure 11). This adult female moved rapidly into the Cul-de-Sac at the south end of Tongue of the Ocean after being close to a 4-hour test with a surface ship on the AUTEC range in late April. Although this species has proved hard to visually locate and tag on the range, further tags will be insightful into the apparent response to sonar sources

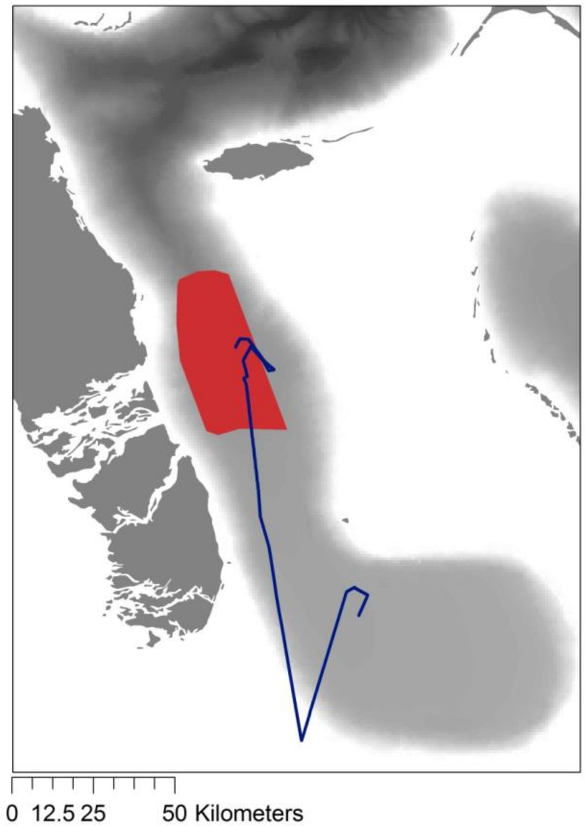

Figure 10. Movement track (blue line) of an adult-female Cuvier's beaked whale over a 10-day tag deployment in April-May 2014. The track was estimated from hourly predictions of *a continuous-time correlated random walk model [14]* fit *to locations derived from tag transmissions to the Argos satellite syste*m (http://www.argos-system.org). *This whale moved rapidly into the Cul-de-Sac at the south end of Tongue of the Ocean after being close to a 4-hour test with a surface ship on the AUTEC range in late April.*

Progress was also made in analyzing dive depth data for *Md* tags previously deployed. Depth data from whales tagged away from sonar exercises are being compared to the two depth recording tags (*Md* 2012.1 & 2012.2, Figure 1) deployed around sonar operations. This preliminary analysis shows that *Md* 2012.2 closest to the top of the AUTEC range shows a change in diving behavior (Figure 11) during displacement, with fewer deep dives (>1000 m) and more dives to intermediate depths (500-1000m) during the mini war phase of the SCC ("Exposed") compared to other times ("Non-exposed"). This likely reflects the shallower water depth in the area NW of the Range to which the whale was "displaced". Preliminary analysis suggests there was no obvious diving response for *Md* 2012.1 (Figure 12) in deeper water to the south of the range. Diving behavior for this whale was similar to a "control" whale that was tagged on the AUTEC range during a period without sonar tests during range maintenance (Figures 14 and 15). Specifically, a tagged adult male *Md* provided dive data in the absence of any tests at AUTEC during range maintenance (Figure 13 and Figure 14). Specifically, a tagged adult male *Md* provided dive data in the absence of any tests at AUTEC (range hydrophone maintenance period in summer 2012; Figure 13). This "control" whale was in the same area as used by *Md* 2012.2 during its period of sonar exposure. Most foraging dives were >1000m, more like the non-exposed deep dives of *Md* 2012.2 and the dives of *Md* 2012.1; not like the shallower 500-1000 m dives during exposure of *Md* 2012.2 (Figure 14**Error! Reference source not found.**).

A more detailed data analysis is currently underway and planned to continue in FY15. Specifically, Durban (NOAA Southwest Fisheries Science Center) is collaborating with statisticians at the NOAA Alaska Fisheries Science Center to develop movement models that fully describe the error ellipses around tag location estimates from the Argos satellite system. This is particularly important for beaked whales, as their long dives and limited surface time often lead to few transmissions being received by satellites and therefore relatively imprecise location estimates (typical error radii of km's). Once complete, the focus will shift to models for understanding the changes in movement and diving, particularly incorporating data on the animals' receive levels as a covariate in dynamic models of movement and diving behavior, in collaboration with NUWC.

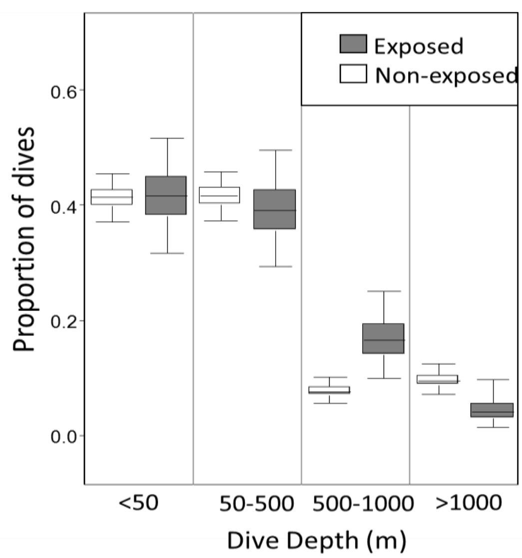

Figure 11. Dive summary for Md 2012.2, comparing periods with and without sonar exposure. Boxes *show medians, 95% probability intervals and the full distributions for proportions across 12-hour histograms for exposed and non-exposed periods (Durban et al. unpublished data).*

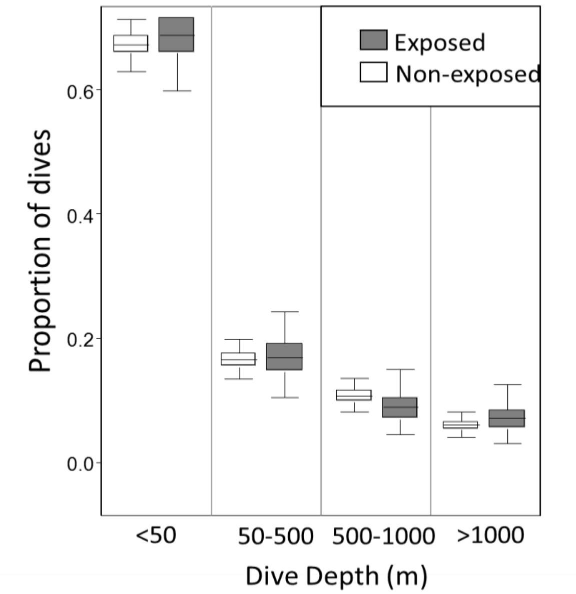

Figure 12. Dive summary for Md 2012.1, comparing periods with and without sonar exposure. Boxes show medians, 95% probability intervals and the full distributions for proportions across 12-hour histograms for exposed and non-exposed periods (Durban et al. unpublished data).

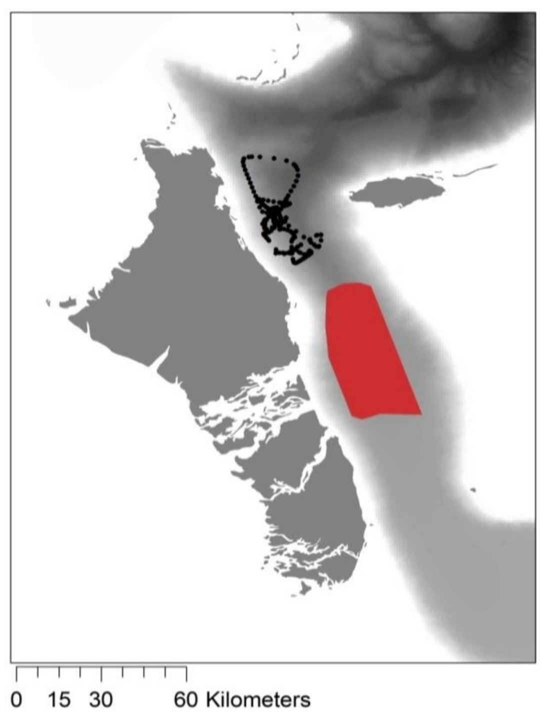

Figure 13. Movement tracks of a tagged Md adult male that used an area north of the AUTEC range (shown in red) during a range maintenance period with no operation in 2012. Location estimates (shown in black) were calculated by fitting a continuous-time correlated random walk model [14] to locations derived from tag transmissions to the Argos satellite system (http://www.argos-system.org), smoothing across the estimated errors for the Argos locations. (Durban et al. unpublished data).

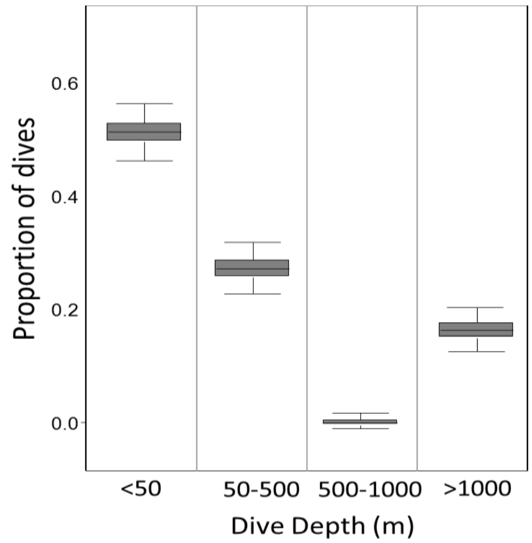

Figure 5

Figure 14. Dive summary for a "control" Md that used an area north of the range during hydrophone maintenance in 2012 (no sonar).

Data Interpretation and Relevance

The output of this research is directly informing the on-going development of a *Md* Population Consequence of Acoustic Disturbance (PCAD) model. The model uses an energetics approach to predict the effect of behavioral disturbance along maternal lines. It requires an understanding of the probable reaction to sonar exposure, notably changes in diving and foraging. The *Md* risk function, derived from the M3R acoustic data, provides a means of estimating the probability at a given RMS exposure level of foraging disruption. However, the exact nature of the behavioral disruption, especially the dive responses, remains largely unknown. To answer this question, a concerted effort is being made to attach further dive recording satellite tags to animals around operations. These efforts are beginning to provide data on animal movement and dive behavior with and without sonar. Eleven satellite tags (8 with depth data) have been deployed on *Md* in the Great Bahama Canyon (Figure 15), including six in TOTO. These data are currently being analyzed to characterize *Md* movement and diving in order to identify any anomalous responses at AUTEC. Hierarchical models are being developed to jointly characterize movement and diving, and to relate these behaviors to key environmental and anthropogenic covariates.

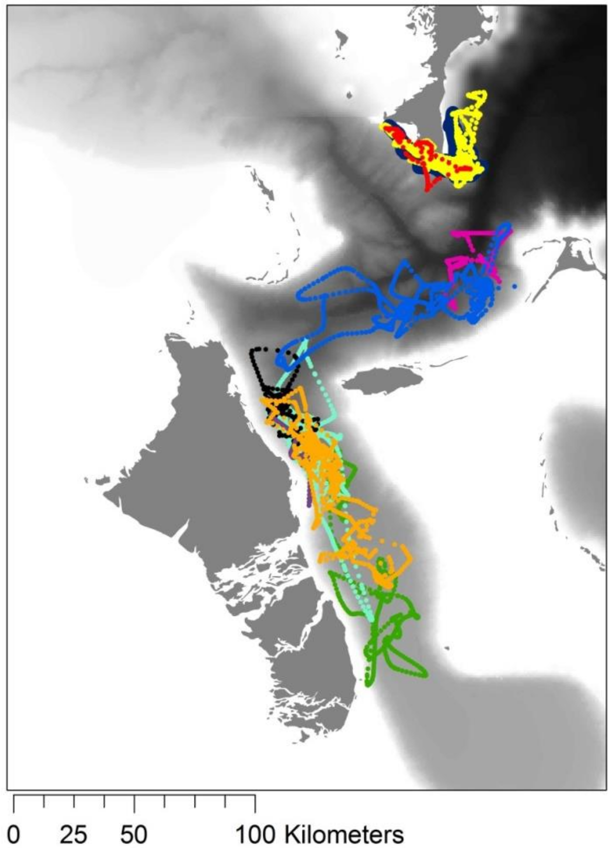

Figure 15. Movement tracks of Md tagged with LIMPET satellite transmitters in the Great Bahama Canyon. Location estimates for each tagged whale is represented by a different color; location estimates were calculated by fitting a continuous-time correlated random walk model [14] to locations derived from tag transmissions to the Argos satellite system (http://www.argos-system.org), smoothing across the estimated errors for the Argos locations. Based on unpublished data (Durban et al. unpublished data).

Our ongoing study indicates the animals in the TOTO represent an isolated population cluster, with no documented movement away from Tongue of the Ocean [17]. Of note, neither photo-identification (over 8 years, Figure 16) nor telemetry data (over 4 years, Figure 15) have documented any exchange between whales using TOTO and those using the coastal waters off Abaco Island, approximately 150 km to the North (Figure 16). The animals at the Abaco site are rarely exposed to MFA sonar, and thus provide a potential “control” population to which data from the TOTO population can be directly compared. Initial comparison of demographic composition has revealed a lower proportion of calf and immature whales at AUTEC/TOTO, an initial indication of a possible population-level response to cumulative sonar exposure [17]. This highlights the value of the multi-disciplinary study, with the collection of biological observations alongside tag deployments and passive acoustic monitoring. Future research plans to augment this study with the use of small unmanned aircraft to collect photogrammetry images (e.g. *http://www.fisheries.noaa.gov/podcasts/2014/10/aerial_vehicle_killer_whale.html#.VMgT89LF-So*); this will help evaluate the hypothesis that repeated sonar exposure may lead to compromised body condition that could explain the apparently low reproductive success at AUTEC.

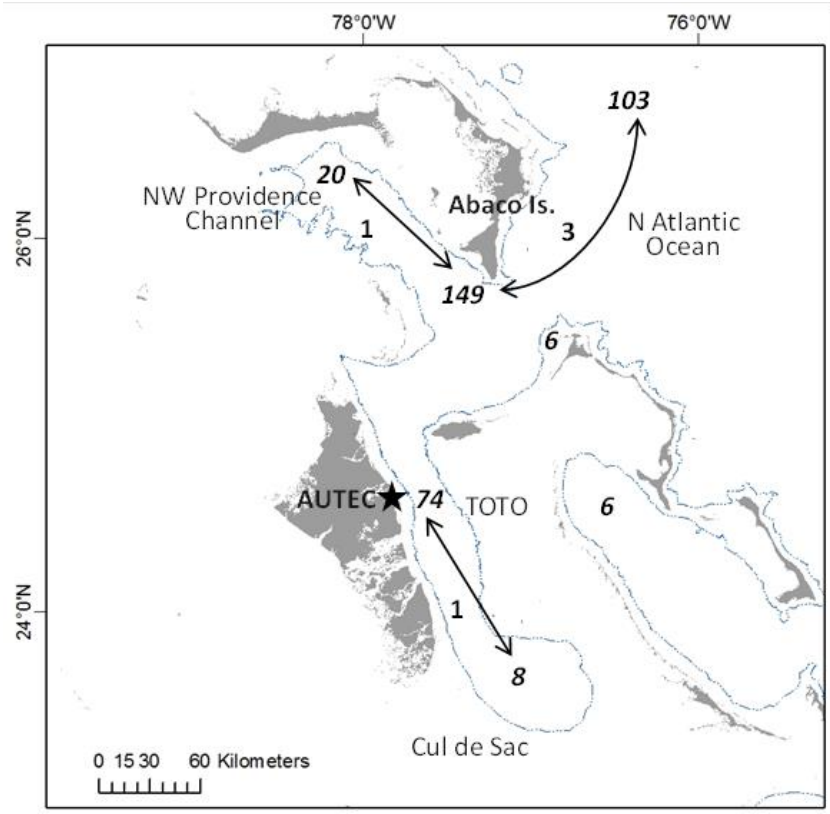

Figure 16. Movements of Md within and outside the Great Bahama Canyon as documented through photo-ID from 1991-2012. Italisized numbers refer to the number of individuals identified from high-quality photographs in each area while numbers next to the arrows represent the number of individuals that have been photographed in both areas. The blue line represents the 1000m isobath.

AUTEC offers a unique opportunity to fill key data gaps on the behavior responses and population-level effect of MFA sonar exposure on cetaceans, including beaked whales. Data from this study have documented the persistent presence of beaked whales despite the repeated use of sonar and contributed to an understanding of animal movement in relation to sonar. Significant data gaps related to avoidance and, in particular, foraging behavior remain. Future work is focused on answering these remaining questions and providing the tools necessary to make long-term measurements for assessing population health.

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