Final

Year 2 Report: Tagging and Tracking of Endangered North Atlantic Right Whales in Florida Waters

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Cover Photo Credits:

Tag attachment to North Atlantic right whale (*Eubalaena glacialis*) in southeastern U.S. waters during 2014. Photo collected under National Marine Fisheries Service Permit #14791 to Douglas P. Nowacek.

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Abbreviations and Acronyms

DTag	Digital Acoustic Recording Tag
HMM	Hidden Markov Model(s)
EWS	Early Warning System

1. Motivation for Proposed Research

North Atlantic right whales (*Eubalaena glacialis*) migrate to coastal waters off Florida and Georgia during the winter months. The planned construction and use of an undersea warfare training range off the Atlantic coast of Florida may result in interactions with the right whale on its winter calving ground. Aerial- and vessel-based visual surveys and passive acoustic monitoring are currently being used to detect right whales in the coastal waters of Florida and Georgia, as well as offshore areas in the planned undersea warfare training range. Aerial surveys give the positions of individual whales, but only provide information about right whale locations at single points in time. Passive acoustic monitoring establishes presence and provides a general location of at least one whale; multiple acoustic sensors can provide more accurate locations, as well as estimates of numbers of whales. Currently, few data exist on the movement patterns of individuals, including movement rates both in north-south and east-west directions, durations and depths of dives, and rates of sound production by individuals on the calving grounds. These data are important to assess the effectiveness of current monitoring techniques and the potential for disturbance to right whales as the construction and operation of the undersea warfare training range commence.

2. Objectives and Background

The primary objective of this targeted tagging program is to fill in these knowledge gaps by collecting data on horizontal movements, dive profiles, and vocal behavior from individual right whales. These objectives were accomplished using non-invasive suction-cup tags (anticipated tag duration from 1 to 36 hours) that included Fastloc® Global Positioning System technology, time-depth recorders, three-dimensional movement measurements, and acoustic recordings. National Marine Fisheries Service permits to conduct this research are held by Duke University with Dr. Nowacek as lead investigator and Dr. Parks as named co-investigator. Institutional Animal Care and Use Committee approval was obtained from Duke University and Syracuse University prior to data collection.

In February 2014, tagging operations were carried out over 11 days, resulting in 7 tag attachments on North Atlantic right whales resulting in over 27 hours of tag data. Data resulted from all lactating females accompanied by calves, and one juvenile male who was entangled in fishing gear. Analysis from the 2014 season indicated highly variable call rates, ranging from 0 calls/h (entangled male whale) to over 20 calls/h for one individual (lactating female), with an average call rate of ~ 9 calls/h. GPS tracked individuals showed variable movement patterns, with individuals showing movement tracks on both N/S and E/W axes. In 2015 our objective was to obtain longer duration attachments with integrated fastloc GPS data for tag attachments.

3. Results from February-March 2015

The second field season for this project took place from February through early March 2015. The field team consisted of members from Duke University and Syracuse University, and operated out of Fernandina Beach, Florida, in the Jacksonville Study Area. Two vessels were

utilized for this work, the R/V *Stellwagen*, a support and overnight follow vessel, and the R/V *Barber*, a SAFE Boat RHIB used for tag deployment and daytime follow vessel. Weather conditions were suitable for tagging (i.e. sea state forecast of Beaufort 3 or less) operations on 8 days during this time (**Table 1, Figure 1**). One tag was successfully deployed on a single right whale, a nursing female accompanied by her calf on February 21 (**Table 1, Figures 1 through 3**). While this low level of tagging success was frustrating, the number of animals on the winter grounds was substantially lower during the 2014–15 calving season than in past years (**Table 2**), and field team effort was comparable or higher than in the previous year. EWS effort was similar to previous years, and their sighting rate was also substantially lower for the season (**Table 2**). Analyses of the data, including dive statistics and acoustic data, are ongoing and are being conducted under the supervision of Dr. Nowacek and Dr. Parks with students and technicians in their laboratories.

Table 1. Summary of 2015 field effort.

Date	Beaufort Sea State	Survey Time (hh:mm)	At Sea Time (hh:mm)	Platform
16-Feb-15	3	3:08	3:46	R/V *R.T. Barber*
21-Feb-15*	2	6:45	8:47	R/V *R.T. Barber*
21-Feb-15*	2	14:42	16:55	R/V *Stellwagen*
22-Feb-15	2-4	7:32	9:14	R/V *R.T. Barber*
23-Feb-15	2-3	2:28	4:12	R/V *R.T. Barber*
25-Feb-15	2-3	6:11	7:11	R/V *R.T. Barber*
03-Mar-15	0-2	6:19	9:04	R/V *R.T. Barber*
03-Mar-15	0-2	8:13	9:48	R/V *Stellwagen*
04-Mar-15	4	3:58	8:45	R/V *R.T. Barber*
08-Mar-15	2-3	8:32	10:36	R/V *R.T. Barber*
08-Mar-15	2	5:33	7:43	R/V *Stellwagen*

* cruise with successful tag deployment and/or tracking.
Key: R/V = Research Vessel

Given the low numbers of both whales and tagging attempts and successes, the group undertook additional analysis tasks to augment this year's field efforts. These tasks are summarized below and described in more detail later in this report (* indicates that a task is ongoing and that results reported here are preliminary). Additional analysis results will be included in future reports, including additional data from the 2016 field campaign. Several aspects of this work have been presented at conferences and integrated into manuscripts over the past year (see **Appendix 1**).

1. Sound propagation modeling*: Completed preliminary work. Taken together with work on vocalization rate and vocal repertoire, understanding the propagation conditions is an integral part in developing detection probabilities.

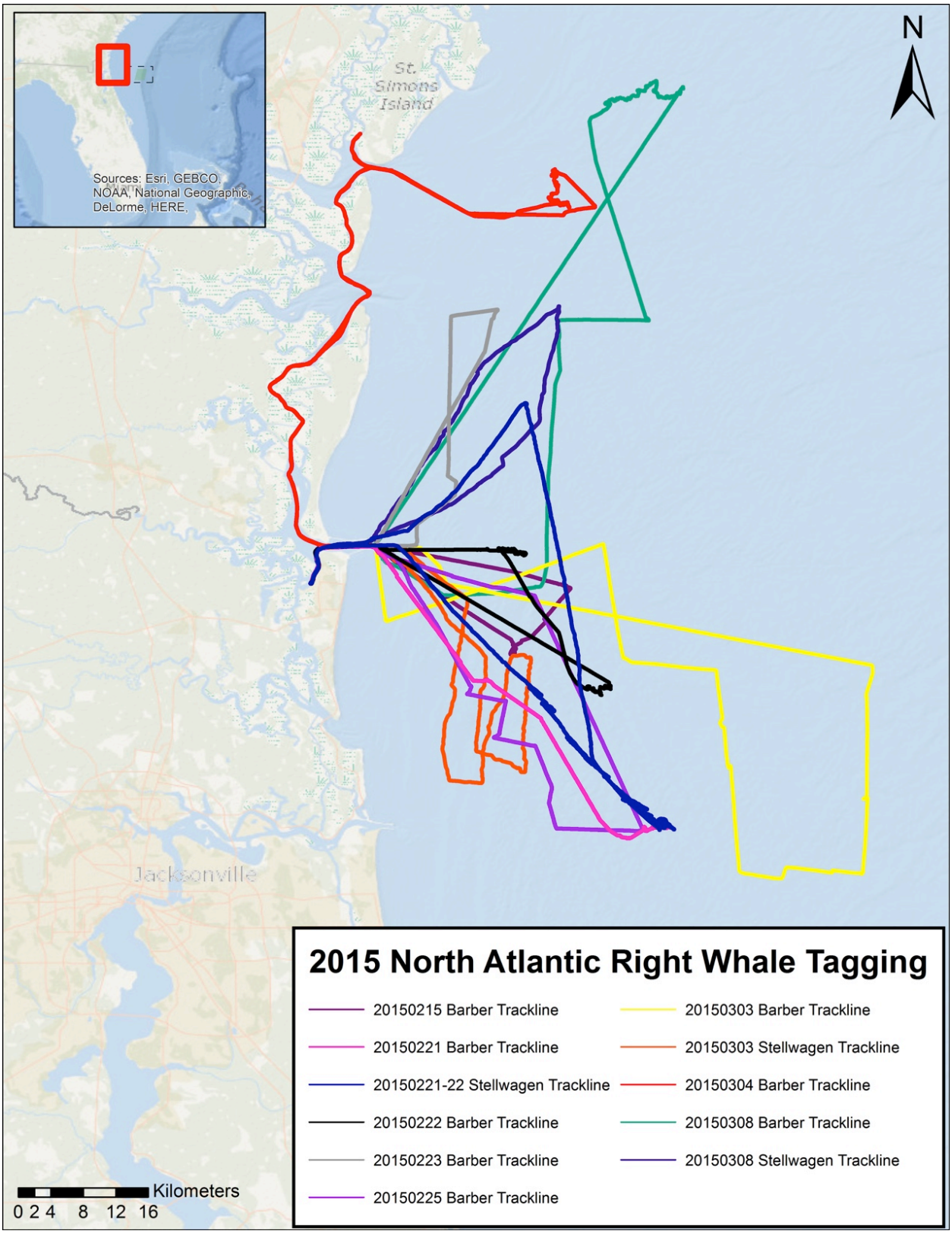

Figure 1. Map of search effort by the two tagging vessels (colored lines) for each survey day. The inset map shows the position of the enlarged map in red, relative to the training range location.

Figure 2. Surface positions for the track of the mother right whale tagged on February 21, 2015. The inset map shows the position of the enlarged map in red, relative to the training range location.

Figure 3. Image of tag attachment to a right whale in the southeastern United States in February 2015. Collected under National Marine Fisheries Service Permit # 14791 to Doug Nowacek.

Table 2. Compilation of right whale sightings from 2007 to 2015 from EWS surveys.

Calving Season	Numbers of aerial survey sightings	Numbers of whales sighted (includes duplicates)	Numbers of calves	Numbers of individual whales identified
2007	419	918	23	112
2008	617	1410	23	153
2009	848	1853	39	198
2010	523	1240	19	216
2011	265	610	22	142
2012	130	339	7	68
2013	184	355	20	41
2014	141	275	11	42
2015	75	149	17	30

Note: The calving season includes November and December of the previous calendar year. Note the overall decrease in sightings since the high of 216 individuals in 2010. The year 2015 has the lowest number of sightings, total whales sighted (includes duplicates), and individual whales sighted. Interestingly, 2015 was not the year with the lowest number of calves sighted of the last 10 years. Data courtesy of New England Aquarium right whale program.

2. Detectors for North Atlantic right whale calls*: Creating and testing algorithms for detection and classification of right whale calls, which is a companion to propagation

modeling to augment detection. Duke University has been working on various aspects of detectors/classifiers for right whale calls. This area has been active for a while. The last International Workshop on Detection, Classification, Localization, and Density Estimation of Marine Mammals using Passive Acoustics focused again on right whales and on developing the ability to distinguish the right whale from the humpback whale (*Megaptera novaeangliae*).

3. Individual distinctiveness of right whale calls: Collaborated with Jess McCordic on individual distinctiveness paper submitted to Endangered Species Research, which included mother-calf data from 2014.
4. Other analyses using the acoustic data from 2014*:
    a. Working on quantitative repertoire analysis using tag data, including sounds recorded in 2014. This paper is under consideration to collaborate with New Zealand/Australian/Brazil researchers for *Eubalaena* inter-species comparisons. The target for completion is later in 2016.
    b. Compiling a vocal ontogeny publication. Our goal is to obtain more data during the 2016 field season to include in this proposed publication.
    c. Mother versus non-mother dive patterns: Preparing a publication submission, led by the Parks lab, with two goals—to be ready by July 2016 and to be augmented by additional tags deployed in 2016.

4. Summary of Findings

Analysis of the tag data from 2015 indicates that the tagged animal moved east after tag deployment and then switched to a more northwesterly direction (**Figure 2**). Researchers conducted a 4.5-hour behavioral focal follow on the tagged animal and her calf. The pair spent 4 hours and 23 minutes of that time in a state of rest, with the remainder of the time spent nursing and travelling. No right whale calls were detected on the tag.

4.1 Acoustic Analyses

Researchers browsed audio recordings visually and aurally in RavenPro 1.5 (Cornell Bioacoustics Research Program) for evidence of right whale vocalizations. The most striking result from the acoustic analyses was the absence of detectable right whale calls over a 24-hour period of recording while the tag was on the mother (**Table 3**). Additional sounds such as anthropogenic noise from nearby ships and vocalizations from fish and other cetacean species were also noted.

Table 3. Summary of acoustic tag data from 2015.

Date	Tag ID	Whale ID (EGNO)	Acoustic record duration (hh:mm)	Demographic	Right whale calls detected (all SNR including calls from other whales	Estimated calls per hour of tag recording
21-Feb-15	Eg06_052a	3292	23:20	Nursing Female	0	0

Propagation modeling of right whale calls

Additional analyses were completed to estimate the transmission loss of right whale vocalizations in this habitat area. Transmission loss estimates were calculated using the Monterey-Miami Parabolic Equation Model (Smith 2001) from the Ocean Acoustics Library (http://oalib.hlsresearch.com). The parameters used to populate the model can be found in **Table 4**. The propagation results indicate that right whale social calls generated near the surface are anticipated to have transmission loss greater than 30 decibels at ranges as close as 100 meters from the source (**Figure 4)**. Further field-testing with tagged animals is necessary to refine these model results. This may limit the effectiveness of the detection range for acoustic signals for this species.

Table 4. Parameters used in the Monterey-Miami Parabolic Equation model.

Southeastern U.S. Habitat Information		
Water Properties	Sound Speed	1500 m/s
Bottom Properties	Sound Speed	1700 m/s
	Density	1.9 g/cm3
	Compressional Attenuation	0.2 dB/m/kHz
	Shear Speed	120 m/s
	Shear Attenuation	30 dB/m/kHz
Source Parameters	Depth	5 m
	Center Frequency	200 Hz
	Frequency Bandwidth	200 Hz

dB/m/kHz = decibels per meter per kilohertz; g/cm3 = grams per cubic centimeter; Hz = hertz; m = meters; m/s = meters per second

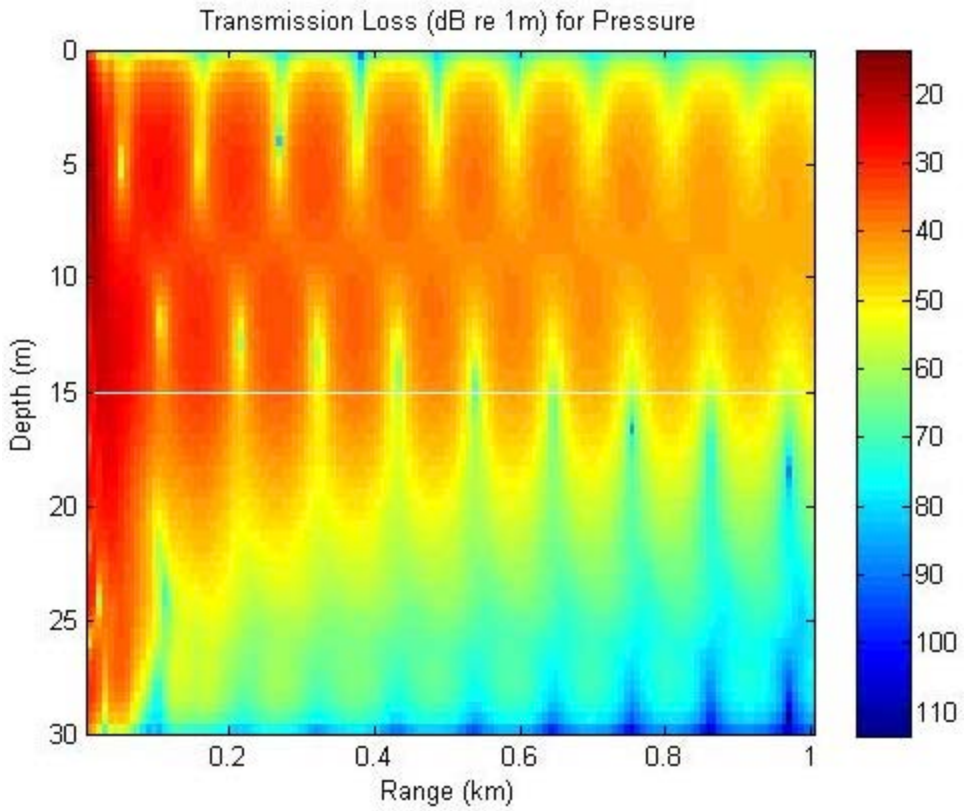

Figure 4. Estimated transmission-loss values for right whale call propagation from the Monterey-Miami Parabolic Equation model.

Right whale call detector

An automated detector was developed by building a variety of Hidden Markov Models (HMMs) with the aid of the HTK Toolkit (University of Cambridge) to process acoustic data and reliably detect right whale calls in conditions with anthropogenic, abiotic, and other biological sounds. Identifying right whale vocalizations from acoustic data begins with building a robust system of HMMs based on parameterized feature vectors of manually labelled data. The acoustic data to be processed are then similarly parameterized and classified based on the HMMs generated. Preliminary development of the detector was done using 2 days of manually labelled data, one with many calls and another with almost none; the source of some of these training data included tag data from the Naval Facilities Engineering Command projects. A right whale up call (**Figure 5**), isolated from one of the tags deployed in 2014, was one of the calls used to train the HMM. The detector was then applied to a longer time series of approximately 5 months and re-tuned based on the resulting outputs. The performance of the detector was comparable to that of a human operator; the detector was able to pick out a large proportion of vocalizations labelled by a human operator while having a relatively low rate of false detections. Being able to process and extract cetacean signals from long periods of acoustic data can improve passive acoustic monitoring of cetaceans and allows for understanding of cetacean range, seasonality and abundance, among other things.

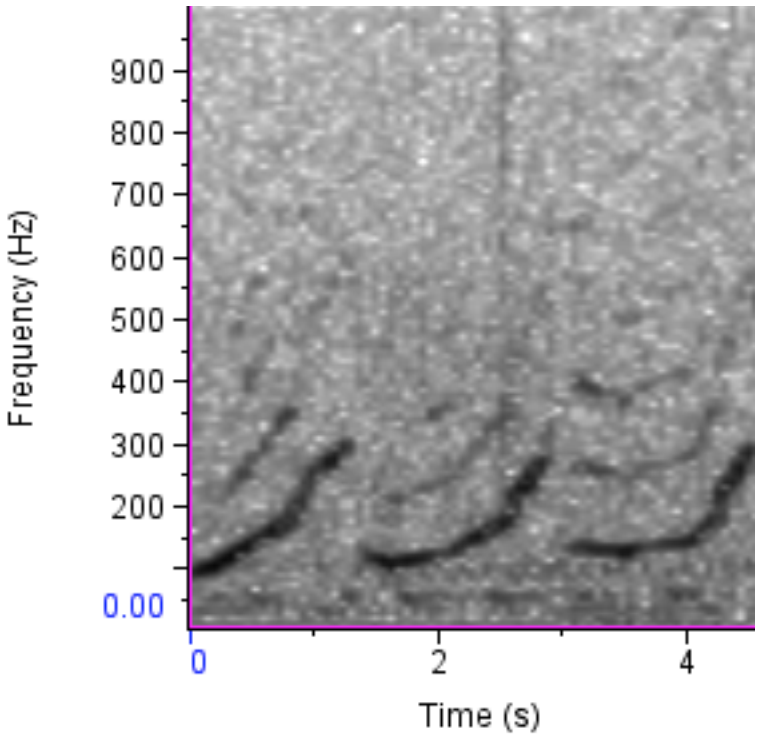

Figure 5. Spectrogram of right whale up call. Generated using RavenPro (source), NFFT = 256, Hann window, 50 percent overlap.

Performance of the detector

Researchers conducted a manual review of all detected right whale up calls over 8 days at two sites off North Carolina on data recorded on MARUs (Cornell University) in collaboration with the Northeast Fisheries Science Center, and the full results are shown below in **Table 4**. The performance of the automated detector on those days was comparable to that of a human operator. Over the time period under review, the detector identified 1,723 right whale up calls, of which 1,459 were 'true' detections and 264 were 'false' detections after manual inspection. An earlier manual review of the whole dataset had been completed and yielded 1,466 identified right whale up calls. This translated to a false positive rate of approximately 15 percent. The automated detector also identified almost as many right whale up calls as a human operator (99.5 percent) although the right whale calls identified by the automated detector might not have been identified by a human operator and vice versa. Further comparison between the results from the automated detector and the human operator showed that 84.1 percent (1,233 out of 1,467) of the calls marked by the human operator were picked up by the automated detector, with the rest of the 'true' detections being unmarked by the human operator.

Table 5. Comparison of numbers of right whale up-calls detected by an automated detector (total, true, false) and a human operator (human) analyzing passive-acoustic data from two monitoring sites off North Carolina.

Date (yyyymmdd)	Site 2				Site 3			
	Number of detections	Number of true detections	Number of false detections	Number manually recorded	Number of detections	Number of true detections	Number of false detections	Number manually recorded
20131116	2	0	2	0	1	0	1	0
20131130	3	0	3	1	36	0	36	1
20131214	25	7	18	2	19	5	14	0
20131228	282	220	62	203	264	198	66	157
20140111	1	0	1	1	21	7	14	8
20140125	3	0	3	0	3	0	3	0
20140208	723	706	17	742	324	316	8	351
20140222	8	0	8	0	8	0	8	0
Site total	1047	933	114	949	676	526	150	517

4.2 Future Directions

A third year of fieldwork took place in February and March 2016. The focus of the additional research was to increase the sample size of tagged individuals, with an emphasis on single animals (not mother-calf pairs) when feasible. A fourth year of data collection may be proposed to further assess movement and dive patterns, as well as acoustic behavior. Additionally, in future years, researchers anticipate pursuing some of these other analyses using the data collected by this project, including new analyses that complement completed and ongoing data-collection efforts, e.g., merging vocalization rates with propagation modeling to start to get at detection probabilities for right whales in the area.

Summary of 2016 Field Effort

During the months of January and February 2016, the research team conducted eleven days of suction-cup tagging effort within the North Atlantic right whale Critical Habitat area off southern Georgia and northern Florida. Approximately 1,035 km of trackline was surveyed during 83.6 hours of effort on the R/V *Richard T. Barber.* There were 16 right whale sightings and Version 2 Digital Acoustic Recording Tags (DTags) were deployed on seven female right whales, six of which were with calves. The mean tag duration was ~5:20. Eg 3101 was tagged on the 17th of February with its calf. This individual had previously been tagged on the 25th of January, at which time she did not have a calf; this repeat tagging was accidental. Eg 1281 was tagged on the 17th of February, and this whale, along with her calf, was within one mile of Eg 3101 during the time both females were simultaneously tagged. During these tag deployments, Michael Moore (Woods Hole Oceanographic Institution-WHOI) and his crew made flights with their

Unmanned Aerial System (UAS) over both tagged whales and collected video and images. There were 46 up-calls documented from Eg16_025a and zero calls on Eg16_030a and Eg 16_031a during preliminary analysis of the acoustic data. Focal follows were conducted on each of the tagged whales to document surface behaviors which will be analyzed with movement and acoustic data recorded from the sensors and hydrophones on the DTag. A fastloc GPS was mounted to the DTag housing and tracked each whale's location throughout the deployment. However, tags Eg16_025a and Eg16_031a slid down the body and below the waterline during their deployments; therefore, data from these tags do not reflect the full tracks of the whale's positions.

In addition to deploying DTags, six UAS flights were conducted in February over two mother calf pairs and one singleton right whale. Video and still digital images were collected from this platform which will be used to document surface and sub-surface behaviors and to assist in a photogrammetry study. During the two flights over Eg 1968, respiratory samples from the whale's blow were also collected for a collaborative study with Michael Moore (WHOI). These samples contain hormones, respiratory microbes, and other health related substances that help gauge the health of an animal.

5. Publications and Presentations

The following list contains the publications and presentations (either made/published or currently in progress) from this effort:

McCordic, J.A., Root-Gutteridge, H., Cusano, D.A., Denes, S.L., and Parks, S.E. Under review. Calls of North Atlantic right whales (*Eubalaena glacialis*) contain information on individual identity and age. *Endangered Species Research*.

Nowacek, D.P., Parks, S.E., and Read, A.J. 2015. Tagging and tracking of North Atlantic right whales in the SE U.S. Presentation to Marine Mammal Commission 2015 Annual Meeting. 5-7 May 2015. Charleston, South Carolina.

Nowacek, D.P. Clark, C.W., Donovan, G.P., Gailey, G., Golden, J., Jasny, M., Mann, D.A., Miller, P.J.O., Racca, R., Reeves, R.R., Rosenbaum, H., Southall, B.L., Vedenev, A., and Weller, D. 2015. Marine seismic surveys and ocean noise: mitigation, monitoring and a plan for international management. 21st Biennial Conference on the Biology of Marine Mammals. San Francisco, California.

Parks, S.E., Root-Gutteridge, H., Cusano, D.A., Conger, L.A., and Van Parijs, S.M. 2015. Insights into the ontogeny of acoustic communication of North Atlantic right whales. 21st Biennial Conference on the Biology of Marine Mammals. San Francisco, California.

Root-Gutteridge, H., McCordic, J.A., and Parks, S.E. 2015. Upcalls of the North Atlantic right whale (*Eubalaena glacialis*) contain individually distinctive parameters. 21st Biennial Conference on the Biology of Marine Mammals. San Francisco, California.

Root-Gutteridge, H., Parks, S.E., Van Parijs, S.M., and Cusano, D.A. 2015. Exploring right whale vocal ontogeny. 2015 Meeting of the North Atlantic Right Whale Consortium. New Bedford, Massachusetts.

6. Literature Cited

Smith, K.B. 2001. Convergence, stability, and variability of shallow water acoustic predictions using a split-step Fourier parabolic equation model. Journal of Computational Acoustics 9:243-285.