FINAL PROGRAMMATIC REPORT TO

NATIONAL FISH AND WILDLIFE FOUNDATION

Using the DTAG and Behavioral Observations to Study the Effects of Vessels on Right Whales in the Southeast United States

Contract Number: 2003-0170-015

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CONTENTS **PAGE**

Final Programmatic Report……..1

Final Financial Report……...…….13

Project Evaluation Report.……15

Appendix 1: Cruise Log…….19

Appendix 2: Nousek & Novacek, In Prep……...……...……22

Appendix 3: Georgia DNR Press Release……..…….38

Summary

The Southeast US DTAG project (SEUS DTAG) had a successful field campaign. The first day of field operations was 20 January, and our last was 2 February. Only 8 of those 14 days were workable, with the other 6 being 'weathered' out by a combination of fog, wind and high seas (see Appendix 1, Cruise log). Of the 8 workable days we: i) tagged whales on 5 days; ii) did not find any whales (neither did the aerial survey teams) on 1 day; iii) found only mother-calf pairs on 1 day (i.e., animals we were not permitted to tag) and iv) made several attempts only to have a tag fall off immediately after attachment on 1 day. In 5 days of tagging we logged 25.1 hours of tag-on time (Table 1) and 23.1 hours of data (tag malfunction resulted in the loss of 2 hours of on-animal data). Tag specifications, including sensors and calibration, as well as attachment and focal-follow techniques have been described previously (Johnson & Tyack, 2003; Nowacek *et al.*, 2001).

Tags were attached to several juvenile animals (age based purely on size estimates; identifications to date unknown) and one adult. The adult whale was identified by the New England Aquarium as Eg1151. Eg1151 was observed with a calf ~10 days post tagging. Most of tags were rubbed off by contact with other whales or the bottom, but the tag attached to Eg1151 remained attached until the automatic mechanism caused it to release after 18 hours. The data from this experiment have already proven to be very useful for understanding the behavior of whales and for management purposes. In the context of the emergency gillnet fishery closure in the area, our data have shown that this was a well justified closure as the whales use the entire water column and so are at risk of net sets at any water depth.

Whale	Date tagged	On-animal time (min)	Comments
RW020a	20 Jan	~120	No data
RW021a	21 Jan	81	
RW024a	24 Jan	114	
RW024b	24 Jan	33	Confirmed tag rub off
RW024c	24 Jan	23	Confirmed tag rub off
RW024d	24 Jan	8	Confirmed tag rub off
RW024e	24 Jan	50	
RW028a	28 Jan	1,080	
Total		1,509	

Table 1. Whales tagged during Southeast US operations. The 'confirmed tag rub offs' were verified by the acoustic record, in which a loud bump can be heard just before the tag data indicate that the tag has released.

Dive behavior

Overall, the dive behavior of right whales on the southeast calving grounds consisted of relatively short 'v-shaped' dives, often to or close to the bottom, and the whales showed no consistent swimming direction during the deployments (Figures 1-8). The whales spent at least as much time at sub-surface depths (1>depth>10 meters) as they did at the surface (<1 meter). Figures 1, 3, 5, and 7 provide examples of dive profiles and time spent within different depth ranges, and Figures 2, 4, 6, and 8 show the track of the whales during the attachments. Water depths in the areas where we tagged whales ranged from ~10-20 m, and though not all whales dove to the bottom, they clearly used virtually the entire water column. One whale did dive to the bottom and stayed there for >10 min (Figure 5), in what resembles a feeding dive based on other right whale tagging data (Baumgartner *et al.*, 2003; Baumgartner & Mate, 2003; Nowacek *et al.*, 2001). While we were not sampling for whale prey, the presence of this dive within our relatively limited sample size could indicate an attempt by these whales to feed.

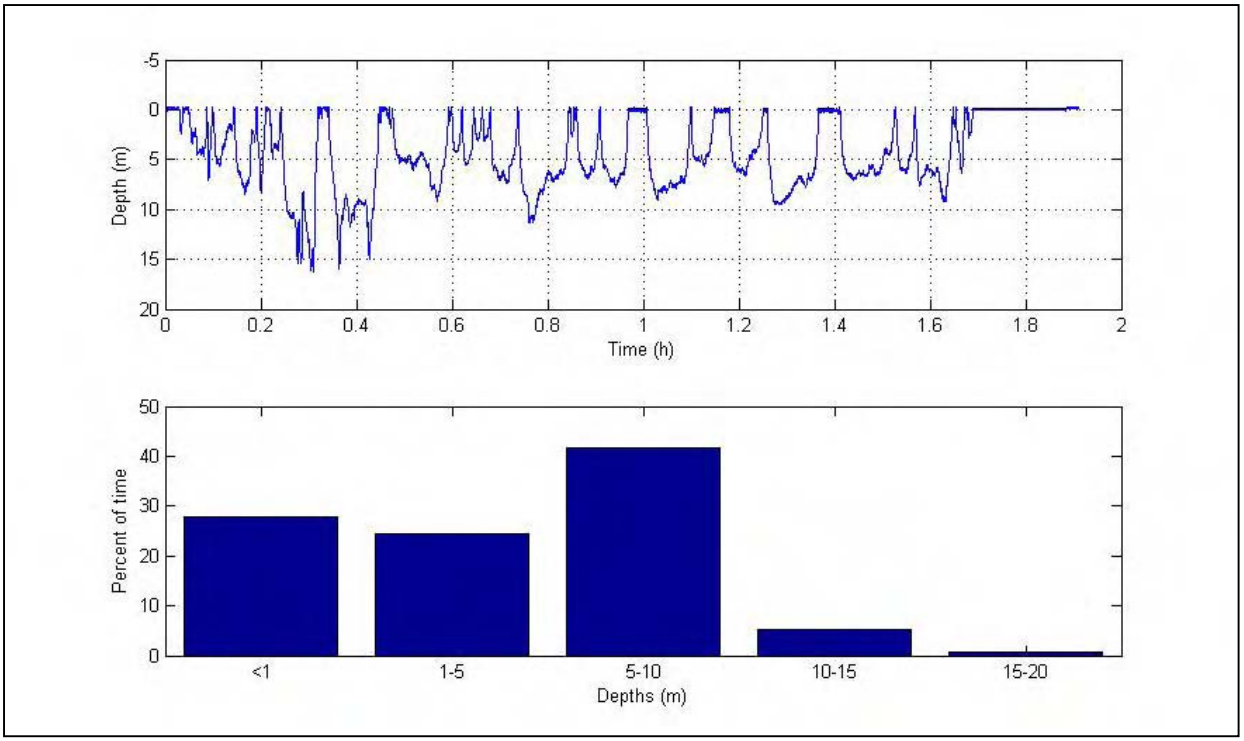

Figure 1. Dive behavior and time spent in depth categories for whale '024a'.

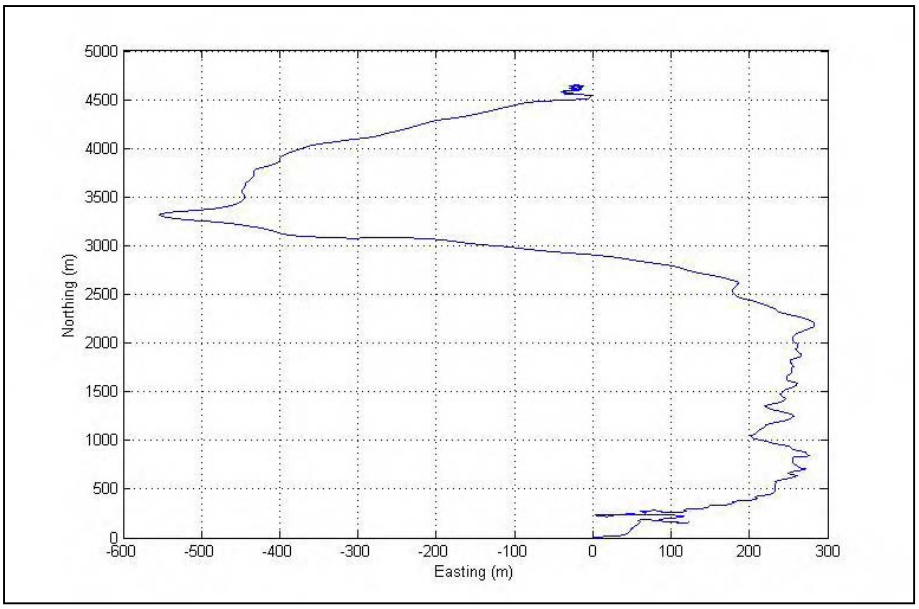

Figure 2. Heading data from whale '024a'. The plot shows 'easting' by 'northing', thus negative movement in the easting direction indicates westward movement; similarly for negative movement in the northing direction indicating southward movement.

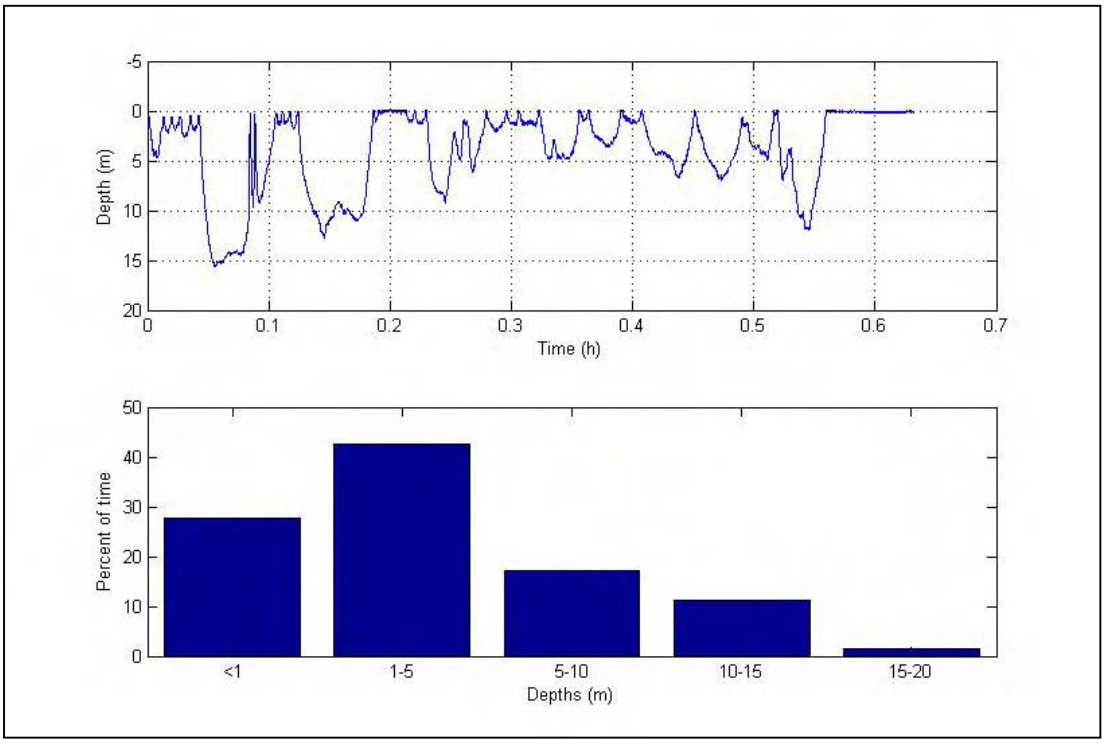

Figure 3. Diving behavior and time at depths for whale '024b'.

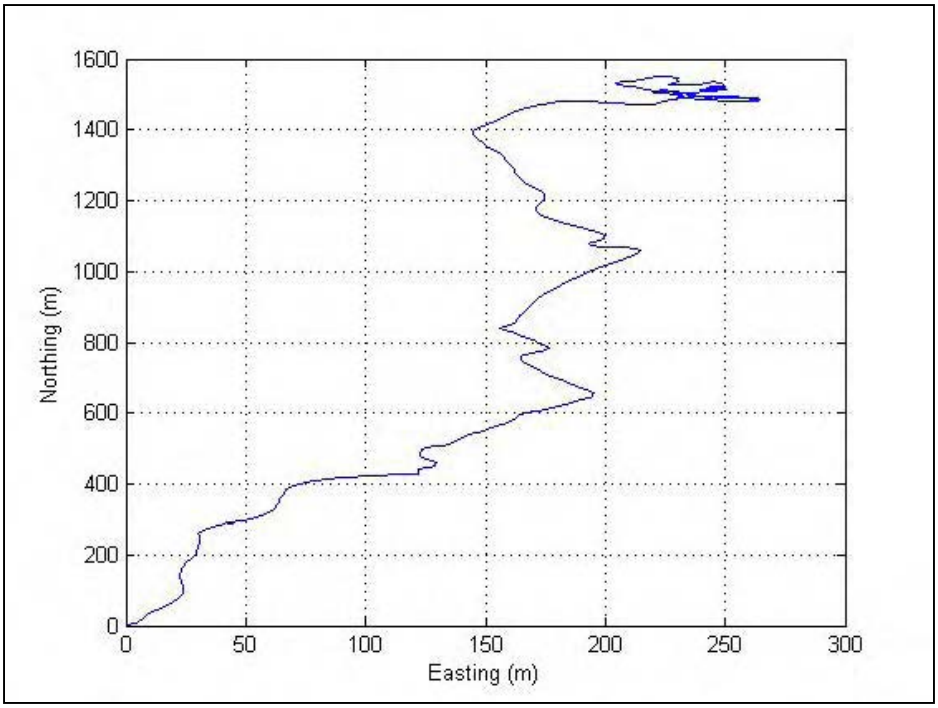

Figure 4. Heading data for '024b'. The whale traveled in a northeasterly direction during the attachment, covering >1500 m in the short ~30 min of tag-on time.

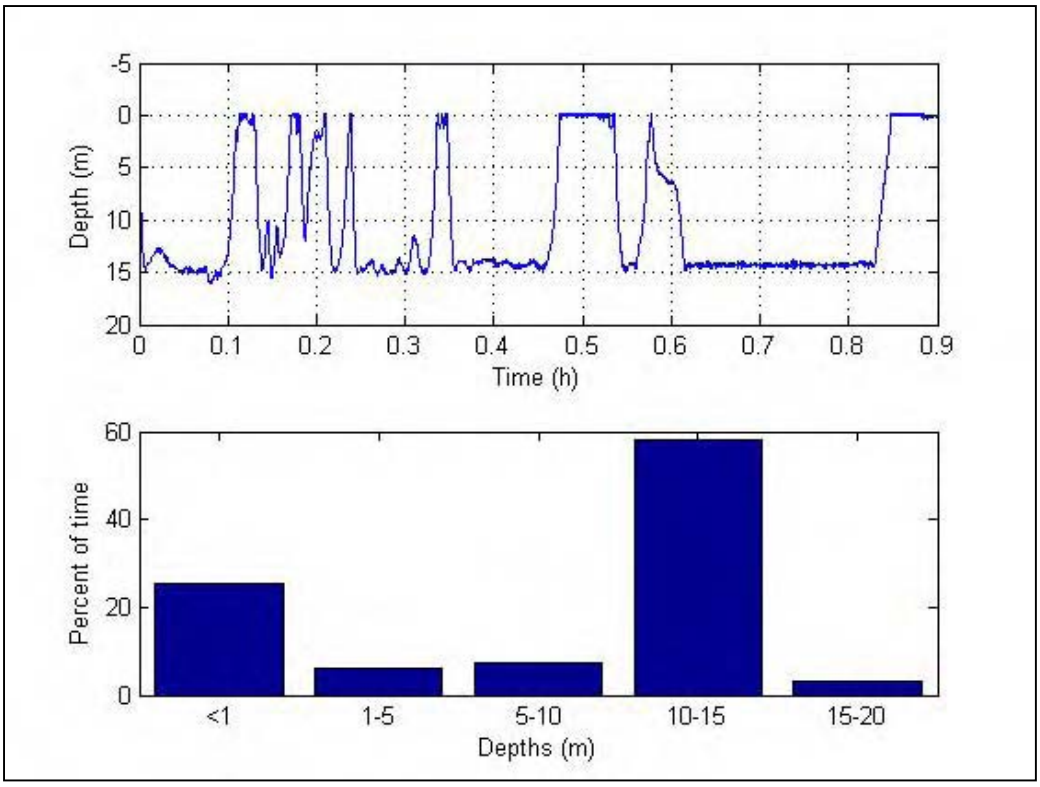

Figure 5. Dive profiles and time at depth for whale '024e'. Worth noting is the prolonged dive starting at 0.6 hours into the record. This dive lasted approximately 15 minutes, and the whale was very close to or on the bottom.

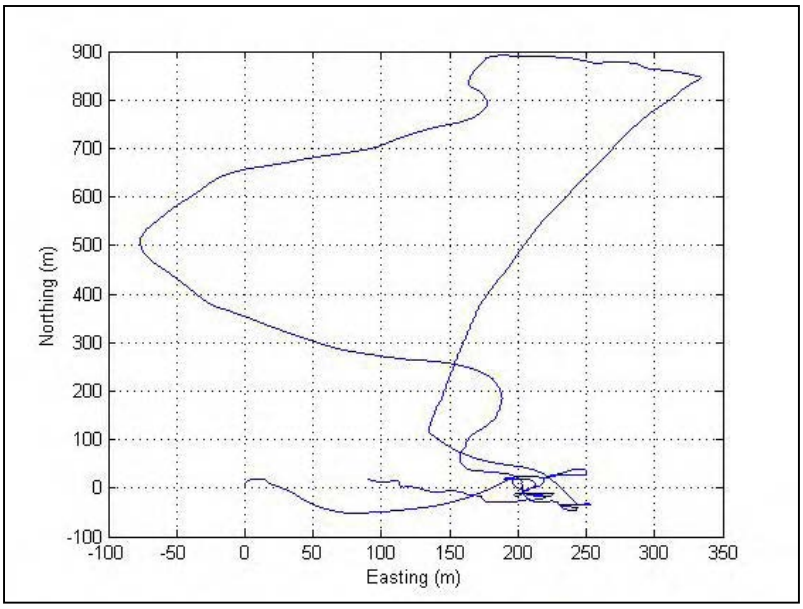

Figure 6. Heading data for whale '024e'. This track is qualitatively different than others, with the whale looping back and returning close to the location where we attached the tag. Also, this whale covered approximately 2000 m within the ~50 minutes the tag was attached.

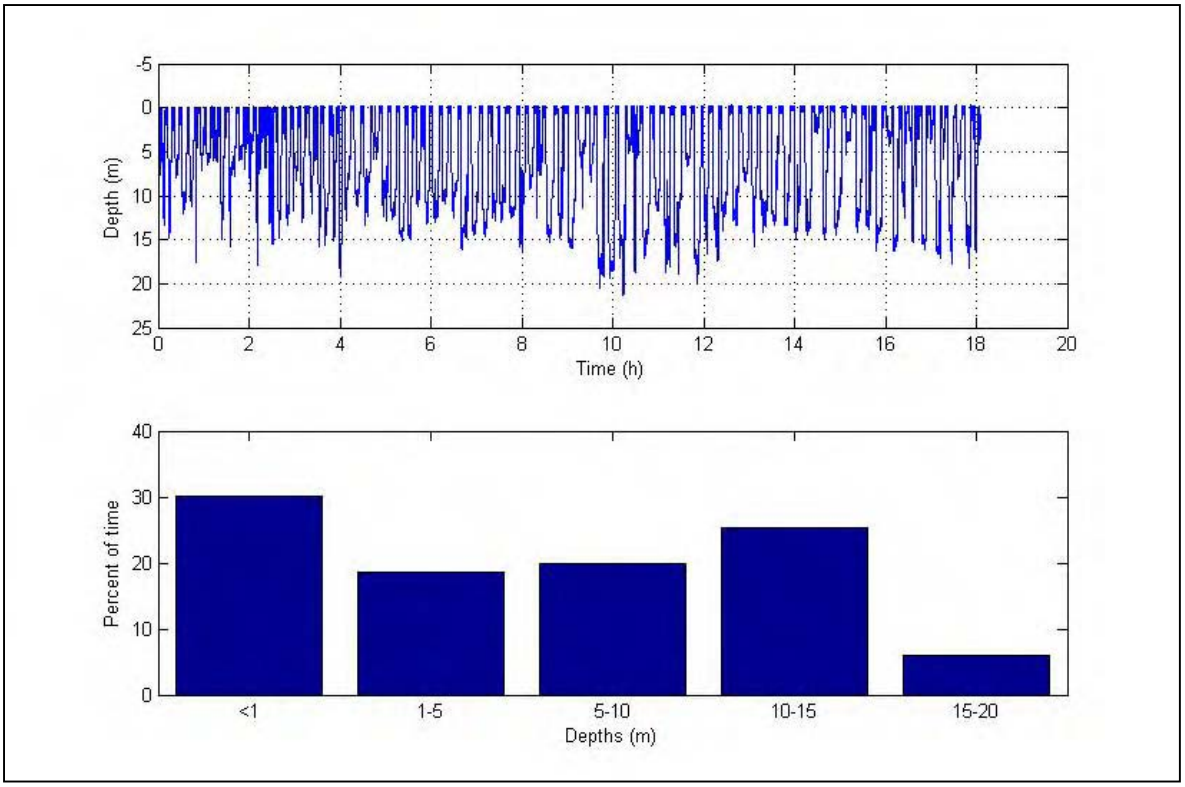

Figure 7. Dive profiles and time at depth for whale Eg1151. As can be seen in the heading data (Fig 8), this whale traveled a great distance while the tag was attached, and during these traveling dives she consistently dove to ~10-15 m, spending a higher percentage of time at the bottom of the dives, but only moderately more than time spent at the depths during descent and ascent. The depth of water varied over the range she covered, but never reached more than 25 m, so she was using the whole water column. Only a few other whales tagged have shown this traveling behavior, and they too routinely dove to ~15 m while traveling.

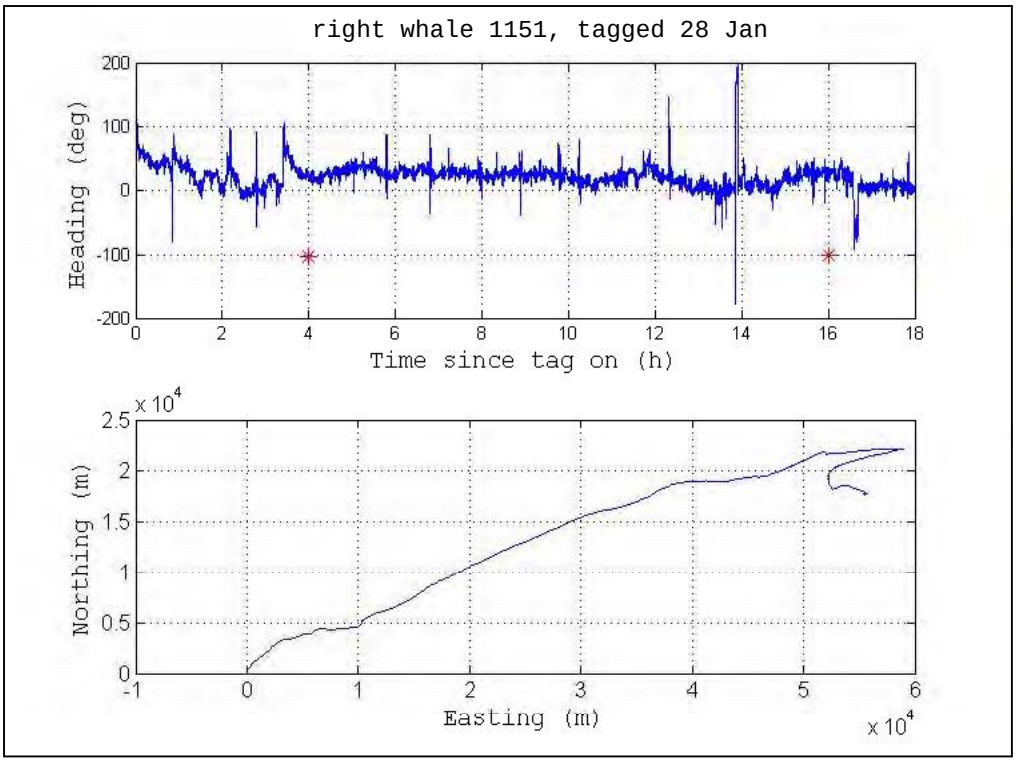

Figure 8. Heading data for 1151. The upper plot shows the raw heading data indicating a north-northeast heading taken by the whale throughout the attachment. * indicates sunset and sunrise, respectively. Eg1151 covered approximately 63 km during the 18 hours the tag was attached.

Vocal behavior

The vocal behavior of right whales has received a good deal of attention historically (Clark, 1982; Clark & Clark, 1980) as well as recently, with a particular focus on northern rights (Matthews *et al.*, 2001; Parks, 2003a,b). One application of these studies has been to inform conservation efforts using passive acoustics (Clark *et al.*, 2007; Gillespie & Leaper, 2001). Characterizing the vocal behavior of the whales is critical for the success of mitigation efforts that utilize passive acoustics.

One of the most critical quantities to understand if one is to use passive acoustics for mitigation is the vocalization rate. Considering all sound types, tonal as well as gunshot calls, vocalization rates for the whales in our study ranged from 0.004 – 1.43 vocalizations/minute (Figures 9-13). Also important for passive acoustic efforts is the depth at which the whales produce sound because the propagation conditions can be highly depth dependent (Urick, 1983). Propagation conditions are important to understand so that the range at which a whale can be detected can be estimated. Most of the vocalizations recorded in our study were produced when the whales were below the surface (Figures 9-13), which under many circumstances is good with respect to detection ranges, i.e., sounds produced at the surface often do not propagate as well (Urick, 1983). Given the shallowness of the waters in which we conducted our work, however, the depth of sound production may be less important as propagation is more uniform. Propagation is also frequency dependent, with high frequencies (>1 kHz) attenuating more quickly due to absorption, but in these very shallow

coastal waters, low frequencies also do not propagate very well as the water column is too narrow to host these long wavelengths (Urick, 1983).

Some of the vocalization rates we recorded were quite high (Figure 12), and this whale was involved in a surface active group (SAG), a social grouping of right whales (Kraus & Hatch, 2001). While this high vocalization rate may be encouraging for passive acoustic efforts, the production of sounds is not uniformly distributed throughout the record with virtually all sounds occurring in the first 1/3 of the record. The very low vocalization rate for Eg1151 is also worth noting (Figure 13). This whale traveled a long distance during the tag deployment and produced very few sounds. Whenever we had visual contact with Eg1151, she was traveling with another adult whale, though we do not know whether this pair stayed together through the night. This low rate of sound production while traveling makes it challenging to use passive acoustic methods to protect whales. No data exist on vocalization rates for migrating whales, and though Eg1151 did travel back to the south and give birth in the SEUS ~10 days after tagging, the behavior we observed could be indicative of migratory behavior.

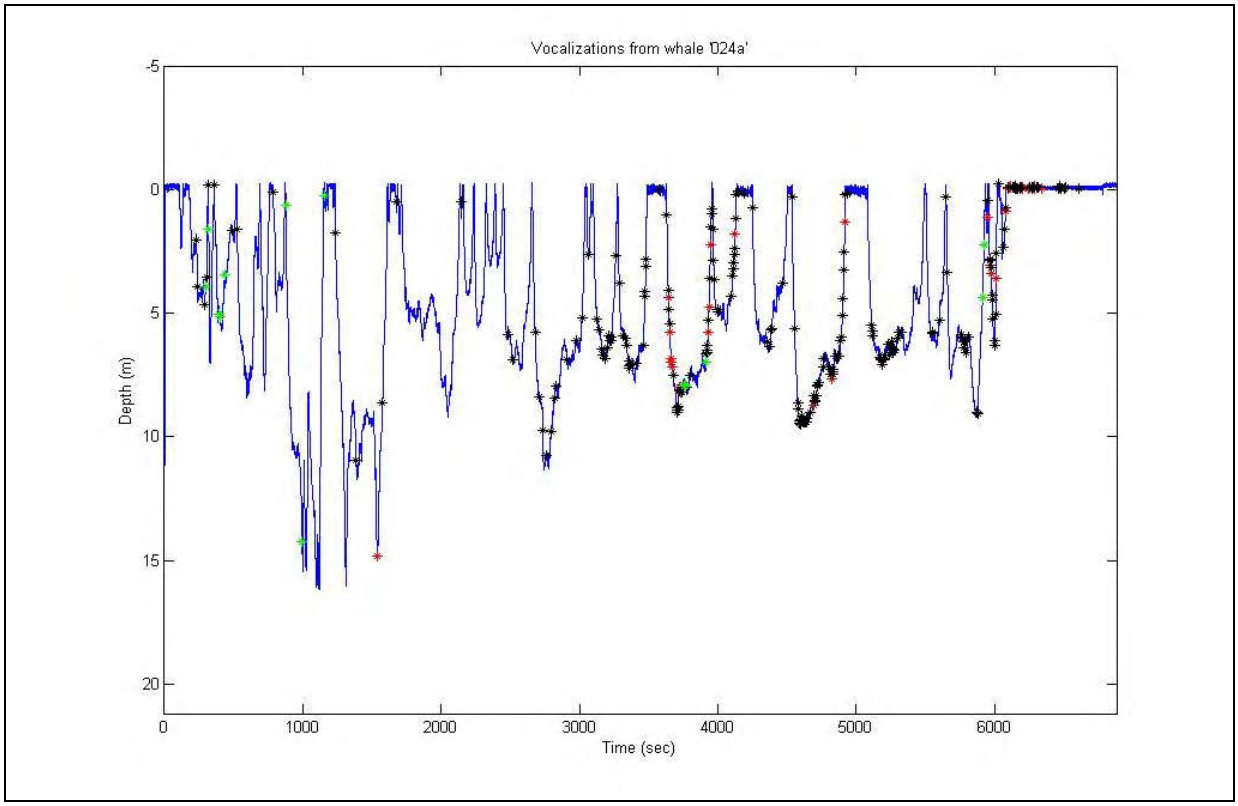

Figure 9. Vocalizations recorded during tag deployment on whale '024a'. Vocalizations by the focal whale, '024a' in this case, are marked with *, focal whale gunshots sounds (Parks, 2003a) are marked with *, and vocalizations not attributed to the focal whale are marked with *. Vocalizations are attributed to the focal whale if they are of relatively high amplitude and have multiple harmonics, which would attenuate quickly if produced by another whale. Vocalization rate for this whale is approximately 0.45 vocalizations/minute, though they are clearly not evenly distributed throughout the record.

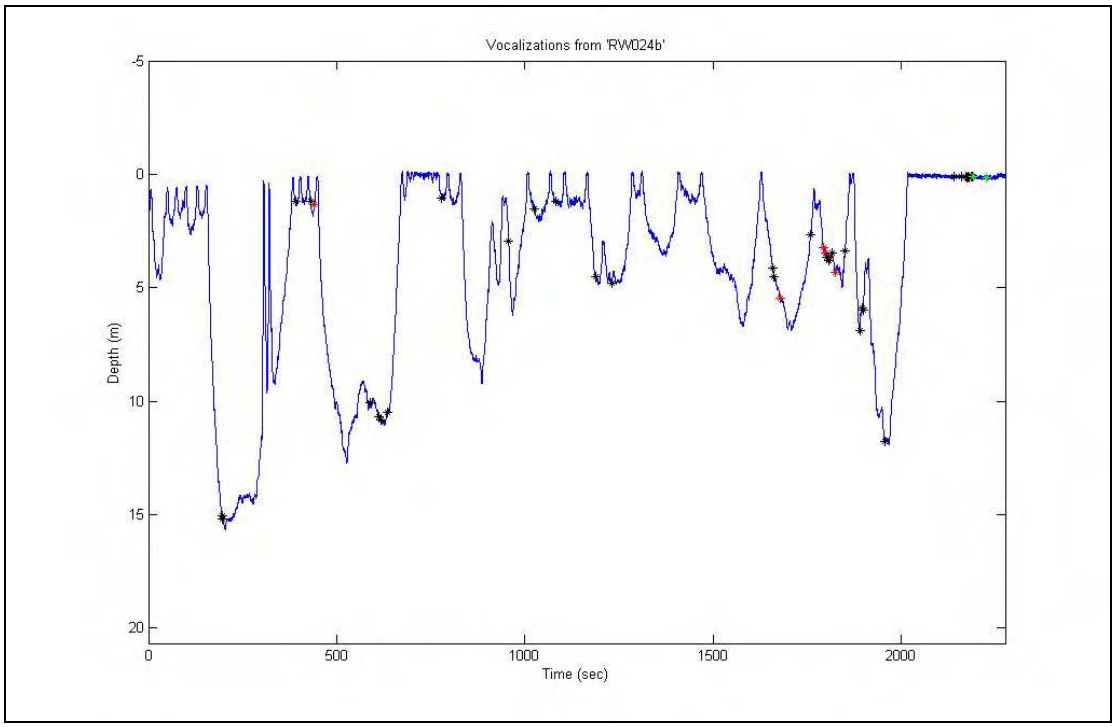

Figure 10. Vocalizations from whale '024b', colored markings for sounds are explained in Figure 9. Vocalization rate is approximately 0.23 vocalizations/minute.

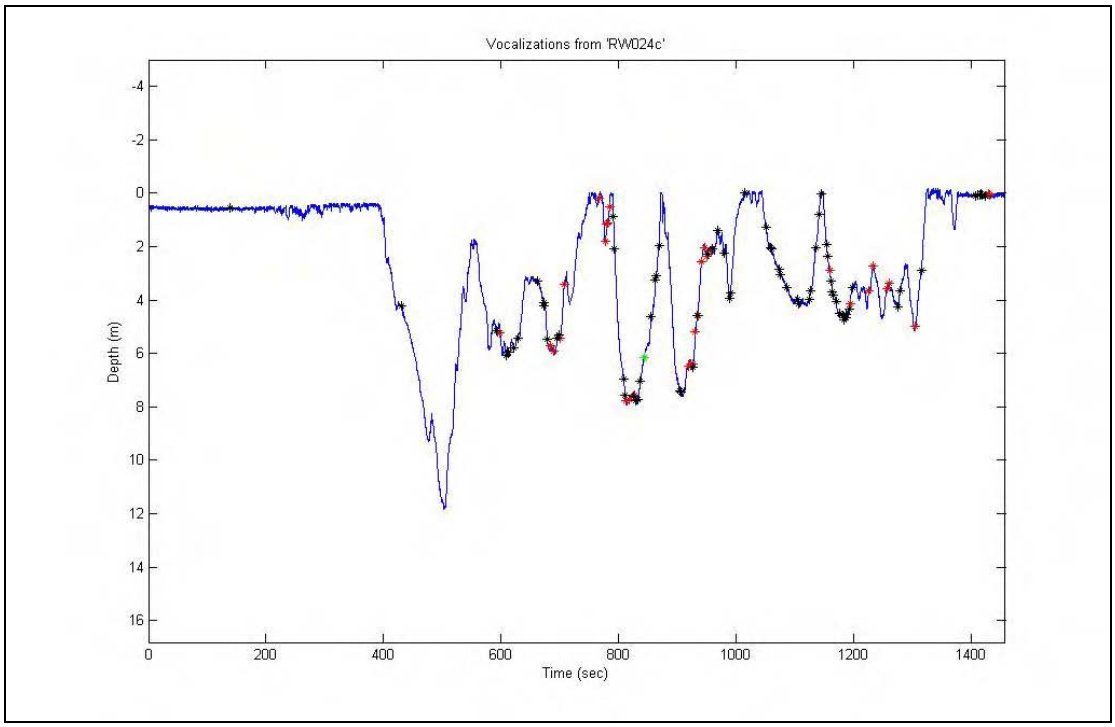

Figure 11. Vocalizations from whale '024c', colored markings for sounds are explained in Figure 9. Vocalization rate is approximately 1.43 vocalizations/minute.

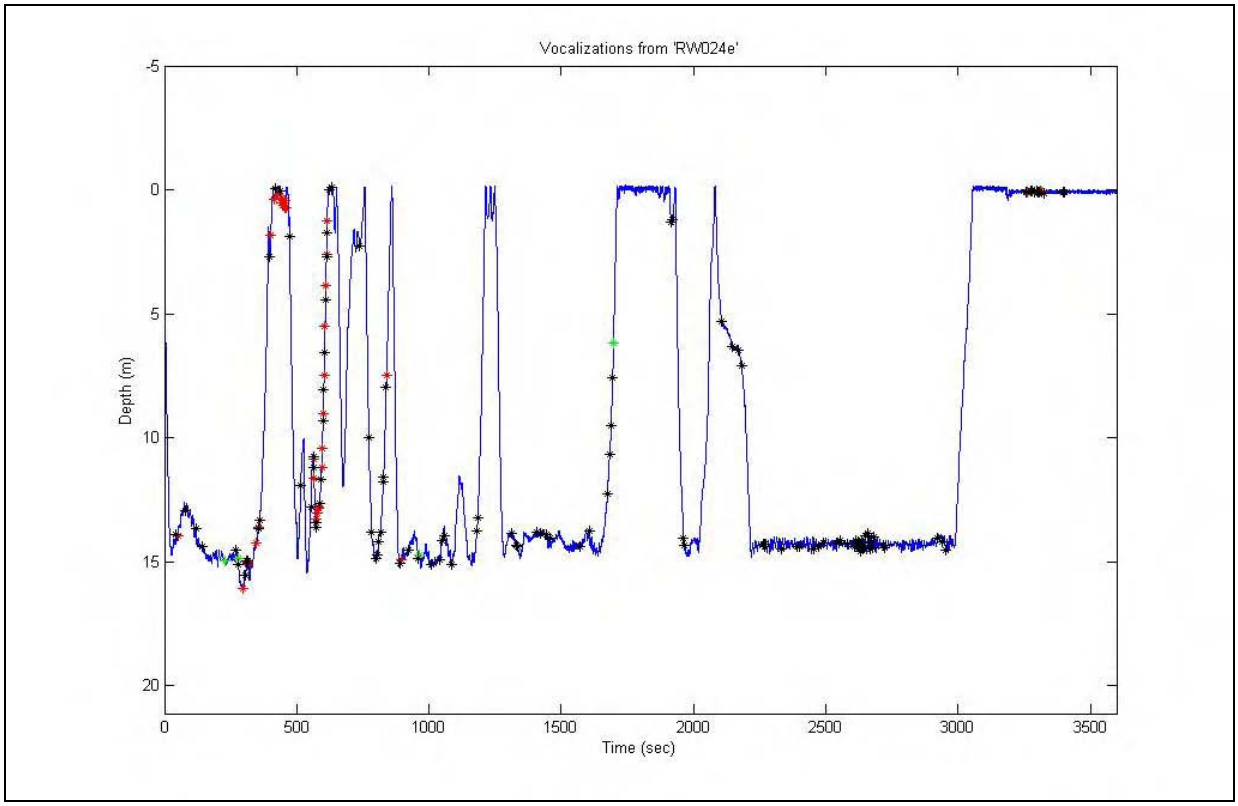

Figure 12. Vocalizations from whale '024e', colored markings for sounds are explained in Figure 9. Vocalization rate is approximately 0.66 vocalizations/minute, though the production of sounds is not uniformly distributed throughout the record.

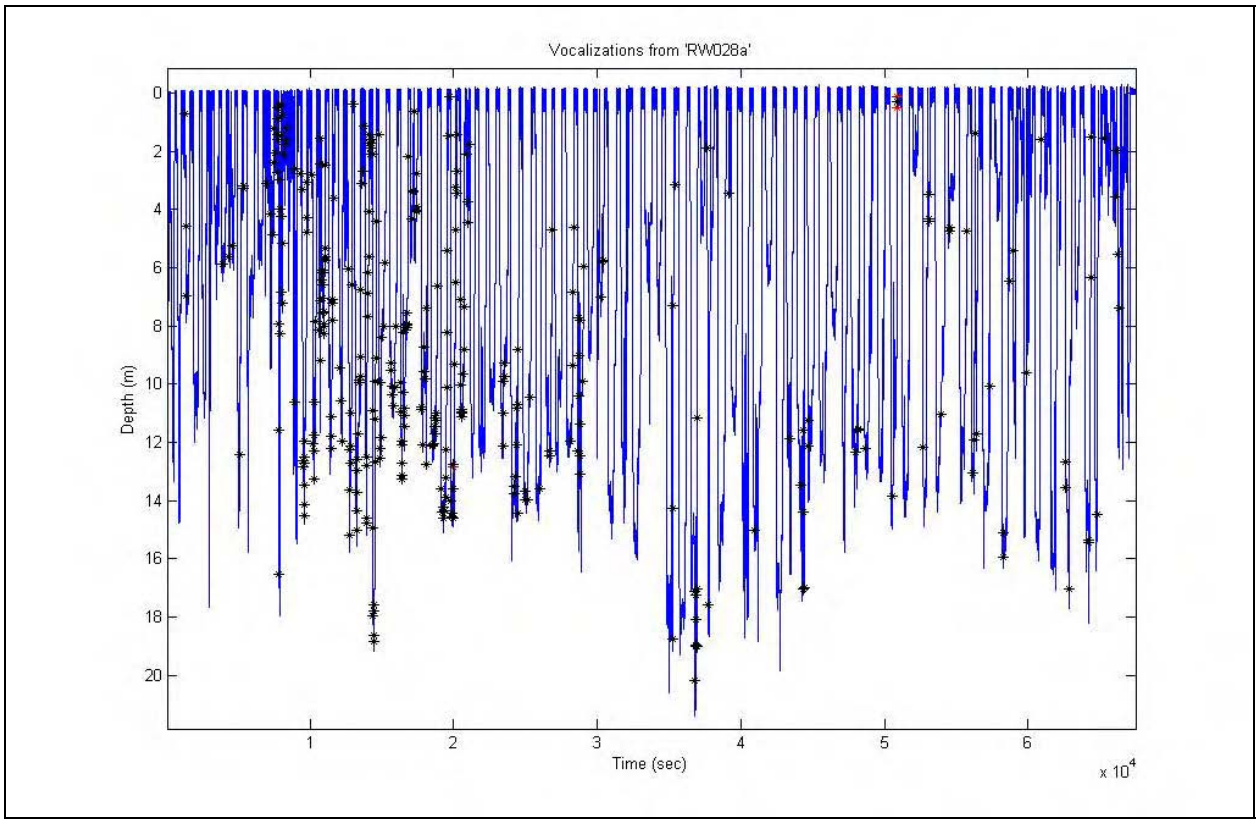

Figure 13. Vocalizations from whale '028a', colored markings for sounds are explained in Figure 9. Vocalization rate is approximately 0.004 vocalizations/minute.

This project has successfully characterized the dive behavior of right whales in the SEUS calving ground, and shown that though they spend a significant amount of time at the surface, they do utilize the entire water column. We have also documented the vocal behavior of these whales. The whales produce sounds that are similar to those produced in other parts of their range, but the rate of production is quite variable. These results should be helpful in informing the design of mitigation measures to protect this critically endangered species. A manuscript summarizing the results of this study is currently in preparation (Appendix 2).

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National Fish and Wildlife Foundation
Final Financial Reporting Form
**Fill in all shaded areas*

Project Name and Number: Measuring the Effects of Vessels on Right Whales #2003-0170-015

Project Administrator: Andrew Nunn-Miller **Email**: Andrew.Nunn-Miller@nfwf.org

Budget for Phase #1:

Category	Approved Budget NFWF Funds *(from Grant Agreement)*	Actual Expenses NFWF Funds
Salaries & Benefits	$0.00	**$0.00**
Equipment	$0.00	**$0.00**
Other	$23,018.01.00	**$23,018.01**

Budget for Phase #2:

Category	Approved Budget NFWF Funds *(from Grant Agreement)*	Actual Expenses NFWF Funds
Salaries & Benefits	$1,651.150	**$1,651,15**
Equipment	$0.00	**$0.00**
Other	$37,929.28	**$37,929.28**

Budget for Phase #3:

Category	Approved Budget NFWF Funds *(from Grant Agreement)*	Actual Expenses NFWF Funds
Salaries & Benefits	$3,068.85.00	**3,068.85**
Equipment	$0.00	**$0.00**
Other	$60,032.71.00	**$60,032.71**

Total Project Budget:

Category	Approved Budget NFWF Funds *(from Grant Agreement)*	Actual Expenses NFWF Funds
Salaries & Benefits	$4,720.00	**$4,720.00**
Equipment	$0.00	**$0.00**
Other	$120,980.00	**$120,980.00**

Describe All Expenses – use additional space if necessary:

Salaries and Benefits:	
GA DNR Staff and Benefits:	$4,720.00
Other:	
Contractor (Wildlife Trust):	
Contractor and Subcontractor Salary and Benefits:	$23,380.17
Research Vessel Charter:	$35,587.31
Field Expenses:	$3,502.83
Travel Expenses:	$511.66
Field Subcontractors (Woods Hole Oceanographic Institution and Florida State University):	$57,998.03
Total:	**$125,700.00**

I hereby certify that the Phase described above has been completed and that the above information is accurate and complete.

Georgia Department of Natural Resources

By: _____ Date: _March 2, 2007_____

__Russell Clay George, Wildlife Biologist I_____
(Print name and title)

E-mail: clay_george@dnr.state.ga.us___ Telephone: __912-262-3336_____

Note: Forms sent by e-mail must come from an e-mail address authorized in the Grant Agreement or an amendment to the Grant Agreement.

National Fish and Wildlife Foundation

Project Evaluation Form

Project Name and Number: Measuring the Effects on Right Whales 2003-0170-015

Recipient: Georgia Department of Natural Resources

Project Location: Fernandina Beach, FL

1) Were the specific objectives as outlined in your application and grant agreement successfully implemented and accomplished? Explain.

   The objectives of this project were to determine, using behavioral observations via ship and aircraft and non-invasive digital tags, whether or not right whales respond to approaching ships in the SEUS and if so, in what way. We intended to look at numerous variables that may have affected such reactions, including distance from the ship, orientation, behavioral responses, etc. Likewise, we intended to determine if there were conditions under which whales did not respond to approaching vessels.

   We were unable to examine the direct effects of vessels on right whales because no ships passed within close proximity to tagged whales during the study. Nonetheless, the results of the study were valuable in providing the first detailed insights into right whale subsurface behavior in the SEUS (e.g. individual vocalizations, dive patterns), which have significant implications for right whale/vessel management. This information has already aided managers in making more informed fisheries and vessel management decisions.

   Our ability to study right whales' direct responses to passing ships was limited by research permit restrictions which prevented us from tagging females with calves. As such, the majority of whales that were available for tagging were juvenile whales socializing in surface active groups. These young whales routinely knocked their tags off shortly after tagging, presumably through body-to-body contact and/or contact with the ocean floor, thereby effectively reducing the amount of tag-on recording time. Numerous mom/calf pairs were available for tagging during the study that would have provided better opportunities to meet our research objectives. In addition to achieving longer tag deployments, the data obtained from females with calves would have provided greater insights into the most important demographic component of the North Atlantic right whale population: reproductively active females.

2) Please assess project accomplishments as quantitatively as possible. For example:

a. Number of miles of stream/river corridor benefited. Categorize by type of benefit (e.g., protected, enhanced, restored, made accessible).

N/A

b. Total acres of land conserved. Categorize by conservation mechanism (e.g., restored, managed, acquired, placed under an easement) and by habitat type (e.g., wetland, deciduous forest, shortgrass prairie).

N/A

c. Species benefited. If possible, report number of individuals of each species.

The endangered North Atlantic right whale faces the threat of ship strikes throughout its range. Ship strike injuries and mortalities are the most signficant known cause of death for the species. Only approximately 350 North Atlantic right whales remain, and all individuals in the population may benefit from the results of this project. Information on how right whales behave in their environment and how they react to sound stimuli such as ships will determine the most appropriate management actions to protect all individuals.

d. Number of meetings/events held.

N/A

e. Presentations made.

Presentations on the plans and results from this project have been made at the spring and fall meetings of the Southeast U.S. Implementation Team for Right Whale Recovery. Results will likely be presented at the Right Whale Consortium meeting in November 2007.

f. Publications and extent of distribution.

Results of this study will be distributed to federal managers who have control over recovery actions and management decisions to protect the species. One publication is already underway (draft manuscript included with final reports) and others will likely follow.

g. Other

N/A

3) Assess the number of people reached through your work (e.g., landowners, students, organizations, agencies). Did other land managers benefit from the project?

Our work provided the opportunity for the local, general public to learn about the plight of the North Atlantic right whale in their region. Partnerships were strengthened amongst collaborators (federal, state, and non-profit).

4) Were any surveys or interviews conducted with partners to help gauge the success of your efforts?

   This project was a collaboration between many organizations, including non-profit organizations, state government, and academic institutions. Despite working in a new study area, difficult field conditions, and unpredictable weather, the results of the study were considered a success.

5) How will the project be evaluated in terms of monitoring or assessment of cause-and-effect response? Describe the evaluation timescale (e.g., one year, five years, ten years). How will monitoring results be reported?

   The management actions that result from this work will be the major source of evaluation for this project. We have no control over federal management actions, therefore the timeline is unknown.

6) Does this project fit into a larger program, spatially or temporally? If so, how has that program benefited from your work? (For example, an easement or on-the-ground work that connects or benefits other protected properties.)

   Researchers from various state, federal, academic and NGO's are conducting research on the North Atlantic right whale. All are collecting information that contributes to the overall understanding of the species and all are working towards recovery of the species. Conservation efforts are strengthened by additional knowledge of species behavior, etc. Our work on right whale behavioral responses to sound in its environment will add more data to the overall picture of the right whale. Monitoring of the calving ground is intensive, and information on how the animals behave underwater, while they aren't visible to aerial or boat-based surveys, is extremely valuable.

7) Does the project incorporate an adaptive management component? If so, please explain. Any lessons learned that will guide future implementation of this, or similar, projects?

   The information documented during this project will be provided to managers in an effort to assist them in making more effective management decisions that will facilitate the recovery of the right whale. Incorporating new data into the traditional management scheme and determining a new, better course of action is our goal.

8) Was there a local/regional/national response? Any media/press involvement?

   Local media covered the project via newspaper articles (see Appendix 3, DTAG Press Release).

9) To what degree has this project contributed to the conservation community as a whole?

   Conservation of a highly endangered species such as the right whale is a good case study for the conservation community. Collaboration amongst researchers, managers, state federal government, NGOs, and others is a great example of how to affect recovery of a species. This project would not have been possible without the cooperation and collaboration of many entities.

10) Did your work bring in additional partners, more landowners, et cetera, who would be interested in doing similar work on their land in the future? If so, please describe.

    N/A

11) Do you have any suggestions for NFWF to guide improvement of our project administration?

    Andrew Nunn-Miller, Whitney Hannah, and Michelle Pico were very helpful and easy to work with. We appreciate NFWF's patience with this project, despite numerous permit-related delays, budget amendments, extensions, etc.

Please share any additional information that you feel is important to the evaluation of your program.

R/V Stellwagen, SEUS Right whale tagging, Jan-Feb 2006

Jan 18 Arrive Fernandina Beach ~1800; Stellwagen docked at the Fernandina Beach Marina (FBM)
Already arrived: Loer, Bocconcelli, Hurst, Moir, Balmer who have rigged Stellwagen

19 Taylor arrived early, Moore at ~1500 and George at ~1800. Finished tag prep with Hurst, went through visual protocol with Balmer and Taylor. Monica Zani, Grace Conger, Meredith Montgomery and Peter the Swede came for dinner. Zani incredibly helpful and willing to pass along sightings to us of all non mother-calf pairs. They fly along the 30^0 50' line out to 80^0 47', then 3 mi tracklines down to 30^0 17'. Final preparations for first full day of tagging.

20 Left dock at ~0645, out the St. Mary's channel and headed north then northeast, found mother and very small calf at ~0900, did not approach or attempt to photograph but notified Skymaster. At ~1000 found a group of juveniles, first 4 and then 5, launched tag boat and attempted to tag. Sea conditions were not ideal with a 4-6' swell and some short chop. Tag fell off the pole 5 times, we returned to Stellwagen to fix that problem, which we did by cleaning the DC11 off the posts and pistons. At 1413 we attached a tag to one of the juveniles, good attachment, with sampling Fs=64 kHz and a 4 hour release. The whales were almost constantly in SAG behavior through the day, but the tag stayed attached for almost 2 hrs. Recovered the tag at ~1615 only to find that it had not recorded, most likely cause was failure to arm the tag before leaving the Stellwagen. Back to the dock at 1820.

21 Left dock at 0640, headed northeast to the 50' line then back to area where we worked yesterday. Fog hanging low over the water, visibility down to ~0.5 nm at 0900, turned to head southwest toward Jax sea buoy and visibility improved. Skymaster called at ~1000 to report they were starting their 50' line. We responded to a call by a fisherman who reported at least one whale near the Jax sea buoy, so we headed that way. We found a whale and attached a tag at 1238h, during the follow we noticed another whale that had some gear around a flipper. We called the plane and Clay called Zoodsma, who wanted Clay to tell the plane to go back to its survey track. Monica came anyway and identified our whale as well as the entangled whale as 'kingfisher'. Our tag released due to a rub at ~1405 and we retrieved it. We tried to look for our whale or another to no avail, then headed north to find others…found a mother-calf pair and radioed to Monica and Grace (NEAq biopsy boat) and they came to identify. Return to dock at 1900.

22 Fog in the morning delayed departure until ~noon, surveyed south to ~halfway to the St. John's sea buoy then northward along a parallel line ~3nm closer to shore. We sighted no whales all day until ~1600 when we found a mother-calf pair en route back to St. Mary's river. We called Skymaster 75M to report the sighting and they came to work the pair. Return to dock ~1800.

23 Predicted fog did not materialize, left dock at ~650, headed northeast to the 30^0 50' line then turned southwest toward the St. John's sea buoy. 75M up in the air ~1000. We found a pair of whales, 1 adult and 1 juvenile, at ~1000 and deployed tag boat to attempt to tag. Tag attached to the adult at 1150 but tag fell off within 1 min. We retrieved the tag and attempted to reattach it to one or both whales. They were elusive and the sea conditions began to deteriorate. At ~1400 we heard from 75M that they had a SAG ~5nm from our location, so we left the pair (which had separated during our tagging attempt period and never reunited) to head for the SAG. We found a single whale along the way but did not stop on the thought that it was one of the pair we had worked and considered our chances for attachment better with a group. We located the SAG by ~1500, approx 5 whales in the area but the sea conditions had further deteriorated with 20-25 kt winds on top of 4-6' swell. We decided the conditions were not conducive to tagging due to danger of transfer to the small boat as well as controlling the pole while tagging. Ceased operations at ~1530 and headed back to FBM, arrived at the dock at 1800h.

24 Left dock at 0640 and headed northeast into the area covered by the Wildlife Trust (WT) aerial survey team on the report that they had recent sightings of ~40 whales in the southern portion of their survey range. We reached the Brunswick sea buoy at ~1100 having seen no whales en route. The WT team, in the NOAA Twin Otter 46, began surveying their southern lines but found no whales and had to abandon the southern area due to squalls in the area. They subsequently reported 2 mother-calf pairs to us, but we had started south and aren't working those pairs. Report from 75M of SAG at 30^0 36.9'N and 81^0 12.2' W, approximately 20nm from our position at the time. Heading for that position at 1213h. Found the SAG and attached a total of 5 tags, 4 of which were apparently knocked off by contact with other whales. The 5th released when the whale made a hard left turn. Attachment durations ranged from a low of 9 min to a high of 1:50. US Navy submarine in the area as we were tagging, asked us to stay clear, but when we radioed that we had a tag on a whale they agreed to stay clear of us then headed out to sea, transiting the area very respectfully with watches posted. Last tag detached at ~1700 and we headed for the dock.

25 High winds precluded operations

26 Winds and seas still too high to operate

27 Another weather day

28 With several visitors on board, we left the dock ~0900 despite questionable weather just to see if conditions were workable. Guests included Buddy Powell, Martha Wells and Anne George, a congressional aide invited by WT. We located two traveling whales at ~1100 and launched the tag boat; conditions were marginal but workable. On our third attempt we attached a tag to one of the two whales at 1442h, which were traveling together closely throughout our approaches. We followed the two whales through the day and conducted a focused behavioral session with the NEAq plane flying overhead. We followed them into the evening, but at ~2100h we began to have trouble staying with the whales, who had continued to travel northeast. The last beep from the VHF we think we received was at ~0200 on 29 Jan. We did not hear the tag through the rest of the morning. At 1000 the Twin Otter took off from St. Simmons and immediately heard the tag on their omni-directional antenna as they could not get

clearance to fly with their directional antenna mounted to the outside of the plane. The tag was well north (~30 nm) of where we last heard it. The Twin Otter, after finishing their channel survey, flew north to get a better position on the tag…farther to the northeast!! Moir, in the Balaena, had ferried our visitors in to shore in the morning, and was to meet us as we transited to retrieve the tag. The sea conditions deteriorated, so we had to steam towards Moir to meet him. When we met, Nowacek joined Moir in the Balaena to go out ahead of the Stellwagen to search for the tag. The tag turned out to be ~1 nm from the position given by the Otter, Nowacek/Moir recovered the tag at ~1635. The seas had further deteriorated, so when we rejoined the Stellwagen we transited into the Brunswick, GA channel and anchored for the night.

29 Transited from Brunswick to Fernandina Beach in the am, no operations in the pm.

30 High winds precluded operations

31 No operations

1 Left dock at 0715 with Wells, Meagher, and Tricia Naessig on board. Surveyed north and then to the south, never sighted any whales. Survey planes spotted some, only eligible ones were ~30 nm north, other sightings were mother-calf pairs. Return to dock ~1830.

2 Weather predicted to deteriorate through the day, left dock at 0700 with Wells, Meagher, Nousek and McGregor aboard. Decided to survey south as the NEAq plane (75M) were planning to survey only the channels. They called with an eligible whale ~20 nm to the north, we decided to continue south with hopes of finding other whales, particularly when 75M came south to survey the St. John's channel. 75M ceased operations at ~1100 due to low ceiling, no word from the Otter or 53L. Surveyed to the south past the Jax sea buoy, turned toward shore and are surveying north.

3 END OF PROJECT

INTRODUCTION

The three-dimensional marine environment presents very few physical obstacles to the movement of a marine mammal, leaving ecological factors to be the principle guiding force. Therefore, there should be a match between distinctive patterns in movement and consistent behaviors that are ecologically important for an animal. By identifying these patterns in diving movements better understanding of the frequency, duration and location of the corresponding behaviors can be inferred during situations and locations when active tracking and observation are difficult. From these inferences, estimates about ecological requirements for a species can be made using knowledge of behavioral patterns (for example, the amount of time spent foraging can be used to calculate energy expenditure). Originally designed for pinnipeds, the use of a data-logging device has allowed diving behavior to be tracked throughout the water column over an extended period of time by recording changes in depth over time, generating considerable amounts of information about deep-diving species (Kooyman et al. 1976). These tags reveal that because animals repeatedly perform behaviors such as foraging and resting, the time-depth profiles of dives made during those behaviors have distinctive and repetitive shapes (Hindell et al. 1991).

Functional analyses of dive shapes have been performed for a variety of pinniped and seabird species (see Schreer et al. 2001for a review). Across all species studied, the predominate dive shape is that of a 'U', formed by a rapid and direct descent, movement over a limited depth range for the majority of the dive duration, and a rapid and direct ascent (Table 1). These dives appear to maximize time at the bottom for foraging and at the surface for recharging oxygen stores, while also minimizing the time spent transitioning between the two (Asaga *et al.* 1994; Schreer *et al.* 2001). Deviations in depth while at the

bottom of the dive, or 'wiggles', occur during 'U' dives and have been attributed to the pursuit and capture of prey (Crocker et al. 1994; Le Boeuf et al. 1988; Lesage et al. 1999).

Additional methodology has been used in conjunction with data-loggers to confirm the correlation between U-shaped dives and foraging in some pinniped species. Lesage *et al.* (1999) inserted temperature sensors into the stomachs of harbor seals to document feeding events during the attachment of a time-depth recorder, and compared the frequency of feeding events during various dive shapes to find that foraging was strongly associated with a 'U' shape. A video recording system coupled to the data recorder also permitted evidence for behavioral correlations with dive shape, again confirming U-shaped dives to be typical of foraging activities (Davis et al. 2003). The second most frequently used dive profile forms a 'V', and has been connected with non-foraging behaviors; these dives include little to no time at depth where prey is located, and therefore no time foraging. 'V' dives consist of a continuous descent followed immediately by an ascent, various behavioral functions for these dives have been suggested. This shape could indicate traveling, as diving below the high-drag surface waters could increase swimming efficiency, avoiding predators, or exploring to locate foraging areas (Hindell et al. 1991; Le Boeuf et al. 1992; Martin et al. 1998). In smaller animals such as penguins, it appears that these dives may have a foraging function because they trade off foraging time for extended depth (Schreer *et al.* 2001).

The diving behavior of cetaceans is much more difficult to study than that of pinnipeds because they lack the semi-aquatic lifestyle that facilitates attaching and recovering equipment. However, the dive types that have been recorded in cetaceans appear to fall into the same patterns used by pinnipeds and seabirds and also demonstrate a connection between dive shape and behavior. Blue whales (*Balaenoptera musculus*) and fin whales (*B. physalus*) make U-shaped and V-shaped dives, verified as foraging and non-foraging dives

respectively by the presence or lack of distinct lunge-feeding events (Croll et al. 2001; Goldbogen et al. 2006) . Both beluga whales (*Delphinapterus leucas*) and narwhals (*Monodon monoceros*) make U-shaped foraging dives with and without 'wiggles' (Martin *et al.* 1998). The U-shaped foraging dives made by sperm whales (*Physeter macrocephalus*) are well documented (Watwood *et al.* 2006), although no work has been done to quantify any other dive shapes in this species. Although they vary slightly between individual animals, the parameters of each dive fall into a consistent and limited range for each species.

Although much work has been done relating the distribution of North Atlantic right whales (*Eubalaena glacialis*) with the distribution and density of their copepod prey (*Calanus finmarchicus*) (Baumgartner et al. 2003; Mayo & Marx 1990; Murison & Gaskin 1989; Woodley & Gaskin 1996), the underwater diving behavior of these whales has not been quantitatively described. Previous studies have monitored the dives of right whales with time-depth recorders and established that, like other pinniped and cetacean species, right whales make U- and V-shaped dives likely linked to foraging and traveling behaviors (Baumgartner & Mate 2003; Goodyear 1993). Although these dive types are visually recognizable, the parameters that distinguish them have not been quantified; this study seeks to identify these and investigate any temporal, population or age/sex class patterns in their usage.

METHODS

During July and August 2001, 2002 and 2005, multisensor digital recording tags (Dtags) (Johnson & Tyack 2003) were temporarily attached to free-swimming North Atlantic right whales in the Bay of Fundy following the methodology described in Nowacek *et al* (2004). These devices contained an accelerometer, a magnetometer, a pressure sensor and a hydrophone that synchronously recorded whale orientation (divided into vertical

movements, or 'pitch' and lateral movements, or 'roll'), heading, depth and acoustic data, respectively (Johnson & Tyack 2003). Acoustic data were recorded at a sampling rate of 16 kHz (2001), 32 kHz (2002) or 96 kHz (2005), while sensor data were recorded at a sampling rate of 23.5 Hz (2001,2002) or 50 Hz (2005), though decimation and interpolation resulted in a processed sample rate of about 0.5 Hz. Tags were attached to the whale's dorsal side, at the approximate midpoint of the animal's length and width and were released via a corrosive wire. Positively buoyant foam served to bring the tag to the surface after release and the emitted VHF signal was used to locate and recover floating tags. After collection, sensor data were calibrated to generate pitch, roll, heading and depth profiles, as described in Johnson & Tyack (2003).

Using custom Matlab software, the time-depth profile for each tag attachment was plotted and used to separate dives. All dives that were greater than 50 meters were selected for analysis. From these dives, the first dive made after tag attachment was removed because the tagging process has been shown to affect the animal's behavior during initial dives (Baumgartner & Mate 2003; Miller et al. 2004). All dives made during playback experiments of high-frequency sounds, alarm signals, and right whale vocalizations were also removed because some whales have been shown to change their behavior in response to these sounds (Nowacek et al. 2004). Dives made during playbacks of sounds that whales did not respond to (vessel noise and silence sounds) were included in the analysis, and compared to other dives to determine if smaller scale behavioral changes had occurred.

Each dive cycle was composed of four phases, descent, bottom, ascent and surface, and only dives with four complete phases were included for analysis. Surface intervals were considered part of the preceding dive as, in some species, dive duration and depth have been shown to significantly influence the following surface interval (Kooyman et al. 1976). Table

1 defines the parameters that were used to quantify dives in this study. All parameters were measured for each dive and averaged by individual. Pitch angles were not calculated for three individuals (rw221d, rw232d and rw241), as tag shifts during attachment produced highly irregular pitch measurements. Vocalizations were counted for each dive phase. The current speed and heading were approximated with data generated by the University of Maine School of Marine Sciences for the Gulf of Maine Ocean Observing System (GoMOOS) model, which produced values at 10-m intervals throughout the water column for three hour time increments at a series of locations 5 kilometers apart (Xue et al. 2000). A depth of 100 meters at the location nearest to that of initial tagging was used to determine the approximate current around each whale.

Dives were visually classified into two dive types based on the patterns used by Schreer et al. (2001) and Baumgartner & Mate (2003): 1) 'U-shaped' dives with the most time at the bottom, and the rest divided equally between the descent and ascent phases and 2) 'V-shaped' dives that consisted entirely of descent and ascent phases (Fig.1). Dives that did not fit into these two categories were classified as 'other' (O) dives. One-way ANOVAs were used to compare parameters between dive types and Pearsons' product-moment coefficients were used to identify correlations between parameters within types. One-way ANOVAs were used to determine patterns in parameters according to time, age and sex.

RESULTS

There were eight, fifteen and twenty successful tag attempts in 2001, 2002 and 2005 respectively. Seven of those tags were attached for less than thirty minutes, resulting in single or incomplete dive cycles to be recorded, and were removed from the analysis. From the remaining 31 tag attachments, 419 dives were recorded. Of those dives, 92 were

removed due to playbacks, the tagging process, incompleteness or single dives. The final set of dives analyzed included 326 dives made by 29 animals, consisting of six animals from 2001, nine from 2002 and 14 from 2005. U-shaped foraging dives made up 86% of these (279), 6% (19) were V-shaped and 8% (28) were classified as other. Table 2 lists the mean and standard deviation of each parameter measured. Comparisons within and across dive types produced the following results.

Dive Type Classification

The relative portion of the total dive cycle spent in each dive phase differed significantly between each dive type (at depth: $F_{2,324}$=1077.2, P<0.001; traveling to/from depth: $F_{2,324}$=1077.2, P<0.001; PSI: $F_{2,324}$=155.5, P<0.001). U-shaped dives have longer bottom durations relative to the other phases, while V-shaped dives consist entirely of 'traveling' and surface phases and O dives include a shortened bottom duration and longer traveling and surface phases. Significant differences between dive types were found for all parameters of the descent (duration: $F_{2,324}$=33.8, P<0.001; vertical velocity: $F_{2,290}$=47.6, P<0.001; pitch: $F_{2,290}$=51.5, P<0.001) and ascent (duration: $F_{2,324}$=349.2, P<0.001; vertical velocity: $F_{2,290}$=169.7, P<0.001; pitch: $F_{2,290}$=171.6, P<0.001) phases.

U-shaped dives had a higher maximum depth, followed by V-shaped dives and then O dives. Maximum depth between U- and O dives was significantly different ($F_{2,323}$=8.45, p<0.001), while it was not between V-shaped dives and the other two types. Mean depth was significantly higher for U-shaped dives than the other two types ($F_{2,323}$=10.42, p<0.000). O dives, however, covered a larger depth range and spent a higher percentage of the bottom duration with high slope than U dives, both at significance levels (depth range: $F_{2,323}$=13.48, p<0.001; %time: $F_{2,323}$=4.57, p=0.01).

Within Type Comparisons

Similar to the results of Nowacek et al. (2001), ascent duration, vertical velocity, and pitch of U-shaped dives were significantly different from those during the descent (duration: t_{558}=3.99, P<0.001; velocity: t_{508}= -6.64, P<0.001; pitch: t_{508}= -57.69, P<0.001); ascent phases had shorter durations, greater vertical velocities and shallower pitch angles. Maximum dive depth was not correlated with bottom phase duration (r^2 = 0.0116, p = 0.0714) or PSI (r^2 = 0.001, p = 0.57).

Additionally, the number of 'wiggles' increased with longer bottom phase durations (r^2 = 0.0177; r = 0.1331, p = 0.0293) and the wiggle count increased significantly correlated with an increased depth range (r^2=0.16, p<0.001).

V-shaped dives

Ascents were significantly longer than descents (t_{36}= -6.23, P<0.001) while ascent vertical velocity was significantly slower (t_{30}=3.85, P<0.001) and ascent pitch was significantly shallower (t_{30}=3.70, P<0.001) than that of descent phases. Bottom duration was not correlated with either maximum dive depth or PSI (r^2 = 0.0139, p = 0.6311; r^2 = 0.04, p = 0.41)

Other Dives

Ascent and descent duration and velocity were not significantly different (duration: t_{27}=1.11, P=0.28; velocity: t_{27}=1.05, P=0.30), while pitch angle was (t_{27}=2.92, P=0.008). O: r^2 = 0.1185, p = 0.0729) O: r^2 = 0.004, p = 0.76)

Dive Type Comparisons

For both dive types with a bottom phase, there was a strong positive correlation between average depth range and both the portion of the bottom phase spent wiggling (U: r^2

= 0.69, $p<0.001$; O: $r^2 = 0.51$, $p<0.001$) and number of wiggles (U: $r^2 = 0.21$, $p<0.001$; O: $r^2 = 0.24$, $p=0.02$). The number of wiggles also increased significantly with bottom durations

Demographic Patterns

Dive type frequency differed significantly according to time of day (ANOVA: $F_{2,342}=4.62$, $P=0.01$). While dives of all three types occurred during these hours, 89.5% of V-shaped dives were made between 1600 and 2000 hours, in comparison to 39.3% of U-shaped dives and 46.4% of other dives (Fig. 2).

Both male and female animals performed dives of all three types. Dive duration, bottom duration, ascent duration and PSI were not significantly different between the sexes. Descent duration differed significantly between males and females for both U and V dives (U: $t_{161}=1.93$, $p<0.000$; V: $t_5=-4.50$, $p=0.006$).

DISCUSSION

Previous studies have correlated the depth of right whale dives with the depth of highest prey concentration. None have quantified behavior at depth during these dives or investigated the parameters that distinguish them, with the goal of identifying behavioral differences between dive types.

The large depth range and high proportion of time spent changing depth during O dives suggest these dives may represent searching behaviors. More time is spent in the traveling and surface phases, yet a bottom phase still exists. These variations in depth indicate active movement and consequent increased energy expenditure, as documented in the extreme example of *Balaenopterae* feeding (Croll et al. 2001), and therefore would not be performed without necessary behaviors. Further work exploring the variation in other dimensions during these dives is necessary to strengthen this possibility. Although these

data show them to reach a shallower depth, Baumgartner & Mate documented some O dives to reach the seafloor and others to reach the depth of the bottom mixed layer. The tendency for O dives and V-shaped dives to occur together in bouts (Baumgartner & Mate 2003) could represent the alternation between efficient travel between searching events departing from the surface.

U-shaped dives have been well-documented to travel to the depths of highest prey concentration, mostly occurring above the bottom mixed-layer (Baumgartner & Mate 2003). The equal

The ascent phases of V-shaped dives were significantly longer and slower than their corresponding descents. The positive buoyancy of these animals reduces the energy expenditure of right whales during this dive phase. As there is no need to increase the available portion of the dive cycle spent foraging, they can conserve even more energy by extending the ascent portion of the dive. Coupled with observational evidence ((Baumgartner & Mate 2003) that traveling whales perform V-shaped dives, this energy saving behavior could allow animals to both reduce surface drag and active swimming necessary to breathe.

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TABLES and FIGURES

Table 1. List of parameters calculated for each dive.
*the first and last 15 seconds of each descent and ascent phase were removed to reduce variation caused by whales reaching and departing from constant velocity.

Parameter	**Definition**
Dive cycle duration (min)	Duration between the descent start of one dive and the following descent start
Dive duration (min)	Duration between the descent start and ascent end (fluke out to next surfacing)
Descent duration (min)	Duration of constant negative pitch with vertical velocity < -0.5 m/s
Descent vertical velocity* (m/s)	Change in depth over change in time, averaged from 15 seconds after fluke out to 15 seconds before descent end
Descent mean pitch* (degrees)	Mean pitch angle during descent, averaged from 15 seconds after fluke out to 15 seconds before descent end
Bottom duration (min)	Duration between descent end and ascent start
Bottom time / duration (%)	Percentage of total dive spent in bottom phase
Ascent duration (min)	Duration of constant positive pitch with vertical velocity > 0.5 m/s
Ascent vertical velocity* (m/s)	Change in depth over time, averaged from 15 seconds after ascent start to 15 seconds before surfacing
Ascent mean pitch* (degrees)	Mean pitch angle during ascent, averaged from 15 seconds after ascent start to 15 seconds before surfacing
Postsurface interval (PSI) duration (min)	Duration between surfacing and start of next dive
PSI / dive cycle duration (%)	Percentage of dive cycle spent at surface
Max Depth (m)	Maximum depth reached during bottom phase
Depth range (m)	Difference in maximum and minimum depths
Wiggle count (no.)	Number of times slope of bottom phase exceeded 0.5 m/s
Mean wiggle distance (m)	Average depth between the maximum and minimum points of a wiggle
Wiggle frequency (%)	Percentage of bottom time spent wiggling (slope change >0.05)

Table 2: Mean (± SE) for right whale dive parameters and grouped by dive type.

	Duration (min)					
Type	**Dive cycle**	**Dive**	**Descent**	**Bottom**	**Ascent**	**PSI**
U	17.1 (0.3)	12.8 (0.08)	1.8 (0.02)	9.3 (0.1)	1.7 (0.02)	4.2 (0.2)
V	39.9 (10.4)	8.0 (0.4)	2.7 (0.2)	0.07 (0.03)	5.2 (0.3)	31.9 (10.4)
O	16.8 (1.9)	8.5 (0.3)	2.2 (0.2)	4.0 (0.3)	2.4 (0.2)	8.3 (1.8)

	Proportions (%)			Depth (m)		
Type	**At Depth**	**At Surface**	**Traveling**	**Mean**	**Maximum**	**Range**
U	72.2 (5.4)	33.5 (2.0)	27.8 (0.3)	128.3 (1.5)	120.6 (1.5)	16.9 (0.6)
V	0.9 (1.9)	411.6 (132.8)	99.1 (0.4))	110.6 (8.4)	108.3 (9.5)	4.5 (3.9)
O	46.7 (3.1)	96.8 (19.7)	53.3 (3.1)	108.1 (6.2)	97.5 (7.0)	23.0 (4.2)

	Vertical Velocity (ms^{-1})		Pitch (deg)		Wiggles	
Type	**Descent**	**Ascent**	**Descent**	**Ascent**	**Count**	**%Time**
U	1.4 (0.02)	1.6 (0.02)	57.6 (0.7)	53.2 (0.6)	1.9 (0.1)	15.1 (1.2)
V	0.8 (0.08)	0.4 (0.04)	31.3 (4.1)	15.3 (1.6)	0	0
O	1.1 (0.07)	1.0 (0.07)	42.2 (2.7)	33.2 (2.7)	0.7 (0.2)	16.7 (5.6)

Fig. 1. Time-depth profiles of U- (a) and V- (b) dive types with corresponding pitch angles (c,d) respectively.

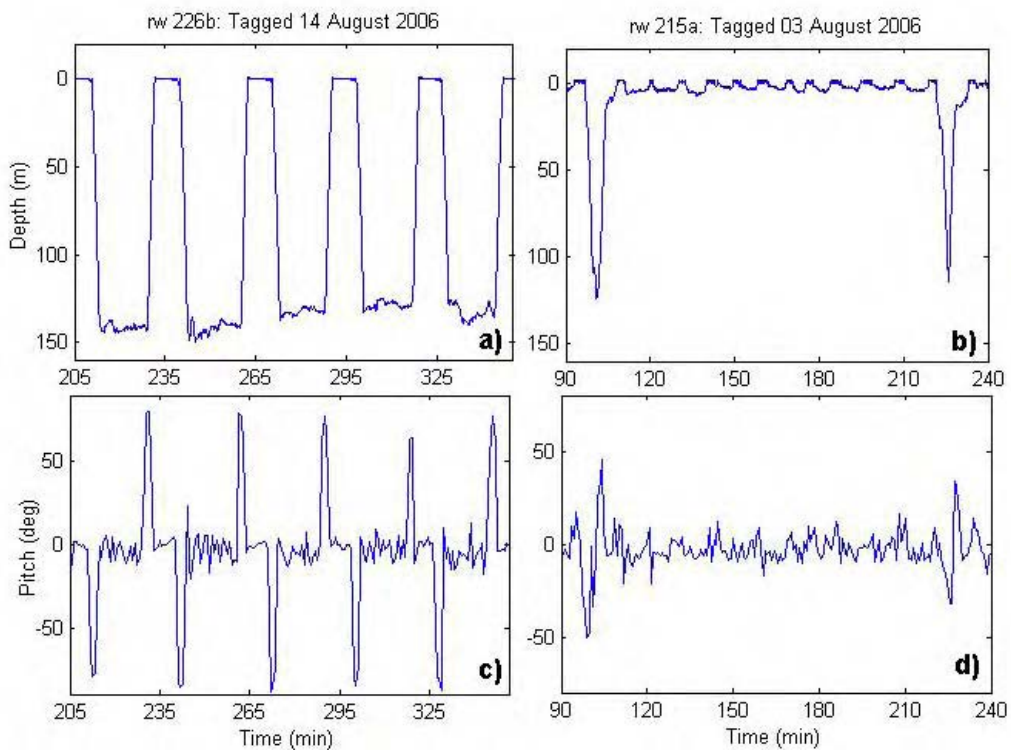


Fig. 2. Distribution of depths visited by tagged whales at their summer feeding grounds in the Bay of Fundy for all dive types.

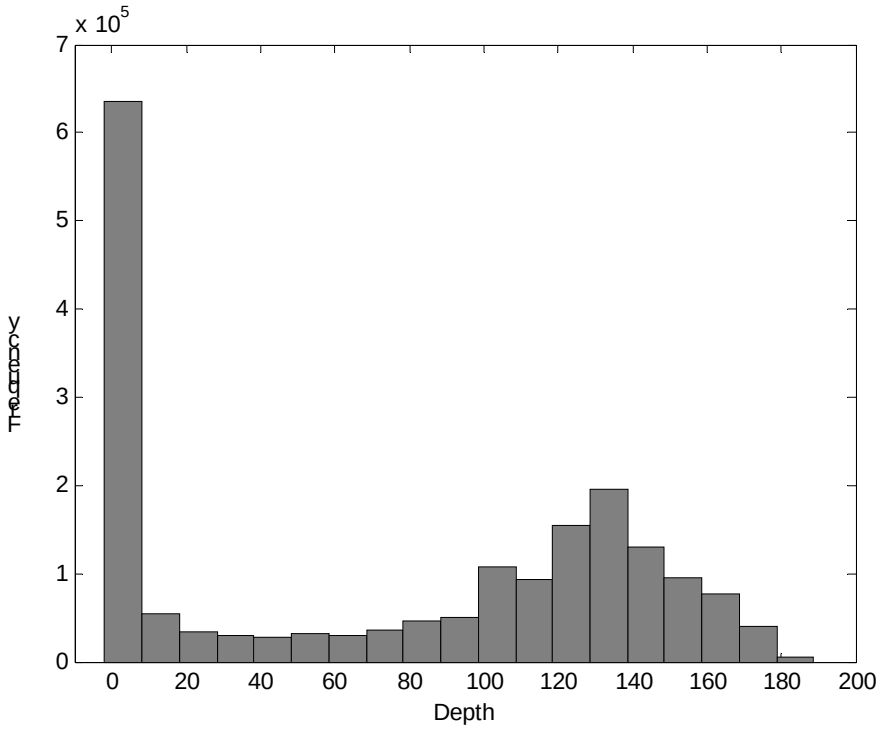


Fig. 3. Histogram of bottom durations for 342 individual dives made by North Atlantic right whales in the Bay of Fundy.

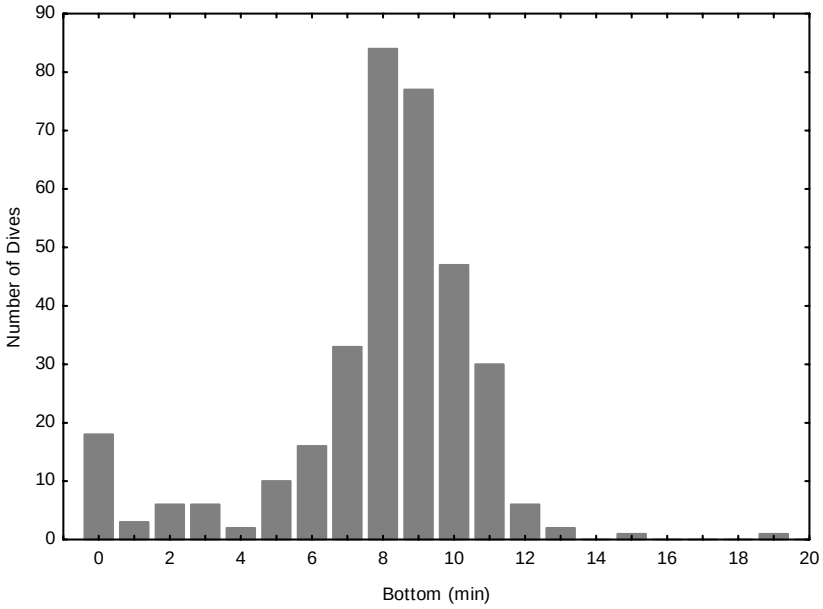


Fig. 4. Correlation between maximum dive depth and bottom phase duration for each dive type.

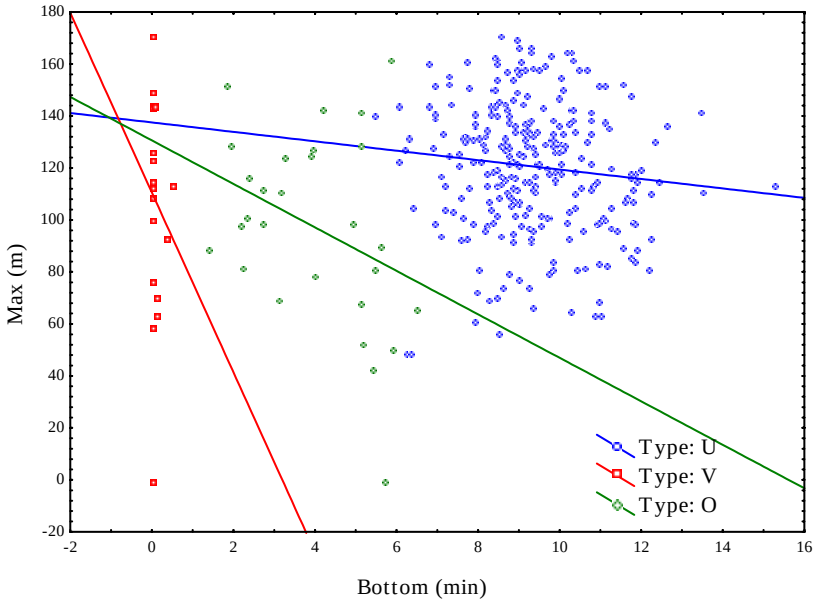


Fig. 5. Frequency of dive types made by each individual in the Bay of Fundy.

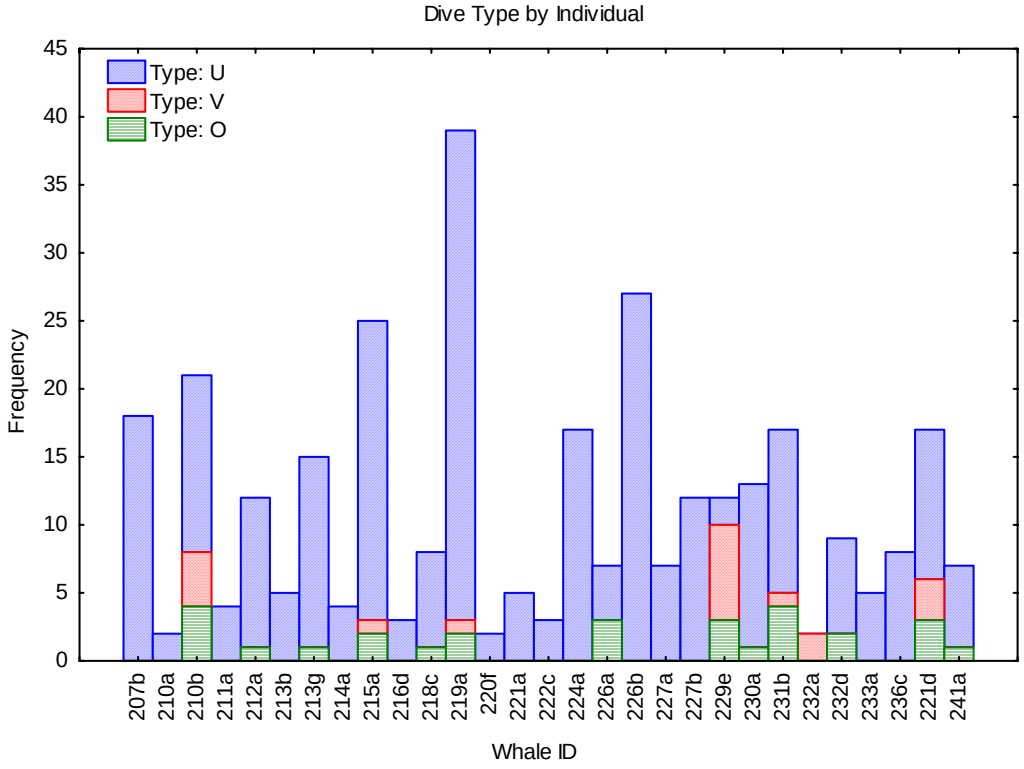
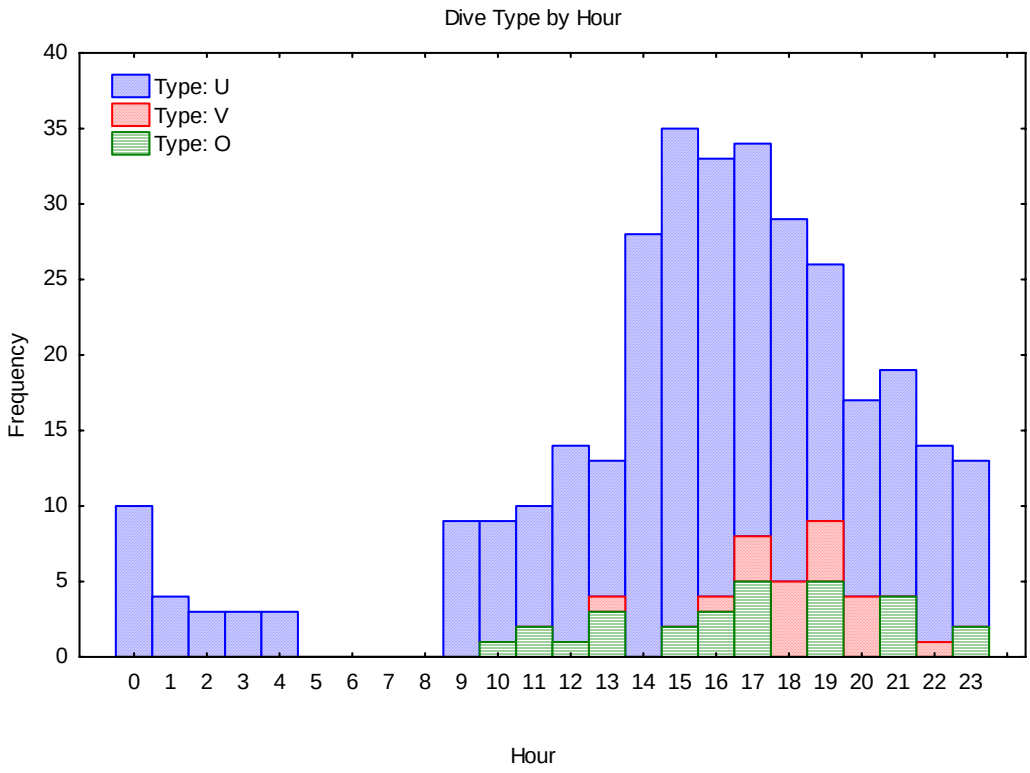


Fig. 6. Temporal frequency of dive types, grouped by the hour of their starting time.



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FOR IMMEDIATE RELEASE

SCIENTISTS TAG ENDANGERED RIGHT WHALES TO STUDY BEHAVIOR AT CALVING GROUNDS

BRUNSWICK, Ga. (March 6, 2006) – As right whales depart from their calving grounds off the Georgia coast this month for cooler waters to the north, they will leave something behind: valuable data about their movements and behavior, which biologists collected through a two-week tagging experiment. The Georgia Department of Natural Resources, Wildlife Resources Division (WRD) participated in the study, which was led by Wildlife Trust, Florida State University and the Woods Hole Oceanographic Institute, with aerial support provided by the New England Aquarium. The project was made possible by a grant awarded to WRD by the National Fish and Wildlife Foundation, with funds from the National Marine Fisheries Service.

Researchers recently placed temporary tags on nine right whales to study how the whales use their underwater habitat. The digital multi-sensory tags – called DTAGs – recorded the whales' vocalizations, depth, heading, fluke rate, and orientation in the water. The tags, roughly the size of a cell phone, were attached to the whales with suction cups and were programmed to release after several hours of tracking. Upon release, each tag floated to the surface and was located via its radio signal. Researchers retrieved the tags and downloaded the information that was recorded during the tracking event. While the DTAGs recorded the behavior of the whales, researchers also made observations of surface behavior aboard a larger support vessel.

"The tags allowed us to monitor ship noise and other sounds in the whales' environment, along with the whales' corresponding behavior," said Doug Nowacek, an assistant professor of oceanography at Florida State University. "This study has improved our understanding of right whale behavior in the southeast calving grounds, which may in turn help us reduce the number of whales killed by ships."

Only about 300 to 400 North Atlantic right whales remain, and ship strikes remain the greatest threat to the critically endangered species. At least four adult right whales

have died from vessel collisions along the east coast since 2004, including two pregnant females. These large marine mammals, which grow to roughly the size of a school bus, spend the summer and fall in waters off the northern United States and Canada. Adult female whales typically migrate to the waters off the coast of Georgia and Florida to give birth during the months of December through March.

To date, 19 calves have been recorded during the 2005-2006 calving season. Of those, two died from human related injuries – one from a ship collision and the other from entanglement in commercial fishing gear. During the 2004-2005 calving season, biologists recorded the births of 28 calves – approaching the record high total of 31 set in 2001. The average from 1990 to 2005 was 14 calves per season.

North Atlantic right whales, also called Northern right whales, can grow to 55 feet and weigh 55 tons or more. Calves are 13 to 16 feet in length. Right whales are black with white patches on their head and underside.

Boaters are encouraged to assist wildlife agencies by reporting any whale sightings. The U.S. Coast Guard can be notified on marine band VHF Channel 16. In Georgia, boaters can call 1-800-2-SAVE-ME to report sightings. Federal law prohibits boaters approaching within 500 yards of a right whale.

Georgians can support nongame wildlife conservation, education and recreation projects by purchasing a wildlife license plate for their vehicles, or by donating to the "Give Wildlife a Chance" State Income Tax Checkoff. The two nongame wildlife license plates – the bald eagle tag and the new hummingbird tag – are the primary source of funding for the WRD Nongame Wildlife and Natural Heritage Section.

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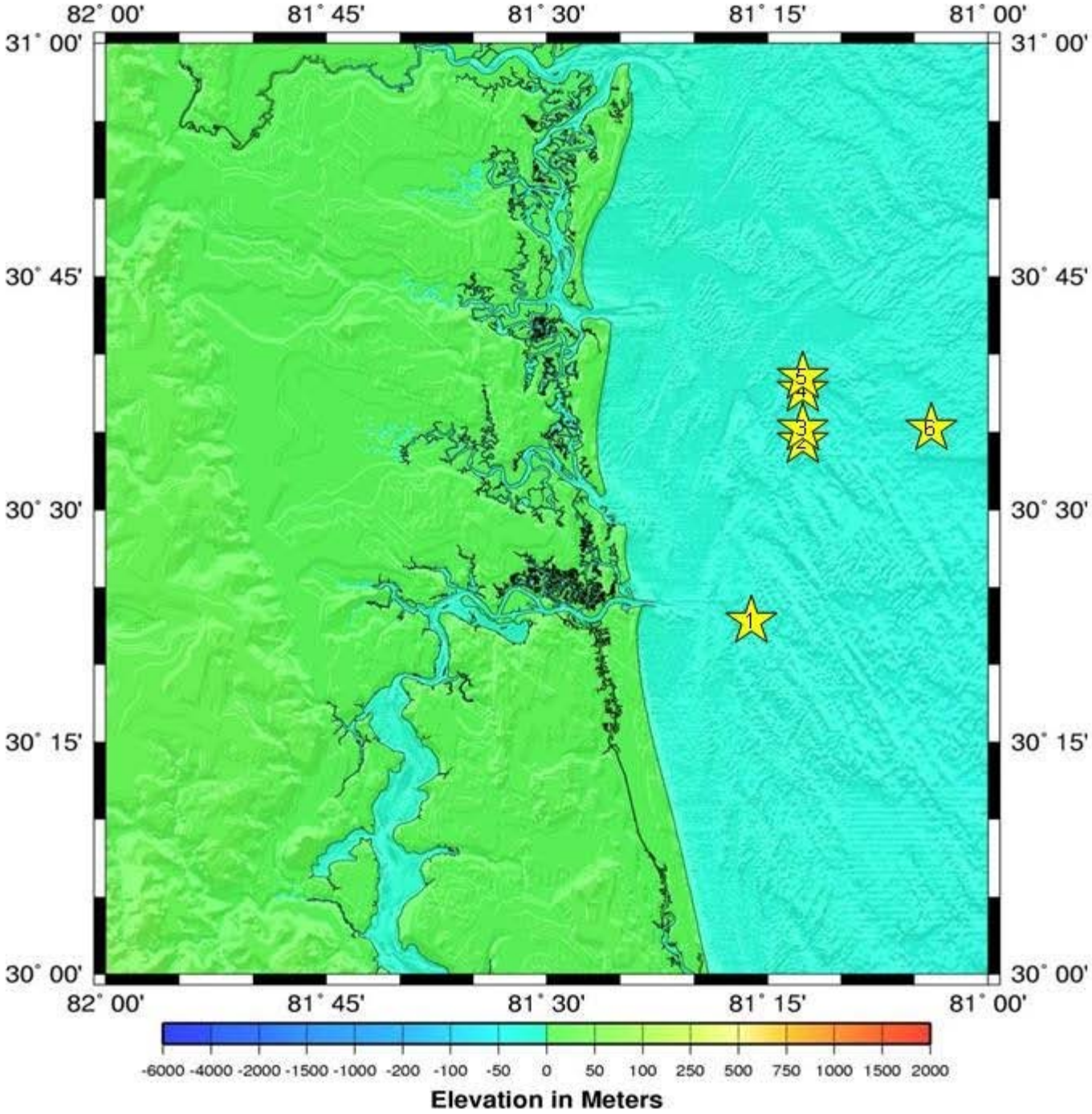

Map number	Whale ID	Date	Lat	Long
1	021A	1/21/2006	30°26'03"	81°18'32"
2	024A	1/24/2006	30°37'51"	81°13'52"
3	024B	1/24/2006	30°37'66"	81°13'59"
4	024C	1/24/2006	30°39'05"	81°13'46"
5	024E	1/24/2006	30°39'58"	81°13'48"
6	028A	1/28/2006	30°37'46"	81°04'06"