

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
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1. REPORT DATE (DD-MM-YYYY) 12/01/05		2. REPORT TYPE Final Report		3. DATES COVERED (From - To) 15-Apr-01 thru 31-Dec-03	
4. TITLE AND SUBTITLE Development and Field Testing of the DTAG for Deep-Diving Odontocetes.				5a. CONTRACT NUMBERS	
				5b. GRANT NUMBER N00014-01-1-0705	
				5c. PROGRAM ELEMENT NUMBER	
				5d. PROJECT NUMBER WHOI 130705SP	
6. AUTHOR(S) Mark Johnson Peter Tyack				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Applied Ocean and Physics and Engineering Dept. Woods Hole Oceanographic Institution 86 Water St., MS#18 Woods Hole, MA 02543				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Dr. Robert C. Gisinier CODE 34 Office of Naval Research One Liberty Center 875 North Randolph Street, Suite 1425 Ocean Engineering & Marine Systems (321OE), Rm. 1092 Arlington, VA 22203-1995 Eric Garfield Administrative Contracting Officer ONR Boston Regional Office 495 Summer Street Boston, MA 02210-2109 Defense Technical Information Center 8725 John J. Kingman Road STE 0944 Ft. Belvoir, VA 22060-6218 Naval Research Laboratory ATTN: CODE 5227 4555 Overlook Avenue SW Washington, DC 20375-5320				10. SPONSORING/MONITORING ACRONYM(S)	
				11. SPONSORING/MONITORING AGENCY REPORT NUMBER	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT See Attached					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT None	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Dr. Mark Johnson
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19 b. TELEPHONE NUMBER (Include area code) 508-289-2605

Final Report: Development and Field Testing of the DTAG for Deep-Diving Odontocetes

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Award Number: N00014-01-10705

LONG-TERM GOALS

The long-term goal of this project was to develop a reliable and sensitive method for establishing the effect of human-source sound on deep-diving marine mammals. Central to this is the development of a digital acoustic recording tag, called the DTAG. Our goal was to produce an integrated system, combining DTAG data with supporting visual observations, to determine the 3-dimensional track and sub-surface behavior of a tagged whale before, during, and after controlled exposures of sound. The tag should be expandable allowing on-going enhancements to the recording capacity and sensor suite to enable increasingly sophisticated measurement of responses to anthropogenic sound and their cost to the animal.

OBJECTIVES

1. Develop a reliable recording tag that can:
 - record the broad frequency range of vocalizations of deep-diving odontocetes.
 - measure the movements of the tagged whale with sub-fluke-stroke resolution.
 - be delivered and remain attached to a wide range of marine mammal species.
2. Develop in-the-field methods to:
 - assess the efficacy of controlled sound exposure experiments.
 - tag and track multiple whales within a group to study social organization and the effect of sound.
3. Acquire and maintain a library of baseline data from field efforts using the DTAG:
 - Maintain an easily-accessible archive of tag data and supporting observations.
 - Develop methods for inferring behavioral, anatomical, and physiological parameters from the tag data.

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APPROACH

This project has focused on developing reliable archival tags for short term (hours to day scale) non-invasive attachment. A specific goal has been to sample the orientation, depth, and sound environment of a tagged whale in sufficient detail as to be able to reconstruct its sub-surface movements at the scale of individual fluke-strokes. By recording orientation and sound synchronously and storing the data in a digital format, the relative timing of sounds and movements can be established with precision. A flexible hardware interface on the DTAG allows new physiological and movement sensors to be incorporated into the device as their level of integration makes it practical to do so. A key design decision has been to develop the tag as a fully integrated device avoiding the use of commercial sub-systems such as the widely-used Tattletail series of single-board computers. This has led to a device with dramatically improved capability and reliability as compared to currently-available tagging devices. An open and extensible set of data analysis tools written in the industry standard mathematical environment MATLAB provide powerful ways to visualize the multi-dimensional data collected by the tag. Tools for quality assurance have been developed hand-in-hand with the analysis tools to ensure data fidelity at each level.

In the course of developing and field testing the DTAG, tags have been applied to a range of deep diving odontocetes, as well as other marine mammal species. This has resulted in a substantial baseline data set archived in digital form at Woods Hole Oceanographic Institution. This data not only sheds light on the foraging and social ecology of these traditionally difficult to study animals but provides a reference point for establishing the significance of any responses found in controlled sound exposure studies.

WORK COMPLETED

Two generations of the DTAG have been developed in the course of the project. The original DTAG was designed in 1999 and has been used successfully on more than 20 campaigns. The weight and size of the device (about 600 g and 45 cm in length) make it well-suited to baleen and sperm whales but restrict its application to larger species. In 2002, in an effort to expand the range of species accessible for tagging, and taking advantage of improved technology, we designed a smaller and more capable tag. The DTAG2 is about one half of the volume and weight of the original tag. However it has more than 12 times the recording capacity as well as substantially improved dynamic range and sensor sensitivity. High quality audio can be recorded at sampling rates up to 192 kHz and a loss-less compression algorithm effectively multiplies the memory capacity (currently 6.6 GBytes) by a factor of 4. Up to 4 hydrophones can be recorded simultaneously enabling on-animal acoustic arrays for determining the direction of arrival of sounds. The new tag design is self-contained and so is easier to use than DTAG1, but it is also modular: new sensors can be added to the tag with minimal re-work and the memory capacity can be readily expanded. A new packaging method has been developed to enhance the pressure tolerance of the device for deep diving animals and the tag has been tested successfully to a depth of 2200 m. In tandem, a new attachment system has

been developed using 4 small custom-designed suction cups to enhance stability and longevity.

To date, the DTAG2 has been used on 16 field experiments and has been applied to 10 species of marine mammal including 2 species (*Mesoplodon densirostris* and *Ziphius cavirostris*) never previously tagged. The average carry times vary with species but are more than twice the average for DTAG1. The high frequency recording capability and small footprint of the DTAG2 make it well-suited to use on beaked whales and other small odontocetes of increasing Navy concern.

The two DTAG devices have now been in use for 5 years and we have amassed a substantial archive of data spanning 11 species and including more than 65 sperm whales, 66 northern right whales, 16 beaked whales and 54 pilot whales. Recognizing the value of this archive, we are committed to maintaining it and increasing its accessibility. On-going analysis of the data set has yielded a number of important results as summarized in the following section.

RESULTS

Data collected by DTAGs have generated a number of unique results. In particular, we have identified a highly energetic deep foraging mode in pilot whales (paper in preparation); we have developed a method for estimating the hydrodynamic drag and buoyancy of sperm whales from DTAG data (Miller et al., 2004); we have found consistent, strong responses of northern right whales to synthetic alarm sounds (Nowacek et al., 2003); and we have provided the first description of the vocalizations of two cryptic species of beaked whales known to be sensitive to Naval sound sources (Johnson et al., 2004).

Here we present a result demonstrating the potential for examining social organization in groups of whales using the DTAG. During a sperm whale CEE cruise in the Gulf of Mexico, three whales were tagged within 20 minutes and all tags remained attached for the following 14 hours. Using only the click sounds made by sperm whales throughout foraging dives, and recorded by the DTAGs, it is possible to measure the distance between each pair of tagged whales with an accuracy of about 3m and a time resolution of seconds. The result for the triple-tag data is shown in Figure 1. The dive profiles in the bottom panel indicate that all three whales performed a number of deep foraging dives and that these dives were often synchronized. The creak rates, shown in the center panel, are a measure of foraging success, pioneered by this research program. It is evident that the highest creak rates are coincident with synchronous diving: the creak rate is lowest right after tagging when the whales dive asynchronously, and prior to a resting period in the evening when whales progressively cease diving. Interestingly, the highest creak rates also coincide with periods of wide separation of the whales, as shown in the top panel. During the most successful dives, the tagged whales were 1500m apart. The fascinating implications of these observations clearly require more multiple tagging data to establish.

However the ability to examine group behavior at this level of detail opens many new opportunities for studying marine mammals.

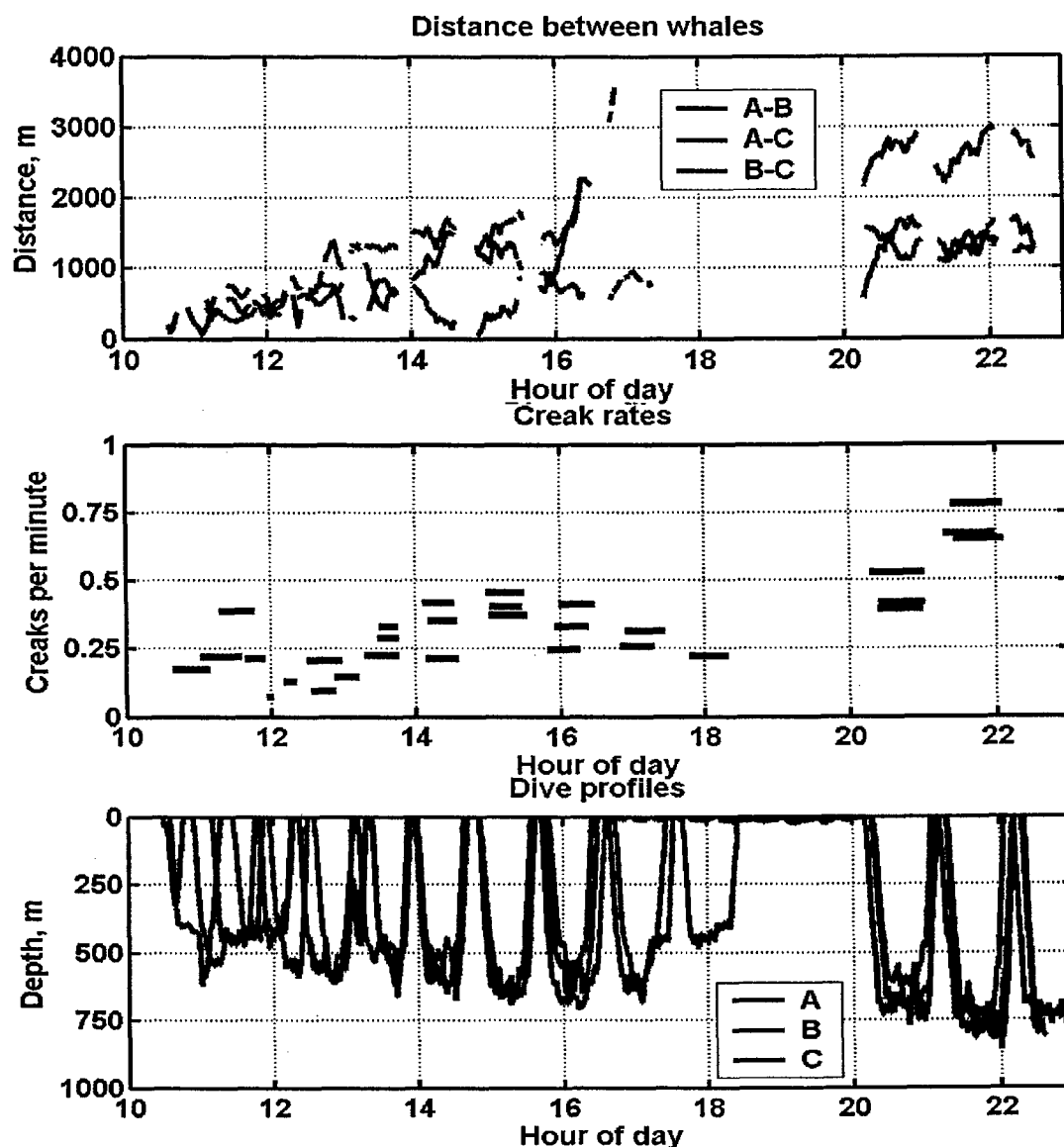


Fig. 1 Bottom: dive profiles of 3 sperm whales simultaneously tagged in the Gulf of Mexico; Center: creak rates per dive for the same whales; Top: distance between each pair of whales calculated from click travel times.

IMPACT/APPLICATIONS

The DTAG, together with the supporting data collection methods we have developed, has proven to be a highly effective tool for examining the sub-surface behavior of wild marine mammals. The combination of synchronous orientation and sound recording enables a wide range of studies in basic ecology, and on the effect of sound. We are now

able to develop a research program to determine how the responses of deep diving whales scale to received level of different manmade sounds. In addition, if we are able to use the DTAG data to understand the function of the animal's behavior, we can hope to interpret the biological significance of behavioral disruptions. The new miniaturized version of the tag is well-suited to smaller odontocetes such as beaked whales. Information on the behavior of these animals is crucial to understanding their apparent sensitivity to Navy sonar.

The on-animal recordings developed in the course of field testing and transitioning the DTAG represent an important community resource for evaluating vocalization rates, movement patterns, and repertoire. Results from studies performed with the tag have been reported in a growing number of refereed publications (14 published or in press at the time of writing) which now represent a significant body of new and original work in the field of marine mammalogy.

TRANSITION

The DTAG is being used for a variety of projects as listed below in addition to the work with deep divers funded under this grant. We have continued our partnership with Becky Woodward of the University of Maine at Orono, providing DTAGs to support her field studies on the locomotion of baleen whales. We have provided DTAGs to Sascha Hooker of the U.K. Sea Mammal Research Unit to support her work on foraging Antarctic fur seals. We have worked with Mote Marine Laboratory and Disney to develop DTAG attachments for dolphins and manatees, and with Mystic Aquarium and Fisheries and Oceans Canada to develop an attachment for belugas. These new attachment methods and partnerships will increase the range of species studied using the DTAG with the goal of attaining a broad understanding of the acoustic ecology of marine mammals. Data products from the DTAG have been distributed to Navy laboratories and contractors (NUWC Newport; ESME modeling group), the NATO Undersea Research Center, NMFS, and to many university groups studying marine mammals. Active research projects involving DTAG data are currently in place at Florida State University (Nowacek), Cornell University (Parks), University of Hawaii (Stimpert), University of Maine (Woodward), University of La Laguna, Spain (Aguilar, Leon and Dominguez), University of St. Andrews, Scotland (Miller), University of Aarhus, Denmark (Madsen and Teloni).

RELATED PROJECTS

During the project, Johnson and Tyack were co-PIs on a number of grants applying the DTAG to specific studies in marine mammal sound response:

- ONR grant N00014-99-10819 for DTAG tagging during the SACLANT Center SIRENA cruises.
- SERDP grant DACA72-01C-0011 for improving detection, localization, and mitigation methods for marine mammals.

- NOAA/NEC grant to study risk factors for vessel collision with northern right whales using DTAGs. This work examines responses to alarm sounds and the potential for collision mitigation. A heat flux sensor is incorporated into the DTAG to determine energy expenditure during foraging.
- ONR-funded study led by Scripps Institute of Oceanography to use DTAGs on migrating humpback whales in Australia to establish the influence of ambient and anthropogenic sound on movement patterns.
- MMS grant 14350102CA85186 to study the effect of air-gun sounds, used in oil exploration, on sperm whales in the Gulf of Mexico. DTAGs have been used to determine the received level of sounds and any responses.
- Evaluation of speed and physiological sensors for the DTAG, funded by WHOI.
- NOPP grant to study beaked whale behavior and risk factors for strandings due to anthropogenic sound.

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