# Acoustic Detection, Behavior, and Habitat Use of Deep-Diving Odontocetes

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## LONG-TERM GOALS

Passive acoustic monitoring is a key enabling technology in mitigating the effects of Naval activities on sound-sensitive cetaceans. The goals of this project are to obtain and disseminate critical information needed for the design of acoustic monitoring systems.

## OBJECTIVES

The primary objectives of the work are:
1. Develop and evaluate passive acoustic detection/classification methods for click and whistle sounds produced by deep-diving toothed whales.
2. Examine the relationships between diving, acoustic behavior, habitat use and group size with implications for acoustic detection and density estimation of toothed whales.
3. Correlate fine-scale oceanographic parameters with foraging behavior of tagged whales to predict habitat suitability and movement patterns.

## APPROACH AND WORK PLAN

The project comprises several parallel tasks:
Task 1 Tagging and acoustic recording of beaked whales
Task 2 Tagging and acoustic recording of pilot whales
Task 3 Habitat of deep-foraging odontocetes
Task 4 Evaluation and application of acoustic detectors
Task 5 Archive and data sharing

Tasks 1-3 involve fieldwork in areas with well-studied coastal resident populations of deep-diving toothed whales (Blainville's beaked whale, *Mesoplodon densirostris*, and Cuvier's beaked whale, *Ziphius cavirostris*, off the island of El Hierro in the Canary Islands, and short-finned pilot whales, *Globicephela macrorynchus*, off the island of Tenerife also in the Canary Islands [Aguilar, 2006]). These sites are unique in providing the opportunity for simultaneous visual and acoustic observations of oceanic species with low-cost shore-based operations. In each site, we will deploy wide bandwidth acoustic recording buoys and visually survey the area around the buoys. Visual sightings will be compared against acoustic detections of whale vocalizations in the buoy recordings to establish the

probability of detecting these species as a function of distance and group size. A subset of whales will be tagged with DTAG acoustic recording tags to obtain a reference set of individual vocalizations to compare with the buoy recordings. We will also continue a seasonal photo-identification study of the El Hierro beaked whales to build on our understanding of residency and habitat use by these species.

In Task 3, we will compare the foraging locations of the study species against nearby sites at which foraging has not been observed. Methods will include physical oceanographic measurements, scientific fishing, hydroacoustics, and baited cameras. The study will contribute towards our understanding of what constitutes a suitable habitat for deep-diving cetaceans and so aid in predicting the likelihood of their occurrence in other sites.

The acoustic recordings to be collected during this project together with prior DTAG recordings represent a unique resource for developing and evaluating acoustic detectors. In Task 4, we will explore this data set both to improve our basic understanding of the acoustic behavior of deep-diving toothed whales and to learn how to maximize the performance of acoustic detectors and classifiers. Acoustic and movement data will be made available to other researchers under Task 5 to accelerate the development of reliable and well-characterized acoustic monitoring systems.

In the first year of the project, field efforts were planned for October 2007 (beaked whales in El Hierro), and April 2008 (pilot whales in Tenerife). Due to the late arrival of funds, we opted for a short field season with beaked whales in October using a prototype acoustic recording buoy (see next section) and thereby saved sufficient funds to perform another short season in spring 2008. The 2008 field work with beaked whales and pilot whales will involve four acoustic recording buoys as well as extended duration DTAGs. The habitat evaluation work (Task 3) will commence in FY2008 and a meeting of the habitat group will be held this winter to plan the study.

Under Task 4, we will continue with analysis work on existing and new DTAG acoustic data. We are currently preparing a report on the vocalization rates of four species of deep-diving toothed-whales. We are also examining the link between clicking rate and searching behavior in beaked whales with implications to acoustic detection. We will hold a meeting in winter 2007-2008 of the project partners involved in data sharing to develop a common data description (metadata) protocol and to schedule data releases of existing DTAG data.

The co-investigators on the project come from the Woods Hole Oceanographic Institution (Johnson and Tyack), the University of La Laguna in Spain (Aguilar and Brito) and the University of Aarhus in Denmark (Madsen). This tightly integrated team has wide expertise in physiological acoustics (Madsen), behavioral use of sound (Tyack and Aguilar), fish and squid biology (Brito) and underwater electronic sensors (Johnson). The team is supported by experts in bioacoustics, visual surveys, fish and squid biology, physical oceanography, acoustic detection, and database design.

## WORK COMPLETED

Although funds were not received until late August, we have made significant progress towards the first year goals. We have constructed a prototype acoustic recording system comprising a GPS-equipped buoy with a DTAG suspended below on a 200 m cable. The DTAG receives and stores timing and position information from the GPS along with acoustic and sensor data. The low-cost device is quick to deploy and retrieve, and can acquire signals from 2 hydrophone channels with

absolute timing and positional accuracy of about 20μS and 3m, respectively. This accuracy is sufficient for precise localization of vocalizing whales when multiple buoys are deployed. The buoy performance was found to be excellent with low coupling of surface movement and low drift rates.

We performed a short field season with beaked whales in El Hierro, combining photo-identification work with an evaluation of the prototype buoy. Beaked whales were spotted on all 17 of the 24 operational days with good weather. The buoy was deployed on 6 days and beaked whale clicks were clearly audible in the recordings in all 4 of the data sets so far evaluated (see example below). During the field season, we hosted a bioacoustics team from Denmark led by Prof. Bertl Mohl. This group deployed a synchronized multi-hydrophone vertical line array in the vicinity of the recording buoy to study the beam-pattern and source level of beaked whale clicks.

We have begun preparing our existing DTAG data holdings for transition to community databases. Initial data postings of beaked whale sound recordings have been made to the MOBYSOUND database and the MBL-WHOI library (https://darchive.mblwhoilibrary.org/handle/1912/1725). These data have been widely used already as part of the test dataset for the 3rd International Workshop on Detection Classification and Localization. We are currently preparing dive profiles from a wide range of tagged whales for transition to these and other databases. We have also been developing a click database comprising inter-click-interval (ICI) samples recorded by DTAGs on a number of deep-diving toothed whales. This database now includes a substantial number (over 350,000) of clicks from 32 individuals from 4 species. This data is needed for developing passive acoustic classification algorithms wherein short sequences of clicks are compared against a probabilistic model of clicking rate to narrow-down the vocalizing species.

## RESULTS

Efforts have been focused in evaluating the recently-obtained buoy acoustic recordings. An example of a recorded signal together with the contemporaneous beaked whale sightings is given in Fig. 1. As is typical for the study area, there were a number of beaked whale sightings in the 2 hour interval shown but no sightings of other cetaceans. Transient signals similar to odontocete clicks are evident in the signal (Fig. 1b). To establish if these were produced by beaked whales, we compare the characteristics of the buoy recorded clicks with those recorded previously by DTAGs on beaked whales (Fig. 2). Three types of information are compared in Fig. 2: the time waveform and time-frequency (T-F) distribution of an individual click, and the inter-click interval (ICI) of a sequence of clicks. We have shown previously that beaked whale clicks have a distinctive long-duration, Gaussian envelope, and FM upsweep T-F distribution (Zimmer et al., 2005; Johnson et al., 2006). These characteristics are evident in the buoy recorded signal and the ICI is consistent with the usual clicking intervals produced by beaked whales. We conclude that the clicks come from beaked whales although we do not yet have a proven means to distinguish the species of beaked whale from the click characteristics. One objective of the current project is to automate the process of click classification assigning a probability that a click sequence was produced by a beaked whale.

In parallel with the buoy recording analyses, we have been continuing our studies of behavior and vocalization rates of tagged beaked whales begun in a prior NOPP award. We have discovered that beaked whale movements during foraging dives alternate between intervals of largely straight-line swimming and highly tortuous swimming, presumably related to patchy distribution of prey. The rate of click production appears to track this change in movement with click rates doubling when tagged

whales performed circling maneuvers. The significance of this is that the clicking rate is highest precisely when the whales are insonifying the largest volume of water and when there is the greatest chance of acoustic detection. Thus, there may be an important distinction between the ICI distribution produced by the whale (e.g., Fig. 2f) and the apparent ICI distribution that would be noted at a distant listening station. Variability in clicking rate also extends into the buzzes generated during prey capture attempts with clicking rates being modulated according to the characteristics of the prey echoes received by the whale (Johnson et al., 2007).

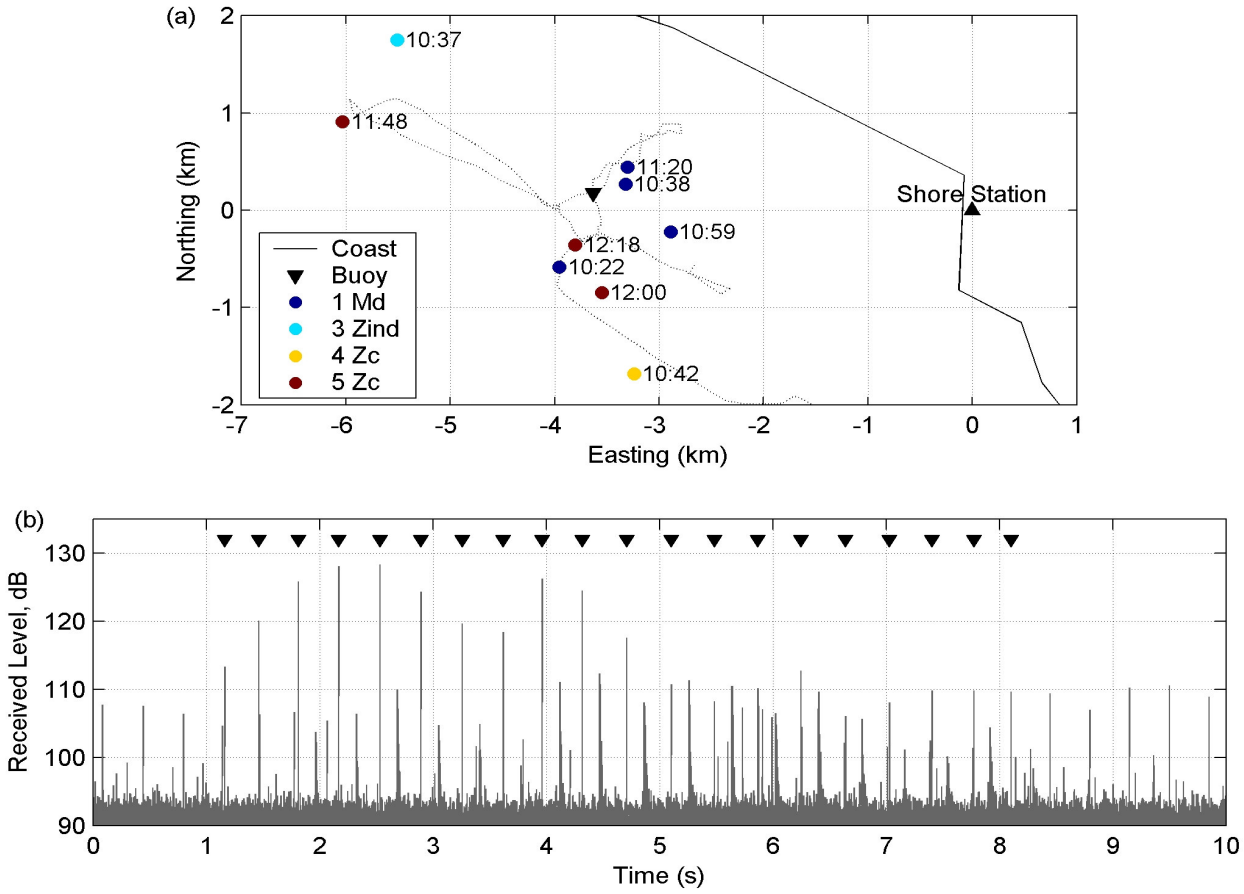


Fig. 1 (a) Map showing the location of the shore observation station, recording buoy, and visual observations of beaked whales over a 2 hour interval on 26 Oct. 2007 off the south-west coast of El Hierro. Nine sightings of beaked whales were made during the 2 hours comprising between 9 and 18 individuals (colored dots). The legend indicates quantity and species of each sighting (Md = *M. densirostris*, Zc = *Z. cavirostris*, Zind = unidentified beaked whales). (b) Envelope of a 10 second extract from the buoy acoustic recording on the same day at 11:10 local time. The buoy was in the position indicated by the black triangle in the upper panel at this time. Several possible beaked whale click sequences are evident. One such sequence is indicated by black triangles.

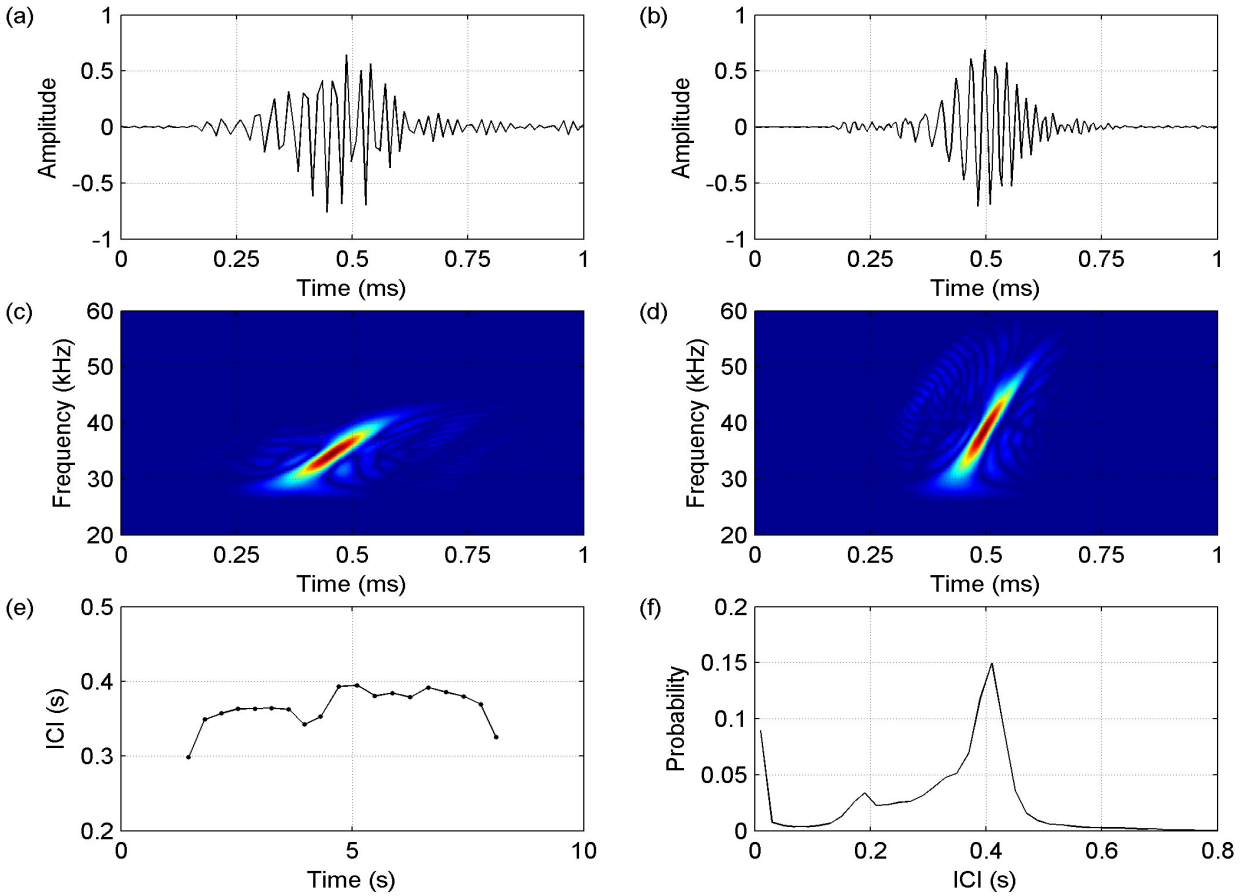


Fig. 2 Comparison of the clicks shown in Fig. 1 with known beaked whale click characteristics. (a) Waveform of a click recorded by the buoy compared to (b) the waveform of a *M. densirostris* click from a DTAG recording. (c) Wigner distribution for the buoy click and (d) the Wigner distribution for the DTAG click. (e) Inter-click interval (ICI) of the sequence of clicks recorded by the buoy compared to (f) the probability distribution of ICI based on 35000 clicks recorded by DTAGs on two *M. densirostris* in the same area.

## IMPACT AND APPLICATIONS

### National Security

The project will result in improved methods for occurrence prediction and acoustic detection of deep-diving cetaceans. Application of these methods could potentially reduce the impact of Naval activities on sensitive cetacean species and so aid the Navy in meeting its stewardship responsibilities.

### Economic Development

The results of the project will lead to the design of portable acoustic detection systems for which there is a market opportunity.

### Quality of Life

The project will contribute to our understanding of deep diving cetaceans, their habitat, and their sensitivity to human interactions. This will aid in the management of the vast and economically significant areas containing these species.

### Science Education and Communication

The project is focused on disseminating information and developing capacity in the area of acoustic monitoring of cetaceans. To this end, we will involve graduate students in the work and will make data publicly available via established databases.

## TRANSITIONS

### National Security

We have made published a set of DTAG acoustic recordings from beaked whales. This data is now being used by a number of groups, including NUWC, who are developing and evaluating passive acoustic monitoring methods.

### Science Education and Communication

The project is providing data and partial support for 3 post-graduate students. Sounds and photographs collected by the project are being used in a traveling museum exhibit, and have been featured in book, newspaper and magazine articles.

## RELATED PROJECTS

Under a funded Phase II SBIR with Rite-Solutions, we are developing a low-cost self-contained acoustic detector/recorder, called the D-MON. This device will be used in the recording buoys in the 2nd and 3rd years of the current project and will be the target platform for detection/classification algorithm development. The design will be made openly available to the community to facilitate in-field performance comparisons of detection algorithms.

Continuing funding from SERDP (CS-1188) and new ONR funding under the BRS is supporting beaked whale tagging work in the Bahamas. Data from this location will amplify and extend the results obtained in the NOPP. The SERDP funds also support continual improvement of the analysis tools for the DTAG data.

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