Measuring the behavior and response to sound of beaked whales using recording tags

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LONG-TERM GOALS

The goals of this project are to understand the reasons for, and to help to reduce, the strandings of two little-known species of beaked whales related to mid-frequency navy sonars. Although widely distributed, these cryptic species are extremely difficult to study and, until recently, almost nothing was known about their sub-surface behavior or vocalizations. The current project combines an advanced acoustic and orientation recording tag with visual survey, photo-identification and habitat characterization in productive field sites. Using these tools, we aim to provide a thorough characterization of the movement patterns, vocalizations, foraging styles, and preferred habitat of the two species. Understanding of these factors is critical to designing, and evaluating the success of, any mitigation measure. Results from the study are directed at two strategies to reduce beaked whale mortality: first, with a specification of how and when these animals vocalize, it may be possible to develop systems for passive acoustic detection of beaked whales. Since beaked whales are so difficult to sight, acoustic detection is a critical method to monitor for the presence of these sensitive species. The second, longer-term strategy is to determine what factors heighten the risk of stranding and to identify opportunities to minimize these. While such risk factors may become evident upon examining the behavior of undisturbed animals, we will also evaluate the practicality of studying the responses of beaked whales to low levels of sonar-like sounds as a means to define safe exposure limits.

OBJECTIVES

We have been performing a multi-year integrated study of the two beaked whale species most represented in the atypical strandings, Cuvier's beaked whale (*Ziphius cavirostris*) and Blainville's beaked whale (*Mesoplodon densirostris*). The study is focused on providing crucial information for the mitigation of sonar-related strandings and is dedicated to the rapid dissemination of this information. The study takes advantage of two productive field sites for the species of concern, developed under a prior program (SERDP), in Italy and the Canary Islands. Cornerstones of the study are:

- Year-round visual observation and photo-identification of beaked whales to establish site fidelity, population size, group composition, patterns of individual associations and habitat preferences.
- Tagging campaigns using high-sampling rate acoustic recording tags to characterize vocalizations, use of sound, movement patterns, and sub-surface behavior.
- Characterization of the habitats in terms of biological and physical parameters. What are the environmental factors that attract beaked whales?

The combination of a long-term visual study with a concentrated tagging effort greatly amplifies the power of each component to describe normal behavior. The study will produce a multi-scale description of beaked whales that can be used to evaluate hypotheses, and mitigation strategies, for the strandings. Comparison of data from this study with that from studies of other deep-diving toothed-whales may pinpoint factors that heighten the sensitivity of beaked whales to sonar sounds.

APPROACH AND WORK PLAN

The project brought together new technology in the form of miniature tag devices, and well-established biological survey methods. We developed a high-frequency acoustic recording tag specifically for studying beaked whales. The multi-sensor tag is attached to whales using suction cups and provides unprecedented detail of the acoustic environment and movements of tagged whales. Although the beaked whale species of concern are notoriously difficult to approach, our success at tagging these animals is improving with each field season. The integration of tagging work within on-going population studies provides a context for the detailed short-term data produced by the tag. Monthly transects of the study areas are carried out by partner groups in Italy and the Canary Islands. Each group of beaked whales encountered is photographed and observed to determine group structure.

The third and final year of the project was a no-cost extension to provide an opportunity to complete visual surveys postponed from the previous year due to poor weather. We have also used the extension year to complete two additional publications (Tyack et al., 2006; Johnson et al., 2006) which describe the deep diving behavior and vocalizations of the study species with implications to acoustic sensitivity and to passive acoustic detection.

WORK COMPLETED

Since the start of the NOPP project in May 2004, we have performed 5 field experiments in Italy and the Canary Islands. We have now placed tags on 11 Cuvier's and 8 Blainville's beaked whales yielding a data set of more than 180 hours of on-animal recording. A majority of the whales were tagged with high sampling-rate (192kHz) stereo DTAGs, specially developed for this study, providing full-bandwidth recordings of the two species. On two occasions, we tagged pairs of whales swimming in the same group providing an opportunity to study the behavioral coordination of these whales and to estimate the source level of vocalizations. Because of the high recording rate of the DTAGs used on beaked whales, a special suite of analysis and quality assurance tools has been developed.

Colleagues at the University of La Laguna (ULL) and BluWest have performed monthly photo-identification surveys since April 2004 amassing photo-identification data bases of over 70 individual beaked whales at each study site. Of these, some 10-15 animals at each site have been re-sighted in different months indicating that at least a part of the population has a pattern of residency and that overall the populations may be quite small. Calves of Blainville's beaked whale have been recorded in the Canary Islands site during most surveys while calves of Cuvier's beaked whale were observed for the first time in September 2005. Calves of Cuvier's beaked whales are often observed in the Italian site where Blainville's beaked whales are not present. About 16 samples of partially eaten deep sea squid and fish have been collected in the vicinity of beaked whales providing a possible indication of diet.

Results from the tagging and survey efforts have been reported in 6 journal papers and 19 presentations at international conferences including two invited talks. We organized a public workshop on beaked whales and sonar at the European Cetacean Society meeting in La Rochelle in April 2005 to share information and identify research priorities.

RESULTS

The unique data set collected during this project has yielded a range of new insights into beaked whale behavior as testified by our growing list of publications. The following is a digest of results obtained to date.

The click sounds made by the study species during foraging dives are unlike any other sounds reported from marine mammals (Fig. 1). This result is important not only in understanding the acoustic behavior of beaked whales but also in developing remote detection methods. We have described the spectral, temporal, and directionality characteristics of the distinctive clicks in three papers (Johnson et al., 2004; Zimmer et al., 2005; Johnson et al., 2006). The results have allowed us to explore the feasibility of detecting beaked whale clicks remotely. Combining the movement data and the vocalization rates and characteristics collected by the tags in a Monte Carlo simulation we have modeled the density of listening stations that would be required to detect beaked whales in a given area with a given level of statistical power. Results have been reported in a conference paper (Tyack et al., IEEE-MTS 2006) and a full paper is in preparation.

The foraging dives made by tagged Blainville's and Cuvier's beaked whales are extreme both in terms of depth (maximum of 2000 m) and duration (maximum of 85 mins). In fact, Cuvier's dive, on average, deeper and longer than reported for any other marine mammal. Using figures extrapolated from deep diving seals, both beaked whale species routinely appear to dive well beyond their aerobic dive limit. Given this, the stereotypical slow ascents from deep dives and the silent shallow dives following deep dives are puzzling (Fig. 2). Necropsies of some sonar-stranded beaked whales revealed symptoms consistent with decompression sickness (Jepson, 2004), and it has been suggested that extreme diving may heighten the risk of this condition. We have described beaked whale diving behavior with an evaluation of the risk of acquiring decompression sickness in a recent paper (Tyack et al., 2006) and are continuing with efforts to model the levels of nitrogen saturation in deep-diving marine mammals.

Fast sequences of special clicks, called buzzes, are made periodically during deep foraging dives. Based on our findings with sperm whales (Miller 2004), we associate buzzes with capture attempts. Recordings of buzzes together with echoes from prey, made by the tag, provide an unprecedented opportunity to investigate prey selection and capture, and to estimate foraging efficiency (Madsen et al., 2005). We have found that Blainville's beaked whales perform stereotypical maneuvers while approaching certain prey and from this have determined that prey selection can occur at least 10-15 seconds prior to the buzz (paper in preparation) while buzzes are initiated when the prey is about 3 m from the whale (Johnson et al., 2006). We have also described an occasion in which a tagged Cuvier's beaked whale appeared to interrupt a foraging dive when sound from a passing ship significantly increased the ambient noise (Aguilar et al., 2006). This may represent the first direct observation of a response of a beaked whale to anthropogenic sound and highlights the need to consider the impact of noise sources other than sonars.

The dive profiles of contemporaneously tagged beaked whales show remarkable coordination of both foraging and shallow dives. Using the click sounds made during foraging we can measure the distance

between each pair of whales and have found that whales separate horizontally by up to 400 m at the base of the dive while joining again for the ascent (Fig. 3). With the stereo tag, it is possible to track untagged whales diving with each tagged whale. We have been able to count the number of individuals present during a foraging dive and compare it to surface observations of the same group. In each case, all of the whales in the group seen at the surface are audible during foraging dives. Given the diving coordination, it appears that dive duration may be determined by the physiological limits of the least-capable (e.g., smallest) animal in the group. If, as is likely, vocalizations mediate social cohesion during dives, then there is an added risk that anthropogenic sound may disrupt communication by masking. We are preparing a paper describing these results.

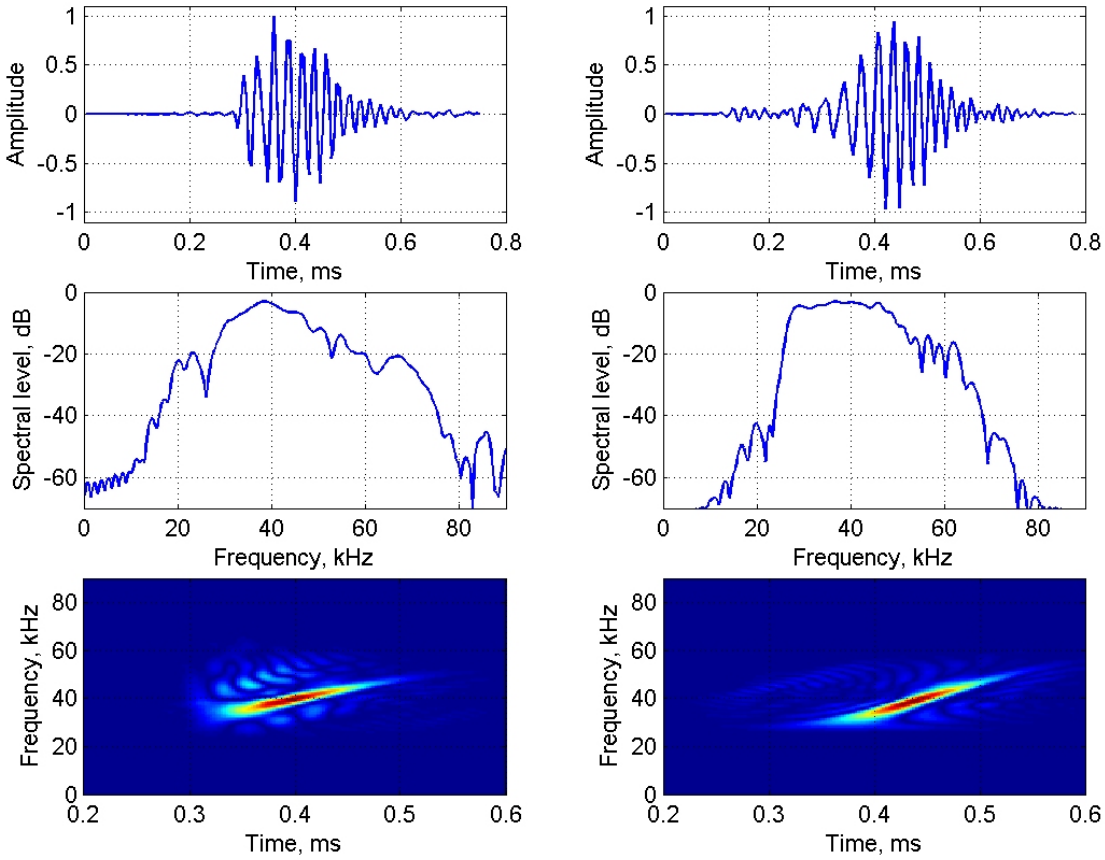

Fig. 1: Distinctive echolocation clicks produced by Ziphius cavirostris (left) and Mesoplodon densirostris (right). The long duration frequency modulated clicks are quite unlike the short transients produced by most delphinids and the high frequency tonal clicks produced by porpoises. The clicks can be detected from several kilometers opening the possibility of remote acoustic detection of both species.

IMPACT AND APPLICATIONS

National Security

The potential for beaked whale strandings during deep-water naval exercises is a significant issue facing the navy. The few options to mitigate such strandings requires that a choice be made between preparedness on the one hand and environmental stewardship on the other. The NOPP project addresses this issue in two ways: first, characterization of the vocalizations and movements of beaked

whales may enable remote detection of these animals. Secondly, examination of the behavior of beaked whales may reveal risk factors which give rise to the apparent high sensitivity of these animals. Such findings may indicate ways to change the usage pattern or the sound of navy sonars in order to reduce mortality.

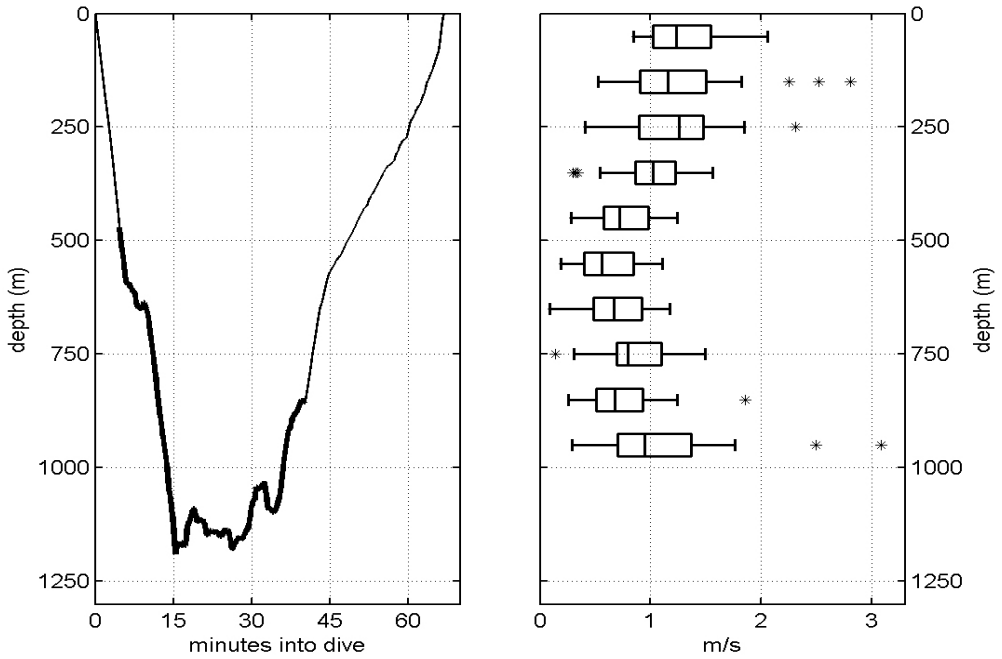

Fig 2: Example dive profile of a Ziphius cavirostris, left, and statistical analysis of vertical ascent rates, right (28 dives from 7 individuals). While the descents are made at a steady vertical rate of some 1.5 m/s, the ascent rate varies widely with depth. Most enigmatically, the ascent rate in the depth range 400-700 m is significantly slower than at other depths.

Economic Development

Evidence is emerging that air-guns used in oil exploration may also trigger beaked whale strandings. The results from the current study will provide insight into the ways in which anthropogenic noise in general may impact beaked whales and how these impacts may be reduced.

Quality of Life

The current study indicates that the populations of beaked whales resident in steep submarine canyons may be quite small. As these habitats coincide with areas of interest for ASW exercises, the resident populations may be repeatedly impacted at an unsustainable level. While the current study is focused on the impact of sonars on individual animals, the resulting mitigation measures will operate at the population level and so improve ecosystem health.

Science Education and Communication

The project has provided data for one PhD and 5 masters-level students in the USA and Europe.

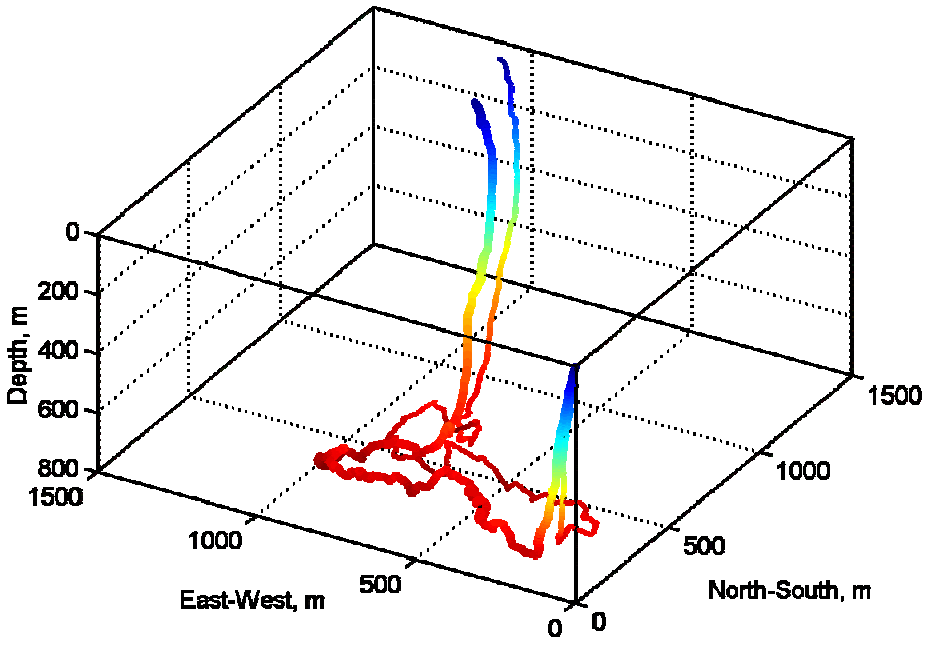

Fig. 3: Three-dimensional reconstruction of the track of two Mesoplodon densirostris tagged simultaneously. Although the dive depths are very similar, the whales separated at the base of the dive to forage independently. The whales rejoined during the ascent and were seen surfacing together.

TRANSITIONS

National Security

We are working with Moretti of the U.S. Naval Undersea Warfare Center and Zimmer of the NATO Undersea Research Center to develop acoustic detection systems based on findings from the study. Using vocalizations recorded by DTAGs, both partners have been able to verify the presence of beaked whales in their own acoustic recordings. In a parallel effort funded by the Navy environmental compliance office, we have performed verification studies with Moretti to match visual observations with acoustic detections of beaked whales in the AUTEC submarine range in the Bahamas.

Economic Development

Acoustic detection of beaked whales prior to sonar use may turn out to be an essential means to mitigate strandings. By defining the vocalizations made by the study species, we have enabled an economic opportunity in designing such systems.

Science Education and Communication

Results from the project have been presented at conferences and workshops, and have been the focus of research by graduate students. The project has been described in numerous newspaper and television pieces. Photographs from our field sites showing distinctive characteristics of the study species have been shared with the Smithsonian Institution for a web-based beaked whale identification resource. Skin samples from the study species are being shared with researchers in Australia who are performing a global genetic analysis of beaked whales.

RELATED PROJECTS

SERDP (www.serdp.org) has funded the PIs under project CS1188 since 2000 to develop methods and field sites for studying beaked whales. The U.S. Navy office N45 has provided funding to the PIs to accelerate beaked whale research. This has provided us with resources to develop DTAGs and to extend the NOPP-funded field efforts. N45 and SERDP have also supported a verification effort with Moretti of NUWC to match visual and acoustic detections of beaked whales in the AUTEC submarine range. The University of La Laguna team who are partners on the NOPP project have received support from the Canary Islands Government and the Spanish Ministry of Defense to support students within the group and to contribute towards a longer tagging effort in El Hierro.

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