

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 they are widely distributed, these cryptic species have proven 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 methods of visual survey, photo-identification and habitat characterization in proven 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. The resulting baseline data will greatly expand our understanding of these animals and of the deep prey on which they feed, both of which are poorly understood. 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 before and during sonar trials. The second, longer-term strategy is to determine what factors heighten the risk of stranding and to identify opportunities to minimize these. If risk assessments continue to highlight an urgent need to define safe exposure limits for beaked whales, we propose to plan a pilot study on the behavioral responses of beaked whales to low levels of sonar-like sounds. Recognizing that research priorities may change as new data come to light, we will work with an international community of stakeholders to evaluate new opportunities.

OBJECTIVES

We are 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 in the two field sites to establish site fidelity, population size, group composition, individual associations and habitat preferences.
- Tagging campaigns using high-sampling rate acoustic recording tags to produce detailed short-term characterizations of sound use, 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 and to detect, and evaluate the cost of, atypical behavior provoked by controlled or opportunistic exposures. 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 produced by studies of other deep-diving toothed-whales (odontocetes) using similar tools will facilitate the detection of factors that may heighten the sensitivity of beaked whales to sonar sounds.

APPROACH AND WORK PLAN

The project brings together new technology in the form of miniature tag devices, and well-established biological survey methods. We have developed a high-frequency acoustic recording tag specifically for studying deep-diving odontocetes such as 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 and behavior. We have worked with the partner groups to produce a uniform protocol and databases for photo-identification and sightings are maintained by these partners. The physical environment of the two study sites will be characterized using fine-scale CTD measurements and archived data. Analysis techniques will be developed to integrate data from each component of the study to produce a picture of how individual beaked whales interact with their environment and with other animals within a group. If there is consensus that controlled exposures of sound are necessary and can be applied with safety, the integrated method developed in this project will provide a sensitive tool for detecting, and assessing the significance of, any deviations in behavior due to exposures.

The project brings together partners from three countries. The PIs at Woods Hole Oceanographic, Johnson and Tyack, represent the technical and biological lead on the project, respectively. Johnson's team produces and deploys the tags used in the study. Tyack provides oversight on the study design and data integration. Joining them from Woods Hole are post-doctoral investigator Madsen and physical oceanographers Polzin and Montgomery. Madsen is expert in marine mammal acoustics and is assisting with data analysis. Polzin and Montgomery are designing the physical habitat characterization study and are analyzing the resulting CTD and bathymetry data. The field effort in Italy is led by Albert Sturlese of whale watching cooperative BluWest. This group has been recording sightings of beaked whales in the Gulf of Genova since 1998 and are expert at sighting and approaching these animals. Biologists at BluWest perform the monthly surveys, manage the sighting database and support WHOI tagging campaigns. The Canary Islands effort is led by Alberto Brito of the University of La Laguna. His team of biology graduate students maintain a field station in the

island of El Hierro adjacent to a significant resident beaked whale population. They perform monthly surveys, maintain the sightings database and work with the WHOI tagging group. Partners Walter Zimmer at the NATO Undersea Research Center and Fabrizio Borsani of Italy's Central Institute for Applied Marine Research (a division of the Ministry of the Environment) assist with data analysis and interpretation.

In 2005 we will continue the successful visual survey and tagging efforts as we work towards accumulating a sufficient dataset for statistical analysis. Results from these efforts are already being prepared for publication and this will continue in the coming year. We intend to deploy increasingly capable tags incorporating sensors developed under other programs to expand our ability to examine the physiological and behavioral determinants in deep-diving. We will expand the habitat characterization effort with temporal and spatial fine-scale CTD and dissolved oxygen sensor deployments in the areas frequented by beaked whales. We will continue with efforts to determine the species occurring at the foraging depth of tagged beaked whales using scientific fishing and by analyzing echolocation signals recorded by the tags. We are planning a public workshop in April bringing together scientists, policy makers and groups with an interest in beaked whales, to disseminate information and identify research priorities.

WORK COMPLETED

Although the NOPP project only began in May 2004, we have already made a number of significant advances. With leverage from SERDP and U.S. Navy (N45) funding, we performed lengthy field seasons in our study sites in Italy and the Canary Islands. We have now placed tags on 7 Cuvier's and 3 Blainville's beaked whales. Our data set contains 97 hours of on-animal recording including 44 deep dives and a remarkable 9 hour set in which two Cuvier's beaked whales were tagged contemporaneously in the same group. Three whales (2 Cuvier's and 1 Blainville's) were tagged with high sampling-rate (192kHz) stereo DTAGs, developed this year, providing full-bandwidth recordings of the two species. The double tagging of Cuvier's beaked whales also provided an opportunity to estimate the source level and beamwidth of the click sounds. With this, and the movement information recorded by the tags, we can begin estimating the practicality of passive acoustic detection of these species as a mitigation measure.

In addition to characterizing their vocalizations, tag data collected this year are a goldmine for understanding the behavior of these species. We are currently examining the stereotypical diving patterns of the beaked whales, in comparison with other deep diving odontocetes, to identify potential risk factors. Numerous echoes from objects in the water, recorded on the tags, are enabling for the first time a study of echolocation in the wild. This work will help us understand the energy balance of these species and their habitat choice. With the stereo tag, it is possible to track untagged whales diving with the tagged whale providing insight into the social organization and communication of these animals. We have published two papers and have submitted another on these topics and are currently preparing several further publications.

Partners University of La Laguna and BluWest have performed monthly photo-identification surveys since April and May 2004, respectively. The University of La Laguna team used research platforms on land (100 m altitude) and a boat, communicating by radio. They performed 45 days of survey, sighting 119 groups of beaked whales (both Cuvier's and Blainville's) with a total of 310 individuals. The larger study area in Italy requires a more expensive vessel limiting the survey to 10-12 days annually. To date, BluWest have performed 10 surveys sighting 20 Cuvier's beaked whales. Calves of Blainville's

and Cuvier's beaked whales were recorded in the Canary Islands and Italy, respectively. Up to 62 and 38 individuals have been photo-identified in Italy and the Canary Islands, respectively, and some re-sightings have been found. Due to equipment problems, only a few CTD deployments have been obtained thus far. We will focus on this effort with repaired equipment in the following year. High resolution bathymetry data has been located for both study sites although we are still awaiting permission to access data from the Spanish Navy.

Results from this year's work form part of 7 papers submitted for presentation at an upcoming European conference (ECS'05). As a prerequisite to planning controlled exposure experiments (CEEs) in the coming years, we have proposed a workshop in combination with ECS'05 in La Rochelle, France, in April 2005. The goals of the workshop will be to review our, and other groups', recent work on beaked whales and to identify research priorities for the mitigation of sonar mortality.

RESULTS

Several key results have already been obtained in the first year of the project. Using data from the new high-sampling rate tag, we have characterized the vocalizations of Cuvier's and Blainville's beaked whales over their full frequency band. These vocalizations consist of two distinct types of clicks which we refer to as regular and buzz clicks. Both click sounds occur at the base of deep foraging dives as shown in Fig. 1. Regular clicks occur at relatively stable intervals of 0.2 to 0.4s throughout the base of the dive while buzz clicks occur in occasional short bursts with inter-click-intervals of about 5ms. Echoes from approaching targets in the water, recorded by the tags, confirm an echolocation function of both click types and represent the first time that echoes from prey have been recorded on a marine mammal. Based on our findings with sperm whales [Miller 2004], we associate buzz clicks with the terminal phase of a capture sequence. Recordings of buzzes with echoes from prey, made by the tag, provide an unprecedented opportunity to investigate prey selection and capture, and to estimate foraging efficiency [Madsen 2005]. Regular clicks from both beaked whale species have a long duration (200 μ s) and a distinctive frequency-modulated sweep characteristic, making them unique amongst the odontocetes studied to date. This kind of click may be tailored to discriminate targets in a highly cluttered acoustic environment such as we have observed in the tag recordings. In contrast, the buzz click is of short duration (about 60 μ s) and is broadband without obvious modulation. The ability to produce two distinct click types has not been described for other odontocetes and may represent a specialization for deep-water foraging. These results have relevance in understanding the habitat selection of beaked whales and in designing passive acoustic monitoring systems for these species. In particular, the distinctive regular clicks may hold the key to discriminating beaked whale sounds from those of ubiquitous species such as dolphin that appear to be less sensitive to sonars. We have submitted a paper describing the broadband clicks of Cuvier's beaked whale [Zimmer, *subm.*] and are currently preparing a paper on those of Blainville's beaked whale.

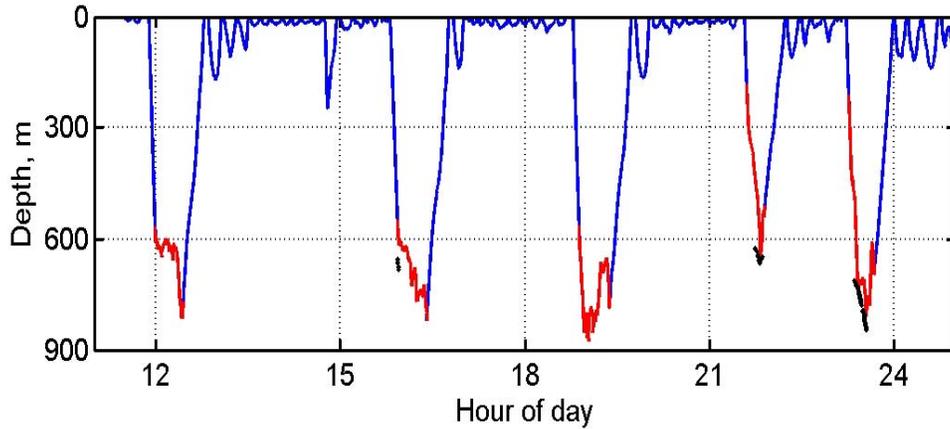


Fig. 1: Dive profile of a tagged Blainville's beaked whale in the Canary Islands. The whale performed 45 minute long foraging dives to 900m about every 2 hours. Vocal times, shown in red, coincide with the base of the foraging dives. Black dots indicating the bottom depth show that the whale preferred to forage close to the bottom.

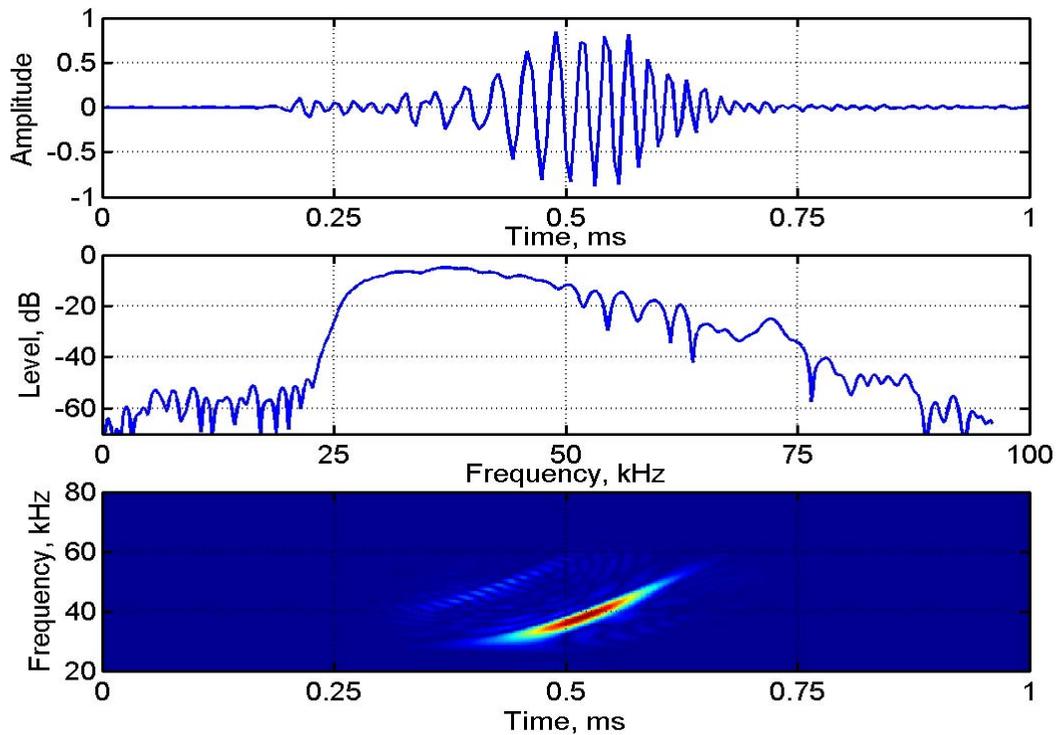


Fig. 2: Broadband recording of an on-axis regular click sound from a Blainville's beaked whale. Upper panel shows the time waveform which, at 200 μ s duration, is significantly longer than those of other odontocetes. The power spectrum of the click (middle panel) indicates that the energy in the click is mostly in the 25kHz to 60kHz range. The lower panel shows the time-frequency characteristic of the click which has a distinctive upsweep form and is different from all other odontocetes studied.

Tags deployed this year have recorded some of the deepest and persistently long foraging dives ever observed for a mammal. Dives to depths of almost 1900m and of up to 1.4 hours were recorded from Cuvier's beaked whales in Italy this summer. It has been suggested that such extreme diving may

expose beaked whales to a heightened risk of decompression-related problems and that the peculiar dive profiles recorded from these animals, as compared to other deep-diving odontocetes, may represent an obligation to manage this condition. We are using current models of breath-hold diving to determine if the natural diving behavior of beaked whales is consistent with problems of nitrogen super-saturation and decompression sickness. A paper on this subject is currently in preparation.

Beaked whales are most often observed in small groups at the surface and are seen to dive synchronously. The use of a stereo acoustic recording tag this year has provided an opportunity to study the behavior of the group during foraging dives. Regular and buzz clicks from untagged whales in the group are frequently heard in the stereo tag recording and the sounds from individuals can be distinguished by their angle-of-arrival. 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, most or all of the whales in the group are present in the deep dive, including juveniles. This suggests that dive duration may be determined by the least-capable (e.g., smallest) animal in the group, an interesting counterpoint to the traditional optimal foraging paradigm. If, as is likely, vocalizations mediate this cohesion, then there is a risk that anthropogenic sound such as from sonars may disrupt group communication and thus behavior.

Although a full year of visual surveys have not yet been completed, there are strong indications that Cuvier's beaked whale is present year-round in the Gulf of Genoa in Italy, and that both species of beaked whale are present year-round in the Canary Island field site of El Hierro (Figs. 3, 4). In analyzing identification photos, the Italian group have confirmed sightings of several individuals in different years, including one seen first in 1998 and re-sighted this year with a calf, suggesting long term site fidelity of this specie. The exceptional sighting rate of both species in El Hierro makes this one of the densest coastal populations of beaked whales known. Blainville's beaked whale calves with foetal folds were sighted in autumn 2003 and 2004, suggesting that El Hierro is a calving ground for this specie with a reproductive peak at the end of summer. In comparison, Cuvier's beaked whales do not appear to reproduce in the waters of El Hierro implying movement of this specie between an as-yet unidentified breeding ground. Although this study focuses on the coastal habitat, beaked whales have been observed in two helicopter surveys 20 nautical miles off-shore of the island suggesting that the habitat may be extensive. These results are significant not only in compiling much-needed life history information but also in defining the extent and usage of beaked whale habitat. This information is necessary to understand the impact of anthropogenic sounds and to evaluate the effectiveness of mitigations methods as they are developed.

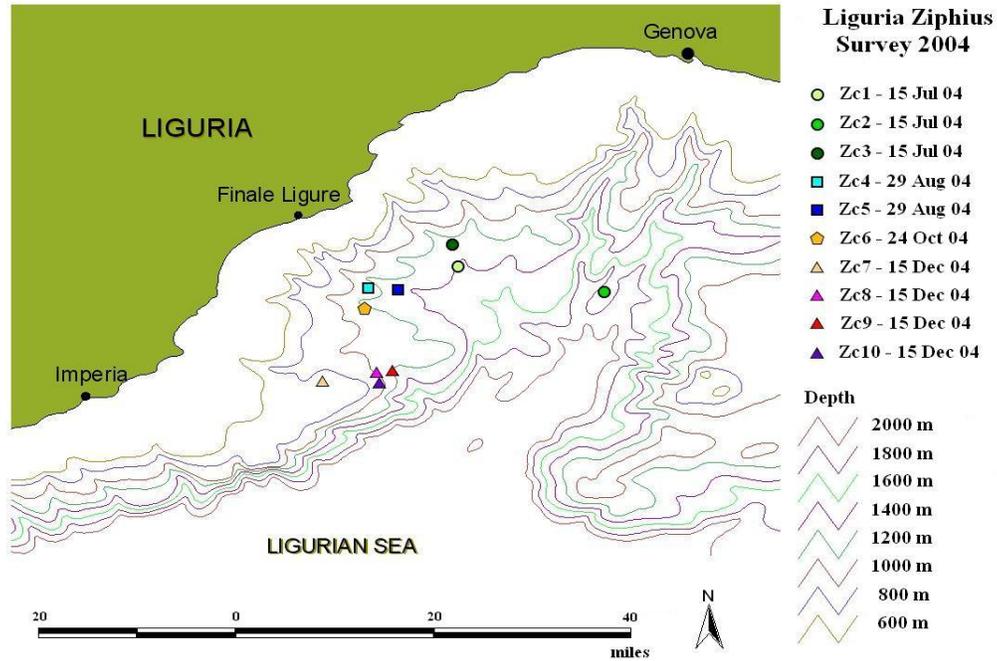


Fig. 3: Sightings of Cuvier's beaked whales in the Gulf of Genova indicating a preference for steep submarine canyons.

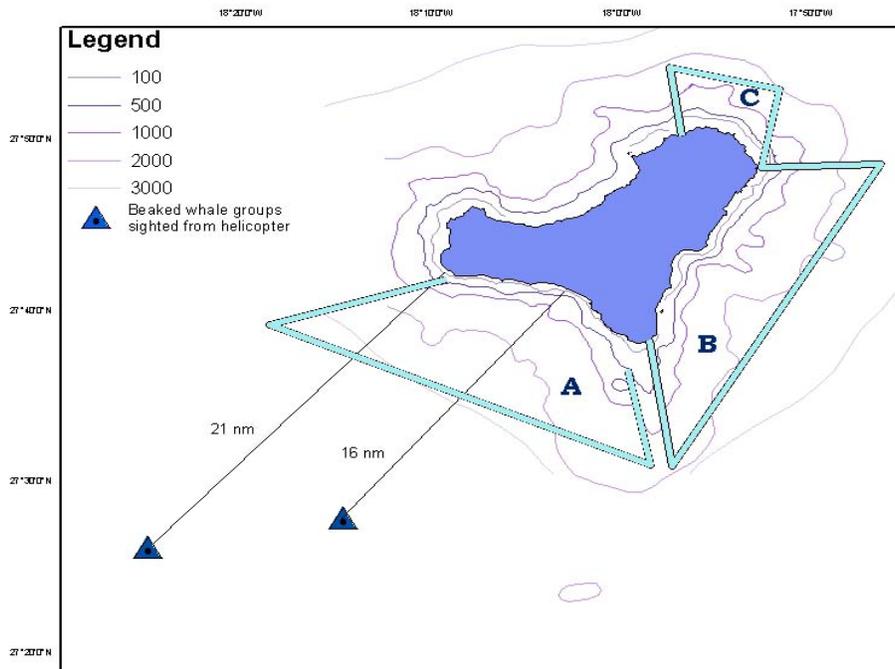


Fig. 4. Beaked whales areas of study off El Hierro in the Canary Islands. Zones A, B and C indicate coastal areas with high numbers of sightings relative to the survey effort. The triangles indicate two

sightings well off-shore of the island made during 5 hours of helicopter survey. No effort has been invested on the northwest side of the island.

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NOTAS:

The group stayed on the surface for 45 minutes, with brief shallow dives during which they could be seen from the focal follow boat.
Photo by Marta Guerra, ULL

Fig. 5: Example entry from the Canary Islands beaked whale database. The scratches on the body appear to be stable from year-to-year and are used to identify individuals.

IMPACT AND APPLICATIONS

National Security

The potential for beaked whale strandings resulting from deep-water naval exercises is currently a significant issue facing the navy. The current project addresses this issue in two ways: first the definition of the vocalizations and movements of beaked whales will lead to an understanding of the practicality of detecting these animals remotely. Secondly, examination of the behavior of beaked whales under undisturbed and, possibly, controlled exposure conditions, may reveal risk factors or conditions which give rise to the apparent high sensitivity of these animals. Such findings may ultimately indicate ways to change the usage pattern or the sound production of navy sonars in order to reduce mortality.

Economic Development

In addition to navy sonars, evidence is emerging implicating air-guns used in oil exploration with beaked whale strandings, and, in general, the cosmopolitan distribution of the sensitive species coupled with the progression of human economic activities into deeper water, is only likely to lead to more interactions. The results from the current study will provide insight into the ways in which economic activities in deep water may impact beaked whales and how these impacts may be reduced.

Science Education and Communication

The current project is supporting and providing data for a number of students in biology and oceanography in the USA and Europe. It is expected that at least one PhD and 5 masters-level students will prepare dissertations based upon this project. A scientific workshop will be conducted in the following year to communicate the project results to a broad community concerned with beaked whales including scientists, policy makers and representatives from military, industry and conservation groups. In order to facilitate an open dialog on acoustic beaked whale detection, we propose to

distribute a reference set of beaked whale vocalizations and related information. This will facilitate a process of consensus building in designing and implementing mitigation strategies.

TRANSITIONS

National Security

We are working with two partners: David Moretti of the U.S. Naval Undersea Warfare Center and Walter Zimmer of the NATO Undersea Research Center to transition findings from the study to develop detection and mitigation systems. Both partners have received data from our experiments and have visited Woods Hole for briefings. Using vocalization examples from DTAGs, both partners have been able to verify the presence of beaked whales in their own hydrophone recordings. Both partners are currently working towards integrating automatic detection methods in their existing acoustic listening infrastructure. A parallel effort by NRL and ONR, undertakes to estimate the exposure conditions during actual navy exercises that have led to beaked whale strandings, such as in the Bahamas in 2002. In support of this effort, we have provided beaked whale dive profiles for use in AIM and ESME simulators and the results have been reported at a conference.

Science Education and Communication

The current project is supporting and providing data to one PhD student and 5 masters level students at Universities in the USA and Spain. In terms of outreach, the PIs and project partners have given presentations at a number of conferences and public fora. A museum exhibit about the project has been prepared by the University of La Laguna group and articles on the work in the Canary Islands and Liguria have appeared in local newspapers and magazines. Data are also being distributed to the University of Rhode Island for incorporation into their educational website on underwater sound and marine mammals.

RELATED PROJECTS

The current project has received substantial leverage from two parallel efforts: SERDP (www.serdp.org) has funded the PIs under project CS1188 since 2000 to develop methods and field sites for studying beaked whales. This led to the selection of the Liguria and Canary Islands study areas and to the first successful tagging of both species of beaked whales. SERDP has renewed funding for this project to allow us to continue developing new field sites with emphasis on U.S. Navy ranges.

The U.S. Navy office N45 has provided funding to the PIs to accelerate beaked whale research. This has provided us with resources to expand the functionality of DTAGs, to improve our field equipment, and to extend the NOPP-funded field efforts. From experience, we have learnt that extended time in the field is the largest single determinant in obtaining data from beaked whales. The N45 project has allowed us to spend considerably more time in the field (4.5 months in 2004) than could be budgeted in the NOPP project and this shows in the results presented here.

The University of La Laguna team who are partners on the NOPP project have received support from the Canary Islands Government and from the Government of El Hierro to purchase field equipment and to support students within the group. A pending proposal with the Canary Islands Government will enable the team to increase the survey effort and to contribute towards a longer tagging effort in El Hierro.

REFERENCES

Miller P.J.O., Johnson M., Tyack P.L., "Sperm whale behaviour is consistent with use of rapid echolocation click buzzes "creaks" in prey capture", Proc. R. Soc. Lond. B, Vol. 27, No. 1554, pp. 2239-2247, 2004.

PUBLICATIONS

Journal Papers

Zimmer W.M.X., Johnson M., Madsen P.T., Tyack P.L., "Echolocation clicks of Cuvier's beaked whales (*Ziphius cavirostris*)", submitted to J. Ac. Soc. Am..

Madsen P.T., Johnson M., Aguilar de Soto N., Zimmer W. M. X., Tyack P.L., "Biosonar performance of foraging beaked whales (*Mesoplodon densirostris*)", J. Exp. Biology, in press.

Johnson M., Madsen P.T., Zimmer W. M. X., Aguilar de Soto N., Tyack P.L., "Beaked whales echolocate on prey", Proc. R. Soc. Lond. B (Suppl.) 271, S383-S386, 2004.

Conference Presentations

Madsen P.T., Johnson M., Tyack P.L., Aguilar de Soto N., Zimmer W. M. X., "Biosonar performance of foraging Blainville's beaked whales (*Mesoplodon densirostris*)", 147th meeting Ac. Soc. Am., NY, May, 2004.

Tyack P.L., Johnson M., Madsen P.T., "Echolocation in wild toothed whales", 147th meeting Ac. Soc. Am., NY, May, 2004.

Ballardini, M., Pusser T., Nani B., "Photo-identification of Cuvier's beaked whales (*Ziphius cavirostris*) in the northern Ligurian sea", submitted to the meeting of the European Cetacean Society, April 2005.

Tyack P.L., Johnson M., Madsen P.T., "Extreme diving behavior of beaked whale species known to strand in conjunction with use of military sonars", submitted to the meeting of the European Cetacean Society, April 2005.

Zimmer W.M.X., Johnson M., Madsen P.T., Tyack P.L., "Echolocation clicks of free-ranging Cuvier's beaked whales (*Ziphius cavirostris*)", submitted to the meeting of the European Cetacean Society, April 2005.

Mark P. Johnson (1), Peter T. Madsen (2), Natacha Aguilar de Soto (3), Peter L. Tyack, "Echolocation and movement of a foraging Blainville's beaked whale (*Mesoplodon densirostris*)", submitted to the meeting of the European Cetacean Society, April 2005.

Aparicio C., Guerra M., Hernández A., Padrón A., Díaz F., Domínguez I., Brito A., Johnson M., Aguilar de Soto N., "Resident and reproductive populations of beaked whales in El Hierro, Canary Islands", submitted to the meeting of the European Cetacean Society, April 2005.

Aguilar de Soto, N., Johnson, M., Madsen, P.T., "Deep foraging of pilot and beaked whales: DTag results", submitted to the meeting of the European Cetacean Society, April 2005.

Madsen P.T., Aguilar de Soto N., Johnson M., Tyack P.T., “Field metabolic rate estimates in large, deep-diving toothed whales with implications for biomass turnover”, submitted to the meeting of the European Cetacean Society, April 2005.