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3S^2: Behavioral Response Studies of Cetaceans to Naval Sonar Signals in Norwegian Waters

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LONG-TERM GOALS

The long term goal of this international cooperative research program is to investigate behavioral reactions and the sound exposures required to elicit them of three species of whales: bottlenose whales, minke whales, and humpback whales to Low Frequency Active Sonar (LFAS) and Mid Frequency Active Sonar (MFAS) signals, in order to establish safety limits for sonar operations for these species.

Another goal of the program is to assess the effectiveness of "ramp-up," a common mitigation protocol in which source levels are gradually increased prior to the onset of full-level transmissions. Ramp-up is thought to give nearby animals some time to move away before sonar transmissions reach maximum levels. However, it is unknown whether or not this protocol is actually effective. We have developed a new experimental design to test whether 'ramp-up' is an effective protocol to reduce risk of harm and our goal is to conduct experiments to test the effectiveness of ramp-up in humpback whales.

OBJECTIVES

In this research project, our objectives are to: 1) Expand our comparative experimental dataset to include species that are potentially more sensitive and difficult to study: Northern bottlenose whale (*Hyperoodon ampullatus*, family Ziphiidae) and minke whale (*Balaenoptera acutorostrata*, family Balaenopteridae); 2) Conduct a directed study of the effectiveness of ramp-up as a mitigation method with abundant and relatively easy-to-study humpback whales, *Megaptera novaeangliae*; 3) Record sufficient no-sonar baseline data of all target species to adequately describe the behavioral significance of recorded changes in behavior and to statistically compare experimental records with baseline records; and 4) Develop collaborations between the 3S research group with other research groups undertaking similar projects to pool data where appropriate, share expertise and reduce overall costs.

APPROACH

Two of the species of whale selected for study here are North Atlantic species for which there is evidence of risk from sonar exposure. Sonar-related strandings have commonly involved Ziphiids in temperate or tropical waters, but have also included species that are more common the North Atlantic: the Northern bottlenose whale (Canary Islands), and the minke whale (Bahamas). It is unclear whether

the low numbers of Northern bottlenose whales and minke whales documented in sonar-related stranding events result from lower sensitivity to sonar or because they are present in lower numbers in the areas where documented stranding events have occurred. To resolve this question, directed research on the behavioral responses of these two species is needed (Tyack et al., 2004). The earlier 3S research effort (see related programs) with killer, sperm, and long-finned pilot whales provides a dataset that enables comparative analysis of behavioral response sensitivities because the $3S^2$ field experiments will follow the same protocol. Broader comparative data are also available from other research teams.

Interestingly, very similar field data are needed to address the question of whether or not 'ramp-up' is an effective mitigation measure. Animals located close to the first full-level sonar transmission are at the greatest risk of severe effects such as hearing damage or strong behavioral responses (left panel of Fig. 1). The 'ramp-up' protocol could be effective if it gives animals time to move away from the immediate location of the full-level sonar pings (right panel of Fig. 1). Thus, the 'ramp-up' protocol is itself is based upon the principle of behavioral response – in this case an avoidance response that protects the animals from receiving intense sound levels.

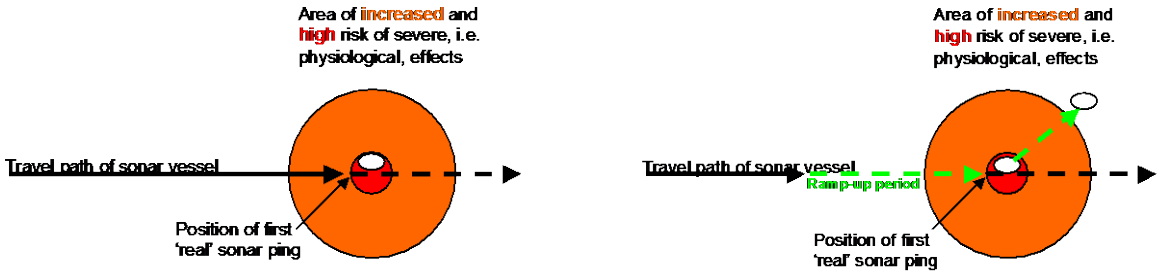

Figure 1. Left: Animals near the position of the first full-power sonar transmissions are at a higher risk of severe physiological or behavioral effects. Right: Sonar sounds are started earlier at lower levels and are gradually increased to full power. These additional 'ramp-up' transmissions are thought to reduce risk by giving animals in the zone of increased risk time to move away.

More specifically, it is assumed that animals will move away from the source of sounds during ramp-up, even if the sounds are transmitted at relatively low source levels. Avoidance has been observed in several studies of marine mammals in the presence of noise (Richardson et al., 1995), but does not necessarily always occur (Miller et al., 2009). It is even possible that starting the sonar sounds at low levels will cause the animals to acclimate to the sound, thereby reducing any tendency to avoid the source. Second, it is assumed that animals will be able to sense the direction and path of the oncoming sound source and formulate a good strategy to move away from the sound source. Moreover, it may take some time for animals to determine the direction and speed of movement of the vessel to make appropriate avoidance movements.

To study the effectiveness of ramp-up as a mitigation tool, we are quantifying the likelihood of avoidance as a consequence of exposure to the ramp-up signals. Thus, it becomes critical to understand what factors affect the probability of avoidance (e.g. received level at the animal, distance

of the source, frequency or amplitude of the sonar, sound propagation conditions, behavioral state of the animal). As in behavioral response generally, we seek to understand what the consequences for the animals are, but in the case of 'ramp-up' we specifically would like to know whether avoidance behavior leads to effective protection from high sound exposure levels.

The research is carried out by an international collaborative team from the Sea Mammal Research Unit (SMRU), Woods Hole Oceanographic Institution (WHOI), Norwegian Defense Research Establishment (FFI), and Netherlands Organization for Applied Scientific Research (TNO). WHOI is providing scientific advice from Dr. Peter Tyack as well as the provision of Dtags. Project management and logistic support, including acquisition of research vessels and permitting are managed through FFI, led by Dr. Petter Kvadsheim. FFI also provides biological and tagging expertise, including the development of a new pneumatic launching system for the Dtag, headed by Lars Kleivane. TNO contributes an advanced towed array system for recording and detecting marine mammal sounds (Delphinus), a multi-purpose towed source (Socrates), and staffing during the cruises under the leadership of Frans-Peter Lam, with collaboration from René Dekeling of the Royal Netherlands Navy. The Socrates source is capable of transmitting 1-2 kHz signals at a source level of 214dB re1µPa m, and 6-7 kHz signals at a source level of 199dB re1µPa m. Miller of SMRU leads the analysis team.

WORK COMPLETED

In this fiscal year, we built upon the successful pilot study and baseline data collection in the summer of 2010. We also developed a modelling study on effectiveness of ramp up, as part of designing the ramp-up experiments. In June 2011, we successfully conducted a month-long experimental trial with the new target species: humpback whales, minke whales, and bottlenose whales. One of the primary goals of this first $3S^2$ trial was to establish new working procedures in a higher-latitude area off Spitsbergen, and to evaluate the presence of the target species. In addition to the June trial, our team continued analysis of the baseline behaviour of 3S species to relate results from the 3S experiments (work done under the first increment of this award). Following our successful collection of additional playback of killer whale sounds to long-finned pilot whales and sperm whales in the 2010 baseline cruise under this award, the behavioural responses of those two species to the sounds have been analysed. Each of the two species responded in a consistent manner, though the responses differed strongly between the two species. Results of these analyses have been presented at the 2011 ECS, ESOMM, and International Bioacoustic Congress (IBAC) meetings, and papers have been submitted to scientific journals for peer review.

RESULTS

In the first experimental trial of the current award, our goals were to establish a new operating research area off Spitsbergen and to begin collecting behavioral response data on the new target species. The 3S-11 research trial took place between Tromsø and Svalbard, 70°-80° northern latitude and 3°-18° eastern longitude, June 1-30, 2011 using the Norwegian military research vessel H.U. Sverdrup II (Fig. 2). The operation area and period were chosen based on a thorough evaluation where the abundance of target species and expected weather conditions were the two most important factors considered. In fact, weather conditions were quite good, with 18 of 25 at-sea days having good conditions, 5 had borderline conditions, and only 2 days had poor conditions. On the trial, a total of 548 sightings including 1680 individual marine mammals were made. We deployed 19 DTAGS, 15 to Humpbacks

and 4 to minke whales, and one CTAG to a minke whale. Northern bottlenose whales were sighted (Fig. 2), though no tags were attached.

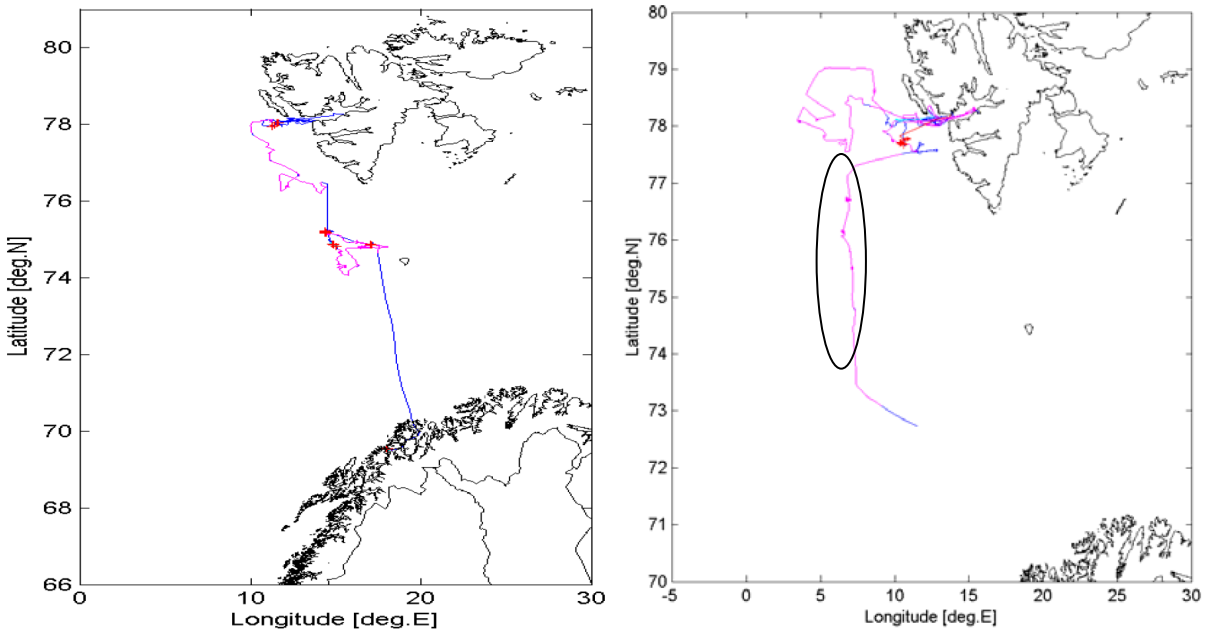

Figure 2. Sailing track of the HU Sverdrup II during the 3S-11 sonar trial. The 1st leg is shown on the left panel, and the 2nd leg is shown on the right. Pink and cyan lines are track-lines with acoustic monitoring by TNO's Delphinus and Captas hydrophone array, and blue lines were transit. Sonar transmissions by the Socrates source during experiments are shown in red. The area where we sighted northern bottlenose whales is shown by an oval in the right panel.

Dtag deployments on humpback whales totalled 124 h and 21 min of data, during which we conducted 3 full ramp-up experiments on humpbacks, including collection of pre-exposure baseline data, sonar exposure, and positive- (killer whale playback) and negative controls (silent approaches). Two additional experiments were conducted on humpbacks with baseline data collection and silent approaches only, and one record with only baseline data. The reason that these experiments were not completed according to protocol was that the tag came off the animal prematurely. The ramp-up experiments were carried out successfully, with good data collection throughout each experiment. For some of the ramp-up experiments, the Dtag was augmented with a Sirtrac GPS logger. To our knowledge, this is the first time a GPS logger has been used in association with a Dtag on a cetacean, and the tracking data provided by the GPS appears to have a great potential to augment the standard procedure of visual sightings of location from a tracking vessel. Our initial inspection of these new data indicates that the design for the experimental testing of the effectiveness of ramp-up works, though more data will be needed to draw firm conclusions.

We made substantial effort to attach Dtags to minke whales during the trial, with 4 attachments, 2 using a standard pole system and 2 with the ARTS pneumatic tag launching system. However, none of those deployments lasted more than one minute, with the tag sliding off almost immediately or not sticking well. In one case, we clearly saw that the suction cups did not stick due to a gelatinous film where the tag touched. Some of this film was collected from the suction cups and was found to contain a combination of sloughed skin from the whale and other organic material likely consisting at least partly of diatoms. Our experience during the 2011 trial mirrored results from the 2010 baseline trial in Iceland, during which a Dtag slid off a minke whale immediately after tagging. Given these results, the 3S team made the decision to switch to an implantable tag ('Ctag'), designed by Lars Kleivane of FFI, Norway. The Ctag is a small and lightweight tag which is anchored under the skin of the whale using a 60mm barb which is disinfected prior to use. The Ctag was deployed successfully on a minke whale on 19 June. This tag released and was recovered following 19 hrs of data collection. During the tag-attachment period, visual tracking of the whale was successfully accomplished from the observation vessel, which made it possible to conduct a sonar exposure experiment. In this first experiment with a minke whale, we were able to successfully collect pre-exposure baseline data, a silent vessel approach control, one sonar exposure and one playback of broadband noise. Initial inspection of the data indicates that the whale did not respond to the silent vessel approach, but strongly changed behaviour to avoid the sonar source.

The overall results of the 3S-2011 trial were positive, although challenges remain. We were able to establish our research method in an offshore area, conducting all of the research based from a single vessel. We only located Northern bottlenose whales near the end of the trial and did not have time to successfully attach a Dtag, but knowledge of their preferred areas will make it easier to find them in future trials. We were able to tag and conduct 3 ramp-up experiments with humpback whales, although in 3 other cases premature detachment of the tag made it impossible to carry-out the full experiment as planned. We found that suction-cups are not effective to attach Dtags to minke whales, but that we were nevertheless able to carry out an experiment using the implant Ctag developed by our Norwegian research partners. The strong response to the sonar by the minke whale commenced at low received levels. Therefore, carrying out additional experiments with minke whales under this award will be a high priority.

Response of long-finned pilot and sperm whales to playback of killer whale sounds:
Throughout the 3S project under award N00014-08-1-0984, and during the 2010 baseline trial under the current award, our team has successfully conducted playback of killer whale sounds to pilot whales and sperm whales. The results of the playback of killer whale sounds to long-finned pilot and sperm whales are striking and consistent within, though different between, the two species. For pilot whales, we played back the sounds of herring-feeding killer whales that were recorded near the study area, so they can be considered possibly familiar sounds. For 4 of the 5 groups tested with killer whale sounds, the sighting tracks indicate strong attraction to the source. The results show that long-finned pilot whales were strongly and consistently attracted to the killer whale playback though they were not consistently affected by the playback of noise. The movement of sperm whales following playback of mammal-eating killer whale sounds, stimulating a predator, largely suggested avoidance. The most consistent change in behaviour, though, was a marked shortening and shallowing of dives from before the playback, though dive patterns were not affected by playback of noise from the same speaker. Overall, these results indicate that the two species have quite different responses to potential predators (or competitors in the case of long-finned pilot whales). While pilot whales respond by approaching the speaker, sperm whales react by surfacing and moving away. These consistent, but different,

reactions to playback of killer whale sounds provides a valuable baseline against which to compare changes in behaviour after sonar transmissions.

IMPACT/APPLICATIONS

The establishment of a dose:response function for the avoidance responses of killer whales exposed to sonar signals is a significant achievement, which will affect regulations regarding exposure of marine mammals to sounds. This study has also built an extensive data set of responses of cetaceans to sonar and other sounds which will enable study of comparative responses of different species to different stimuli in different contexts.

RELATED PROJECTS

This study is an extension of the project "Cetaceans and naval sonar: behavioral response as a function of sonar frequency" Award Number: N00014-08-1-0984, which expired in 2011.

BRS Socal. Involves playback of sonar and killer whale sounds to a variety of cetacean species in the southern California region. Succeeded in the first two sonar playbacks to *Ziphius*.

Tagging and Playback Studies to Toothed Whales. ONR Award Number: N000140910528. Included playbacks of killer whale sounds to pilot whales – data being pooled for analyses from similar 3S playbacks.

REFERENCES

Miller, P. J. O., Johnson, M. P., Madsen P. T., Biassoni, N., Quero, M., Tyack, P. L. 2009. Using at-sea experiments to study the effects of airguns on the foraging behavior of sperm whales in the Gulf of Mexico. *Deep-Sea Research I* **56**, 1168-1181.

Richardson, W.J., Greene, C.R. Jr., Malme, C.I., Thomson, D.H., 1995. Marine Mammals and Noise. Academic Press, San Diego, CA.

Tyack, P. L., Gordon, J. and Thompson, D. 2004 Controlled Exposure Experiments to Determine the Effects of Noise on Marine Mammals. *Marine Technology Society Journal* **37**, 41-53.

PUBLICATIONS

Alves, A, Antunes R, Lam FPA, Kvadsheim PH, Tyack PL, Bird A, Miller PJO. (submitted) Vocal matching of sonar signals by long-finned pilot whales (*Globicephala melas*). Naturwissenschaften.

Miller P, Kvadsheim P, Lam FP, Tyack P, Kuningas S, Wensveen P, Antunes R, Alves AC, Kleivane L, Ainslie M. (submitted) Dose–response relationships for avoidance of sonar by free-ranging killer whales (*Orcinus orca*). Journal of the Acoutical Soceity of America.

Miller, PJO, Antunes R, Wensveen P, Alves, AC, Kvadsheim P, Kleivane L, Lam FP, Visser F, Tyack PL, Doksæter L. Severity scores of killer, pilot and sperm whales exposed to sonar, with revisions to severity scoring. In preparation.

Miller PJO, Antunes R, Alves AC, Wensveen P, Kvadsheim P, Kleivane L, Nordlund N, Lam F-P, van Ijsselmuide S, Visser F, Tyack PL. (2011) The 3S experiments: studying the behavioural effects of naval sonar on killer whales (*Orcinus orca*), sperm whales (*Physeter macrocephalus*), and long-finned pilot whales (*Globicephala melas*) in Norwegian waters. Scottish Oceans Institute Technical Report SOI-2011-001.

http://soi.st-andrews.ac.uk/pageset.aspx?psr=443 [published, reviewed]

Von Benda-Beckman S (2011) 3S2 Ramp-up experiment - experimental protocol and theoretical ramp-up design. 3S-2011 Cruise Plan. [published]