

Cetacean Social Behavioral Response to Sonar

Dr. Fleur Visser
Kelp Marine Research
Lonijsstraat 9
1624 CJ
Hoorn, the Netherlands
phone: (+31) 6 280 75 836 email: fvisser@kelpmarineresearch.com

Award Number: N000141110298

<http://www.onr.navy.mil/Home/Science-Technology/Departments/Code-32.aspx>

LONG-TERM GOALS

The goal of this effort is to investigate cetacean social behavioral response to sonar signals.

OBJECTIVES

The scientific objectives of this effort are 1) to study social, group-level behavioral responses of cetaceans to sonar signals and other stimuli, including tagging; 2) to study natural, baseline social behavior; 3) to develop quantitative sampling methodology for the study of group-level and surface behavior of cetaceans; 4) to investigate the potential to study behavioral responses of cetaceans to sonar signals in situations where tagging is not at present possible (tagless playbacks); 5) to facilitate the compatibility of methods and the comparison of results between behavioral response studies.

APPROACH

Social, group-level cetacean behavioral responses to sonar signals and other stimuli (tagging effort, killer whale playbacks) as well as baseline behavior, are studied within the larger framework of controlled exposure experiments (CEEs) conducted as part of the 3S/3S² and SOCAL behavioral response studies (BRS) off Norway and California. Visual sampling of cetacean group-level behavioral parameters is executed concurrently with focal individual tracking and data-collection from digital archival suction-cup tags and towed hydrophone arrays.

Additional data on the baseline behavior of the studied cetacean species is obtained during dedicated baseline behavior research at the Azores (shore- and vessel-based), Azores-Baseline Project, enabling the collection of larger sample sizes than is generally possible within the framework of CEEs, to augment the understanding of the natural behavior of the cetaceans studied in relation to observed behavioral responses to stimuli.

Focal follow sampling protocols for visual sampling of cetacean group behavior were developed specifically for the use in this project. Specific requirements for the protocols included non-biased, systematic and generic collection of cetacean group behavior, providing quantitative, high quality data allowing for comparison across species, studies and areas. Generic properties of sampling protocols

facilitating cross-comparison of data are deemed to be of special importance in BRS studies, which are conducted over a wide range of species and areas, and may be characterized by relatively limited sample sizes.

In cooperation with the 3S and SOCAL-BRS projects, we test the compatibility of the developed group-level methodology within BRS projects, the potential for comparison of cetacean behavior between research areas and the performance of group-level focal follow protocols for use in tagless playbacks.

Data analysis specifically focuses on the integration between concurrent recordings of surface group behavior (focal follows), vocal behavior (suction-cup tags, towed hydrophone arrays), movement behavior (focal follow, tags) and diving behavior (tags).

Key individuals

Dr. Fleur Visser (Kelp Marine Research & Leiden University, the Netherlands), project PI. Patrick Miller (SMRU, Scotland), Peter Tyack (SMRU, Scotland), Frans-Peter Lam (TNO, the Netherlands) and Petter Kvadsheim (FFI, Norway) form the board of the 3S-project. Brandon Southall (SEA.inc), is the PI of the SOCAL-BRS project. Together with Hans Slabbekoorn, associate professor at the Behavioural Biology Group of Leiden University, the Netherlands, they act as scientific advisors.

WORK COMPLETED

In the last year of this project, focus has shifted from methodological development and integration and collection of data, to data-analysis, processing of the BRS datasets and writing of manuscripts.

- Project publications
 - Publication of BRS group-sampling methodology in peer reviewed journal
Visser F, Miller P, Antunes R, Oudejans M, Mackenzie M, Aoki K, Lam FP, Kvadsheim PH, Huisman J, Tyack P. (2014). The social context of individual foraging behaviour in long finned pilot whales. Behaviour 151:1453-1477.
 - The project has thus far contributed to 6 peer-reviewed publications. A further 3 lead and 11 co-author manuscripts for the 3S, SOCAL-BRS and Azores-Baseline projects are currently in review or in preparation.
- Full implementation protocol for group behavior sampling across BRS studies
 - Status: operational in 3S², SOCAL-BRS and Azores-Baseline projects since 2011
 - Species: social odontocetes, beaked whales, baleen whales
- Fieldwork projects FY2014
 - SOCAL-BRS field studies (September 2013)
- Data-collection: Social behavioral response FY2014
 - Response to experimental sonar exposure in SOCAL-BRS (Risso's dolphin)
- Data-collection: Baseline social behavior
 - SOCAL-BRS projects (Risso's dolphin)
- Development and testing of protocols for tagless playbacks
 - Status: Finalized test-phase in SOCAL-BRS (2012)
 - Reported: recommendations for set-up tagless playbacks using visual observation techniques

- Species evaluated: long-beaked common dolphin, bottlenose dolphin, killer whale
- 2014: Design tagless playback project: tailored, multidisciplinary methodology and approach
- Cross-study and -species comparison of (group-level) behavioral response
 - Group-level sampling protocols used in four BRS studies since 2011: 3S², SOCAL-BRS, Azores-Baseline, BRS-Med
 - Cross-study cooperation in data processing and analysis for Risso's dolphin sonar response (SOCAL-BRS, Azores-Baseline)
 - Cross-study cooperation in data processing and analysis for minke whale sonar response (3S², SOCAL-BRS)
 - Incorporation in social behavior data stream in BRS analytical design and cross-study/species comparative approach efforts led by MOCHA project
 - Cruise planning and progress meetings 3S², SOCAL-BRS and MOCHA projects
 - Continued training of social behavior observer for SOCAL-BRS
- Data analysis and analytical design
 - Development of statistical methodology to integrate social behavior data stream into BRS datasets and analysis: Random Forests and GEE analysis (Visser et al. 2014). Close cooperation with MOCHA Project.
 - Development of statistical methodology using GEEs for the comparison of responses to multiple stimuli (sonar, tagging and killer whale vocalizations) in one statistical model, under a BDA analytical design. Close cooperation with MOCHA project.
 - Development of multinomial GEE for the analysis of behavioral response in timeseries data using parameters from multiple data streams. Methodology designed by MOCHA project.
- Project presentations
 - Presentation of project results at the ONR Program Review meeting, May 12-14 2014.

RESULTS

Operational protocol for group-level and surface behavior sampling of cetaceans

Application of the group sampling protocol during 2012-2014, on a set of target cetacean species in different field sites, confirmed that the group behavior sampling protocol is widely applicable to cetacean species forming relatively stable, small-medium sized groups (<30). The project has thereby delivered a group sampling protocol enabling the comparison of social, surface behavior data across BRS studies (Fig. 1). Additional added value of the protocol was found in the recording of surface behaviors for species which typically spend longer times at or near the surface, including when foraging, potentially limiting the capability of the tag to differentiate between behavioral states (e.g. baleen whales). The protocol has to date been used to record short- and long-finned pilot whale, Risso's dolphin, killer whale, sperm whale, Northern bottlenose whale, Sowerby's beaked whale, humpback whale, Cuvier's beaked whale, bottlenose dolphin, false killer whale, blue whale, fin whale, and minke whale social and/or surface behavior in waters off Norway, Spitsbergen, Jan Mayen, the Azores, California and Cape Hatteras and in the Mediterranean Sea and the Gulf of St Lawrence.

The social context of individual foraging behaviour in long-finned pilot whales (*Globicephala melas*)

Fleur Visser^{a,b,c,d}, Patrick J.O. Miller^d, Ricardo N. Antunes^d,
Machiel G. Oudejans^c, Monique L. Mackenzie^e, Kagari Aoki^f, Frans-Peter
A. Lam^a, Petter H. Kvadsheim^g, Jef Huisman^b and Peter L. Tyack^d

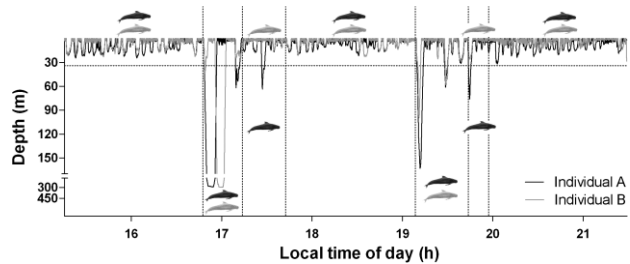


Figure 1. Left: Peer-reviewed publication of integrated BRS group-level sampling methodology. Right: Concurrent sampling of group-level surface behavior and individual-level diving behavior (here with 2 tagged whales) in the 3S Project revealed that long-finned pilot whales employ a social foraging strategy and coordinate the timing of their foraging periods. This shows that pilot whale individual foraging decisions influence and are influenced by those of group members. This has strong implications for their behavioral decisions during potential disturbance (e.g. sonar), as these will also be strongly impacted by group-level mechanisms of response.

Tagless playback protocols

Tagless playbacks are particularly important for species for which it is currently not possible to deploy a tag for longer durations (> 30 minutes), and which generally occur in high densities (high probability of being exposed to sonar). These species include pelagic Delphinids such as common and bottlenose dolphins. The size and fluid nature of groups of these species require a different protocol than is used for the previously studied species. A structural difference is that it is not possible to select a focal individual and its associated focal (sub)group for the duration of the follow; the entire group needs to be included in sampling. Methods for optimal conduct of tagless playbacks were evaluated during SOCAL-BRS field efforts in 2011 and 2012, and formalized in recommendations for the set-up of tagless playbacks in future research projects, in 2013. Continued evaluation effort in 2014 has included exploration of alternative methodology, including shore-based tracking and advanced video and acoustic data recording technology.

Cross-study and cross-area comparison of behavioral response

Risso's dolphin – SOCAL-BRS & Azores-Baseline

Cross-project and cross-area (SOCAL/Azores-Baseline; California/Azores) comparison of Risso's dolphin social behavior indicates strong similarities as well as marked differences in the social behavior of these two populations. For highly social cetaceans such as Risso's, whose behavior strongly depends on the behavior of their associates, this generates a powerful tool to investigate how sociality will shape their behavioral response. In total, 3.5 hours of group behavior with concurrent tag and tracking data was collected for 2 Risso's dolphin groups during experimental research effort in SOCAL-BRS in 2014. Group behavior data was collected during 1 control exposure (silent) and 1 baseline experiment. The SOCAL-BRS Risso's dolphin database now holds 13 focal follows (46 h) with the all data streams collected (tag data, track and social behavior), of which 3 with MFA exposure, 1 with MFA from a naval source, 1 with noise exposure and 4 with a silent control exposure. We aim to collect more data on Risso's dolphin behavioral response during the fieldwork for SOCAL-BRS and Azores-Baseline in 2015 to further enhance this database (proposal pending).

The SOCAL-BRS Risso's dolphin data will be combined with data collected using the same methodology during the Azores-Baseline Project 2012-2014 (12 follows; 32 h). In addition, shore-based observations conducted at the Azores allow for extended investigation of baseline behavior,

without any vessels present near the focal whales. This multi-sensor dataset allows for analysis of Risso's dolphin natural patterns of behavior, of behavioral responses to tagging and vessel noise using behavioral metrics from the different data streams. In addition, it allows for the comparison of Risso's dolphin natural behavior, and behavioral responses, between two BRS research areas, California and the Azores. The tagging data obtained for Risso's dolphin in the Azores forms the first extended dataset able to give insight into underwater behavior and vocalizations of the species in the North Atlantic ocean.

Data analysis & analytical development

During field efforts between 2011 and 2014, a large amount of data was collected on the group-level behavior of BRS target species. Concurrent sampling of behavior with digital archival tags, towed arrays and photo-identification during baseline, tagging and exposures phases, have yielded multi-sensor databases from which natural patterns of behavior of the target species, and their behavioral responses to tagging and sonar exposure can be analyzed (Fig. 2). Analytical effort focusses on long-finned pilot whale, Risso's dolphin, humpback whale and Northern bottlenose whale, in close cooperation with the research groups of the 3S², SOCAL-BRS and MOCHA projects.

Focus points analytical development

1. Integration of group-level data with multiple individual-level data streams
Status: accomplished. Methodology published in Visser et al. 2014. Random forest analyses, GEE time series analyses. GEE analysis designed in close cooperation between 3S and MOCHA Projects.
2. Social behavioral response: multi-stimulus response in multi-sensor time series data
Status: accomplished, processed in Visser et al. (*in prep. a*). GEE analysis incorporating Before-During-After analytical design, multiple stimuli (tagging, sonar, killer whale playbacks) and their controls, as well as baseline behavior, while incorporating social, dive and acoustics data (Figs. 2 & 3). The GEE analysis controls for our repeated measures design, as well as potential autocorrelation in the time series. GEE analysis designed in close cooperation between 3S and MOCHA Projects.
3. Develop multinomial techniques
Group-level, acoustic, dive and movement data from the focal follows and tags consist of many parameters that are often co-dependent (e.g. % of time clicking and buzzing). Therefore, cases where these parameters are the response variables (e.g. effects of social behavior on vocal parameters), call for a multinomial approach (Fig. 3). Building on the developed GEE methodology, the 3S Project and MOCHA are developing multinomial analysis techniques to investigate relations between long-finned pilot whale vocal, social and diving behavior, and behavioral response (Visser et al. *in prep. b*).

Cooperation between BRS research projects

Exchange of methods and knowledge between BRS research projects in the field was deemed highly valuable since the start of the research project in 2011. It strongly facilitated the implementation and exchange of different methods, and cooperation in data analysis. Exchange of scientists between the 3S/Azores-Baseline and SOCAL-BRS project took place in 2012, 2013 and 2014. The use of the operational protocols in different BRS projects has strongly facilitated cross-comparison and joint analysis of BRS data.

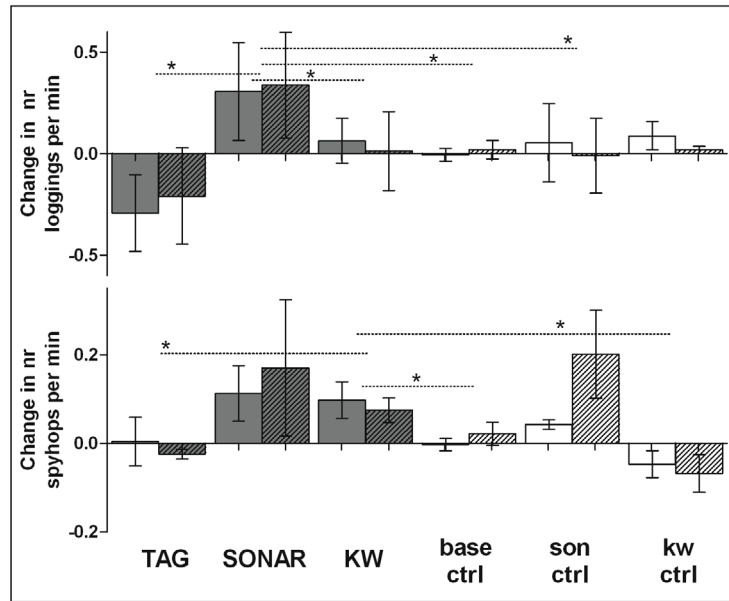


Figure 2. Magnitude, direction and significance of behavioral changes (nr of surface active behaviors per min) in long-finned pilot whales during 6 exposure conditions (3 stimuli and 3 controls): tagging, sonar, killer whale (kw) vocalisations, baseline, sonar control (silent control) and kw control (noise).

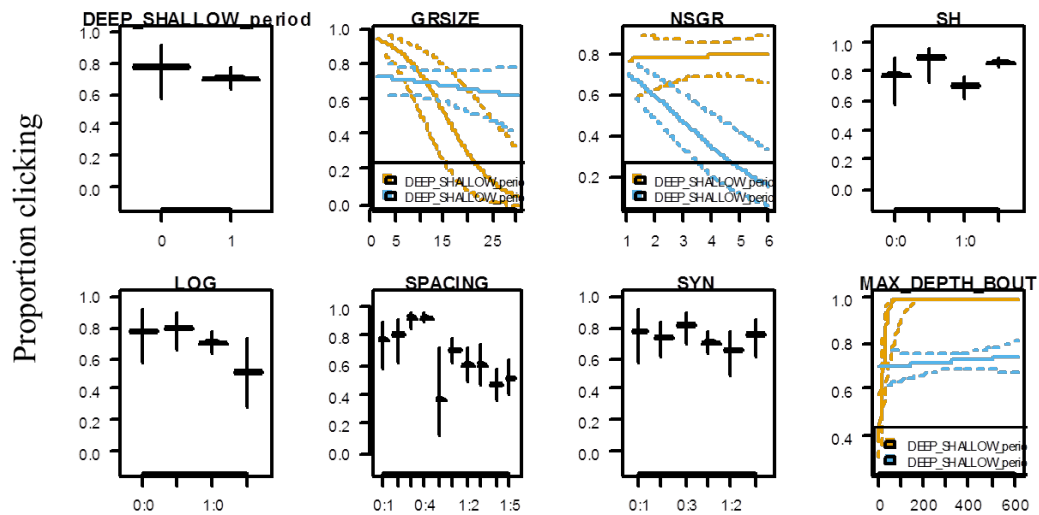


Figure 3. Example model-output for the GEE analysis investigating the effects of diving behavior (deep or shallow diving, max dive depth) and social behavior (e.g. group size, nr of nearby subgroups, nr of spyhops and loggings, spacing between individuals in the group) on the vocal behavior (proportion of time clicking) of long-finned pilot whales.

IMPACT/APPLICATIONS

Social behavior of cetaceans, and social responses to changes in their environment form an essential element in our understanding of the complex nature of cetacean behavioral response to sonar. The generic nature of the methods and protocols developed in this effort facilitate cross-comparison of data between BRS projects, species and areas. It also may serve as a tool to tailor and specifically target BRS methodology to include species for which tagging methodology currently is not available.

RELATED PROJECTS

3S Project. A substantial part of this work is and has been executed as an integral part of the 3S project, in close cooperation with the 3S research team. Group sampling methodology for BRS as described here was developed within the 3S project and is now continuing in 3S². ONR Award number: N000141010355

SOCAL-BRS. Cooperation in the development and execution of tagless playbacks, cross-study, -species and -area comparison of response, and group sampling methodology in BRS. SOCAL-13 project website: <http://sea-inc.net/SOCAL-brs/SOCAL-13/>

Azores' Beaked whale project. Cooperation in tagging and tracking effort of target species in the Azores. ONR Award number: N000141210897

REFERENCES

Visser F, Kok ACM, Alves AC, Oudejans MG, Antunes RN, Isojunno S, Lam FPA, Pierce GJ, Slabbekoorn H, Huisman J and PJO Miller (in prep.a). Silent crowds: the socio-behavioural context of long-finned pilot whale vocalisations.

Visser F, Curé CM, Kvadsheim PH, Lam FPA, DeRuiter SL, Tyack PL and PJO Miller (in prep. b). Long-finned pilot whales show threat-sensitive social responses to disturbance.

PROJECT PUBLICATIONS

Visser F, Miller PJO, Antunes RA, Oudejans MGO, Mackenzie ML, Aoki K, Lam FPA, Kvadsheim PH, Huisman J and Tyack PL (in review). The social context of individual foraging behaviour in long-finned pilot whales (*Globicephala melas*).

Aoki K, Sakai M, Miller JO, Visser F and Sato K (2013) Body contact and synchronous diving in long-finned pilot whales. *Behavioural Processes* 99: 12-20.

Miller PJO, Kvadsheim PH, Lam FPA, Wensveen PJ, Antunes RN, Alves AC, Visser F, Kleivane L, Tyack PL and L Doksæter-Sivle (2012). The severity of behavioral changes observed during experimental exposures of killer (*Orcinus orca*), long-finned pilot whale (*Globicephala melas*), and sperm whale (*Physeter macrocephalus*) whales to naval sonar. *Aquatic Mammals* 38: 362-401.

Lam FP, Kvadsheim PH, Miller PJO, Tyack PL, Ainslie M, Curé C, Kleivane L, Sivle LD, van IJsselmuide SP, Visser F, von Benda-Beckmann AM, Wensveen PJ, Dekeling RPA (in review). Controlled sonar exposure experiments on cetaceans in Norwegian waters; overview of the 3S-

project. In: Proceedings from The Effect of Noise on Aquatic Life 3rd International Conference, Budapest, Hungary, August 11-16 2013.

Curé C, Antunes R, Samarra F, Alves A, Visser F, Kvadsheim P and Miller PJO (2012) Responses of male sperm whales (*Physeter macrocephalus*) to killer whale sounds: implications for anti-predator strategies. *Nature Scientific Reports* 3: 1579.

Curé C, Antunes R, Samarra F, Alves A, Visser F, Kvadsheim P and Miller PJO (2012) Pilot whales attracted to killer whale sounds: acoustically-mediated interspecific interactions in cetaceans. *PLoS ONE* 7(12): e52201. doi:10.1371/journal.pone.0052201.

Kvadsheim, P., Lam, FP., Miller, P., Wensveen, P., Visser, F., Sivle, LD., Kleivane, L., Curé, C., Ensor, P., van Ijsselmuide, S., and Dekeling, R. (2012). Behavioural responses of cetaceans to naval sonar signals in Norwegian waters – the 3S-2012 cruise report. FFI-rapport 2012/02058. (<http://rapporter.ffi.no/rapporter/2012/02058.pdf>).

Kvadsheim et al. (2013). Behavioural response studies of cetaceans to naval sonar signals in Norwegian waters - 3S-2013 Cruise Report. FFI-rapport 2013