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MOCHA - Multi-Study Ocean Acoustics Human Effects Analysis

Len Thomas & Catriona Harris
Centre for Research into Ecological and Environmental Modelling (CREEM)
University of St Andrews
St Andrews, UK
phone: UK+1334 461801 fax: UK+1334 461800 email: len.thomas@.st-andrews.ac.uk
email: catriona.harris@st-andrews.ac.uk

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LONG-TERM GOALS

The long-term goal is to substantially enhance our quantitative understanding of the response of marine mammals to navy sonar and other acoustic stimuli, by maximizing the information gain from Behavioural Response Studies (BRSs). We aim to develop and implement innovative methods for the analysis of BRS data, and to complement and enhance analyses already taking place as part of each current Navy-funded BRS project. We aim for synergies by looking at the studies in combination.

OBJECTIVES

The overall objective of this project is to develop and implement innovative statistical methodologies for the analysis of behavioral response study data. Our focus is on studies estimating the response to mid-frequency active sonar, but the methods developed will be widely applicable. We aim to maximize the inferences that can be drawn from current and ongoing studies as well as to provide advice on future studies. Advances will be made in close collaboration with those involved in existing BRS projects, using a working group format. This approach enables us to complement and enhance the analytical work already being undertaken, as well as to be flexible and incorporate new ideas as they arise in working group sessions.

The project has four specific objectives:

1. Improve methods for combining diverse behavioral measures into metrics of behavioral response. Consideration will be given to obtaining metrics that can be linked to biological consequences.

2. Improve methods for estimating dose-response functions for individual studies. This involves both developing and applying cutting-edge statistical methods, as well as considering which contextual variables in addition to acoustic dose can be incorporated into the analysis. The output will be improved estimates of response curves (with uncertainty) for each study.

3. Combine information across studies and species ("meta-analysis"), making use of expert biological opinion, to make predictions about taxa and contexts not yet studied. Differences in methods/protocols between studies will need to be accounted for.

4. Based on the above, determine where major uncertainties still lie (for example, through sensitivity analyses), and hence suggest where future experimental effort might be applied most fruitfully.

APPROACH

We have formed a working group, supported by two full-time post-doctoral researchers, to develop and implement innovative methods for the analysis of the results from BRSs. The working group is composed of the chief scientists of existing BRS projects (Sirena sonar trials on sperm whales, Bahamas BRS, SOCAL BRS, Norwegian 3S and 3S2, Duke University Cape Hatteras EK60 experiments and Cape Hatteras/SOCAL BRS), together with other scientists working on BRS issues and statisticians who have expertise in the analysis of biological data of this kind. A smaller steering committee, comprising the PIs on this project and the BRS PIs, is providing overall direction.

Over the course of the project we are holding a series of workshops attended by the working group, steering group and project post-doctoral researchers. Each workshop is focusing on a functional/taxonomic group of marine mammals (deep divers, other odontocetes, pilot whales and baleen whales). We began with deep divers (beaked whales and sperm whales) because this group contains species of concern, there are data for these species across multiple BRS projects, the metrics measured are fairly well defined, and the social complexities are minimized. We then increased social complexity by looking at other odontocetes (killer whales, Risso's dolphins, false killer whale, melon-headed whale) followed by pilot whales for which there are data from most BRSs. The 5th workshop focussed on baleen whales. The final workshop will be held in December 2014 and will provide an opportunity for feedback and external peer-review.

Two post-doctoral researchers (Stacy DeRuiter and Dina Sadykova) are conducting the majority of the research and model development over the course of the project under the supervision of Harris and Thomas, with frequent inputs from other project partners as required.

In the periods between workshops, small sub-sets of the working group are participating in technical groups to advance particular aspects of the project in parallel with the main effort. This format of separating conference call meetings into small technical meetings and larger progress meetings has worked very well within other projects coordinated by the PIs (such as the NOPP-facilitated DECAF project and the ONR-funded LATTE project).

WORK COMPLETED

The 5th working group meeting has taken place within the last fiscal year, and was hosted by Cascadia Research Collective in Olympia, Washington in March 2014. The workshop focussed on baleen whales. The reports of all working group meetings can be found at http://www.creem.st-and.ac.uk/mocha/project-outputs.

Alongside initiation of work on baleen whales we have continued our method development for deep divers and odontocetes. We have now completed 17 working documents outlining analysis methods

pertaining to a range of species from each group. In addition, within the last year we have co-authored five publications in peer-reviewed journals (see publications below). Two of these relate to the application of a Bayesian hierarchical model for exposure-response functions developed by MOCHA and applied to data from the 3S project (see results below). Some of methods developed to detect change-points in an individual's behaviour in the presence of sound exposure have also been applied by project teams, such as the application of the Mahalanobis distance change-point method to data from a CEE conducted on a Baird's beaked whale (Stimpert et al., in press). Other examples are currently being prepared for submission (e.g. northern bottlenose whale, blue whale). We are preparing a manuscript which compares variants of the application of Mahalanobis distance techniques using simulated DTAG data, which will provide guidance to the community on the application of this method.

We have also made progress in the application of process-based time series models such as hidden Markov models (HMMs) and other latent-state models to BRS data. These models allow multiple metrics to be combined into one analysis, but they also explicitly acknowledge the time-series nature of the data, and provide an opportunity to explore behavioral states and the probability of transitioning between these states as a function of sound exposure. Two manuscripts are currently being prepared for submission, one on blue whales and another on sperm whales.

All of the partner projects agreed to produce comparable datasets in the form of expert scored responses with corresponding dose measurements. These datasets have been provided to the MOCHA project and will allow meta-analysis to be conducted within the exposure-response and exposure-response intensity frameworks (see results).

As well as leading on some research avenues, we have also provided support to the individual BRS projects when requested. This has led to a number of collaborative publications (see publication list), with more in the preparation stage.

RESULTS

We have developed a Bayesian hierarchical model for fitting exposure-response functions to BRS data. Two publications have resulted from this, one on killer whales (Miller et al. 2014) and the other on pilot whales (Antunes et al. 2014). We have since extended these analyses to include data from multiple species (killer whales, sperm whales and pilot whales) in a single model and have used Gibbs variable selection as a model selection tool to determine if models fitted with combinations of species and signal types fit better than those where all species and signal types are treated separately. From this dataset we concluded that pilot whales and sperm whales showed an avoidance response at similar sound levels and can thus be treated together as one species group, whilst killer whales responded at lower levels (Figure 1). Model selection also indicated that MFAS (6-7kHz) and LFAS (1-2kHZ) signals can be treated as one signal type.

Alongside this we have been investigating methods for fitting exposure-response intensity functions. We have succesfully applied recurrent event survival analysis to the same multi-species dataset. Again we concluded that killer whales are likely to respond at lower exposure levels than pilot whales and sperm whales, and that this holds true across responses of all severities and not just for avoidance responses.

Both methods have been found to be effective and will be used further for meta-analysis with data from multiple BRS projects on multiple species.

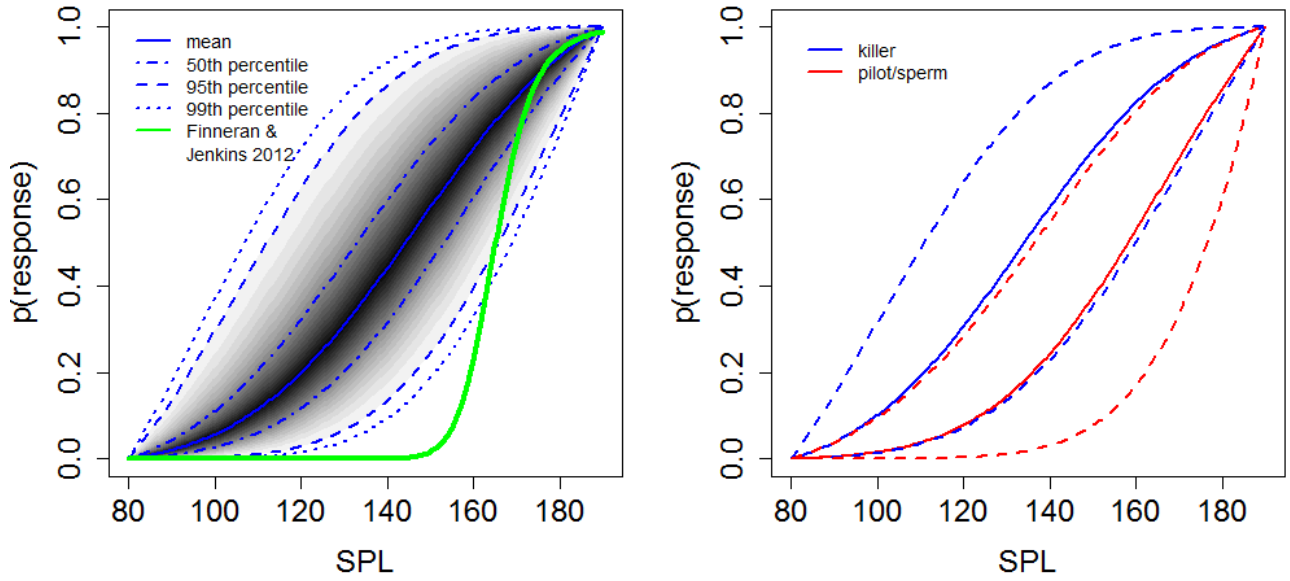

Figure 1: Exposure-response relationships for response to MFAS&LFAS signals averaged across all three species (left) and for killer whales (blue) and pilot/sperm whales (red) (right) resulting from the best fitting model. The dashed lines on the left panel represent the 50th , 95% and 99% credible intervals (see internal legend) and the 95% credible intervals on the right panel. The green line on the left panel is a behavioural response function described in Finneran and Jenkins (2012).

IMPACT/APPLICATIONS

This project aims to significantly enhance the Controlled Exposure Experiments component of the Marine Mammals and Biology Program, and it will also address broader commitments of the Navy for environmental compliance. As part of rule making under the US Marine Mammal Protection Act, the Navy has committed to an Integrated Comprehensive Monitoring Program with the following objectives: monitor and assess the effects of Navy activities on protected marine species; ensure that data collected at multiple locations is collected in a manner that allows comparison between and among different geographic locations; assess the efficacy and practicality of the monitoring and mitigation techniques; add to the overall knowledge base of protected marine species and the effects of Navy activities on these species (Stone 2009). As part of its environmental compliance, the Navy must attempt to quantify the effect of sonar operations on marine mammals in all of its operating areas. This requires methods to estimate the relationship between acoustic dosage and other factors with behavioral responses. Here we are developing frameworks for pooling data across studies and areas to develop more systematic models to quantify these effects.

RELATED PROJECTS

Data being analysed in the MOCHA project comes from a number of BRS projects that have focussed on different geographic areas and species. Below is a list of the projects providing data and links to

websites with further information on each project, where available. More information about each project can be found in links listed at http://www.creem.st-and.ac.uk/mocha/links

- Sirena sonar trials on sperm whales
- BRS Bahamas (AUTEC): http://www.nmfs.noaa.gov/pr/acoustics/behavior.htm
- SOCAL BRS: http://sea-inc.net/socal-brs/
- 3S: http://soi.st-andrews.ac.uk/documents/424.pdf
- 3S2: http://www.ffi.no/no/Rapporter/11-01289.pdf
- Cape Hatteras: http://www.serdp.org/Program-Areas/Resource-Conservation-and-Climate-Change/Natural-Resources/Living-Marine-Resources-Ecology-and-Management/RC-2154/RC-2154

Other related research projects are:

- LATTE - This three year project is developing and implementing statistical models that integrate passive acoustic monitoring data and animal-borne tag data to estimate the effect of Mid Frequency Active (MFA) sonar on beaked whales at AUTEC.
- M3R program – This is the passive acoustics monitoring algorithms and tools development program at NUWC that has facilitated much of the data processing work used in the current project.
- PCADs – This project aims to operationalize the Population Consequences of Acoustic Disturbance framework, focusing (currently) on four case study species, including beaked whales at AUTEC.

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PUBLICATIONS

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2nd MOCHA Working Group Meeting Report, 2012. (Technical Report) Available at http://www.creem.st-and.ac.uk/mocha/project-outputs

3rd MOCHA Working Group Meeting Report, 2013. (Technical Report) Available at http://www.creem.st-and.ac.uk/mocha/project-outputs

4th MOCHA Working Group Meeting Report, 2013. (Technical Report) Available at http://www.creem.st-and.ac.uk/mocha/project-outputs

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