A Population Consequence of Acoustic Disturbance Model for Cuvier's beaked whale (*Ziphius cavirostris*) in Southern California

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LONG-TERM GOALS

Our goal is to create a Population Consequences of Acoustic Disturbance (PCAD) model for evaluating and monitoring the health of Cuvier's beaked whales (*Ziphius cavirostris*, hereafter Zc) populations on the US Navy Southern California Offshore Range (SCORE) off San Clemente Island in California. Our focus will be on the possible population-level affect of Navy mid-frequency active sonar, and therefore our geographic focus within SCORE will be on the Southern California Anti-submarine warfare Range (SOAR), where these animals are regularly exposed to Navy sonar

OBJECTIVES

We will extend a PCAD model created to describe the Blainville's beaked whale (*Mesoplodon densirostris*, hereafter Md) population at the Atlantic Undersea Test and Evaluation Center (AUTEC) (New et al. 2013) to the new species and location. We will assemble the data required to parameterize the extended model using ship track and passive acoustic beaked whale data collected at SCORE, as well as photo-ID, sattelite tag and D-tag data collected in the area by members of the Cascadia Research Collective.

The project started in March 2015 and is due to run until September 2018.

APPROACH

The US National Research Council developed a framework called Population Consequences of Acoustic Disturbance (PCAD; NRC 2005) that can be used to address the question: do changes in cetacean behavior in response to sound, such as those observed at SCORE and AUTEC, affect the overall health of the population to which these animals belong? This framework is being translated into a formal mathematical structure by a Working Group (Fleisman et al 2009) established by the Office of Naval Research (ONR). At its May meeting in May 2014 that Working Group reviewed the model ongoing model development for Md along with the derived risk function.

The main effect of disturbance that has been detected in other cetacean species (e.g. coastal bottlenose dolphins) is on calf survival and inter-calf interval. The current Md model focuses on these two demographic variables and how they might vary between individual females depending on their exposure to disturbance.

Based on recommendations from the PCAD working group, an Md energetics-based model is currently being implemented. The model predicts how changes in behavior can affect maternal calorie intake, and how this in turn may affect calf survival and inter-calf interval. The model is being fit to data derived from extended passive acoustic monitoring of vocal groups and sonar for over a year at AUTEC. With the installation of a duplicate system at SCORE, these same data are being collected for Zc, and a similar method may ultimately be applied.

It is recognized that this simplistic approach does not account for several complications. These include:

- Changes in the daily cost of lactation as the size of the calf ages. This is likely to increase initially as the calf grows, but decrease towards the end of lactation as the calf is weaned.

- Changes in the mother's foraging behavior associated with the presence of a calf. Md data from the Bahamas suggest the calf does not constrain its mother's foraging behavior. However, Md data from the Canary Islands suggests that females with young calves make shorter (~10 min) dives than females without calves.

- The possibility that animals that leave SOAR feed less, or less efficiently, until they return. Recent depth-recording sat tag data from Southern California will help inform the model.

We will investigate the validity and effect of these simplifications for Zc at SCORE.

A number of data types are required to adapt the PCAD model to Zc. As with Md, isolation of Zc echolocation clicks on DTags strongly suggests that foraging only occurs during deep dives (Zimmer et al. 2005). Therefore, the number of these deep dives per day can be used as a proxy for energy gain. Mean daily dive rate will be derived from published data and from animals tagged directly within SOCAL. Recent data from depth recording satellite tags on Zc at SCORE markedly expands our knowledge of Zc foraging dives in and around SOCAL, and this dataset will continue to expand with ongoing field efforts (Schorr, 2014) . A local Advanced Research and Global Observation Satellite (ARGOS) receiver has greatly enhanced the dive data throughput from tags around SOCAL.

The energetic gain from each of these deep dives will be calculated from an estimate of daily energy requirements for adult females in different reproductive states (resting, pregnant, lactating, lactating and pregnant). Madsen et al. derived field metabolic rate estimates for large, deep-diving toothed whales using onboard multi-sensor Dtags (Madsen et al. 2011). These included estimates for metabolic rates of both Md and Zc. We will use these figures to provide baseline estimates of energy requirements for resting adult female Zc and their calves. In order to estimate the weight of these animals, we will follow the approach developed by Hooker et al. (2002) and Bloch et al. (1996) for bottlenose whales using data from stranded animals and general length-weight relationships for cetaceans. The additional daily costs of pregnancy and lactation will be calculated using the approach developed by Lockyer (2007) for a range of cetacean species.

The frequency of periods of disruption will be estimated using passive acoustic data collected on SOAR throughout the year along with SCORE records of range activity. This will lead to an estimate of total yearly disruption, which will then be used to estimate the total energetic costs to adult females.

Photo-ID data from SCORE will provide demographic metrics for this model, such as the proportion of mothers, calves, and juveniles in the population at a given time, and the amount of time calves remain associated with their mothers. Initial estimates from the Bahamas suggest Md calves remain with their mothers and continue to nurse for at least 2 years, though it is unlikely that calves are entirely dependent on their mothers during this period. The rate and proportion of independent feeding is unknown. The worst case assumption is that calves do not feed independently through this period.

It is not known how long after parturition mothers resumes normal foraging. Data from the Bahamas indicate that mothers with very young calves dive synchronously with their social group. However, from surface observations, it is impossible to tell if they and their calves dive to the same depths as the rest of the group. Time-depth recorders would provide a direct measurement of this, but tagging protocols prohibit attaching tags to mothers with calves. However, it may be possible to gain some insight into this by estimating what proportion of the members of group whose size has been verified visually are foraging during a dive by counting the number of clicks detected. Exploratory studies of data from AUTEC have already indicated that click counting may provide reliable estimates of group size. Recent studies by C. Dunn at AUTEC into the nature of echolocation clicks from identified mother-calf pairs during deep foraging dives may provide further insight. Zc click detection data combined with observational data from SCORE may help inform this question as well.

If mother-calf pairs synchronize their foraging dives with the group but do not dive to the same depths, they may be exploiting a different food resource from the rest of the group, and this may be apparent in the analysis of fatty acids obtained through biopsy samples. Data that can be used to relate body condition to reproductive success may be derived from the ongoing observations and biological sampling conducted by Cascadia Research. Biopsies samples may provide an additional source of information on foraging ecology and the degree of genetic separation between animals in SCORE and a comparative site, if one is identified in the course of this work.

An important element to the interpretation of the PCAD model results at AUTEC has been the availability of a comparative dataset from a population without routine sonar exposure. For Md at AUTEC, a comparative site is provided through the work BMMRO has completed off Abaco.

A separate proposal to establish a comparative Zc west coast study site outside of SCORE is being considered. As with Md off Abaco, Zc data collected at a similar site, but one free of sonar

transmission, would provide comparison of population sex/age class structure. A simple measure of the ratio of adult females to calves and juvenile animals among populations could be used to inform the Zc model. Monterey Canyon, of perhaps offshore canyons north of SCORE should be considered as candidate sites.

As with Md at AUTEC, we will investigate the consequences of two different assumptions about the life history strategies of female Zc at SCORE:

1. Time to weaning will remain constant for disturbed and undisturbed animals. If the energetic costs of disturbance are high this could result in the calves of disturbed animals having lower reserves at weaning than the calves of undisturbed females, with consequent effects on calf survival.

2. Disturbed mothers may increase the duration of the lactation period to compensate for lost energy, or deplete their own reserves to order to continue feeding their calves during periods of disturbance. Either of these strategies will result in an increase in the inter-calf interval for disturbed females.

The two assumptions result in different predictions about the age structure of a disturbed population. A comparative site free of sonar could provide the requisite data for estimating this information, as well for estimating vital rates, such as survival, age at maturity and inter-calf interval. It is would also begin to provide insights into population age and sex distribution, reproductive histories, and habitat use in SoCal. If assumption 1 is correct, the ratio of calves to adult females, and inter-calf interval will be the same at SCORE(disturbed) and undisturbed populations, but the proportion of sub-adult animals in the SCORE population will be lower. If assumption 2 is correct, the ratio of calves to adult females, and inter-calf interval will be lower in SCORE than the comparative site.

It is recognized that the proposed studies of Zc demographic rates in the Pacific will not provide sufficiently precise estimates to allow a robust comparison of disturbed and undisturbed population values within the time frame of the proposal. However, such comparisons are always likely to be controversial because any observed differences could be due to many factors other than disturbance. Instead, we will use information on the relationship between these vital rates and disturbance levels for Md on AUTEC to infer the potential effects of the sound exposure histories we will calculate for Zc on SCORE. We will compare these predicted effects with baseline estimates of these rates from other Zc populations, including the population at El Hierro in the North Atlantic. With a developed Zc PCAD framework, results can be compared to other Pacific populations as data become available.

The Zc model will build on the current Md PCAD case study. A methodology for deriving a risk curve relating the probability of a behavioral response to received sound level for Md on AUTEC has been published (Moretti et al. 2014), and we will use exactly the same methodology to obtain a similar risk curve for Zc at SCORE. We will compare, and possibly combine, this risk curve with the one currently being developed for Zc by the ONR-funded MOCHA project using data collected on SCORE as part of the BRS II project. This will allow us to compare the response of Zc to real sonar emissions and to the simulated emissions used in BRS, and hopefully resolve the apparent contradictory response of Zc to these two sources.

The energetics model that will underpin both PCoD models for Md and Zc has also been published (New et al 2013). The full PCoD model for Md at AUTEC was presented to the 2015 meeting of the

ONR Working Group on the Population Consequences of Disturbance; we will adapt this model to Zc on SCORE. We will also be able to use the simplified PCoD model for beaked whales currently being developed under the ONR-funded project "Using an interim PCoD protocol to assess the effects of disturbance associated with US Navy exercises on marine mammal populations". This project will provide a transfer function linking the number of days on which an individual beaked whale experiences sonar-induced disturbance to its vital rates.

Regarding personnel, the primary PI is Mr David Moretti of NUWC, who will be leading on the model development and implementation. He will be guided in this by Dr Len Thomas and Professor John Harwood of the University of St Andrews. Moretti will also lead the NUWC team in the required data extraction and processing tasks; staff involved here are Dr Stephanie Watwood, Dr. Ronald Morrissey and Ms. Jessica Ward. The PIs at Cascadia Research Collective, Dr. Erin Falcone and Dr. Greg Schorr will provide access to data and analytical products related to photo-id and satellite telemetry studies of Zc at SCORE.

WORK COMPLETED

We took advantage of convergent travel schedules among the majority of the project team to hold a start-up meeting in Monterray, CA, in June 2015. Our main initial tasks involve data extraction and processing, and this has been scheduled. To date, we have accessed passive acoustic data for 2014 and 2015 (to present time) from SCORE and are undertaking acoustic processing to extract Zc dive statistics. We have obtained surface ship tracks and records of sonar activity; we are undertaking the propagation modelling required to predict the sound field.

Some initial model development has been undertaken, but the majority of this will be done over the next fiscal year, as will the remaining bulk of data extraction and processing.

RESULTS

No results to date.

IMPACT/APPLICATIONS

One of the Navy's ultimate goals is to measure the "health of populations", rather than simply monitoring their size. This program focuses directly on Zc, the "most sonar sensitive" species. It combines visual, tag, biophysical, direct ship tracks and passive acoustic data for this purpose. This multidisciplinary approach is reflected in the composition of the program team, which combines expertise in statistical modelling, passive acoustic signal processing, behavioral biology, and animal tagging. Using these data sets and expertise, we will extend the PCAD model for evaluating the population level effect of sonar on Zc, a priority species, at SCORE and AUTEC. In the process, we will make use of relevant results from a number of Navy-funded programs on beaked whales. These including Marine Mammal Monitoring on Navy Ranges (M3R), the Behavioral Response Study (BRS), Density Estimation for Cetaceans from Fixed Acoustic sensors (DECAF), the Bahamas Beaked whale Ecology Study (BBES), Linking Acoustic Tests and Tagging using statistical Estimation (LATTE), and Behavioral Ecology of Deep-diving Odontocetes in the Bahamas, and Multi-Study Ocean Acoustics Human Effects Analysis (MOCHA) . As a first step, a Zc risk function for behavioral disturbance will be completed using methods developed for Md at AUTEC.

TRANSITIONS

We plan to transition the methodology developed under this project to the Navy's Integrated Comprehensive Monitoring Program (ICMP). This provides an "overarching framework for marine mammal monitoring on ranges, including consistent approaches for reporting and analyzing monitoring data and a review of best practices from the Fleets". In addition, annual marine mammal monitoring reports are provided to NMFS for each major training range and operating area. The methodology developed by this program will, for the first time, provide a basis for monitoring Zc population health and will therefore fill a critical gap in the current ICMP plan.

RELATED PROJECTS

This project is closely related to the ONR Working group projects, especially N000141210286 Statistical Tools for "Fitting Models of the Population Consequences of Acoustic Disturbance to Data from Marine Mammal Populations (PCAD Tools II)".

The project would not be possible but for the Marine Mammal Monitoring on Navy Ranges program.

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