Develop a General Framework for Estimating Cetacean Density from Data Collected by Slow-Moving Autonomous Ocean Vehicles, Investigating Key Aspects of Survey Design, Data Collection, and Data Analysis

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Award Number: N00014-15-1-2142
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LONG-TERM GOALS

In this project, which started in April 2015, we focus on cetacean density estimation using autonomous underwater vehicles such as ocean gliders. These instruments are of particular interest to the Navy and have the potential to play a key role in future marine mammal monitoring efforts. The major advantage of gliders and other autonomous vehicles over prior methods is their ability to provide both spatial and temporal coverage of an area during a survey. However the methods for estimating cetacean density from autonomous vehicles do not currently exist.

Our goal is to develop a general framework for estimating cetacean density from data collected by autonomous ocean vehicles. We will investigate key aspects of survey design, data collection and data analysis, leveraging already-funded projects that are collecting data from profiling gliders to form case studies. Data from three different Navy-relevant locations (Gulf of Alaska, Mariana Island Range Complex, Hawaii Range Complex) will be utilized. We will select three species for analysis: a baleen whale, a deep diving odontocete (sperm or beaked whale) and a delphinid; final species selection depends on which are found to be most suitable after initial acoustic processing, with our preference being to select species whose acoustic behavior has been most extensively studied. For each species and site, we will demonstrate how the general framework can be applied to produce estimates of animal density, or call density if call rates are needed for the method but not available.

One key component of the framework is to estimate the probability of detecting vocalizations on the autonomous vehicles as a function of range. To do this, we will utilize the tracking abilities of the hydrophones at the Southern California Offshore Range (SCORE) Navy range during an additional glider deployment. We will also investigate the detection probability of drifting profiling sensors (or floats), which will also be deployed at SCORE. However, relying on the instrumented ranges necessarily restricts the inferences about density that can be made in other locations; we will therefore also undertake an additional experiment to estimate glider detection probability in a non-instrumented area, using an ad-hoc array of non-profiling drifting sensors.

OBJECTIVES

The overall goal is to develop a general framework for estimating cetacean density from data collected by autonomous ocean vehicles such as ocean gliders and floats, taking into account species' acoustic and behavioral differences and environmental variation. We have identified five primary objectives, four of which make use of data from previous or planned glider/float deployments; in the fifth we will conduct an additional field experiment to estimate the probability of detecting cetacean vocalizations from a glider without the requirement for a dense array of fixed hydrophones.

1. Evaluate whether ocean glider data can be analyzed in a design-based framework using surveys done as part of an existing project in three areas of naval interest (Gulf of Alaska, Mariana Island Range Complex, Hawaii Range Complex). This objective does not apply to floats as they cannot be steered along designed survey tracks.
2. Quantify ocean glider/float survey effort and evaluate encounter rates of example species at the same three areas of naval interest. The example species will include at least one deep diving odontocete (sperm or beaked whale), one shallow-diving delphinid, and one baleen whale.
3. Develop a methodology for estimating the probability of detecting cetacean vocalizations on ocean gliders/floats using data collected as part of an existing project at the Southern California Offshore Range (SCORE).
4. Estimate population densities, or call densities if average call rates are needed but not available, of example species at the three areas of naval interest using ocean glider data.
5. Develop an experiment that does not rely on a large Navy test range to estimate a species' probability of detection by an ocean glider. Perform a test at or close to SCORE and compare results with detection probability estimates derived using the SCORE array.

APPROACH

This project leverages the following realized or planned ocean glider deployments:

- a 4-week deployment in the Mariana Island Range Complex (MIRC) in October 2014 using single glider and in February 2015 using two gliders;
- a 4-week deployment in the Hawaii Range Complex (HRC) in January 2015 using a single glider;
- a 4-week deployment in the Gulf of Alaska (GOA) in July 2015, also using a single glider; and

- a further 2-week deployment of two gliders and three floats will take place at SCORE in winter 2015.

To achieve the primary objectives, we will first evaluate all deployment tracks from the GoA, HRC, and MIRC sites to assess whether ocean glider data is suitable for design-based analyses – i.e., the degree to which the planned track lines were adhered to. Ocean current data from the glider/float deployments, as well as online databases such as Ocean Surface Current Analysis Real-time (OSCAR) hosted by the Physical Oceanography Distributed Active Archive Center, will be used to help quantify whether survey effort for both instruments is most appropriately defined in terms of time or distance. Furthermore, a small simulation study will be conducted to demonstrate the interaction between glider/float movement and animal movement, and the potential effects of movement on encounter rate estimates, which may lead to bias in eventual density estimates.

Cetacean detection records for all sites will be produced as part of other projects. Using these results, example species will be selected and encounter rates for these species calculated at the GOA, HRC, and MIRC sites. A literature review will be conducted to see whether encounter rates of the example species could be compared with encounter rates from previous visual surveys in these areas. Finally, using the estimated encounter rates, we will estimate the required glider survey effort in these naval areas of interest to achieve density estimates with a reasonable level of precision. These estimates will aid the design of future surveys in these areas for continued monitoring. Typically, density estimates with a coefficient of variation of less than 20% are desirable (Buckland *et al*, 2001). Encounter rates for floats will also be estimated from the SCORE dataset.

Data collected at SCORE will be used to develop a method to estimate the probability of detecting vocalizations on an ocean glider/float. For some species, the range hydrophones at SCORE can be used to localize individuals, effectively setting up detection trials for the ocean glider/float, which can be modelled using a logistic regression approach (similar to Marques *et al*., 2009; Kyhn *et al.,* 2012). For example, tracking of beaked whales is already planned as part of another project ("Demonstration of commercially available high-performance PAM glider and profiler float" funded by the U.S. Navy Living Marine Resources Program). Alternatively, in the event that localization is not successful for a given species, the range can likely be used as an array for a spatially explicit capture-recapture (Borchers, 2012; Borchers *et al.,* 2015), particularly for baleen whale calls, including the glider/float as an additional sensor. For species where neither of these prove feasible, or if the SCORE trials do not yield sufficient data, a simulation approach can be implemented using existing acoustic tag data combined with propagation modelling (similar to approaches used in Marques *et al*., 2009 and Küsel *et al*., 2011). Although it is not our preference, due to heavy reliance on model assumptions, this approach can be expected to work for baleen whales and deep-diving odontocetes but will possibly not for delphinid species, where there is a lack of information on animal movement patterns and other required parameters. In summary, we expect to empirically model the detection probability of the glider/float, but have a back-up plan should adequate data not be available. If deemed suitable, the detection function generated for the ocean glider will be used to estimate call densities from the surveys in the GOA, MIRC, and HRC. For species for which suitable call rate data are available, animal densities will be estimated.

Most development of passive acoustic density estimation methods for marine mammals has been undertaken on instrumented Navy ranges, where many hydrophones are installed in closely spaced arrays. This wealth of data has made it tractable to estimate all of the components required to obtain absolute density. However, there is often a need for density estimation outside of Navy ranges, and there is no reason to suppose that estimates of components such as detectability that are obtained on ranges are applicable outside of them.

We will, therefore, conduct a small field effort (two weeks in 2016) that will attempt to estimate detectability of a glider without using instrumented Navy range hydrophones. We will do this using acoustically-equipped gliders, which the Oregon State University team has developed in collaboration with other institutions, and autonomous non-profiling drifting hydrophones, which have been developed by Jay Barlow's team at NOAA/NMFS Southwest Fisheries Science Center. We will co-deploy these sets of instruments in an area south and east of Santa Barbara Island in the Channel Islands archipelago, California. We will use the drifting sensors in the same way as the range hydrophones – either to localize vocalizations, which can be used to set up trials for the glider, or to use the drifting sensors and the glider in a spatially explicit capture-recapture analysis, which would allow estimation of detection probability for both types of sensor.

WORK COMPLETED

Two in-person meetings have taken place since the start of the project due to project members' attendance at other meetings. A project start-up meeting was arranged with the whole project team in San Diego in April 2015. In this meeting, updates regarding the planned glider deployments were given and the fieldwork planned for summer 2016 was discussed. A second meeting took place in San Diego in July 2015, taking advantage of the presence of all of the team at the same conference. In this meeting, updates regarding the planned glider deployments and ongoing data processing were given, including, where possible, a summary of detected species. In addition, as a result of a meeting with other CREEM colleagues, details of the simulation exercise to determine the effects of animal movement have been finalized and were outlined by Harris (CREEM) to the rest of the team.

All track data from the HRC deployment and the first MIRC deployment have been shared between project members and evaluation of the track data has begun. Data from the second MIRC deployment and the GOA deployment are currently being processed. A further dataset has also been incorporated into the analysis. The data are from a 2-week deployment in the Quinault Underwater Tracking Range (QUTR) in September 2014 using a single glider and a float.

RESULTS

Example results are given for the track evaluation of the MIRC 2014 deployment (Figure 1). A total of 763 km of trackline was initially planned and approximately 830 km was completed by the glider. Aside from an intitial change to the planned start of the deployment due to logistical reasons, the glider closely followed the planned route. Several cetacean species were detected acoustically including Blainville's beaked whale (*Mesoplodon densirostris)*, Risso's dolphin (*Grampus griseus*) and humpback whale (*Megaptera novaeangliae*). This is an encouraging result; we will be able to investigate three different types of cetacean species at this site, as outlined in Objective 2.

IMPACT/APPLICATIONS

The Navy has shown increasing interest in using autonomous mobile platforms such as ocean gliders and floats for marine mammal monitoring. By developing methods for density estimation using these platforms, we will enhance the Navy's ability to predict when its operations may come into conflict with marine mammals, particularly acoustically sensitive, prominent/charismatic, or threatened/endangered species. This will enable the Navy to prevent and mitigate harm to those species, better comply with the law, and reduce negative public perception of Navy impacts on these species.

TRANSITIONS

To be determined as this project unfolds.

RELATED PROJECTS

Demonstration of a commercially available high-performance PAM glider and profiler float. Funded by the US Navy's Living Marine Resources Program. PI: Haru Matsumoto, Oregon State University.

Autonomous passive acoustic monitoring of marine mammals in the Hawaii Range Complex (HRC), the Gulf of Alaska (GoA), and the Mariana Island Range Complex (MIRC). Funded by U.S. Pacific Fleet/NAVFAC Pacific through HDR, Inc.

PhD research by Selene Fregosi, a graduate student at OSU, funded by a National Defense Science and Engineering Graduate (NDSEG) Fellowship.

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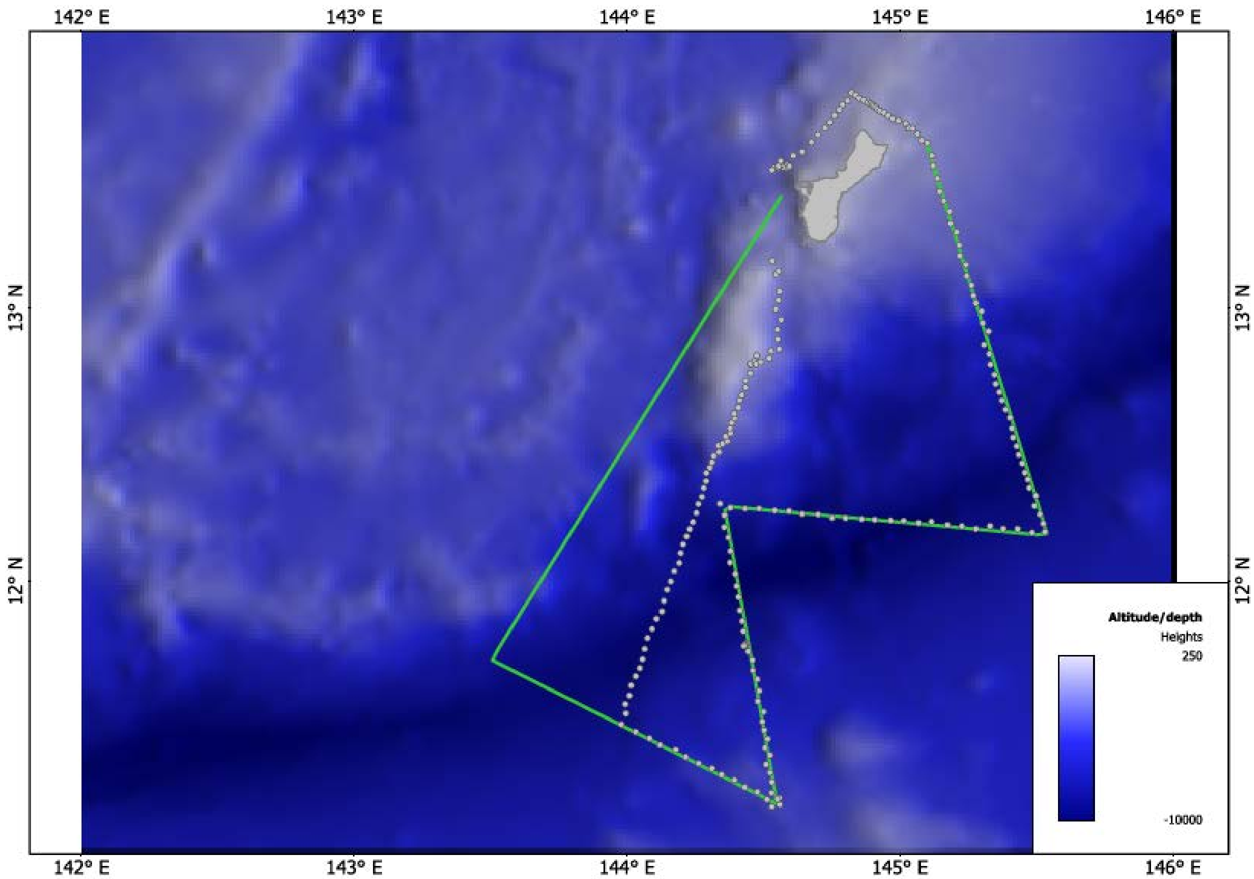

Figure 1. Planned route (green line) and actual route (gray dots) from a glider deployment at MIRC in October 2014. The gray dots are the GPS start coordinates of each dive made by the glider. The coastline of Guam is outlined and altitude/depth is given in m.