DECAF – Density Estimation for Cetaceans from passive Acoustic Fixed sensors

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LONG-TERM GOALS

Determining the density and distribution of cetacean species is fundamental to understanding their basic biology, and also to monitoring and mitigating the effect of man-made impacts on their populations. However, this task is difficult because most cetacean species occur at low density and over enormous areas, and because they spend relatively little time at the surface where they can be seen using standard, visual surveys. Our primary long-term goal is to develop and test methods for estimating cetacean density based on detecting the sounds cetaceans make underwater, using fixed hydrophones. There are many potential configurations of such devices, so if it does prove possible to estimate density reliably using passive acoustics, an important second goal (not addressed in this work) is to determine which configurations is best for a each of a common suite of monitoring scenarios.

OBJECTIVES

1. Develop statistical methods for estimating the density of cetacean species from fixed passive acoustic devices. Methods should be applicable to a wide range of scenarios, including dense and sparse arrays of permanent, bottom-mounted sensors and single bottom-mounted or floating sensors.

2. Demonstrate the utility and generality of the methods by implementing them in a set of key test case studies. These test cases will also focus the methodological development to ensure their relevance to real-world applications. We aim as far as possible to leverage data that have already been collected, and classification and localization methods that have already been developed.

3. Promote adoption of the new methods in the marine mammal research community by (a) publishing results in the peer-reviewed literature, (b) archiving data and results in publicly available electronic storehouses (e.g., the Ocean Biogeographic Information System, OBIS), (c) holding one or more workshops open to all interested researchers (participants at these will be self-funded).

APPROACH AND WORK PLAN

Technical approach

In developing the statistical methods, we will build upon the existing substantial body of work on distance sampling survey methods (e.g., Buckland et al. 2001, 2004). Fixed passive devices are conceptually most similar to a type of distance sampling called point transect sampling. However, there are several important issues that prevent a straight application of existing methods, as described in the project proposal and in Thomas and Martin (2006). We propose to develop methods to address these issues through a series of case studies, formulated as a set of linked tasks (see below). We will start with situations where we believe it is feasible to produce robust estimates of absolute density, and proceed incrementally to situations where our inferences may be less reliable. Our basic approach throughout will be to develop the new statistical methods required for the situation and to apply the methods using acoustic data that have already been collected (but in most cases will require processing). In doing this, we will leverage the very significant efforts that have already been expended in data collection, and also in the development of methods for data processing and analysis. We stress that although we will be analyzing specific datasets, our methods are designed to be general.

The case studies are as follows:
- estimation of humpback whale density at the Pacific Missile Range Facility (PMRF), Hawai'i.
- estimation of sperm whale density at the Atlantic Undersea Test and Evaluation Center (AUTEC) range, Bahamas
- estimation of beaked whale density at the AUTEC range, Bahamas.
- estimation of sperm whale density at AUTEC using single hydrophone data.

Project investigators and roles

The research is being undertaken by an internationally-leading, multi-disciplinary team of statisticians, acousticians, cetacean survey specialists and biologists, drawn from academia and the US military. In summary, our major roles are as follows:
- University of St. Andrews (UStA), St. Andrews, UK. Dr. *Len Thomas*, is project PI, and is collaborating with Dr. *Tiago Marques* and Dr. *David Borchers* on development of the new statistical methods and testing by simulation. Overall project management and coordination across all institutions is performed by Dr. *Catriona Stephenson*.
- Space and Naval Warfare Systems Center (SSD), San Diego, CA. Mr. *Steve Martin* is overseeing the first test case (Humpbacks at Hawai'i). Martin was PI on the ONR-funded project to collect these data.
- Oregon State University (OSU), Newport, Oregon. Dr. *David Mellinger* is developing an automatic classifier for humpback whales; he is also taking the lead on developing methods for estimating density from single fixed sensors.
- Naval Undersea Warfare Center (NUWC), Newport, RI. Mr. *David Moretti* is leading a team of engineers and acousticians, including Ms. *Jessica Ward*, Dr. *Ron Morrissey* and Ms. *Nancy DiMarzio*. They will use new detection algorithms developed under this project, together with the large collection of algorithms and hardware developed previously at NUWC (under the Marine Mammal Monitoring on Navy Ranges (M3R) program, funded by N45 and ONR) to extract data required for the case studies, as well as participating in developing and applying the new density estimation methods.
- Woods Hole Oceanographic Institution (WHOI), Woods Hole, MA. Dr. *Peter Tyack* will, in collaboration with others at WHOI (including Dr. *Mark Johnson* and Ms. *Amanda Hansen*), provide estimates of vocalization behavior and movement data for sperm whales and beaked whale species required to convert estimates of click density to estimates of animal density.

In addition to the core team of investigators, there is a project steering group of acknowledged experts in the above fields, who provide annual feedback on progress and advice on future directions. The steering group is composed of Dr. *Jay Barlow* (NOAA Southwest Fisheries Science Centre), Prof. *Stephen Buckland* (University of St. Andrews) and Dr. *Walter Zimmer* (NATO Undersea Research Centre).

Work plan for coming year

At time of writing, we are still negotiating details of the funding contract, and this is beginning to become a significant impediment to research progress. We hope that this will be finalized soon. Assuming this is resolved, we intend to follow our work plan as laid out in the project proposal, although some tasks have been put back to account for the late start. Specifically, we do not expect to complete the work on humpback whales in the 2007-8 fiscal year, although we expect to make significant progress on this task. We also expect to make significant progress on the other three case

studies, with processed acoustic data being available to project investigators from both PMRF and AUTEC. In the coming year, we will complete development of the new humpback whale detector, and develop methods for analysis of these data, together with distance-based multiple hydrophone data for sperm and beaked whales. Project progress will continue to be monitored through monthly telephone progress meetings, and we plan to hold an annual progress meeting in July 2008.

WORK COMPLETED

The project is still in its early stages, and some project partners have not been able to commence work due to the delay in finalizing the funding agreement. Nevertheless, we held the project startup meeting in July 2007, to coincide with a workshop in Boston that most co-investigators were already attending. Initial data provision activities have been completed. OSU has begun development of the humpback whale song unit detector based on data from PMRF. UStA has begun development of methods based on those of Moretti *et al*. (2006). This UstA work is on the case of a dense array of hydrophones where accurate localizations cannot be made on detected vocalizations, but for which detections on one or more hydrophones are certain for a group of animals diving together. The test data for this work is beaked whales at AUTEC (Figure 1), although the methods are designed to be general.

RESULTS

The humpback detection results are too preliminary to report, so we focus on the count-based density estimation methods. Assessment of previous methods and respective assumptions led us to propose new approaches to the estimation procedures described in Moretti (2006). Specifically, a new "dive counting" algorithm has been developed, where a spatial smoother is applied to a moving window time-series of detected vocalizations at an array of hydrophones (Figure 2). This is used to determine the number of group dive initiations per unit time. This can, in turn, be converted to an estimate of animal group density, provided we have some information on the frequency at which groups start dives. Such information is available from DTAG data. With knowledge of the mean group size, the estimate of animal group density can be used to estimate animal density. On first investigation, this approach appears promising, but it will take further development and validation before it can be applied in more general situations. Another promising alternative is closer to standard cue counting methods as described in Buckland *et al*. (2001), and we plan to process data into the required format and investigate this in the coming year.

IMPACT AND APPLICATIONS

National Security

The US Navy is committed to marine mammal risk mitigation, both on testing ranges and exercises outside of these areas. Methods developed under this project will contribute substantially to risk mitigation capabilities, both in enabling more effective planning of testing and training for times and places that minimize exposure of marine mammals to underwater sound, and also potentially in real-time monitoring of marine mammal presence.

Quality of Life

Cetaceans are an iconic part of the world's biodiversity; the project will enable us to better monitor their numbers and so conserve them for future generations.

TRANSITIONS

None at present.

RELATED PROJECTS

- The N45 and ONR-funded Marine Mammal Monitoring on Navy Ranges (M3R) program has developed tools capable of detecting and tracking marine mammals in real time on Navy ranges (see proposal). Archival and new data from this program is being used to provide much of the input data for the current project.
- US Navy Pacific Fleet and Office of Naval Research have funded PMRF data collection and analysis (see project proposal), including a manual analysis of acoustic snapshots of data that will form the basis for a 'quasi ground truth' for evaluation of the Humpback whale song unit detector.
- The UK Defense Science Technology Laboratory (DSTL) is funding a PhD student based at UStA from 2007-2010, co-supervised by Thomas, John Harwood (UStA) and Chris Clarke (Cornell), to work on estimation of cetacean density from sparse arrays of hydrophones, such as those of the IUSS SOSUS array. This work will proceed in close collaboration with DECAF.

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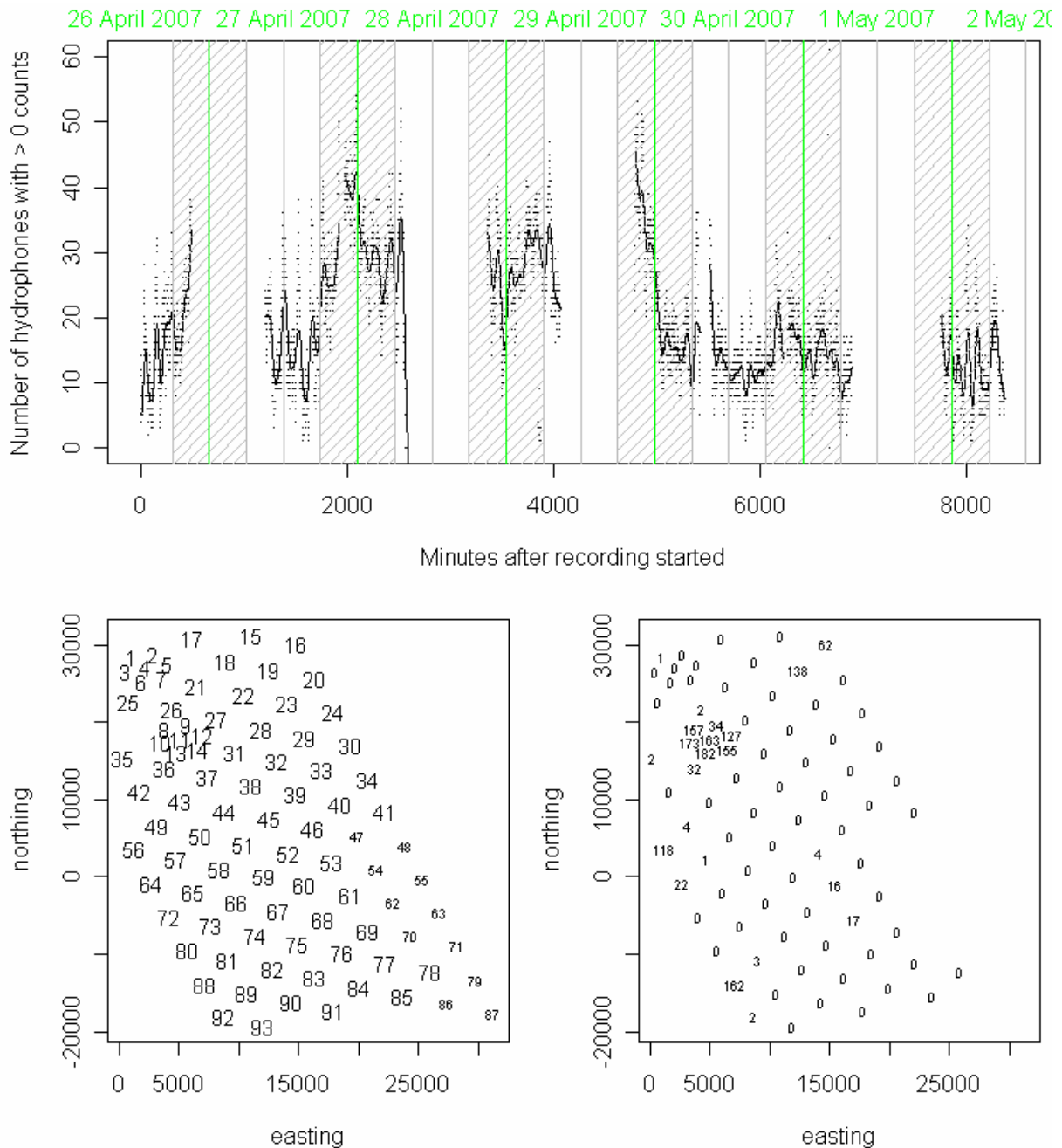
Figure 1. The beaked whale test data set at AUTEC span sapproximately 6 days, from April 26th 2005 till May 2nd 2005. On the top panel each small dot represents the number of hydrophones with non-zero counts per minute, as a function of minutes since the beginning of the recording. The shaded areas represent night periods (18:00-06:00). The green vertical lines represent 24:00. The bottom left plot represents the spatial layout of the AUTEC range, with each number representing a hydrophone ID (smaller ID numbers represent inactive hydrophones during the recording period). The bottom right plot represents a typical data set of counts of detected clicks (vocalizations) for a given minute, illustrating the data from which we aim to estimate beaked whale density.
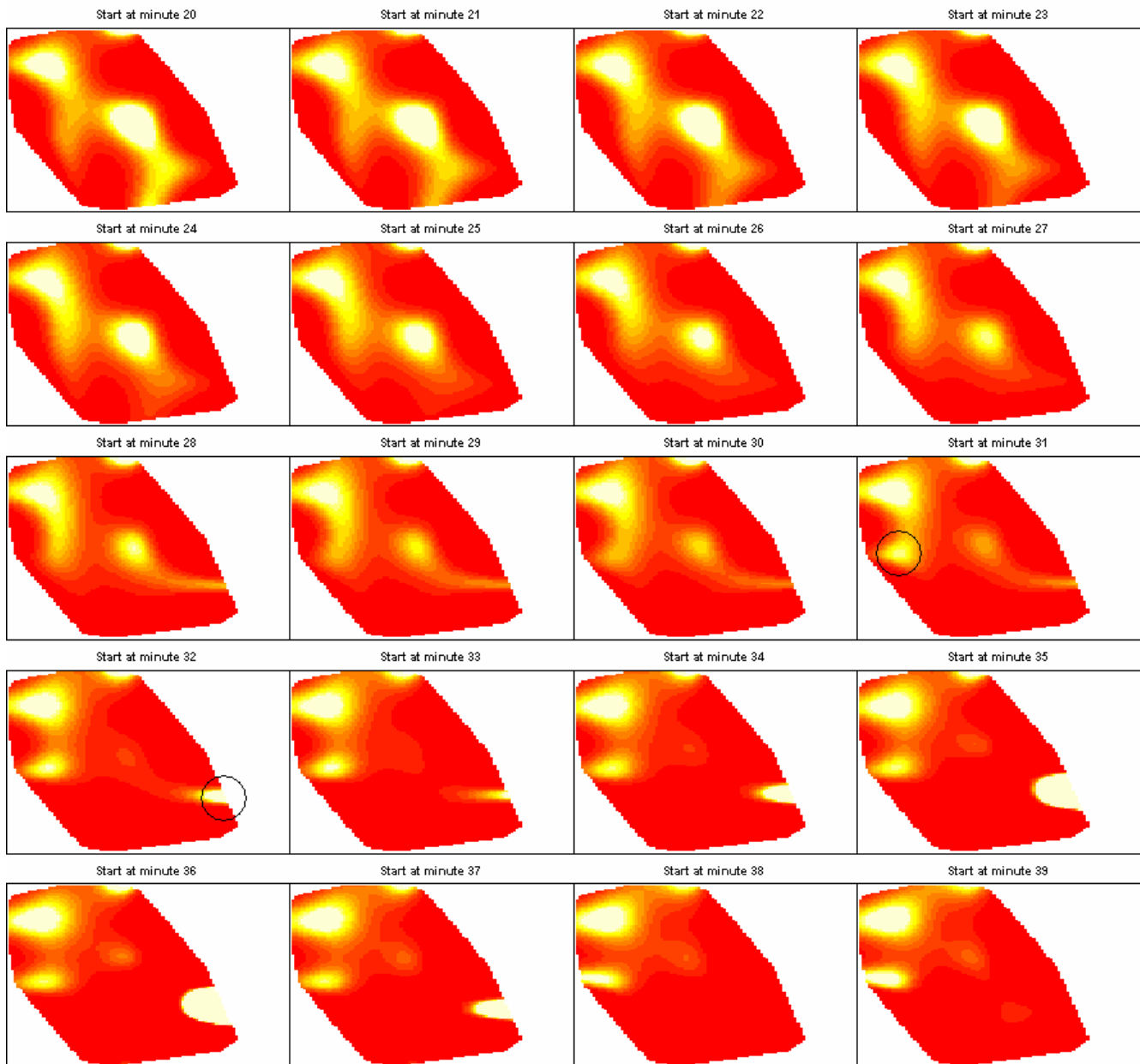
Figure 2. Illustration of the dive counting method, applied to beaked whale detections for a selected 29 minute period at the AUTEC range. Compare with the bottom panels of Figure 1 for spatial reference and units. Each frame shows spatial smoothing (using a generalized additive model) applied to click counts over a moving window of length 10 minutes, shifted by 1 minute in each frame. A new dive was initiated in minute 31 (probably before this and then detected in this minute), as indicated by the black circle. Similarly, the dive that started in minute 32 (black circle) is likely outside the range boundary, and hence would be ignored in the analysis.