SC/64/O13 - Annual Report of the Southern Ocean Research Partnership (SORP) 2011/12

ELANOR M. BELL[1] (Compiler)

[1] *Australian Marine Mammal Centre, Australian Antarctic Division, DSEWPAC, 203 Channel Highway, Kingston Tasmania 7050, AUSTRALIA*

ABSTRACT

The Southern Ocean Research Partnership (SORP) was proposed by the Australian Government to the International Whaling Commission (IWC) in 2008 with the aim of developing a multi-lateral, non-lethal scientific research program that will improve the coordinated and cooperative delivery of science to the IWC. A framework and set of objectives for SORP were presented to the IWC in 2009 where they were endorsed. Several international research projects were selected to form the basis of SORP research and progress reports were presented to the IWC in 2010 and 2011. This paper reports on the continued progress of SORP and those projects since the IWC meeting in 2011.

KEYWORDS: SOUTHERN OCEAN RESEARCH PARTNERSHIP, IWC, SORP, ANTARCTICA

INTRODUCTION

In 2008 Australia proposed to the International Whaling Commission (IWC) the development of regional non-lethal cetacean research partnerships. These research partnerships would use modern, non-lethal, scientific methods to provide the information necessary to best conserve and manage cetacean species. The proposal was received very positively by IWC member nations. The Australian Government is now supporting the Southern Ocean Research Partnership (SORP), established in March 2009. The aim of SORP is to develop a multi-lateral, non-lethal scientific whale research program that will improve the coordinated and cooperative delivery of science to the IWC.

The objectives, research plan, and procedural framework for the partnership were developed through a workshop held in Sydney, Australia in March 2009 that was attended by 50 participants representing 12 countries (Australia, Argentina, Brazil, Chile, Costa Rica, France, Italy, Mexico, New Zealand, South Africa, Uruguay and USA) and several research and environment consortiums.

A framework and set of objectives for SORP were endorsed by the IWC at its Annual Meeting in June 2009. An Annual Report of SORP (Paper SC/63/O12) and revised project plans (SC/63/O13) were presented to the IWC in 2011 which summarised progress within SORP and the six SORP research projects. This paper reports on SORP progress since that time.

BRIEF SUMMARY OF PROGRESS

The following items detail the major progress that has been made by SORP since the last SC meeting. Further details of this work can be found on the SORP website presently hosted by the Australian Antarctic Division at http://www.marinemammals.gov.au/sorp.

Appointment of new SORP coordinator

In April 2012, Dr. Elanor Bell was appointed to coordinate the Southern Ocean Research Partnership. The International Project Office is located at the Australian Marine Mammal Centre, Australian Antarctic Division in Hobart. As coordinator, Elanor will oversee the progress of projects and facilitate their continued success, in conjunction with the Chair and SORP Steering Committee. A meeting of the SORP SC is planned later in 2012.

SORP Research Projects

Brief summaries of progress on each of the six current SORP research projects are given below. Full project reports are included in Annex 1.

SORP Project 1: Antarctic Blue Whale Project (ABWP; formerly known as the 'Year of the Whale' project)

The Antarctic Blue Whale Project (ABWP) is one of the core SORP research projects. The ABWP has the primary aim of developing non-lethal research methods to estimate circumpolar abundance of Antarctic blue whales (*Balaenoptera musculus intermedia*). Other objectives are to improve our understanding of population structure, the linkages between breeding and feeding grounds and the behaviour on the feeding grounds

Mark-recapture methods, using genetics and photo-ID, will form the foundation of future Blue Whale circumpolar abundance estimates produced by the ABWP, but the success of these methods require a high number of encounters with these animals. In the Southern Ocean, acoustic detection ranges of Blue Whales far outstrip visual sighting ranges, so real-time acoustic tracking can be used to increase the total number of whale encounters, thus making more efficient use of expensive ship time.

Further information about ABWP is available in papers SC/63/O13, SC/63/SH3, SC/64/SH11 and SC/64/SH13, and this project will be discussed in detail at SC 64. A full Antarctic Blue Whale Project report is presented in Annex 1.

SORP Project 2: Distribution, relative abundance, migration patterns and foraging ecology of three ecotypes of killer whales in the Southern Ocean

The principle investigators once again participated as 'visiting scientists' on board the tour vessel M/V National Geographic Explorer, during four consecutive trips to the Antarctic Peninsula from 7 January to 15 February, 2012. Seven killer whale sightings were recorded (6 small type B killer whales; 1 large type B); approximately 3000 photo-id images of over 200 individually-recognizable animals for future mark-recapture analyses were obtained; 2 skin biopsy samples were obtained (samples archived at SWFSC), and 3 individuals were satellite-tagged. Data are presented in the full project report (Annex 1).

Other tour ships operating in the Antarctic Peninsula area were also canvassedfor killer whale photographs and we obtained thousands of images from over two dozen killer whale encounters. The principle investigators feel confident that within the next year or two they should have enough images to estimate population sizes for the three types of killer whales that we recognize in the Peninsula Area.

SORP Project 3: Foraging ecology and predator-prey interactions between baleen whales and krill: a multi-scale comparative study across Antarctic regions

During the funding period, significant progress was made towards the overall goal understanding the foraging ecology and predator-prey interactions between baleen whales and krill in the waters around the Western Antarctic Peninsula. Analysis was completed describing the diving behavior of humpback whales from suction-cup tags deployed in 2009 and 2010. These results were presented at numerous scientific meetings including the Biennial Conference on the Biology of Marine Mammals (Tampa, FL, November 2011), and the recently SORP workshop on non-lethal research techniques for studying cetaceans (Puerto Varas, Chile, March 2012). A full project report is included in Annex 1.

SORP Project 4: What is the distribution and extent of mixing of Southern Hemisphere humpback whale populations around Antarctica? Phase 1: East Australia and Oceania

Over the past year the project steering group has focussed on preparing for the proposed 2013 satellite tagging work at the Kermadec Islands and American Samoa (refer to SC/63/O13). The Oceania population estimate has been published (Constantine *et al.*, 2012) with a sex-specific POPAN super-population model, which accounted for residents and whales migrating through the survey areas, giving an estimate of 4329 whales (3345−5313) in 2005. Future work will focus on addressing the questions:

1. What is the connection between the humpback whales from Area V feeding grounds and their migratory corridors and breeding grounds in Australia and Oceania?
2. Do whales from Area V represent a single breeding ground or are they a mix of individuals from several distinct breeding grounds?

A full project report is included in Annex 1.

SORP Project 5: Acoustic trends in abundance, distribution, and seasonal presence of Antarctic blue whales and fin whales in the Southern Ocean

Understanding baleen whale distribution and abundance in the Antarctic, particularly blue and fin whales, is complicated by the pelagic distribution of both species, the difficulty of working in the Southern Ocean (SO) and the massive decline of both due to commercial whaling. After a half-century of protection, little is known about the present-day status of each species. Blue (*Balaenoptera musculus*) and fin (*B. physalus*) whales are congeners that are the largest mammals on earth. Both occur in in all oceans of the world with similar distribution patterns. In particular, each species occurs in high latitudes in the Southern Hemisphere (SH). In the Antarctic, blue whales are generally thought to occur closer to the ice edge than fin whales. While blue whales in this region are designated as different subspecies (*B.m. intermedia, B.m. brevicauda*, respectively), fin whales worldwide are considered a single species.

Both blue and fin whales were targets of commercial whaling, particularly from the early 1900's through the 1930's. Despite heavy depletion during this era, commercial exploitation continued into the mid and late 20th century. Blue whales were protected internationally from whaling in 1966 and fin whales in 1985. At present, both species are listed as endangered by the International Union to Conserve Nature (www.iucn.org) and there are no reliable population estimates for either species globally. A recent examination of almost 40 years of sighting data resulted in an estimate of 1,700 (C.I. 860-2,900) Antarctic blue whales, which is less than 1% of the original population (Branch *et al.* 2004). There are no equivalent estimates for SH fin whales.

From 1978 to 2010 the International Whaling Commission supported first the International Decade of Cetacean Research (IDCR, 1978-1996) and then the Southern Ocean Whale Ecosystem Research (SOWER, 1996-2010) programs. These were annual sighting surveys which consisted of three circumpolar sets of cruises over multiple years that focused primarily on minke whale (*B. acutorostrata*) abundance but that also provided an estimate of abundance for Antarctic blue whales (Branch *et al.* 2004). Only two of the recent cruises focused on fin whales (Ensor *et al.* 2006, 2007). Given the amount of effort, ship time, high risk of poor weather and cost of sighting cruises, it is unlikely that the tremendous shipboard effort of IDCR/SOWER will be repeated. In order to continue to monitor Antarctic blue and fin whales, the use of a network of long-term passive acoustic recorders has been proposed in lieu of dedicated circumpolar visual surveys. A full project report is included in Annex 1.

SORP Project 6: Living Whales Symposium: Advances in non-lethal research techniques for whales in the Southern Hemisphere.

The Living Whales Symposium and accompanying workshops were held in Puerto Varas, Chile, 27-29th March 2012. The first day (27th March) was an open Symposium with invited experts who showcased new non-lethal research methods for whales in the Southern Hemisphere. The Symposium was followed by two days of Workshops that covered specific research areas. The Workshops were each one day in duration and covered the following topics:

- Health assessment of live cetaceans;
- Advances in long term Satellite Tagging Techniques for Cetaceans;
- Population dynamics and environmental variability; and
- Estimation of diet and consumption rates from non-lethal methods.

There were 124 people registered for the symposium from 17 countries (Argentina, Chile, Brazil, Australia, Colombia, Ecuador, France, Germany, Madagascar, Mexico, New Caledonia, Norway, Panama, Paraguay, South Africa, United Kingdom, the United States of America). The Symposium was also live streamed on the web allowing an additional 1,553 viewers to be involved, mostly from the United States of America, Chile, Brazil, Argentina, Australia, Spain, Colombia, United Kingdom, Canada, and Germany. Paper SC/64/O14 presents a full Symposium report, programme and list of participants.

LIST OF SORP RELATED PAPERS AT SC 64

SC/63/O12	Childerhouse S (2012) Annual Report of the Southern Ocean Research Partnership 2011.
SC/63/O13	Childerhouse S (2012) Southern Ocean Research Partnership Revised project plans.
SC/64/O14	Baker CS *et al.* (2012) Report of the Living Whales Symposium: Advances in non-lethal research techniques for whales in the Southern Hemisphere.
SC/64/IA9	Kelly N *et al.* (2012) Where did those minke whales go? - A discussion.
SC/64/IA10	Kelly N *et al.* (2012) Estimating abundance and distribution of Antarctic Minke Whales within sea ice areas: data requirements and analysis methods.
SC/64/SH10	Kelly N *et al.* (2012) Strategies to obtain a new circumpolar abundance estimate for Antarctic Blue Whales: survey design and sampling protocols.
SC/64/SH11	Miller BS *et al.* (2012) Development of acoustic methods: cruise report on SORP 2012 Antarctic Blue Whale voyages.
SC/64/SH12	Miller BS (2012) Real-time tracking of Blue Whales using DIFAR sonobuoys.
SC/64/SH13	Wadley V *et al.* (2012) Abundance estimation of Antarctic Blue Whales: preliminary voyage plan for SORP in March 2013.
SC/64/SH14	de la Mare WK (2012) Estimating relative abundance from historic Antarctic whaling records.
SC/64/SH15	Schmitt NT *et al.* (2012) Low levels of genetic differentiation characterize Australian humpback whale (*Megaptera novaeangliae*) populations.

Annex 1: PROGRESS REPORTS ON THE SORP RESEARCH PROJECTS FOR 2011/12

1. Antarctic Blue Whale Project (formerly The SORP 'Year of the Whale')

Dr. Victoria Wadley, Scientific Coordinator, Antarctic Blue Whale Project
Australian Marine Mammal Centre, Australian Antarctic Division, 203 Channel Highway, Kingston, Tasmania 7050, Australia

The Antarctic Blue Whale Project (ABWP) is one of the core SORP research projects. The overall aim of the project is the development of non-lethal research methods to allow for an estimate of Antarctic blue whale circumpolar abundance. Other objectives are to improve our understanding of population structure, the linkages between breeding and feeding grounds and the behaviour on the feeding grounds. Further information about ABWP is available in papers SC/63/O13 and SC/63/SH3 and this project will be discussed in detail at SC 64.

The project is expected to continue for at least three years. The activities in the last year include:

i. *Results from two voyages using passive acoustics (refer to SC/64/SH11)*
Two voyages conducted in early 2012 demonstrated the potential for passive acoustics using DIFAR-sonobuoys to increase the encounter rate with Blue Whales. The method used real-time acoustic tracking as part of a strategy using mark/recapture statistics and biopsy sampling to develop the potential for estimating circumpolar Antarctic blue whale abundance.

ii. *Appointment of ABWP Scientific Coordinator*
In April 2012 Dr. Victoria Wadley was appointed to coordinate the international research for the ABWP, as a project of SORP. The International Project Office is located at the Australian Antarctic Division in Hobart. As Scientific Coordinator she will plan the priorities for the next three years and develop a Science Statement for the project, in conjunction with the Chair and Scientific Steering Committee. A meeting of the SSC is planned later in 2012.

Victoria has experience as coordinator of the Census of Antarctic Marine Life, coordinating the research on 18 research icebreakers during the International Polar Year 2007/08. The project was awarded the Overall Excellence award from the global Census of Marine Life and was one of six projects out of the total of 228 projects which were highlighted in the results of the IPY.

iii. *Plans for acoustics voyage March 2013 (refer to SC/64/SH13)*
The Voyage Plan for 2013 is under development for discussion with the relevant Technical Committees of IWC. Feedback on the preliminary voyage plan and interest in collaboration are invited from participants at IWC64.

iv. *Participation in other activities*

- Members of the ABWP participated in the Living Whales workshop in Chile (April 2012) (refer to SC/64/O14).
- Victoria Wadley presented a paper on the project in a plenary panel entitled "Ecosystems – science and stewardship" at the IPY conference, Montreal, April 2012.
- The ABWP participants are active in contributing to developments in statistical methods, population structure and identification of individual whales (using images, genetics).
- Papers and posters have been submitted to the AMSA-NZMSS conference (Hobart 1-5 July) by Dr. Natalie Kelly (Estimating abundance of Antarctic Blue Whales) and Dr. Brian Miller (Real-time acoustic tracking method).
- Dr. Natalie Kelly has submitted a paper to the Australian Statistics Conference in Adelaide, July 2012 (Mark recapture method to estimate the abundance of ABW).

2. Distribution, relative abundance, migration patterns and foraging ecology of three ecotypes of killer whales in the Southern Ocean

Dr. Robert L. Pitman, Principle Investigator
Protected Resources Division, Southwest Fisheries Science Center, National Marine Fisheries Service, 8604 La Jolla Shores Dr., La Jolla, California 92037, USA

Pitman and Durban participated again this year as 'visiting scientists' on board the tour vessel M/V National Geographic Explorer, during four consecutive trips to the Antarctic Peninsula from 7 January to 15 February, 2012. We recorded 7 sightings of killer whales (6 small type B killer whales; 1 large type B); obtained approximately 3000 photo-id images of over 200 individually-recognizable animals for future mark-recapture analyses; collected 2 skin biopsy samples (samples archived at SWFSC), and satellite-tagged 3 individuals. The tags included 2 location-only LIMPET transmitter tags and 1 LIMPET tag also recorded and transmitted dive-depth data. The depth tag transmitted for 16 days and the depth profiles indicated that small type B killer whale dive to at least 600 m (almost 3 times the previous-recorded maximum), probably feed at or near the bottom, and can initiate feeding bouts at any time during the day or night – Figure 1 shows the depth profiles and movements of this animal. We view this as additional evidence that small type B killer whales are ecologically (and probably phylogenetically) distinct from large type B killer whales. This year we canvassed other tour ships operating in the Antarctic Peninsula area for killer whale photographs and we obtained thousands of images from over two dozen killer whale encounters. We feel confident that within the next year or two we should have enough images to estimate population sizes for the three types of killer whales that we recognize in the Peninsula Area. We published one paper on our previous seasons' satellite tagging results: Durban, J.W., and R.L. Pitman. 2011. Antarctic killer whales make rapid, round-trip movements to sub-tropical waters: evidence for physiological maintenance migrations? Biology Letters doi: 10.1098/rsbl.2011.0875. We also published a popular publication that summarized a lot of our research on Antarctic killer whales: Pitman, R. L. (ed.). 2011. Killer whale: the top, top predator. Whalewatcher (Journal of the American Cetacean Society) 40(1):1-67. In addition to killer whales, we attached LIMPET satellite tags to three humpback whales as a feasibility study. Our best tag lasted 20 days; Figure 2 shows the high-resolution track of this whale.

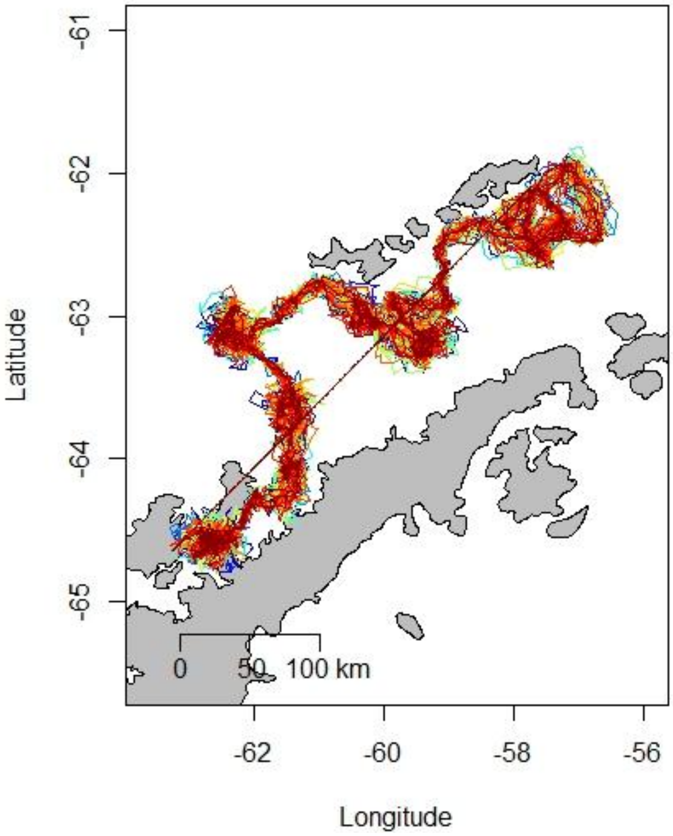


Figure 1a. A 16-day high-resolution track of killer whale movement off the west side of the Antarctic Peninsula. A total of 328 locations were estimated by the ARGOS satellite system, based on transmissions from a LIMPET transmitter tag (Andrews *et al*. 2009; Durban and Pitman, 2011). A movement track was estimated by fitting a continuous-time correlated random walk model (Johnson et al. 2008) to the locations with their estimated error (average location estimate error was 2217m), and drawing Bayesian predictions from the fitted model (Johnson *et al.* 2011) to provide probabilistic inference about space use (more red = higher probability of use).

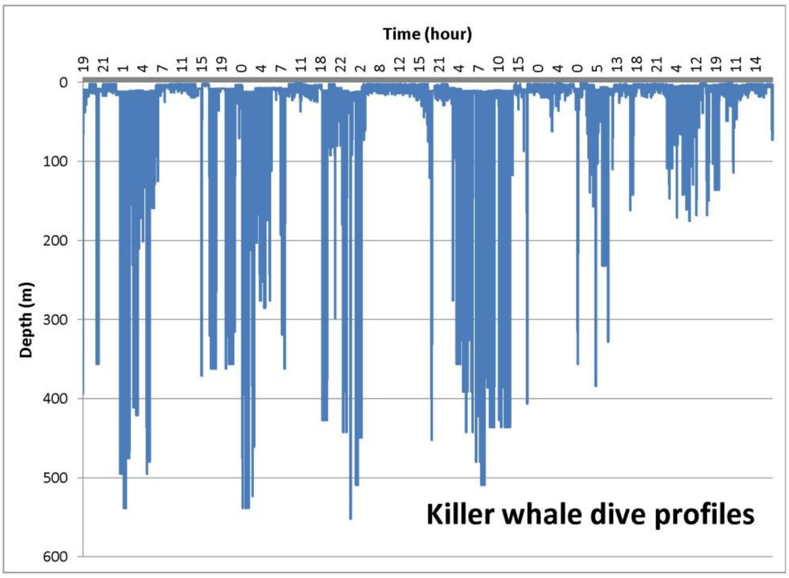


Figure 1b. A plot of dive profiles compiled from depth readings transmitted to the Argos satellite system across the duration of the tag track depicted in (A).

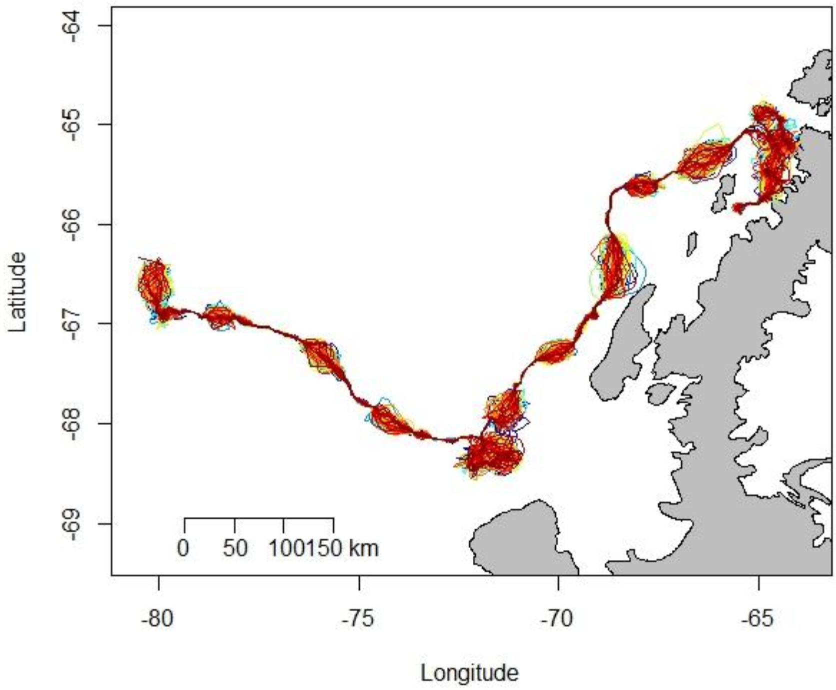


Figure 2. A 20-day high-resolution track of humpback whale movement off the west side of the Antarctic Peninsula. A total of 475 locations were estimated by the ARGOS satellite system, based on transmissions from a LIMPET transmitter tag (Andrews et al. 2009; Durban and Pitman, 2011). A movement track was estimated by fitting a continuous-time correlated random walk model (Johnson et al. 2008) to the locations with their estimated error (average location estimate error was 990m), and drawing Bayesian predictions from the fitted model (Johnson et al. 2011) to provide probabilistic inference about space use (more red = higher probability of use).

References cited

Andrews R, Pitman R, Ballance L (2008) Satellite tracking reveals distinct movement patterns for Type B and Type C killer whales in the southern Ross Sea, Antarctica. Polar Biology 31:1461-1468

Durban J, Pitman R (2011) Antarctic killer whales make rapid, round-trip movements to subtropical waters: evidence for physiological maintenance migrations? Biology Letters, doi: 10.1098/rsbl.2011.0875

Johnson D, London J, Lea M, Durban J (2008) Continuous-time correlated random walk model for animal telemetry data. Ecology 89:1208-1215

Johnson DS, London, JM, Kuhn CE (2011) Bayesian Inference for Animal Space Use and Other Movement Metrics. Journal of Agricultural, Biological, and Environmental Statistics 16:357-370

3. Foraging ecology and predator-prey interactions between baleen whales and krill: a multi-scale comparative study across Antarctic regions

Dr. Ari S. Friedlaender, Principle Investigator
Duke University, Suite 710 Erwin Square, 2200 West Main Street, Durham, NC 27705, USA

Summary

During the funding period, significant progress was made towards the overall goal understanding the foraging ecology and predator-prey interactions between baleen whales and krill in the waters around the Western Antarctic Peninsula. Analysis was completed describing the diving behavior of humpback whales from suction-cup tags deployed in 2009 and 2010. These results were presented at numerous scientific meetings including the Biennial Conference on the Biology of Marine Mammals (Tampa, FL, November 2011), and the recently SORP workshop on non-lethal research techniques for studying cetaceans (Puerto Varas, Chile, March 2012). A PDF copy of this presentation is attached for information.

While numerous insights were made from this study, some of the main findings can be summarised as:

- Humpback whales were found to feed almost exclusively during night-time hours in late fall (May/June), spending daylight hours either resting or traveling. The initiation of feeding was often proceeded by deep exploratory dives that are hypothesized to sample the water column to determine where prey are distributed.
- Humpback whales appear to achieve or conform to ecological predictions of optimal foraging theory in two significant ways:
    - Humpback whales increase the number of feeding lunges executed per dive with increased dive depth.
    - Humpback whales target higher densities of krill as feeding depth increases
- While both of these findings are significant, the fact that we have been able to quantify increases in prey density concurrent to whale feeding is novel. The information provided from this relationship will be a substantial component of the manuscripts that are currently in preparation to be submitted for peer review.
- Humpback whales vary the depth of their feeding in relation to the diel vertical movement of krill in the water column.

In January 2012, research was conducted on the US Antarctic Program's National Science Foundation Long-Term Ecological Research cruise. During this time, six satellite linked tags were deployed on humpback whales, averaging a transmission period of over 60 days. At the time of this report, two tags are still transmitting and thus, final analysis of these data cannot be done. When the data have ceased to be collected, the tag information will be used to prepare and submit a manuscript describing the movement patterns of these whales and testing this against the ecological hypothesis that during summer months, the distribution of humpback whales is primarily related to the distribution and abundance of their prey, Antarctic krill. A second PDF is presented below that presents the raw, uncorrected satellite locations for each of the six whales tagged during this effort. All of the tags and the satellite time were donated by the Australian Antarctic Division as part of the international research collaboration supported by the SORP and IWC.

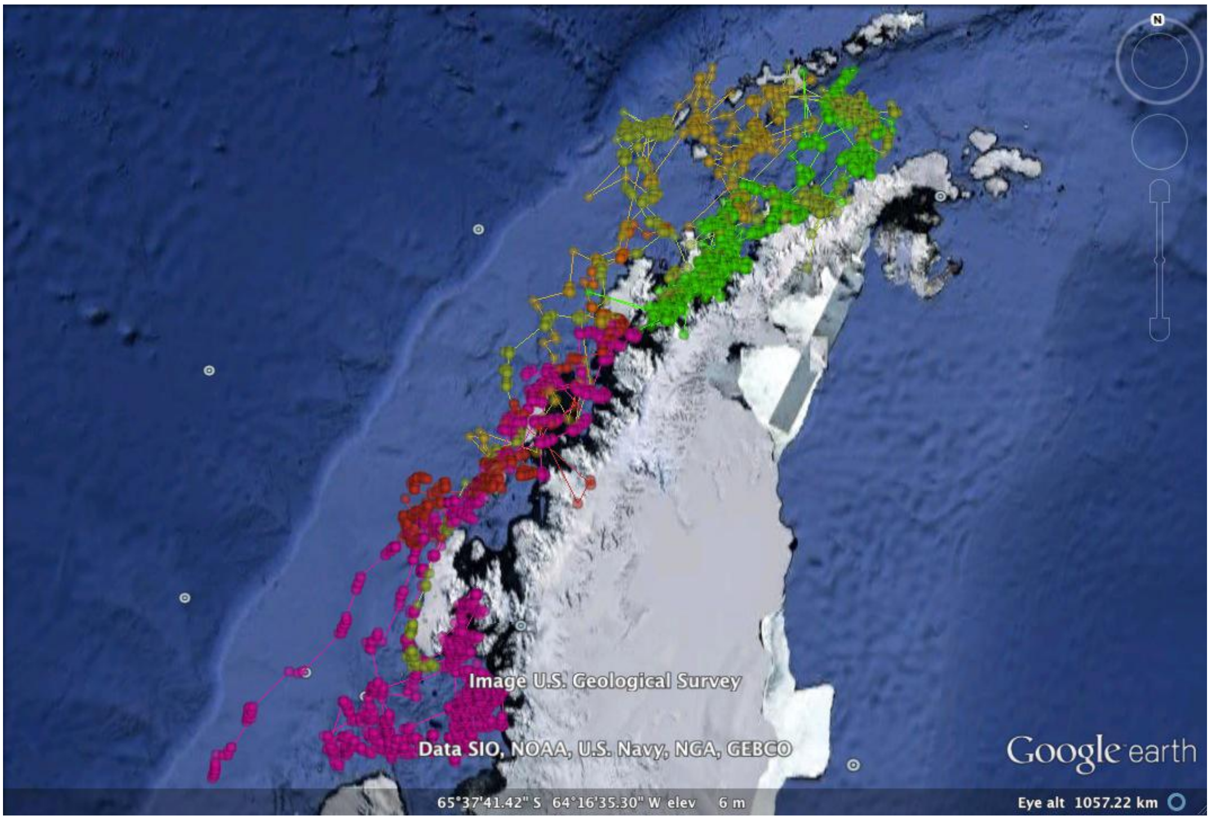


Image: Tracks of 6 humpback whales tagged during the US Antarctic Program's National Science Foundation Long-Term Ecological Research cruise, January 2012.

Manuscripts in preparation, including estimated submission date and target journal

Friedlaender, A.S., Hazen, E.L., Halpin, P.N., Stimpert, A., Tyson, R.B., Ware, C., Curtice, C., and Nowacek, D.P. *in prep.* Decisions, decisions: daily activity and foraging behavior of humpback whales in relation to prey availability.
Submission date: June 2012; Target Journal: *Functional Ecology*

Friedlaender, A.S., Johnston, D.W., Gales, N., Curtice, C., Nowacek, D., and H. Ducklow. *In prep.* Spatio-temporal movement patterns of humpback whales during summer in the nearshore waters off the Western Antarctic Peninsula.
Submission date: November 2012; Target Journal: *PLoS One*

4. What is the distribution and extent of mixing of Southern Hemisphere humpback whale populations around Antarctica? Phase 1: East Australia and Oceania

The SORP southern hemisphere humpbacks steering committee: Rochelle Constantine[1], Mike Double[2], Scott Baker[3], Phil Clapham[4], Alex Zerbini[5] Claire Garrigue[6] and Jooke Robbins[7]

[1]*School of Biological Sciences, University of Auckland, Private Bag 92019, Auckland, New Zealand*
[2]*Australian Marine Mammal Centre, Australian Antarctic Division, Channel Highway, Kingston, Tasmania 7050, Australia*
[3]*Oregon State University Marine Mammal Institute, Hatfield Marine Science Center, 2030 SE Marine Science Drive, Newport, Oregon 97365, USA*
[4,5] *National Marine Mammal Lab, NOAA, Seattle, Washington, USA*
[6]*Opération Cétacés, Noumea, New Caledonia*
[7]*Center for Coastal Studies, Provincetown, Massachusetts, USA*

Over the past year the project steering group has been focusing on preparing for the proposed 2013 satellite tagging work at the Kermadec Islands and American Samoa (refer to SC/63/O13). The Oceania population estimate has been published (Constantine *et al.*, 2012) with a sex-specific POPAN super-population model, which accounted for residents and whales migrating through the survey areas, giving an estimate of 4329 whales (3345−5313) in 2005.

In the winter of 2011, satellite tagging work was undertaken in New Caledonia (Garrigue in collaboration with Zerbini and Clapham) adding to the 2007 (Garrigue *et al.*, 2010) and 2010 tagging efforts. The general trend observed was for the majority (~75%) of whales to head in a south-southeasterly direction once they left the New Caledonia breeding grounds. Some whales stopped at seamounts or other undersea geographic features along the way for varying lengths of time.

The Raoul Island (Kermadec group) single day four hour survey conducted between 0800 and 1200 hrs was conducted on the 8th October 2011. This adds to the previous three years of October surveys using a standard set of seven land-based locations (Potier, 2008; Brown, 2009; Brown, 2010). Previous whale-counts from these surveys have ranged from 62-153 whales and the 2011 survey counted 126 individual whales (Potier and Shanley, 2012). The consistently high number of humpback whales observed migrating past Raoul Island, peaking in October, confirms the Kermadec Islands as the southernmost location in Oceania with regular whale sightings and the ideal site to attach satellite tags as the whales migrate south. Constantine will visit the Kermadec Islands in August 2012 to consider this research site. Research in American Samoa conducted in the 2011 field season continued preparation for the planned satellite tagging in 2013.

Specific objectives

Based around the AWE 2010 genetic and photo-identification data collection we propose a two phase approach to the research with Year 1 focused on Oceania and Year 2 focused on east Australia. This order is determined by availability of data. In addition, and as part of a larger study, we will use satellite tags deployed on whales on their southern migration to determine migratory corridors and links to feeding grounds. The two main questions are:

3. *What is the connection between the humpback whales from Area V feeding grounds and their migratory corridors and breeding grounds in Australia and Oceania?*

4. *Do whales from Area V represent a single breeding ground or are they a mix of individuals from several distinct breeding grounds?*

Year 3 – Oceania

a) Planning for the satellite tagging programme in Oceania with Consortium members and other interested parties about other priority locations and potential matching funding. The Kermadecs and American Samoa have been nominated as priority regions with a strategic focus on breeding grounds and migratory corridors and an emphasis on the unresolved feeding grounds for E2, E3 and F whales. Data will be collected from the

Kermadecs and American Samoa in years 3 *and* 4 and further consultation with the Consortium will be sought to identify individuals, and work out the optimal time for tagging whales as they migrate south.

Year 4 – Satellite tagging

a) Deployment of tags on whales. Approximately 60 tags will be deployed at two locations (30 at Raoul Island and 30 in American Samoa). Tissue samples, photo-ID and group composition data will be collected and compared to existing databases.
b) Analysis of data that integrates satellite tag, genotype and photo-ID information.

References cited

Brown N (2009) Raoul Island Whale Survey. Unpublished Field Season Report. 6 pp.

Brown N (2010) Raoul Island Whale Survey. Unpublished Field Season Report. 30 pp.

Constantine R, Jackson JA, Steel D, Baker CS, Brooks L, Burns D, Clapham P, Hauser N, Madon B, Mattila D, Oremus M, Poole M, Robbins J, Thompson K, Garrigue C (2012) Abundance of humpback whales in Oceania using photo-identification and microsatellite genotyping. Marine Ecology Progress Series 453:249-261

Garrigue C, Zerbini AN, Geyer Y, Heide-Jørgensen M-P, Hanaoka W, Clapham P (2010) Movements of satellite-monitored humpback whales from New Caledonia. Journal of Mammalogy 9:109-115

Potier S (2008) Raoul Island Whale Survey. Unpublished Field Season Report. 8 pp.

Potier S, Shanley T (2012) Raoul Island Whale Survey. Unpublished Field Season Report. 31 pp.

5. Acoustic trends in abundance, distribution, and seasonal presence of Antarctic blue whales and fin whales in the Southern Ocean

The SORP blue and fin whale acoustics steering committee: Flore Samaran[1], Kathleen Stafford[2], Jason Gedamke[3], Ilse Van Opzeeland[4], Brian Miller[5] with contributions from Olivier Adam[6], Mark Baumgartner[7], Sarah Mussoline[7] and Guillaume Pressiat[6].

[1] *PELAGIS Observatory CNRS-UMS 3462, University of La Rochelle, France*
[2] *Applied Physics Lab University of Washington Seattle WA, USA*
[3] *NOAA Ocean Acoustics Program Manager Office of Science and Technology National Marine Fisheries Service Silver Spring, MD, USA*
[4] *Alfred-Wegener Institute for Polar and Marine Research, Bremerhaven Germany*
[5] *Australian Marine Mammal Centre, Australian Antarctic Division, DSEWPaC, Hobart, Australia*
[6] *Centre Neurosciences Paris Sud CNRS-UMR 8195, Université Paris Sud, Orsay, France*
[7] *Woods Hole Oceanographic Institution, Woods Hole, MA, USA*

Introduction

Understanding baleen whale distribution and abundance in the Antarctic, particularly blue and fin whales, is complicated by the pelagic distribution of both species, the difficulty of working in the Southern Ocean (SO) and the massive decline of both due to commercial whaling. After a half-century of protection, little is known about the present-day status of each species. Blue (*Balaenoptera musculus*) and fin (*B. physalus*) whales are congeners that are the largest mammals on earth. Both occur in in all oceans of the world with similar distribution patterns. In particular, each species occurs in high latitudes in the Southern Hemisphere (SH). In the Antarctic, blue whales are generally thought to occur closer to the ice edge than fin whales. While blue whales in this region are designated as different subspecies (*B.m. intermedia, B.m. brevicauda*, respectively), fin whales worldwide are considered a single species.

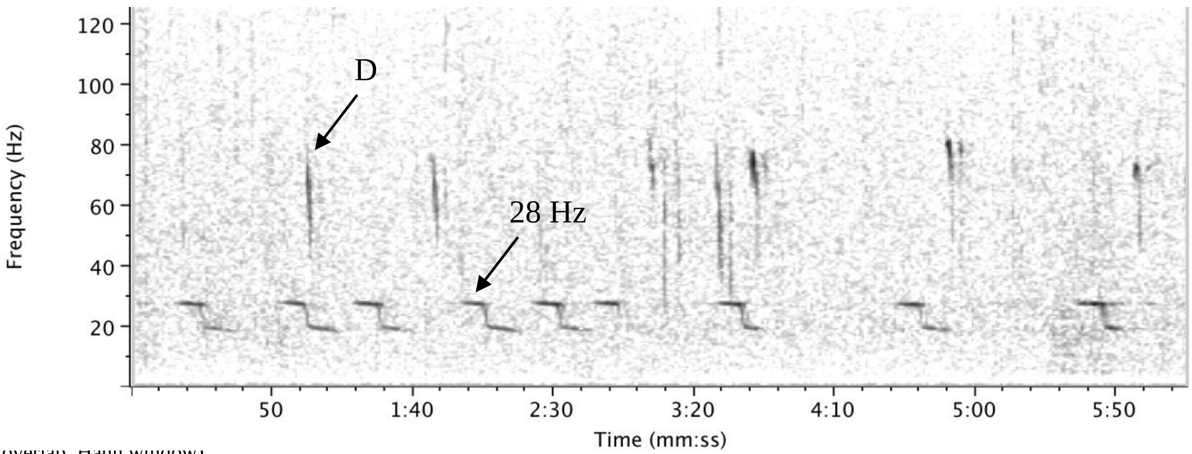
Both blue and fin whales were targets of commercial whaling, particularly from the early 1900's through the 1930's. Despite heavy depletion during this era, commercial exploitation continued into the mid and late 20th century. Blue whales were protected internationally from whaling in 1966 and fin whales in 1985. At present, both species are listed as endangered by the International Union to Conserve Nature (www.iucn.org) and there are no reliable population estimates for either species globally. A recent examination of almost 40 years of sighting data resulted in an estimate of 1,700 (C.I. 860-2,900) Antarctic blue whales which is less than 1% of the original population (Branch *et al.* 2004). There are no equivalent estimates for SH fin whales.

From 1978 to 2010 the International Whaling Commission supported first the International Decade of Cetacean Research (IDCR, 1978-1996) and then the Southern Ocean Whale Ecosystem Research (SOWER, 1996-2010) programs. These were annual sighting surveys which consisted of three circumpolar sets of cruises over multiple years that focused primarily on minke whale (*B. acutorostrata*) abundance but that also provided an estimate of abundance for Antarctic blue whales (Branch *et al.* 2004). Only two of the recent cruises focused on fin whales (Ensor *et al.* 2006, 2007). Given the amount of effort, ship time, high risk of poor weather and cost of sighting cruises, it is unlikely that the tremendous shipboard effort of IDCR/SOWER will be repeated. In order to continue to monitor Antarctic blue and fin whales, the use of a network of long-term passive acoustic recorders has been proposed in lieu of dedicated circumpolar visual surveys.

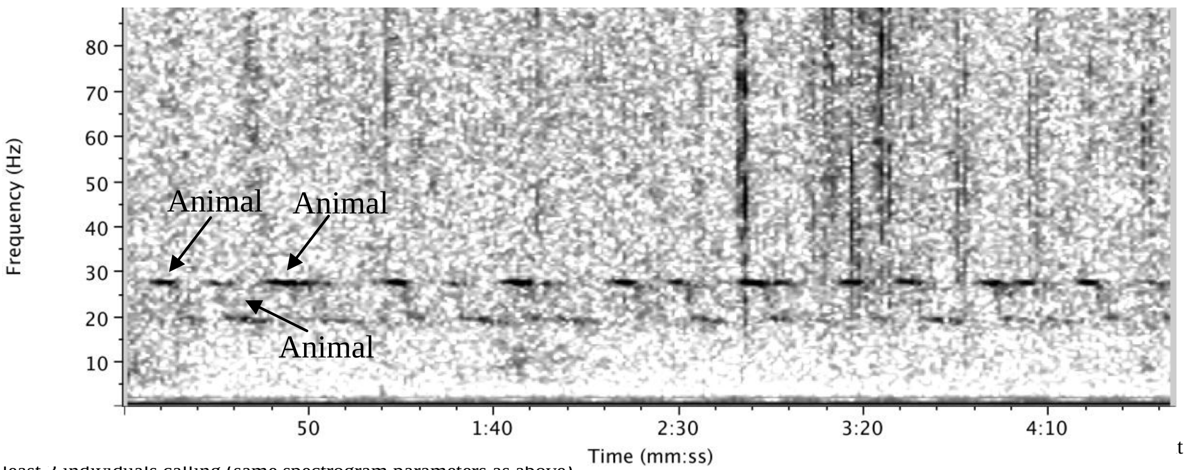
Blue and fin whale acoustic signatures

The use of passive acoustic recordings of blue and fin whales to examine the geographic and seasonal occurrence of calling whales has become commonplace (Thompson and Friedl 1982; Stafford *et al.* 1999, 2007; Nieukirk *et al.* 2004; 2012, Širović *et al.* 2004). This is largely due to the distinctive and repetitive nature of certain call types produced by these two species.

All blue whales produce long, relatively simple, tonal, low frequency calls as part of their acoustic repertoire. Despite these similarities, geographic variation in blue whale calls has been well documented with distinct call types recorded in the Antarctic (Ljungblad *et al.* 1997; Rankin *et al.* 2005). In the Antarctic the call is often Z-shaped with a strong tone at 28 Hz that sweeps down to another tone at 19 Hz and lasts roughly 15 s (Figure 1; Ljungblad *et al.* 1997; Rankin *et al.* 2005). Blue whales in the circumpolar Antarctic all produce the 28 Hz pulses and to date, no regional differences have been documented. Additionally, blue whales produce "D" calls which are variable, higher frequency calls that have been suggested as contact calls or feeding calls (Rankin *et al.* 2005; Oleson *et al.* 2007).



overlap, Hann window).



least 3 individuals calling (same spectrogram parameters as above).

Fin whales worldwide produce long sequences of pulses between ~15-40 Hz usually referred to as “20 Hz pulses” (Watkins 1981). These are much shorter in duration and generally broader in bandwidth than blue whale calls. There is some evidence for geographic variation in fin whale calls in the duration of the interval between successive pulses (Delarue *et al.* 2009, Castellote *et al.* 2011) and in the presence/absence and frequency of a higher frequency pulse concurrent with the 20 Hz pulses. Two different frequency pulses have been noted in the Antarctic, one at 89 Hz from the Antarctic Peninsula region and another, from East Antarctica, at 99 Hz (Širović *et al.* 2009, Gedamke 2009).

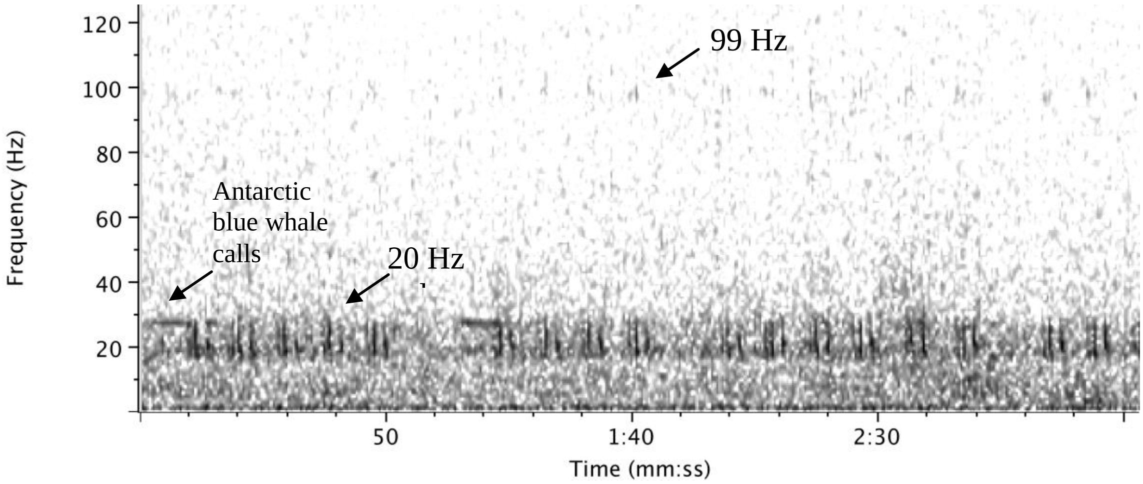


Figure 3. Fin whale 20 Hz pulses from Prydz Bay, with 99 Hz faint high pulses shown. Two blue whale calls are visible showing the overlap in frequency of the two species.

I. *Review of blue and fin whale acoustic monitoring the Southern Hemisphere*

During the past decade, fixed instruments were moored in the SH (Figure 4). Recordings were obtained from different instrument types in 10 different areas in sub-tropical (areas 1, 2, 3, Figure 4), sub-Antarctic (areas 4, 5, 6, Figure 4) and Antarctic (7, 8, 9, 10; Figure 4) waters. These included bottom mounted autonomous packages (ARPs, Wiggins 2003) and instruments suspended in the deep sound channel: Curtin University acoustic loggers (www.cnst.curtin.edu.au), hydrophones from the Comprehensive Nuclear-Test Ban Treaty Organization (CTBTO), AURAL (www.multi-electronique.com), autonomous hydrophones designed by NOAA's Pacific Marine Environmental Laboratory (HARUphone – PMEL, Fox *et al.* 2001) and University of Britanny (UBOphone) and from the PerenniAl Acoustic Obervatory in the Antarctic Ocean (PALAOA, Boebel et., 2006). One year of acoustic data were analyzed from each instrument (Table 1), using at least one of this different methods: Visual Display (VD), Long Term Spectrogram (LTS), Power Spectral Density (PSD) or automatic detection (Ishmael, X-Bat) (see *review of detection methods* below). Data were not available for the same years. A comparison of widely distributed previous recordings from the SH can be used to assess geographic and seasonal differences, and perhaps movements, from calling behavior of each species.

The distance at which calls can be detected depends of many factors including ambient noise levels, instrument type and depth of receiver. For most of the available data that we have, this information was lacking so it was not possible to estimate how far away the calling whales were. Širović *et al.* (2007) estimated that Antarctic blue whale calls from the Antarctic Peninsula could be detected up to 200km from bottom-mounted instruments while Samaran *et al.* (2010b) estimated the detection range to be at most 180 km off the northeast part of the Crozet Islands using a single hydrophone located in the sound channel axis.

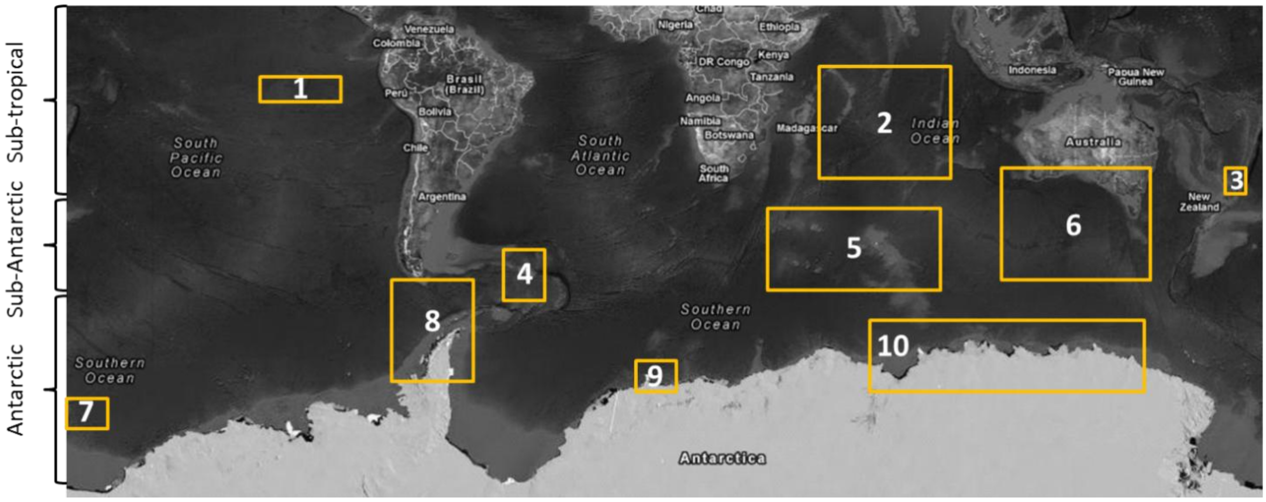


Figure 4. Areas where acoustic records were obtained in the SH.

Table 1. Location, instrument type and status of analysis for blue and fin whale calls from long term acoustic recordings in the SH. Area corresponds to that shown on figure 4.

Area	name	lat	lon	instrument type	depth(m)	SR	Blue whale call analysis		Fin whale call analysis	References
3	NZ	-36,35	179,90	CMR	70	160	1997 VD	Y	1997 visual	McDonald et al 2006
7	RS-AS	-71,40	172,65	ARP	2198	1000	2004 Ishmael	Y	2004 Ishmael	Sirovic et al 2009
1	ETP1	-8,00	95,00	auto hydro	700	100	mix 1996 - 2002 ishmael	Y	x	Stafford et al 2004
1	ETP2	-8,00	110,00	auto hydro	700	100	mix 1996 - 2002 ishmael	Y	x	Stafford et al 2004
8	Drake	-60,50	-61,00	HARUphone	350	250	2006 LTS	Y	2006 LTS	Unpublished data
8	Bransfield5	-62,25	-57,10	HARUphone	350	250	2006 LTS	Y	2006 LTS	Unpublished data
8	Bransfield4	-62,30	-57,90	HARUphone	350	250	2006 LTS	Y	2006 LTS	Unpublished data
8	Bransfield3	-62,53	-58,00	HARUphone	350	250	2006 LTS	Y	2006 LTS	Unpublished data
8	Bransfield2	-62,52	-58,90	HARUphone	350	250	2006 LTS	Y	2006 LTS	Unpublished data
8	Bransfield1	-62,85	-59,46	HARUphone	350	250	2006 LTS	Y	2006 LTS	Unpublished data
8	Bransfield6	-62,92	-60,20	HARUphone	350	1000	2006 LTS	Y	2006 LTS	Unpublished data
8	WAP1	-62,27	-62,17	ARP	1600	500	2002 ishmael	Y	2002 ishmael	Sirovic et al 2004
8	WAP2	-63,84	-67,14	ARP	3000	500	2002 ishmael	Y	2002 ishmael	Sirovic et al 2004
8	WAP3	-64,98	-69,15	ARP	3000	500	2002 ishmael	Y	2002 ishmael	Sirovic et al 2004
8	WAP7	-65,38	-66,14	ARP	450	500	2002 ishmael	Y	2002 ishmael	Sirovic et al 2004
8	WAP4	-65,97	-71,07	ARP	3000	500	2002 ishmael	Y	2002 ishmael	Sirovic et al 2004
8	WAP5	-66,58	-72,69	ARP	3000	500	2002 ishmael	Y	2002 ishmael	Sirovic et al 2004
8	WAP6	-67,14	-74,17	ARP	3000	500	2002 ishmael	Y	2002 ishmael	Sirovic et al 2004
8	WAP9	-67,91	-68,38	ARP	870	500	2002 ishmael	N	2002 ishmael	Sirovic et al 2004
4	Scotia_TP	-53,80	37,94	MARU	300	1000	mix 2006-2007 - VD	Y	mix 2006-2007 - VD	Pangerc 2010 PhD
4	Scotia4	-56,41	-33,93	HARUphone	350	250	2007 LTS	Y	2007 LTS	Unpublished data
4	Scotia3	-57,44	-36,57	HARUphone	350	250	2007 LTS	Y	2007 LTS	Unpublished data
4	Scotia1	-57,52	-41,45	HARUphone	350	250	2007 LTS	Y	2007 LTS	Unpublished data
4	Scotia5	-58,87	-37,00	HARUphone	350	250	2007 LTS	Y	2007 LTS	Unpublished data
4	SS	-60,00	-51,88	ARP	2813	1000	2003 ishmael	Y	2003 ishmael	Sirovic et al 2009
9	AWI 230-6	-66,00	0,00	AURAL	200	32000	x	x	x	Unpublished data
9	AWI 232-9	-68,00	0,00	AURAL	216	32000	x	x	x	Unpublished data
9	PALAOA	-70,31	-8,13	PALAOA	180	32000	2009 3x5min/3j VD	Y	2009 3x5min/3j VD	Van Opzeeland 2010 PhD
2	DGN	-6,30	71,00	CTBT	x	250	2002 ishmael	Y	x	Stafford et al 2004/2010
2	DGS	-7,60	72,50	CTBT	x	250	2002 ishmael	Y	x	Stafford et al 2004/2010
2	MAD	-26,08	58,15	HARUphone	1300	250	2007 XBAT	Y	2007 LTS	Unpublished data
5	NCRO	-41,00	53,17	UBOphone	1100	250	2011 LTS	Y	2011 LTS	Unpublished data
5	WKER	-46,63	60,12	UBOphone	500	250	2011 LTS	Y	x	Unpublished data
5	Crozet	-46,00	51,00	CTBT	300	250	mix 2003-2004 AD	Y	mix 2003-2004 LTS	Samaran et al 2010
2	NEAMS	-31,59	83,23	HARUphone	1200	250	2007 XBAT	Y	2007 LTS	Unpublished data
6	CL	-34,90	-114,10	CTBT	x	250	2002 ishmael	Y	x	Stafford et al 2004/2010
5	SWAMS	-42,98	75,60	HARUphone	1000	250	2007 XBAT	Y	2007 LTS	Unpublished data
6	Curtin 44S	-44,00	144,67	Curtin Acoustic Logger	1866	4000	2006 PSD	Y	x	Gedamke et al, IWC SC/59/SH5
6	Curtin 54S	-53,74	144,77	Curtin Acoustic Logger	1600	4000	2006 PSD	Y	x	Gedamke et al, IWC SC/59/SH5
10	Prydz	-62,59	81,26	ARP	1800	500	mix 2005-2006 ishmael	Y	mix 2005-2006 PSD	Gedamke et al, IWC SC/59/SH5
10	Casey	-63,82	111,75	ARP	3000	500	2004 XBAT	Y	x	Gedamke et al, IWC SC/59/SH5
10	Curtin 64S	-65,55	140,54	Curtin Acoustic Logger	1100	4000	PSD	Y	x	Gedamke et al, IWC SC/59/SH5
10	Kerguelen	-66,21	74,51	ARP	2700	500	2006 XBAT	Y	2006 PSD	Gedamke et al, IWC SC/59/SH5
10	EA	-66,74	69,80	ARP	1321	500	2003 ishmael	Y	2003 ishmael	McKay 2005-Sirovic et al 2009

I.1. Antarctic blue whale calls

Seasonal occurrence of Antarctic blue whale calls at different recording stations in the SH is presented in Figure 5 and in Table 2.

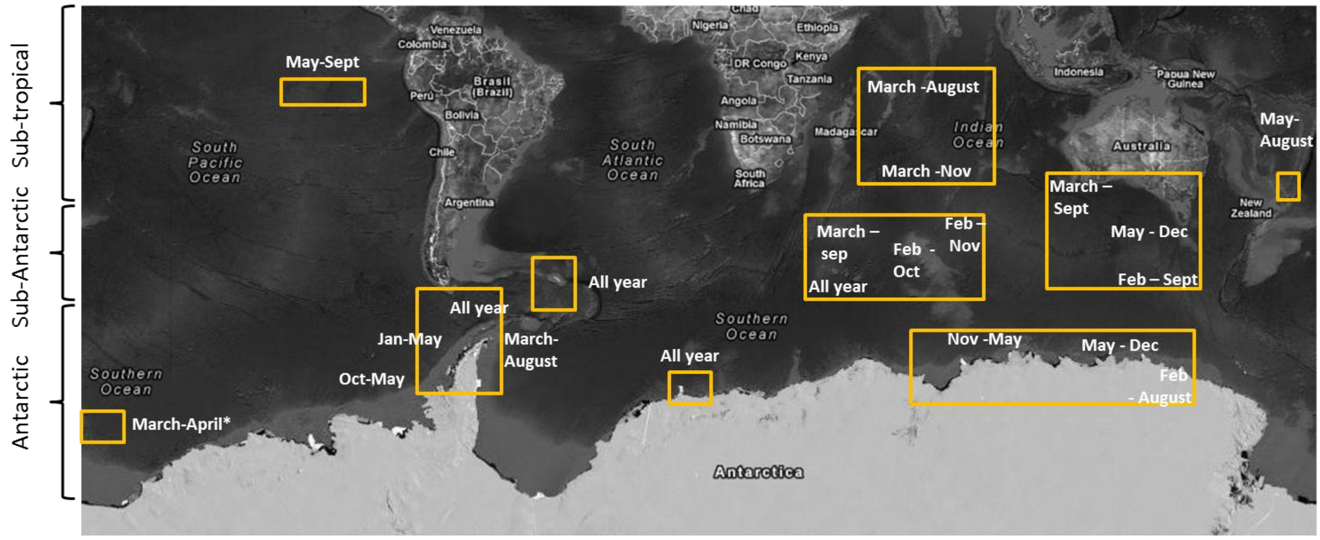
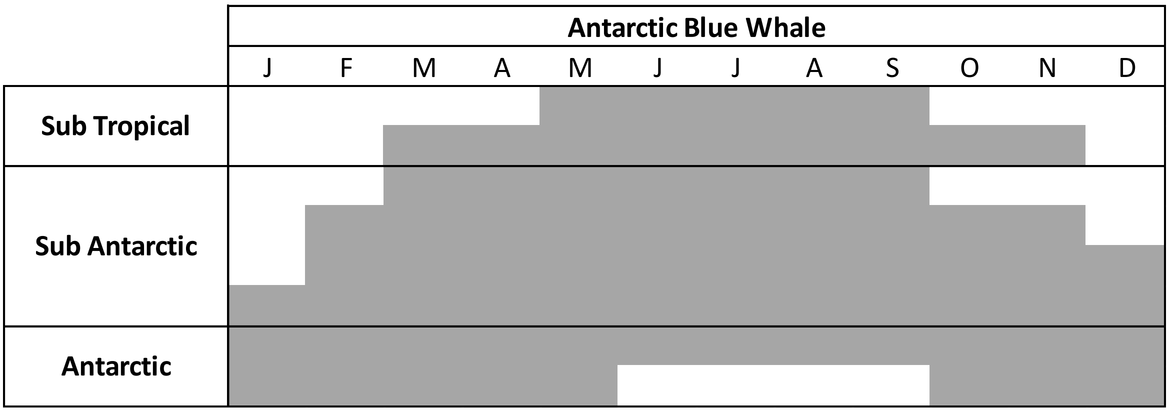


Figure 5. Seasonal occurrence of Antarctic blue whale calls in the SH (* indicates areas without a full year of acoustic coverage).

Table 2. Seasonal occurrence of Antarctic blue whale calls recorded at different latitudes in the SH. Grey indicates months in which calls were recorded.



During winter (May - September), Antarctic blue whales appear to use low-latitudes of the Pacific (east and west) and Indian Oceans concurrently, indicating that there is not a single migratory destination for this species (Stafford *et al.* 2004). There were no instruments in the sub-tropical Atlantic Ocean but the pattern should be the same. Based on these results, there does not appear to be a single wintering destination for Antarctic blue whales. Note that in most of these sub-tropical stations very few calls were detected and during relatively short periods (Stafford *et al.* 2004, McDonald 2006, Samaran *et al.* unpublished data), suggesting that there may be only a few calling animals migrating so far north (Stafford *et al.* 2004).

In the sub-Antarctic, Antarctic blue whales calls have been detected from the end of fall until late spring. Most calls were detected during winter months (Samaran *et al.* unpublished). Antarctic blue whales appear to migrate and stay at these latitudes during winter months. However, Antarctic blue whale calls were recorded year-round at stations located further south (between 45°S and 60°S; Scotia, Drake and Crozet) indicating a continuous presence in these regions. There are two possible explanations for this pattern. First, part of the population may stay in this highly productive area throughout summer feeding months; which contradicts the migration paradigm attributed to this species (Mackintosh 1966, Samaran *et al.* 2010a). Or, on the other hand, the year-round presence of blue whales could indicate a constant migration of animals into and out of the area, possibly due to differential migratory timing depending on sex, age etc. Moreover, the largest number of calls are detected at these stations during late fall and beginning of winter (April to July, Samaran et al 2010b, Mellinger et al 2007, Stafford et al unpublished data) suggesting that most of the population leave the sub-Antarctic during summer to feed in the Antarctic.

Acoustic stations around the Antarctic showed strong seasonal occurrence of blue whale calls during the summer period. Blue whales arrive on this summer feeding ground at the beginning of the winter and leave during spring but this pattern varies with the ice coverage. Indeed, detected calls showed a negative correlation with sea ice concentrations in the Western Antarctic Peninsula suggesting an absence of blue whales in areas covered by sea ice (Širović *et al.* 2004). It is likely that blue whales move north as sea ice forms while some remain close to the ice edge at high latitude year-round, including during winter months. The only acoustic station in the southern part of the Pacific Ocean only worked for a few months. Calls were detected throughout the entire recording period.

I.2. Fin whale calls

Relatively little has been published about the acoustic occurrence of fin whales in the SH. Seasonal occurrence of fin whale calls at different recording stations in the SH is presented in Figure 6 and in Table 3.

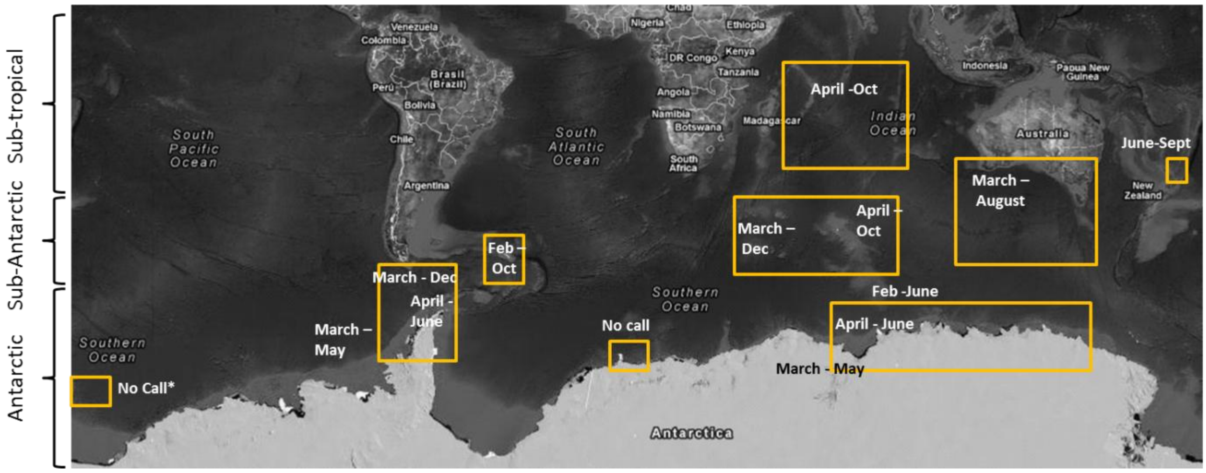


Figure 6. Seasonal occurrence of fin whale calls in the SH (* indicates areas without a full year of acoustic coverage).

Table 3. Seasonal occurrence of fin whale calls recorded at different latitudes in the SH. Grey indicates months in which calls were recorded.

	Fin whale											
	J	F	M	A	M	J	J	A	S	O	N	D
Sub Tropical				■	■	■	■	■	■	■		
Sub Antarctic		■	■	■	■	■	■	■	■	■		
			■	■	■	■	■	■	■	■	■	■
Antarctic			■	■	■	■	■	■	■	■	■	■
		■	■	■	■	■						
				■	■	■						

In the sub-tropical area, the calling activity of fin whales appears highly seasonal, occurring during winter months. This suggests the presence of this species during the breeding period but not during the summer feeding period. However in sub-Antarctic latitudes, fin whale calls are detected year-round except during summer months. As with Antarctic blue whales, latitudes between 45°S and 60°S appear to be an important area for fin whales throughout the whole year. Around the Antarctic, fin whale calls were detected on very few stations, primarily around the Antarctic Peninsula (Širović *et al.* 2004, 2009). Here, fin whale calls occurred during a few months at the end of the summer and into the fall. The absence of calls during summer months means either there are no fin whales or, more likely, that the fin whales are not calling. Fin whales in other high latitude areas such as Gulf of Alaska or the northern Atlantic are present but relatively silent (Stafford *et al.* 2007, Simon *et al.* 2010).

It is worth underscoring that the results discussed above come from different instruments, different time periods and different analysis methods. In order to best exploit the advantages of passive acoustic methodology for monitoring blue and fin whales in the SH, a coordinated effort needs to be undertaken. This includes standardizing instruments and analysis tools used for recordings made during the same time periods.

I.3. An example of long term monitoring of Antarctic blue whale calls

The only long-term data for Antarctic blue whale calls comes from a Comprehensive Test Ban Treaty Organization site off Western Australia, Cape Leeuwin. Acoustic data have been collected from this location since 2002. Although this region is well north of the Antarctic (at latitude 34 S) Antarctic blue whales have been recorded here (Stafford *et al.* 2004). As an initial test of the use of acoustic data to examine changes over time in call detections, a detector for the 28 Hz calls of Antarctic blue whales was run on 8.5 years of data (from 2002-mid 2010). We used the template detector in Xbat (which uses spectrogram correlation) with the correlation threshold set at 0.25. This resulted in very few false positives and very few missed calls for loud and medium amplitude calls but faint calls were often missed. Nevertheless, if the question of interest is whether the number of calls (or animals in the vicinity of the hydrophone) stays the same over time then a comparison of the number of similarly loud calls is adequate.

The number of Antarctic blue whales detected is shown in Figure 7. There was a great deal of interannual variation, and 2008 had an anomalously high number of detected calls. Tables 4 and 5 show the number of days per month with calls and the number of calls per month, respectively. With the exception of February, calls were recorded in all months of the year but there was an overall seasonal pattern to the call detections with most calls in winter (Figure 8). Overall there were very few calls detected per year, in comparison to Širović *et al.* (2004) and Samaran *et al.* (2010a) for instance.

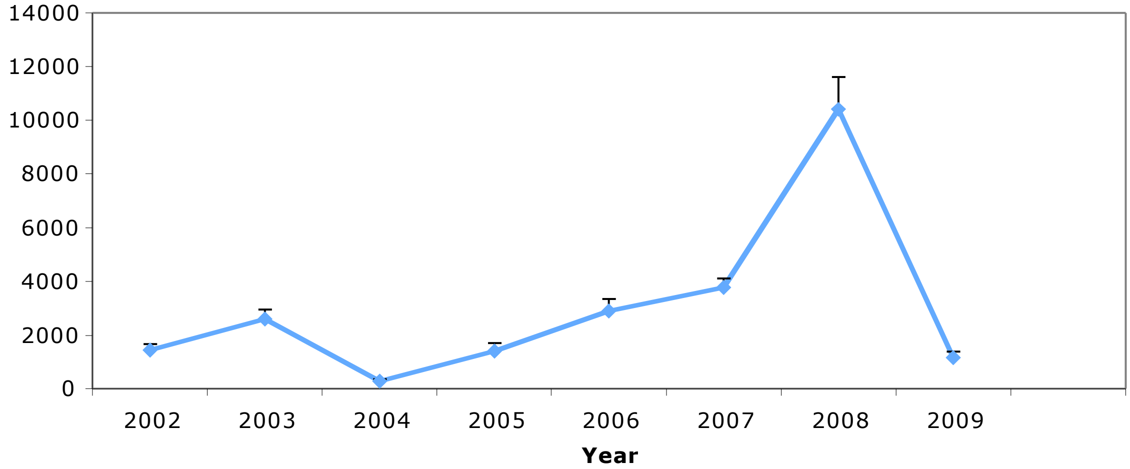


Figure 7. Number of 28 Hz calls by year detected at Cape Leeuwin. y axis is the total number of calls.

Table. 4 Number of days per year by month with Antarctic blue whale call detections (**missing data)

	2002	2003	2004	2005	2006	2007	2008	2009	2010	sum	mean
Jan	0	0	0	0	0	0	0	1	2	3	0.3
Feb	0	0	0	0	0	2	1	19	7	29	3.2
Mar	0	0	0	0	0	11	16	21	7	55	6.1
Apr	1	0	0	0	4	15	24	15	24	83	9.2
May	5	9	2	0	7	20	29	22	27	121	13.4
Jun	12	16	10	3	18	17	24	15	14	129	14.3
Jul	4	17	11	12	26	12	**	8	**	90	12.9
Aug	2	17	11	12	17	17	10	0	**	86	10.8

Sep	10	12	0	11	14	15	24	0	**	86	10.8
Oct	10	0	0	4	17	17	19	0	**	67	8.4
Nov	3	0	0	0	14	3	25	0	**	45	5.6
Dec	0	0	0	0	4	0	2	0	**	6	0.8

Table 5. Number of Antarctic blue whale call detections by year and month 2002-2010 (missing data)

	2002	2003	2004	2005	2006	2007	2008	2009	2010	Sum	Mean
Jan	0	0	0	0	0	0	0	1	32	33	3.7
Feb	0	0	0	0	0	0	0	0	0	0	0.0
Mar	0	0	0	0	0	434	641	767	33	1875	208.3
Apr	0	0	0	0	70	414	3192	72	191	3940	437.8
May	509	919	6	0	48	1032	2292	244	247	5297	588.6
Jun	181	317	221	6	569	861	2860	73	1419	6507	723.0
Jul	671	920	27	202	1578	303	**	22	**	3723	531.9
Aug	3	402	31	1080	184	347	78	0	**	2125	265.6
Sep	54	41	0	104	98	224	321	0	**	842	105.3
Oct	16	0	0	16	183	163	270	0	**	648	81.0
Nov	18	0	0	0	144	6	738	0	**	906	113.3
Dec	0	0	0	0	24	0	12	0	**	36	4.5

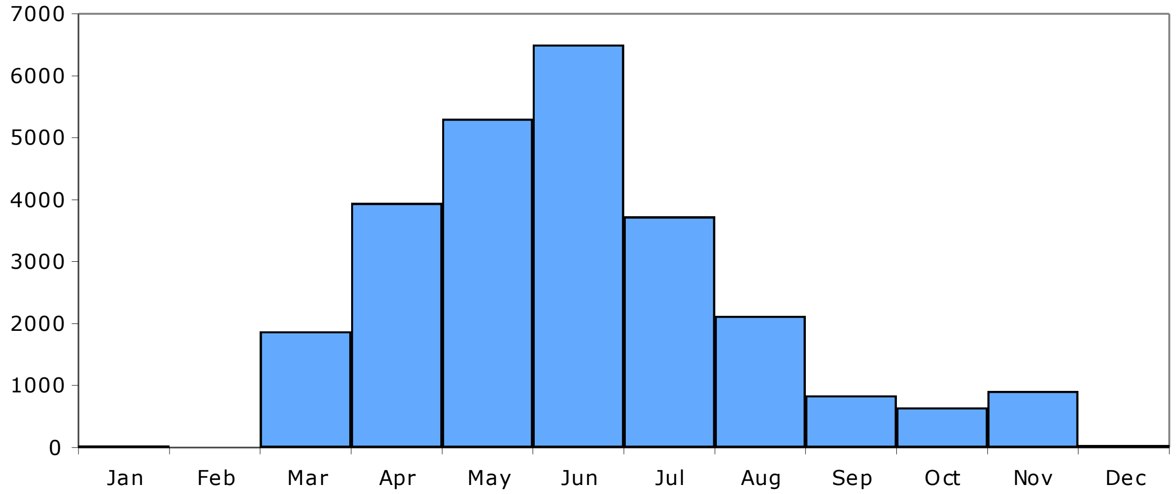


Figure 8. Total number of Antarctic blue whale calls by month detected at Cape Leeuwin, 2002-2009.

II - Current and future PAM in Antarctic waters

II.1 – Current PAM in Antarctic waters

At present the only ongoing passive acoustic monitoring effort in Antarctic waters is being undertaken by the Alfred Wegener Institute (AWI), Germany. The effort consists of the PALAOA research station that monitors under the Ekstrom ice shelf and transmits broad-band passive acoustic data in near real-time to AWI (http://www.awi.de/en/news/background/palaoa_what_does_the_southern_ocean_sound_like/livestream/). The station will be maintained indefinitely thereby providing long-term data by which blue and fin whales populations can be monitored acoustically. In addition to PALAOA, AWI has 13 oceanographic moorings on which hydrophone packages have been, and will continue to be, deployed (Figure 9).

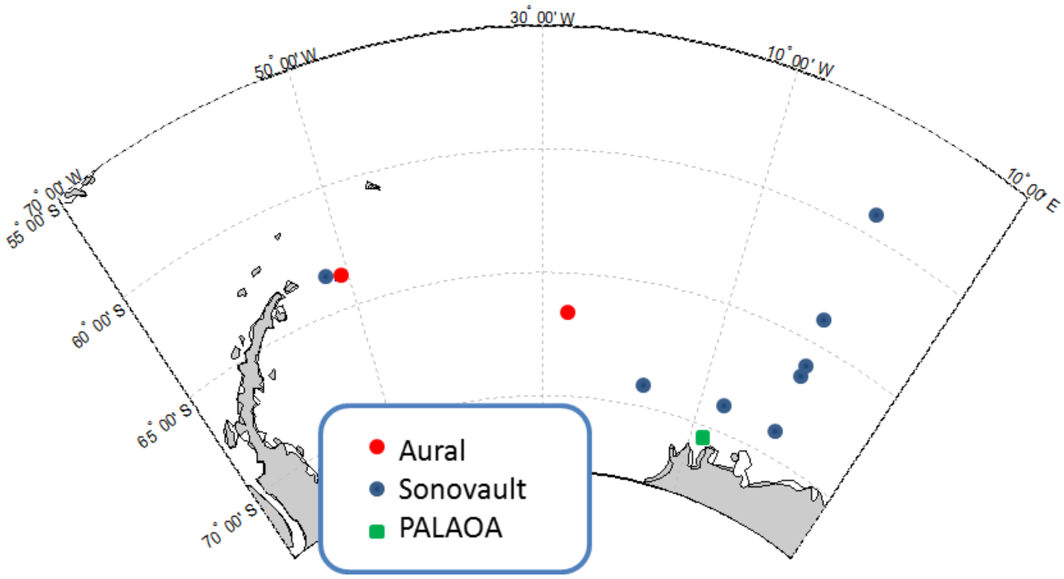


Figure 9. Current ten recorder positions of AWI in Antarctic waters and the position of PALAOA station. Three additional PAM recorders will be deployed late 2012/ early 2013 (recorder positions not included in the figure).

The South African National Antarctic Program has recently funded a 2 year-effort to deploy hydrophones in the Southern Ocean. These instruments will be deployed in late 2012/early 2013.

II.2 - Possible future deployments

Ideally, in order to monitor blue and fin whales in Antarctic waters, a necklace of dozens of hydrophones would be deployed randomly around the Antarctic and serviced annually. Logistically, however, such a plan would require dedicated ship and personnel time which are unlikely to be available. Instead, hydrophones should be placed in areas that are served annually by national Antarctic programs and/or on extant oceanographic moorings as one of a suite of instruments. If the former, the instrument needs to be able to be deployed and retrieved easily; if the latter, it needs to be designed to fit into a mooring. The Australian Antarctic Division is in the process of testing a stand-alone acoustic recorder that may be made available in the near future for exactly this purpose (Miller *et al.* 2012). Whenever possible, it is recommended that the hydrophone package be integrated into long term oceanographic moorings to best assure that the instruments are retrieved. Figure 10 shows locations of stations visited annually by different national Antarctic programs that have been contacted and expressed interest in deploying hydrophones either as stand-alone deployments or as part of extant moorings. Most of these bases are serviced annually by ship generally from four main ports: Cape Town, South Africa, Ushuaia, Argentina, Punta Arenas, Chile, and Hobart, Tasmania. Ideally, hydrophones would be deployed quasi-continuously at each of these sites, during the same time period so that simultaneous passive acoustic data from around the Antarctic might be obtained. The gaps in coverage in Areas I and VI (Bellingshausen and Amundsen Seas) are partly due to a lack of any bases in these regions therefore ships do not necessarily sail these waters regularly. Fewer blue whales were caught in these regions than in others (Branch *et al.* 2007) but this does not diminish the need to acoustically monitor these regions.

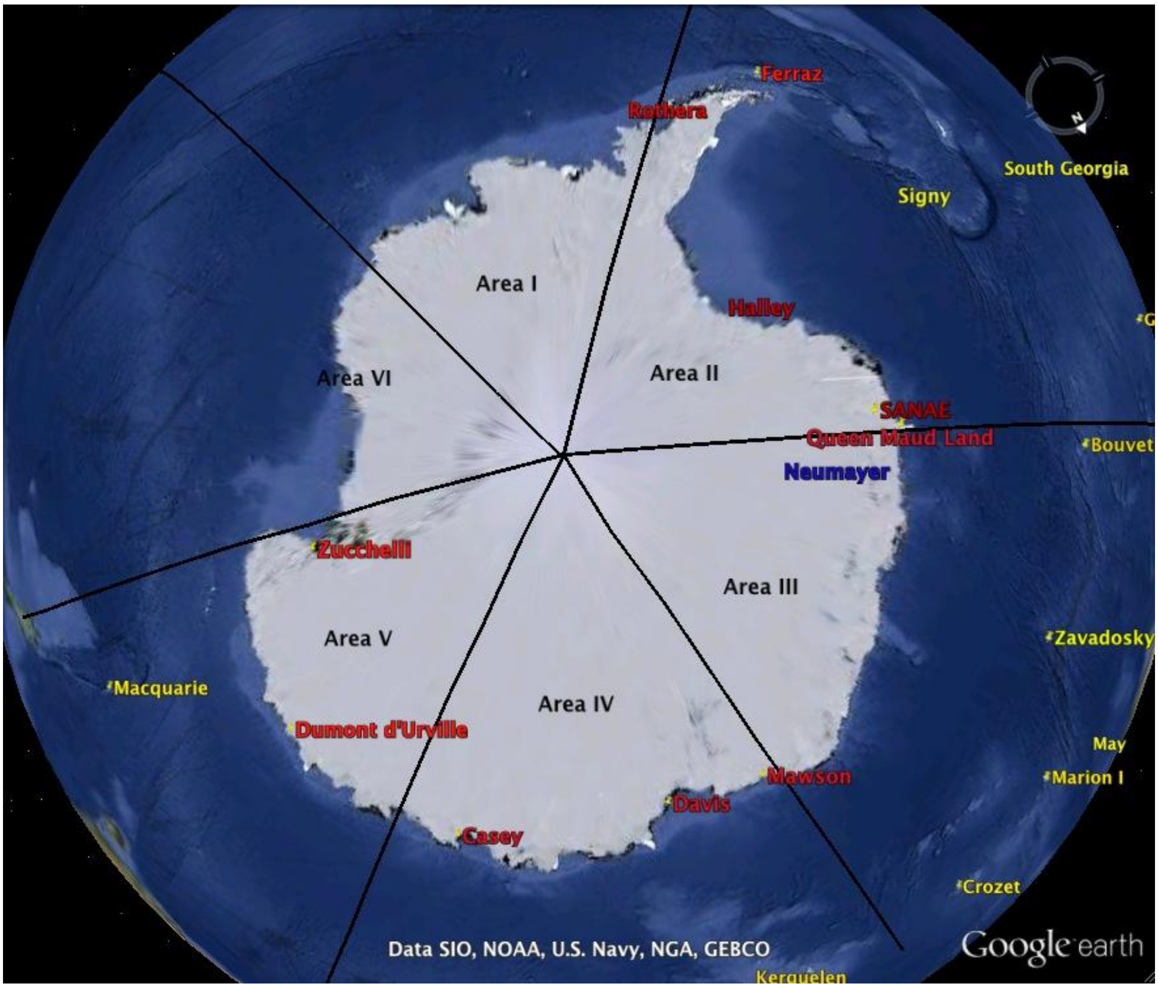


Figure 10. Locations of bases serviced annually by ship for which the possibility of deploying hydrophones has been broached. Antarctic bases in red, sub-Antarctic in yellow and Neumayer (PALAOA – current long term monitoring occurring here) in blue.

III – Acoustic analysis methods for blue and fin whale calls.

The acquisition of a year's worth of acoustic data, even when sampled at relatively low rates results in hundreds of gigabytes, if not terabytes of data. It is therefore impractical to analyze all of the data in real time. How to process terabytes of acoustic data efficiently has been the subject of many efforts in the past twenty years and has resulted in a robust body of literature on automatic detection methods (*cf* Mellinger and Clark 1996; 2000; 2006; Mellinger *et al.* 2011; Baumgartner and Mussoline 2011; Thode *et al.* 2012). The best tool, however, depends largely on the scientific question of interest and the time-frequency characteristics of the signal of interest. Most blue and fin whale calls, for example, are highly stereotyped, simple, and repetitive and therefore are good candidates for many automatic detection methods. It is more difficult to design and assess detectors for species that produce many, variable, calls, such as, for instance, humpback whales. The automatic detection of blue and fin whale calls can, however, present challenges. For instance, fin whales can produce 20 Hz pulses every 20-40 s resulting in, potentially, millions of detections over a year that can be laborious to quality control or even analyze. Antarctic blue whale signals are relatively long and tonal so the signals from multiple whales can overlap resulting in a detection being rejected (if it is too long, for instance) or not being counted because the detector did not distinguish between two overlapping signals. Further, the stereotypy of both blue and fin whale calls make it difficult to assign different calls to different individuals. In general, the temporal pattern of repeated calls is used to determine the minimum number of animals present during a certain period of time (*cf* Stafford *et al.* 2010) but this can generally only distinguish up to ~4 individuals at best. Finally, in almost every ocean in the world, including the Southern Ocean, blue and fin whale calls overlap in the frequency band used by these two species. In the Antarctic, however, there is a high frequency pulse that is often (but not always) associated with fin whale 20 Hz pulses; this appears to vary geographically, and is usually well above the frequency band of typical blue and fin whale calls (Širović *et al.* 2009; Gedamke 2009; Gedamke and Robinson 2010).

III.1 - Long Term Spectrogram (LTS) Analysis

This method is the preliminary means to assess the broad scale presence or absence of different species of calling whales in a long term recordings. Spectrograms for one year of data (or more) are produced (for example using 1 sample / 5 min and 1 sample / 0,125 Hz) to illustrate the seasonal bands of acoustic energy that clearly rise above background noise. Intense (loud) segments can be closely examined to determine the sound sources and the months of occurrence. Sound sources are determined by their frequency bands. Frequency band around 18-28 Hz is commonly used as the frequency band of Antarctic blue whale calls. Frequency band around 89 or 99 Hz are commonly used as the frequency band of fin whale calls.

The overlap between frequency bands of blue, fin and pygmy blue whale (*B.m. brevicauda*) or noise can confound the ability to distinguish between blue and fin whales. Moreover, a higher intensity in a specific frequency band could indicate either that calls were produced by many animals far from the recording station or by few animals very close to the station. Nevertheless, as a first step, LTS presents a quick way to display lots of data and to have a rough idea of what sound sources are present, the overall quality of the recordings and to determine which other tools can be applied for more detailed analysis.

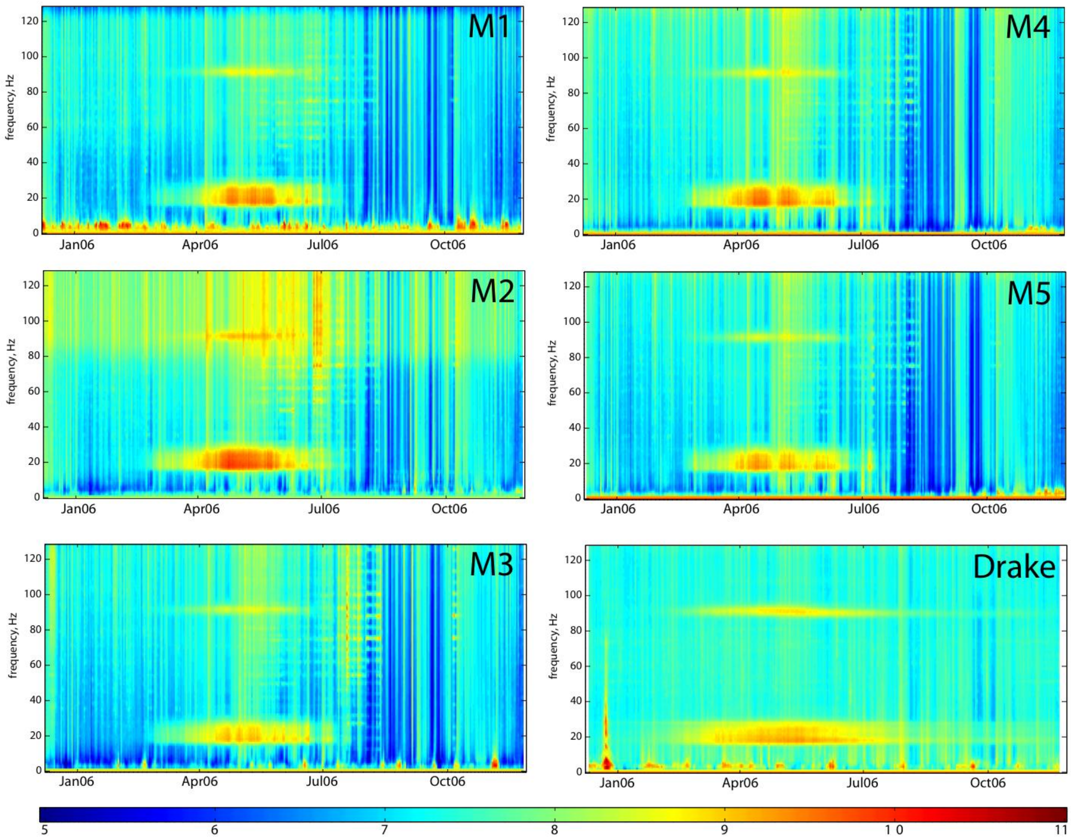


Figure 41. Long term spectrograms from 6 hydrophones in the Bransfield Strait and Drake Passage for 2006. Fin whale presence is clearly seen as the band of energy at ~89 Hz while blue whale and fin whales appear in the band from 30-15 Hz.

III.2 - Power Spectral Density (PSD) Analysis

This method is another preliminary means to assess the broad scale presence or absence of calling whales in long term recordings. Recordings are analyzed by comparing the acoustic power in the frequency bands characteristic for whale calls to the acoustic power of adjacent frequency bands (Širović *et al.* 2004). The PSD is calculated for periods of interest from days to years and averaged over 15 minute samples using the Pwelch function in Matlab 7.1 (www.mathworks.com). The one –day or one-week averages of the ratios are calculated to plot relative changes in PSD ratios with time over the recording period.

For Antarctic blue whales power at 28 Hz is commonly used as the calling band and it is compared to powers at surrounding frequencies (e.g. 15 Hz and 41 Hz ; Širović *et al.* 2004). For fin whales, to avoid overlap with blue whale calls, the higher frequency component of the call is commonly used as the calling bands. Powers at 89 Hz or 99 Hz are used and it is compared to powers at 80 / 98 Hz or 90 / 108 Hz noise (Širović *et al.* 2009, Gedamke 2009).

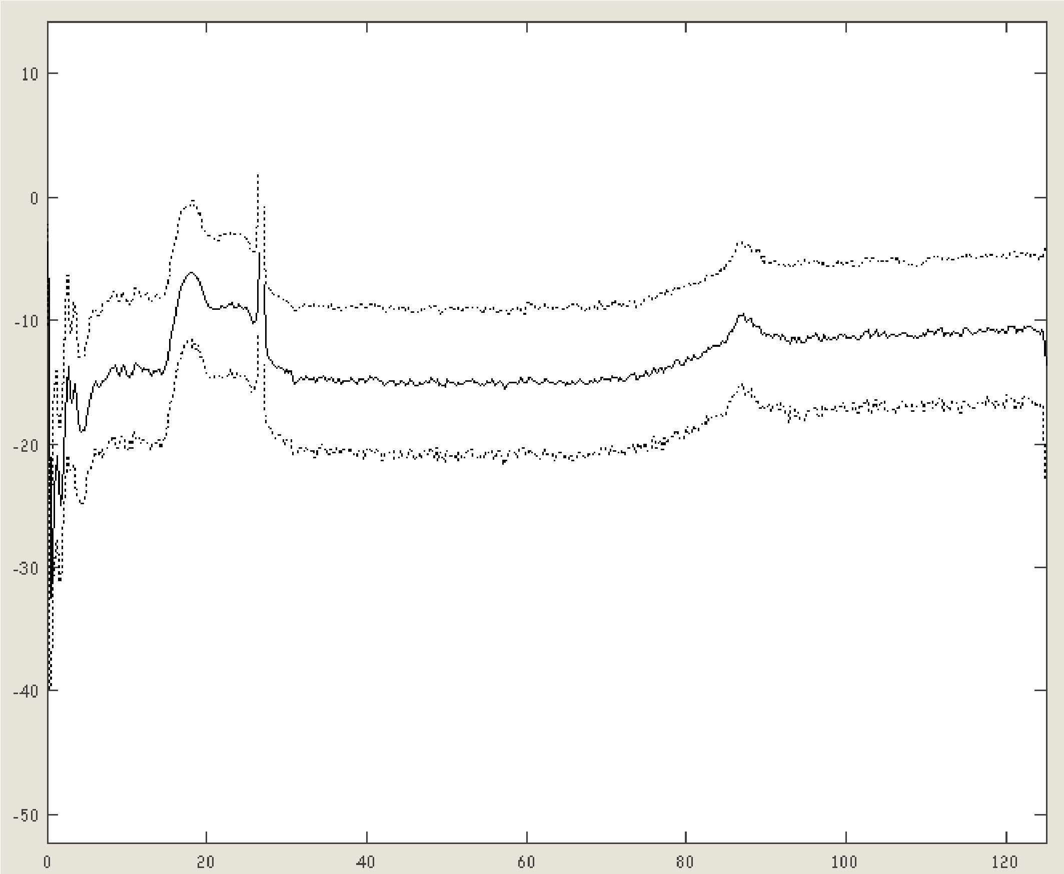


Figure 15. PSD from data recorded near Scotia Sea in June 2008. Antarctic blue whale contribution to the noise levels at 28 and 19 Hz as well as fin whale 89 Hz pulses can be seen.

However, this method includes some assumptions. That is, there is not contribution from calling whales in the two adjacent frequency bands that are used to compare the power in the whale call frequency band. This assumption may be violated in the Southern Ocean in that pygmy blue whales produce calls in various low frequency bands including the 20-40 Hz bands (Samaran *et al.* 2010a, Stafford *et al.* 2010) that could overlap Antarctic blue and fin whale calling bands and/or the adjacent frequency bands. At frequencies around the whale call, noise is presumed to be constant. The PSD ratio is entirely ambient noise dependent and difference in ambient noise within a year at the same location or between different locations made the comparison of the results difficult (Gedamke *et al.* 2007 and 2009). Moreover, the chosen frequencies which characterize the calling band or the noise band are usually calculated in 1 Hz bands centered around the loudest or most stereotyped part of the whale call. As with LTS analysis, a higher ratio could indicate either calls were produced by many animals far from the recording station or by few animals very close to the stations. However, PSDs show a generally similar pattern of seasonal variation as the automatic call detection (Širović *et al.*, 2004).

Recent modification of this method has been applied to fin whale 20 Hz calls in the North Atlantic in which the authors accounted for changes in time-varying ambient noise and excluded blue whale calls (Nieukirk et al

2012). This revised method may work well for fin whales around the Antarctic and a comparison of the 20 Hz "fin index" with the same index for the higher frequency pulses to determine which method is more robust.

III.3 - Automatic detection via spectrogram correlation

Automatic detection is, as the name indicates, a method of pulling out the signal of interest from large data sets. This method uses software that works in the frequency or time domain and compares a long term dataset with a "template" designed to mimic the call of interest. Many methods have been developed and tested and most are based on detection either in a time series or in spectrogram (Mellinger *et al.*, 2007).

The most commonly used frequency domain detectors for blue and fin whales use spectrogram correlation, including *Ishmael* (Mellinger and Clark 2000; Mellinger, 2001) or the eXtensible BioAcoustic Tool (*Xbat*; Figueroa 2006) a custom designed MATLAB program. The data set spectrogram is cross correlated with an artificial kernel that represents a whale call. The number of detected calls is pooled by day, month or year to show the occurrence of the whale species at the station (e.g. Figure 7 and 8).

- *Ishmael:* To build the kernel of a specific call, frequency contours and durations that matched average characteristics of the whale calls are specified by the user in the software (e.g. a 9s long 27.7 Hz tone, a 1 s long frequency decrease from 28 to 19.5 Hz and a 10 s long tone that decrease at 18.8 Hz for the Antarctic blue whale call, Stafford *et al.*, 2004). Spectrogram noise equalization with a time constant longer than the signal of interest (e.g. 40s) is employed to eliminate continuous interfering tones such as ship noise. The user sets a detection threshold above which signals are considered detections. Anything below the threshold is rejected. Detected calls are saved as individual sound files, along with the information on the day and time when the call occurred. These files, the detections, are then checked for accuracy. At present, *Ishmael* can only detect on signal at a time.

- *Xbat: This program uses as a* kernel a short spectrogram or "clip" of the signal of interest. Information on date, time and correlation coefficient of detected calls are saved in a matlab array and can be extracted as *.csv files. *Xbat* allows different call types to be detected at the same time and allows the user to scroll back and forth through the data to check the accuracy of detections. Figure 13 shows an example of Antarctic blue whale call detections.

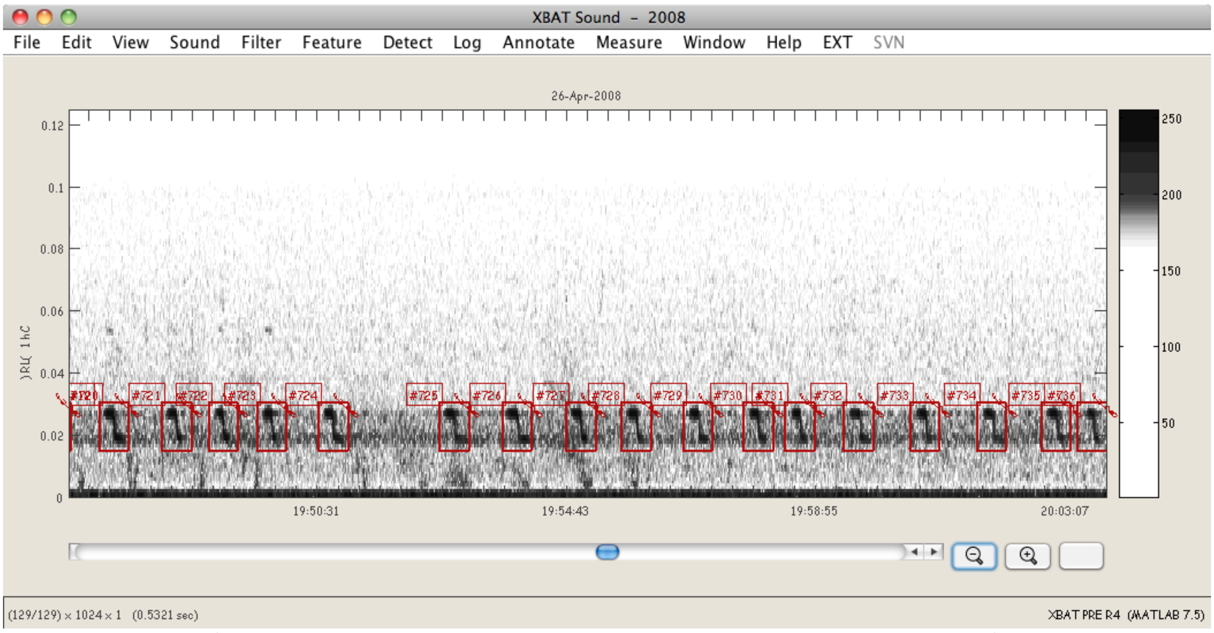


Figure 13. An example of Antarctic blue whale call detections where the calls were very loud and the detection rate for this series was 100%.

In both *Ishmael* and *Xbat*, the detection threshold is often set high to minimize false detections (Širović *et al.* 2004); if the interest is in detecting as many calls as possible, the threshold may be set lower but this will increase the rate of false detections (signals that are not those of interest but that may share some similarities) (Stafford *et al.* 2004). A high detection threshold means calls with low signal-to-noise ratios will be missed, especially faint calls underestimates the total number of calls recorded. A low detection threshold can overestimate the number of the calls recorded. In long-term datasets it may be overly time-consuming to double check ALL the detections therefore understanding the performance of the detector is important. Some percentage (10%-20%) of the detections should be manually checked to determine the number of false positives and missed calls in the data set. Further, some subset of time periods where no calls were detected should be checked to establish the rate of missed calls, which is often due to increases in ambient noise levels. Finally, the choice of the threshold can determine the detection range of calls from the instrument.

Overall, spectrogram correlation works well for detecting loud or medium amplitude the Antarctic blue whale calls and has been widely used (see Table 1, Stafford *et al.* 2004, Širović *et al.* 2004, 2009). However works less well when Antarctic blue whale calls are very dense in the dataset, either due to overlap between calls (as in PALAOA dataset) or because the instrument was in the sound channel and calls from distant animals increased "noise" in the frequency band of interest. Spectrogram correlation has also been used for fin whale calls but, as noted above, the great number of these produced can quickly overwhelm both human observers and computing systems.

III.4 - Detection and classification system

A newer detection methodology, the detection classification system (DCS; Baumgartner *and* Mussoline 2011) has recently been developed that operates on spectrograms to identify low-frequency narrowband calls. Rather than using a template matching system (as in spectrogram correlation above), the DCS scans noise-adjusted spectrograms for signals that exceed a user-set threshold in dB. The DCS draws contours of continuous signals that exceed this threshold and compares them to a library of pre-analyzed signals and performs a statistical analysis to determine the similarity of the detected call to the library and assigns the detection an call identity. The promise of this methodology is detecting and classifying many different sound types from different species all at the same time. Further, detailed statistics on the detected and classified calls are presented. In order to test the feasibility of using it to detect both blue and fin whale calls with the same methodology, it was used on data collected from several locations around the Antarctic.

Because it is less well known, more detail on the methodology is presented here than would be for a general review of the method. The DCS first accounts for persistent narrowband and transient broadband noise and then characterizes the temporal variation of dominant call frequencies via pitch-tracking. Once identified, several attributes (e.g. start frequency, end frequency, frequency range, duration, slope of frequency variation) that characterize the narrowband sound are extracted, and quadratic discriminant function analysis (QDFA) is performed to classify the sound. QDFA assesses to which call type an unknown call belongs using two quantities: (1) the relative posterior probability of membership and (2) the Mahalanobis distance (MD). The call type with the highest relative posterior probability of membership is considered the call type to which the unknown call belongs, and MD indicates how closely the attributes of the unknown call match the mean vector of a call type.

Spectrograms were created from acoustic recordings using the short time Fourier transform. The power spectrum for each spectrogram frame was computed using the fast Fourier transform (FFT) and a Hann window, and the resulting spectrogram was smoothed with a 3×3 smoothing operator. The spectrograms were produced from audio data originally sampled at 500 Hz. The FFT frame size was 256 samples and the overlap between frames was 50 samples (80.47%), resulting in a temporal resolution of 0.100 s and a frequency resolution of 1.95 Hz.

Exemplars for blue whale 28-Hz call (3 call types; n = 300), blue whale D call (2 call types; n = 659), and fin whale 20-Hz call (1 call type; n = 277) were manually extracted from recordings collected from Casey. Pitch tracks were generated for all calls in this dataset, and calls that were clearly audible and accurately pitch tracked were selected as exemplars. Noted above, more than one call type was used to build the blue whale exemplars in an effort to capture any variation present. For example, the blue whale 28-Hz call exemplar is comprised of 3 call types: (1) 28-Hz tone, (2) 28-Hz long tone with ending downsweep, and (3) 28-Hz tone with very short downsweep at end. The addition of new call types to the call library is trivial and the QDFA can then use these new call types to improve classification accuracy.

The DCS was evaluated using recordings collected from Kerguelen and Prydz Bay. For practical reasons, we were unable to evaluate the DCS for Casey with an independent dataset (i.e. we did not have at our disposal a second dataset with plentiful blue whale calls). A single analyst manually reviewed the first 100 automated detections for each call type for specific sets of amplitudes (8 – 10 dB, 10 – 12 dB, and > 12 dB) starting at 00:00:00 local time on 01/01/05 and again on 01/01/06 for a total of 600 classifications per call type (i.e. 100 '8 – 10 dB' blue D calls, 100 '10 – 12 dB' blue D calls, and 100 '> 12 dB' blue D calls for both 2005 *and* 2006). The start of each year was chosen for consistency and two years were chosen to capture any variation present. Finally, all calls were aurally and visually reviewed to confirm call type.

False detection rates are reported as the percentage of automatically detected and classified calls that were subsequently identified as incorrect by the analyst for specific sets of amplitudes (8 – 10 dB, 10 – 12 dB, and > 12 dB) and Mahalanobis distances (0.0 – 5.0). The performance of the DCS will vary with the selection of the MD threshold (Figure 15). In applications requiring as many calls to be detected as possible, a higher MD threshold may be warranted, and manual verification of every automated detection may be helpful to lower the false detection rate. However, in applications where the best evidence of call presence over a specified time period is desired, a lower MD threshold may be warranted, resulting in a lower false detection rate (i.e. only calls are reported for which the DCS has high confidence).

The false detection rates are low for blue D calls at Prydz with low MD and high amplitude calls, though are 100% at Kerguelen. The false detection rates are also low for blue 28-Hz calls at both Prydz and Kerguelen, though are irrespective of the amplitude of the call. Finally, the false detection rates are decent for fin 20-Hz calls with low MD and high amplitude calls, though again, are 100% at Kerguelen. The higher false detection rates for lower amplitude blue D calls and fin 20-Hz calls at Prydz and lower amplitude blue 28-Hz calls at Kerguelen demonstrate that an analyst can correctly classify calls at a much lower SNR than our automated procedure. As for the 100% false detection rates for blue D calls and fin-20 Hz calls at Kerguelen, further investigation is required.

Missed call rates were partially evaluated and therefore are not reported here. This evaluation requires a comparison of autodetections with calls detected and classified during an independent manual review. This review, however, becomes challenging with low calling rates as it is difficult to manually detect and classify enough calls required for an effective evaluation. Furthermore, as our procedure currently stands, amplitudes cannot be extracted from the manually detected calls. And while we assume missed call rates will increase with the presence of fainter calls and decrease with the presence of louder calls, we have yet a way to represent this with numbers. The ability to add pitch tracks to a manual detection will soon be incorporated, thus allowing us to compare amplitudes extracted from the DCS and analyst's pitch tracks. Missed call rates can be reported at that time.

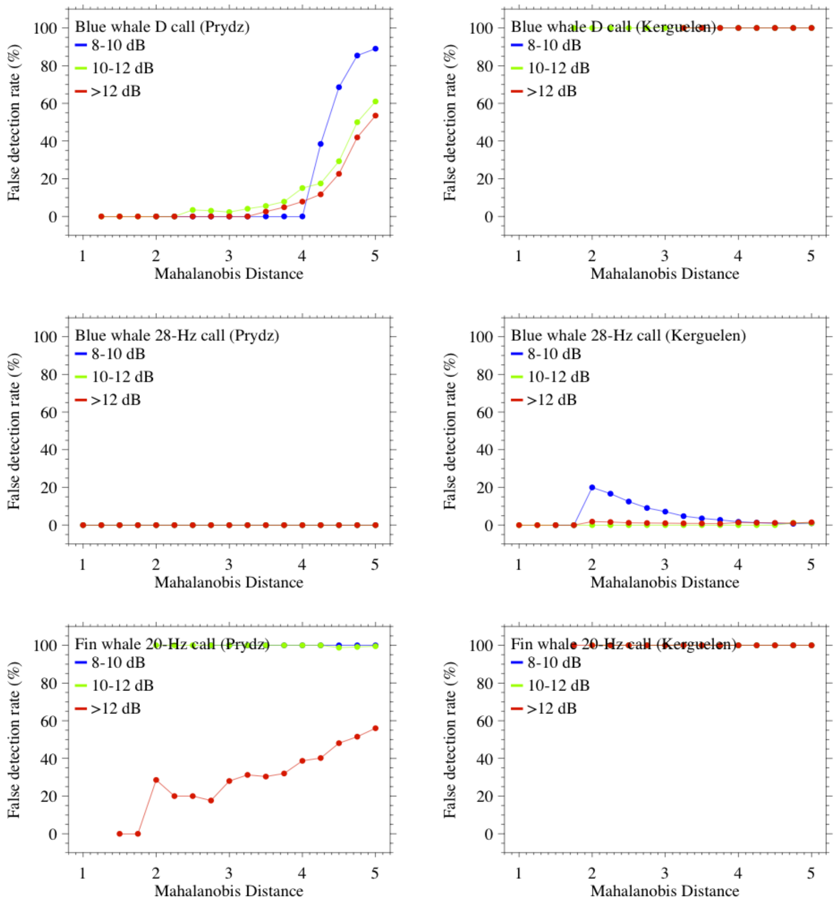


Figure 15. Performance of the DCS with varying Mahalanobis distance thresholds and amplitudes for blue whale D calls, blue whale 28-Hz calls, and fin whale 20-Hz calls for Prydz and Kerguelen sites.

IV - A review of methods for estimating relative abundance from passive acoustic sensors

> *"Population density estimation based on passive acoustics is in its infancy. However, the approach looks promising."* (Küsel *et al.* 2011).

Determining the geographic and seasonal presence of marine mammals by use of passive acoustic monitoring (PAM) has become commonplace. Acoustic data have several advantages over traditional means of monitoring marine mammals via visual surveys; acoustic data can be collected 24 hours a day throughout an entire year (or longer), signals can be heard over much greater ranges than animals can be seen; data can be collected in poor weather conditions or under ice. This allows animals to be monitored in regions and times that are not feasible (logistically or financially) otherwise. The biggest constraint of PAM is that it consists of presence-only data, that is, only animals that vocalize are detected. Silent animals are not accounted for. For odontocetes, this problem is somewhat overcome because they are obligate sound producers (they use echolocation clicks to navigate and find food and are seldom silent). Baleen whales, on the other hand, do not always produce sounds. Further, there is little information available as to *who* is producing the sounds (i.e. only males? Only mature animals?), the behavioral contexts in which certain sounds are produced (i.e. traveling? Feeding? Displaying?) and whether sounds are produced year-round (among other constraints). Nevertheless, long-term PAM may be the best way at present to monitor these species in the Southern Ocean. While information on when and where whales are heard is useful in providing seasonal and geographic presence, the ability to determine *how many* individuals are in an area, is more useful for population monitoring and management. In the past five years, great strides have been made in applying the methods for visual-based abundance estimates to passive acoustic data. These methods are reviewed below in order to evaluate how passive acoustic detection data can be used to estimate relative abundance and/or trend data for Antarctic blue and fin whales**.**

An assessment of the number of Antarctic blue or fin whale *calls* recorded at one on more stations can provide an estimate of the *acoustic density* of calls of these species. i.e. the number of detected sounds emitted by some unknown number of calling animals is known. With these data it can be possible to map where and when the sounds were recorded and analyze the trend of this acoustic density year by year. Passive acoustic data have been used to infer relative increases in abundance of calling whales in the North Pacific and North Atlantic Oceans. In the North Pacific, analysis of the number of blue and fin whale call events was used to examine population trends in acoustic data over six years. During that time the number of fin whale events increased significantly in all four regions monitored while the number of blue whale call events increased in four of six regions (Stafford *et al.* 2009). During a ten year study of fin whale calls in the North Atlantic, the index of fin whale calling increased significantly over time at a site in the subtropical North Atlantic (Nieukirk et al, 2012). In neither of these studies is it known definitively that there are more fin or blue whales in these regions but the relative index of acoustic activity supports the hypothesis that greater call events or increased acoustic energy in the fin whale band is the result of more vocal animals.

Estimating the density or abundance of individual whales, versus acoustic activity, is more complicated but is fundamental to assessing the status of conservation and obtaining rates of population growth or decline in a population because these methods can provide estimates of the *number of individuals* in a specific area. Any estimate of abundance, be it visual- or acoustic-based, requires knowledge of how the environment and behavior of animals affects detection probabilities. Environmental information needed includes: the type of recording instruments (frequency response and sensitivity of the hydrophone and recording system); the depth of the instrument (on the seafloor or in the water column); ambient noise levels in the area (and ideally how they change over time); the physical properties of the water column (particularly sound speed profiles) that determine how sound propagates. These are all data that can be relatively easy to obtain. Behavioral information, on the other hand, is considerably more difficult. This includes, but is not limited to: what percentage of animals in a given region produce sound; what is the call rate per sound-producing individual; how does call rate change with behavioral state and season; how loud are calls; at what depth are they produced.

In an ideal world, all of these parameters (or the ranges associated with them) would be known, but in the real world, this is seldom the case. Therefore, numerous methodologies have been developed to determine the probability of detection of a signal and use this to estimate the relative abundance of a species in a given area. The utility of these methods relies on the detection effectiveness, characterized by the probability of detection, and the probability of false alarm relation to the signal to noise ratio. The probability of detection can be predicted using accepted, but not necessarily accurate, models of the underwater acoustic environment (Ward *et al. in press*). The DeCAF project (Density Estimation for Cetaceans from passive Acoustic Fixed sensors; http://www.creem.st-and.ac.uk/decaf/) has made great strides in developing and exploring different methodologies for population estimation using passive acoustics. Some of these are reviewed below.

At least four methods have been proposed for estimating cetacean density using passive acoustics: 1) from individual acoustic signature, 2) estimating the position of vocal animals relative to the receiver (hydrophone), 3) using *distance sampling* methodology and 4) using the distribution of the detected cetacean sounds. The last two are the most promising.

IV.1 - Individually identifiable sounds (signature calls)

If each emitted sound can be assigned to the individual who emitted it, then it is relatively simple to count the number of animals present in an area at a given time. There are some studies that have looked at signature calls for individuals in a group (Brown *et al.* 2010, Lopez-Rivas and Bazua-Duran 2010, Zaugg et al 2010). This approach has primarily been used with odontocetes whose population structure is relatively well known. Extracting individually identifiable features that remain stable over time in vocalizations or clicks is extremely difficult, even for animals in captivity. Individual signatures, even if it is possible to define it for certain terrestrial mammals, is not easy to extract from sounds emitted by cetaceans and up to now, this method has not been used to estimate the density of calling animals. If the specific ‘speaker’ cannot be identified, another solution is to identify specific sounds, and to use a Capture/ Recapture approach. This technique is well known for applications on visual observations and a version was proposed for application to acoustic observations of birds but not yet to cetacean sounds (Dawson and Efford 2009).

IV.2 - Localization techniques

If different individuals are not too close to each other, it is possible to count them by estimating their positions from the sounds they produce. This requires multiple receivers to estimate the positions using time delay of arrivals (TDOA) of the same sound on multiple instruments, the use of a directional hydrophone to determine the approximate bearing to each sound or the received acoustic level (assuming fainter calls are further away). Therefore, each detection could provide an estimated position of each vocal individual. When sounds are repeated in a bout, this redundancy can provide finer scale information on movements. (Glotin *et al.* 2007, Nosal 2011). It is also possible to estimate the distance of a vocal animal by using multipath arrivals of a signal at a single receiver and estimating the transmission loss to obtain a minimum estimate of abundance in the area of interest (McDonald *et al.* 1999). Estimates are more reliable when the individual is relatively closed to the receiver.

IV.3 - Distance Sampling

Distance Sampling (Buckland *et al.* 2001, Thomas *et al.* 2002) is a well-established method for density estimation of the cetacean populations by use of visual observations. A new version is proposed based on the detected whale sounds. This method applies the principles of '*point transect sampling'* to acoustic data. Omni-directional hydrophones are moored in a region of interest and, rather than using visual detections to establish the presence of animals, the detection of species-specific sounds produced by these animal is used. Relative density is derived by determining the number of detections over the observed area, which depends on the maximum distance at which the whale sounds can be detected. In theory, this distance is based on the performance of the data acquisition process (sensitivity of hydrophone and recording system), the features of the cetacean sounds to be detected, variations in ambient noise, and the performance of the detector. In practice, we consider a reasonable distance in which the false detection is minimum. The probability of detection is deduced from the distribution of the detected sounds. It means that the distance of each detected sound from the receiver has to be estimated, either by estimating propagation losses or from the TDOA for an array of hydrophones. Because the cetaceans produce repetitive sounds, the estimation of the call rate (how many calls per animal per unit time) is needed for this approach.

The estimation of the density is given by (Marques *et al*. 2009):

$$\hat{D} = \frac{n_c(1-\hat{c})}{K\pi w^2 \hat{P} T \hat{r}}$$

- n_c is the number of cetacean sounds detected by K hydrophones during T,
- $\hat{c}$ is the estimation of the rate of the false detections,
- w is the maximum distance between hydrophones and cetaceans,
- $\hat{r}$ is the estimated call-rate (mean of the number of calls emitted by individual per time)
- $\hat{P}$ is the probability of detected sounds inside the area πw^2.

Currently, the biggest hurdle to using density estimation to determine the density of whales in a region at given time is the lack of information on *cue rate* (how often does an animal call?). Call production can vary by individual, gender, season, location, and behavioral context (Matthews *et al.* 2001). At present there are few studies that examine how acoustic behavior changes over time. Because we are interested in the number of calls produced per animal and assuming that a series of calls is produced by a single animal, information on the acoustic behavior of different individuals in different behavioral states in the study area of interest is needed. One way to obtain such information is to deploy acoustic tags on individuals to measure the vocal pattern (Oleson *et al.* 2007, Marques *et al*. 2009). Unfortunately there are some species for which this has not yet been possible, including Antarctic blue whales. Another possible way to determine this information is to calculate the cue rate of vocal individuals during ship-board studies that integrate visual and acoustic data and attribute each vocalization recorded to an individual whale by using multiple receivers (Marques *et al.* 2011).

Harris and collaborators (2011) used this methodology in two ways to estimate whale density. In the first, they estimated the density of fin whales in the Northeastern Atlantic. An array of twelve ocean bottom seismometers was used to localize animals, thereby providing both ranges to the calling animals and call rate to be estimated. These distances were then used to calculate the average probability of detecting a call, which allowed missed calls to be accounted for. In the second study, they attempted to estimate blue whale density from vocalizations recorded on a single hydrophone in the Indian Ocean. In this case, ranges to animals were not known, so the average probability of detection was estimated in a Monte Carlo simulation framework, which incorporated information about the source levels of the calls, the propagation of the calls in the Diego Garcia region, ambient noise levels, and the efficiency of the automatic detector that was used to classify and extract the calls from the dataset. Only call density could be estimated in this case, due to lack of information about the average call rate.

IV.4 - Distribution of the detected cetacean sounds

It is reasonable to assume that the density of signals within an area is related to the relative index of abundance of animals in the area (Schwarz *and* Seber 1999). Extrapolating from the number of sounds to the number of animals requires understanding how the number of sounds received, and the temporal distribution of these sounds is related to the number of vocal individuals. This approach is based on the statistics extracted from the emitted calls and is based on the assumption that the number of detected calls has a different distribution if they are emitted by a single animal, 2 animals, 3, etc.. The predicted distribution is used to give an estimation of the number of whales.

Whitehead (2009) proposed 4 methods based on whether or not the parameters of his model were known. Assumptions of the model include:

- The zone of acoustic detection is made up of receivers that are aligned (as in *point distance sampling*) and regularly spaced at distance *d* ;
- Individuals are distributed randomly and independently in space with a density of $\alpha / unit^2$;
- Individuals are detected by hydrophones along a range of unit *r* ;
- Each individual produces sounds that are audible to the detector with a constant probability u throughout the duration of the study (Bernoulli) ;
- Individuals don't move;
- The detection probabilities for different receivers are not correlated when an individual signal is audible at two or more stations;
- The probability that at least one vocalization is detected at a station is : $1 - e^{-\alpha\mu\pi r^2}$ If the vocalizations are heard at a proportion of *p* stations, then the density estimation by this method can be described as : $\ddot{\alpha} = -\log(1-p)/\mu\pi r^2$

If μ and *r* are known, then the density of cetaceans in the study area is known. Whitehead (2009) provides the equations to estimate μ and *r* when only one of the two is known. The utility of this method is that the estimation of μ, the probability that an animal vocalizes, is integrated into the model and does not need to be calculated as in cue counting methods.

Where neither μ nor *r* are known, the estimate has a weak bias when the distance between the receivers is between 30% and 80% of the distance *r*, and when μ > 0.7, which is quite restrictive in practice.
This method was used by Horrocks *et al.* (2011), where the data were modeled with a Poisson distribution. This model allows an estimate of the probability of detection, the vector of detection and the population density. Estimates obtained thusly from the Sargasso Sea for sperm whales (an animal that vocalizes almost constantly) were reasonable whereas for humpback whales, a species that is not on obligate vocalizer, the estimates obtained were poor.

Prieto Gonzalez *et al.* (2010) proposed another approach based on the combination of 2 Poisson models to estimate the number of individuals from the time distribution of the emitted calls. The advantages are that the estimation of the call rate and the estimation of the distance between whales and receivers have to be known for this approach. This approach was tested on Antarctic blue whale calls from a single hydrophone located in the Crozet archipelago. Antarctic blue whales emit calls every 60 s or so; these are low frequency call (from 28 Hz to 20 Hz), lasting 15-20 sec, with high intensity. Algorithms for automatic whale call detection, extraction and discrimination were developed and used on a one-year continuous acoustic dataset (2003-2004) recorded in the station located in sub Antarctic area near Crozet Islands (IMS-CTBTO / data available under contract with CEA –DAM Ile de France). The aim was to assess the seasonal occurrence of blue whale in a specific area. The detection procedure was based on a matched filter model (Samaran *et al*. 2008). This approach does not require the call rate or positions of the calling animals to estimate density (Prieto Gonzales *et al*. 2010).

The number of calls produced by one blue whale per hour and the number of blue whales present in the study area were modeled using two independent Poisson distributions:

$$P(B(s)=k)=e^{-\lambda s}\frac{(\lambda s)^k}{k!}$$

$$P(C(t)=k)=e^{-\mu t}\frac{(\mu t)^k}{k!}$$

B(s) is the random variable representing the number of whales present in the region *s*.
C(t) is the random variable representing the number of calls of one whale at time *t*
The number of calls per hour is modeled by:

$$N(t,s)=\sum_{j=1}^{B(s)}C_j(t)$$

At the same time, the time difference between two consecutive calls is modeled as:

$$F_{T(s)}(t)=P(T(s)\leq t)=1-e^{-\lambda s\left(e^{-\mu t}-1\right)}$$

The number of individuals in this area during *t* can then be obtained by the method of moments, using later the maximum likelihood estimation (Prieto Gonzales *et al.* 2010):

$$\hat{\mu}=\frac{\sigma_{\overline{N}}^2-\overline{N}}{\overline{N}t}$$ and $$\hat{\lambda}=\frac{\overline{N}^2}{\left(\sigma_{\overline{N}}^2-\overline{N}\right)s}$$

Where N is the number of detected calls in the area s during t,   is the mean and   is the standard deviation. The results so obtained give the number of individuals present in the Crozet Archipelago, during the year (Table 6). This type of results is only possible with passive acoustics because no visual observations can be provided during the whole year in this area, highlighting the importance of having a permanent recording system installed in the area.

Table 6. Estimate of the number of Antarctic blue whale individuals around the Crozet Archipelagos (from Prieto Gonzalez *et al.* 2010)

IC	90% λN	95% λN	90% λT	95% λT
May	[1, 8]	[1, 8]	[3, 12]	[2, 13]
June	[1, 8]	[1, 9]	[3, 12]	[2, 13]
July	[1, 7]	[0, 7]	[2, 10]	[2, 11]
August	[1, 7]	[0, 7]	[3, 11]	[2, 12]
September	[0, 6]	[0, 6]	[3, 11]	[2, 12]
October	[1, 6]	[0, 7]	[2, 10]	[2, 11]
November	[1, 7]	[0, 8]	[3, 11]	[2, 12]
December	[0, 6]	[0, 7]	[3, 11]	[2, 12]
January	[0, 5]	[0, 6]	[3, 11]	[2, 12]
February	[1, 7]	[1, 8]	[2, 10]	[2, 11]
March	[0, 3]	[0, 3]	[2, 10]	[2, 11]
April	[0, 6]	[0, 7]	[2, 10]	[1, 11]
Anual	[0, 3]	[0, 4]	[3, 11]	[2, 12]

This method could be improved by introducing *a priori* information using call sequences and different features implicitly indicating the number of calling whales. In using call sequences, one must assume that calls are not independent of each other. Further, this dependence may be extended from one whale to others; i.e. if one the calling behavior of a second whale is influenced by that of the first, the temporal distribution of these sounds is not random. Therefore data on the regularity of call series and the inter call interval (ICI) values can be used to obtain the likelihood that a call will be produced after a preceding call. This transition matrix is used to classify different call series, assuming that different ICI values can be attributed to a minimum number of calling whales.

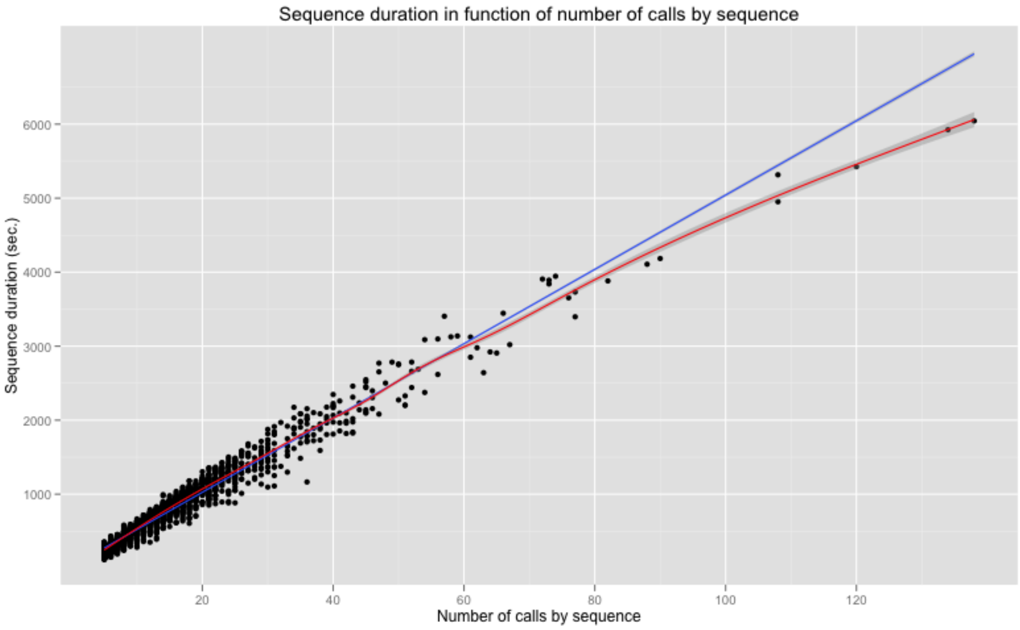


Figure. 16: Duration of the series in function of the number of calls in the Crozet data set (2003-2004)

Figure 16 shows the series durations of different numbers of calls over similar time periods. This shows that there is a linear relationship between the number of calls and the time duration of the series. Additionally, this regularity shows that Antarctic blue whales off Crozet tend to favor very patterned series of calls. From here, call series are classified as long (single animal) or short (multiple animals) ICI and whether a time link exists between these different types of series exists is examined. To do this, a Markov model is used to describe the link between successive series with some probability. A matrix of transitions for different states is chosen as a first step for long ICI (state #1) and short ICI (state #2). Finally, the matrix of transition is:

$$p_{ij} = P\left(X_t = j \middle| X_{t-1} = i \right)_{i,j \in \{1,2\}}$$

$$P = \begin{pmatrix} p_{11} & p_{12} \\ p_{21} & p_{22} \end{pmatrix} = \begin{pmatrix} 0.6 & 0.4 \\ 0.2 & 0.8 \end{pmatrix}$$

This matrix confirms that 1) the regularly of the series is robust (the transition from one state to the same state is stronger than from one state to the other) and 2) the transition state "normal ICI" is dominant (sequences from a single individual are most common in this dataset). These results could be extended to consider more than 2 states, and provide the optimal number from a statistical Gaussian distribution. This approach provides promising results based on time structure of calls and series. As with any method however, the results presented here are valid only for the data set used. However, it may be possible to generalize the model to other datasets given a more robust understanding of mean call series durations and ICIs for different species under different behavioral contexts.

V. Conclusions and recommendations for future work

Passive acoustic monitoring is a robust means of monitoring blue and fin whales in remote areas over long time periods, including around the Antarctic. The present analysis of all the available data shows the geographic and seasonal occurrence of blue and fin whales around the Antarctic. However the lack of overlap in the years and locations monitored, the differences among instruments and analysis methods used, underlines the need for coordinated effort. To best exploit passive acoustic data long term, a pan-Antarctic monitoring system needs to be put in place and maintained. Thus far there has been a positive response from many countries regarding this project. In the near term we need to find the finances and continue the instrument development to make this happen. Further a single method either for each species or for both needs to be adopted for analyzing the data. A review of existing analysis methods demonstrate that the scientific question of interest will drive the analysis methods chosen. When collected, we suggest that the AAD maintain a database of the metadata and data from hydrophones and make these freely available if possible.

Acoustic data from a single hydrophone present unique challenges to density estimation: to overcome these we need to improve our knowledge of call rate, acoustic behavior and source level of whales; detection distance and sound propagation (environmental parameters and ambient noise level). Methodology to estimate the density of whales from acoustic data is advancing rapidly and we anticipate that if we improve our understanding of the parameters above, density estimation using passive acoustic data will become the state of the art for monitoring Antarctic blue and fin whales.

Acknowledgments

This report was supported by the Southern Ocean Research Partnership of the International Whaling Commission. The data described and/or presented in this report come from a number of sources including the Australian Antarctic Division, Scripps Institution of Oceanography, Curtin University, the Korea Research Institute, the Pacific Marine Environmental Laboratory, the Centre d'Etudes Biologiques de Chizé, the Laboratoire des Domaines Océaniques – University de Bretagne Occidentale. We thank the many colleagues with whom we have discussed this project.

References cited

Baumgartner MF, Mussoline SE (2011) A generalized baleen whale call detection and classification system. Journal of Acoustical Society of America 129:2889–2902

Branch T, Matsuoka K, Miyashita T (2004) Evidence for increases in Antarctic blue whales based on Bayesian modelling. Marine Mammal Science 20:726–754

Branch TA, Stafford KM, Palacios DM, Allison C, Bannister JL, Burton CLK, Cabrera E, Carlson CA, Galletti Vernazzani B, Gill PC, Hucke-Gaete R, Jenner KCS, Jenner MNM, Matsuoka K, Mikhalev YA, Miyashita T, Morrice MG, Nishiwaki S, Sturrock VI, Tormosov D, Anderson Rc, Baker An, Best Pb, Borsa P, Brownell Jr Rl, Childerhouse S, Findlay KP, Gerrodette T, Ilangakoon AD, Joergensen M, Kahn B, Ljungblad DK, Maughan B, Mccauley RD, Mckay S, Norris TF, Oman Whale And Dolphin Research Group, Rankin S, Samaran F, Thiele D, Van Waerebeek K, Warneke Rm (2007) Past and present distribution, densities and movements of blue whales *Balaenoptera musculus* in the Southern Hemisphere and northern Indian Ocean. Mammal Review 37:116–175

Brown JC, Smaragdis P, Nousek-McGregor A (2010) Automatic identification of individual killer whales. Journal of Acoustical Society of America 128(3): 93-98

Buckland ST, Anderson DR, Burnham KP, Laake JL, Borchers DL, Thomas L (2001) Introduction to Distance Sampling: Estimating abundance of biological populations, Oxford University Press.

Castellote M, Clark CW, Lammers MO (2011) Fin whale (Balaenoptera physalus) population identity in the western Mediterranean Sea. Marine Mammal Science:no–no

Dawson DK, Efford MG (2009) Bird population density estimated from acoustic signals. Journal of Applied Ecology 46: 1201–1209

Delarue J, Todd SK, Van Parijs SM, Di Iorio L (2009) Geographic variation in Northwest Atlantic fin whale (*Balaenoptera physalus*) song: implications for stock structure assessment. Journal of Acoustical Society of America 125:1774–1782

Ensor PH, Komiya H, Beasley I, Fukutome K, Olson P, Tsuda Y (2007) 2006-2007 International Whaling Commission – Southern Ocean Whale and Ecosystem Research (IWC-SOWER) cruise. SC/59/IA1, International Whaling Commission (unpublished).

Ensor P, Komiya H, Olson P, Sekiguchi K, Stafford K (2006) 2005-2006 International Whaling Commission-Southern Ocean Whale and Ecosystem Research (IWC-SOWER) cruise. Paper SC/58/IA1 presented to the 2006 IWC Scientific Committee (unpublished). 63pp.

Figueroa H (2006) Extensible bioacoustics tool (XBAT). Available at http://xbat.org/home.html.

Gedamke J (2009) Geographic variation in Southern Ocean fin whale song. Paper SC/61/SH16 presented to the 2009 IWC Scientific Committee (unpublished). 8 pp

Gedamke J, Gales N, Hildebrand J, Wiggins S (2007) Seasonal occurrence of low frequency whale vocalisations

across eastern Antarctic and southern Australian waters, February 2004 to February 2007. Paper SC/59/SH5 presented to the 2007 IWC Scientific Committee (unpublished). 11pp
Gedamke J, Robinson SM (2010) Acoustic survey for marine mammal occurrence and distribution off East Antarctica (30-80°E) in January-February 2006. Deep-Sea Research Part II 57:968–981
Glotin H, Caudal F, Giraudet P (2008) Whale cocktail party: real-time multiple tracking and signal analysis. Canadian Acoustics, 36(1): 139-145
Fox CG, Matsumoto H, Lau TKA (2001) Monitoring Pacific Ocean seismicity from an autonomous hydrophone array Journal of Geophysical. Research 106, 4183–4206.
Harris D, Thomas L, Matias L, Mellinger DK, Wiggins SM, Hildebrand JA, Harwood, J (2011) Estimating whale population density using sparse hydrophone arrays. Poster presented at the 19th Biennial Conference of the Biology of Marine Mammals. November 27 to December 2, 2011, Tampa, Fl, USA.
Horrocks JJ, Hamilton DCD, Whitehead HH (2011) A likelihood approach to estimating animal density from binary acoustic transects. Biometrics 67:681–690
Küsel ET, Mellinger DK, Thomas L, Marques TA, Moretti D, Ward J (2011) Cetacean population density estimation from single fixed sensors using passive acoustics. Journal of the Acoustical Society of America. 129:3610–3622
Ljungblad, DK, Clark CW, Shimada, H (1998) A comparison of sounds attributed to pygmy blue whales (*Balaenoptera musculus brevicauda*) recorded south of the Madagascar Plateau and those attributed to 'true' blue whales (*Balaenoptera musculus*) recorded of Antarctica. Report of International Whaling Commission 48:439-42.
Lopez-Rivas RM, Bazua-Duran C (2010) Who is whistling? Localizing and identifying phonating dolphins in captivity. Applied Acoustics 7:1057–1062
Mackintosh NA (1966) Distribution of southern blue and fin whales. In: Norris KS (ed) Whales, dolphins, and porpoises. University of California Press, Berkeley, CA, p 125–144
Marques T, Munger L, Thomas L, Wiggins S, Hildebrand J (2011) Estimating North Pacific right whale *Eubalaena japonica* density using passive acoustic cue counting. Endangered Species Research 13:163–172
Marques TAT, Thomas LL, Ward JJ, DiMarzio NN, Tyack PLP (2009) Estimating cetacean population density using fixed passive acoustic sensors: an example with Blainville's beaked whales. Journal of the Acoustical Society of America.125:1982–1994
Matthews J, Brown S, Gillespie D, Johnson M, McLanaghan R, Moscrop A, Nowacek D, Leaper R, Lewis T, Tyack P (2001) Vocalisation rates of the North Atlantic right whale (*Eubalaena glacialis*). Journal of Cetacean Research and Management 3:271–282
McDonald M (2006) An acoustic survey of baleen whales of Great Barrier Island New Zealand. New Zealand Journal of Marine and Freshwater Research 40:519-529
McDonald M, Fox C (1999) Passive acoustic methods applied to fin whale population density estimation. Journal of the Acoustical Society of America 105:2643–2651
Mellinger DK (2001) Ishmael 1.0 User's Guide. NOAA Technical Memorandum OAR‑PMEL-120, available from NOAA/PMEL, 7600 Sand Point Way NE, Seattle, WA 98115.
Mellinger DK, Clark CW (1996) Methods for automatic detection of mysticete sounds. Marine and Freshwater Behaviour and Physiology 29:163–181
Mellinger DKD, Clark CWC (2000) Recognizing transient low-frequency whale sounds by spectrogram correlation. Journal of the Acoustical Society of America 107:3518–3529
Mellinger DK, Clark CW (2006) MobySound: A reference archive for studying automatic recognition of marine mammal sounds. Applied Acoustics 67:1226–1242
Mellinger DK, Martin SW, Morrissey RP, Thomas L, Yosco JJ (2011) A method for detecting whistles, moans, and other frequency contour sounds. Journal of the Acoustical Society of America 129:4055–4061
Mellinger DK, Stafford KM, Moore SE, Dziak RP, Matsumoto H (2007) An Overview of Fixed Passive Acoustic Observation Methods for Cetaceans. Oceanography 20:36–45
Miller BS, Kelly N, Double MC, Childerhouse SJ, Laverick S, Gales N (2012) Cruise report on SORP 2012 blue whale voyages : Development of acoustic methods. Working paper SC/SH/64
Nieukirk SL, Mellinger DK, Moore SE, Klinck K, Dziak RP, Goslin J (2012) Sounds from airguns and fin whales recorded in the mid-Atlantic Ocean, 1999–2009. Journal of the Acoustical Society of America 131:1102–1112
Nieukirk SL, Stafford KM, Mellinger DK, Dziak RP, Fox CG (2004) Low-frequency whale and seismic airgun sounds recorded in the mid-Atlantic Ocean. Journal of the Acoustical Society of America 115:1832–1843
Nosal EM (2011) Tracking minke whales: Results from the 2011 DCL localization dataset, International

workshop on detection, classification and localization of marine mammals using passive acoustics, Portland, USA
Oleson EM, Calambokidis J, Burgess WC, McDonald MA, LeDuc CA, Hildebrand JA (2007) Behavioral context of call production by eastern North Pacific blue whales. Maine Ecology Progress Series 330:269–284
Pangerc T (2010) Baleen whale acoustic presence around South Georgia. PhD Thesis, University of East Anglia, Norwich and British Antarctic Survey, Cambridge.pp 242
Prieto Gonzales RP, Cruz Valsero M, Samaran F, Adam O (2010) A spatio-temporal Poisson model to estimate the density of the Antarctic blue whales in the Austral Ocean using fixed passive acoustic sensors. (unpublished).
Rankin S, Ljungblad D, Clark C, Kato H (2005) Vocalisations of Antarctic blue whales, *Balaenoptera musculus intermedia*, recorded during the 2001/2002 and 2002/2003 IWC/SOWER circumpolar cruises, Area V, Antarctica. Journal of Cetacean Research and Management 7:13–20
Samaran F, Adam O, Guinet C (2010a) Discovery of a mid-latitude sympatric area for two Southern Hemisphere blue whale subspecies. Endangered Species Research 12:157–165
Samaran F, Adam O, Guinet C (2010b) Detection range modeling of blue whale calls in Southwestern Indian Ocean. Applied Acoustics 71:1099–1106
Samaran F, Adam O, Motsch JF, Guinet C (2008) Definition of the Antarctic and pygmy blue whale call templates. Application to fast automatic detection, Canadian Acoustics 36 (1) 93-102
Schwarz C, Seber G (1999) Estimating animal abundance: Review III. Statistical Sciences 14:427–456
Simon M, Stafford K, Beedholm K, Lee C, Madsen P (2010) Singing behavior of fin whales in the Davis Strait with implications for mating, migration and foraging. Journal of the Acoustical Society of America 128:3200–3210
Širović A, Hildebrand JA, Wiggins SM, McDonald MA, Moore SE, Thiele D (2004). Seasonality of blue and fin whale calls and the influence of sea ice in the Western Antarctic Peninsula, Deep-Sea Research, Part II 51, 2327–2344.
Širović A, Hildebrand JA, Wiggins SM (2007) Blue and fin whale call source levels and propagation range in the Southern Ocean. Journal of the Acoustical Society of America 122:1208–1215
Širović A, Hildebrand JA, Wiggins SM, Thiele D (2009) Blue and fin whale acoustic presence around Antarctica during 2003 and 2004. Marine Mammal Science 25:125–136
Stafford KM, Bohnenstiehl DR, Tolstoy M, Chapp E, Mellinger DK, Moore SE (2004) Antarctic-type blue whale calls recorded at low latitudes in the Indian and eastern Pacific Oceans. Deep Sea Research Part I: Oceanographic Research Papers 51:1337–1346
Stafford KM, Chapp E, Bohnenstiel DR, Tolstoy M (2010) Seasonal detection of three types of “pygmy” blue whale calls in the Indian Ocean. Marine Mammal Science 27:828–840
Stafford KM, Citta JJ, Moore SE, Daher MA, George JE (2009) Environmental correlates of blue and fin whale call detections in the North Pacific Ocean from 1997 to 2002. Maine Ecology Progress Series 395:37–53
Stafford KM, Mellinger DK, Moore SE, Fox CG (2007) Seasonal variability and detection range modeling of baleen whale calls in the Gulf of Alaska, 1999–2002. Journal of the Acoustical Society of America 122:3378
Stafford K, Nieukirk S, Fox C (1999) Low-frequency whale sounds recorded on hydrophones moored in the eastern tropical Pacific. Journal of the Acoustical Society of America 106:3687–3698
Thode AM, Kim KH, Blackwell SB, Greene CR, Nations CS, McDonald TL, Macrander AM (2012) Automated detection and localization of bowhead whale sounds in the presence of seismic airgun surveys. Journal of the Acoustical Society of America 131:3726
Thomas L, Buckland ST, Burnham KP, Anderson D R, Laake, JL, Borchers DL, Strindberg S (2002) Distance Sampling. Encyclopedia of Environmetrics.
Thompson PO, Friedl WA (1982) A long-term study of low frequency sound from several species of whales off Oahu, Hawaii. Cetology 45:1-19
Van Opzeeland Ilse (2010) Acoustic ecology of marine mammals in polar oceans. Alfred Wagner Institute, hdl:10013/epic.36260. pp 334
Ward JA, Thomas L, Jarvis S, DiMarzio N, Moretti D, Marques TA, Dunn C, Claridge D, Hartvig E, Tyack P (2012) Passive acoustic density estimation of sperm whales in the Tongue of the Ocean, Bahamas. Marine Mammal Science *In press*
Watkins WA (1981) Activities and underwater sounds of fin whales. Sciencific Report Whales Research Institute Tokyo 33:83-117.
Whitehead H (2009) Estimating Abundance From One-Dimensional Passive Acoustic Surveys. Journal of Wildlife Management 73:1000–1009

Wiggins S (2003) Autonomous Acoustic Recording Packages (ARPs) for long-term monitoring of whale sounds. Marine Technology Society Journal 37 (2), 13–22.

Zaugg S, Van der Schaar M, Houegnigan L, Gervaise C, André M (2010) Real-time acoustic classification of sperm whale clicks and shipping impulses from deep-sea observatories, Applied Acoustics 71(11): 1011-1019

6. Living whales in the Southern Hemisphere

Please refer to **SC/64/O14**: Baker, C.S. *et al.*, 2012. Report of the Living Whales Symposium: Advances in non-lethal research techniques for whales in the Southern Hemisphere, for a full project report.