# SC/68D/SH/08Rev

**Sub-committees/working group name: SH**

**IWC-SORP Research Fund: 2022 progress reports from funded projects**

**Elanor M. Bell (Compiler)**

Revised

# IWC-SORP Research Fund: 2022 progress reports from funded projects


ELANOR M. BELL[1] (Compiler)

[1] *IWC-SORP Secretariat, Australian Marine Mammal Centre, Australian Antarctic Division, Department of the Environment and Energy, 203 Channel Highway, Kingston Tasmania 7050, AUSTRALIA.* https://iwc.int/sorp

# Contents

# IWC-SORP Research Fund: 2022 progress reports from funded projects


## ABSTRACT

Following open, competitive Calls for Proposals in 2016/17, 2018/19 and 2019/20 a total of £144,058 GBP, £489,154 GBP and £129,955 GBP, respectively, were allocated from the IWC-Southern Ocean Research Partnership (IWC-SORP) Research Fund to 31 research projects in total. This paper summarises the progress of the ongoing research projects and acknowledges the many impacts that the global COVID-19 pandemic has had.


KEYWORDS: SOUTHERN OCEAN RESEARCH PARTNERSHIP, IWC-SORP, RESEARCH FUND, PROJECT PROGRESS REPORTS

## BACKGROUND ON THE IWC-SOUTHERN OCEAN RESEARCH PARTNERSHIP (IWC-SORP)

The IWC's Southern Ocean Research Partnership (IWC-SORP) was proposed to the International Whaling Commission (IWC) in 2008 with the aim of developing a multi-lateral, non-lethal scientific research programme that would deliver coordinated and cooperative Southern Ocean science to the IWC. Currently, there are 13 member countries in the Partnership: Argentina, Australia, Belgium, Brazil, Chile, France, Germany, Italy, Luxembourg, New Zealand, Norway, South Africa and the United States. IWC-SORP is an open Partnership that welcomes new members. Its ethos is one of open collaboration, communication and data sharing.

There are currently seven endorsed and ongoing IWC-SORP themes: 1) 'The Antarctic Blue Whale Project'; 2) A project aimed at describing the 'Distribution, relative abundance, migration patterns and foraging ecology of three ecotypes of killer whales in the Southern Ocean'; 3) The 'Foraging ecology and predator-prey interactions between baleen whales and krill' project; 4) A project to investigate the 'Distribution and extent of mixing of Southern Hemisphere humpback whale populations around Antarctica?' focused initially on east Australia and Oceania; 5) The 'Acoustic trends in abundance, distribution, and seasonal presence of Antarctic blue whales and fin whales in the Southern Ocean' project; 6) The right sentinel for climate change: linking foraging ground variability to population recovery in the southern right whale; and 7) Recovery status and ecology of Southern Hemisphere fin whales. Further details of all the IWC-SORP themes can be found in the IWC-SORP Annual Report, SC/68d/SH07, and at https://iwc.int/sorp.

## IWC-SORP CALLS FOR PROPOSALS

Following voluntary financial contributions to the IWC-SORP Research Fund by the governments of Australia and The Netherlands, the International Fund for Animal Welfare, and WWF-Australia, the Fund held a balance of £781,833 GBP (2016). Since that time three Calls for Proposals have been completed: 2016/17, 2018/19 and 2019/20.

*2016/17*

The first IWC-SORP Call for Proposals opened on 26 July 2016 and closed on 17 August 2016. Eleven proposals were received by the IWC-SORP Secretariat and assessed for eligibility in accordance with criteria clearly stated in the guidelines associated with the Call. An interim proposal assessment procedure, developed by the Scientific Committee (Item 1.2 of Annex W (IWC/66/Rep01), was followed. The evaluation process was coordinated by Chair of the Scientific Committee of the IWC and the IWC-SORP Secretariat. Nine members of the IWC-SORP Scientific Steering Committee (SSC) reviewed the proposals. Conflicts of interests were reported by both proponents and assessors. The coordinators decided on a case-by-case basis if the assessor(s) should be excluded from the assessment of individual project(s).

A total of £144,058 GBP was allocated to 10 research projects, ahead of the 2016-2017 austral summer survey season. All of these projects have now finished and final reports can be found in SC/68a/SH11, SC/67b/SH18 and SC/68c/SH12.

*2018/19*
A second IWC-SORP Call for Proposals opened on 5 September 2017 and closed on 5 January 2018. An Assessment Panel (hereafter, the Panel) composed of 15 members of the IWC Scientific Committee and chaired by the Chair of the Scientific Committee of the IWC, assessed 19 eligible proposals submitted during the Call. The composition of the Panel was agreed by the Scientific Committee at SC/67a (IWC/67/Rep01 (2017) Annex V, Appendix 1, pp 7-8).

The Panel proposed to the IWC-SORP SSC and subsequently the IWC/SC, the allocation of a total of £489,154 GBP from the IWC-SORP voluntary fund to 15 projects. This allocation was endorsed during IWC67.

*2019/20*
A third IWC-SORP Call for Proposals opened on 7 October 2019 and closed on 10 January 2020. The Assessment Panel included 13 members of the IWC Scientific Committee and was chaired by the Chair of the Scientific Committee of the IWC. Nine eligible proposals were assessed. Subsequently, the Panel proposed to the IWC-SORP SSC and the IWC/SC the allocation of a total of £129,955 GBP from the IWC-SORP voluntary fund to 6 projects. This allocation was endorsed by the Commission via a postal vote concluded in July 2020.

A further £1328.46 GBP were allocated intersessionally in 2021 by the IWC-SORP Scientific Steering Committee (SSC) to Dr Fannie Shabangu of the Acoutic Trends Working Group, to support the freight of an acoustic instrument from France to South Africa and the purchase of consumables. The instrument will be deployed off Marion Island in June 2021 and will contribute data to both the IWC-SORP Acoustic Trends and Killer Whale Themes over a number of years.

A financial report of the IWC-SORP Research Fund is detailed in the IWC Research Fund Financial Report (SC/68d/O04). **£24,844 GBP** remain unassigned and unspent. This figure includes interest and bank fees.

*IWC-SORP sincerely thanks the Governments of Australia, the Netherlands, France, WWF-Australia and the International Fund Animal Welfare for financial contributions to the IWC-SORP Research Fund.*

## FUNDING ALLOCATIONS

The Chair of the Scientific Committee in conjunction with the IWC-SORP SSC, sought endorsement from the F&A Committee and the Commission (IWC/66; IWC/67; postal vote 2020) on the Call procedures and all aspects of their implementation, including the allocations of funding outlined in Tables 1, 2 and 3. Full endorsement was received at IWC/66, IWC67 and via postal vote in 2020, respectively. Disbursement of funds to successful applicants commenced in January 2017, December 2018 and January 2020, respectively.

**Table 1: List of the projects that received funding from the IWC-SORP Research Fund in 2016/17. Amounts are in GBP.**

| Project # | Chief Investigator | Co-Investigators | Title | Allocated funding (£) | Project status |
|---|---|---|---|---|---|
| 1 | Baker, C. Scott | Sremba, Angie; Jackson, Jen | Beached bones: assessing genomic diversity and population differentiation of historical blue whales | 11,000 | Completed final report received SC67b |
| 2 | Constantine, Rochelle | Zerbini, Alex; Riekkola, Leena; Friedlaender, Ari; Andrews-Goff, Virginia | Habitat use of humpback whales and their Antarctic feeding grounds: Areas V, VI & I | 7,740 | Completed final report received SC68a |
| 3 | de Bruyn, Nico | Reisinger, Ryan | Habitat use of killer whales at the Prince Edward Islands | 10,000 | Completed final report received SC67b |
| 4 | Friedlaender, Ari | Weinstein, Ben; Double, Michael | Foraging ecology and predator-prey interactions between baleen whales (humpback and minke) and krill: a novel analysis of long-term dive data to quantify feeding rates | 20,883 | Completed final report received SC67b |
| 5 | Harcourt, Robert | Miller, Elanor; Cox, Martin; Miller, Brian; Double, Michael | Antarctic blue whale-krill interactions: an analysis | 18,804 | Completed final report received SC67b |
| 6 | Miller, Brian | Samaran, Flore; Sirovic, Ana; van Opzeeland, Ilse; | An annotated library of underwater acoustic recordings for testing and training automated algorithms for detecting Southern Ocean baleen whales | 22,000 | Completed final report received SC68c |
| 7 | Moller, Luciana | Attard, Catherine; Beheregaray, Luciano | Population genomic structure of Antarctic blue whales in the Antarctic feeding grounds | 19,381 | Completed final report received SC67b |
| 8 | Olson, Paula | | Photo-identification of Antarctic blue whales | 2,250 | Completed final report received SC67b |
| 9 | Paton, Dave | Baker, C. Scott; Dietrich-Steel, Debbie; Garrigue, Claire; Noad, Michael; Childerhouse, Simon | Who are the real East Australian (E1) breeding group of humpback whales? Genetic characterisation of E1 and the influence of E1 across Oceania | 23,000 | Completed final report received SC68a |

| | | | | | |
|---|---|---|---|---|---|
| 10 | Samaran, Flore | Stafford, Kate; Miller, Brian; van Opzeeland, Ilse; Harris, Danielle; Findlay, Ken; Sirovic, Ana; Buchan, Susannah; Gedamke, Jason | IWC-SORP Project 5. Acoustic trends in abundance, distribution and seasonal presence of Antarctic blue whales and fin whales in the Southern Ocean: 5-year strategic meeting | 9,000 | Completed final report received SC67b |
| | | | **TOTAL** | **144,058** | |

**Table 2: List of the projects that received funding from the IWC-SORP Research Fund in 2018/19. Amounts are in GBP. Project status notations highlighted in red indicate projects for which reports are included in this document.**

| Project #/page | Chief Investigator | Co-Investigators | Title | Recommended amount (£) | Project status |
|---|---|---|---|---|---|
| 11 pp. 10-11 | Baker, C. Scott; Steel, Debbie | Ari Friedlaender, Renee Albertson, Michael Poole, Susana Caballero, Logan Pallin, Jooke Robbins, Ana Lucia Cypriano-Souze, Rochelle Constantine | Is migratory connectivity of humpback whales in the Central and Eastern South Pacific changing? A decadal comparison by DNA profiling | **26,375** | Final report received SC68d |
| 12 | Charrassin, Jean-Benoit | Laurene Trudelle, Virginia Andrews-Goff | Application of satellite telemetry data to better understand the breeding strategies of humpback whales in the Southern Hemisphere | **21,200** | Final report received SC68b |
| 13 pp. 12-16 | Branch, Trevor | | Modelling somatic growth and sex ratios to predict population-level impacts of whaling on Antarctic blue whales | **32,594** | Ongoing Interim report received SC68d |
| 14 pp. 17-21 | Friedlaender, Ari | Rochelle Constantine Jooke Robbins, Scott Baker, Claire Garrigue, Logan Pallin | Pregnancy rates in Southern Ocean humpback whales: implications for population recovery and health across multiple populations | **19,984** | Ongoing Interim report received SC68d |
| 15 pp. 22-26 | Herr, Helena | Sacha Viquerat, Simone Panigada, Bettina Meyer, Anna Panasiuk, Natalie Kelly, Jennifer Jackson, Paula Olson, Ursula Siebert | Recovery status and ecology of Southern Hemisphere fin whales (*Balaenoptera physalus*) | **81,900** | Ongoing Interim report received SC68d |
| 16 pp. 27-34 | Friedlaender, Ari; Constantine, Rochelle | Alex Zerbini, Ben Weinstein | A circumpolar analysis of foraging behaviour of baleen whales in Antarctica: Using state-space models to quantify the influence of oceanographic regimes on behaviour and movement patterns | **34,711** | Final report received SC68d |
| 17 pp. 35-43 | Buchan, Susannah; Miller, Brian | Flore Samaran, Danielle Harris, Kate Stafford, Ken Findlay, Ana Širović | A standardized analytical framework for robustly detecting trends in passive acoustic data: A long-term, circumpolar comparison of call-densities of Antarctic blue and fin whales | **41,369** | Ongoing Interim report received SC68c |
| 18 pp. 44-45 | Lang, Aimee; Archer, Frederik | Robert L Brownell, Kelly Robertson, Michael R McGowan | Inferring the demographic history of blue and fin whales in the Antarctic using mitogenomic sequences generated from historical baleen | **22,710** | Final report received SC68d |
| 19 pp. 46-54 | Zerbini, Alex; Clapham, Phillip | Yulia Ivashchenko, Mike Double, John Bannister, Els Vermuelen, Ken Findlay | Assessing blubber thickness to inform satellite tag development and deployment on Southern Ocean whales | **22,426** | Final report received SC68d |

| | | | | | |
|---|---|---|---|---|---|
| 20<br>pp. 55-59 | Širović Ana, Stafford Kate, | | Acoustic ecology of foraging Antarctic blue whales in the vicinity of Antarctic krill studied during AAD interdisciplinary voyage aboard the *RV Investigator* | **30,107** | Final report received SC68d |
| 21<br>pp. 60-64 | Kelly, Natalie; Maire, Frederic | Amanda Hodgson, David Peel, Helena Herr, Phil Trathan, Jennifer Jackson; Guy Williams | Development of statistical and technical methods to support the use of long-range UAVs to assess and monitor cetacean populations in the Southern Ocean | **30,576** | Ongoing Interim report received SC68d |
| 22<br>pp. 65-73 | Reisinger, Ryan; de Bruyn, Nico | A. Rus Hoelzel, Christophe Guinet, Simon Elwen | An integrative assessment of the ecology and connectivity of killer whale populations in the southern Atlantic and Indian Oceans | **33,650** | Ongoing Interim report received SC68d |
| 23<br>pp. 74-75 | Bengston Nash, Susan | Ari Friedlaender, Frederik Christiansen, Juliana Castrillon, David Johnston | Implementation of humpback whales for Antarctic sea-ice ecosystem monitoring; Inter-program methodology transfer for effective circumpolar surveillance | **51,555** | Ongoing Interim report received SC68d |
| 24<br>pp. 76-77 | Carroll, Emma; Torres, Leigh; Graham, Brittany | Luciano O Valenzuela, Darren Gröcke, Scott Baker, Rochelle Constantine, Ken Findlay, Robert Harcourt, Pavel Hulva, Petra Neveceralova, Larissa Rosa de Oliveira, Paulo Henrique Ott, Per Palsbøll, Vicky Rowntree, Jon Seger | Circumpolar foraging ecology of southern right whales: past and present | **21,290** | Ongoing Interim report received SC68d |
| 25<br>pp. 78-79 | Iñíguez Bessega, Miguel | Simone Baumann-Pickering<br>Marta Hevia<br>John Hildebrand<br>Alexander Marino<br>Mariana Melcón<br>Maria Vanesa Reyes Reyes<br>Ana Širović<br>Juan Pablo Torres Florez | Habitat use, seasonality and population structure of baleen and toothed whales in the Scotia Sea and the western Antarctic Peninsula using visual and passive acoustic methods and genetics | **23,097** | Ongoing Interim report received SC68d |
| | | | **TOTAL** | **493,544** | |

**Table 3: List of the projects that received funding from the IWC-SORP Research Fund in 2019/20. Amounts are in GBP. Project status notations highlighted in red indicate projects for which reports are included in this document.**

| Project #/page | Chief Investigator | Co-Investigators | Title | Recommended amount (£) | Project status |
|---|---|---|---|---|---|
| 26 pp. 80-84 | Andrews-Goff, Virginia; Double, Michael | Alex Zerbini, Guy Williams, Rob Harcourt, Natalie Kelly, William de la Mare, Alastair Smith | Remote aerial deployment and sampling: development of a new sampling platform for large cetaceans | **9,520** | Ongoing Interim report received SC68d |
| 27 pp. 85-87 | Bengtson-Nash, Susan | Ari Friedlaender, Claire Garrigue, John Totterdell, Milton Marcondes, Natalia Botero Acosta | Extracting standardised health parameter data from five Southern Hemisphere humpback whale populations; facilitating direct inter-population comparison of circum-polar foraging success | **40,230** | Ongoing Interim report received SC68d |
| 28 pp. 88-94 | Branch, Trevor | Paula Olson, Virginia Andrews-Goff, Michael Double, Jennifer Jackson, | Insights into Antarctic blue whale population structure and movements from photo-identification, Discovery marks and satellite tags | **30,255** | Ongoing Interim report received SC68d |
| 29 pp. 95-104 | Buchan, Susannah; Stafford Kate | Ana Širović, Ilse van Opzeeland, Carlos Olavarria | A comparison of acoustic population identifiers for fin whales off Chile and in the Southern Ocean: a passive acoustic monitoring approach for gaining insights into population structure | **8,800** | Ongoing Interim report received SC68d |
| 30 pp. 105-112 | Butterworth, Doug; Cooke, Justin | Els Vermeulen, Claire Charlton, Anabela Brandão, Andrea Ross-Gillespie, Mariano Sironi, Vicky Rowntree, Karina Groch, Michael Double, Mandy Watson, Will Rayment, Emma Carroll, Stehen Burnell | Multi-ocean assessment of southern right whale demographic parameters and environmental correlates | **25,250** | Ongoing Interim report received SC68d |
| 31 | Carroll, Emma; Childerhouse, Simon | Alex Zerbini, Virginia Andrews-Goff, Rochelle Constantine | Foraging ecology of the southern right whale in the Indo-Pacific | **15,900** | Final report received SC68c |
| | | | **TOTAL** | **129,955** | |

## IWC-SORP FUNDED RESEARCH PROJECT PROGRESS REPORTS

Progress reports for the IWC-SORP Research Fund funded projects follow. In some instances, only brief summaries are provided because projects either the reader is guided toward separate, more detailed, primary papers submitted to the IWC Scientific Committee for consideration or the COVID-19 pandemic has led to the postponement of research activities and difficulties in providing detailed reports.

### PROJECT 11 (Baker et al., 2018/19). Is migratory connectivity of humpback whales in the Central and Eastern South Pacific changing? A decadal comparison by DNA profiling

*C. Scott Baker[1], Debbie Steel[1], Ari Friedlaender[2], Renee Albertson[3], Michael Poole[4], Susana Caballero[5], Logan Pallin[2], Jooke Robbins[6], Ana Lúcia Cypriano-Souza[7], Rochelle Constantine[8]*

*1. Marine Mammal Institute, Oregon State University, 2030 SE Marine Science Drive, Newport, OR 97365, USA*
*2. Ecology and Evolutionary Biology, UC Santa Cruz, 115 McAllister Way, Santa Cruz, CA 95060, USA*
*3. Department of Fisheries and Wildlife, Oregon State University, 2030 SE Marine Science Drive, Newport, OR 97365, USA*
*4. Marine Mammal Research Program, BP 698, Marharepa, Moorea 98728, French Polynesia*
*5. Departamento de Ciencias Biológicas, Universidad de los Andes, Carrera 1 # 18 A-10, Bogotá, Colombia*
*6. Center for Coastal Studies, 5 Holway Avenue, Provincetown, MA 02657, USA*
*7. Pontifical Catholic University of Rio Grande do Sul, Imbuia Street 13, Coqueiral-Aracruz 29190-066, ES, Brazil*
*8. School of Biological Sciences, University of Auckland, Private Bag 92019, Auckland, New Zealand*

**Executive summary**

We have now integrated existing DNA profiles of humpback whales from the South Pacific and Southern Ocean into a single, curated DNA register, representing more than 5000 individuals.

**Introduction**

Humpback whales wintering along the Pacific coast of South America, referred to as Breeding Stock G (BSG) are unusual in having well-defined migratory destinations near the western Antarctic Peninsula (AP) and in their degree of genetic differentiation from other breeding stocks in Oceania and the South Atlantic. However, the extent of this isolation might be changing as populations are increasing at variable rates, perhaps encouraging individual whales to explore alternate migratory destinations. Here we report initial progress on the investigation of decadal changes in connectivity between BSG and the 'adjacent stocks' of Oceania using DNA profiling, including sex and 10-15 microsatellites for individual identification and sequencing of the mtDNA haplotype for maternal lineages. For this, we are building on efforts of the South Pacific Whale Research Consortium and collaborators in assembling a 'DNA register' of profiles representing 2,104 individual humpback whales sampled on wintering grounds and in the Antarctic from 1991 to 2005.

**Objectives**

1. Update the existing DNA register of humpback whales in the South Pacific with recently available DNA profiles and complete analysis of existing samples, for an anticipated grand total of more than 4,500 individual DNA profiles;
2. Reconcile matching DNA profiles (capture-recapture) from the updated register, to document migratory interchange, with an emphasis on Oceania and BSG, including the Antarctic Peninsula;
3. Update mixed-stock analysis of humpback whales from the Antarctic Peninsula, to estimate the allocation of whales from Oceania (BSE and BSF) and those from BSG, using Brazil (BSA) as an outgroup;

4. Compare rates of interchange and mixed-stock allocation for two approximately decadal periods, 1991-2005 and 2006-2016, to look for changes in connectivity; and,
5. Provide information on individual identification and sex to regional collaborators and contribute to related IWC-SORP programs, including the previously funded 'The Great Humpback Whale Trail' and the proposed 'Rates of pregnancy in humpback whales in the Southern Ocean'.

**Results (against objectives)**

A detailed report of the final results of this study can be found in SC/68d/SH07.

**a)** The DNA register has been updated and now represents a total of over 5000 DNA profiles. This includes collaborative contributions of unanticipated samples collected in Panama (courtesy K. Rasmussen) and in the Pitcairn Islands (courtesy T. Dawson) as well as an additional year of sampling in Colombia (courtesy S. Caballero). These samples increased the geographic coverage and improved the genetic resolution of BSG.

**b)** A total of 21 records of migratory interchange were documented between the Antarctic Peninsula and either Colombia (BSG) or French Polynesia and American Samoa (BSF).

**c)** Mixed-stock analyses apportioned the majority of the Antarctic Peninsula to BSG with some evidence of a small (<5% total) apportionment to BSA, BSE and BSF.

**d)** The decadal comparison shows remarkable stability in the frequencies of mtDNA haplotypes across the almost 30 yr sampling period.

**e)** Information on individual identification and sex was provided to regional collaborators and to Principal Investigators of related IWC-SORP programs, including the 'The Great Humpback Whale Trail' (R. Constantine); 'Rates of pregnancy in humpback whales in the Southern Ocean' (A. Friedlaender, L. Pallin) and 'Who are the real East Australian (E1) breeding group of humpback whales' (D. Paton and C. Garrigue). The results of these SORP collaborations resulted the project outputs listed below.

**Project outputs**

*Primary papers (*Collaborative analyses and publications with other IWC-SORP partners)

Caballero S, Steel D, Pallin L, Botero-Acosta N, Felix F, Olavarría C, Diazgranados MC, Bessudo S, Friedlander A, Baker CS (2021) Migratory connections among breeding grounds off the Eastern Pacific and feeding areas in the Antarctic Peninsula based on genotype matching. Bulletin of Marine and Coastal Reserch-Invemar 50: 31-40.

Garrigue C, Derville S, Bonneville C, Baker CS, Cheeseman T, Millet L, Paton D, Steel D (2020) Searching for humpback whales in a historical whaling hotspot of the Coral Sea, South Pacific. Endangered Species Research 42: 67-82.

*Meeting presentations*

An update on samples and preliminary results of migratory interchange was presented to regional collaborators at the 2019 and 2021 meetings of the South Pacific Whale Research Consortium, 4-6 February 2019 (Auckland, New Zealand) and 1-4 February 2021 (held virtually).

Final results of migratory interchange were presented to regional collaborators at the 2022 meeting of the South Pacific Whale Research Consortium (held virtually, 28 – 31 March, 2022).

**PROJECT 13 (Branch, 2018/19). Modelling somatic growth and sex ratios to predict population-level impacts of whaling on Antarctic blue whales**

*Professor Trevor Branch*[1]

*1. School of Aquatic and Fishery Sciences, university of Washington, Seattle, WA 98195, USA*

## Executive summary

The examination of sex ratios of Antarctic blue whales both foetal and postnatal, is completed and published. A model of foetal growth has been developed but fitting this to the available data has been challenging, given a multimodal likelihood surface. A length-based simulation model was also developed and included in the sex ratio paper, however, this has not been extended yet to examine the impact of whaling on mean length of Antarctic blue whales.

## Introduction

Antarctic blue whales were whaled to near extinction, declining to just 0.15% of pre-whaling levels (Branch et al. 2004, Branch 2008). Despite extensive length data for both foetuses and from whales caught during whaling, a length-based model has never been developed for this population that takes into account the different growth rates among sexes, and explores how lengths may have been impacted by whaling and the subsequent recovery period post-whaling. This project aims to fill that gap.

## Objectives

The proposed project on Antarctic blue whales is intended to:

1) assess sex ratios in both foetuses and in the population as a whole;
2) build somatic growth models from conception to birth, and from birth to physical maturity; and
3) predict changes in length distributions of Antarctic blue whales during decline and recovery periods.

## Results

*Sex ratios among catches (postnatal)*

This portion of the project is described at length in the 2021 report, and is now published (Branch & Monnahan 2021).

*Conceptual model of adult growth rates*

A conceptual model of adult growth in length was developed as part of the sex ratio paper (Branch & Monnahan 2021) and is described at length in the 2021 report. Work is planned to project this conceptual model to account for the impact of whaling on length frequencies.

*Model of foetal growth rates*

Data show clear patterns of foetal growth by day of the year in catches of Antarctic blue whales (Figure 1). A Bayesian model developed in the software package Stan has been created, as detailed below, but the many missing days of data (in winter months when few foetal data are available) results in some model fitting issues which have yet to be resolved. The model fitting is difficult because the likelihood surface appears to be multimodal.

The model is developed under the following general assumptions, developed in more detail below: (1) conception dates are drawn from a distribution of dates, (2) foetal growth roughly follows a power model, or similar model. (3) There is a period of time between conception and implantation during which it is not possible to detect the embryo since it is too small to detect and has not attached to the placenta. (4) Small foetuses, after implantation, are less likely to be detected than large foetuses. (5) Large foetuses disappear from the foetal data through a combination of birth and emigration of mothers from the Antarctic to dispersed temperate calving regions.

1) Conception dates are assumed to come from a normal distribution with estimated parameters μconc and σconc. This seems to be a reasonable assumption given that there is a clear mode of foetal lengths by day of the year, and given the wide distribution of foetal lengths at a given day of the year.
2) Power model of growth: foetal growth in length (L, cm) is assumed to follow a power model: L = a(d - dconc - timplant)b where a and b are constants to be estimated, d is the day of the year, dconc is the conception date in days of the year, and dimplant is the number of days from conception to implantation. It is assumed that there is a small amount of variability in length (a fixed CV of 4%) based on variability in length at age for human foetuses. Alternative models of growth that have been applied to foetal growth in whales include exponential, two-phase, von Bertalanffy, and Gompertz. All these models offer similar predictions.
3) Pre-implantation period: after fertilization (conception), it takes some time for the fertilized cell to form a blastula, implant in the placenta, and grow to a size where it can be detected when conducting biological examinations. This period is assumed to be 30 days in the model, but could be shorter based on data from a wide variety of other species. The smallest detected blue whale fetus was 6.5 mm (Gill 1926).
4) Lower detectability of small foetuses: it is well known that small foetuses (even after implantation) were missed when examining blue whales. I assume that detectability is model by a logistic function with two estimated parameters, L50 and L95, at which 50% and 95% of foetuses were detected.
5) Birth process: I assume that birth (or emigration from the Antarctic) results in larger foetuses disappearing from the foetal data, and that this can be modelled by a logistic function with two estimated parameters B50 and B95, representing the lengths at which 50% and 95% of foetuses are born (or their mothers emigrate).

The model is implemented by combining the proportion of foetuses conceived on a given day of the year, and the predicted length of foetuses born on each day of the year, together with the pre-implantation period, lower detectability of small foetuses, and birth process. This results in a predicted proportion of foetuses at each length on each day of the year that is compared to the observed data. The model is implemented in the Bayesian software package Stan [], which promises faster convergence using the no-U-turn sampler (NUTS) (Monnahan et al. 2017). At this time, however, Bayesian convergence has proven elusive despite the relatively small number of parameters in the model (n = 9).

One intended application of this model is to address whether blue whales in the northern Indian Ocean have a breeding season that is 6 months out of phase with Southern Hemisphere blue whale populations, as suggested by Mikhalev (2000). Applying the model with 50% of births following the SH pattern, and 50% being 6 months out of phase (NH pattern), yields Figure 3, suggesting that it should be possible to adjust the Antarctic foetal model to apply it to the northern Indian Ocean, and estimate the proportion of fetuses that are conceived following SH, NH, or constant year-round conception patterns.

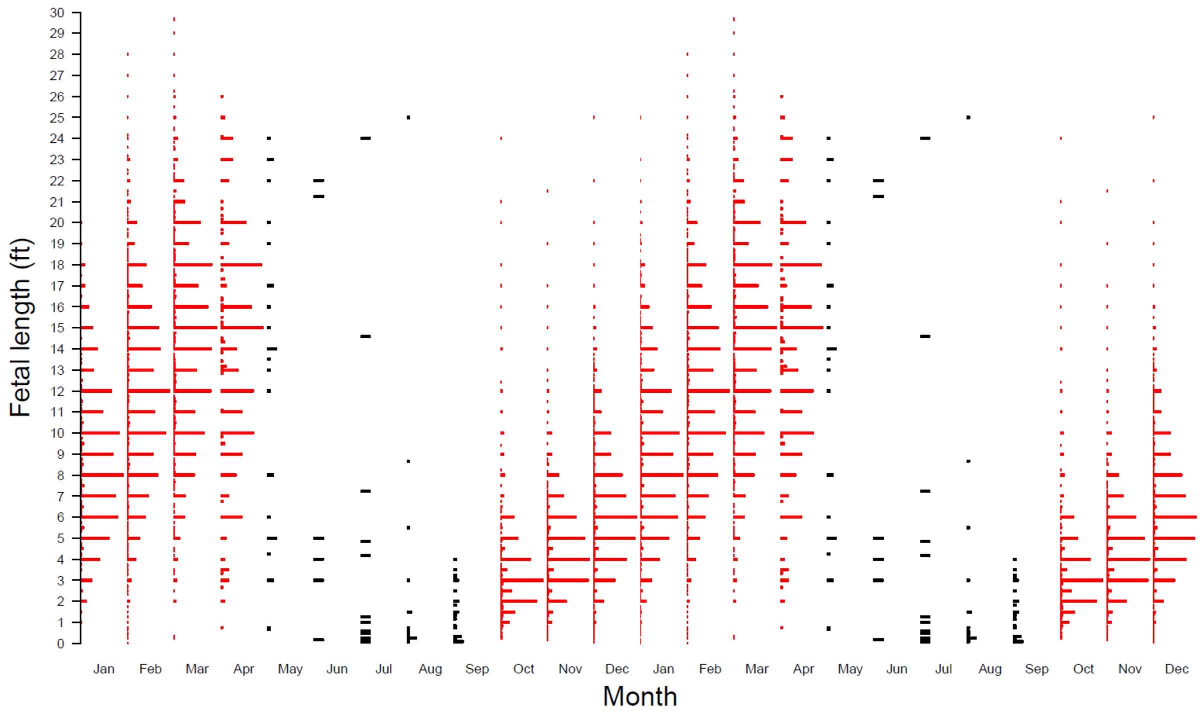



**Figure 1** Histograms of foetal lengths for Antarctic blue whales by month, showing that most data were rounded to the nearest whole foot. For months with fewer than 30 data points, the heights of the bars are reduced by a factor of five and plotted in black. The data are repeated twice from left to right to more clearly see the pattern of foetal growth. Branch (unpublished).

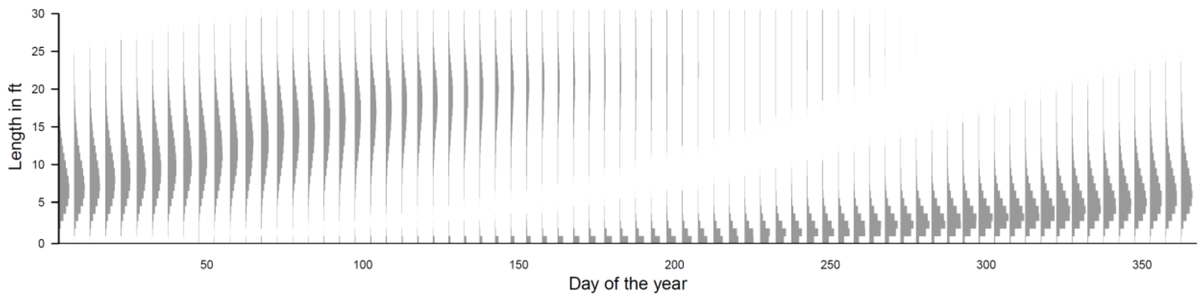



**Figure 2** Example output from the foetal growth model, assuming Southern Hemisphere conception dates. Branch (unpublished).

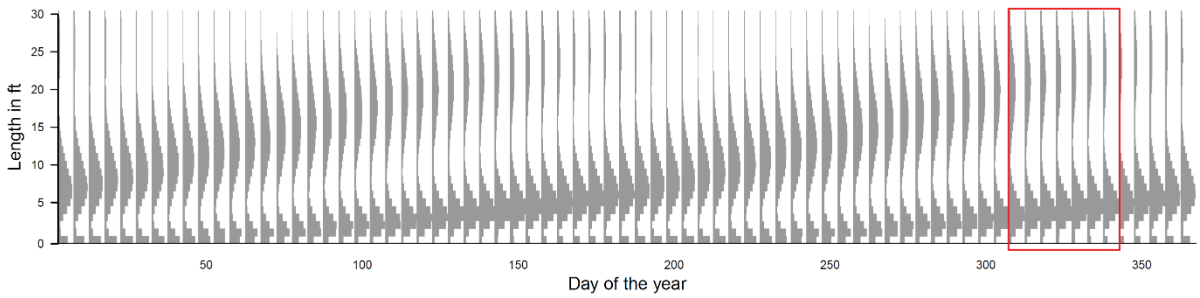



**Figure 3** Example of model output that could be used to model the northern Indian Ocean population, showing foetal growth if 50% of foetuses followed Southern Hemisphere conception dates and 50% were six months out

of phase (NH conception dates). Foetal data in that region were collected entirely in November (red box) by Soviet vessels en route to the Antarctic.

**Conclusions**

Problems with model convergence preclude making conclusions about foetal growth in Antarctic blue whales, but it is hoped this will be corrected in time for an SC publication. The model work does raise interesting questions about missing portions of the data set, especially regarding the time between conception and implantation, the effects of detectability, and the relative influence of birth and emigration on foetal growth data.

**Challenges**

COVID continues to disrupt time available in completing this work, preparing SC documents and publishing results. Notably, teaching has shifted from in person to online, to hybrid, to pre-recorded with in-person discussions. Unfortunately this resulted in predictions of changes in length distributions of Antarctic blue whales during decline and recovery periods remaining unaddressed.

In addition, recoding the foetal growth model from R to Stan did not result in the hoped-for rapid convergence of the Bayesian model, and this portion of the project remains in-progress.

**Outlook for the future**

It is hoped that the foetal growth model will reach convergence soon, and the predictions of changes in length distribution due to whaling can be addressed in the coming year.

**Project outputs**

*Peer-reviewed papers*

Branch TA, Monnahan CC (2021) Sex ratios in blue whales from conception onward: effects of space, time, and body size. Marine Mammal Science 37:290-313

Calderan SV, Black A, Branch TA, Collins MA, Kelly N, Leaper R, Lurcock S, Miller BS, Moore M, Olson PA, Širović A, Wood AG, Jackson JA (2020) South Georgia blue whales five decades after the end of whaling. Endangered Species Research 43: 359-373.

Pastene LA, Acevedo J, Branch TA (2020) Morphometric analysis of Chilean blue whales and implications for their taxonomy. Marine Mammal Science 36: 116-135.

Rojas-Cerda C, Buchan SJ, Branch TA, Malige F, Patris J, Staniland L, Pangerc T (2022 accepted) Presence of Southeast Pacific blue whales (Balaenoptera musculus) off South Georgia in the South Atlantic Ocean. Endangered Species Research

Zhong M, Torterotot M, Branch TA, Stafford KM, Royer J-Y, Dodhia R, Ferres JL (2021) Detecting, classifying, and counting blue whale calls with Siamese neural networks. Journal of the Acoustical Society of America 149: 3086-3094.

*IWC/SC papers*

Branch TA (2020) Assignment of South Georgia catches between Southeast Pacific blue whales and Antarctic blue whales. IWC paper SC/68b/SH/16.

Branch TA, Monnahan CC (2020) Sex ratios in blue whales from conception onward: a comparative analysis across space, time, and size. IWC paper SC/68b/SH01. 24 pp.

Branch TA (2021) Little evidence for interchange between north-east Pacific and south-east Pacific blue whale populations despite morphological similarities. IWC paper SC/68c/SH/20

Branch TA, Monnahan CC, Širović A, Al Harthi S, Allison C, Balcazar NE, Barlow DR, Calderan S, Cerchio S, Double MC, Dréo R, Gavrilov AN, Gedamke J, Hodge KB, Jenner KCS, Leroy EC, McCauley RD, Miksis-Olds JL, Miller BS, Panicker D, Rogers T, Royer J-Y, Samaran F, Shabangu FW, Stafford KM, Thomisch K, Torres LG, Torterotot M, Tripovich JS, Warren VE, Willson A, Willson MS (2021) Monthly movements and historical catches of pygmy blue whale populations inferred from song detections. IWC paper SC/68c/SH/17

Lang AR, Archer FI, Attard C, Baker CS, Branch TA, Brownell Jr RL, Buss D, Jackson J, Kelly N, Moller L, Olson P, Sirovic A, Sremba A (2020) Evaluating the evidence for population structure within Antarctic blue whales. IWC paper SC/68b/SH/03. 23 pp.

*Presentations*

*Popular talk*: Branch TA. *A glimmer of hope for Antarctic blue whales: the largest of them all*. Monterey Bay chapter of the American Cetacean Society, December 2020.

*Popular talk*: Branch TA. *Sex ratios in blue whales from conception onward: effects of space, time, and body size*. Marine Mammal Science Editors' Select Series, January 2021.

*Popular talk*: Branch TA. *A glimmer of hope for Antarctic blue whales*. San Diego chapter of American Cetacean Society, 9 June 2021.

*Popular talk*: Branch TA. *How many and where were they? The value of sightings and other data in assessing status of marine mammals*. Virtual gear-down workshop for marine naturalists, The Whale Museum, 13 November 2021.

*Popular talk*: Branch TA. *Blue whales: in crisis or increases?* Bevan Series: Living with Marine Mammals, School of Aquatic and Fishery Sciences, 6 January 2022.

*Social media*

Science outreach: the PI uses social media (Twitter, @bluewhalenews) extensively to post about his research on blue whales, and other blue whale papers published each month. On average this activity amounted to 20 tweets per month, and over the course of the project so far (May 2019-present) these tweets have been viewed 936,000 times.

**Scientific references cited in report**

Branch TA (2008) Current status of Antarctic blue whales based on Bayesian modeling. IWC paper SC/60/SH7

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

Branch TA, Monnahan CC (2021) Sex ratios in blue whales from conception onward: effects of space, time, and body size. Marine Mammal Science 37: 290-313

Gill EL (1926) An early embryo of the blue whale. Transactions of the Royal Society of South Africa 14:295-300

Monnahan CC, Thorson JT, Branch TA (2017) Faster estimation of Bayesian models in ecology using Hamiltonian Monte Carlo. Methods in Ecology and Evolution 8:339-348

**PROJECT 14 (Friedlaender et al., 2018/19). Pregnancy rates in Southern Ocean humpback whales: implications for population recovery and health across multiple populations**

*Ari Friedlaender[1], Rochelle Constantine[2], Jooke Robbins[3], C. Scott Baker[4], Claire Garrigue[5], Logan Pallin[1]*

*1. Ecology and Evolutionary Biology, UC Santa Cruz, 115 McAllister Way, Santa Cruz, CA 95060, USA*
*2. Center for Coastal Studies, 5 Holway Avenue, Provincetown, MA 02657, USA*
*3. School of Biological Sciences, University of Auckland, Private Bag 92019, Auckland, New Zealand*
*4. Marine Mammal Institute, Oregon State University, 2030 SE Marine Science Drive, Newport, OR 97365, USA*
*5. Institute of Research for Development, Centre Nouméa, 101 av, Roger Laroque, Anse Vata, BP A5. 98848, Nouméa, New Caledonia*

## Executive summary

Little is currently known about the post-exploitation reproductive dynamics and pregnancy rates of Southern Hemisphere baleen whales. Understanding reproductive rates will provide insight into the population health and recovery of these species. Biochemical methods for studying pregnancy in free-ranging humpback whales have been developed and validated. Results show that there is an average 50% pregnancy rates of humpback whales in the West Antarctic Peninsula, and similar findings from whales in the Ross Sea and from the southern migratory corridor of the Kermadec Islands. The fluctuation is interesting and will be important in future work to map prey availability, habitat choice and reproductive success of these whales. The variation in hormone levels is an important finding for ascertaining research seasons in the future.

## Introduction

Estimates of pregnancy rates can indicate population status, health, and growth; important details for understanding population recovery from recent or historical exploitation. Around the Southern Ocean, recovering populations of humpback whales are recolonizing feeding grounds in the Antarctic and sub-Antarctic (Gales et al. 2011; Johnson et al. 2011). Unfortunately, little is currently known about their pregnancy and reproductive dynamics, apart from data evaluated during the height of whaling in the early 20th century (Chittleborough 1965; Symons et al. 1958).

Gross reproductive rates have been estimated for some humpback whale populations from analysis of long-term sighting histories of mature females (Clapham & Mayo 1990; 1987; Glockner-Ferrari & Ferrari 1990; Herman et al. 2011; Gabriele et al. 2017; Chero 2017) however, almost all of these studies are in the Northern Hemisphere. In these studies, estimates of reproductive rates were generated through repeated observations of known adult females with and without calves (Clapham & Mayo 1987; Glockner-Ferrari & Ferrari 1990). This approach is helpful in estimating the number of recruits entering a population, but without correction, inherently underestimates true fecundity rate, because it does not account for perinatal mortality. It also provides limited insight into the underlying processes of reproduction and the potential for population growth under changing ecological conditions. Alternatively, pregnancy status has been determined more directly in marine mammals by measuring the concentration of steroid hormones from several biological matrices (Atkinson et al. 1999; Pietraszek & Atkinson 1994; Walker et al. 1988; Wells et al. 2000; West et al. 2000.  However, such methods are not practical for use with large, free-swimming whales. The measurement of progesterone in samples collected in the field from whales, such as faecal material (Rolland et al. 2005), blow (Hogg et al. 2009; Hunt et al. 2014), and skin biopsies (Trego et al. 2013; Mansour et al. 2002; Kellar et al. 2006), offers a pragmatic alternative.

Progesterone is a lipophilic circulatory steroid hormone produced by the reproductive system to help regulate pregnancy (Pineda 2003).  Progesterone's lipophilic properties make skin-blubber biopsy samples a readily obtainable, non-lethal, analytical matrix for assigning pregnancy in wild cetaceans. Due to the relative ease of collection, high sampling rate, and capacity to archive samples over time, assessing pregnancy via collection of biopsy samples provides a unique opportunity to measure this vital demographic parameter in Southern Hemisphere humpback whales overtime (Hunt et al. 2013).

**Objectives**

1. Collect biopsy samples throughout the breeding and feeding season to quantify progesterone, a lipophilic sex steroid hormone, in order to determine pregnancy in sampled female humpback whales across a number of breeding and feeding sites in the Southern Hemisphere.
2. Assess the inter-annual and seasonal variation in the rates of pregnant females across all sampled sites.
3. Assess the seasonal variation in progesterone concentrations relative to estimated peak conception and parturition.

**Results**

Progesterone analyses have been focused on samples from humpback whales on the breeding grounds (New Caledonia and American Samoa), migratory pathways (Kermadec Islands and mainland New Zealand) and feeding grounds (West Antarctic Peninsula (WAP) and Ross Sea). Feeding areas and migration pathways were characterised by a high proportion of pregnant females (Figure 1). Within the New Caledonia breeding ground, research to date has focused 199 samples from 2016-2019 that have been quantified and extracted. Preliminary analyses reveal patterns of progesterone, testosterone and oestradiol consistent with sex- and age-class (Figure 2). Additionally, we observed variation relative to basic oestrus cycles across the season (Figure 3). Specifically, we may be seeing follicular activity (high oestrogen) in the early season followed by corpus luteum activity (progesterone) increasing at least in the first month of sampling and then potentially a second phase of follicular activity at the end of the season. To our knowledge, this is the first documentation of these cycles in live baleen whales. However, more work and analyses are underway to better understand these temporal and population endocrine dynamics on the breeding ground which will better inform our interpretation of these hormone levels while they are on their Southern Ocean feeding grounds (see Pallin et al., 2018).

We have now characterised a nine-year temporal analysis of female humpback whales along the WAP (Figure 1 in blue). This feeding aggregation is still characterised by a high proportion of pregnant females (50%). Additional work is currently underway to explore the relationship between environmental cues and the observed pregnancy rates.

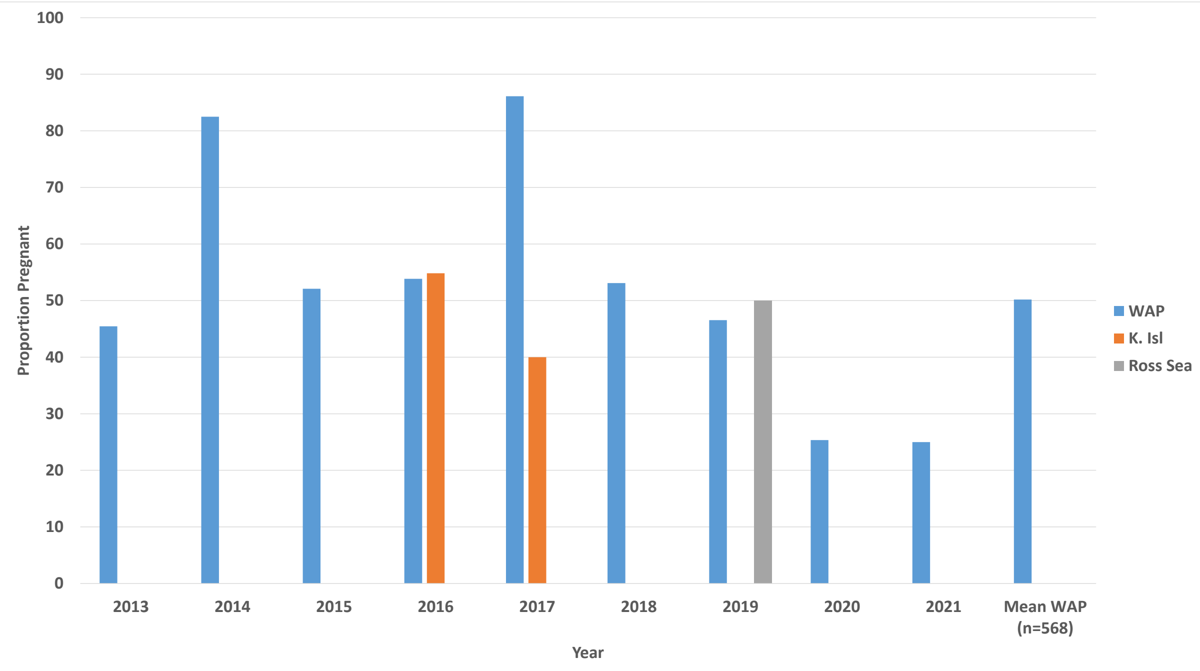



**Figure 1** Inter-annual variation in the pregnancy rate of female humpback whales sampled along the Western Antarctic Peninsula (WAP), the Kermadec Islands, and in the Ross Sea.

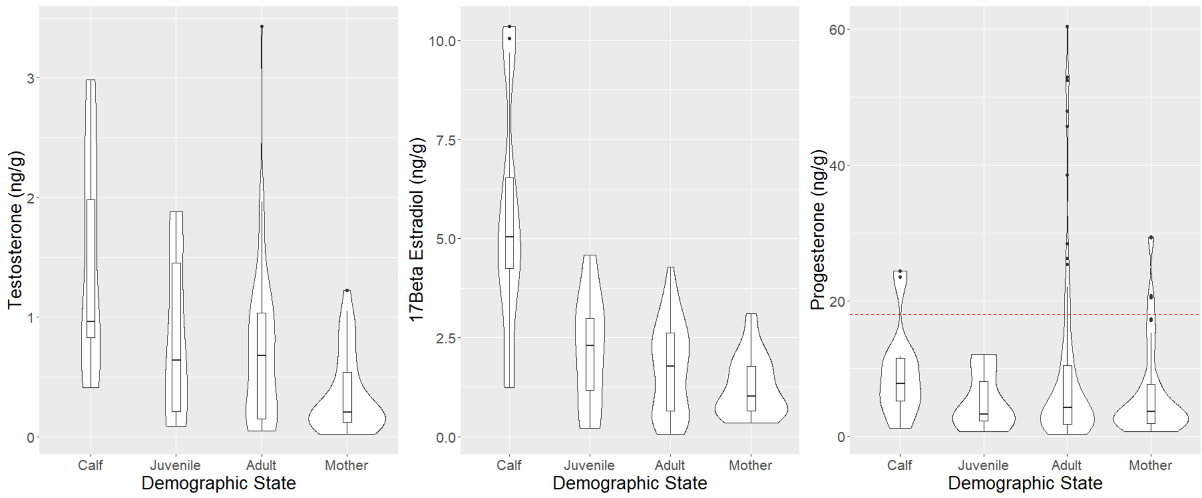



**Figure 2** Demographic variation in testosterone (ng/g), 17β-oestradiol (ng/g) and, progesterone (ng/g) among female humpback whales sampled on the New Caledonia breeding ground. The red line in the progesterone plot designates levels indicative of pregnancy based on Pallin et al. (2018).

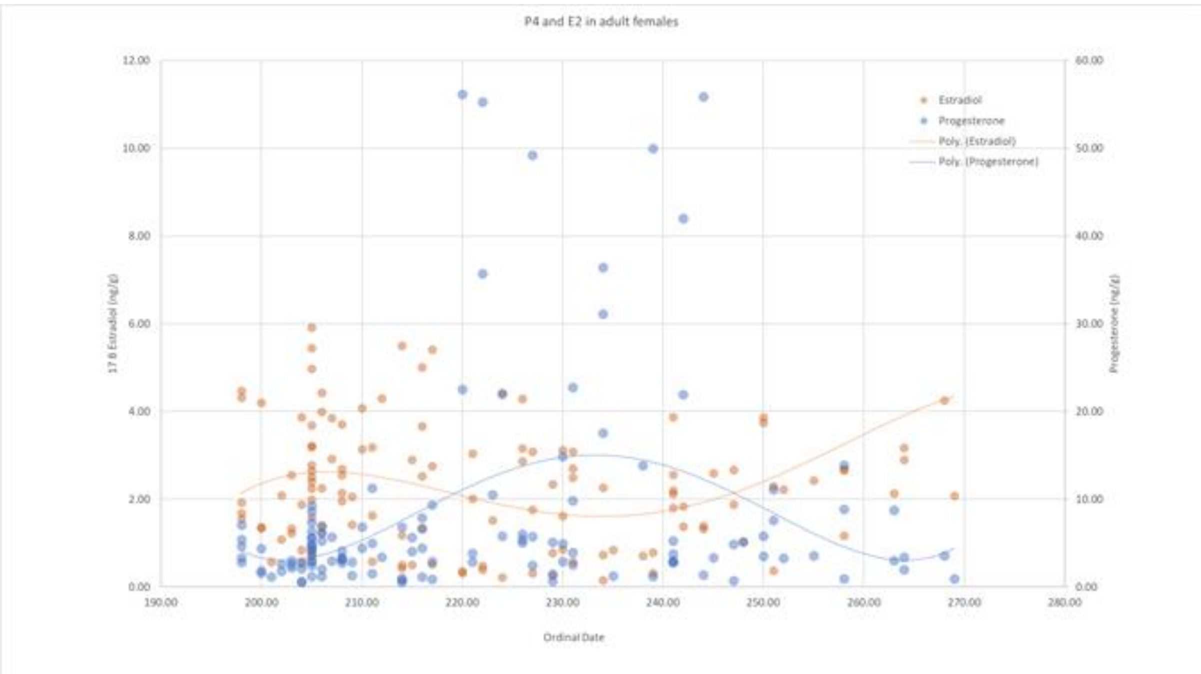



**Figure 3** Temporal variation in 17β-oestradiol (ng/g) and progesterone (ng/g) across the New Caledonia breeding season.

## Conclusions

There is an average 50% pregnancy rates of humpback whales in the West Antarctic Peninsula, and similar findings from whales in the Ross Sea and from the southern migratory corridor of the Kermadec Islands (see also report from Friedlaender, Pallin et al. 2022, SH/68d/SH07). The fluctuation is interesting and will be important in future work to map prey availability, habitat choice and reproductive success of these whales. The variation in hormone levels is an important finding for ascertaining research seasons in the future.

COVID-19 has slowed progress on this project but it is still producing valuable outputs for our understanding of humpback whales in the Southern Ocean.

**Outlook for the future**

We now have the opportunity for the IWC-SORP Humpback Whale Connectivity Theme research (see also SC/68d/SH07) to move to another ocean basin. The circum-polar analysis of tag data establishes a platform upon which we can use changes in Southern Ocean productivity to understand the future mixing of stocks and movements of whales. The large, collaborative partnerships formed within the Theme, alongside well established regional collaborations in other regions mean there is a bright future for data sharing and open access arrangements to inform management of humpback whales into the future.

**Project outputs**

*Conference presentations*

Logan J. Pallin, C. Scott Baker, Debbie Steel, David W. Johnston, Doug P. Nowacek, Andrew J. Read, Nick Kellar, Megan Cimino, Ari S. Friedlaender. (2019) Ecological drivers of reproductive rates in humpback whales (*Megaptera novaeangliae*) along the Western Antarctic Peninsula. 2019 World Marine Mammal Conference, 13-17 December, Barcelona, Spain (Oral).

*Students and theses*

**Logan Pallin**. Using tissue biomarkers to better understand the population demography and recovery of historically extirpated baleen whales in a rapidly changing ecosystem. PhD Thesis ongoing. NSF Graduate Research Fellow, Bio-Telemetry & Behavioral Ecology Laboratory, Department of Ecology and Evolutionary Biology, University of California, Santa Cruz.

**Scientific references cited in report**

Atkinson S et al. (1999) Monitoring of progesterone in captive female false killer whales, *Pseudorca crassidens*. General and comparative endocrinology. 115(3): 323-332.

Chero G (2017) Dynamique de population liée au comportement de reproduction des baleines à bosse de Nouvelle-Calédonie., in Ecologie Biodiversité Evolution. Université Pierre et Marie Curie.

Chittleborough R (10965) Dynamics of two populations of the humpback whale, *Megaptera novaeangliae* (Borowski). Marine and Freshwater Research 16(1): 33-128.

Clapham PJ, Mayo CA (1987) Reproduction and recruitment of individually identified humpback whales, *Megaptera novaeangliae*, observed in Massachusetts Bay, 1979-1985. Canadian Journal of Zoology 65(12): 2853-2863.

Clapham PJ, Mayo CA (1990) Reproduction of humpback whales (*Megaptera novaeangliae*) observed in the Gulf of Maine. Rep. Int. Whal. Commn. (Special) 12: 171-175.

Gabriele CM et al. (2017) Natural history, population dynamics, and habitat use of humpback whales over 30 years on an Alaska feeding ground. Ecosphere 8(1).

Gales N, IWC (2011) Humpback whales: status in the southern hemisphere: International Whaling Commission.

Glockner-Ferrari DA, Ferrari MJ (1990) Reproduction in the humpback whale (*Megaptera novaeangliae*) in Hawaiian waters, 1975–1988: the life history, reproductive rates and behavior of known individuals identified through surface and underwater photography. Reports of the International Whaling Commission 12: 161-169.

Herman LM et al. (2011) Resightings of humpback whales in Hawaiian waters over spans of 10–32 years: Site fidelity, sex ratios, calving rates, female demographics, and the dynamics of social and behavioral roles of individuals. Marine Mammal Science 27(4):m736-768.

Hogg C et al. (2009) Determination of steroid hormones in whale blow: It is possible. Marine Mammal Science 25(3): 605-618.

Hunt KE et al. (2013) Overcoming the challenges of studying conservation physiology in large whales: a review of available methods. Conservation Physiology 1(1): cot006.

Hunt KE, Rolland RM, Kraus SD (2014) Detection of steroid and thyroid hormones via immunoassay of North Atlantic right whale (*Eubalaena glacialis*) respiratory vapor. Marine Mammal Science 30(2): 796-809.

Johnston S, Zerbini AN, Butterworth DS (2011) A Bayesian approach to assess the status of Southern Hemisphere humpback whales (*Megaptera novaeangliae*) with an application to breeding stock G. Journal of Cetacean Research and Management (special issue) 3: 309-18.

Kellar NM et al. (2006) Determining pregnancy from blubber in three species of delphinids. Marine Mammal Science 22(1): 1-16.

Mansour AA et al. (2002) Determination of pregnancy status from blubber samples in minke whales (*Balaenoptera acutorostrata*). Marine Mammal Science 18(1): 112-120.

Pallin LJ et al. (2018) High pregnancy rates in humpback whales (*Megaptera novaeangliae*) around the Western Antarctic Peninsula, evidence of a rapidly growing population. Royal Society Open Science 5(5).

Pietraszek J, Atkinson S (1994) Concentrations of estrone sulfate and progesterone in plasma and saliva, vaginal cytology, and bioelectric impedance during the estrous cycle of the Hawaiian monk seal (*Monachus schaunslandi*). Marine Mammal Science 10(4): 430-441.

Pineda M (2003) Female reproductive system. In: Veterinary endocrinology and reproduction. 2003, Iowa State Press, 293-341.

Riekkola L et al. (2018) Application of a multi-disciplinary approach to reveal population structure and Southern Ocean feeding grounds of humpback whales. Ecological Indicators 89: 455-465.

Reisinger RR, Friedlaender AS, Zerbini A, Palacios D, Andrews-Goff V, Dalla Rosa L, Double M, Findlay K, Garrigue C, How J, Jenner C, Jenner M-N, Mate B, Rosenbaum H, Seakamela SM, Constantine R (2021) Combining regional habitat selection models for large-scale prediction: circumpolar habitat selection of Southern Ocean humpback whales. Remote Sensing, 13(11): 2074. https://doi.org/10.3390/rs13112074

Reisinger RR, Zerbini A, Friedlaender AS, Andrews-Goff V, Dalla Rosa L, Double M, Findlay K, Garrigue C, How J, Jenner C, Jenner M-N, Mate B, Palacios D, Rosenbaum H, Seakamela SM, Constantine R. (Under revision) A circumpolar analysis of habitat-use variation among humpback whales in the Southern Ocean.

Rolland RM et al. (2005) Assessing reproductive status of right whales (*Eubalaena glacialis*) using fecal hormone metabolites. General and Comparative Endocrinology 142(3): 308-317.

Symons H, Weston R, Weston R (1958) Studies on the humpback whale (*Megaptera nodosa*) in the Bellingshausen Sea. Nor. Hvalfangst Tid 47: 53-81.

Trego ML, Kellar NM, Danil K (2013) Validation of blubber progesterone concentrations for pregnancy determination in three dolphin species and a porpoise. PloS one 8(7): e69709.

Walker L et al. (1988) Urinary concentrations of ovarian steroid hormone metabolites and bioactive follicle-stimulating hormone in killer whales (*Orcinus orca*) during ovarian cycles and pregnancy. Biology of Reproduction 39(5): 1013-1020.

Wells RS et al (2014) Fetal survival of common bottlenose dolphins (*Tursiops truncatus*) in Sarasota Bay, Florida. Aquatic Mammals 40(3): 252.

West K et al. (2000) Concentrations of progesterone in milk from bottlenose dolphins during different reproductive states. General and Comparative Endocrinology. 117(2): 218-224.

**PROJECT 15 (Herr et al., 2018/19). Recovery status and ecology of Southern Hemisphere fin whales (*Balaenoptera physalus*) – Western Antarctic Peninsula**

*Helena Herr[1], Sacha Viquerat[2], Simone Panigada[3], Bettina Meyer[4], Anna Panasiuk[5], Natalie Kelly[6], Jennifer Jackson[7], Paula Olson[8], Dr Ursula Siebert[2]*

*1. University of Hamburg, Centre of Natural History (CeNak), Martin-Luther-King-Platz 3, 2-146, Hamburg, Germany*
*2. University of Veterinary Medicine, Hannover (TiHo), Werfstrasse 6, 25761 Büsum, Germany*
*3. Tethys Research institute, Viale G.B. Gadio, 20121 Milan, Italy*
*4. Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Am Handelshafen 12, 27570 Bremerhaven, Germany*
*5. University of Gdansk, Institute of Oceanography, Al. J.M. Pilsudskiego 46, 81-378 Gdynia, Poland*
*6. Australian Marine Mammal Centre, Australian Antarctic Division, 203 Channel Highway, Kingston, Tasmania 7050, Australia*
*7. British Antarctic Survey, High Cross, Madingley Road, Cambridge, CB30ET, UK*
*8. Southwest Fisheries/NMFS/NOAA, 8901 La Jolla Shores Drive, La Jolla, CA 92037, USA*

**Executive summary**

During the third year of the project, the joint analysis of compiled fin whale data sets was finalised. A manuscript detailing the analysis and results has been drafted and revised by all contributors and will be submitted to the journal Frontiers in Marine Science' after a final circulation at the end of April.

Remaining funds from the research cruise MSM90 – FINWAP of *RV Maria S. Merian*, originally planned for March/April 2020 and cancelled on short-notice due to the COVID-19 pandemic, were used to fund a scientist to join a media cruise to Elephant Island with the opportunity to tag fin whales. Four animals were successfully tagged and tracked, providing first insights into migratory movements of fin whales feeding at the Antarctic Peninsula.

In March 2022, we were informed that the FINWAP cruise has been rescheduled for February/March 2023. We therefore intend to extend the project duration for another year to allow for collection of data during the voyage and analysis thereafter as part of this project.

A network of Southern Hemisphere fin whale researchers has been established, forming an excellent basis for exchange of information and future collaboration.

**Introduction**

Southern Hemisphere fin whales (SHFW) were the most numerously exploited whale species in the Southern Ocean during the commercial whaling period, reduced to app. 2% of their pre-whaling population size (Clapham and Baker 2002). Catch numbers suggest that they once were one of the most abundant Southern Hemisphere whale species. Very little dedicated research has been conducted on fin whales in the Southern Hemisphere since the termination of commercial whaling and little is known about their population status and ecology. High densities of fin whales and re-occurring feeding aggregations recently observed the Western Antarctic Peninsula (WAP) suggest a return of fin whales to this area and may provide indication for population recovery (Herr et al. accepted). However, information on larger scale distribution and movements of these fin whales is lacking. In this project, we aim to collate all available data on fin whale sightings from dedicated as well as opportunistic data collections in the Scotia Sea and Antarctic Peninsula Region. We want to use these data to gain information on distribution and abundance and seasonal movements. Furthermore, we aim to collect genetic samples from the fin whales feeding at the Antarctic Peninsula to gain information on population structure, and by deployment of satellite tags we want to track their movements and to follow them after leaving the feeding area.

**Objectives**

The specific objectives of the project are:

i. Compilation and analysis of existing data on fin whales from the WAP and Scotia Sea region for background information on spatio-temporal distribution, density and movements during past years.
ii. Dedicated abundance estimation of fin whales in the WAP and Scotia Sea.
iii. Investigation of predator-prey relationships between fin whales and different krill species in the WAP region to identify potential drivers of fin whale distribution and the return of SHFW to the WAP.
iv. Collection and genetic analyses of biopsy samples to investigate population structure of the species across the Southern Hemisphere (in particular between the Pacific and Atlantic Oceans and between hemispheres).
v. Collection of photo-ID to provide the foundation for a SHFW photo-ID catalogue.
vi. Analyses of short-term and long-term movement patterns to assess habitat use, to describe migratory patterns and to deduce migratory destinations.
vii. Creation of a collaborative network of fin whale researchers for future projects and continued efforts to investigate the recovery status of SHFWs.

The project is composed of two major parts:

A. Compilation of existing data on fin whale sightings around the Western Antarctic Peninsula and Scotia Sea region

Data on fin whales that have been collected (partly opportunistically) as part of different research projects by several research groups during past decades will be compiled and analysed together in order to investigate distribution and abundance around the Antarctic Peninsula.

B. New data collections

New data have been collected as part of this project:

*RV Polarstern cruise PS119 (March-May 2019)*

During cruise PS119, *RV Polarstern* was used as a platform of opportunity for an ad hoc helicopter survey collecting line transect distance sampling data on fin whales in the Scotia Arc region around South Georgia and the South Sandwich Islands.

*Pelagic Australis cruise 'FinEphant' (March/April 2021)*

Wildstar Media provided us with one berth on their *Pelagic Australis* expedition to Elephant Island. One scientist joint the cruise as a dedicated tagger to deploy satellite tags.

*RV Maria S. Merian cruise MSM90 – FINWAP (March/April 2020)*

A dedicated fin whale research cruise was to be conducted around the tip of the Western Antarctic Peninsula in 2020. A suite of non-lethal research methods was to be employed to analyse distribution, population structure, movement and migration, habitat use, behaviour and feeding ecology. The outbreak of the COVID-19 pandemic caused a last minute cancellation of the cruise in March 2020. The cruise has now been rescheduled to take place from 15 February to 17 March 2023.

**Results**

*Compilation of existing data on fin whale sightings around the Western Antarctic Peninsula and Scotia Sea region*

The data collection and analysis detailed in the previous report were completed this project year. A manuscript entitled 'Identifying seasonal distribution patterns of Southern Hemisphere fin whales from multiple data sources using a novel approach combining habitat suitability models and ensemble learning methods' has been drafted and circulated among all contributors and is in a near-final stage. It will be submitted to the Journal Frontiers in Marine Science before the end of April 2022. The current draft manuscript represents the most complete and comprehensive description of the joint data analysis and its results, and is provided as an appendix to SC/68d/SH07.

*New data collections*

*Pelagic Australis* cruise – project FinEphant
In search of alternatives to work towards the project objectives related to the data collection planned for the MSM90-FINWAP cruise, a berth for a scientist was secured on 5-week expedition of the 23m sailing vessel 'Australis' to the Antarctic Peninsula in March 2021. Re-allocation of project funds originally intended for the MSM90-FINWAP cruise allowed us to send a researcher on the cruise. The main focus of this expedition was for media purposes, but providing the opportunity for tagging.

Seven fin whales were tagged at the north-western coast of Elephant Island (S61°W55°), Antarctica in March and April 2021. Tagging was conducted upon encounter of fin whale aggregations from a 4.7m rigid keeled inflatable boat. Tags were deployed using a crossbow (Excalibur APEX XLT, 150 lb draw weight). We deployed low-impact minimally percutaneous (LIMPET) tags carrying either Splash10-333 or SPLASH10-F-333 GPS Fastloc® transmitters from Wildlife Computers. Tag locations were obtained from the ARGOS System. Of the seven deployed tags, only four started transmitting after deployment. Transmission duration of the 4 tags ranged from 3 to 28 days (Table 1; Figure 1).

All four tagged animals spent the first days after being tagged close to the tagging location (Figure 2). One tag (PTT199804) stopped transmitting after 3 days while the animal was still around the tagging site. All other three animals left the area on the same day (15 April 2021), two (PTT199805 and PTT199815) to the northwest one to the south-east (PTT199809) (Figure 1). The one that left to the south-east (PTT199809) returned to the tagging site again after 3 days (18 April 2021) and then started following a similar course to the north-west like the other two whales. However, shortly after picking up this course the tag stopped transmitting on 22 April 2021 (after a total of 12 transmission days). The remaining two animals followed a relatively straight course north-northwest (Figure 1, Figure 3). PTT199815 crossed the Drake Passage in 5 days and reached the tip of South America (S51.17 W67.03) on 20 April. It then continued into the Pacific and moved up the Chilean coast along the shelf edge. Transmissions stopped after a total of 15 days at S53.89, W76.23. PTT199805 took a little longer to cover the same distance. It stayed further away from the South American Coast than PTT199815. Travelling parallel to the course of PTT199815 into the Pacific, it reached the latitude of the tip of the South American continent (S51.17) after 11 days on 26 April. It was tracked further up north to S47.87 when the tag stopped transmitting after 28 days. From leaving Elephant Island to the end of transmissions, the whale covered a distance of 2,300 km in 16 days.

These are preliminary results of the tagging data as detailed analysis is still ongoing. However, the results provide a first indication for migratory movement of fin whales feeding at the Antarctic Peninsula into the South Pacific. Furthermore, the successful deployment of tags at Elephant Island at the end of the feeding season serves as a feasibility study for future deployments.

**Table 1** Overview of tags deployed during the Australis cruise in April / March 2021.

| PTT | Deployment date/time (dd/mm/yy) | Last transmission (dd/mm/yy) | Transmission duration (days) |
|---|---|---|---|
| PTT198904 | 28/03/21 | 31/03/21 | 3 |
| PTT198905 | 03/04/21 | 01/05/21 | 28 |
| PTT198907 | 06/04/21 | - | 0 |
| PTT198908 | 10/04/21 | - | 0 |
| PTT198909 | 10/04/21 | 22/04/21 | 12 |
| PTT198914-Fastloc | 10/04/21 | - | 0 |
| PTT198915-Fastloc | 10/04/21 | 25/04/21 | 15 |

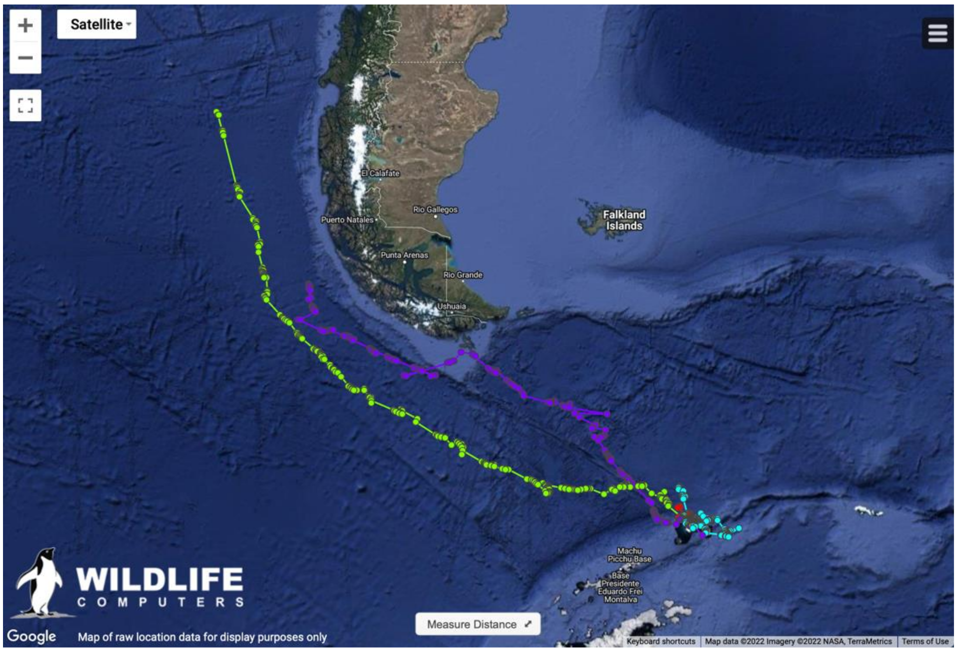



**Figure 1** Tracks of four fin whales tagged at the northern coast of Elephant Island in the first half of April 2022. Figure 1: Display of all tracks: Red = PTT198904, Green=PTT198905, light blue=PTT198909, purple=PTT198915.

*RV Maria S. Merian cruise MSM90-FINWAP*

Cruise MSM90 – FINWAP, originally planned for March / April 2020 and cancelled due to the COVID-19 pandemic (see previous report), has now been rescheduled by the German research fleet coordination and will be carried out from 15 February - 17 March 2023 as MSM115 – FINWAP.

**Conclusions**

The finalisation of the joint data analysis represents the completion of a project milestone. Furthermore, we successfully deployed the first satellite tags on fin whales at the feeding ground around Elephant Island and tracked their migration into the Pacific at the end of the feeding season. Especially given the limited opportunities for fieldwork during the COVID-19 pandemic, we value this as a great success. A network of Southern Hemisphere fin whale researchers has been established, forming an excellent basis for exchange of information and future collaboration.

**Challenges**

The information that the FINWAP cruise will be re-scheduled was only released on 11 March 2022. With less than a year at hand organising logistics for the cruise will be a challenge. Furthermore, most of the funds (mainly travel costs) that were available for the cruise in this project were spent on travel arrangements for the original cruise in 2020. Due to the cancellation on very short notice (5 days before the cruise) hardly any money was refunded. We will have to seek additional funds to ensure participation of all cruise members as planned. Furthermore, we will seek funding for additional tags. Firstly, because 7 out of 13 tags that were originally available to the cruise have been deployed already. Secondly, because we will have to consider the use of implantable tags for long-term tracking. The cruise is scheduled for mid-February 2023. Based on the tags deployed in 2021, we assume that fin whales start their northwards migration in mid- April. In order to track migration we need to ensure that tags will last until this time and beyond.

**Outlook for the future**

The manuscript 'Identifying seasonal distribution patterns of Southern Hemisphere fin whales from multiple data sources using a novel approach combining habitat suitability models and ensemble learning methods' will be submitted to Frontiers in Marine Science by the end of April.

The MSM115-FINWAP cruise is a very promising outlook for the future. The cruise will provide the opportunity for tagging of fin whales not only at Elephant Island but also at the feeding grounds around the South Orkney Islands and the South Shetland Islands. Furthermore, photo-ID data and biopsy samples will be collected and analysed to potentially shed some light on population structure and population connectivity. The combined visual and krill survey will provide insights on prey-related distribution of fin whales in the survey area. Altogether, the data that will be collected during the cruise will contribute greatly to our knowledge about fin whale ecology and provide a data basis for many analyses working towards the objectives of our project.

**Project outputs**

*Peer-reviewed papers*

Herr H (2020) Rückkehr der Finnwale in die Antarktis - 30 Jahre nach Beendigung des kommerziellen Walfangs (Return of the fin whales to Antarctica). Biologie in unserer Zeit 50(5): 338-345. https://doi.org/10.1002/biuz.202010716

Herr H, Viquerat V, Lees A, Wells L, Devas F, Gregory B, Meyer B (*Accepted*) Large fin whale aggregations at Southern Ocean feeding grounds five decades after the end of commercial whaling in the Southern Ocean. Scientific Reports.

Herr H, Viquerat S, Naujocks T, Gregory B, Lees A, Devas F. (*Submitted*) Skin features of Antarctic fin whales documented by aerial footage. Marine Mammal Science.

*Reports*

Herr H, Viquerat S, Kesselring T, Krieger C, Gischler M, Zillgen C, Richter R, Santos V (2019) Large whale distribution around South Georgia and the South Sandwich Islands in the post-whaling era. In: Bohrmann G (Ed) The Expedition PS119 of the Research Vessel POLARSTERN to the Eastern Scotia Sea in 2019. Berichte zur Polar- und Meeresforschung (= Reports on polar and marine research) Bremerhaven, Alfred Wegener Institute for Polar and Marine Research, 736, 236 p. doi: 10.2312/BzPM_0736_2019

*Conference presentations*

Herr H, Viquerat S, Lees A, Devas F, Meyer B (2019) Return of the fin whales: Feeding aggregations of fin whales around the Northern Antarctic Peninsula (oral). World Marine Mammal Conference 2019, 9-12 December, Barcelona, Spain.

**Scientific references cited in report**

Clapham PJ, Baker CS (2002) Modern Whaling. In: Perrin WF, Würsig B, Thewissen JGM (Eds) Encyclopedia of Marine Mammals, pp 1328-1332.

Herr H, Viquerat V, Lees A, Wells L, Devas F, Gregory B, Meyer B (*Accepted*) Large fin whale aggregations at Southern Ocean feeding grounds five decades after the end of commercial whaling in the Southern Ocean. Scientific Reports.

**PROJECT 16 (Friedlaender, Constantine et al., 2018/19). A circumpolar analysis of foraging behaviour of baleen whales in Antarctica: Using state-space models to quantify the influence of oceanographic regimes on behaviour and movement patterns**

*Ryan Reisinger[1], Alex Zerbini[2], Ari Friedlaender[1,3], Virginia Andrews-Goff[4], Luciano Dalla Rosa[5], Mike Double[4], Ken Findlay[6], Claire Garrigue[7], Jason How[8,9], Curt Jenner[10], Micheline-Nicole Jenner[10], Bruce Mate[11], Daniel Palacios[11], Howard Rosenbaum[12], Mduduzi Seakamela[13], Rochelle Constantine[14]*

*1. Institute of Marine Sciences, UC Santa Cruz, 115 McAllister Way, Santa Cruz, CA 95060, USA*
*2. Marine Mammal Laboratory, Alaska Fisheries Science Center, NOAA Fisheries, 7600 Sand Point Way NE, Seattle, WA 98115-649, USA, & Marine Ecology and Telemetry Research, 2468 Camp McKenzie Trail NW, Seabeck, WA 98380-4513, USA*
*3. Ecology and Evolutionary Biology, UC Santa Cruz, 115 McAllister Way, Santa Cruz, CA 95060, USA*
*4. Australian Marine Mammal Centre, Australian Antarctic Division, 203 Channel Highway, Kingston, Tasmania 7050, Australia*
*5. Institute of Oceanography, Universidade Federal do Rio Grande, Av. Itália, s/n - km 8 - Carreiros, 96203-900, Rio Grande, RS, Brazil*
*6. Cape Peninsula University of Technology, Cape Town, South Africa*
*7. Institute of Research for Development, Centre Nouméa, 101 av, Roger Laroque, Anse Vata, BP A5. 98848, Nouméa, New Caledonia*
*8. Department of Primary Industries and Regional Development, 140 William St, Perth, Western Australia, 6000, Australia*
*9. Western Australian Fisheries and Marine Research Laboratories, PO Box 20, North Beach, Western Australia, 6920, Australia*
*10. Centre for Whale Research, PO Box 1622 Fremantle WA 6959, Australia*
*11. Marine Mammal Institute, Oregon State University, Hatfield Marine Science Center, 2030 SE Marine Science Dr, Newport, Oregon 97365, USA*
*12. Wildlife Conservation Society, 2300 Southern Boulevard Bronx, New York 10460, USA*
*13. Department of Environmental Affairs, Branch Oceans and Coasts, Victoria & Alfred Waterfront, Cape Town, South Africa*
*14. School of Biological Sciences & Institute of Marine Science, University of Auckland, Private Bag 92019, Auckland, New Zealand*

## Executive summary

Determining how baleen whale movement and distribution patterns in the Southern Ocean relate to the biophysical environment is critical for understanding and predicting the recovery and distribution of baleen whales in the context of climate change. Immediately, knowledge of their distribution patterns will support better decision making around protection of critical foraging areas. This project aims to provide such information using satellite tracking data on humpback whales. Here, we report results towards our objective of modelling the circumpolar habitat selection of humpback whales. Specifically, we present approaches for incorporating regional variation in habitat selection of humpback whales into circumpolar predictive models. Using a circumpolar satellite tracking dataset, we compared the predictive performance of these approaches to a naïve circumpolar model and found that the multi-regional ensemble approaches we propose resulted in models with higher predictive performance than the circumpolar naïve model. One implication of the habitat-use variation suggested by these results is that regional variation in environmental change could result in different post-whaling recovery among southern hemisphere humpback whale populations and region-specific impacts of future climate change, issues that should be addressed in future work.

## Introduction

Determining how baleen whale movement and distribution patterns in the Southern Ocean relate to the biophysical environment is critical for understanding and predicting the recovery and distribution of baleen whales in the context of climate change. Immediately, knowledge of their distribution patterns will support better decision making around protection of critical foraging regions (e.g., Andrews-Goff et al., 2018, Bestley et al., 2019, Constantine et al. 2014, Dalla Rosa et al. 2008. Rosenbaum et al. 2014, Weinstein et al. 2017, Weinstein & Friedlaender, 2017).

One of the best tools to study animal movement and behaviour is animal-borne telemetry (biotelemetry). Using these data in a habitat selection modelling framework, we can predict areas of importance for wide-ranging animals in the Southern Ocean, where traditional survey approaches are logistically and financially challenging (e.g., Hindell et al. 2020).

Among Southern Ocean baleen whales, humpback whales are the species most often tracked using satellite telemetry (e.g., Fossette et al. 2014, Riekkola et al. 2018, Zerbini et al. 2006, Andrews-Goff et al., 2018, Bestley et al., 2019, Constantine et al. 2014, Dalla Rosa et al. 2008. Rosenbaum et al. 2014, Weinstein et al. 2017, Weinstein & Friedlaender, 2017). Typically, tags are deployed on the breeding grounds or early on their migration from their breeding grounds, as these regions are logistically more accessible than the Southern Ocean; with the exception of the Antarctic Peninsula (e.g., Garrigue et al., 2010, Fossette et al. 2014, Weinstein & Friedlaender 2017). For almost two decades, humpback whale researchers have been deploying satellite tags to provide insights into the movements of humpack whales, and connectivity between breeding and feeding grounds. Through the formation of a large, international collaboration we have collated a circumpolar dataset of humpback whale satellite telemetry data in the Southern Ocean to support our aim of understanding the circumpolar foraging behaviour of humpback whales.

**Objectives**

Broadly, the project's aims are to:

1. Understand the ecological roles of baleen whales distributed throughout the circumpolar waters of the Southern Ocean.
2. Determine the relationship between baleen whale foraging, krill, and biophysical environmental factors across different feeding grounds.
3. Investigate the potential for differences in foraging strategies among spatially discrete feeding aggregations of humpback whales around Antarctica.
4. Determine what regions and conditions promote differences in foraging behaviour and if this leads to differences in the amount of time required by the whales to meet their energetic demands.
5. Enhance understanding of humpback whale stock recovery through integration with genetic, age and reproductive status findings from other IWC-SORP-supported studies.

Here, we report results towards our objective of modelling the circumpolar habitat selection of humpback whales. Specifically, we present an approach for incorporating regional variation in habitat selection of humpback whales into circumpolar predictive models.

**Results**

We aggregated data from 11 research programmes spanning all IWC management areas (Areas I-VI) and breeding grounds (A-G) (Table 1). We compiled satellite tracking data from 378 individual humpback whales, totaling 291,628 location records. Argos satellite-linked telemetry tags were deployed on humpback whales in their breeding areas and Antarctic foraging areas from 2002–2018 (Table 1).

We fitted a state-space model (Jonsen et al. 2019) to these tracking data to estimate the locations of the whales at 24-hour intervals, at the same time accounting for uncertainty in the locations estimated by the Argos system. After filtering the tracking data and fitting state-space models, we retained a set of 168 tracks, totalling 9219 regularized location estimates. (Figure 1). To investigate regional differences in the habitat use of whales, we divided the tracking data into five broad geographic regions, based on a visual assessment of the circumpolar distribution of the tracks together with information on the putative 'breeding stock' (IWC 1998) of the tracked individuals (Figure 1).

To estimate the habitat selection of humpback whales, we used a case-control design (Aarts et al. 2008) wherein we modelled the environmental characteristics of the locations where whales were present (the utilized habitat, or cases, here represented by the observed tracks) compared to environmental characteristics of locations that whales could potentially have used (the available habitat, or controls). To estimate the available habitat, for each observed track we simulated 50 tracks using a first-order vector autoregressive model (Raymond et al. 2015) using the availability package (Raymond et al. 2018). These simulated tracks preserve the duration, speed and turning angle characteristics of the corresponding observed track, indicating where a given animal could have travelled if it had no habitat preference (Raymond et al. 2015, Reisinger et al. 2018, Hindell et al. 2020). Together, this yielded a dataset of 468,588 locations comprising 9,188 observed locations and 459,400 simulated locations.

Using random forests, we fitted a large-scale model relating humpback whale locations, versus background locations, to ten environmental covariates and made a circumpolar prediction of humpback whale habitat selection. We also fitted five regional models, the predictions of which we used as input for four ensemble approaches: an unweighted ensemble, an ensemble weighted by environmental similarity in each cell, stacked generalization, and a hybrid approach where the environmental covariates and regional predictions were used as input features in a new model. We tested the predictive performance of these approaches on an independent validation dataset of humpback whale sightings and whaling catches. These multi-regional ensemble approaches resulted in models with higher predictive performance than the circumpolar naïve model (Figure 2).

Scripts associated with the analyses are available at: https://github.com/ryanreisinger/megaPrediction.

**Table 1** Table summarising the number of tracks contributed to the dataset by various providers from different regions.

| Dataset name | Deployment region | Contributor | IWC breeding stock | n |
|---|---|---|---|---|
| AMMC | Australia (west and east), East Antarctica | Andrews-Goff & Double | D (west Australia)<br>E1 (east Australia) | 32 |
| Constantine_Raoul_2015 | Raoul Island | Constantine | E2 - F (Oceania) | 20 |
| CWR_WAVES_2014 | East Antarctica | Jenner & Jenner | D (west Australia) | 6 |
| DallaRosa_AP | Antarctic Peninsula | Dalla Rosa | G | 10 |
| Friedlaender | Antarctic Peninsula | Friedlaender | G | 58 |
| New-Caledonia-HW | New Caledonia | Garrigue | E2 (Oceania) | 2 |
| Oceans&Coasts_Seakamela | South Africa | Seakamela | B2 (west South Africa)<br>C1 (east South Africa) | 27 |
| OSU_2007ANT | Antarctic Peninsula | Mate & Palacios | G | 12 |
| Rosenbaum | Gabon | Rosenbaum | B1 | 2 |
| WA_Fisheries | Australia (west) | Andrews-Goff, Double & How | D (west Australia) | 56 |
| Zerbini | Brazil | Zerbini | A | 153 |

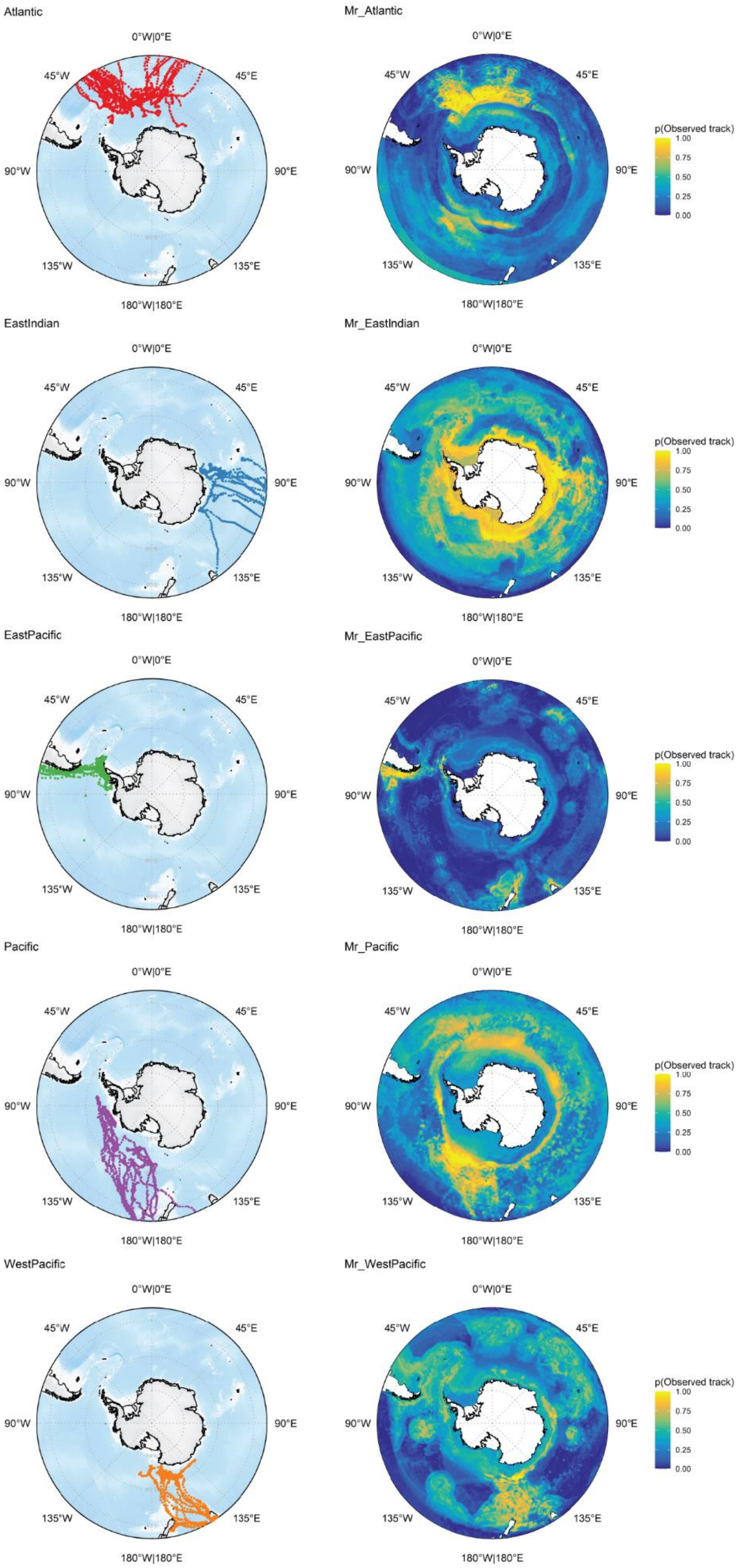

Atlantic
Mr_Atlantic
EastIndian
Mr_EastIndian
EastPacific
Mr_EastPacific
Pacific
Mr_Pacific
WestPacific
Mr_WestPacific
0°W|0°E
45°W
45°E
90°W
90°E
135°W
135°E
180°W|180°E
p(Observed track)
1.00
0.75
0.50
0.25
0.00

**Figure 1** Humpback whale regional tracking data and habitat selection model predictions. Maps in the left column show tracking locations for 168 humpback whale tracks, derived from a random walk state-space model fitted to Argos telemetry data. The tracks are divided into five geographic regions (rows) based on a visual assessment of the circumpolar distribution of the tracks together with information on the putative 'breeding stock'. The right column shows, for each regional habitat selection model, circumpolar predictions of the probability that a given grid cell contains an ob-served rather than simulated track location [p(Observed track)]. Higher values indicate higher probability of habitat selection. From Reisinger et al. (2021).

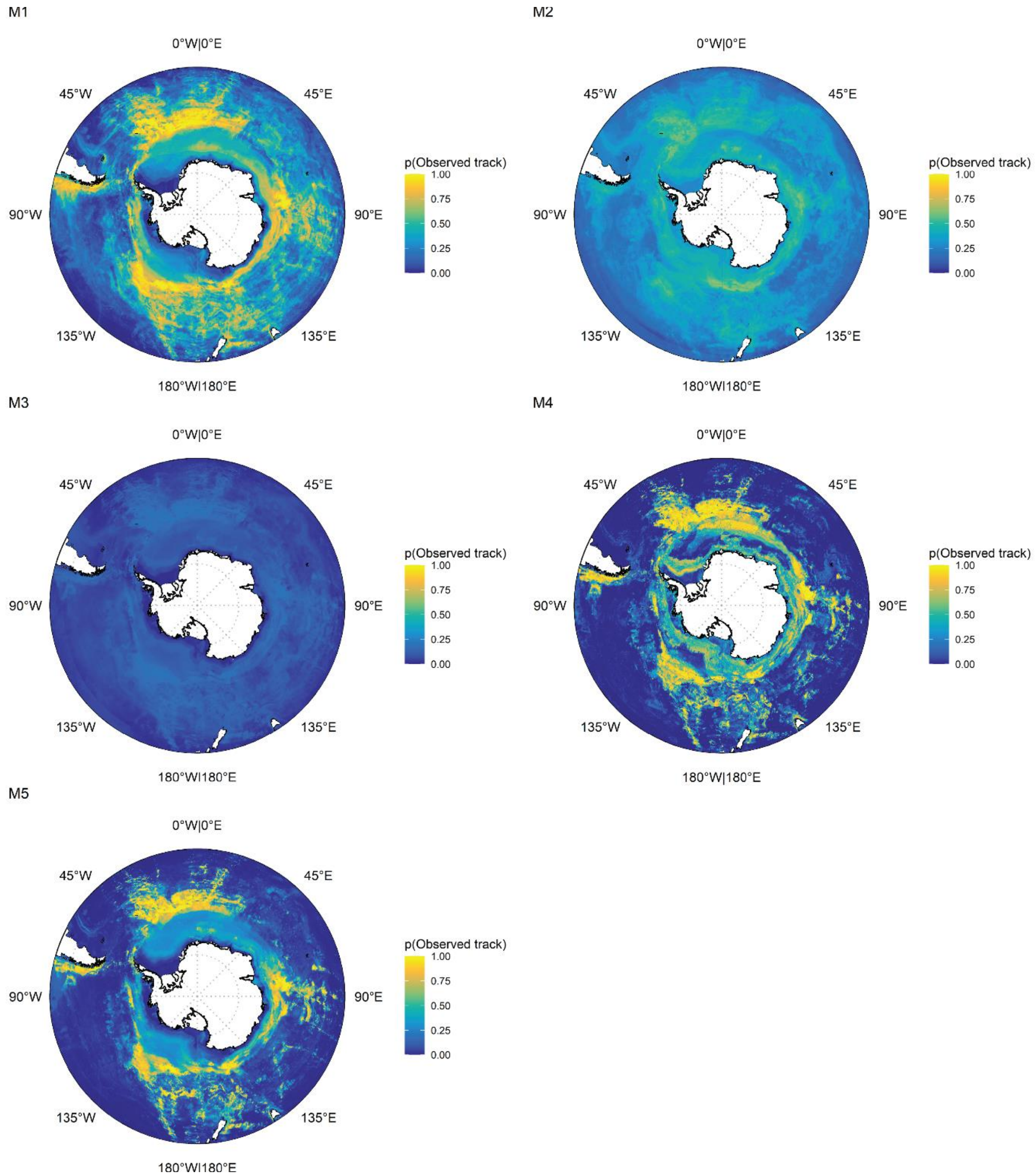



**Figure 2** Circumpolar model predictions. For circumpolar models M1 to M5, circumpolar predictions of the probability that a given grid cell contains an observed rather than simulated track location [p(Observed track)]. Higher values indicate higher probability of habitat selection. From Reisinger et al. (2021).

**Conclusions**

Using the large, circumpolar tracking dataset that we compiled for humpback whales, we developed a predictive habitat modelling approach to account for regional variation in habitat selection among Southern Ocean humpback whale populations, producing a circumpolar prediction of humpback whale habitat selection. More broadly, the approaches can be used to incorporate regional variation in animal habitat selection when fitting range-wide predictive models using machine learning algorithms. This can yield more accurate predictions across regions or populations of animals that may show variation in habitat selection.

One implication of these results is that regional variation in environmental change could result in different post-whaling recovery among populations and region-specific impacts of future climate change. We are currently revising a paper that examines the nature of these variations in habitat selection among populations in more detail (Reisinger et al. under revision). Further, the results underline the importance of tracking predators in different regions and using analytical approaches, such as those we used, that can incorporate such variation. Our longer-term work will focus on the ecological implications of these results, including assessments of the climate change exposure of humpback whale Antarctic foraging grounds, projecting the potential future distribution of these, and assessing potential competition among Antarctic baleen whales mediated through environmental change.

**Challenges**

Restrictions due to COVID-19 have limited opportunities for collaborative interaction among project participants.

**Outlook for the future**

A paper analysing the regional variation in habitat selection of humpback whales is under revision (Reisinger et al. under revision). Longer term, planned outputs will focus on the ecological implications of the results presented here, including 1) assessments of the differences in past and future (projected) environmental conditions among humpback whale foraging areas as drivers of different population trajectories; and 2) assessing potential competition among Antarctic baleen whales mediated through environmental change.

**Project outputs**

*Peer-reviewed papers*

Reisinger RR, Friedlaender AS, Zerbini A, Palacios D, Andrews-Goff V, Dalla Rosa L, Double M, Findlay K, Garrigue C, How J, Jenner C, Jenner M-N, Mate B, Rosenbaum H, Seakamela SM, Constantine R (2021) Combining Regional Habitat Selection Models for Large-Scale Prediction: Circumpolar Habitat Selection of Southern Ocean Humpback Whales. Remote Sensing 13:2074. DOI: 10.3390/rs13112074

Reisinger RR, Zerbini A, Friedlaender AS, Andrews-Goff V, Dalla Rosa L, Double M, Findlay K, Garrigue C, How J, Jenner C, Jenner M-N, Mate B, Palacios D, Rosenbaum H, Seakamela SM, Constantine R (*Under revision*) A circumpolar analysis of habitat-use variation among humpback whales in the Southern Ocean.

*Conference presentations*

Reisinger RR, Friedlaender AS, Zerbini AN, Palacios DM, Andrews-Goff V, Dalla Rosa L, Double M, Findlay K, Garrigue C, How J, Jenner C, Jenner M-N, Mate B, Rosenbaum HC, Seakamela SM, Constantine R (2021) Combining Regional Habitat Selection Models for Large-Scale Prediction: Circumpolar Habitat Selection of Southern Ocean Humpback Whales. The 7th International Bio-Logging Symposium, 18-22 October 2021, virtual meeting hosted in Honolulu, USA.

*Reports*

Johnson C, Reisinger RR, Friedlaender A, Palacios D, Willson A, Zerbini A, Lancaster M, Cosandey-Godin A,

Jacob T, Battle J, Graham A, Shahid U, Houtman N, Alberini A, Montecinos Y, Najera E, Kelez S, Felix F (2022) Protecting Blue Corridors. Challenges and solution for migratory whales navigating national and international seas. WWF. https://wwfwhales.org/s/WWF_Blue_Corridors_Report-Feb2022_web.pdf

**Scientific references cited in report**

Aarts G, MacKenzie M, McConnell B, Fedak M, Matthiopoulos J (2008) Estimating space-use and habitat preference from wildlife telemetry data. Ecography 31(1): 140–160. doi:10.1111/j.2007.0906-7590.05236.x

Andrews-Goff V, Bestley S, Gales NJ, Laverick SM, Paton D, Polanowski AM, Schmitt NT, Double MC (2018) Humpback whale migrations to Antarctic summer foraging grounds through the southwest Pacific Ocean. Scientific Reports 8: 1–14

Bestley S, Andrews-Goff V, van Wijk E, Rintoul SR, Double MC, How J (2019) New insights into prime Southern Ocean forage grounds for thriving Western Australian humpback whales. Scientific Reports 9:1–12

Constantine R, Steel D, Allen J, Anderson M, Andrews O, Baker CS, Beeman P, Burns D, Charrassin J-B, Childerhouse S, Double M, Ensor P, Franklin T, Franklin W, Gales N, Garrigue C, Gibbs N, Harrison P, Hauser N, Hutsel A, Jenner C, Jenner M-N, Kaufman G, Macie A, Mattila D, Olavarría C, Oosterman A, Paton D, Poole M, Robbins J, Schmitt N, Stevick P, Tagarino A, Thompson K, Ward J. (2014) Remote Antarctic feeding ground important for east Australian humpback whales. Marine Biology 161: 1087-1093.

Dalla Rosa L, Secchi ER, Maia YG, Zerbini AN, Heide-Jørgensen (2008) Movements of satellite-monitored humpback whales on their feeding ground along the Antarctic Peninsula. Polar Biology 31:771-781

Donovan GP (1991) A review of IWC stock boundaries. Reports of the International Whaling Commission (Special Issue) 13: 39-68

Fossette S, Heide-Jørgensen MP, Jensen MV, Kiszka J, Bérubé M, Bertrand N, Vély M (2014) Humpback whale (Megaptera novaeangliae) post breeding dispersal and southward migration in the western Indian Ocean. Journal of Experimental Marine Biology and Ecology 450:6–14

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 91:8–13

Hindell MA, Reisinger RR, Ropert-Coudert Y, Hückstädt LA, Trathan PN, Bornemann H, Charrassin J-B, Chown SL, Costa DP, Danis B, Lea M, Thompson D, Torres LG, Putte AP Van de, Alderman R, Andrews-Goff V, Arthur B, Ballard G, Bengtson J, Bester MN, Blix AS, Boehme L, Bost C-A, Boveng P, Cleeland J, Constantine R, Corney S, Crawford RJM, Dalla Rosa L, Bruyn PJN de, Delord K, Descamps S, Double M, Emmerson L, Fedak M, Friedlaender A, Gales N, Goebel ME, Goetz KT, Guinet C, Goldsworthy SD, Harcourt R, Hinke JT, Jerosch K, Kato A, Kerry KR, Kirkwood R, Kooyman GL, Kovacs KM, Lawton K, Lowther AD, Lydersen C, Lyver PO, Makhado AB, Márquez MEI, McDonald BI, McMahon CR, Muelbert M, Nachtsheim D, Nicholls KW, Nordøy ES, Olmastroni S, Phillips RA, Pistorius P, Plötz J, Pütz K, Ratcliffe N, Ryan PG, Santos M, Southwell C, Staniland I, Takahashi A, Tarroux A, Trivelpiece W, Wakefield E, Weimerskirch H, Wienecke B, Xavier JC, Wotherspoon S, Jonsen ID, Raymond B (2020) Tracking of marine predators to protect Southern Ocean ecosystems. Nature 580:87–92

Jonsen ID, Flemming J, Myers R (2005) Robust State-Space modeling of animal movement data. Ecology 86: 2874–2880

Jonsen ID, McMahon CR, Patterson TA, Auger-Méthé M, Harcourt R, Hindell MA, Bestley S (2019) Movement responses to environment: fast inference of variation among southern elephant seals with a mixed effects model. Ecology 100: 1–8

Raymond B, Lea M-A, Patterson T, Andrews-Goff V, Sharples R, Charrassin J-B, … Hindell M. (2015) Important marine habitat off east Antarctica revealed by two decades of multi-species predator tracking. Ecography 38(2): 121–129. doi:10.1111/ecog.01021

Raymond B, Wotherspoon SJ, Jonsen ID, Reisinger RR (2018) Availability: Estimating geographic space available to animals based on telemetry data. R package version 0.13.0. https://github.com/AustralianAntarcticDataCentre/availability

Reisinger RR, Raymond B, Hindell MA, Bester MN, Crawford RJM, Davies D, … Pistorius PA (2018) Habitat modelling of tracking data from multiple marine predators identifies important areas in the Southern Indian Ocean. Diversity and Distributions 24(4): 535–550. doi:10.1111/ddi.12702

Riekkola L, Zerbini AN, Andrews O, Andrews-Goff V, Baker CS, Chandler D, Childerhouse S, Clapham P, Dodémont R, Donnelly D, Friedlaender A, Gallego R, Garrigue C, Ivashchenko Y, Jarman S, Lindsay R, Pallin L, Robbins J, Steel D, Tremlett J, Vindenes S, Constantine R (2018) Application of a multi-disciplinary approach to reveal population structure and Southern Ocean feeding grounds of humpback whales. Ecological Indicators 89:455–465

Riekkola L, Andrews-Goff V, Friedlaender A, Constantine R, Zerbini AN (2019) Environmental drivers of humpback whale foraging behavior in the remote Southern Ocean. Journal of Experimental Marine Biology and Ecology 517:1–12

Rosenbaum HC, Maxwell SM, Kershaw F, Mate B (2014) Long-range movement of humpback whales and their overlap with anthropogenic activity in the South Atlantic Ocean. Conservation Biology 28:604–615

Weinstein BG, Double M, Gales N, Johnston DW, Friedlaender AS (2017) Identifying overlap between humpback whale foraging grounds and the Antarctic krill fishery. Biological Conservation 210:184–191.

Weinstein BG, Friedlaender AS (2017) Dynamic foraging of a top predator in a seasonal polar marine environment. Oecologia 185:427–435

Zerbini A, Andriolo A, Heide-Jørgensen M, Pizzorno J, Maia Y, Van Blaricom G, DeMaster D, Simões-Lopes P, Moreira S, Bethlem C (2006) Satellite-monitored movements of humpback whales Megaptera novaeangliae in the Southwest Atlantic Ocean. Marine Ecology Progress Series 313:295–304

**PROJECT 17 (Buchan, Miller et al., 2018/19). A standardized analytical framework for robustly detecting trends in passive acoustic data: A long-term, circumpolar comparison of call-densities of Antarctic blue and fin whales**

*Susannah Buchan[1], Brian Miller[2], Flore Samaran[3], Danielle Harris[4], Kate Stafford[5], Ken Findlay[6], Ana Širović[7]*

*1. Department of Oceanography, Universidad de Concepción (UdeC), COPAS Sur-Austral, Piso 2, Concepción, Región del Bio Bio, Chile*
*2. Australian Marine Mammal Centre, Australian Antarctic Division, 203 Channel Highway, Kingston 7050, Australia*
*3. ENSTA Bretagne Lab-STICC UMR CNRS 6285, France*
*4. Centre for Research and Ecological Modelling, University of St Andrews, The Observatory, Buchanan Gardens, St Andrews, Fife, Scotland, UK*
*5. Applied Physics Lab, University of Washington Seattle, WA, United States of America*
*6. Centre of Sustainable Oceans Economy, Cape Peninsula University of Technology, Symphony Way, Bellville, Cape Town, 7535, South Africa*
*7. Department of Marine Biology, Building 3029, Room 248, Texas A&M University Galveston, P.O. Box 1675, Galveston, TX 77553, USA*

## Introduction

*A standardized analytical framework for robustly detecting trends in passive acoustic data: A long-term, circumpolar comparison of call-densities of Antarctic blue and fin whales* is a project of the IWC-SORP Antarctic blue and fin whale acoustic trends working group (ATWG). This project funds a postdoctoral researcher based at the University of Concepcion, Chile, to implement a standardized analytical framework for estimating call densities of Antarctic blue whales and fin whales, with a long-term view of using call densities to determine animal densities and examine population trends of Antarctic blue and fin whales in the Southern Ocean based on ATWG passive acoustic data.

During the 14 months of activity, the postdoctoral researcher performed the analysis steps to estimate the whales call density, testing their applicability to the acoustic dataset recorded in the Southern Ocean circumpolar sites (see appendix at the end of this document). The site, species and call initially chosen were the South Kerguelen Plateau (Year 2014), Antarctic blue whales z-calls.

## Objectives

Apply a standardized analytical framework for estimating whales call density, particularly effective when recordings are made using single or sparse sensors.

More specifically the objectives of this project were:

1. Evaluate the performance of existing automatic detectors in a dataset from the ATWG call library;
2. Estimate the survey area via acoustic propagation modelling;
3. Estimate site-specific probability of detection using the passive sonar equation;
4. Estimate whales call density with coefficient of variation.

## Methods, software, and databases

Passive acoustic recordings of Antarctic blue whales were continuously collected in the South Kerguelen Plateau on the Southern Ocean Indian Sector. A single instrument AAD-MAR was deployed at 1980 m depth (62° 22.81' S, 81° 47.81'E) from 22 February 2014 to 20 February 2015.

The raw acoustic data, as well as the manual annotations spreadsheet (from the annotated library) and the automatic detections were made available by Dr. Brian Miller. We also counted on his analytical support for the measurement of noise levels (NL) and received levels (RL) of the manual annotated calls, and in the overlap identification between the calls manually annotated and automatically detected.

The received level (RL) was measured for the full duration of the Raven (Raven Pro 1.5) annotation box in time and 25-29 Hz in frequency (units: dB re 1 μPa2 RMS, 25-29 Hz, t100). The noise level was measured 26 seconds (25 seconds + 1 seconds) prior the start of the manual detection. When the annotation was at the beginning of the file, with no 25 seconds of preceding audio, the noise was measured immediately after the detection.

Simultaneously, search and access to environmental databases (e.g., bathymetry data, sound speed profiles), required for the site-specific modeling of transmission loss (TL), was conducted.

We started TL modelling from cylindrical and spherical spreading models. Then, a parabolic equation model approach (RAMGeo, assuming a fluid seabed) was used to model the transmission loss through a free Graphic User Interface (GUI) (Duncan & Maggi, 2006), known as Acoustics Toolbox User interface and Post processor (AcTUP version 2.2*l*), via a Matlab interface (see Harris, 2012 for details). *[The AcTUP user manual, application and run definition can be found in the folder: ATWG_PostDoc\AcTup (MATLAB)]*.

To sample the site-specific bathymetry, eight 1000 km-long radial transects (45° degrees interval) were defined, starting from the deployment position, using QGis (version 3.12). The bathymetry was sampled at 99 equally spaced points (maximum accepted by AcTUP) along each transect. The bathymetry dataset adopted was the General Bathymetric Chart of the Oceans (GEBCO). Tests were made with the inclusion of a sound speed profile (Transect 270°), but we still do not have this parameter sampled for all transects and its manual way of inclusion in AcTUP limited the evolution at this point.

With the required inputs: (1) a published source level (SL) estimates from Antarctic blue whale calls (average: 189 dB re: 1 μPa @ 1m, standard deviation: 3 dB; Širović *et al*., 2007), (2) RL, (3) NL, (4) whether the manually annotated calls were automatically detected (1) or not (0), and (5) the TL model, we started a new round of tests for the Monte Carlo simulation using the software R (R version 4.0.4). The Monte Carlo simulation original code (written and made available by Dr. Danielle Harris) uses a Generalized Additive Model (GAM) to model the relationship between the Signal to Noise Ratio (SNR) of the calls manually annotated and if they were automatically detected or not (the model relationship is used to define the detector characterization curve). However, due to the GAM being poorly constrained at the extremes of the SNR distribution, this original code was adjusted to initially run Generalized Linear Model (GLM) rather than GAM, with Binomial family. *[Simulation codes and data files can be found in the folder: ATWG_PostDoc\Last tests\1_ Monte Carlo simulation\Codes and data files (Monte Carlo simulation)]*.

Based on the probability of detection resulting from the Monte Carlo simulation (adopting GLM / Binomial family) we tested the call density formula:

$$\widehat{D}_c = \frac{N_c\,(1-\hat{c})}{k\pi w^2 \hat{P}_a T},$$

where, $D_c$ = call density; $N_c$ = number of calls automatically detected; $c$ = false positive rate; $k$ = number of instruments; $w$ = maximum detection distance; $P_a$ = probability of detection; and $T$ = monitoring time. *[Consult: ATWG_PostDoc\Last tests\2_Density estimation and CV (still manual) \4_Density of calls_Dc]*.

It was also necessary to calculate $N_c$, corresponding to the automatic detections obtained for the full dataset; the false positive rate ($c$), still indirectly estimated, based on the automatic detection performed for South Kerguelen Plateau annotated library subsample (200h); $w$ also defined from the Monte Carlo simulation; and $T$, corresponding to the entire deployment period. $D_c$ was initially estimated for the entire deployment year and by season, also using R.

The last step of analysis was the calculation of the variance and coefficient of variation (CV) for the parameters: $N_c$, $c$ and $P_a$, each following a specific method (see Harris, 2012). An associated CV was also estimated using the delta method (Seber, 1982). *[Consult: ATWG_PostDoc\Last tests\2_Density estimation and CV (still manual)]*.

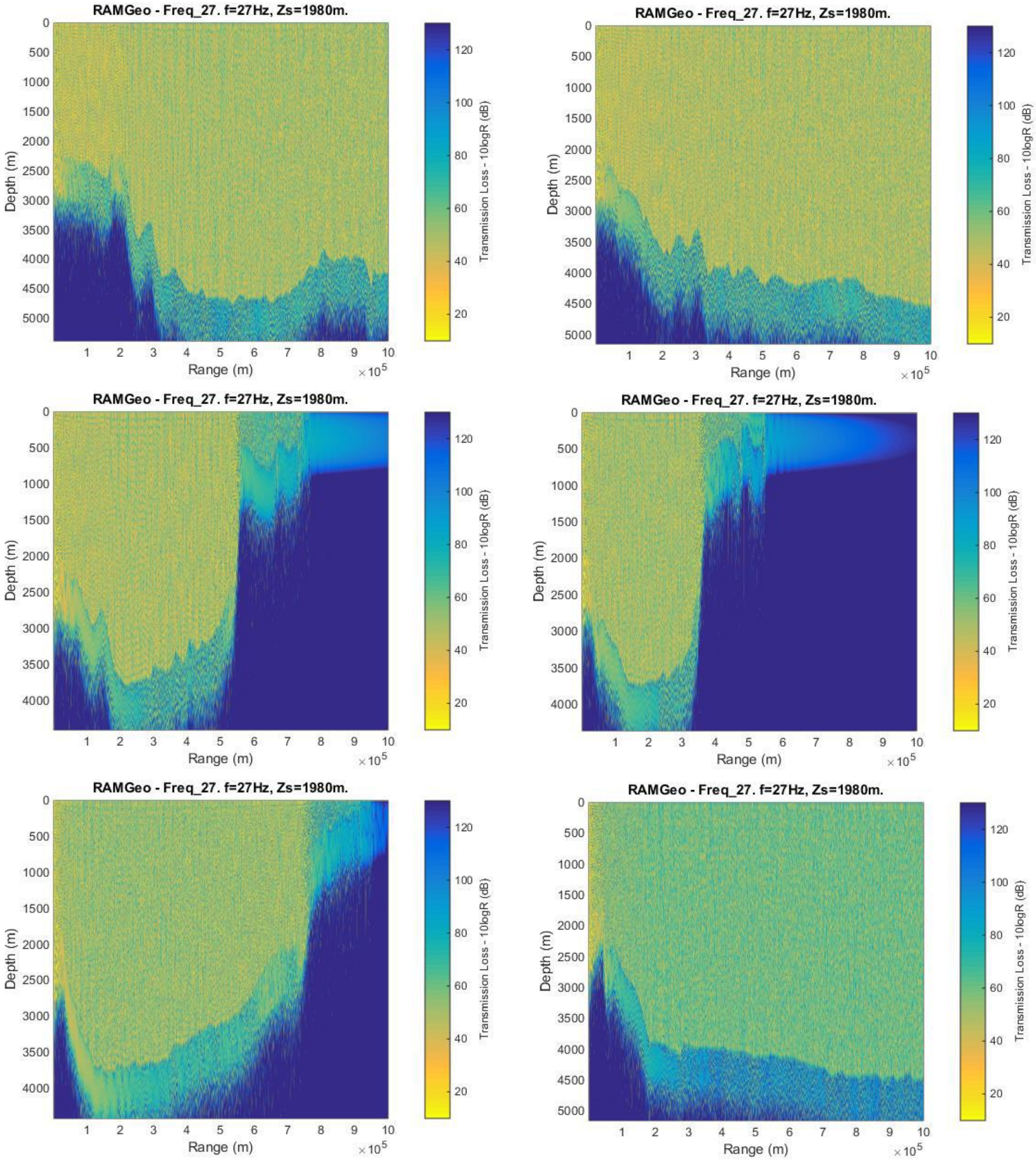
**Results**

The automatic detection resulted in 77905 detections, present in approximately 8639 hours of recording, corresponding to the total time of deployment, while in 200 hours of subsampled data the number of detections were 1590. For the full year of deployment, the false positive rate (*c*) was 0.266. The results per season are presented in the Table 1.

**Table 1** Number of detections ($N_c$), time of recording (*T*), false positive rate (*c*) and probability of detection (*Pa*) by season.

| Season | $N_c$ | *T (hours)* | *c* | Overall $P_a$ |
|---|---|---|---|---|
| Summer 2014 | 8027 | 932.5 | 0.3821 | 0.0075 |
| Fall 2014 | 22646 | 2220.86 | 0.2318 | 0.0011 |
| Winter 2014 | 28101 | 2173.2 | 0.0976 | 0.0109 |
| Spring 2014 | 11498 | 2166.52 | 0.4286 | 0.0386 |
| Summer 2015 | 7633 | 1145.82 | 0.6703 | 0.0051 |

The transmission loss model was estimated based in a site-specific bathymetry profiles. The resulted transmission loss per transect (profile) are presented in the Figure 1.


RAMGeo - Freq_27. f=27Hz, Zs=1980m.
Depth (m)
Range (m)
×10^5
Transmission Loss - 10logR (dB)
RAMGeo - Freq_27. f=27Hz, Zs=1980m.
RAMGeo - Freq_27. f=27Hz, Zs=1980m.
RAMGeo - Freq_27. f=27Hz, Zs=1980m.
RAMGeo - Freq_27. f=27Hz, Zs=1980m.
RAMGeo - Freq_27. f=27Hz, Zs=1980m.

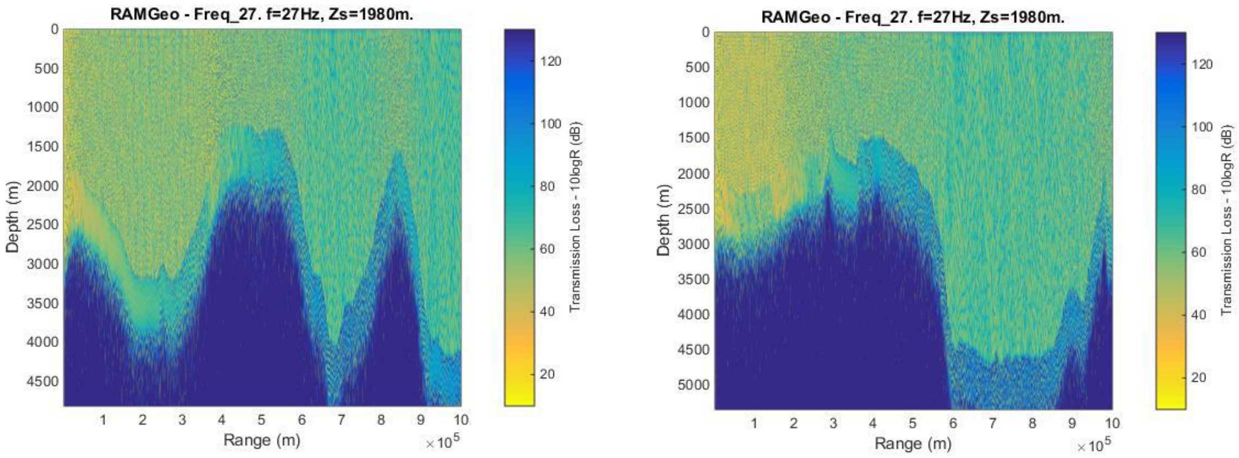



**Figure 1** Transmission loss model per profile: 45°, 90°, 135°, 180°, 225°, 270°, 315° and 360°, respectively.

The measured RL and NL for the Antarctic blue whales z-calls manually annotated (n=4297), as well as the SNR can be observed in the Figure 2. A total of 1166 calls manually annotated were detected by the automatic detector. The mean RL of the detected calls was 99.34 dB, with a mean associated NL of 95.77 dB. The mean RL of the non-detected calls was 96.45 dB, with a mean associated NL of 95.23 dB.

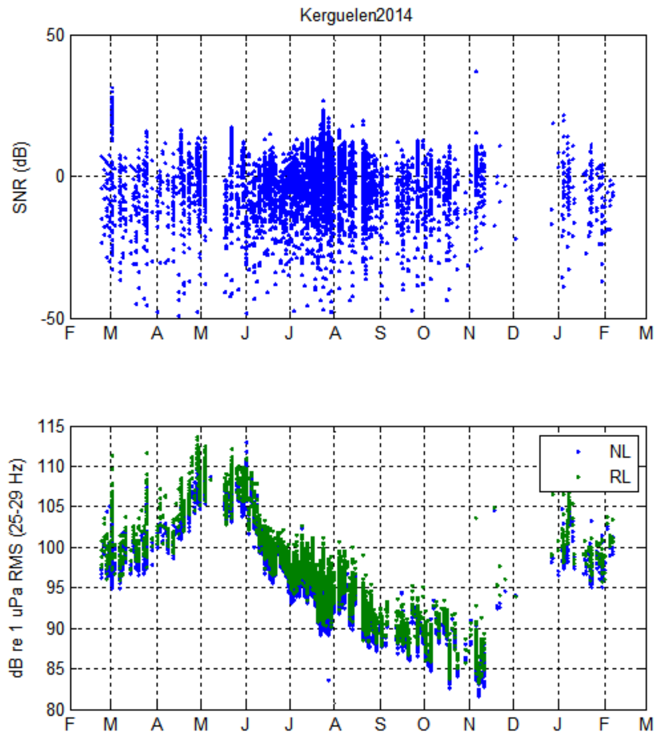



**Figure 2** SNR, RL and NL measured for the Antarctic clue whales z-calls manually annotated.

The relationship between the SNR of the calls manually annotated and if these calls were automatically detected or not, fitted by the GLM, can be observed below (Figure 3).

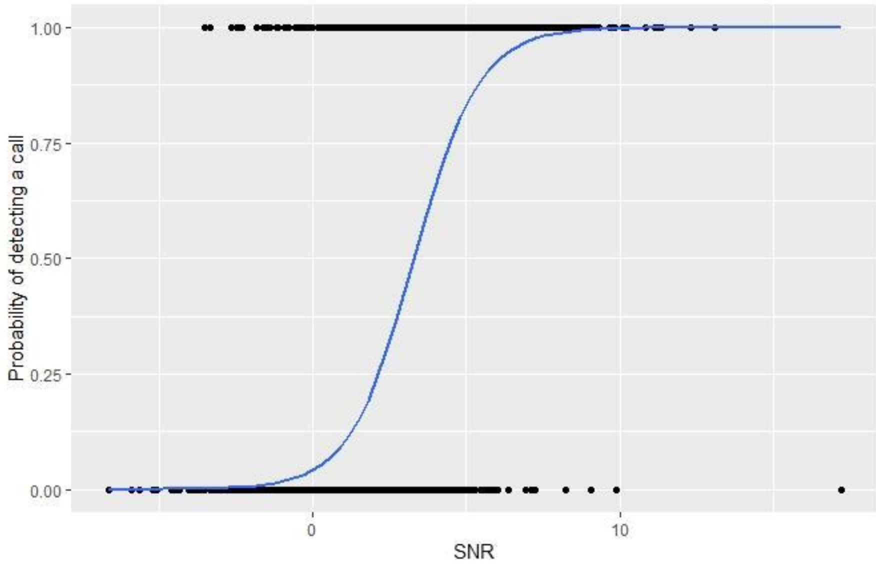



**Figure 3** Probability of detecting a call given a SNR.

The maximum distance from the instrument beyond which detections are likely to be zero, or negligible, (*w*) was defined as 1000 km. The overall probability of detection throughout the survey area ($P_a$) resulted from the Monte Carlo simulation for the total time of deployment was 0.0125 (Figure 4). Results per season are also present in the Table 1. The highest probability of detection having been observed for spring 2014, and the lowest for fall 2014.

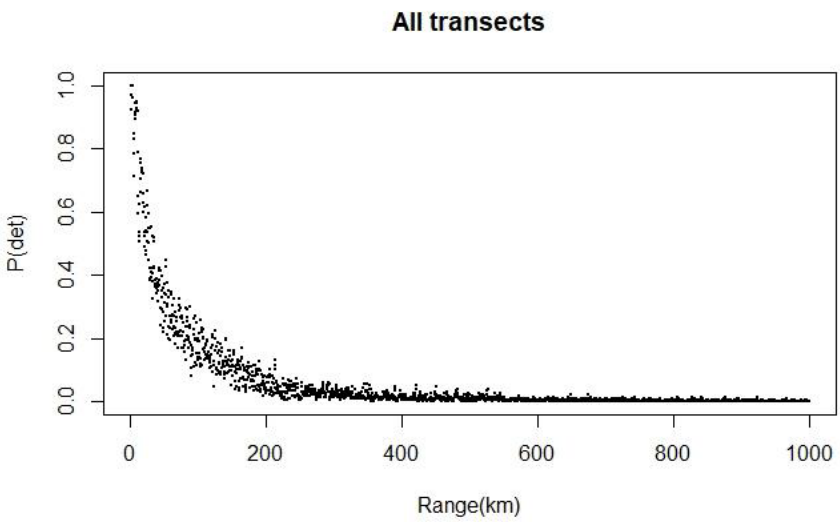



**Figure 4** Overall probability of detection for the full year of recording.

The call density for the full year of deployment was estimated as 0.168 calls per 1,000 km$^2$ per hour. By season, the highest call density was estimated for fall 2014, and the lowest for spring 2014 (Table 2). Table 2 presents the coefficient of variation for the parameters *Nc*, *c* and *Pa*, and the total CV for each density estimated.

**Table 2** Density of call ($D_c$), coefficient of variation for the parameters $N_c$, *c* and $P_a$, respectively, and the Total CV.

| Year/ Season | $D_c$ * | CV $N_c$ | CV c | CV $P_a$ | CV Total |
|---|---|---|---|---|---|
| **Year** | 0.168555 | 0.000398 | 0.00876 | 0.325651 | 0.325769 |
| **Summer 2014** | 0.225741 | 0.000963 | 0.0692 | 0.585313 | 0.589391 |
| **Fall 2014** | 2.266737 | 0.00022 | 0.0302 | 0.371128 | 0.372355 |
| **Winter 2014** | 0.340756 | 0.000619 | 0.0363 | 0.327453 | 0.329459 |
| **Spring 2014** | 0.025007 | 0.001797 | 0.0307 | 0.316763 | 0.318252 |
| **Summer 2015** | 0.137081 | 0.000815 | 0.023 | 0.811445 | 0.811771 |

*Units: calls per 1,000 $km^2$ per hour

**Points to review and improve**

It is important to note that the analysis steps were carried out in a simple way, with the objective of becoming familiar with each one and the results they generate. As a next stage, it is recommended to return to the initial steps making them increasingly complex, as originally planned. Some important points to be reviewed and improved are:

(1) Transmission loss (TL) site-specific modelling:

a. inclusion of acoustic properties of the water column and sediment information (e.g., sound speed profiles, density, sediment thickness) in the model;
b. review the parameters adopted in AcTUP (e.g., depth and range steps);
c. evaluate the need for increasing both: the number of radial transects, reducing the degree interval between them; and the length of each transect (>1000km);
d. automate the sampling of environmental variables and their inclusion in the model, as well as the process for modelling the TL.

IMPORTANT: Bathymetry only brings spatial information. If it is intended to estimate the density by season or month, it would be important to include temporal site-specific information such as sound speed profiles (per season/ month) in the transmission loss model.

(2) Monte Carlo simulation: Considering SNR = RL - NL (the simple way to calculate SNR), it is recommended to test GAM with different number of knots starting from 3 (minimum). Prioritize GAM, running GLM as a last alternative. If GLM is chosen, check the predict function in the inner loop (step 4(e) of the Monte Carlo simulation).

(3) Estimate *c* directly (recommended), through a random and systematic sampling of automatic detections corresponding to the entire deployment period dataset. Then, check through the spectrogram, whether these detections correspond (true positives) or not (false positives) to the calls of interest.

(4) Automate the *Dc* estimation. Code still simple.

(5) Check the variance and CV calculation methods for each of the parameters: *Nc*, *Pa* and *c* (Cochran approximation). Also improve the codes, automating them.

**Challenges**

1. The biggest challenge faced during this period was the COVID-19 pandemic. In this context, the work became more remote than initially planned. This limited or took more time for the understanding of some analysis steps, since not always communication via email was enough to present and solve all doubts. However, the ATW group members, especially Dr. Susannah Buchan, Dr. Danielle Harris and Dr. Brian Miller were excellent and incredibly supportive. They dedicated themselves to dealing with the communication limitations through emails and video calls, providing the material and support needed to drive the project.

2. It is a complex and experimental project for its complete execution in 14 months. Thus, the results so far are still simple, and each step need to be reviewed and improved.

**Scientific references cited in report**

Duncan AJ, Maggi AL (2006) A consistent, user friendly interface for running a variety of underwater acoustic propagation codes. Proceedings of acoustics. Christchurch, New Zealand.

Harris D (2012) Estimating whale abundance using sparse hydrophone arrays. Ph.D. University of St Andrews.

Samaran F, Guinet C, Adam O, Motsch JF, Cansi Y (2010) Source level estimation of two blue whale subspecies in southwestern Indian Ocean. The Journal of the Acoustical Society of America 127. doi: 10.1121/1.3409479

Seber GAF (1982) The estimation of animal abundance and related parameters. 2nd Edition. New York Chapman, London and Macmillan.

Širović A, Hildebrand JA, Wiggins SM (2007) Blue and fin whale call source levels and propagation range in the Southern Ocean. The Journal of the Acoustical Society of America, 122(2):1208-1215. doi: 10.1121/1.2749452

## Project 17, Appendix 1

Summary of the analysis steps:

1) Choose the study area and year of data collection.

2) Choose the target species and 'call type'.

3) Automatic detection:

i. Annoted library subsample;

ii. Full dataset.

4) Comparison of manual annotations (already available) x annotated library subsample automatic detections (3i) →1 For overlapping detections / 0 for non-overlapping detections.

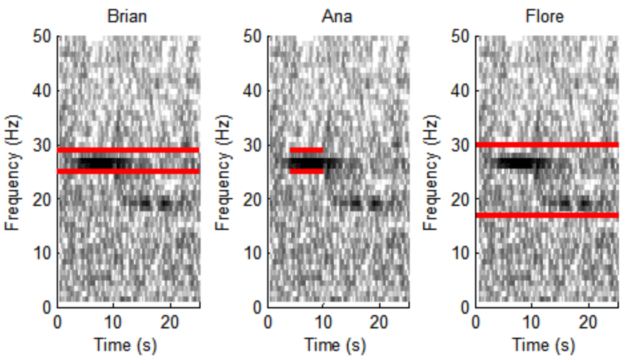
5) Measurements of NL and RL for each call manually annotated. These measurements were carried out by Dr. Brian Miller (via Matlab code).

a. The NL is measured in an interval (considering the call duration) pre or post each annotated call. We choose to measure 26s (25 + 1s) pre call. When it was not possible, an interval post call was measured.

b. The RL can be measured based on the Selection Box corresponding to the annotation.

i. In relation to the frequency band: as Ana Širović et al. (2007), we considered: 25 to 29 Hz / Flore Samaran et al. (2010) considered: 17 to 30hz.

ii. Regarding the duration: Brian, as well as Flore, considered all the duration of the annotation box, while Ana considered the 6 seconds corresponding to the portion 'A' of the z-call (see below):



6) Source Level (SL)
From literature – Širović et al. 2007

7) Transmission Loss (TL)

i. Environmental data (Bathymetry, Sound Speed Profile, sediment) →Search sources and download the data corresponding to the working site.
Examples:

- GEBCO (Bathymetry) - https://www.gebco.net/data_and_products/printable_maps/
- WOA (salinity and temperature) - https://www.ncei.noaa.gov/access/world-ocean-atlas-2018/

ii. Choose the program (e.g., Actup, Matlab) and the propagation model (e.g., RAM, RAMGeo) that will be adopted;

iii. Run the propagation model; TO BE DONE: run a more complex TL model considering water column (e.g., sound speed profile) and sediment acoustic properties.

iv. TO BE DONE: test a more automatic method of (1) accessing the environmental data corresponding to the entire length of sampling transect, (2) include them in the propagation model, and (3) run the TL model (e.g., MATLAB).

8) Monte Carlo simulation:
Inputs: SL (from literature), RL and NL, detection (0 and 1) and TL.
Output: probability of detection ($P_a$) and *w* (maximum detection distance).

The SNR can be calculated in two ways:

a. Simple: RL – NL (in dB) → Best results (ADOPTED)
b. As Brian: $(RL\text{-}NL)^2$/noiseVar – this is calculated in linear units, then converted to dB.

The relationship between detection (0 and 1) and SNR can be obtained from GAM or GLM (last alternative). For Kerguelen 2014, it was adopted GLM. However, GAM with knots = 3 (minimum) also worked. The results for probability of detection were higher than those obtained from GLM, but acceptable. See codes adjusted.

9) Density formula:

$$D = \frac{Nc\,(1-c)}{k\pi w^2 PaTr},$$

where, $D$ = animal density; $N_c$ = number of calls automatically detected; $c$ = false positive rate; $k$ = number of instruments; $w$ = maximum detection distance; $P_a$ = probability of detection; $T$ = monitoring time, and $r$ = cue production rate i.e., the rate at which the target species produce the calls of interest (still not available).

*$N_c$ – count the number of automatic detections obtained for the full dataset.*
*c – two ways of estimation:*
Direct form of sampling (recommended): systematically and randomly sample the above detections and check (through spectrogram) whether or not they are calls of interest.
Indirect form of sampling: use the result of automatic detection performed in the annotated library subsample. Compare to the manual annotations made for the same dataset (subsample) and check whether the automatic detections were manually annotated or not →Check if this form of estimating c is correct.
*T* – From the acoustic raw data count how many files lasted 1 hour and add them to the duration of files less than one hour long (done manually)
*K* – Number of instruments. For single instrument, k=1.
*W* and $P_a$ – Monte Carlo simulation results
With no *r*, we are estimating call density (*Dc*).

10) Variance/ Coefficient of Variation (CV): Calculated for $N_c$, $c$ and $P_a$ (different methods – to check)

**PROJECT 18 (Lang, Archer et al., 2018/19). Inferring the demographic history of blue and fin whales in the Antarctic using mitogenomic sequences generated from historical baleen**

*Aimee Lang[1], Frederik Archer[1], Robert L. Brownell, Jr.[1], Kelly Robertson[1], Michael McGowan[2]*

*1. Southwest Fisheries Science Center, 8901 La Jolla Shores Drive, La Jolla, CA 92037, USA*
*2. Department of vertebrate Zoology, National Museum of Natural History, Smithsonian Institution, 10th St. & Constitution Ave., NW Washington, DC 20560, USA*

## Introduction

Within the Southern Hemisphere, over two million baleen and sperm whales, including over 350,000 blue whales and 725,000 fin whales, were killed as part of modern commercial whaling operations in the 1900s. Assessing the contemporary status of these species in Antarctic waters requires evaluating changes in abundance over time as well as understanding how commercial exploitation has affected genetic diversity. During the 1946-47 and 1947-48 Japanese whaling seasons in the Antarctic, a large number of baleen plates were collected from blue and fin whales. Approximately 1600 bundles of plates from this series were sent to the United States, where they were recently rediscovered at the National Museum of Natural History (NMNH), Smithsonian Institution (Potter et al. 2016).

## Objectives

For this project, we plan to use next generation sequencing technology to sequence the complete mitogenomes (~16K base pairs) from a subset (n=48 from each species) of these plates. This data will be combined with existing mitogenome sequence data generated from Antarctic blue and fin whales, biopsied during the IWC's IDCR/SOWER surveys between 1996 and 2009, in order to:

1) Make inferences about the minimum number of whales surviving exploitation;
2) Evaluate the loss of genetic diversity over time; and
3) Examine the demographic histories of both species in the Antarctic using techniques such as Bayesian skyline plots and Approximate Bayesian Computation.

## Progress to date

As part of a pilot project that was conducted in 2018, DNA was extracted from a subset of these baleen plates (n=11 blue whales, n=1 fin whale). Although mtDNA sequence data was obtained for all samples, sequencing depth and complexity varied markedly among the samples. Based on these results, we determined that subsequent efforts would include two independent mitogenome library preparations for each sample in order to increase sequence complexity. One DNA extraction and library prep will be conducted at the Southwest Fisheries Science Center (SWFSC), while the second will be done at the NMNH.

NMNH staff conducted an initial test during 2019/2020 to see if DNA quality varied when samples were collected from different portions of the baleen (i.e., close to the gum line v. further down the length of the baleen). Nuclear DNA was obtained from the extractions; no variation with sampling site along the length of the baleen was detected.

Archer travelled to the NMNH in November 2019 and collected samples from the baleen plates of 48 blue whales and 48 fin whales. Each sample was split in two, and one subsample was retained at the NMNH while the other subsample was shipped to the SWFSC for processing. Robertson began DNA extractions from the baleen in February 2020. Shortly thereafter, however, progress on the project was suspended due to closure of the SWFSC genetics lab due to COVID-19. The SWFSC lab re-opened in a limited capacity in fall 2021, and Robertson completed the DNA extraction from all 96 samples. Subsequent quantification revealed that DNA was successfully extracted from 88 samples. We expect to begin preparing sequencing libraries for the SWFSC extracts in April 2022.

**Outlook for the future**

We anticipate presenting a draft manuscript(s) summarising the results at SC/69a (2023).

**Scientific references cited in report**

Potter CW, Ososky JJ, Mead JG, Brownell RL, Jr. (2016) Appendix 4. Baleen plates from the Hashidate-Maru and Nisshin-Maru during the 1946-47 season: Their collection, 'disappearance', and rediscovery. Journal of Cetacean Research and Management 17 (Suppl.): 280-281.

**PROJECT 19 (Zerbini, Clapham et al., 2018/19). Assessing blubber thickness to inform satellite tag development and deployment on Southern Ocean whales**

*Brenda Rone[1], Alexandre Zerbini[1,2], Phillip Clapham[2], Yulia Ivashchenko[2], Michael Double[3], John Bannister[4], Els Vermeulen[5], Ken Findlay[6]*

*1. Marine Ecology and Telemetry Research, 2468 Camp McKenzie Trail NW, Seabeck, WA 98380-4513, USA*
*2. Marine Mammal Laboratory, Alaska Fisheries Science Center, NOAA, 7600 Sand Point Way NE, Seattle, WA 98115-6349, USA*
*3. Australian Marine Mammal Centre, Australian Antarctic Division, 203 Channel Highway, Kingston, Tasmania 7050, Australia*
*4. Western Australian Museum, Locked Bag 49, Welshpool, DC, WA 6986, Australia*
*5. Mammal Research Institute, Whale Unit, University of Pretoria, 16 Ebor Road, Wynberg 7800, Cape Town, South Africa*
*6. Centre of Sustainable Oceans Economy, Cape Peninsula University of Technology, Symphony Way, Bellville, Cape Town, 7535, South Africa*

**Executive summary**

Satellite tracking has greatly improved our understanding of cetacean ecology and is an important tool used to explore research questions relevant to the various management and conservation issues addressed by the International Whaling Commission (IWC). Satellite tracking is also an integral component of many core projects currently developed by the IWC-Southern Ocean Research Partnership (IWC-SORP). Long-term satellite tag attachment in large whales has generally been improved using implantable tags with both anchoring systems and electronics embedded in the body. These tags often penetrate the blubber layer and anchor below the blubber-muscle interface (fascia). Recent studies have shown that while these tags appear to have limited to no effect on survival and reproduction of individual animals, they can cause persistent trauma, resulting in discomfort and potentially pain. These observations suggest the need for further innovation to satellite tags to reduce the likelihood of impact to individual whales. Advances in tagging technology will likely include tags that minimize trauma, for example, by being embedded only in the blubber, by complying with the extent of movement between blubber and muscle if penetrating the fascia, by miniaturization and/or by a combination of these factors. Development of new technology and performance testing of existing implantable tags requires an understanding of the variability of blubber thickness in large whales. The goal of this study was to review whaling and stranding records and to evaluate the variation of blubber thickness in whales taking into consideration species, sex, and length. Statistical models were developed to predict blubber thickness for eleven species of large whales commonly tracked with these tag types. In addition, information on blubber thickness was provided for another species, the gray whale (Eschrichtius robustus). Results showed a positive linear relationship between lateral and dorsal blubber thickness and variation in blubber parameters across species. They also provided a range of blubber thickness for various species of large whales that can be used to assess depth of tag implantation in the body across these species. These results highlight the effectiveness of assessing the strengths of various data sources to obtain measurements that will be used to guide the development and management of invasive, implantable satellite tags and to inform best tagging practices.

**Introduction**

We conducted a review of information on blubber thickness from both whaling and stranding data and integrated these data into statistical models to evaluate blubber thickness variation according to specific covariates (sex, length and body condition). An extensive dataset (n=38,164 large whales) for which lateral blubber layer thickness were consistently measured were acquired for 10 species of large whales from whaling records (sources include primarily the Yuri Dolgorukiy Soviet factory fleet containing the largest sample size = 37,486 individuals from 9 species, Nishiwaki & Hayashi 1950, Omura 1950, 1958, Nishiwaki & Oye 1951, Nishiwaki 1959, Klumov 1962, Omura et al. 1969) and stranding records (Smithsonian Institute). However, because implantable tags are typically deployed in the dorsal surface of the whale, information on dorsal blubber is preferred. For this reason, stranding data (n=366 individuals from 23 species of large and small cetaceans) from Cascadia Research Collective, the Whale Unit at the University of Pretoria, International Fund for Animal

Welfare, and reports by Daoust et al. 2018 and Bourque et al. 2020[1] containing measurements for both dorsal and lateral blubber thicknesses were modelled to predict dorsal blubber thickness for the larger, robust dataset containing only lateral measurements.

**Objectives**

This project aims to describe variations in the thickness of mid-dorsal blubber layers in large whales with the following objectives:

1. Assess variations in blubber thickness of large whales taking into consideration species, sex, and length.
2. Develop species-specific parameters for blubber thickness and depth of penetration to guide development and deployment of implantable satellite tags.

**Methods**

To assess variations in blubber thickness of large whales, we created generalized linear regression models fit as Gamma distributions with identity link functions to assess changes in dorsal blubber thickness in the stranding dataset as a function of lateral blubber thickness, body length, sex, taxonomic family, and a categorical variable differentiating between large (baleen and sperm whales) and small cetaceans. We accounted for variations in blubber thickness across stranded whale conditions by including the square root of whale condition scores (scored subjectively from zero to one based on whale health and decomposition at time of necropsy, where one represented a robust animal necropsied prior to decomposition onset) as model weights to favor samples from cetaceans with better body and carcass conditions. Two slightly different models were created: one model included interactions between whale size (large versus small cetaceans) and sex, body length, and lateral blubber thickness, while the other model included similar interactions but with taxonomic family instead of whale size. For both models, we minimized Bayesian information criterion (BIC) across all possible combinations of interaction terms (keeping all fixed effects) to determine which model and interactions best fit the stranding dataset. The model that minimized BIC was then used to predict dorsal blubber thickness for the whaling dataset and analyze changes in dorsal blubber thickness across large whale species. Model development, assessment, and visualization was performed using the following auxiliary R packages (R Core Team 2019): *performance* v0.7.2 (Lüdecke et al. 2021), car v3.0-10 (Fox & Weisburg 2018), MuMIn v1.43.17 (Barton 2020), *ggplot2* v3.3.3 (Wickham 2016), *ggformula* v0.10.1 (Kaplan & Pruim 2020), and *tidyverse* v1.3.1 (Wickham et al. 2019).

**Results**

A total of 23 species from 6 data sources totaling 613 records from the stranding dataset contributed to model development (Table 1). Dorsal blubber thickness was reported or predicted for 12 species totaling 37,616 whales from the whaling dataset (Table 2). Samples where only dorsal blubber thickness was available were included in the observed column for dorsal blubber thickness (Table 2) to provide a general comparison of observed versus predicted measurements. These samples were also included in Figure 2 to provide additional information on their relationship with whale length.

The final model used to predict dorsal blubber thickness for the whaling dataset contained whale condition weights (Table 1) and the following predictors: sex, whale length, taxonomic family, whale size, lateral blubber thickness, and the interaction between lateral blubber thickness and whale size. Despite the use of model weights that complicate interpretation of residual-based model performance metrics due to the bias placed on better-conditioned whales, the final model fit the training data with reasonable accuracy (Nagelkerke's $R2$ = 0.92, RMSE = 1.44 cm). Of the 613 records in the stranding dataset, 224 carcasses were fresh dead and 98 of these were in either excellent or good body condition (Table 3). There were 301 carcasses where body and/or carcass conditions were not specified or could not be determined and for which conservative conditions scores were used in determining proper condition weights (Table 3). The sum of whale condition weights in the final model was 348.2, which is equivalent to 56.8% of the stranding dataset sample size (Table 1).

[1] The following organizations contributed to the datasets in Daoust et al. 2018 and Bourque et al. 2020: Canadian Wildlife Health Cooperative, Marine Animal Response Society, Woods Hole Oceanographic Institute, Virginia Aquarium and Marine Science Center, University of New Brunswick, New England Aquarium.

Due to strong collinearity within the final model, parameter coefficient estimates, and significance levels could not be accurately calculated for most variables. Whale length and lateral blubber thickness were significantly correlated ($r = 0.77$, 95% CI = [0.74, 0.80], $p < 0.001$). Although sex was not collinear with other predictors, it was not a significant predictor of dorsal blubber thickness in the final model ($p = 0.62$). Model results show positive linear relationships between dorsal blubber thickness and both lateral blubber thickness (Figure 1) and whale length (Figure 2). Dorsal blubber thickness varied across species with the thinnest maximum values in minke whales (*B. acutorostrata* and *bonaerensis*) and the thickest in Southern right whales (Table 2 and Figure 2).

**Table 1** Sample sizes, calculated whale condition scores from both carcass and body condition, and source(s) for each species within the stranding dataset used in model development. CRC=Cascadia Research Collective; IFAW=International Fund for Animal Welfare; PBB = archives of Peter B. Best.

| Species | Species Size | Family | Stranding Samples (sum of condition weights) | Source(s) |
|---|---|---|---|---|
| *Eubalaena australis* | Large | Balaenidae | 254 (116.3) | Maron et al. 2021; PBB |
| *Eubalaena glacialis* | Large | Balaenidae | 11 (5.2) | Bourque et al. 2020; Daoust et al. 2018; IFAW |
| *Balaenoptera acutorostrata* | Large | Balaenopteridae | 27 (17.3) | CRC; IFAW |
| *Balaenoptera borealis* | Large | Balaenopteridae | 1 (0.3) | CRC |
| *Balaenoptera edeni* | Large | Balaenopteridae | 2 (1.2) | CRC |
| *Balaenoptera physalus* | Large | Balaenopteridae | 7 (4.2) | CRC; IFAW |
| *Megaptera novaeangliae* | Large | Balaenopteridae | 15 (7.9) | CRC; IFAW |
| *Eschrichtius robustus* | Large | Eschrichtiidae | 81 (35.6) | CRC |
| *Physeter macrocephalus* | Large | Physeteridae | 5 (2.9) | CRC |
| *Delphinus capensis* | Small | Delphinidae | 4 (3.3) | CRC |
| *Delphinus delphis* | Small | Delphinidae | 4 (3.1) | CRC |
| *Grampus griseus* | Small | Delphinidae | 1 (0.4) | CRC |
| *Lagenorhynchus obliquidens* | Small | Delphinidae | 2 (0.9) | CRC |
| *Orcinus orca* | Small | Delphinidae | 6 (4) | CRC |
| *Stenella coeruleoalba* | Small | Delphinidae | 4 (2.6) | CRC |
| *Tursiops truncatus* | Small | Delphinidae | 2 (1) | CRC |
| *Kogia breviceps* | Small | Kogiidae | 2 (1.3) | CRC |
| *Phocoena phocoena* | Small | Phocoenidae | 174 (132.5) | CRC |
| *Phocoenoides dalli* | Small | Phocoenidae | 5 (4.1) | CRC |
| *Phocoenoides dalli/Phocoena phocoena Hybrid* | Small | Phocoenidae | 1 (0.9) | CRC |
| *Berardius bairdii* | Small | Ziphiidae | 2 (1.3) | CRC |
| *Mesoplodon densirostris* | Small | Ziphiidae | 2 (1.6) | CRC |
| *Ziphius cavirostris* | Small | Ziphiidae | 1 (0.3) | CRC |

**Table 2** This table contains the 12 species of large whales that have been identified as cetaceans that would be targeted for implantable tags. Both observed and predicted dorsal blubber thickness are shown to give a general comparison of the range of dorsal blubber thickness from measurements (observed) and the model (predicted). Refer to Figure 2 for more detailed information on dorsal blubber thickness versus length (m). Observed measurements are regionally widespread and where possible, general geographic location is noted. Geographic regions for each species from the Yuri Dolgorukiy database were too expansive to list. Refer to Figure 3 for regional catches by species. IFAW = International Fund for Animal Welfare; CRC = Cascadia Research Collective; SNMNH = Smithsonian National Museum of Natural History.

| | | | | | Blubber Thickness (cm) | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Lateral Blubber Thickness | Dorsal Blubber Thickness | | |
| **Species** | **Family** | **Sample Size (% Predicted)** | **Geographic Region** | **Body Length Range (m)** | **Observed** | **Observed** | **Predicted** | **Source(s)** |
| *Eubalaena australis* (Eaus) Southern Right Whale | Balaenidae | 354 (27%) | SW Atlantic | 3.1-15.8 | 1-24.4 | 1-19.5 | 2.6-15.9 | Maron et al. 2021 |
| | | 14 (0%) | South Africa | 3.9-10.1 | 3-11 | 2-17 | NA | Peter B. Best |
| | | 620 (100%) | Figure 3 | 8.2-16.5 | 3-49 | NA | 4.3-33.1 | *Yuri Dolgorukiy* database |
| *Eubalaena glacialis* (Eglac) North Atlantic Right Whale | | 12 (17%) | NW Atlantic | 11.1-15.1 | 8.3-21 | 7.6-17 | 11.3-12.5 | Daoust et al. 2018 Bourque et al. 2020 |
| | | 2 (0%) | NW Atlantic | 8.2-9 | 8-11.5 | 7-10 | NA | IFAW |
| | | 38 (0%) | NW Atlantic | 8.7-14.7 | NA | 9.7-22.3 | NA | Miller et al. 2011 |
| *Eubalaena japonica* (Ejap) North Pacific Right Whale | | 10 (100%) | NW Pacific | 10.8-18.3 | 19-25.3 | NA | 14.1-19.3 | Klumov 1962 |
| | | 2 (100%) | NW Pacific | 11.7-12.4 | 13-14.5 | NA | 10.6-11.6 | Omura 1958 |
| | | 9 (100%) | N Pacific | 14.1-17.1 | 17.5-24.5 | NA | 13.9-18.5 | Omura et al. 1969 |
| *Balaenoptera acutorostrata* (Bacu) Common Minke Whale | Balaenopteridae | 1 (0%) | NE Pacific | 6.9 | 2.5 | 4.1 | NA | CRC |
| | | 27 (4%) | NW Atlantic | 3.9-7.9 | 1.8-4.9 | 1.3-4.2 | 2.2 | IFAW |
| | | 4 (100%) | NW Atlantic | 3.6-4.7 | 2-2.6 | NA | 1.9-2.2 | SNMNH |
| *Balaenoptera bonaerensis* (Bbon) Antarctic Minke Whale | | 1,018 (100%) | Figure 3 | 5.3-12.1 | 1-9 | NA | 2-7.7 | *Yuri Dolgorukiy* database |
| *Balaenoptera borealis* (Bbor) Sei Whale | | 1 (0%) | NE Pacific | 13 | 2.7 | 2.6 | NA | CRC |
| | | 10,042 (100%) | Figure 3 | 1.3-17.5 | 1-15 | NA | 1.3-12.1 | *Yuri Dolgorukiy* database |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Balaenoptera edeni* (Bede) Bryde's Whale | | 2 (0%) | NE Pacific | 10.5-11.8 | 4-4.5 | 3-5 | NA | CRC |
| | | 4 (100%) | Figure 3 | 10.5-14.1 | 3-8 | NA | 3.7-7.4 | *Yuri Dolgorukiy* database |
| *Balaenoptera musculus* (Bmus) Blue Whale | | 333 (100%) | Figure 3 | 13.4-28.2 | 1-20 | NA | 4.2-17.4 | *Yuri Dolgorukiy* database |
| *Balaenoptera physalus* (Bphy) Fin Whale | | 5 (0%) | NE Pacific | 14.2-18.4 | 4-6.5 | 3-6.5 | NA | CRC |
| | | 2 (0%) | NW Atlantic | 13.1-15.5 | 3-4.5 | 2.3 | NA | IFAW |
| | | 7 (100%) | NW Atlantic | 5.3-15.3 | 2.5-7 | NA | 2.4-6.6 | SNMNH |
| | | 4,697 (100%) | Figure 3 | 2-26.5 | 1-24 | NA | 2.9-18.4 | *Yuri Dolgorukiy* database |
| *Megaptera novaeangliae* (Mnov) Humpback Whale | | 7 (0%) | NE Pacific | 7-11.9 | 5.6-10.5 | 5-8.3 | NA | CRC |
| | | 15 (40%) | NW Atlantic | 6.8-13.6 | 4.2-9.7 | 2.8-10 | 4-6.7 | IFAW |
| | | 3,873 (100%) | Figure 3 | 0.9-18.2 | 1-24 | NA | 2.6-17.5 | *Yuri Dolgorukiy* database |
| *Eschrichtius robustus* (Erob) Gray Whale | Eschrichtiidae | 81 (0%) | NE Pacific | 3.2-13.9 | 1.6-14 | 1.6-14 | NA | CRC |
| *Physeter macrocephalus* (Pmac) Sperm Whale | Physeteridae | 5 (0%) | NE Pacific | 4.4-11.7 | 4.1-11 | 5.8-12 | NA | CRC |
| | | 1 (100%) | NW Atlantic | 3.8 | 3.4 | NA | 5.8 | SNMNH |
| | | 16,893 (100%) | Figure 3 | 0.1-23 | 1-25 | NA | 3.8-21.4 | *Yuri Dolgorukiy* database |

**Table 3** Distribution of body and carcass conditions within the stranding dataset used for model development. These classifications are approximate, especially given that they were obtained and standardized across numerous different organizations and researchers, many of whom utilized differing methods of classifying body and carcass conditions. NA represents cases where body and/or carcass conditions were not specified.

| | | Body Condition | | | | | |
|---|---|---|---|---|---|---|---|
| | | Excellent | Good | Fair | Fair-Poor | Poor | NA |
| Carcass Condition | Fresh | 24 | 74 | 47 | 5 | 36 | 38 |
| | Fresh-Moderate | 4 | 10 | 11 | 0 | 21 | 3 |
| | Moderate | 7 | 17 | 25 | 3 | 9 | 92 |
| | Moderate-Advanced | 0 | 6 | 3 | 0 | 1 | 2 |
| | Advanced Decomposition | 0 | 4 | 2 | 0 | 3 | 143 |
| | NA | 1 | 0 | 1 | 0 | 0 | 21 |

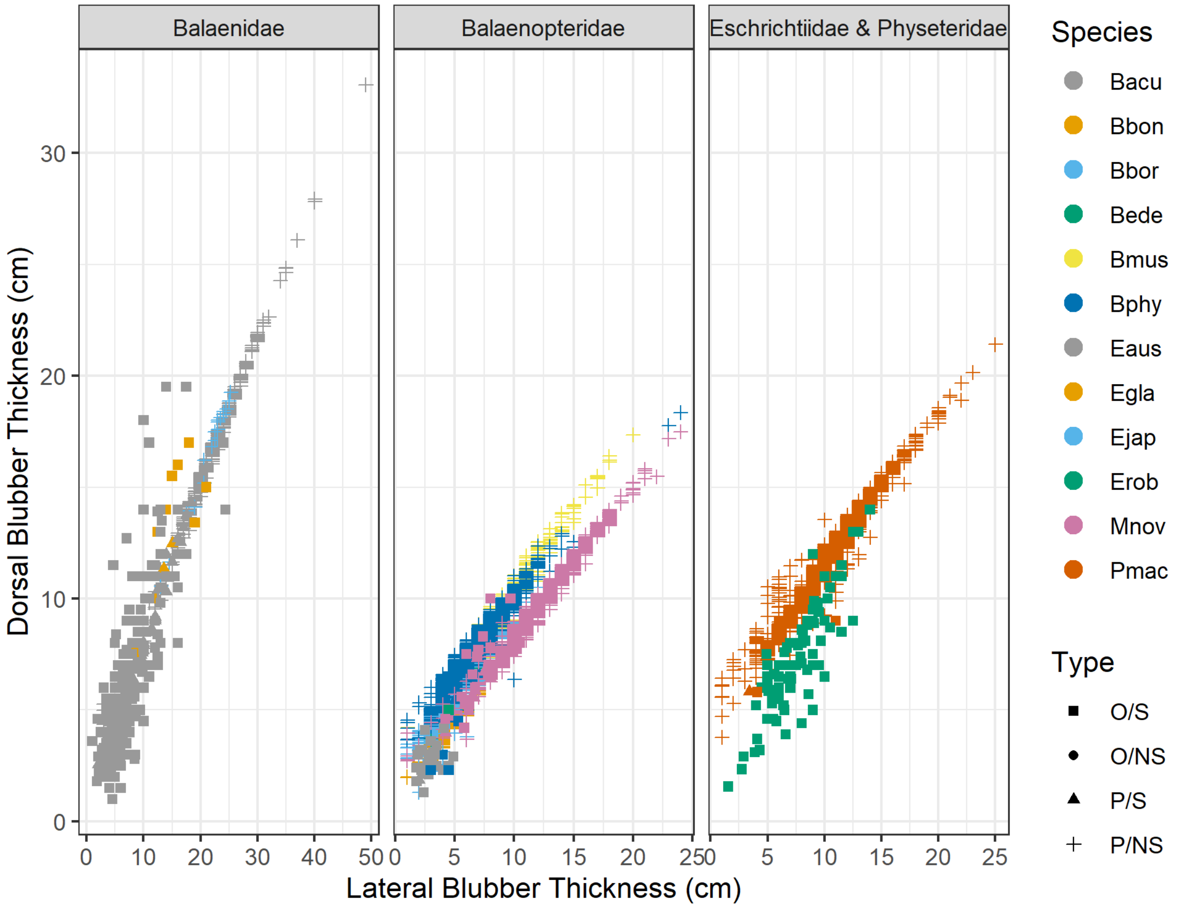



**Figure 1** Plot of dorsal blubber thicknesses (predicted and observed) as a function of lateral blubber thickness across large whale species (first letter of Genus, first three letters of species) from all available datasets. Figure panels show separations by taxonomical families, shapes represent dorsal blubber measurement sources, and colours represent species. Note that horizontal axes are different across panels to zoom in on relevant data points. Type: O=Observed; P=Predicted; NS=Not Stranded; S=Stranded.

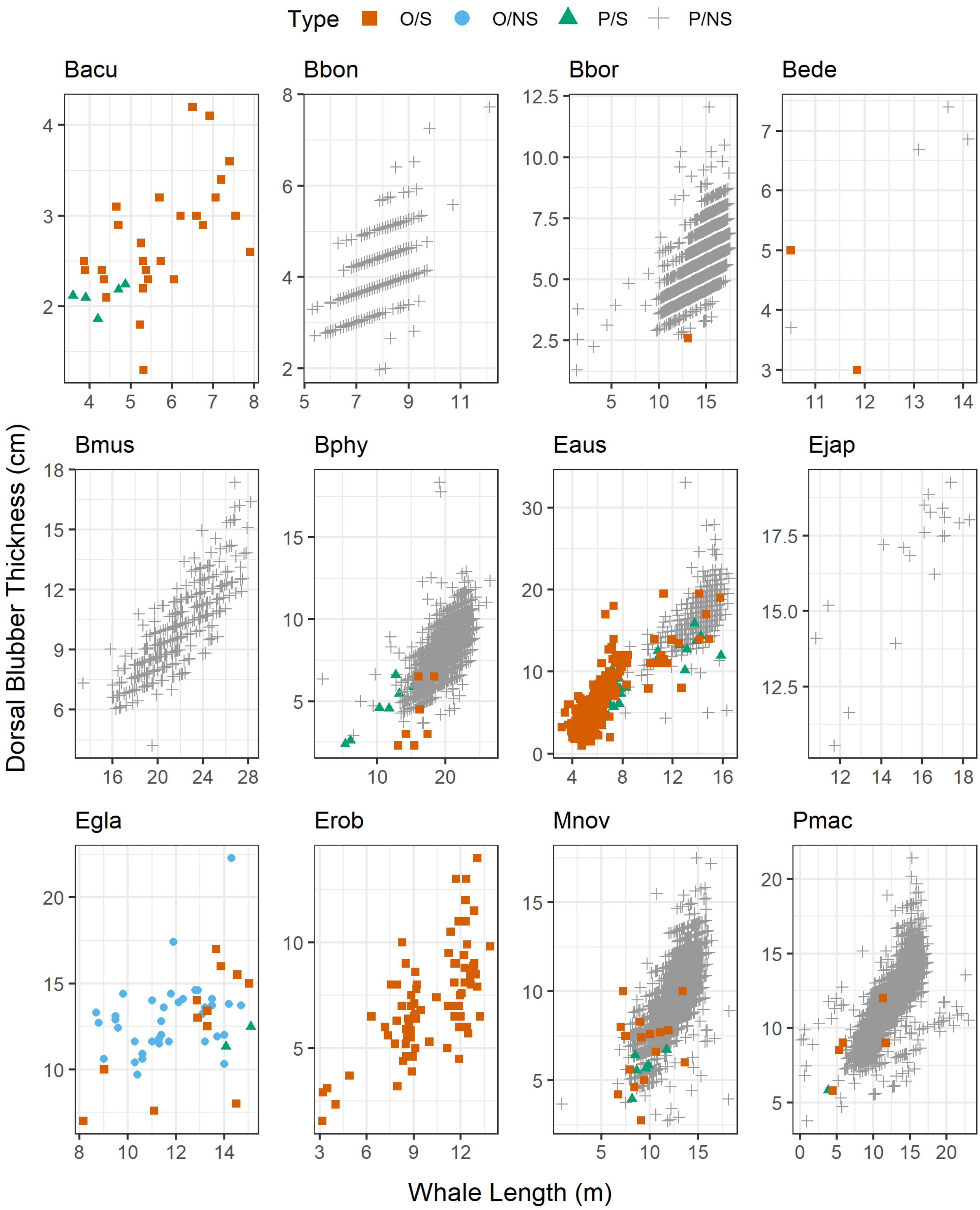



**Figure 2** Plot of dorsal blubber thicknesses (predicted and observed) as a function of whale length across large whale species from all available datasets. Figure panels show sources of measurements (shape and color) by species (first letter of Genus, first three letters of species). Note that both horizontal and vertical axes vary across panels to zoom in on relevant data points. Type: O=Observed; P=Predicted; NS=Not Stranded; S=Stranded.

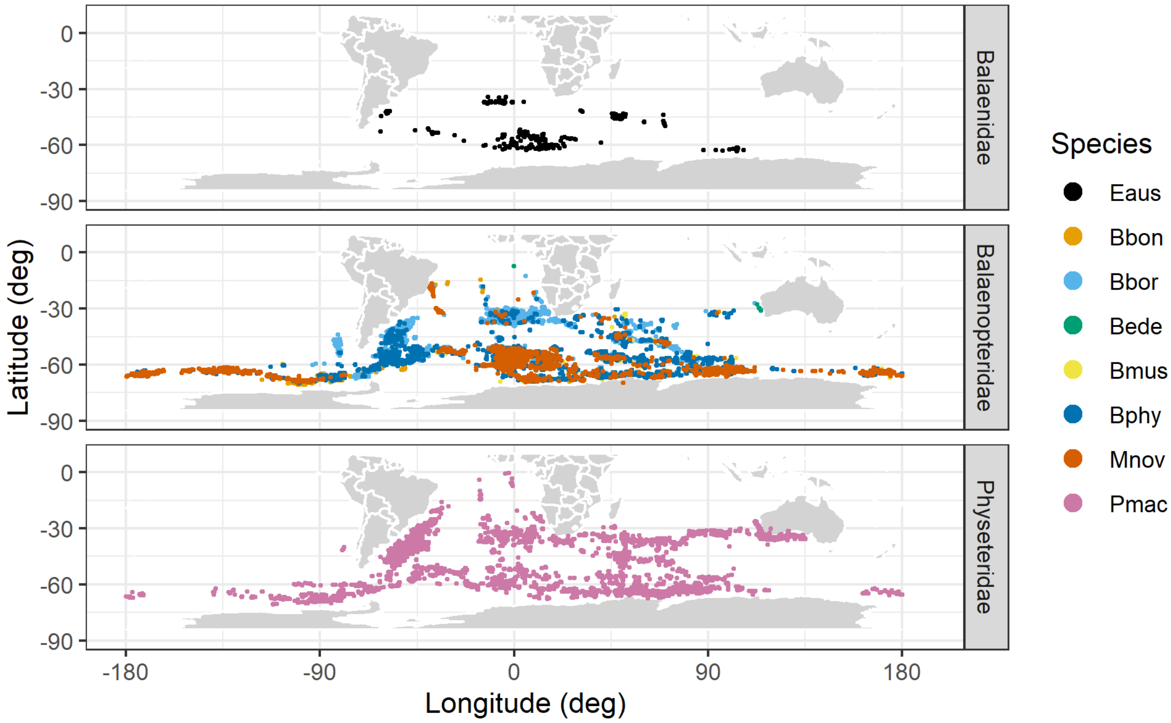



**Figure 3** Geographic regions for each large whale species (first letter of Genus, first three letters of species) from the *Yuri Dolgorukiy* Soviet fleet whaling database (see Table 3 for details). These data consisted of lateral blubber thickness measurements and were used in the final model to predict dorsal blubber thickness measurements.

**Conclusions**

Results from this project show that cetacean stranding data can inform development of statistical models capable of predicting dorsal blubber thickness as a function of lateral blubber thickness, whale length, and sex in large whales. These results also show that application of these models to a large, robust whaling dataset provides an effective means of assessing variations in blubber thickness of large whales. This is currently difficult for many species because of limitations associated with stranding data (e.g., small samples, carcass conditions often in severely decomposed state).

Satellite tagging is a valuable tool that has given researchers a means to further our understanding of many species of free-ranging cetaceans. While valuable, this procedure is invasive and the research and conservation questions should justify the means, particularly for endangered species. Tag developers continue to strive for more sophisticated sensors in smaller packages while increasing the duration of tag transmission. The minimization of tissue trauma and the potential short- and long-term impacts that may arise as a result have become equally important. Until now, there was limited cohesive information on the dorsal blubber thickness for large whale tagging candidates. Our understanding of trends in large whale blubber thickness was typically described from lateral-anus measurements from whaling data. With the demonstrated linear relationship between lateral and dorsal blubber thickness and in turn, with dorsal blubber thickness and length, we can bridge the gap between stranding and historic whaling data, thereby allowing access to a robust dataset to guide present-day science. By utilizing the strengths of these two datasets, we now have information that may be used to guide future tag development and deployment. It is our intention that these efforts will result in tag technology that reduces impacts to animals, improves tag deployment durations and assists the collective scientific community in making informed decisions about large whale satellite tagging.

**Challenges**

Model development within this study is faced with a couple of challenges. Sample sizes of stranded species that are the focus of implantable tag research are often limited or non-existent. In addition, stranded animals are often compromised in condition and only on the rare occasion were necropsied in excellent condition (e.g., a healthy individual ship struck and retrieved promptly). On the other hand, whaling data provide a robust dataset of presumably healthy individuals. Preliminary evaluations of the model suggested that removal of stranding data of whales with relatively poor conditions did not drastically alter model predictions but reduced sample sizes significantly. We therefore developed a method to weight carcasses in different conditions, which maximized the use of the sample available to us, while relying more heavily on better quality information.

**Outlook for the future**

At the time this report was prepared, a manuscript was being finalized for review by the co-authors and subsequent submission. We expect the manuscript to be submitted by June 2022.

**Project outputs**

*Peer-reviewed papers*

Rone BK, Sweeney DA, Calambokidis J, Clapham PJ, Double M, Findlay K, Huggins J, Ivashchenko YV, Marón C, Uhart M, Vermuelen E, Zerbini AN (*In preparation*) Predicting blubber thickness in large whales: an analysis to inform satellite tag development.

**Scientific references cited in report**


Barton K (2020) MuMIn: Multi-Model Inference.

Bourque L, Wimmer T, Lair S, Jones M, Daoust P-Y (2020) Incident Report: North Atlantic Right Whale Mortality Event Eastern Canada, 2019. Collaborative Report Produced By: Canadian Wildlife Health Cooperative and Marine Animal Response Society.

Daoust P-Y, Couture EL, Wimmer T, Bourque L (2018) Incident Report: North Atlantic Right Whale Mortality Event in the Gulf of St. Lawrence, 2017. Collaborative Report Produced By: Canadian Wildlife Health Cooperative, Marine Animal Response Society, and Fisheries and Oceans Canada.

Fox J, Weisburg S (2018) An R Companion to Applied Regression, 3rd. Sage, Thousand Oaks, California, US.

Lüdecke D, Ben-Shachar M, Patil I, Waggoner P, Makowski D (2021) Performance: An R Package for Assessment, Comparison and Testing of Statistical Models. J Open Source Softw 6:3139.

Kaplan D, Pruim R (2020) Ggforumla: Formula Interface fo the Grammar of Graphics.

Klumov SK (1962) The right whale in the Pacific Ocean. Proc Inst Oceanol Acadamy Sci USSR: 202–297.

Miller C, Reeb D, Best P, Knowlton A, Brown M, Moore M (2011) Blubber thickness in right whales *Eubalaena glacialis* and *Eubalaena australis* related with reproduction, life history status and prey abundance. Mar Ecol Prog Ser 438: 267–283.

Nishiwaki M (1959) Humpack whale in Ryukyuan waters. Sci Rep Whales Res Inst 14: 49–87.

Nishiwaki M, Hayashi K (1950) Biological survey of fin and blue whales taken in the Antarctic season 1947-48 by the Japanese fleet. Sci Rep Whales Res Inst 3: 132–190.

Nishiwaki M, Oye T (1951) Biological investigation on blue whales (*Balaenoptera musculus*) and fin whales (*Balaenoptera physalus*) caught by the Japanes Antartic whaling fleets. Sci Rep Whales Res Inst 5: 91–167.

Omura H (1958) North Pacific right whale. Sci Rep Whales Res Inst 13: 1–52.

Omura H (1950) On the Body Weight of Sperm and Sei Whales located in the Adjacent Waters of Japan. Sci Rep Whales Res Inst 4: 1–13.

Omura H, Ohsumi S, Nemoto T, Nasu K, Kasuya T (1969) Black right whale in the North Pacific. Sci Rep Whales Res Inst 21: 1–78.

Wickham H (2016) *Ggplot2*: Elegant graphics for data analysis. Springer-Verlag New York.

Wickham H, Averick M, Bryan J, Chang W, McGowan L, François R, Grolemund G, Hayes A, Henry L, Hester J, Kuhn M, Pedersen T, Miller E, Bache S, Müller K, Ooms J, Robinson D, Seidel D, Spinu V, Takahashi K, Vaughan D, Wilke C, Woo K, Yutani H (2019) Welcome to the *Tidyverse*. J Open Source Softw 4:1686.

**PROJECT 20 (Širović & Stafford, 2018/19). Acoustic ecology of foraging Antarctic blue whales in the vicinity of Antarctic krill studied during AAD interdisciplinary voyage aboard the *RV Investigator***

*Ana Širović[1], Kate Stafford[2]*

*1. Department of Biology, Norwegian University of Science and Technology, Trondheim, Norway*
*2. Marine Mammal Institute, Oregon State University, Newport, OR, United States of America*

## Executive summary

In austral summer 2019, a 48 day, multi-country, interdisciplinary research voyage mapped Antarctic krill (*Euphausia superba*) and baleen whale, blue whale (*Balaenoptera musculus*) and fin whale (*B. physalus*) distributions in particular off East Antarctica. We detected, tracked and localized blue whales and mapped prey fields in the vicinity of a fixed acoustic mooring that combined passive and active acoustics for collection of concurrent predator and prey data. By coupling moored data collection with the ship-based survey focusing on Antarctic blue whale behaviour and krill dynamics, we investigated the dynamics of blue whales and their prey. We found that the production of social calls, D calls of blue whales and 40 Hz calls of fin whales, was correlated with the krill biomass over a week-long period. Further analysis of the scale-relationships among the data sets will be undertaken to evaluate relationships among whale abundance, their calling behaviour, and krill abundance.

## Introduction

Antarctic krill (*Euphausia superba*) is the keystone species of the Southern Ocean marine ecosystem. While many Antarctic upper trophic level predators are sympatric in space and time, different species have evolved unique foraging strategies allowing them to fill different ecological niches despite being potential competitors for food (Kawamura 1994, Friedlaender et al. 2009, Friedlaender et al. 2011). For example, blue whales are generally sighted near the marginal ice zone, often associated with krill patches (Nicol et al. 2000, Murase et al. 2002), however, how they best exploit Antarctic krill has not been well studied. Based on data from a limited number of tagged whales in the North Pacific, blue whales feed primarily during daylight hours and appear to track their prey's vertical migration into early evening before ceasing feeding behaviour at night (Friedlaender et al. 2014). Likewise, blue whales in the Northeast Atlantic also change depth of dive in correspondence with the time of day and prey depth (Doniol-Valcroze et al. 2011). Off the Western Antarctic Peninsula, calling blue whales were found to be negatively correlated with krill (Širović and Hildebrand 2011).

Blue whales also vary their acoustic behaviour with the time of day (Stafford et al. 2005, Wiggins et al. 2005), with Antarctic blue whales calling more often during the day (Leroy et al. 2016). There is likely a trade-off between foraging and vocal displays: when prey is more dispersed and foraging therefore less efficient, blue whales may spend more effort on acoustic displays. Blue whales worldwide produce two general categories of acoustic displays in different behavioural contexts. The best studied are long, low-frequency signals that may be produced as individual calls or in long sequences referred to as "song." These geographically variable signals are referred to Z-calls in the Antarctic and have been recorded around the Antarctic (Širović et al. 2009). Songs are produced by traveling males (McDonald et al. 2001, Oleson et al. 2007). All blue whales also produce D-calls, which are variable frequency modulated downswept calls with no clear geographic variation (Thompson et al. 1996, Rankin et al. 2005, Širović et al. 2006). D-calls are produced during foraging by both males and females (Oleson et al. 2007). Both types of vocalization are produced at relatively shallow depths (Oleson et al. 2007, Lewis et al. 2019). Fin whale also produce song and social calls, called 20 Hz can 40 Hz calls, respectively (Širović et al. 2013).

## Objectives

By coupling moored data collection with the ship-based survey focusing on Antarctic blue whale behaviour and krill dynamics, we aim to interpret and quantify the presence of blue whales and their prey. Specifically, we want to test the following hypotheses:

1) Production of D-calls is directly related to krill swarm density.
2) Blue whale vocal behaviour will vary with time of day in relation to krill diel vertical migration, with more Z-calls produced at night when foraging is less efficient (krill swarm density is lower at night when krill are shallower).
3) Foraging blue whales produce D-calls or single Z-calls and traveling animals produce series of Z-calls (song).

**Results**

During the last year, we finalized comparison of blue and fin whale call detections from fixed mooring to those from concurrent sonobuoy deployments. The goal of this effort was to estimate the probability of detection of a call on a fixed mooring as a function of range by comparing calls from "known" locations (recorded on multiple sonobuoys at the same time) with calls recorded on the fixed recorder (HARP). Overall, data from 30 sonobuoys were used in final analysis, for a total of 59:49:09 hours of data. From those sonobuoys, 2903 calls were detected and of these, 1704 calls matched on HARP. Analysis of the detection range from comparing blue whale calls from the sonobuoy and the HARP indicate that our mooring detected blue and fin whale calls out to a range of about 50 km in the study area.

A further study was undertaken to estimate the source level of two types of blue whale calls (song note Z-calls and D-calls) and two types of fin whale calls (20 Hz and 40 Hz calls) based on data collected using sonobuoys deployed during the voyage. Based on data obtained from sonobuoys during the research voyage, it was determined that the source levels of blue whale calls were 188–191 ± 6–8 dB re: 1 μPa and fin whale call types were 189–192 ± 6 dB re: 1 μPa (Miller et al. 2021). These estimates of source level are the first from the Southern Hemisphere for D-calls and 40 Hz downsweeps, and the largest sample size to-date for Antarctic blue whale song.

Time series analyses of whale call occurrence and krill biomass indicate that social calls are produced by blue and fin whales more commonly at times of high krill biomass (Figure 1). In fact, high production of social calls occurred during times of higher krill biomass for both species, while song production did not appear to be related to krill biomass (Figure 2).

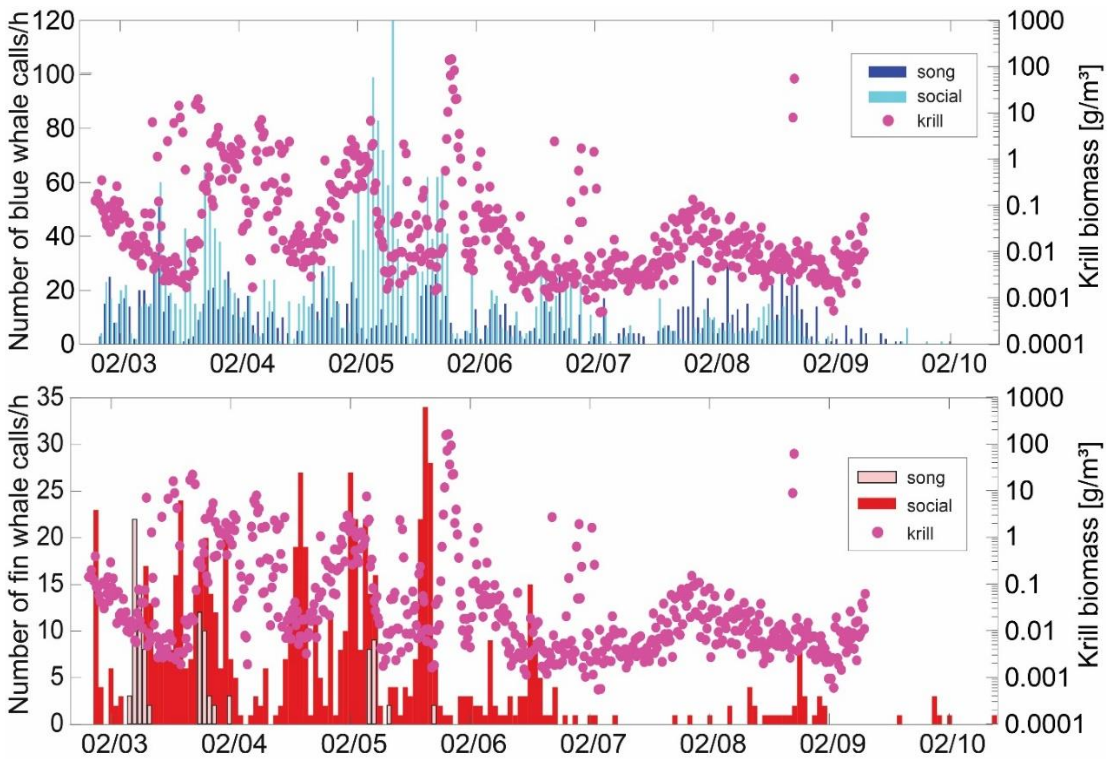



**Figure 1** Hourly call rate for blue (top panel) and fin whale (bottom panel) song and social calls (bars) along with krill biomass (circles) calculated from volume backscatter measured at 70 kHz. Data represent a week of concurrent passive and active acoustic data collected by the mooring off East Antarctica.

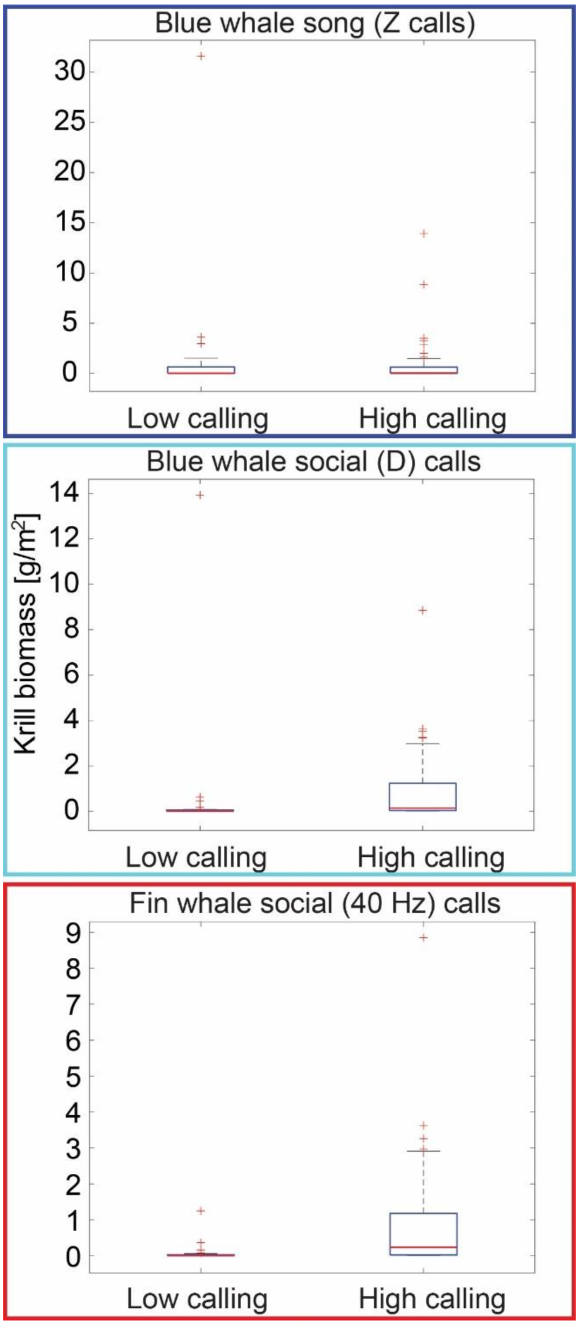



**Figure 2** Krill biomass estimated from mooring echosounder during times of low hourly calling production and high hourly calling production for blue whale song (top panel) and social calls (middle panel), and fin whale social calls (bottom panel). There was no difference in krill biomass during varying song level production for blue whales, but krill biomass was generally significantly higher during high call production of blue and fin whale social calls.

**Conclusions**

Combined passive and active acoustic mooring data, coupled with ship-based observations, is shedding new light on the mesoscale relationships between baleen whales and their prey. Links between social calls and prey may serve to further clarify possible function and use of those calls. Understanding those relationships may also be important for interpreting passive acoustic data for abundance estimation.

**Project outputs**

*Peer-reviewed publications*

Miller BS, Calderan S, Leaper R, Miller EJ, Širović A, Stafford KM, Bell E, Double MC (2021) Source level of Antarctic blue and fin whale sounds recorded on sonobuoys deployed in the deep-ocean off Antarctica. Frontiers in Marine Science 8: 792651.

*Reports*

Annual report submitted to the National Science Foundation, September 2019
Annual report submitted to the National Science Foundation, September 2020
Final report submitted to the National Science Foundation, September 2021

*Conference presentations*

Širović A, Wood M, Warren JD, Stafford KM, Miller B (2019) Mesoscale dynamics of blue and fin whales and Antarctic krill of East Antarctica. Marine Mammal World Congress, 9-12 December, Barcelona, Spain (Poster).

Širović A, Wood M, Warren JD, Stafford KM, Miller B (2019) Mesoscale dynamics of blue and fin whales and Antarctic krill of East Antarctica. Ocean Sciences Meeting, 17-21 February, San Diego, California, USA (Oral).

*We gratefully acknowledge the CSIRO Marine National Facility staff and vessel crew for their incredible support before and during the voyage.*

**Scientific references cited in report**

Doniol-Valcroze T, Lesage V, Giard J, Michaud R (2011) Optimal foraging theory predicts diving and feeding strategies of the largest marine predator. Behavioral Ecology 22: 880–888.
Friedlaender AS, Goldbogen JA, Hazen EL, Calambokidis J, Southall BL (2014) Feeding performance by sympatric blue and fin whales exploiting a common prey resource. Marine Mammal Science 31: 345–354.
Friedlaender AS, Johnston DW, Fraser WR, Burns J, Halpin PN, Costa DP (2011) Ecological niche modeling of sympatric krill predators around Marguerite Bay, Western Antarctic Peninsula. Deep-Sea Research Part II 58: 1729–1740.
Friedlaender, AS, Lawson GL, Halpin PN (2009) Evidence of resource partitioning between humpback and minke whales around the western Antarctic Peninsula. Marine Mammal Science 25:402–415.
Kawamura A (1994) A review of baleen whale feeding in the Southern Ocean. Reports of the International Whaling Commission 44: 261-271.
Leroy EC, Samaran F, Bonnel J, Royer J-Y (2016) Seasonal and diel vocalization patterns of Antarctic blue whale (*Balaenoptera musculus intermedia*) in the Southern Indian Ocean: A multi-year and multi-site study. PLoS ONE 11:e0163587.
Lewis LA, Calambokidis J, Stimpert AK, Fahlbusch J, Friedlander AS, McKenna MF, Mesnick SL, Oleson EM, Southall BL, Szesciorka AR, Širović A (2018) Context-dependent variability in blue whale acoustic behavior. Royal Society Open Science. 5: 180241.10.1098/rsos.180241
McDonald M, Calambokidis J, Teranishi A, Hildebrand JA (2001) The acoustic calls of blue whales off California with gender data. Journal of the Acoustical Society of America 109: 1728–1735.
Murase H, Matsuoka K, Ichii T, Nishiwaki S (2002) Relationship between the distribution of euphausiids and baleen whales in the Antarctic (35°E - 145°W). Polar Biology 25: 135-145.
Nicol S, Pauly T, Bindoff NL, Wright S, Thiele D, Hosie GW, Struuron PG, Woehler E (2000) Ocean circulation off east Antarctica affects ecosystem structure and sea-ice extent. Nature 406: 504-507.
Oleson EM, Calambokidis J, Burgess WC, McDonald MA, LeDuc CA, Hildebrand JA (2007) Behavioral context of call production by eastern North Pacific blue whales. Marine Ecology Progress Series 330: 269-284

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.

Širović A, Hildebrand JA (2011) Using passive acoustics to model blue whale habitat off the Western Antarctic Peninsula. Deep Sea Research Part II: Topical Studies in Oceanography 58: 1719-1728.

Širović A, Hildebrand JA, Thiele D (2006) Baleen whales in the Scotia Sea in January and February 2003. Journal of Cetacean Research and Management 8: 161-171.

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.

Širović A, Williams LN, Kerosky SM, Wiggins SM, Hildebrand JA (2013) Temporal separation of two fin whale call types across the eastern North Pacific. Marine Biology. 160: 47-57.

Stafford KM, Moore SE, Fox C (2005) Diel variation in blue whale calls recorded in the eastern tropical Pacific. Animal Behaviour 69: 951–958.

Thompson PO, Findley LT, Vidal O, Cummings WC (1996) Underwater sounds of blue whales, *Balaenoptera musculus*, in the Gulf of California, Mexico. Marine Mammal Science, 12(2): 288-293.

Wiggins S, Oleson EM, McDonald MA, Hildebrand J (2005) Blue whale (*Balaenoptera musculus*) diel call patterns offshore of Southern California. Aquatic Mammals 31: 161–168.

**PROJECT 21 (Kelly, Maire et al., 2018/19). Development of statistical and technical methods to support the use of long-range UAVs to assess and monitor cetacean populations in the Southern Ocean**

*Natalie Kelly[1], Frederic Maire[2], Amanda Hodgson[3], David Peel[4], Helena Herr[5], Jennifer Jackson[6], Phil Trathan[6], Guy Williams[7]*

*1. Australian Marine Mammal Centre, Australian Antarctic Division, 203 Channel Highway, Kingston, Tasmania 7050, Australia*
*2. Robotics and Autonomous Systems School of EECS, Science and Engineering Faculty, Queensland University of Technology, Box 2434, Brisbane, Queensland 4001, Australia*
*3. Murdoch University Cetacean Research Unit, Biological Science, Murdoch University, South Street, Murdoch, WA 6150, Australia*
*4. Data61, CSIRO, Castray Esplanade, Hobart, Tasmania 7000, Australia*
*5. University of Hamburg, Centre of Natural History (CeNak), Martin-Luther-King-Platz 3, 2-146, Hamburg, Germany*
*6. British Antarctic Survey, High Cross, Madingley Road, Cambridge, CB30ET, UK*
*7. Institute of Marine and Antarctic Studies (IMAS), ACE-CRC, 24 Athleen Avenue, Lenah Valley, Tasmania 7008, Australia*

## Executive summary

In the past year, progress was made in development of software to help process aerial images from surveys and deep neural networks to detect multiple marine species in aerial imagery. The *Dugong Detector* software (soon to be renamed to reflect the now wider range of capabilities and applications) is a toolbox that allows users to analyse images collected from aerial platforms (note: developed using in-kind support). The *Marine Animal Detector* (or *MAD*) is an AI detector designed to find dugongs, whales, dolphins, turtles, belugas, sharks and rays in aerial imagery, and is the culmination of many year's work. MAD is currently being tested using naïve labelled images and is being integrated with the *Dugong Detector* to form one tool available within that software package. Work towards developing tools to for aerial imagery surveys in the Southern Ocean is complementary with work being undertaken in dugong research. This work progressed despite COVID-19 having an impact on time available to co-investigators.

## Introduction

Traditional survey methods, such as vessel or aerial line transect surveys, are expensive to run in vast and remote areas, such as the Southern Ocean; new approaches are needed to provide safe, cheap and effective future data streams for conservation and management of whales. Recent studies have demonstrated the potential for the combination of digital imagery and Unoccupied Aerial Vehicles (UAVs) to replace human observers on aerial surveys for marine mammals. This project seeks to advance the statistical and technical methods to support the use of UAVs and aerial imagery to assess and monitor cetacean populations in the Southern Ocean.

## Objectives

This project involves desktop studies, using existing data. The novel components of the project are method development, and strategic and operational planning. The specific objectives are:

1. To develop techniques/methods to deal with post-processing of digital imagery (will also involve the collation of a global library of aerial images of whales for training automatic detection algorithms). In particular, the aim is to detect and classify various species of cetaceans in aerial digital images using machine-learning algorithms.
2. Continue developing analytical methods/statistics for using digital imagery for deriving abundance and distribution data for cetaceans
3. To develop a plan for future field work and testing of long-range UAVs to study marine species around Antarctica and the Southern Ocean

Coverage of each of these three components is fundamental to the success of future efforts to use long-range UAVs/digital aerial imagery to survey for whales in the Southern Ocean, even before the technical aspects of various UAV platforms/models are considered.

**Results**

*Image search and labelling software*

The *Dugong Detector* software (soon to be renamed to reflect the now wider range of capabilities and applications) is a toolbox that allows users to analyse images collected from aerial platforms. The *Dugong Detector* software has been developed using in-kind support. The current version of the software allows the user to conduct the following image processing tasks where the identification of sightings in the images is done manually:

- create georeferencing information of images from drone telemetry data
- import and map orthoimages
- label sightings and add metadata with zoom functionality (free zoom, grid zoom and walk mode)
- project sightings from overlapping images
- map the positions of sightings and image footprints
- export all information in various GIS and file formats

Further expansion of the software capabilities are currently being undertaken to integrate the automated detection of animal sightings (AI detections) and provide further functionality as follows:

- Improvement of Digitization view
    - Objects will be named and projected objects will show which image they are from
    - Objects can be grouped to indicate they are sightings of the same animal
- New Grid view
    - Objects can be classified, deleted, tagged, and metadata added/changed and validated
    - Objects can be filtered
- New AI interface – to allow AI detected objects to be processed, validated and added to a database with those from the Digitisation process
- New GIS view
    - User can see the spatial distribution of objects and image footprints
    - Attributes can be added (e.g. transect number) and changed
- Ability to import data from other software (e.g. the ImageViewer custom software previously developed)
- New Review mode
    - Ability to import two database and compare sightings from the same set of images to create a third database showing which sightings were seen by reviewer 1, reviewer 2 or both
- Ability to add modules to allow for defining habitat and environmental classifications (which would propagate through to subsequent images unless changed).

Additional environmental and seagrass classification modules designed to be added to the software are currently under development. This would allow the user to manually assign environmental data categories and label potential seagrass (or to classify other environmental/habitat covariates). It would also address external AI software to allow the user to automatically classify the images and validate the results.

*Image catalogue*

To date, the project has collected >8,000 aerial images of cetaceans, and has enabled labelling (where location of animal in aerial image is identified) of >4,000 of those images; a further 30,000 aerial images of cetaceans have recently been offered to the project. To our knowledge, this represents the largest catalogue of aerial images of cetaceans that have been collated. Additional funding has been secured to allow these new images to be labelled (i.e., have the pixel coverage of animals in the images specifically delineated within a bounding box), which will be used to inform future versions of a neural network (more details below).

*Deep neural network*

The key deliverable of the project was a computer application for the detection of whales in images collected in aerial surveys.

We have developed an application based on deep neural networks to detect multiple species of animals from aerial images. The *Marine Animal Detector* (or *MAD*) is an AI detector designed to find large marine animals in aerial imagery, and is the culmination of many year's work. The species considered are whales, turtles, dugongs, dolphins, belugas, sharks and rays (non-cetacean images collected as part of a concurrently running projected headed up by Dr Amanda Hodgson). This list of species reflects the contents of the images we have access too. However, the software architecture was designed so that it will be easy to add other categories in the future. The project code and documentation has been uploaded on the web-based software repository called *GitLab*. The choice of *GitLab* shortens the system development and provides continuous delivery of evolving software.

Two repositories were created for this project. Namely,
- https://gitlab.com/f.maire/multi-species-detector
- https://gitlab.com/f.maire/dataset-curator

The "dataset-curator" repository is dedicated to the curation of the different datasets that were used for training the neural network based multi-species detector. The different sources of images (mainly marine biologists from universities and government departments) do not follow the same convention and format for the annotations of the datasets. Code was written to convert these annotations to a unified format. All the scripts are documented and can easily be adapted to new datasets.

The "multi-species-detector" contains the code to create the deep neural network, initialise its parameters with those of networks that have been trained on the ImageNet image database. This initialisation step is needed as we only have a few thousands images of whales whereas the neural network has millions of parameters to fit. This repository also contains code for the preprocessing of the survey images. Preprocessing is needed to accommodate the size difference between images from a standard image database like ImageNet. The images in ImageNet are smaller than 500 by 500 pixels whereas it is common to have 20 Mega pixels-sized images from aerial surveys. The code we provide is a collection of scripts that are grouped into training scripts and detection scripts.

*Testing deep neural network*

The *MAD* software is currently being tested using images not used in developing the existing neural network. We hope to present these, and all other results from this project, in IWC-SC meeting in 2023.

*Statistical approaches for estimating cetacean abundance and distribution from image data*

Despite aerial digital imagery/UAVs being recognised as a promising method for surveying marine mammals, little attention has been given until recently to either: a) understanding and quantifying biases in this method, and b) comparing UAV to human observers operating on aerial surveys, quantities that are fundamental for returning accurate and precise abundance and distribution results, and for ensuring continuity in existing series of abundances. Progress has been made towards testing several of these points. Analyses of dugong UAV surveys enabled development of workflows for: designing robust aerial surveys under UAV flight-constraints; converting image footprints into transect-like objects; and then using the dugong detections in these transect-like sampling units to estimate densities and abundances in the survey area (Cleguer et al. 2020; Cleguer et al 2021; Hodgson et al. *in prep*.; Kelly et al. *in prep.*). Furthermore, methods developed for estimating availability from UAV focal follows, as reported in Hodgson et al. (2017), were successfully applied in a study of coastal dolphins (Brown et al. *in review*).

**Conclusions**

Previous work to grow (and label) the image catalogue has led to the development of the *MAD* software, which is currently being tested; results from this will be presented to IWC-SC in 2023. The Dugong Detector software will allow processing and labelling of more aerial imagery for future iterations of the *MAD* software (or other software, as appropriate).

Furthermore, a number of promising data workflow and statistical methods to estimate abundance and distribution from aerial image surveys have been developed and tested.

**Challenges**

The timeline of the project was revised because of COVID-19 disruptions in 2021-22.

**Outlook for the future**

Last year we requested a 12-month extension on the project, to allow the image catalogue to further grow, for image labelling to occur, and for the neural network algorithms to be developed and tested; we may do so again pending discussions around left-over funding. We are currently testing the *MAD* software, in addition to developing the *Dugong Detector* software to streamline the process of labelling of images (from other funding sources). Regardless, we remain confident that we have the resources to complete all stated aims.

In addition to our recent publication, several manuscripts that describe methods we have developed to use aerial image to estimate distribution and abundance of cetaceans/sirenians are in progress, and we hope to submit these for publication in the next 12 months.

**Project outputs**

*Peer-reviewed papers*

Bamford CCG, Kelly N, Dalla Rosa L, Fretwell P, Trathan PN, Cubaynes H, Mesquita A, Gerrish , Jackson JA (2020) Space vs Sea: a novel method for estimating baleen whale density, Scientific Reports 10(1): 12985. DOI: 10.1038/s41598-020-69887-y

Brown AM, Allen SJ, Kelly N, Hodgson AJ (*In Review*) Using Unmanned Aerial Vehicles (UAVs) to estimate availability and group size error for aerial surveys of coastal dolphins. Remote Sensing in Ecology and Conservation.

Cleguer C, Kelly N, Tyne JA, Wieser M, Peel D, Hodgson AJ (2021) A novel method for using small unoccupied aerial vehicles to survey wildlife species and model their density distribution. Frontiers in Marine Science 8: 462. DOI: 10.3389/fmars.2021.640338

*Peer-reviewed papers (In preparation/nearing submission)*

Hodgson A, Kelly N, Peel, D (*In prep.)* Unmanned versus manned: a direct comparison between sightings from an unmanned aerial vehicle (UAV) and human observers during a dugong aerial survey.

Kelly N, Hodgson A, Cleguer C, Peel D et al. (*In prep.)* Marine mammal distribution and abundance from aerial imagery: some statistical considerations.

*Reports*

Cleguer C, Derville S, Kelly N, Lambourne R, Garrigue C (In prep.) Projet SIREN: Suivi à fine échelle de la fréquentation et du déplacement des dugongs dans la zone Voh-Koné-Pouembout, pour une gestion améliorée de l'espèce. Rapport final. 108 pp.

*Conference presentations*

Cleguer C, Tyne J, Wieser M, Kelly N, Peel D, Hodgson A (2019) Development of a novel drone-based method to survey marine megafauna at local spatial scales. Lessons learnt from a dugong drone survey in the Pilbara, Western Australia. 2019 World Marine Mammal Conference, 9-12 December, Barcelona, Spain (Oral).

Hodgson A, Cleguer C, Kelly N, Peel D, Maire F, Wieser M. (2021) Using drones, artificial intelligence and geospatial techniques to create surface density models. Online workshop on the use of "Aerial Imagery for Density Surface Modelling", hosted by the Centre for Research into Ecological and Environmental Modelling (CREEM; St Andrews University) and Duke University, 17-18 March (Oral).

Cleguer C, Hodgson A, Tyne J, Kelly N, Peel D, Wieser M (2021) Developing methods to conduct wildlife surveys using small unmanned aerial vehicles. Online workshop on the use of "Aerial Imagery for Density Surface Modelling", hosted by the Centre for Research into Ecological and Environmental Modelling (CREEM; St Andrews University) and Duke University, 17-18 March (Oral).

Kelly N, Cleguer C, Hodgson A, Peel D (2021) Marine mammal distribution and abundance from aerial imagery: some statistical considerations. Online workshop on the use of "Aerial Imagery for Density Surface Modelling", hosted by the Centre for Research into Ecological and Environmental Modelling (CREEM; St Andrews University) and Duke University, 17-18 March.

*Media interest*

https://www.abc.net.au/news/2021-05-12/studying-dugongs-with-drones/100122416

**Scientific references cited in report**

Hodgson A, Peel D, Kelly N (2017) Unmanned aerial vehicles for surveying marine fauna: assessing detection probability. Ecological Applications 27(4): 1253-1267.

**PROJECT 22 (Reisinger, de Bruyn et al., 2018/19). An integrative assessment of the ecology and connectivity of killer whale populations in the southern Atlantic and Indian Oceans**

*Ryan R. Reisinger[1], P.J.N. (Nico) de Bruyn[2], Rus Hoelzel[3], Christophe Guinet[4], Simon Elwin[5], Paul Tixier[6], Rowan K. Jodaan[2], Danielle Conry[7]*

*1. Institute for Marine Sciences, University of California Santa Cruz, Santa Cruz California, USA*
*2. Mammal Research Institute, Department of Zoology and Entomology, University of Pretoria, Pretoria, South Africa*
*3. School of Biosciences, Durham University, Durham, UK*
*4. Centre d'Etudes Biologiques de Chizé (CEBC), UMR 7372, Université de la Rochelle-CNRS, Villiers en Bois, France*
*5. Department of Botany and Zoology, Stellenbosch University, Stellenbosch, South Africa*
*Sea Search Research and Conservation, Muizenberg, Cape Town, South Africa*
*6. School of Life and Environmental Sciences, Deakin University, Burwood, Victoria, Australia*
*7. Sea Search Research and Conservation, Muizenberg, Cape Town, South Africa*

**Executive summary**

We have started integrating data on habitat use, feeding ecology, population connectivity, historical population dynamics and regional patterns of diversity in killer whales (Orcinus orca) using state-of-the-art methodologies. We focus on three locations in the southern Atlantic and Indian Oceans, significant because this represents a region of potential transition between temperate and polar waters, and includes the South African region, proposed to reflect much greater genetic diversity for killer whales than seen anywhere else so far investigated around the world. This work also builds on long-term studies at Marion Island and the Crozet Islands, providing new data to help address key questions about essential prey and habitat resources, and the evolutionary implications of movement patterns and insularity.

At Marion Island, we investigated the relationship between killer whale social network structure and prey abundance. Our results suggest that killer whales at Marion Island were more social, formed larger groups and had more associations during periods of high prey abundance. During periods of lower prey abundance, we observed fewer interactions, stronger clustering and more division in the association network. These results indicate that the social organisation of this population of killer whales is seasonally dynamic, with increased sociality measures coinciding with periods of higher prey abundance.

We are collating updated information on the distribution and hunting behaviour of killer whales in South African waters. Efforts to sample and satellite track South African killer whales have been hampered by COVID-related restrictions. We are presently analysing 4 genomes from southern African killer whales in the context of 8 other killer whale genomes generated earlier. These analyses include the pattern and level of genomic diversity within individuals, assessments of historical demography, phylogenomics and patterns of admixture.

Studies using photo-identification data from Crozet demonstrated, firstly, that toothfish consumed on fishing lines by killer whales contributed to 2-9% of the annual energetic requirements of individuals from the "regular" population and, secondly that numbers of individuals involved in interactions with fishing lines have increased since 2003.

**Introduction**

Killer whales (*Orcinus orca*) are alpha predators which can exert significant top-down influences on marine ecosystems (e.g., Reisinger et al. 2011b). However, their influence on ecosystems is modulated by their movement patterns, diet and abundance, since these determine the structure and dynamics of their trophic linkages with other species. Given killer whales' high mobility (e.g., Reisinger et al. 2015) and dietary flexibility (reviewed in de Bruyn et al. 2013), these factors become even more important in determining what impacts killer whales may have.

There is an additional layer of complexity in that the population structure of killer whales is driven in part by their foraging specializations in different environments, in conjunction with their social structure (Hoelzel et al.

2007, Moura et al. 2014a, 2014b, 2015). For example, in the eastern North Pacific three sympatric but genetically distinct killer whale populations ('ecotypes') occur, which have different diets, behaviour and social structure (reviewed by de Bruyn et al. 2013). In the Antarctic, at least four ecotypes have been identified based on morphology, diet and behaviour (Pitman et al. 2007, Pitman & Durban 2010, 2012) and these are also genetically distinguishable (Morin et al. 2010, Foote et al. 2011a). A fifth type, which seems morphologically and genetically distinct, has recently been described mainly from at-sea observations in the Subantarctic (Pitman & Ensor 2003, Pitman et al. 2011, Foote et al. 2013). Along the South African coast, Best et al. (2014) described a second regional killer whale morphotype, which appears to be a dietary specialist. A global analysis of killer whale mitochondrial DNA revealed exceptionally high genetic diversity among samples from South Africa, in contrast to low diversity observed in other populations (Moura et al. 2014b). This led to the hypothesis that South Africa hosted a relatively abundant refugial population of killer whales during the Last Glacial Maximum (Moura et al. 2014b). This phylogeographic mosaic has prompted different evolutionary explanations, debate about the relative roles of various evolutionary drivers, and questions about the global patterns and consequences of ecological specialization among killer whales (Foote et al. 2011b, de Bruyn et al. 2013, Moura et al. 2014a, 2014b, 2015, Foote & Morin 2016, Hoelzel & Moura 2015, 2016).

The vast Southern Ocean is dotted with a few small islands. Two such island groups are South Africa's Prince Edward Islands and France's Crozet Islands, situated ~1,000 km apart (at a similar latitude) in the Indian Ocean sector of the Southern Ocean. These two archipelagos are similar in hosting massive populations of land-breeding seals and seabirds which attract killer whales to their inshore waters (Guinet 1991, Reisinger et al. 2011c). These two killer whale populations have a similar diet including elephant seals, fur seals and penguins, and – at the Crozets – fishes and large cetaceans (Guinet 1991, Reisinger et al. 2011c). Depredation of Patagonian toothfish (*Dissostichus eleginoides*) from longline fishing vessels occurs around both archipelagos (Williams et al. 2009, Guinet et al. 2015 and references therein). The killer whale populations frequenting the inshore zone of the islands are quite small, numbering ~37 (95% CI 32-62) in 1998-2000 at the Crozets (Poncelet et al. 2010) and ~37 (95% CI 29-44) in 2006-2007 at the Prince Edwards (Reisinger et al. 2011a). The populations exhibit the same seasonal occurrence pattern, with peak inshore abundance in summer and a secondary peak in autumn (Reisinger et al. 2011c).

Despite the proximity of the two archipelagos (which is well within the movement range of killer whales – Durban & Pitman 2012, Reisinger et al. 2015), photographic mark-recapture previously revealed that only a few (~8) individual killer whales have been recorded at both archipelagos (Reisinger & de Bruyn 2014; Tixier et al. 2014a). Further, satellite tracking of killer whales from the Prince Edward Islands shows movements only in the region of that archipelago, or rapid northward movements towards and beyond the Subtropical Front (Reisinger et al. 2015).

There is a significant gap in our understanding of the structure, movement and distribution of killer whale populations in the Subantarctic and how their movements, dietary specialization and phylogenetics interact as drivers or consequences of the observed population structure. Of particular interest is any ecotype divergence or convergence in response to environmental conditions, which could address the proximate mechanisms responsible for ecotype dynamics in this species.

The Prince Edward Islands, Crozet Islands and South African coastal waters provide a regional system with environmental similarities and contrasts that will allow us to test hypotheses about the mechanisms that determine population structure in the context of environment and ecology. This is facilitated by long-term photographic identification studies (Guinet et al. 2015, Reisinger et al. 2017), which provide socio-demographic context (e.g., Reisinger et al. 2015, 2016, 2017, Tixier et al. 2015, 2017) together with existing telemetry (Reisinger et al. 2015) and genetic data (Moura et al. 2014; A.R. Hoelzel, unpubl. data).

**Objectives**

1. Our primary objective is to provide sufficient integrative data on ecology (through stable isotope, photo-identification and telemetry data), population history and connectivity (through genetic analyses) to test alternative hypotheses about the evolutionary mechanisms that determine population structure and dynamics in this region. The relatively high diversity found off South Africa in contrast to lower levels at the Prince Edward Islands and the Crozet Islands permits a key hypothesis to be tested about the relative importance of long-term demographic stability and population mixing.

2. A further objective is to consider the transferable inference from these data in the context of extensive data on the ecology and population genetics of killer whales elsewhere in the world. While regional systems differ (e.g. strong natal fidelity in the piscivorous ecotype in the North Pacific, not seen to the same extent elsewhere), we don't yet understand if the key drivers are associated with resource use or ancestry or some other combination of factors.

3. We will provide data with direct relevance to the conservation and management of regional killer whale populations through the provision of data on their distribution, population connectivity and evolutionary diversity (including diversity at functional loci).

**Results**

*Marion Island*

To date, 2,290 shore-based observation sessions, totalling 12,825 search hours have been conducted at Marion Island since 2008. These sessions have yielded 3,152 killer whale sightings and more 93,000 images. Additionally, more than 36,000 images have been taken during ~2,627 opportunistic sightings since 2008. A total of 38 tags have been successfully deployed and 77 biopsy samples obtained (Table 1).

**Table 1** Killer whale fieldwork effort summary for fieldwork conducted by the Marion Island Marine Mammal Programme at Marion Island for 2008-2019. *During the 2020-2021 field year, no dedicated killer whale field assistant was present on Marion due to COVID-19 restrictions.

| | **2008 - 2011** | **2011 - 2012** | **2012 - 2013** | **2013 - 2014** | **2014 - 2015** | **2015 - 2016** | **2016 - 2017** | **2017 - 2018** | **2018 - 2019** | **2020 - 2021 *** | **2021 - 2022 (to date)** | **TOTAL** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Observation sessions* | | | | | | | | | | | | |
| **Number** | 481 | 210 | 273 | 231 | 216 | 170 | 196 | 165 | 181 | 23 | 144 | 2290 |
| **Hours** | 2511 | 1145 | 1846 | 1380 | 1247 | 916 | 951 | 918 | 979 | 82 | 850 | 12825 |
| *Sightings* | | | | | | | | | | | | |
| **Dedicated** | 406 | 413 | 466 | 399 | 402 | 217 | 149 | 216 | 255 | 27 | 202 | 3,152 |
| **Opportunistic** | 670 | 270 | 265 | 153 | 273 | 123 | 108 | 209 | 156 | 175 | ~225 | ~2627 |
| *Images* | | | | | | | | | | | | |
| **Dedicated** | 9160 | 5354 | 7833 | 6288 | 8313 | 6453 | 6224 | 9413 | 12412 | 898 | >21000 | >93348 |
| **Opportunistic** | 6420 | 5803 | 2346 | 876 | 4639 | 1918 | 1177 | 7575 | 4180 | 1559 | Not yet reported | >36493 |
| *Tagging* | | | | | | | | | | | | |
| **Attempts** | - | 25 | 7 | 10 | 6 | 0 | 2 | 6 | 5 | 0 | 2 | 63 |
| **Successful** | - | 10 | 6 | 6 | 2 | - | 2 | 6 | 5 | - | 1 | 38 |
| **Tags lost (without transmitting)** | - | 6 | 1 | 4 | 0 | - | 0 | 0 | 0 | - | 1 | 12 |
| **Duration (average days)** | - | 7.5 | 26.6 | 8.2 | 5.9 | - | 30 | 12.7 | 20 | - | 15 | Not yet reported |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Biopsy* | | | | | | | | | | | | |
| **Attempts** | - | 63 | 9 | 18 | 15 | 9 | 14 | 14 | 8 | 0 | 13 | 163 |
| **Samples** | - | 24 | 5 | 6 | 6 | 7 | 8 | 10 | 4 | - | 7 | 77 |

Rowan Jordaan completed his PhD under direction of Nico de Bruyn and Ryan Reisinger. He has published two chapters from his PhD (Jordaan et al., 2020, 2021). Jordaan et al. (2020) is summarised in our 2020-2021 report. In Jordaan et al. (2021), we investigated the relationship between social organisation and prey abundance in Marion Island killer whales, using the same dataset as above. We compared association network measures between intra-annual periods of high and low prey availability. Our results suggest that killer whales at Marion Island were more social, formed larger groups and had more associations during periods of high prey abundance. During periods of lower prey abundance, we observed fewer interactions, stronger clustering and more division in the association network. These results indicate that the social organisation of this population of killer whales is seasonally dynamic, with increased sociality measures coinciding with periods of higher prey abundance (Figure 1).

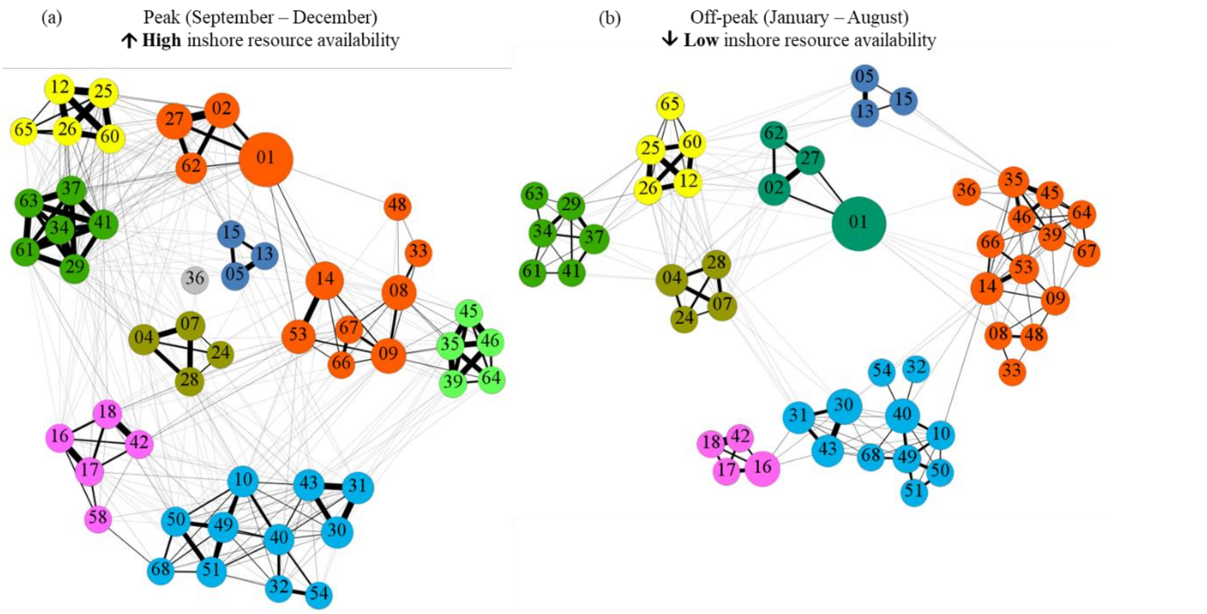



**Figure 1** Network plots for Marion Island killer whales over a) all peak periods (September- December) and b) all off-peak periods (January-August) during 2006-2018. Each node (coloured circle) represents an individual killer whale and each vertex/edge (line between two nodes) represents the association between two killer whales. Numbers in nodes indicate the unique ID code for each individual but 'M0' was omitted from node labels (e.g. M001 is labelled as 01). The size of the node represents 'betweenness' centrality (how social, or gregarious, the killer whale is) with larger nodes reflecting more social individuals. Edges are weighted by the half-weight association index (HWI; higher HWI indicated with darker lines) and only weights > 0.01 are shown. Individuals were grouped into social units, represented by different colours, using the Louvain method for community detection. From Jordaan et al. (2021).

Among the individuals photographically recorded from shore at Marion Island, eight have been resighted from fishing vessels in the Marion/Prince Edward Islands EEZ, confirming that animals in the Marion Island population do depredate Patagonian toothfish from longlines (Tixier et al. 2021), as speculated by Reisinger et al. (2016) and Tixier et al. (2019).

*South Africa*

Elwen et al. have been collating sightings records and photographs of killer whales around southern Africa (Namibia/South Africa/Mozambique) focusing on the period since 2009, with the goal of updating the information used in Best et al. (2011) and developing a photo-ID catalogue of individuals. Records and photographs are being collated from scientific research cruises, whale watching companies, opportunistic sightings and a review of social media. Additionally, records from fisheries observers working on long-line fishing vessels have been included. A manuscript presenting these results is currently in preparation and the data below should be considered as preliminary and not quoted without prior permission of the lead authors. To date, 240 records from 01 January 2009 to December 2020 have been collated from mostly inshore waters with a bias towards eco-tourism hotspots. More than 10 million hook deployments were observed from the tuna long-line fishery between April 2012 and September 2019. Observers reported 1129 cases of marine mammal depredation and 391 direct observations interactions with catches at an average of 0.043 sightings /1000 hooks or one sighting every 10 sets.

Preliminary results show similar patterns of seasonality in sightings to those reported by Best et al. (2010), with a peak in sightings during late summer and autumn months (Mar-May). Annual sighting numbers have increased since 2015, but this is at least partly attributable to an increase in sightings of two unusual and highly distinctive killer whales which are known to target inshore sharks (both animals have completely bent over dorsal fins and are known locally as "Port" and "Starboard"). Predation or attempted predation was reported with many sightings and included a wide range of subjects including common dolphins, Indo-Pacific bottlenose dolphins, game fish, sun fish, sharks (bronze whaler, white, seven-gill) and baleen whales (humpback and Bryde's).

Collation of photographic records has been a little slower as it is heavily reliant on gathering photographs from others and the need for them to delve into their archives to find high resolution images. Working with images available to date, 55 individuals have been identified. These individuals have been resighted between 1 and 22 times.

Besides Port and Starboard that were biopsied in 2018, only one additional biopsy has been collected from a lone young male that spent roughly 3 weeks within False Bay, near Cape Town. The latter animal was also recorded acoustically during both boat-based follows and from a moored hydrophone in the bay, resulting in the first good recordings of the vocalisations of South African killer whales. Two prior recording attempts on a group of 12-14 individuals in 2020 and on Port and Starboard resulted in a few distant calls only.

One male, potentially of the smaller shark-eating ecotype stranded in Port Elizabeth in April 2021 - the sample is potentially available through Greg Hofmeyr, Bayworld Museum but is quite degraded as the stranding was only attended a few days post death. Only four previous records of this eco-type are known (Best et al. 2010). No satellite tagging attempts have been made.

*Crozet Islands*

Between 2003 and 2020, a total of 138,339 photographs usable for killer whale photo-identification were taken during 2,075 encounters around the Crozet islands. These included 1,855 encounters of the “regular” morphotype, i.e., the morphotype most similar to that observed from Marion, from both the shore of Possession Island (429 encounters) and from licensed longliners targeting toothfish offshore (1,426 encounters during events when killer whales fed on toothfish caught on fishing lines), and 220 encounters of Type-D killer whales from toothfish longliners only.

A detailed update on the photo-identification information from the “regular” morphotype was published in 2021 as a report (Tixier et al., 2021). From data collected from toothfish longliners, in the Crozet Exclusive Economic Zone (EEZ) but also in adjacent waters, the report indicated that 22 individuals previously photographed at Crozet (12% of all individuals identified at Crozet in 2003-2020) were resighted in the Kerguelen EEZ, 13 (7%) in the Prince Edward and Marion EEZ, and 13 (7%) in international waters between EEZs.

Two studies that used the photo-identification monitoring data from Crozet were published in scientific journals in 2021 and 2022. Faure et al. (2021) demonstrated that toothfish consumed on fishing lines by killer whales contributed to 2-9% of the annual energetic requirements of individuals from the “regular” population. Amelot et al. (2022) assessed the annual numbers of individuals involved in interactions with fishing lines through a CMR approach. They showed that for both the “regular” and Type-D morphotypes, these numbers have increased since 2003, reaching a total of around 126 individuals in 2018 (86 “regular” and 40 Type-Ds). The authors also reported low survival rates for both morphotypes, suggesting that these increases were not attributed to increasing population sizes but rather to increasing numbers of individuals acquiring feeding on fishing lines as a new behaviour.

*Genetics*

We have shotgun sequenced material from the two South African killer whales Port and Starboard using the Illumina PCR-free True-seq method, and achieved ~20x coverage for each genome. We have also sequenced by the same method two further killer whales, one from a stranding in Namibia, and the other the aforementioned young male that spent several weeks in False Bay. These achieved ~65X coverage each, and will allow further analysis based on annotation and comparative exomic analyses. We are presently analysing these 4 additional genomes in the context of 8 other killer whale genomes generated earlier. These analyses include the pattern and level of genomic diversity within individuals, assessments of historical demography, phylogenomics and patterns of admixture.

**Conclusions**

Analysis of photographic identification data from the subantarctic are providing updated information on demographic parameters, social structure and population connectivity. Analyses of data from South Africa are yielding novel longitudinal data on individuals in this region. Genetic results will soon give insights into the comparative ecology of killer whale populations in the southern Atlantic and Indian Oceans.

**Challenges**

The COVID-19 pandemic has caused significant disruptions to the research project. Fieldwork in South Africa and on Marion Island faced disruptions and delays. During the 2020-2021 field season no dedicated field assistant was present on Marion Island. Travel to South African has been difficult until recently, due to COVID-related travel restrictions. Genetics analyses were delayed due to university closures. In the past year it has been challenging to deploy satellite tags; in South African waters, a more dedicated effort, which is more feasible now that travel restrictions have eased, appears to be required to tag killer whales, since the responsive mode we have used to date has been unsuccessful for tagging.

**Outlook for the future**

Fieldwork at Marion Island resumed this year after COVID-related disruptions, and we hope that fieldwork will continue as normal from 2022 onwards. South African fieldwork has also been impacted by COVID, but we expect to plan dedicated fieldwork there in the coming year, with the aim of collecting biopsy samples and deploying satellite tags. Due to the continued impact of COVID on field- and lab-work in the last year, we request a further 1-year extension to the project.

**Project outputs**

*Peer-reviewed papers*

Amelot M, Plard F, Guinet C, Arnould JP, Gasco N, Tixier P (2022) Increasing numbers of killer whale individuals use fisheries as feeding opportunities within subantarctic populations. Biology Letters 18(2): 20210328.

Busson M, Authier M, Barbraud C, Tixier P, Reisinger RR, Janc A, Guinet C (2019) The role of sociality in the response of killer whales to an additive mortality event. Proceedings of the National Academy of Sciences of the USA 116: 11812–11817. doi: https://doi.org/10.1073/pnas.1817174116

Faure J, Péron C, Gasco N, Massiot-Granier F, Spitz J, Guinet C, Tixier P (2021) Contribution of toothfish depredated on fishing lines to the energy intake of killer whales off the Crozet Islands: a multi-scale bioenergetic approach. Marine Ecology Progress Series 668: 149-161.

Jordaan RK, Oosthuizen WC, Reisinger RR, de Bruyn PJN (2020) Abundance, survival and population growth of killer whales *Orcinus orca* at subantarctic Marion Island. Wildlife Biol 2020:wlb.00732

Jordaan R, Reisinger RR, Oosthuizen WCO, de Bruyn PJN (2021). Seasonal fission and fusion of killer whale social structure at sub-Antarctic Marion Island. Animal Behaviour 177: 223-230.

*Reports*

Jordaan R, Reisinger RR, de Bruyn PJN (2020) Marion Island Killer Whales 2006-2018. University of Pretoria. doi: https://doi.org/10.6084/m9.figshare.11938680.v1

Tixier P, Gasco N, Towers JR, Guinet C (2021) Killer whales of the Crozet Archipelago and adjacent waters: photo-identification catalogue, population status and distribution in 2020. Centre d'Etudes Biologiques de Chizé, Centre National de la Recherche Scientifique, France, 167p. DOI:10.6084/m9.figshare.13677145.v1

*Conference presentations*

Busson M, Authier M, Barbraud C, Tixier P, Reisinger RR, Janc A, Guinet C (2019) Role of sociality in the response of killer whales to an additive mortality event. World Marine Mammal Conference, 9-12 December, Barcelona, Spain (Oral).

Jordaan RK (2020) The influence of environmental and social factors on the demography of killer whales (*Orcinus orca*) at Subantarctic Marion Island. 9th SCAR Open Science Conference 2020, 31 July - 11 August 2020 (Virtual poster).

*Students and theses*

Jordaan RK (2021) The demography and sociality of killer whales *Orcinus orca* at subantarctic Marion Island. PhD thesis. University of Pretoria, Pretoria.

**Scientific references cited in report**

Amelot M, Plard F, Guinet C, Arnould JP, Gasco N, Tixier P (2022) Increasing numbers of killer whale individuals use fisheries as feeding opportunities within subantarctic populations. Biology Letters 18(2): 20210328.

Best PB, Meÿer MA, Lockyer C (2010) Killer whales in South African waters — a review of their biology. African Journal of Marine Science 32:171–186

Best P, Meÿer M, Thornton M, Kotze P, Seakamela S, Hofmeyr G, Wintner S, Weland C, Steinke D (2014) Confirmation of the occurrence of a second killer whale morphotype in South African waters. African Journal of Marine Science 36:215–224.

Busson M, Authier M, Barbraud C, Tixier P, Reisinger RR, Janc A, Guinet C (2019) Role of sociality in the response of killer whales to an additive mortality event. Proc Natl Acad Sci 116:11812–11817. doi: 10.1073/pnas.1817174116

de Bruyn PJN, Tosh CA, Terauds A (2013). Killer whale ecotypes: is there a global model? Biol Rev 88: 62–80.

Durban JW, Fearnbach H, Burrows DG, Ylitalo GM, Pitman RL (2017) Morphological and ecological evidence for two sympatric forms of Type B killer whale around the Antarctic Peninsula. Polar Biology 40: 231–236.

Durban JW, Pitman RL (2012) Antarctic killer whales make rapid, round-trip movements to subtropical waters: evidence for physiological maintenance migrations? Biology letters 8:274–7.

Faure J, Péron C, Gasco N, Massiot-Granier F, Spitz J, Guinet C, Tixier P (2021) Contribution of toothfish depredated on fishing lines to the energy intake of killer whales off the Crozet Islands: a multi-scale bioenergetic approach. Marine Ecology Progress Series 668: 149-161.

Foote AD, Morin PA (2016). Genome-wide SNP data suggest complex ancestry of sympatric North Pacific killer whale ecotypes. Heredity.

Foote AD, Morin PA, Durban JW, Willerslev E, Orlando L, Gilbert MTP (2011). Out of the Pacific and back again: insights into the matrilineal history of Pacific killer whale ecotypes. PLoS One 6: e24980.

Foote AD, Morin PA., Pitman RL, Ávila-Arcos MC, Durban JW, Helden A, Sinding M-HS, Gilbert MTP (2013) Mitogenomic insights into a recently described and rarely observed killer whale morphotype. Polar Biology 36:1519–1523.

Guinet C (1991) L'Orque (*Orcinus orca*) autour de l'Archipel Crozet. Comparaison avec d'autres localites. Rev Ecol (Terre Vie) 46:321–337.
Guinet C (1992) Comportement de chasse des orques (*Orcinus orca*) autour des iles Crozet. Canadian Journal of Zoology 70:1656–1667
Guinet C, Tixier P, Gasco N, Duhamel G (2015) Long-term studies of Crozet Island killer whales are fundamental to understanding the economic and demographic consequences of their depredation behaviour on the Patagonian toothfish fishery. ICES Journal of Marine Science 72:1587–1597
Hoelzel AR, Dahlheim ME, Stern SJ (1998) Low genetic variation among killer whales (*Orcinus orca*) in the Eastern North Pacific and genetic differentiation between foraging specialists. Journal of Heredity 89:121–128.
Hoelzel AR, Dover GA (1991) Genetic differentiation between sympatric killer whale populations. Heredity 66:191–195.
Hoelzel AR, Hey J, Dahlheim ME, Nicholson C, Burkanov V, Black N (2007). Evolution of population structure in a highly social top predator, the Killer Whale. Molecular Bioliogy and Evolution 24: 1407–1415.
Hoelzel AR, Moura AE (2015). Resource specialisation and the divergence of killer whale populations. Heredity 115: 93–95.
Hoelzel AR, Moura AE (2016) Killer whales differentiating in geographic sympatry facilitated by divergent behavioural traditions. Heredity 117:481–482
Jordaan RK, Oosthuizen WC, Reisinger RR, de Bruyn PJN (2020) Abundance, survival and population growth of killer whales *Orcinus orca* at subantarctic Marion Island. Wildlife Biol 2020:wlb.00732
Jordaan R, Reisinger RR, Oosthuizen WCO, de Bruyn PJN (2021). Seasonal fission and fusion of killer whale social structure at sub-Antarctic Marion Island. Animal Behaviour 177: 223-230.
Morin PA, Archer FI, Foote AD, Vilstrup J, Allen EE, Wade P et al. (2010). Complete mitochondrial genome phylogeographic analysis of killer whales (*Orcinus orca*) indicates multiple species. Genome Research 20:908–916.
Moura AE, Kenny JG, Chaudhuri R, Hughes MA, Welch A, Reisinger RR, … Hoelzel AR (2014a). Population genomics of the killer whale indicates ecotype evolution in sympatry involving both selection and drift. Molecular Ecology 23: 5179–5192.
Moura AE, Janse van Rensburg C, Pilot M, Tehrani A, Best PB, Thornton M, … Hoelzel AR (2014b). Killer whale nuclear genome and mtDNA reveal widespread population bottleneck during the Last Glacial Maximum. Molecular Bioliology and Evolution 31: 1121–1131.
Moura AE, Kenny JG, Chaudhuri R, Hughes MA, Reisinger RR, de Bruyn PJN, … Hoelzel AR (2015) Phylogenomics of the killer whale indicates ecotype divergence in sympatry. Heredity 114: 48–55.
Pitman RL, Durban JW (2010) Killer whale predation on penguins in Antarctica. Polar Biology 33:1589–1594.
Pitman RL, Durban JW (2012) Cooperative hunting behavior, prey selectivity and prey handling by pack ice killer whales (*Orcinus orca*), type B, in Antarctic Peninsula waters. Marine Mammal Science 28:16–36.
Pitman RL, Durban JW, Greenfelder M, Guinet C, Jorgensen M, Olson PA, Plana J, Tixier P, Towers JR (2011) Observations of a distinctive morphotype of killer whale (Orcinus orca), type D, from subantarctic waters. Polar Biology 34:303–306.
Pitman RL, Fearnbach H, LeDuc R, Gilpatrick Jr. JW, Ford JKB, Ballance LT (2007) Killer whales preying on a blue whale calf on the Costa Rica Dome: genetics, morphometrics , vocalisations and composition of the group. Journal of Cetacean Research and Management 9:151–157.
Poncelet E, Barbraud C, Guinet C (2010) Population dynamics of killer whales (Orcinus orca) in the Crozet Archipelago, southern Indian Ocean: a mark-recapture study from 1977 to 2002. Journal of Cetacean Research and Management 11:41–48.
Reisinger RR, Beukes (née Janse van Rensburg) C, Hoelzel AR, de Bruyn PJN (2017) Kinship and association in a highly social apex predator population, killer whales at Marion Island. Behavioral Ecology 0:1–10
Reisinger RR, de Bruyn PJN (2014) Marion Island killer whales: 2006-2013. Mammal Research Institute, University of Pretoria. doi: 10.6084/m9.figshare.971317
Reisinger R, de Bruyn PJN, Bester M (2011a) Abundance estimates of killer whales at -subantarctic Marion Island. Aquatic Biology 12:177–185.
Reisinger RR, de Bruyn PJN, Bester MN (2011b) Predatory impact of killer whales on pinniped and penguin populations at the Subantarctic Prince Edward Islands: fact and fiction. Journal of Zoology 285:1–10
Reisinger R, de Bruyn PJN, Tosh C, Oosthuizen W, Mufanadzo N, Bester M (2011) Prey and seasonal abundance of killer whales at sub-Antarctic Marion Island. African Journal of Marine Science 33:99–105.

Reisinger RR, Gröcke D, Lübcker N, McClymont E, Hoelzel AR, de Bruyn PJN (2016) Variation in the diet of killer whales *Orcinus orca* at Marion Island, Southern Ocean. Marine Ecology Progress Series 549:263–274..

Reisinger RR, Keith M, Andrews RD, de Bruyn PJN (2015) Movement and diving of killer whales (*Orcinus orca*) at a Southern Ocean archipelago. Journal of Experimental Marine Biology and Ecology 473:90–102.

Reisinger RR, Oosthuizen WC, Péron G, Cory Toussaint D, Andrews RD, de Bruyn PJN (2014) Satellite Tagging and Biopsy Sampling of Killer Whales at Subantarctic Marion Island: Effectiveness, Immediate Reactions and Long-Term Responses. PLoS ONE 9:e111835

Richard G, Bonnel J, Tixier P, Arnould JPY, Janc A, Guinet C (2020) Evidence of deep-sea interactions between toothed whales and longlines. Ambio 49:173–186.

Tixier P, Authier M, Gasco N, Guinet C (2015) Influence of artificial food provisioning from fisheries on killer whale reproductive output. Animal Conservation 18:207–218.

Tixier, P, Gasco N, Guinet C (2014a) Killer whales of the Crozet Islands: photoidentification catalogue 2014. Centre d'Etudes Biologiques de Chizé-CNRS, Villiers en Bois. doi: 10.6084/m9.figshare.1254810

Tixier P, Gasco N, Poupart T, Guinet C (2014b). Type-D killer whales of the Crozet Islands. doi: 10.6084/m9.figshare.1060259

Tixier P, Gasco N, Towers JR, Guinet C (2021) Killer whales of the Crozet Archipelago and adjacent waters: photo-identification catalogue, population status and distribution in 2020. Centre d'Etudes Biologiques de Chizé, Centre National de la Recherche Scientifique, France, 167p. DOI:10.6084/m9.figshare.13677145.v1

Tixier P, Giménez J, Reisinger R, Méndez-Fernandez P, Arnould J, Cherel Y, Guinet C (2019) Importance of toothfish in the diet of generalist subantarctic killer whales: implications for fisheries interactions. Mar Ecol Prog Ser 613:197–210

Williams AJ, Petersen SL, Goren M, Watkins BP (2009) Sightings of killer whales *Orcinus orca* from longline vessels in South African waters, and consideration of the regional conservation status. African Journal of Marine Science 31:81–86.

**PROJECT 23 (Bengtson Nash et al., 2018/19). Implementation of humpback whales for Antarctic sea-ice ecosystem monitoring; Inter-program methodology transfer for effective circumpolar surveillance**

*Susan Bengtson Nash[1], Ari Friedlaender[2], Fredrik Christiansen[3], Juliana Castrillion[1], David Johnston[4]*

*1. Southern Ocean Persistent Organic Pollutants Program (SOPOPP), Griffith University, 170 Kessels Road, Griffith, Australia*
*2. Ecology and Evolutionary Biology, UC Santa Cruz, 115 McAllister Way, Santa Cruz, CA 95060, USA*
*3. Murdoch University Cetacean Research Unit, Murdoch University, South Street, Murdoch WA, Australia*
*4. Nicholas School of the Environment, Duke University, 135 Duke Marine Lab Road, Beaufort, NC, USA*

**Executive summary**

The above-named project continues to be impacted by COVID-19-related delays. Whilst field components have been successfully completed and Colombian samples successfully transported to Griffith University, transport of Antarctic samples out of Antarctica to the US was delayed by 12 months. Similarly, interruptions to permit processing by the US Environmental Protection Agency, meant that CITES export permits have been over 18 months in processing, and have yet to be finalised. Finally, Griffith University has over the past two years taken a conservative approach to allocation of PhD scholarships by not considering international students in the ranking process. The PhD candidate selected for this project, Alexandre Bernier-Graveline, is a Canadian citizen and has therefore been unsuccessful in scholarship application. The CI has now secured a ring-fenced scholarship for Alex, and we look forward to his commencement mid-year. In light of the significant delays, the team have restructured planned manuscripts and will progress publication of UAV measurements initially separately to biochemical measures.

**Introduction**

The Humpback Whale Sentinel Program (HWSP) is a long-term biomonitoring program for circum-polar surveillance of the Antarctic sea-ice ecosystem. It is designed to complement existing efforts under the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR) Ecosystem Monitoring Program and provide open source data for the Antarctic and cetacean research communities.

Inclusion of further breeding stocks into monitoring under the HWSP translates to greater visibility of the circum-polar region as it experiences increasing climatic variability. As such, the HWSP scaffolded inclusion of breeding stocks A, EII and D into monitoring between 2016 and 2018. The current IWC-SORP effort aimed to include population G into monitoring through new partnerships, and to integrate the findings and ongoing efforts of PI Friedlaender and PI Bengtson Nash's respective long term monitoring programs, targeting humpback whale foraging ecology in relation to the dynamics of their principal prey item, Antarctic krill. Methodological integration was proposed via, a) Fundamental method comparison and validation, and b) Same-year feeding vs breeding ground population comparisons (diet and energetic reserves). The anticipated outcomes of the project are a translation of methods, as well as the establishment of a logistical framework (breeding stock representative), along the Colombian Pacific Coast for ongoing collaborative population assessment.

**Objectives**

1. Collect parallel adiposity measures (Adipocyte Index (AI); UAV morphometry measures, Persistent Organic Pollutant POPs Concentration Indices (CI)) on population G individuals; targeting the population in the breeding ground, and also at two time-points (early and late) in the feeding ground.

2. Interpret dietary markers (Lipid profiles; Bulk Stable C and N Isotopes, and POP biomagnification factors) in whales in their winter breeding grounds vs early- (return to Antarctica) and late-summer (post-summer feeding).

3. Determine the average energetic cost of migration through adiposity measures between feeding and breeding ground. These will serve both as a reference point for future monitoring program comparisons for the G population, as well as empirical measures for future energetic modelling.

**Results**

- All samples were successfully collected during the 2019 austral winter. CITES permits have been obtained, and transfers completed for Colombian samples. The transfer of Antarctic samples out of the Antarctic was delayed due to a cancelled 2020/21 field season but have now reached the US. We are awaiting US CITES export permits and anticipate transfer of samples to Griffith University mid-2022.

- Genetic sexing, fatty acid and bulk stable isotope analysis have been performed on Colombian samples.

- UAV body condition analyses have been performed via co-PI Christiansen and co-PI Johnston.

- Alexandre Bernie-Graveline, the proposed PhD student on energetic project aspects, applied unsuccessfully for a Griffith University scholarship in 2020 and 2021, due to an institutional restriction on international students. The CI has now secured a ring-fenced scholarship for his commencement mid-2022.

**Conclusions**

Field components of the project have been successfully completed. Sample analysis is underway, interpretation and publication are yet to be initiated.

**Challenges**

A review and restructure of planned manuscripts will take place early 2022 to navigate the delays in chemical and biochemical analyses.

**Outlook for the future**

IWC-SORP support for the HWSP, both through this and our 2020-awarded project, has given the overall program a significant boost. In 2021, the CI successfully proposed the Antarctic Monitoring and Assessment Programme (AnMAP) as a United Nations endorsed Ocean Decade Activity. The HWSP is the principal surveillance activity of AnMAP, and as such the importance of spatial and temporal monitoring of climate change and pollution in the Antarctic region is gaining recognition.

**Project outputs**

*Media interest*

https://news.griffith.edu.au/2021/03/04/using-whales-to-study-antarcticas-changing-environment/

https://www.abc.net.au/news/science/2021-01-31/humpback-whale-blubber-antarctic-ecology/13006580?utm_source=abc_news_web&utm_medium=content_shared&utm_content=twitter&utm_campaign=abc_news_web

*Other*

https://www.southernoceansentinel.org/

*Students and theses*

PhD student Alexandre Bernie-Graveline.

**PROJECT 24 (Carroll, Graham et al., 2018/19). Circumpolar foraging ecology of southern right whales: past and present**

*Dr Emma Carroll[1], Dr Leigh Torres[2], Dr Luciano O Valenzuela[3,4], Dr Darren Gröcke[5], Professor C. Scott Baker[2], Dr Simon Childerhouse[6], Professor Rochelle Constantine[1], Dr Glenn Dunshea[7,8,9], Professor Ken Findlay[10], B. Galletti Vernazzani[11], Professor Robert Harcourt[12], Ass. Professor Pavel Hulva[13,14], Petra Neveceralov[14,15], Assistant Professor Seth Newsome[16], Professor Larissa Rosa de Oliveira[17], Professor Paulo Henrique Ott[18], Professor Per Palsbøll[19], Dr Vicky Rowntree[5], Professor Jon Seger[5], Dr Brittany Graham, Dr Els Vermeulen[20], Dr Seth Newsome[21], Dr Hannah Vander Zanden[22], Dr Chris Somes[23], Dr Solène Derville[2]*

*1. School of Biological Sciences, University of Auckland, Private Bag 92019, Auckland, New Zealand*
*2. Marine Mammal Institute, Oregon State University, 2030 SE Marine Science Drive, Newport, OR 97365, USA*
*3. CONICET – Universidad Nacional del Centro de la Pcia. De Buenos Aires, Street 508 #881, Quequén, Argentina*
*4. Department of Biology, University of Utah, Salt Lake City, UT 84112, USA*
*5. Stable Isotope Biogeochemistry Laboratory (SIBL), Durham University, South Road, Durham, County Durham, DH1 3LE, UK*
*6. Cawthorn Institute, 98 Halifax Street East, Nelson 7010, New Zealand*
*7. Institute of Marine and Antarctic Studies, University of Tasmania, Tasmania, Australia*
*8. Ecological Marine Services Pty Ltd, Queensland, Australia*
*9. Department of Biology, University of Copenhagen, Copenhagen, Denmark*
*10. Centre of Sustainable Oceans Economy, Cape Peninsula University of Technology, Symphony Way, Bellville, Cape Town, 7535, South Africa*
*11. Centro de Conservación Cetacea, Casilla 19178 Correo 19, Santiago, Chile*
*12. Department of Biological Sciences, Macquarie University, Building E8B, NSW 2109, Australia*
*13. University of Ostrava, Vinicna 7, Door No. 207, 2nd Floor, Prague, Czech Republic*
*14. Department of Zoology, Faculty of Science, Charles University, Vinicna 7, Door No. 207, 2nd Floor, Prague, Czech Republic*
*15. Dyer Island Conservation Trust, Great White House, Kleinbaai - Gansbaai, South Africa*
*Ivanhoe Sea Safaris, 83 Vyfer Street, Gansbaai, South Africa*
*16. University of New Mexico, Department of Biology, Albuquerque, NM 87131 USA*
*17. Grupo de Estudos de Mamiferos Aquáticos do Rio Grande do Sul, and Laboratório de Ecologia de Mamiferos, Universidade do Vale do Rio dos Sinos, Centro de Ciêntas da Saúde, Avenida Unisinos 950, Cristo Rei, Sao Leopoldo 93022-000, RS, Brazil*
*18. Universidade Estadual do Rio Grande do Sul, Unidade Litoral Borte, Osório Rua Machado de Assis 1456, Sulbrasileiro, Osório 95520-000, RS, Brazil*
*19. Marine Ecology and Conservation, Groningen Institute for Evolutionary Life Sciences, University of Groningen, Nijenborgh 7, 9747 AC Groningen, The Netherlands*
*20. Mammal Research Institute Whale Unit, Department of Zoology and Entomology, University of Pretoria, South Africa*
*21. Biology Department, University of New Mexico, Albuquerque, New Mexico, USA*
*22. Department of Biology and Archie Carr Center for Sea Turtle Research, University of Florida, Gainsville, Florida, USA*
*23. GEOMAR Helmholtz Centre for Ocean Research Kiel, Düsternbrooker Weg 20, 24105 Kiel, Germany*

## Introduction

During the 2018 IWC-SORP Call from Proposals, the first research project was funded under the auspices of IWC-SORP Theme 6, entitled, Circumpolar foraging ecology of southern right whales: past and present (see

SC/68a/SH11 for details). This project originally involved 21 researchers from 10 countries, but has since expanded to include experts in isotope ecology and spatial ecology from Germany, the USA and New Caledonia.

**Objectives**

1. Compilation and validation of southern right whale isotope dataset
   a. Compile existing stable isotope data (δ13C and δ15N), and associated metadata on individual SRW (e.g., sex and demographic class).
   b. Compile data on methodology used to generate these stable isotope data, including lipid extraction procedures, international and internal standards and corrections used.

2. Undertake a validation study whereby a subset of samples are analysed in each of the two main laboratories that generated the stable isotope data (Durham and Utah).

3. Isoscape modelling
   a. Identify location of foraging grounds by comparison of stable isotope data from skin samples with Southern Ocean isoscapes. Both isoscapes developed from empirical data (particulate organic matter collected by many oceanographic voyages) and modelled outputs will be used to compare to the compiled SRW stable isotope dataset.

4. Habitat modelling: present and past distribution
   a. Create habitat models for those summer foraging grounds associate with populations strongly recovering and those that are poorly recovered
   b. Compare the geographic location of foraging grounds identified through habitat modelling to published historical whaling data and the putative historical and contemporary foraging grounds to understand changes in SRW foraging ecology over the last 200 years.

5. Pilot study to investigate heterogeneity and historical stable isotope data
   a. Use sex and demographic class metadata associated with the stable isotope profiles, and augmented by new data supplementing under-represented classes (e.g., males), to explore whether there is heterogeneity in prey or foraging ground location choice across age classes.
   b. Conduct a pilot study to generate stable isotope profiles for historical (pre-whaling or whaling era) bone collagen samples. This will allow us to begin to understand what proportion of whales were foraging in regions not captured by whaling voyage data.

**Results**

This work is using modelled δ13C and δ15N isoscape of the Southern Hemisphere's oceans from 30°S to the ice edge, developed by Dr Chris Somes (Somes et al. 2017, 2021; Schmittner and Somes, 2016), in combination with bulk skin stable isotope data from 967 southern right whales (SRW) to identify foraging grounds on a circumpolar sale. This isoscape model provides an estimate of the stable isotope values at the base of the food chain (phytoplankton) for the oceans. Individual whale foraging locations were estimated using a modified version of the assignment model from Vander Zanden et al (2015) and this isoscape model.

A challenge in identifying potential foraging grounds from the stable isotope data has been to identify a trophic enrichment factor or trophic discrimination factor (hereafter TDF) that provides a correction to apply to the isoscape that brings it to the trophic level of the SRW. This was addressed using mid to high-latitude SRW satellite track data provided by Dr Alex Zerbini and Dr Jen Jackson and colleagues of whales tagged in the western South Atlantic (Zerbini et al 2015, J. Jackson unpublished data) and by Dr Emma Carroll, Dr Alex Zerbini and Dr Simon Childerhouse and colleagues of whales tagged in the Indo-Pacific (unpublished data).

An analytical framework developed and implemented by Dr Solène Derville has optimized the TDF to maximise overlap between the area restricted search positions identified in the satellite track data and the isoscape assignments. This approach has proven effective at identifying a TDF that can be applied to the bulk skin isotope data. Initial results have shown the location of both the key foraging grounds for the New Zealand and Argentine wintering grounds, but also the wide distribution of foraging grounds inferred at a lower frequency in the population. Regular meetings are being conducted by the project steering committee (Carroll, Torres, Valenzuela, Newsome, Vander Zanden and Derville) to progress the project analyses and publications.

**PROJECT 25 (Iñíguez Bessega et al., 2018/19). Habitat use, seasonality and population structure of baleen and toothed whales in the Scotia Sea and the western Antarctic Peninsula using visual and passive acoustic methods and genetics**

*Miguel Iñíguez Bessega[1], Dr Simone Baumann-Pickering[2], Marta Hevia[1,3], Dr John Hildebrand[2], Alexander Marino[1], Mariana Melcón[1], Vanesa Reyes Reyes[1], Dr Ana Širović[4], Dr Juan Pablo Torres Florez[5], Nicolas Valese[2], Rodrigo Genoves[6]*

*1. Fundacion Cethus, Gdor Luis Monteverde 3695(B1636AEM), Olivos, Prov. Buenos Aires, Argentina*
*2. Scripps Acoustic Ecology Lab, Scripps Institute of Oceanography, University of California San Diego, 9500 Gilman Drive, La Jolla, CA 92093-0205, USA*
*3. Whale and Dolphin Conservation, Brookfield House, 38St Paul Street, Chippenham, Wiltshire SN151LJ, United Kingdom*
*4. Department of Marine Biology, Building 3029, Room 248, Texas A&M University Galveston, P.O. Box 1675, Galveston, TX 77553, USA*
*5. Departamento de Genetica e Evolução, Universidade Federal de São Carlos, Rod. Washington Luis, s/n, São Carlos, SP, Brazil*
*6. Ecopelagos – Universidade Federal do Rio Grande - FURG, Rio Grande, Brazil*

## Introduction

Since 2014, eight summer season cruises to the Antarctic have been conducted on board Argentinean vessels. Five of them were undertaken with Coast Guard vessels to the western part of the Peninsula, with the first one additionally including the Mar del Scotia/ Scotia Sea and Islas Orcadas del Sur/ South Orkney Islands (SOI), and three of them, including a recent voyage in 2022, on-board the Navy icebreaker *ARA Almirante Irizar*. These latter three voyages voyaged along the north-eastern part of the Peninsula, into the Mar del Scotia/ Scotia Sea, Mar de Weddell/ Weddell Sea and around the Islas Orcadas del Sur/ South Orkney Islands, as well as the southern area of the Mar de Weddell/ Weddell Sea.

## Results

Between 24 February and 3 April 2022, visual and acoustic surveys were conducted by dedicated observers along the Drake Passage, Islas Shetland del Sur/ South Shetland Islands, northeastern and northwestern Antarctic Peninsula, and Mar de la Flota/ Bransfield Strait using the Argentinean Icebreaker *ARA Almirante Irizar* as platform of opportunity.

During this time, 80 sightings (56 on-effort) of cetaceans were registered. Visually detected species included humpback, fin, minke and killer whales. Photographs were obtained from all species registered, some of which are suitable for photo-ID and will also be used to assess anthropogenic interactions.

A total of 110 hours of acoustic recordings were gathered by towing a four-element hydrophone array along the ship transect; the data is still to be analysed. In addition, a semi-rigid boat was used on two occasions to collect acoustic recordings using a single hydrophone in the vicinity of the Argentinean Base, Petrel (63°28′S; 56°17′W). 188 minutes of acoustic data were collected. During the first of the recordings, minke whales were sighted, as well as humpback whales apparently engaged in feeding activity. A preliminary analysis showed no vocalizations during this event.

## Project outputs

*Reports*

Marino A, Valese NV, Genoves R y Hevia M (2020) Informe de actividades realizadas en el marco del Consorcio para la Investigación del Océano Austral perteneciente a la Comisión Ballenera Internacional (IWC-SORP) Enero – febrero 2020

*Media interest*

https://gacetamarinera.com.ar/el-rompehielos-traslado-equipo-cientifico-y-personal-que-lo-opera-hasta-belgrano-ii/

https://gacetamarinera.com.ar/el-irizar-arribo-a-ushuaia/ (includes video images of staff working)

https://gacetamarinera.com.ar/finalizo-la-segunda-etapa-de-la-campana-antartica-de-verano-2/ (includes video images of staff working)

https://gacetamarinera.com.ar/cientificos-a-bordo-del-irizar/

https://www.facebook.com/FundacionCethus/ post from 28/02/2020

*Other*

Dirección Nacional del Antártico. Instituto Antártico Argentino. 2019. Uso de habitat, estacionalidad y estructura poblacional de cetáceos del Mar del Scotia y Peninsula Antártica utilizando métodos visuales, acústica pasiva y genética.” *In* Programa Antártico Argentino / Plan Annual Antártico 2019 – 2020. 41-42 pp.

*IWC-SORP and PIs of this project would like to thank the following persons and institutions: Ministry of Foreign Affairs of Argentina, Dirección Nacional del Antártico, Instituto Antártico Argentino, Dirección de Consejería Legal, COCOANTAR, Capitán de Navío Maximiliano Mangiaterra and crew of the icebreaker “ARA Almirante Irizar”, Dr. Antonio Curtosi, colleagues from Fundación Cethus, ECOPELAGOS/PROANTAR (Brazil), Centro Ballena Azul/ Universidad de Chile, Scripps Institution of Oceanography and Whale and Dolphin Conservation. This work was funded by the IWC/SORP funds, the Prince Albert II of Monaco Foundation and the Whale and Dolphin Conservation. This project is under the Programa Antártico Argentino / Plan Annual Antártico 2019 – 2020.*

**PROJECT 26 (Andrews-Goff, Double et al., 2019/20). Remote aerial deployment and sampling: development of a new sampling platform for large cetaceans**

*Virginia Andrews-Goff[1], Michael Double[1], Alex Zerbini[2], Guy Williams[3], Rob Harcourt[4], Natalie Kelly[1], William de la Mare[5], Alastair Smith[6]*

*1. Australian Antarctic Division, 203 Channel Highway, Kingston, Tasmania 7050, Australia*
*2. Marine Mammal Laboratory, Alaska Fisheries Center, 7600 Sand Point Way NE, Seattle, WA 98115-6349, USA*
*3. Institute of Marine and Antarctic Studies, University of Tasmania, 20 Castray Esplanade, Battery Point, Tasmania 7004, Australia*
*4. Department of Biological Studies, Macquarie Universit, Balaclava Road, North Ryde, NSW 2109, Australia*
*5. Independent Contractor, 72 Hillcrest Road, Tolmans Hill, Tasmania, Australia*
*6. Heliguy Scientific, 155 Catherine Street, Leichhardt, NSW, Australia*

**Executive summary**

Satellite telemetry, biopsy collection and photogrammetry generate data streams critical to the conservation and management of cetacean populations, revealing movement paths, foraging ecology, habitat preferences, population structure and health. However, undertaking vessel-based fieldwork to deploy a satellite tag, collect a biopsy sample or collect high-resolution imagery can be logistically costly, especially for Southern Ocean whales and safety concerns exist for the researchers involved as well as potential physiological and behavioural impacts for whales.

The widespread, scientific uptake of unmanned aerial vehicles/systems (drones) and the ability to take advantage of payload and sensor capabilities has highlighted the potential for an alternative, safer, quieter, cost-effective platform for satellite tagging and biopsy of cetaceans. The development of an entirely new biopsy sampling and tagging platform for large cetaceans is not without significant technical, ethical and possible legal challenges. However, there are examples of deployment capabilities in civilian drones. The dividends that such a platform could deliver for Southern Ocean cetacean science are likely to be considerable especially for areas where prevailing conditions impose logistical constraints and safety concerns that result in fewer opportunities to launch small boats to conduct cetacean science.

**Introduction**

Satellite telemetry, biopsy collection and photogrammetry generate data streams critical to the conservation and management of cetacean populations (e.g., Christiansen et al., 2016a; Andrews-Goff et al., 2018; Riekkola et al., 2018). These data streams, which can elucidate cetacean movement paths, foraging ecology, habitat preferences, population structure and health, are essential components of six of the seven International Whaling Commission (IWC) – Southern Ocean Research Partnership (SORP) themes. The IWC Scientific Committee encourage and recommend the use of these approaches to fill current knowledge gaps for whale populations globally including species of blue, fin and right whales (IWC, 2019). However, undertaking vessel-based fieldwork to deploy a satellite tag, collect a biopsy sample or collect high-resolution imagery can be logistically costly, especially for Southern Ocean whales (e.g., Double et al., 2013). Additionally, there exists safety concerns for the researchers involved (e.g., Friday et al., 2013) and the potential for physiological and behavioural impacts due to whales reacting to the vessel (Rolland et al., 2012; Blair et al., 2016; Williamson et al., 2016).

The widespread, scientific uptake of unmanned aerial vehicles/systems (UAV, UAS, referred to here as drones) and the ability to take advantage of payload and sensor capabilities has highlighted the potential for an alternative, safer, quieter, cost-effective platform for satellite tagging and biopsy of cetaceans. Drones have been successfully employed to assess cetacean body condition and mass (Christiansen et al., 2016a; Christiansen et al., 2019), collect exhalant samples (Acevedo-Whitehouse et al., 2010; Pirotta et al., 2017), study behavioural ecology (Nowacek et al., 2016; Torres et al., 2018) and hold potential as an aerial survey tool to derive abundance, distribution and habitat use (Colefax et al., 2017; Hodgson et al., 2017) as well as a tool to collect environmental DNA from seawater in the wake of whales (Baker et al., 2018). It is well established that for traditionally aerial based methods, utilising drones can reduce human risk (Torres et al., 2018) and minimise noise related behavioural and physiological impacts on study species (Christiansen et al., 2016b). No doubt, the same would hold true for methods such as satellite tag and biopsy dart deployment that are traditionally undertaken from small boats and research vessels (i.e. Bennett et al., 2015).

The utility of drones in the Southern Ocean was evident during the 2019 IWC-SORP ENRICH voyage led by the Australian Antarctic Division. During this 49-day Antarctic voyage, 134 flights were undertaken from a 94m research vessel (*RV Investigator*) to conduct a range of activities including photogrammetry, photo-identification, whale 'blow' sampling, surface water sampling, general whale and scenic imagery and surveillance for acoustic mooring retrieval. While the ENRICH voyage demonstrated the research opportunities drones can currently deliver, it also highlighted a new opportunity – the potential use of drones to deploy small satellite tags (e.g., LIMPET tags – Owen et al., 2019) and biopsy darts from large ships (e.g. Double et al., 2013), small vessels (e.g., Durban et al., 2016) and land stations (e.g., Christiansen et al., 2018). The dividends that such a platform could deliver for Southern Ocean cetacean science are likely to be considerable.

The development of an entirely new biopsy sampling and tagging platform for large cetaceans is not without significant technical, ethical and possible legal challenges. In assessing the applicability of a new sampling platform, it is necessary to examine the ethical implications. It is highly likely drones will provide considerable ethical advantages over the use of small boats near whales. While physiological and behavioural responses to visual cues and noise associated with the drone is a consideration (Smith et al., 2016), emerging evidence suggests that underwater noise from drones has little or no effect on the behaviour of baleen whales (Christiansen et al., 2016b). Whale behavioural response to drone presence has not been detected across various studies (Koski et al., 2015; Christiansen et al., 2016a; Torres et al., 2018; Fiori et al., 2019) with the exception of a minor behavioural response to a drone approaching from the direction of the head of the animal (Domínguez-Sánchez et al., 2018). Additional ethical considerations may be similar to those associated with other platforms such as cetacean encounter duration, ability to deploy tags and biopsy darts accurately, the impact force of these projectiles and the resulting biopsy sample volume.

It is also imperative to assess the legality of a new aerial deployment platform for biopsy darts and satellite tags. Biopsy and tagging devices are classified as firearms in Australia but are classified as scientific instruments elsewhere. Clearly, the dart/tag deployment mechanism may affect the drone's legality or classification. The applicable legislation may be dependent upon whether the darts/tags are passively released from the drone (gravity drop) or if physical devices (bows, elastics), compressed air or pyrotechnic propellants provide propulsive forces.

**Objectives**

This project intends to employ a formal engineering design process as an initial step towards producing a physical representation of an ethically and legally sound drone-based system intended as a safer method to generate satellite telemetry, biopsy and photogrammetry data streams. Our objectives are:

**Phase 1:** employs a formal engineering design process as an initial step towards producing a physical representation of an ethically and legally sound drone-based system intended as a safer method to generate satellite telemetry, biopsy and photogrammetry data streams. We are in the process of:

> Compiling pertinent information to inform our design process:
> a) Physical measurements (weight, velocity, force of impact) for all currently employed projectiles (biopsy darts, satellite tags) from all current AAD firearms by way of ballistics testing recorded using a high-speed camera.
> b) Assessing the specifications of commercially available quadcopters (maximum payloads, flight times and thrust) and their suitability for biopsy or tag deployment.
> c) Undertaking an ethical assessment and legal review.

**Phase 2:** an approach to suitable engineering consultants in order to generate projectile design solutions given our current needs.

**Phase 3:** will involve coordination of the development of an engineering specification and subsequently the manufacture and testing of a mechanism that can effectively and reliably deploy projectiles from a drone whilst also complying with safety and legal considerations.

**Results**

*Phase 1*

- We have successfully completed ballistics testing. In July 2021, we spent two days at the Tasmanian Policy Academy indoor shooting range firing projectiles at a foam target and filming their flight with a high frame rate camera. We undertook the following testing:

| Projectile | Firearm | Distance (m) | Shot pressure (bar) | Replicates |
|---|---|---|---|---|
| AAD biopsy dart | Paxarms biopsy rifle | 10, 15 | 15, 25 | 5 |
| Paxarms biopsy dart | Paxarms biopsy rifle | 10, 15 | 15, 25 | 5 |
| LIMPET | Dan-Inject | 6.38 | 10, 15, 20 | 5 |
| Implantable satellite tag | ARTS | 6.38 | 8, 12, 16 | 5 |

- Using the Tracker software, we have derived the mean speed of projectiles as they leave the firearm and as they hit the target as well as overall mean flight speed.

*Phase 2*

- We have secured additional funding from the Australian Government Department of Agriculture, Water and the Environment in order to subcontract design and testing of a drone-based projectile deployment system (initially just for biopsy sampling) by aeronautical engineers based jointly at the Swiss Materials, Science and Technology Institute and Imperial College of London.

*Phase 3*

- Additional time has been spent briefing aeronautical engineers and preparing a specifications document related to the operating conditions and requirements of biopsy sampling and satellite tagging of large whales in the Southern Ocean.
- Products associated with this contract are due in June 2022.

**Conclusions**

The involvement of a new team of aeronautical robotics engineers on this project has resulted in a slight alteration to the timing of intended activities. With a drone based projectile deployment system for biopsy darts expected by June 2022, much of the focus has been on briefing the team of engineers and ensuring ballistics data is ready to be fed into testing. This has resulted in the ethical and legal component of this project being delayed. However, this delay is likely to result in the ability to approach ethical and legal organisations with a bit more clarity around the type of projectile design solution to be employed and therefore feedback is likely to be more applied and relevant to future use of the system. Assuming the engineering tem are successful in their development of a drone based projectile system for biopsy darts, we will then move onto the problem of deploying implantable satellite tags.

**Challenges**

COVID-19 is still interfering with day to day productivity in general and project specific activities have been rearranged or slightly delayed accordingly.

**Outlook for the future**

The project is roughly tracking along the timeline and work plan initially developed. Currently there is no obvious need for additional resources to continue progress.

**Project outputs**

*Media interest*

https://www.antarctica.gov.au/news/2021/hide-and-seek-with-giants/

**Scientific references cited in report**

Acevedo-Whitehouse K, Rocha-Gosselin A, Gendron D (2010) A novel non-invasive tool for disease surveillance of free-ranging whales and its relevance to conservation programs. Animal Conservation 13(2): 217-225.

Andrews-Goff V, Bestley S, Gales N, Laverick S, Paton D, Polanowski A, Schmitt N, Double M (2018) Humpback whale migrations to Antarctic summer foraging grounds through the southwest Pacific Ocean. Scientific Reports 8(1):12333.

Baker CS, Steel D, Nieukirk S, Klinck H (2018) Environmental DNA (eDNA) From the Wake of the Whales: Droplet Digital PCR for Detection and Species Identification. Frontiers in Marine Science 5(133).

Bennett A, Barrett D, Preston V, Woo J, Chandra S, Diggins D, Chapman R, Wee A, Wang Z, Rush M (2015) Autonomous vehicles for remote sample collection: Enabling marine research. OCEANS 2015-Genova:1-8.

Blair HB, Merchant ND, Friedlaender AS, Wiley DN, Parks SE (2016) Evidence for ship noise impacts on humpback whale foraging behaviour. Biology Letters 12(8): 20160005.

Christiansen F, Dujon AM, Sprogis KR, Arnould JP, Bejder L (2016a) Noninvasive unmanned aerial vehicle provides estimates of the energetic cost of reproduction in humpback whales. Ecosphere 7(10): e01468.

Christiansen F, Rojano-Doñate L, Madsen PT, Bejder L (2016b) Noise Levels of Multi-Rotor Unmanned Aerial Vehicles with Implications for Potential Underwater Impacts on Marine Mammals. Frontiers in Marine Science 3(277).

Christiansen F, Sironi M, Moore MJ, Di Martino M, Ricciardi M, Warick HA, Irschick DJ, Gutierrez R, Uhart MM (2019) Estimating body mass of free-living whales using aerial photogrammetry and 3D volumetrics. Methods in Ecology and Evolution 10(12):2034-2044.

Christiansen F, Vivier F, Charlton C, Ward R, Amerson A, Burnell S, Bejder L (2018) Maternal body size and condition determine calf growth rates in southern right whales. Marine Ecology Progress Series 592:267-281.

Colefax AP, Butcher PA, Kelaher BP (2017) The potential for unmanned aerial vehicles (UAVs) to conduct marine fauna surveys in place of manned aircraft. ICES Journal of Marine Science 75(1):1-8.

Domínguez-Sánchez CA, Acevedo-Whitehouse KA, Gendron D (2018) Effect of drone-based blow sampling on blue whale (Balaenoptera musculus) behavior. Marine Mammal Science 34(3):841-850.

Double MC, Barlow J, Miller BS, Olson PA, Andrews-Goff V, Kelley N, Peel D, Leaper R, Ensor P, Calderan S, Collins K, Davidson M, Deacon C, Donnelly D, Lindsay M, Olavarria C, Owen K, Rekdahl M, Schmitt N, Wadley V, Gales NJ (2013) Cruise report on SORP 2013 Antarctic blue whale voyage. Paper SC/65a/SH21 presented to the IWC Scientific Committee, June 2013, Jeju, Republic of Korea.

Durban JW, Moore MJ, Chiang G, Hickmott LS, Bocconcelli A, Howes G, Bahamonde PA, Perryman WL, LeRoi DJ (2016) Photogrammetry of blue whales with an unmanned hexacopter. Marine Mammal Science 32(4):1510-1515.

Fiori L, Martinez E, Bader MK-F, Orams MB, Bollard B (2019) Insights into the use of an unmanned aerial vehicle (UAV) to investigate the behavior of humpback whales (*Megaptera novaeangliae*) in Vava'u, Kingdom of Tonga. Marine Mammal Science 36(1):209-223.

Friday NA, Clapham PJ, Berchok CL, Crance JL, Zerbini AN, Rone BK, Kennedy AS, Stabeno PJ, Napp JM (2013) ARCWEST (Arctic Whale Ecology Study) (2013) Cruise Report. Submitted to The Bureau of Ocean Energy Management under Inter-Agency Agreement Number M12PG00021 (AKC 108) November 2013.

Hodgson A, Peel D, nd Kelly N (2017) Unmanned aerial vehicles for surveying marine fauna: assessing detection probability. Ecological Applications 27(4): 1253-1267.

IWC (2019). Annex H. Report of the Sub-Committee on the Other Southern Hemisphere Whale Stocks. Report of the Scientific Committee of the International Whaling Commission, SC/68A. Nairobi, Kenya, 10-23 May 2019.

Koski WR, Gamage G, Davis AR, Mathews T, LeBlanc B, Ferguson SH (2015) Evaluation of UAS for photographic re-identification of bowhead whales, *Balaena mysticetus*. Journal of Unmanned Vehicle Systems 3(1):22-29.

Nowacek DP, Christiansen F, Bejder L, Goldbogen JA, Friedlaender AS (2016) Studying cetacean behaviour: new technological approaches and conservation applications. Animal Behaviour 120:235-244.
Owen K, Jenner KCS, Jenner M-NM, McCauley RD, Andrews RD (2019) Water temperature correlates with baleen whale foraging behaviour at multiple scales in the Antarctic. Marine and Freshwater Research 70(1):19-32.
Pirotta V, Smith A, Ostrowski M, Russell D, Jonsen ID, Grech A, Harcourt R (2017) An Economical Custom-Built Drone for Assessing Whale Health. Frontiers in Marine Science 4(425).
Riekkola L, Zerbini AN, Andrews O, Andrews-Goff V, Baker CS, Chandler D, Childerhouse S, Clapham P, Dodémont R, Donnelly D (2018) Application of a multi-disciplinary approach to reveal population structure and Southern Ocean feeding grounds of humpback whales. Ecological Indicators 89:455-465.
Rolland RM, Parks SE, Hunt KE, Castellote M, Corkeron PJ, Nowacek DP, Wasser SK, Kraus SD (2012) Evidence that ship noise increases stress in right whales. Proceedings of the Royal Society B: Biological Sciences 279(1737):2363-2368.
Smith CE, Sykora-Bodie ST, Bloodworth B, Pack SM, Spradlin TR, LeBoeuf NR (2016) Assessment of known impacts of unmanned aerial systems (UAS) on marine mammals: data gaps and recommendations for researchers in the United States. Journal of Unmanned Vehicle Systems 4(1):31-44.
Torres LG, Nieukirk SL, Lemos L, Chandler TE (2018) Drone Up! Quantifying Whale Behavior From a New Perspective Improves Observational Capacity. Frontiers in Marine Science 5(319).
Williamson MJ, Kavanagh AS, Noad MJ, Kniest E, Dunlop RA (2016) The effect of close approaches for tagging activities by small research vessels on the behavior of humpback whales (*Megaptera novaeangliae*). Marine Mammal Science 32(4):1234-1253.

**PROJECT 27 (Bengtson Nash et al., 2019/20). Extracting Standardised Health Parameter Data from Five Southern Hemisphere Humpback Whale Populations; Facilitating Direct Inter-Population Comparison of Relative Circum-polar Foraging Success**

*Susan Bengtson Nash[1], Ari Friedlaender[2], Claire Garrigue[3], John Totterdell[4], Milton Marcondes[5], Natalia Botero Acosta[6]*

*1. Griffith University, 170 Kessels Road, Griffith, Queensland, Australia*
*2. Institute for Marine Sciences, University of Santa Cruz, 115 McAllister Way, Santa Cruz, CA 95060, USA*
*3. Institute of Research and Development, 44 Boulevard de Dunkerque, CS 90009, 13572 Marseille cedex 02, France*
*4. Cetacean Research Western Australia, PO Box 140, Exmouth, WA 6707, Australia*
*5. Instituto Baleia Jubarte, Rua Barao do Rio Branco 125, Caravelas, Brazil*
*6. Fundación Macuáticos Colombia, Calle 27 Nº 79-167, Medellin, Antioquia, Colombia*

**Executive summary**

The above-named project has made good progress over the 2021-2022 reporting period, despite significant COVID-related delays. Samples from all five study populations have been transferred to Griffith University. Fatty acid and bulk stable isotope analyses have been performed and prepared for publication via the PhD thesis of Jasmin Gross. Energetic sentinel parameter analyses have been delayed due to COVID-related delays to the commencement of the intended project PhD student. A new, PhD student will be appointed to oversee fecundity parameter analyses, boosting this aspect of the project.

**Introduction**

The IWC's Southern Ocean Research Partnership (IWC-SORP) seeks to maximise conservation-orientated outcomes for Southern Ocean cetaceans through an understanding of the health, dynamics and environmental linkages of their populations, and the threats they face.

The Humpback Whale Sentinel Program (HWSP) is a biomonitoring-based, surveillance program of the Antarctic sea-ice ecosystem. It derives chemical and biochemical measures of southern hemisphere (SH) humpback whale adipose stores, diet and fecundity on an annual basis. These measures have been shown to oscillate closely with environmental conditions in the Antarctic feeding grounds, validating their functionality as 'sentinel parameters'.

The HWSP operates through widespread, inter-disciplinary collaborations with Breeding Stock Representatives (BSRs). BSRs conduct annual biopsy sampling of humpback whales in their respective breeding grounds. The location and timing of sampling is standardised to ensure that populations are at comparable stages of migration/fasting, and therefore, that distinct populations can be confidently compared in a robust manner. The HWSP seeks to provide open access data for further population health and ecosystem dynamics research applications.

Between 2016 and 2019, the HWSP expanded its annual monitoring campaigns from just one, to five populations. The putative feeding grounds of the 5 distinct SH humpback whale populations currently targeted under the HWSP, correspond to c.a. 80% of the circum-Antarctic region now under surveillance. 2019 represented the largest, synchronized field campaign of the HWSP to date with five populations sampled throughout the month of August. In preparation for this event, 2018/19 austral summer sampling of Antarctic krill (*Euphausia superba*) was performed in the corresponding feeding grounds via the IWC-SORP Blue Whale Voyage, Tokyo University, Arker Biomarine and Co-PI Friedlaender.

Consequently, the 2019 HWSP sample archive now signifies an unprecedented opportunity of comprehensive, robust comparison of 5 SH humpback whale populations according to standardised health parameters. Population health data, combined with regionally and temporally relevant prey references, provides new possibilities for deepening our understanding of SH humpback whale foraging dynamics (IWC-SORP Theme # 3). In turn, inter-population variability regarding health parameters will offer insights of direct relevance to IWC-SORP Theme # 5, such as implications for differential population recovery rates. In accordance, this proposal has been developed in consultation with the respective Theme Leaders with the proposed research expected to generate outcomes against objectives of both Themes.

This IWC-SORP project will apply a tool-box of chemical and biochemical analyses to 2019 biopsied humpback whale samples, and Antarctic krill samples collected in associated Antarctica feeding grounds the preceding summer. Analyses will include routine trophodynamic measures, such as lipid profiles and Bulk Stable Isotope (BSI) analysis, as well as a diverse array of novel biomarkers of adiposity and fecundity developed within CI Bengtson Nash's Southern Ocean Persistent Organic Pollutants Program (SOPOPP). These analyses will generate a comprehensive parameter set, unique in cetacean field biology in that it pertains to standardised measures concerning multiple population, representative of a vast geographical area. This in turn offers an opportunity for robust, temporally synchronized, comparison of health parameters and exploration of how these vary with each other, and geographically relevant environmental variables.

**Objectives**

1. Analyse adiposity measures (Inverse Adipocyte Index (AI-1); Persistent Organic Pollutant (POP) Concentrations) in samples derived from breeding stocks A, D, EI and EII in 2019. These will be collated with measures obtained for population G under 2019 IWC-SORP efforts for inter-population comparison.

2. Screen the blubber of female individuals, from all five populations, for steroid hormone markers of pregnancy (Liquid Chromatography tandem Mass Spectrometry (LC-MS)).

3. Interpret dietary markers (Lipid profiles; Bulk Stable C and N Isotopes, and POP biomagnification factors) in samples derived from breeding stocks A, D, EI and EII in 2019, as well as Antarctic krill derived from corresponding feeding grounds. These will be collated with measures obtained for population G under 2019 IWC-SORP efforts for inter-population comparison.

4. Explore inter-population differences in sentinel parameters in the context of environmental conditions in the Antarctic feeding grounds, the summer preceding sampling (e.g. krill abundance, sea-ice concentration, sea-surface temperature, ocean chlorophyll and climate indices).

**Results**

- All samples from all five populations have been successfully transferred to Griffith University.

- Fatty Acid and Bulk Stable Isotope analyses have been performed on samples from all five populations, as well as krill.

- The population comparison study has been prepared for publication, both via the PhD thesis of Jasmin Gross, and a manuscript currently being prepared for submission.

**Conclusions**

Sample analysis is underway, and complete for dietary components. Analyses related to energetic parameters will commence at the end of 2022 when Alexandre Bernier Graveline takes up his PhD appointment. Ella Hearne, has been recruited to work with fecundity aspects of the project and will commence her PhD on the same topic in late 2022.

**Challenges**

Work has been impacted by the delays to the commencement of project associated PhD students. Project plans and deliverables, however, remain unchanged.

**Outlook for the future**

IWC-SORP support for the HWSP, both through this and our 2020-awarded project, has given the overall program a significant boost. In 2021, the CI successfully proposed the Antarctic Monitoring and Assessment

Programme (AnMAP) as a United Nations endorsed Ocean Decade Activity. The HWSP is the principal surveillance activity of AnMAP, and as such the importance of spatial and temporal monitoring of climate change and pollution in the Antarctic region is gaining recognition.

**Project outputs**

*Peer-reviewed papers*

Gross J et al. (*In Preparation*) No local cuisines for humpback whales: a population comparison in the Southern Hemisphere (also published as PhD Thesis chapter).

*Media interest*

https://news.griffith.edu.au/2021/03/04/using-whales-to-study-antarcticas-changing-environment/

https://www.abc.net.au/news/science/2021-01-31/humpback-whale-blubber-antarctic-ecology/13006580?utm_source=abc_news_web&utm_medium=content_shared&utm_content=twitter&utm_campaign=abc_news_web

*Other*

https://www.southernoceansentinel.org/

**PROJECT 28 (Branch et al., 2019/20). Insights into Antarctic blue whale population structure and movements from photo-identification, Discovery marks, and satellite tags**

*Professor Trevor Branch[1], Paula Olson[2], Virginia Andrews-Goff[3], Michael Double[3], Jennifer Jackson[4]*

*1. School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA 98195, USA*
*2. National Oceanic and Atmospheric Administration (NOAA), Southwest Fisheries Sctence Center/NMFS/NOAA, La Jolla, CA 92037, USA*
*3. Australian Antarctic Division, 203 Channel Highway, Kingston, Tasmania 7050, Australia*
*4. British Antarctic Survey, High Cross, Madingley Road, Cambridge, CB3 0ET, United Kingdom*

## Executive summary

The IWC is planning an in-depth assessment of Antarctic blue whales, but one of the key issues for the assessment remains unresolved: is this subspecies comprised of a single population or multiple populations separated by either Management Areas or oceanic basins? We propose to apply modern mark-recapture statistical techniques to the extensive and under-tapped Discovery mark data from the 1930s to 1960s, estimating the amount of longitudinal movement within the Antarctic within and across years, and also testing whether the lack of recaptures showing movements between temperate regions and the Southern Ocean is evidence for no migration between these regions, or a result of low blue whale catches in temperate regions during the years in which marks were placed. In addition, we plan to similarly analyse recent photo-ID catalogue data, and then combine the Discovery marks, photo-ID and satellite tag tracks to determine which hypotheses of population structure and movement best explain the available data. The resulting papers, one on the Discovery mark data, and one synthesis paper pulling together the available information, will be submitted to both the IWC Scientific Committee, and to peer-reviewed journals.

## Introduction

Antarctic blue whales (*Balaenoptera musculus intermedia*) are likely at no more than 1-3% of their pre-whaling abundance of 239,000 individuals despite an increasing trend in recent decades (Branch et al. 2004, Branch 2008). This iconic subspecies, the largest and formerly most numerous of all the blue whale subspecies, is currently the target of a new in-depth assessment by the IWC Scientific Committee (IWC, 2017), but it is not clear whether a new assessment should assume that Antarctic blue whales are one population or multiple populations. The key available evidence for spatial distribution, population structure, and movements comes from song types, morphology, genetics, satellite tags, and mark-recaptures from genetics, Discovery marks, and photo-identification databases. However, available mark-recapture data have not been analysed to their full potential, which is what we propose to do here.

## Objectives

1) Estimate movement rates among IWC Management Areas using Discovery marks that takes into account marks, recaptures, mark losses, imperfect detection of marks, and whaling effort (catches) across space and time.

2) Assess the likelihood that Antarctic blue whales were captured both in the Antarctic and temperate land stations, given that no marked Antarctic blue whales were recaptured in any temperate land stations (notably, Saldanha Bay and Durban, South Africa).

3) Combine mark-recaptures of Antarctic blue whales obtained from Discovery marks, photo-ID, and satellite tags into a synthetic account of movements within and across years.

4) Assess whether movement data of Antarctic blue whales provide evidence for a single panmictic population, some population structure, or multiple populations.

**Results**

*Satellite tag results*

The dataset remains at n = 2 satellite tag deployments that yielded useful information for Antarctic blue whales, both tagged in 2013 (Figure 1). One whale, PTT 123223 (tagged 320 km from the ice edge), initially travelled north and then west for a minimum of 6107km across 74 days. The other whale, PTT 121205 (tagged 200km from the ice edge), covered 1287km in a south easterly direction over 13 days. Average travel speed also differed with PTT 123223 travelling at a lower speed (2.2 ± 0.8 kmh-1 - mostly due to the northward leg of the track) than PTT 121205 (4.0 ± 0.3 kmh-1). Excluding the initial northwards movement by PTT 123223, the dominant direction of travel covered a track line from IWC Management Area V to Area IV, remaining around 130km from the ice edge and through an area bordered to the north by the polar front and to the south by the Antarctic circumpolar current. PTT 121205 tracked the ice edge closely (62.95 ± 60.75 km) for the majority of the 14 day tracking period remaining in IWC Management Area V.

*Mark-recapture overview*

We examined combined Discovery mark (n = 45) and photo-ID (n = 17) inter-seasonal recaptures for evidence of ocean basin fidelity and migratory movement (Figure 2). Over half of data came from the Indian Ocean, so for this exercise the Indian Ocean was subdivided into western and eastern portions at 70°E—the generally accepted division based on the Mid-Indian Ocean Ridge.

Distances between marked and recapture locations were calculated as the shortest distance between the two points and were variable. In the Atlantic, the mean distance between mark and recapture was 1,338 km (SD = 1,361); for the western Indian 1,726 km (SD = 1,066); for the eastern Indian 2,678 km (SD = 1,539); and for the Pacific 2,706 km (SD = 1,867).

Based on the mark-recapture data, the movement patterns of individual Antarctic blue whales on the summer feeding grounds is highly variable. Blue whales roam widely. Fidelity to specific feeding grounds south of 60°S by individual whales was not evident in these data. In three of the four regions examined, most of the marked whales were recaptured within the same ocean basin, suggestive of some fidelity to the same region, or of slow spreading out over time.

Little additional evidence has been uncovered of migratory movement between the Antarctic and lower latitude regions. New photo-ID data from researchers in Brazil (n=4) and Uruguay (n=1) were compared to the Antarctic Blue Whale Catalogue (n=552), but no matches were found. There were also never any recaptures of Discovery marked Antarctic blue whales in any mid-latitude whaling stations. Thus while it has long been assumed that Antarctic blue whales migrated to mid-latitude regions (particularly the west coast of southern Africa), based on seasonal timing, morphometrics, and song detections, this assumption has yet to be confirmed by any direct photo-ID, satellite tag, or Discovery mark data.

Mark-recapture movement model: we have created a spatially-explicit Bayesian mark-recapture model that combines population dynamics, whale movement, and catches, fitting to abundance estimates and inter-annual Discovery mark-recapture data (within-season recaptures are not included, Table 1). The model estimates movement of Antarctic blue whales between the three major oceanic basins (Pacific, Atlantic, and Indian Oceans, separated at longitudes 67.26°W, 20°E, 146.9167°E). The model consists of separate abundance and mark components, which share movement parameters and harvest rates.

The following components are included in the animal abundance and movement model: (1) Total carrying capacity (K) for the entire population of Antarctic blue whales (one parameter). (2) Movement rates between each basin, constrained so that at least one-third of whales remain in the same basin each year. Since movement rates must sum to one, six movement parameters are estimated (the movement rates out of each area into one of the other areas). (3) Given values for the movement rate parameters, we assumed the population is in equilibrium, calculated the ratios in each basin at equilibrium, and applied these ratios to find carrying capacity in each of the three ocean basins. (4) The population dynamics model is a theta-logistic parameterised with z = 2.39 so that maximum productivity occurs at 60% of carrying capacity. (5) Catches were used from Branch et al. (2004), and split among ocean basins in each whaling season using the proportions of catches with recorded locations in the corresponding seasons. (6) Abundance estimates for ocean basins were derived from estimates for IWC areas (periods during 1978/9-2003/4) were obtained from Branch (2007), that were then allocated to basins in proportion to the longitudinal range within each basin. (7) Trajectories that result in extinction are set to an abundance of 1, and the likelihood penalized to avoid these regions.

The model of Discovery marks uses the same ocean basins and predict recaptures from the harvest rates. This model assumes three "groups" of marks are deployed each season (one for each basin), and keeps track of how many are expected to be in each ocean basin given natural survival, whaling harvest rates (from the abundance component), and movement rates (shared with the abundance component). Recaptures are a function of tag loss, reporting rates, harvest rates, and mark abundance in each basin. For simplicity, we assumed a fixed natural survival of 0.96 in all years and basins (based on Branch et al. 2004). We also combined tag loss and reporting rate into a single estimated parameter ("tag loss"), since it is expected that tag loss largely occurs in the first year of deployment, while reporting rate affects values only once (at capture).

For the first iteration of the model, due to a difficult posterior surface, we further simplified the model to fix the rate of increase in the theta-logistic to r = 0.073 (Branch et al. 2004), and did not fit the model to abundance estimates in the 1980s and 1990s, instead fitting the model to reasonable abundance estimates at the low abundance point (in 1973) that were consistent with this rate of increase and the later abundance in each of the ocean basins. These abundances were assumed to be 50 (Atlantic), 100 (Indian) and 150 (Pacific). This simplified Bayesian model implemented in Stan, reaches convergence.

All versions of the model tested to this point reach similar conclusions, thus while the results presented here are for just one preliminary iteration of the model, it is likely that the final model will find similar patterns. Notably, posterior estimates of movement rates are high (and highly uncertain), with only around two-thirds of whales remaining in a basin from one year to the next (Figure 3). Additionally, while the abundance model explained declines and movements to low levels in 1973, carrying capacity in the Indian and Pacific basins was estimated to be higher than in the Atlantic. This is counter-intuitive given the very high catches in the Atlantic (where whaling first concentrated) and Indian Oceans (where most pelagic catches came from) compared to the Pacific (where whaling on blue whales was restricted or absent for most decades). The model estimates that movement out of the Pacific was sufficiently high to maintain catches in the other two basins.

**Table 1** Number of Antarctic blue whale marks released and recovered in each ocean basin (excluding same season recoveries).

| | | **Atlantic** | **Indian** | **Pacific** |
|---|---|---|---|---|
| **Marked** | N marked | 772 | 1012 | 326 |
| | p(basin) | 0.37 | 0.48 | 0.15 |
| | N recovered | 8 | 29 | 9 |
| | p(recovered) | 0.010 | 0.029 | 0.028 |
| | | Prop. | Prop. | Prop. |
| **Recovered** | Atlantic | 0.87 | 0.21 | 0.00 |
| | Indian | 0.13 | 0.76 | 0.44 |
| | Pacific | 0.00 | 0.03 | 0.56 |

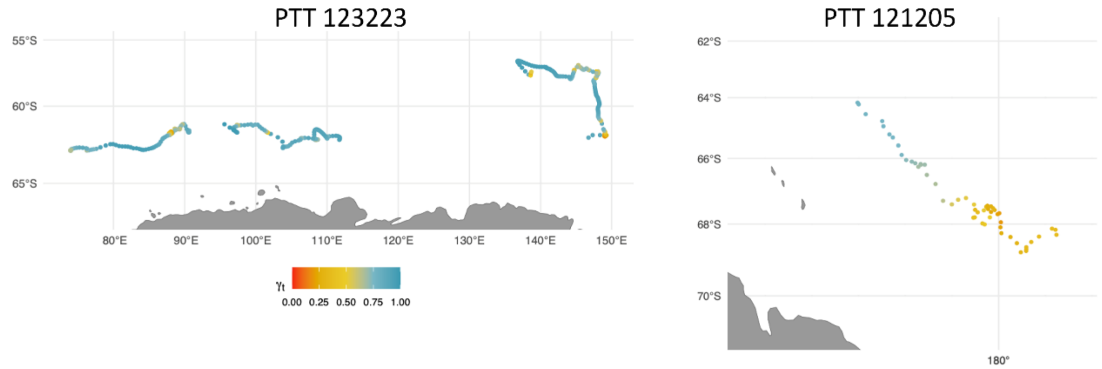



**Figure 1** Satellite tag derived movements of two Antarctic blue whales, with colors coding move persistence: redder colors (close to zero) indicate area-restricted search (possible feeding areas), while bluer values (approaching one) indicate transit from one region to another.

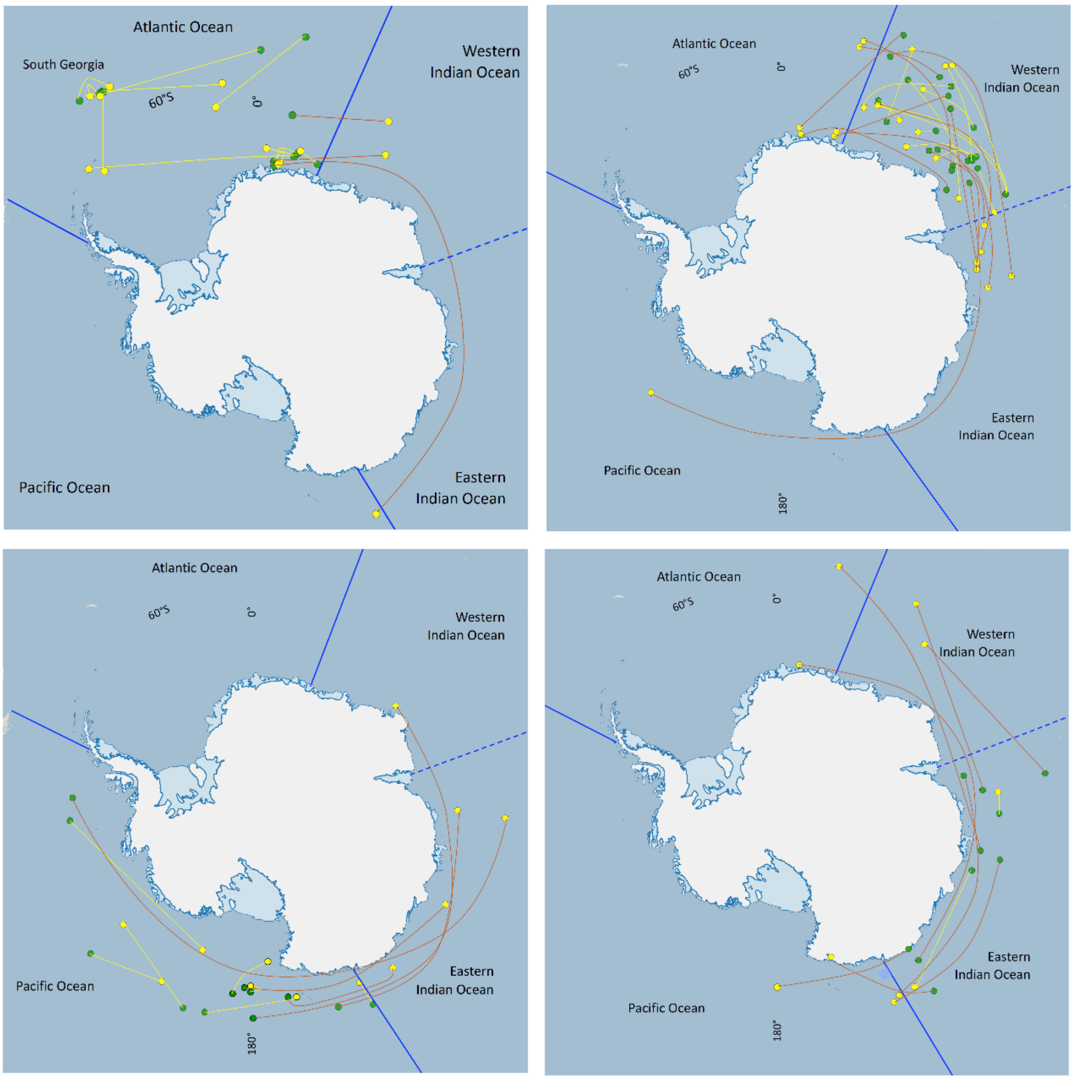



**Figure 2** Locations of Antarctic blue whales marked and recaptured either using Discovery marks or photo-ID. Each map represents whales marked in one of four oceanic regions demarcated by blue lines—ocean basins except with the Indian Ocean split into eastern and western sectors. Green lines represent mark-recaptures within the same region, and red lines movement between regions. The mark location is represented by a green circle and the recapture by a yellow circle. Lines connect the two locations and do not represent whale movement.

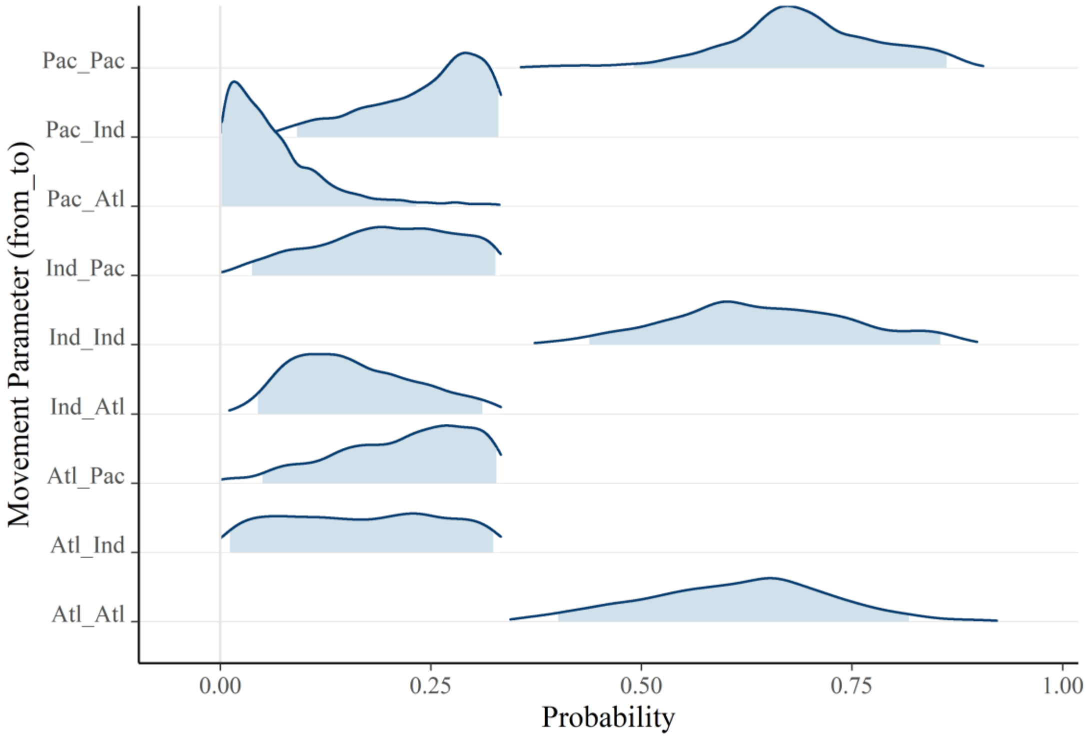



**Figure 3** Estimated movement rates from a preliminary version of the mark-recapture model, between the three ocean basins. Movements out of a basin are constrained to lie between 0 and 0.33, and thus the proportion remaining in a basin must be between 0.34 and 1.00.

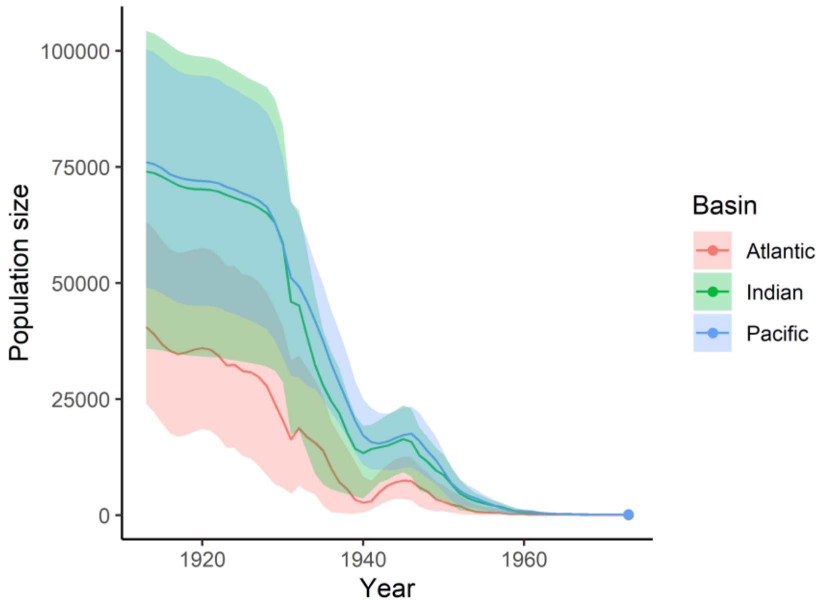



**Figure 4** Estimated Antarctic blue whale abundance in each ocean basin from a preliminary version of the mark-recapture model, showing the higher initial abundances in the Pacific and Indian Oceans, which the model estimates to move to the Atlantic Ocean to maintain the high catches there.

**Conclusions**

Final conclusions will need to wait for the end of the modeling project, but it is clear from Discovery marks, photo-ID data, and satellite tags that Antarctic blue whales are capable of travelling vast distances around the

Antarctic, among years. Nevertheless, completely free movement around the Antarctic has not been established. Notably, no individuals with photo-ID data have crossed the Antarctic Peninsula, and there are no records of individual whales being recorded in both the Pacific and Atlantic sectors, so it is possible that the Antarctic Peninsula represents some kind of barrier to Antarctic blue whale movement.

**Challenges**

COVID-19 has imposed a huge challenge to this project. The lead PI has had to repurpose his time to converting teaching from in-person, to online-only, to flipped classroom and finally hybrid teaching, and all personnel have faced logistic, coordination, and other challenges related to Covid.

Additionally, we lost a key personnel, originally identified to conduct the Discovery mark-recapture modelling. Due to COVID-19 and other factors, they were unable to begin work on the project. As a result, a new PhD student, Zoe Rand, was hired in January 2021 under the direct supervision of PI Branch at the University of Washington, who began work at the end of her main PhD coursework (July 2021), resulting in a no-cost extension to May 2022.

Convergence issues: the mark-recapture movement model has broad posteriors, resulting in long convergence times and requiring substantial reformulation. Final results are still pending.

**Outlook for the future**

The project is on course for final results in time for SC, although as with all modelling projects, there is no guarantee of convergence.

**Project outputs**

*Peer-reviewed papers*

Branch TA, Monnahan CC (2021) Sex ratios in blue whales from conception onward: effects of space, time, and body size. Marine Mammal Science 37:290-313.

Calderan SV, Black A, Branch TA, Collins MA, Kelly N, Leaper R, Lurcock S, Miller BS, Moore M, Olson PA, Širović A, Wood AG, Jackson JA (2020) South Georgia blue whales five decades after the end of whaling. Endangered Species Research 43: 359-373.

Pastene LA, Acevedo J, Branch TA (2020) Morphometric analysis of Chilean blue whales and implications for their taxonomy. Marine Mammal Science 36: 116-135.

Rojas-Cerda C, Buchan SJ, Branch TA, Malige F, Patris J, Staniland L, Pangerc T (2022 *Accepted*) Presence of Southeast Pacific blue whales (*Balaenoptera musculus*) off South Georgia in the South Atlantic Ocean. Endangered Species Research.

Zhong M, Torterotot M, Branch TA, Stafford KM, Royer J-Y, Dodhia R, Ferres JL (2021) Detecting, classifying, and counting blue whale calls with Siamese neural networks. Journal of the Acoustical Society of America 149:3086-3094.

*IWC/SC papers*

Branch TA (2020) Assignment of South Georgia catches between Southeast Pacific blue whales and Antarctic blue whales. IWC paper SC/68B/SH/16.

Branch TA, Monnahan CC (2020) Sex ratios in blue whales from conception onward: a comparative analysis across space, time, and size. IWC paper SC/68b/SH01. 24 pp.

Branch TA, Monnahan CC, Širović A, Al Harthi S, Allison C, Balcazar NE, Barlow DR, Calderan S, Cerchio S, Double MC, Dréo R, Gavrilov AN, Gedamke J, Hodge KB, Jenner KCS, Leroy EC, McCauley RD, Miksis-Olds JL, Miller BS, Panicker D, Rogers T, Royer J-Y, Samaran F, Shabangu FW, Stafford KM, Thomisch K, Torres LG, Torterotot M, Tripovich JS, Warren VE, Willson A, Willson MS (2021) Monthly movements and historical catches of pygmy blue whale populations inferred from song detections. IWC paper SC/68C/SH/17

Branch TA (2021) Little evidence for interchange between north-east Pacific and south-east Pacific blue whale populations despite morphological similarities. IWC paper SC/68C/SH/20

Lang AR, Archer FI, Attard C, Baker CS, Branch TA, Brownell Jr RL, Buss D, Jackson J, Kelly N, Moller L, Olson P, Sirovic A, Sremba A (2020) Evaluating the evidence for population structure within Antarctic blue whales. IWC paper SC/68B/SH/03. 23 pp.

*Presentations*

*Popular talk*: Branch TA. *A glimmer of hope for Antarctic blue whales: the largest of them all*. Monterey Bay chapter of the American Cetacean Society, December 2020.

*Popular talk*: Branch TA. *Sex ratios in blue whales from conception onward: effects of space, time, and body size*. Marine Mammal Science Editors' Select Series, January 2021.

*Popular talk*: Branch TA. *A glimmer of hope for Antarctic blue whales*. San Diego chapter of American Cetacean Society, 9 June 2021.

*Popular talk*: Branch TA. *How many and where were they? The value of sightings and other data in assessing status of marine mammals*. Virtual gear-down workshop for marine naturalists, The Whale Museum, 13 November 2021.

*Popular talk*: Branch TA. *Blue whales: in crisis or increases?* Bevan Series: Living with Marine Mammals, School of Aquatic and Fishery Sciences, 6 January 2022.

*Socila media*

The PI uses social media (Twitter, @bluewhalenews) extensively to post updates on blue whale research. On average this activity amounted to 20 tweets per month, and over the course of the project so far (May 2019-present) these tweets have been viewed 936,000 times.

**Scientific references cited in report**

Branch TA (2007) Abundance of Antarctic blue whales south of 60°S from three complete circumpolar sets of surveys. Journal of Cetacean Research and Management 9:253-262.

Branch TA, 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 M-NM, Matsuoka K, Mikhalev YA, Miyashita T, Morrice MG, Nishiwaki S, Sturrock VJ, 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.

**PROJECT 29 (Buchan, Stafford et al., 2019/20). A comparison of acoustic population identifiers for fin whales off Chile and in the Southern Ocean: a passive acoustic monitoring approach for gaining insights into population structure**

*Susannah Buchan[1], Kate Stafford[2], Maximiliano Vega[1], Giselle Alosilla[1], Carlos Olavarria[1], Brian Miller[3], Ana Širović[4], Ilse van Opzeeland[5] and the IWC-SORP Acoustic Trends Working Group*

*1. Centro de Estudios Avanzados en Zonas Áridas (CEAZA), Raul Bitran, La Serena, Chile*
*2. Applied Physics Lab, University of Washington, 1013 NE 40th Street, Seattle, WA 98105, USA*
*3. Australian Antarctic Division, 203 Channel Highway, Kingston, 7054 Tasmania, Australia*
*4. Trondhjem Biological Station, Department of Biology, Norwegian University of Science and Technology (NTNU), N-7491 Trondheim, Norway*
*5. Alfred Wegner Institute, Klußmannstr. 3d, 27570 Bremerhaven, Germany*

## Executive summary

Little is known about the population identity of fin whales off the coast of Chile. Based on whaling observations, they might be part of a population that migrates to the Southern Ocean, or they could be a separate population altogether. No studies have examined this connection. The central question of this proposal is: Are the fin whales off the coast of Chile part of the same population as animals in the Southern Ocean? This project seeks to compare acoustic population identifiers of fin whale 20-Hz song at different locations in the southeast Pacific and in IWC Areas I and II of the Southern Ocean to gain insights into the connections between fin whales across these regions.

Using standard bioacoustic computational analysis techniques (automatic detection and manual annotation), measurements of the following potential population identifiers were made on high Singal to Noise (SNR) calls: Inter-Pulse Interval for the 20-Hz song; the high pulse associated with the 20-Hz song; the starting and ending frequencies and bandwidth of the 20-Hz song pulses. 20-Hz song calls were selected from northern Chile and the oceanic archipelago of Juan Fernandez (Chile) for this analysis. Other colleagues (Dr. Ilse van Opzeeland, Dr. Brian Miller, Dr. Ana Širović) from the IWC-SORP Acoustic Trends Working Group have made similar analyses for their regions and during 2022 an effort will be made to pull these analyses together for publication, making a comparison between Chile, South Shetland Islands, the Antarctic Peninsula, Greenwich Meridian, and other sites.

## Introduction

*Southeast Pacific and Southern Ocean fin whales*

Fin whales (Balaenoptera physalus) were reduced to 2% in the Southern Hemisphere during 20th century whaling. Off the coast of Chile, fin whales were the most widely caught species of baleen whale by commercial whaling fleets, comprising 46.9% of all catches, totaling 4,512 individuals (Aguayo-Lobo et al., 1998). This species has been assessed as Vulnerable by the International Union for Conservation of Nature (IUCN; www.iucn.org) and Endangered in Chilean waters by (Aguayo-Lobo et al., 1998). Visual sightings of fin whales occur off central Chile (approximately 33ºS-40ºS), but also in high numbers off northern Chile ((Capella et al., 1999, Pérez et al., 2006, Toro et al., 2016, Sepúlveda et al., 2018) and southern Chile, the Juan Fernandez Archipelago (JFA), and Easter Island (Aguayo-Lobo et al., 1998, and references therein). A strong seasonal trend in the acoustic presence of fin whale song off JFA was observed by Buchan et al., (2019) with a peak in the austral winter.

Extremely little is known about the population identity of fin whales off the coast of Chile, and although they might be part of a population that migrates to the Southern Ocean based on whaling observations (Clarke et al., 1978), it is possible they form a separate population. No studies have examined this connection. The central question of this proposal is: Are the fin whales off the coast of Chile part of the same population as animals in the Southern Ocean?

*Fin whale song and possible population identifiers*

Passive acoustic monitoring (PAM) is a widely used method to examine the temporal and spatial distribution of large whales throughout the world's oceans, including for fin whales (e.g. Watkins et al., 2000, Stafford et al., 2009, Širović et al., 2017). Male fin whales are known to produce song in loud repetitive sequence of pulses around 20 Hz (e.g. Croll et al., 2002). Associated with the 20 Hz song, fin whales in some areas produce a higher frequency pulse, which we will call "high pulse" here. These are regionally specific and thought to be population identifiers: the high pulses recorded off the Western Antarctic occur around 89 Hz, off the Eastern Antarctic around 99 Hz (Širović et al., 2009); off JFA around 85 Hz (Buchan et al., 2019); and in the North Atlantic around 135 – 140 Hz (Castellote et al., 2012).

Another fin whale song characteristic which may be a population identifier is the Inter-Pulse Interval (IPI) between the 20 Hz pulses, sometimes also referred to as the Inter-Note Interval (INI). Hatch and Clark (2004) found that IPI was the most distinguishing characteristic among regional songs. The 20 Hz pulses can occur in singlets, doublets or triplets (Širović et al., 2017 and references therein) with varying IPIs. Depending on location, IPIs vary from 9 to 34 s (Hatch and Clark, 2004, Castellote et al., 2012, Soule and Wilcock, 2013, Oleson et al., 2014, Širović et al., 2017). Seasonal changes in IPIs have also been reported: In the Pacific, IPIs were found to be shorter in summer and longer IPIs in winter (Oleson et al., 2014) ; in the Atlantic, IPIs were short (9.6 s) in late summer to early winter, and long (15.1 s) in spring (Morano et al., 2012). Lastly, annual increases in IPI have been reported in the northeast Pacific (Širović et al., 2017), regionally at a rate of 0.54 s/yr over a decade (Weirathmueller et al., 2017).

*Gaining insights into Southern Hemisphere population structure with passive acoustics*

Off the coast of Chile, there are several acoustic datasets that can be used to examine possible acoustic population identifiers for fin whale song in the southeast Pacific and compare these to measurements from data available from the Southern Ocean. The Preparatory Commission for the Comprehensive Nuclear Test Ban Treaty Organization (CTBTO; www.ctbto.org) has an International Monitoring Station called HA03, located approximately 670 km west of mainland Chile, on Robinson Crusoe Island, part of the JFA. HA03 has 6 hydrophones that collect acoustic data for the primary purpose of detecting underwater explosions. This data is available to Susannah Buchan and Kathleen Stafford through a CTBTO contract with the University of Washington (UW). A previous study with the CTBTO data off JFA by Buchan et al. (2019) examined the temporal occurrence of fin whale 20-Hz song but did not make any exact measurements of IPI or the frequency of high pulses. Another research project off Northern Chile led by Carlos Olavarría and Susannah Buchan at the Centro de Estudios Avanzados en Zonas Áridas (CEAZA) has generated two years of acoustic data, which is being analyzed currently for the presence of fin whale vocalizations, and 20-Hz song has been identified in this data (Buchan et al. unpublished).

In the Southern Ocean, datasets from the Greenwich Meridian are available through the Alfred Wegner Institute (AWI) (Ilse van Opzeeland) and data from the South Shetland Islands and the Antarctic Peninsula are available through Texas A&M University Galveston (Ana Širović). This project seeks to compare acoustic population identifiers of fin whale song at different locations in the southeast Pacific and the Southern Ocean to gain insights into the connections between fin whales in both regions.

**Objectives**

1) Compare Inter-Pulse Interval duration (s) of fin whale 20-Hz songs off Chile and in the Southern Ocean.

2) Compare the frequency of the "high pulse" associated with the fin whale 20-Hz songs off Chile and the Southern Ocean.

3) Compare the bandwidth of the of fin whale 20-Hz songs off Chile and the Southern Ocean.

## Methods

*Data collection*

Data from Juan Fernandez (Figure 1) was obtained from the HA03 station managed by the Preparatory Commission of the Nuclear Test Ban Treaty (CTBTO). The HA03 station collects continuously data at 250 Hz sample rate with a hydrophone deployed at 813 m in total water column depth of 1538 m.
Data from Isla Chañaral was collected by the Centro de Estudios Avanzados en Zonas Aridas (CEAZA), Chile, with a Soundtrap hydrophone sampling continuously at 24kHz, bottom-mounted at 170m depth.

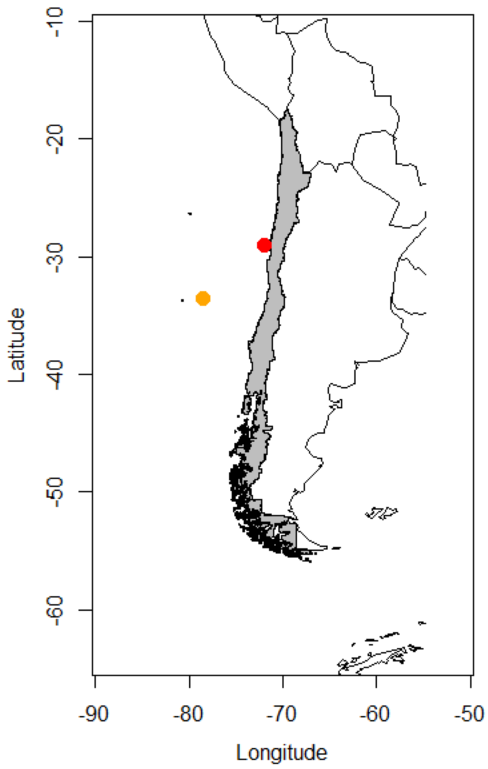



**Figure 1** Map of study sites of the coast of Chile: Juan Fernendez (orange dot) and Isla Chañaral (red dot).

*Data selection*

For the Juan Fernandez data, two days per month were selected at random, one day in the first half of the month and one in the second half of the month, between April 2014 and December 2016. These days were reviewed and annotated manually by an analyst (MV). For the data off Isla Chañaral, Northern Chile, data from 2018 was reviewed and manually annotated by an analyst (GA), identifying only 20-Hz song calls in June 2018. Then available data for winter months (June, July 2018 and May 2020) were all reviewed and manually annotated by an analyst (MV).

*Manual annotation in Raven*

Selected data was reviewed manually in Raven by an analyst (MV) who annotated all sequences of 20-Hz song calls (Figure 2). Sequences were determined by a pause of 90s between two 20-Hz pulses.

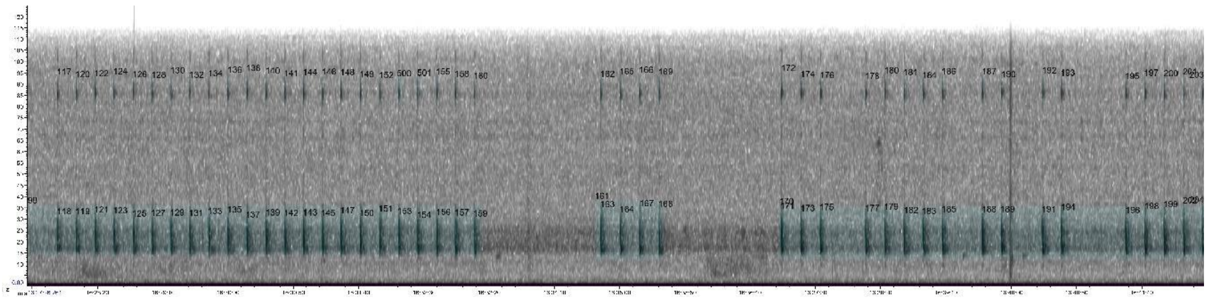


**Figure 2** Raven Pro 1.6 Window showing an example of manual annotation of Antarctic fin whale 20-Hz song calls. Numbers indicate 20-Hz pulse annotations and high frequency pulse annotations; the two black arrows indicate an inter-pulse interval annotation longer than 90s. Spectrogram parameters: Hann windows; FFT: 512; overlap; 50%.

By default, Raven selection tables are specific to a sound file as loaded into the Raven workspace. To share selection tables across computers, one must also share the exact same sound files, including the Raven settings used to open them. Similarly, by default Raven selection tables don't contain sufficient links back to the original wav files to easily make measurements in Matlab or other software. Thus, measurements for each selection table in Raven were:

- o Min Freq.
- o Max. Freq.
- o Peak Freq.
- o Delta time
- o Begin File
- o Peak Freq Contour (Hz)
- o End File
- o Begin Time (s)
- o Begin File Samp (samples)
- o End File Samp (samples)
- o Begin Date Time

*Signal to Noise ratio (SNR) estimation in MATLAB*

SNR was estimated using custom code developed by Brian Miller, which takes the dB of the annotated signal, as delimited by the duration and frequency band of the annotation; and the dB of noise taken as half of the duration of the signal before the annotation and half of the duration of the signal after the annotation within the same frequency band as the annotation. SNR is defined by equation 6.26 in Lurton (2010) "An Introduction to Underwater Acoustics, Principles and Applications. 2nd Edition".

Frequency and IPI measurements were done only for the "high" SNR calls. Histograms of SNR for each site and year were reviewed for each site (see results Fig. 3 and 4). For Juan Fernandez, all calls with the top 50% of SNR values were included in the analysis. All SNR values for Isla Chañaral were around 0 (Fig. 4) and therefore were considered too low to include in this analysis.

*Frequency measurements*

Calls selected for analysis were filtered from the Raven selection tables and from these, average peak frequency and average frequency bandwidth (= maximum frequency – minimum frequency) were calculated.

*Inter-pulse Interval measurements*

For each sequence of 20-Hz song calls, the IPI was determined by the duration between the ending of one pulse and the beginning of the next. Average IPI was calculated for each year.

**Results**

*Selection and analysis of datasets*

a) From Juan Fernandez, a total of 32 days were reviewed manually between April 2014 and December 2016 and a total of 7635 20-Hz song calls were manually annotated, 2014 (n = 3560), 2015 (n = 1814) and 2016 (n = 2261). Calls were generally present between April and December, with some interannual variation (no data was available for January to April 2014) (Figure 3).

b) From Isla Chañaral, a total of 92 days were reviewed manually June, July 2018 and May 2020 and a total 327 20-Hz song calls were manually annotated (Figure 4).

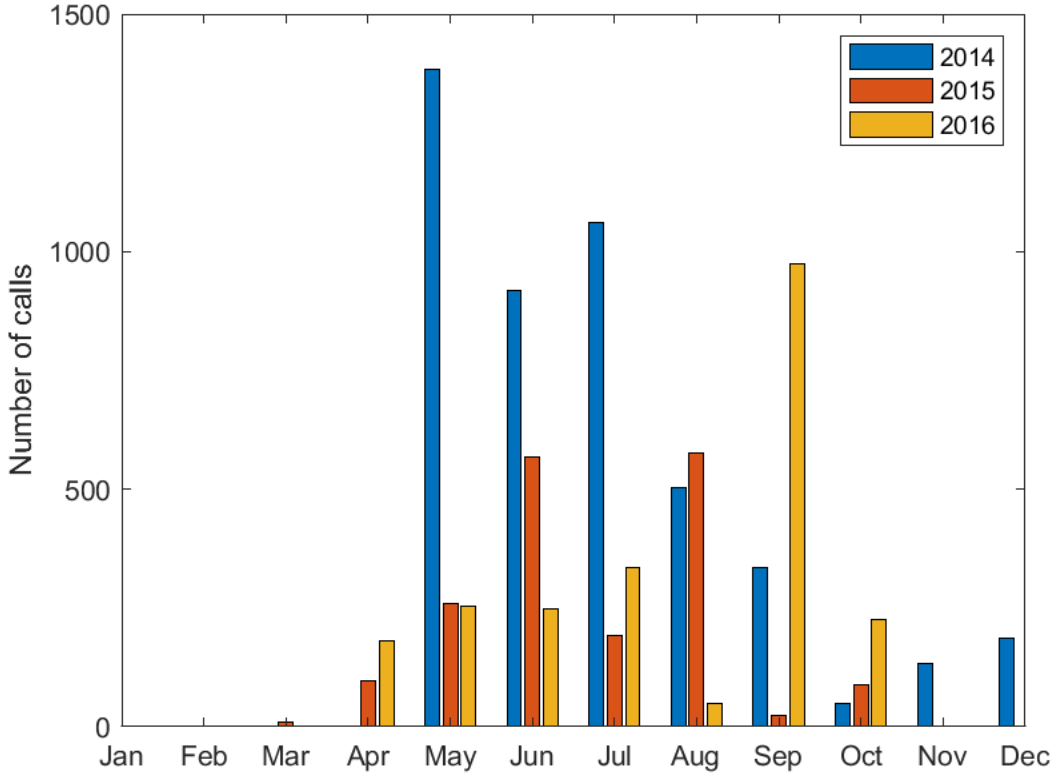



**Figure 3** Temporal variation of 20-Hz calls between April 2014 and December 2016 of Juan Fernandez, Chile.

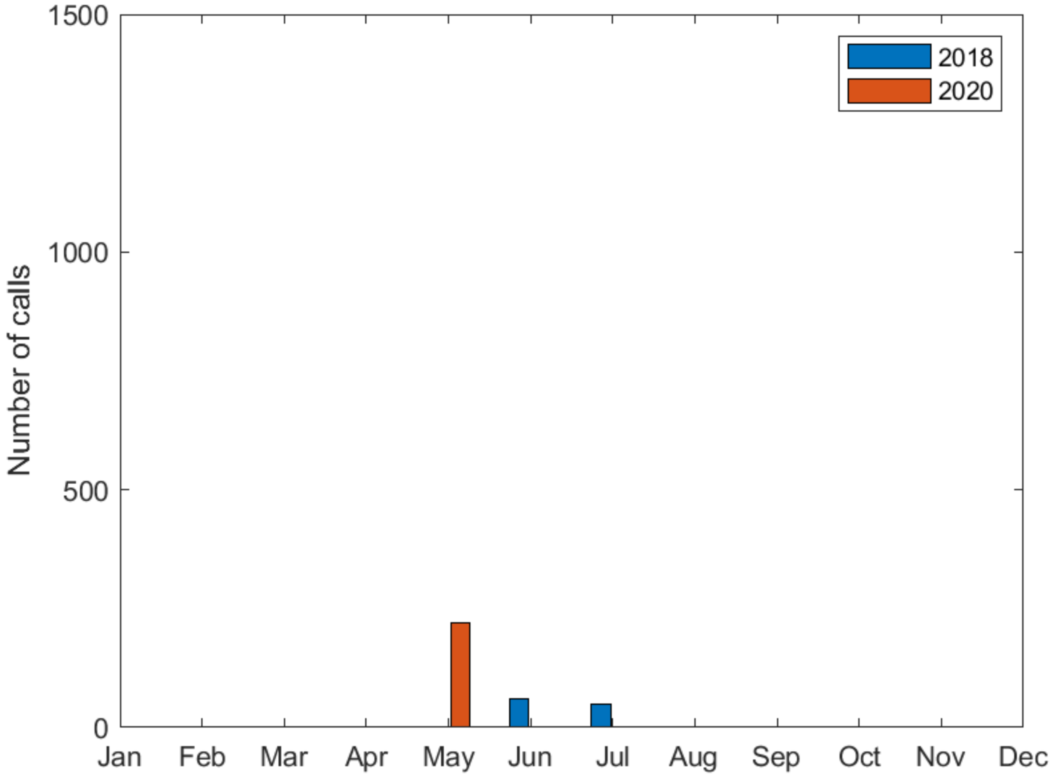



**Figure 4** Temporal variation of 20-Hz calls from July to July 2018 and May 2020 of Isla Chañaral, Chile.

*Signal to Noise ratio analysis*

All calls (n=7642) were found to have an SNR of -41.44 dB or above. SNR of Juan Fernandez of calls was centred around 10 to 20 dB (Figure 5) and around 0 dB for Isla Chañaral (Figure 6). All calls from Isla Chañaral were discarded from the analysis due to low SNR; for Juan Fernandez calls with the top 50% of SNR values were selected for analysis (see line that marks the cut-off in Figure 5). This resulted in 2785 calls from Juan Fernandez selected for analysis for a cutoff at 16.11 dB.

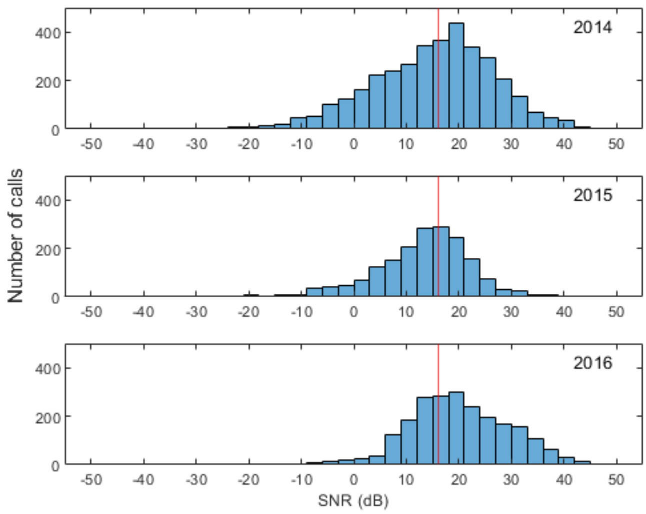



**Figure 5** Histogram of call SNR for Juan Fernandez for 2014 (n = 3563), 2015 (n = 1814) and 2016 (n = 2265).

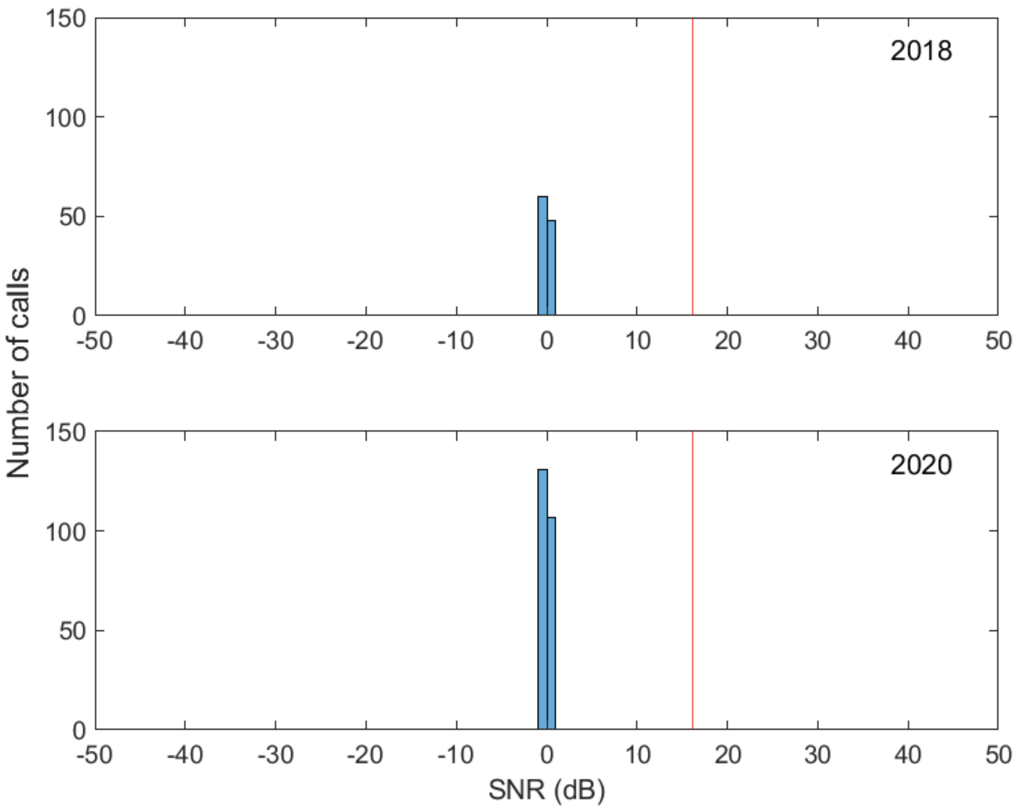



**Figure 6** Histogram of call SNR for Isla Chañaral for 2018 (n = 108) and 2019 (n = 238).

*Frequency characteristics of 20-Hz song calls*

Based on the 3980 20-Hz calls annotated from Juan Fernandez, Chile, we found an overall average bandwidth of 15.57 ± 2.24 Hz and average peak frequency of 18.45 ± 3.76 Hz for the 20-Hz pulse and 85.3 ± 1.64 Hz for the high frequency pulse (Table 1). No marked differences were apparent between years (Figures 7, 8, 9).

**Table 1** Frequency characteristics of 20-Hz song calls from Juan Fernandez, Chile.

| | **n** | **Min Frequency (Hz) ± sd** | **Max Frequency (Hz) ± sd** | **Frequency Bandwidth ± sd** | **Peak Frequency (Hz) ± sd of 20-Hz pulse** | **Peak Frequency (Hz) ± sd of high frequency pulse** |
|---|---|---|---|---|---|---|
| 2014 | 1813 | 14.53 ± 3.73 | 30.35 ± 3.82 | 15.82 ± 2.3 | 18.27 ± 4.09 | 85.69 ±0,67 |
| 2015 | 725 | 14.65 ± 4.46 | 29.38 ± 4.29 | 14.73 ± 2.19 | 18.57 ± 4.78 | 85.05 ± 24.08 |
| 2016 | 1442 | 14.41 ± 0.87 | 30.07 ± 1.88 | 15.67 ± 2.08 | 18.62 ± 2.53 | 84.71 ± 2.10 |
| All years | 3980 | 14.51 ± 3.20 | 30.07 ± 3.37 | 15.57 ± 2.24 | 18.45 ± 3.76 | 85.30 ± 1.64 |

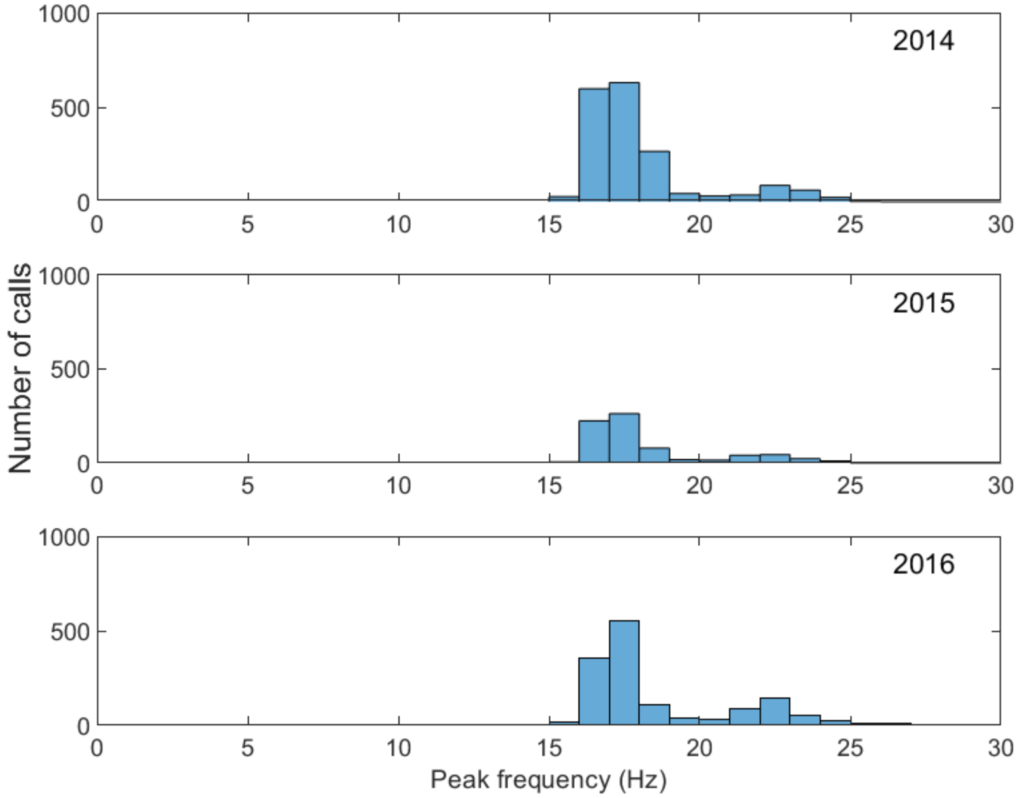



**Figure 7** Histogram of peak frequency characteristics per year for the 20-Hz pulse.

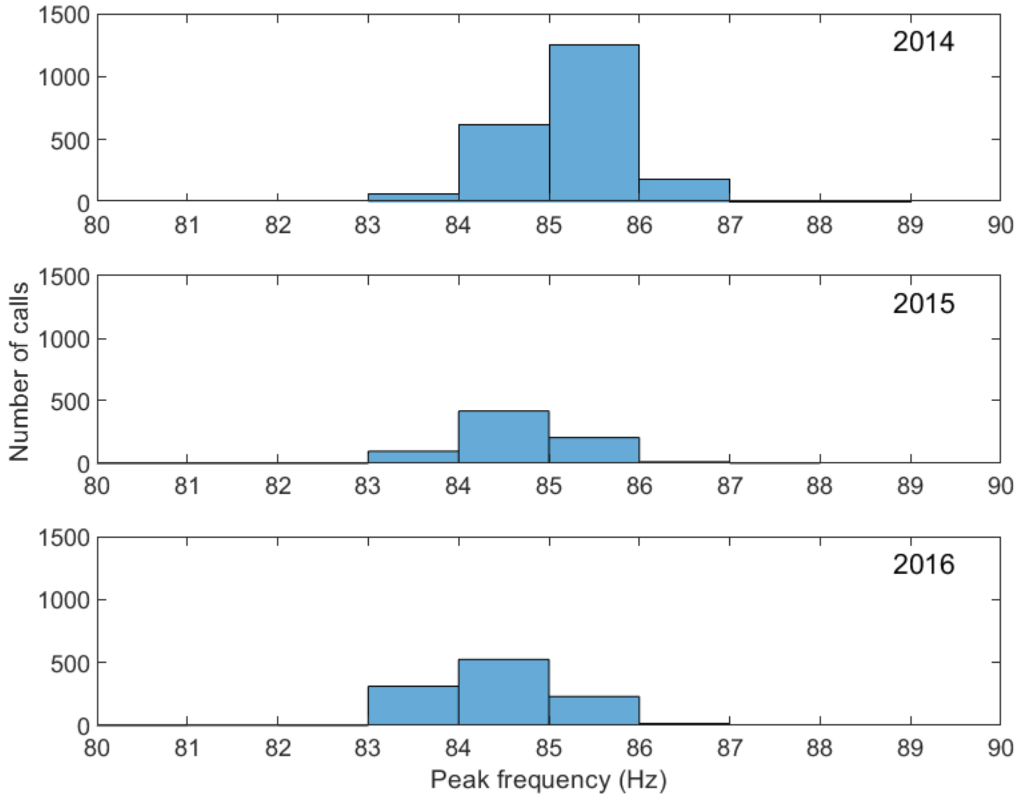



**Figure 8** Histogram of peak frequency characteristics per year for the high frequency pulse.

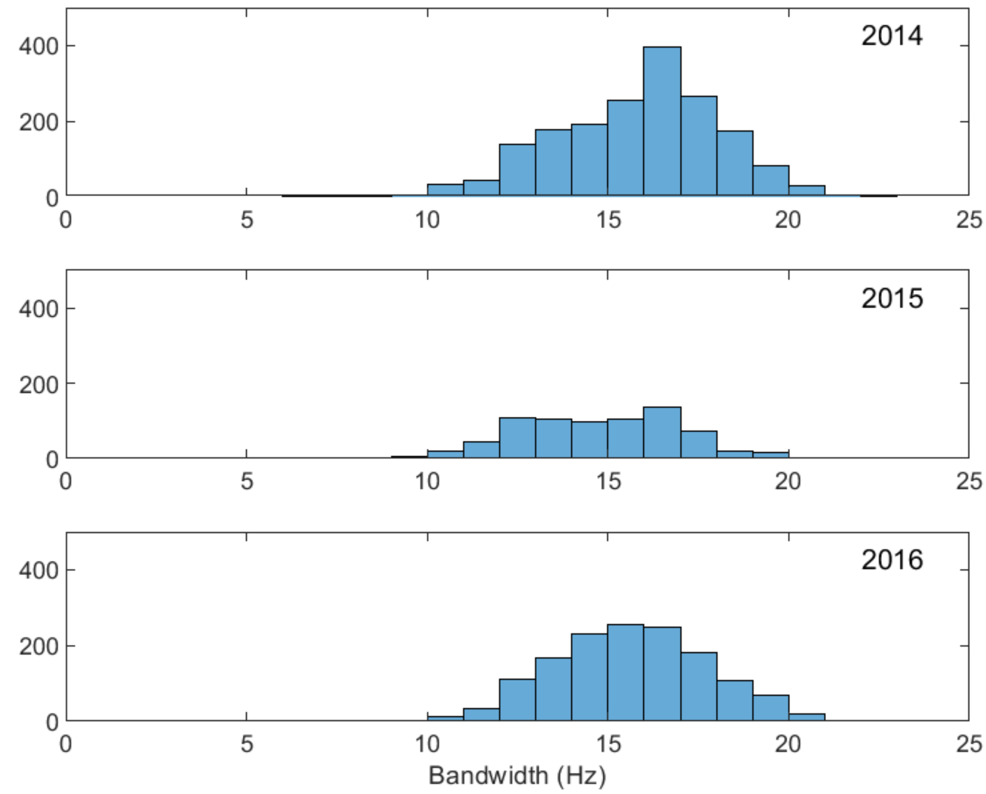


**Figure 9** Histogram of frequency bandwidth of 20-Hz pulse calls.

*Inter-Pulse Intervals (IPIs) of 20-Hz song calls*

Only singlet 20-Hz pulses were detected of Juan Fernadez. A total of 3854 IPIs were measured and were overall 18.01 ± 8.98 in duration (Table 2; Figure 10). Figure 10 also shows that IPIs increased slightly during the year, but further statistical analyses will need to corroborate if this is statically significant.

**Table 2** Inter-Pulse Intervals of 20-Hz song calls from Juan Fernandez, Chile.

| | **n** | **IPI (s) ± sd** |
|---|---|---|
| **2014** | 1747 | 17.54 ± 8.56 |
| **2015** | 697 | 17.89 ± 8,47 |
| **2016** | 1397 | 18.31 ± 8,99 |
| **All years** | 3854 | 18.01 ± 8.98 |

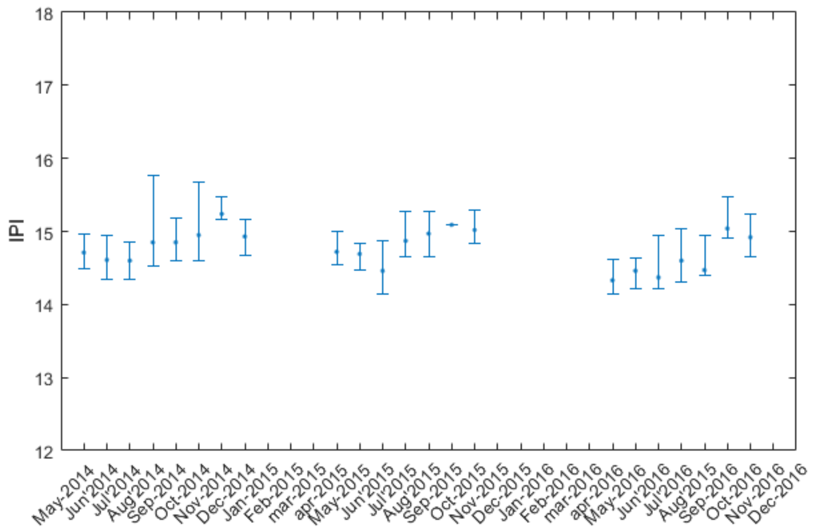



**Figure 10** Inter-Pulse Interval for 20-Hz calls recorded off Juan Fernandez between April 2014 and December 2016.

**Outlook for the future**

More work needs to be done in order to complete the objective of comparing the characteristics of fin whales calls at sites across the Southern Hemisphere. This will be done in collaboration with the SORP acoustic trends working group with the objective of working on a paper that integrates multiple sites, during 2022. Similar analyses have been done by Dr. Ilse van Opzeeland for Elephant Island and Dr. Ana Širović for the Antarctic Peninsula. All the analyses presented here for Chile were coordinated with these colleagues so comparisons can be made efficiently and in a timely manner during 2022. We expect to submit a paper this year that integrates finding from multiple sites.

**PROJECT 30 (Butterworth, Cooke et al., 2019/20). Multi-ocean assessment of southern right whale demographic parameters and environmental correlates**

*Doug Butterworth[1#], Justin Cooke[2#], Claire Charlton[#*3], Els Vermeulen[4#]*, Andrea Ross-Gillespie[1], Anabela Brandão[1], Karina Groch[5], Russell Leaper[6], Will Rayment[7], Vicky Rowntree[8], Mariano Sironi[8,9], Macarena Agrelo[9], Gideon van den Berg[4], Mandy Watson[10], Emma L. Carroll[11], Kris Carlyon[12], Stephen Burnell[13], Michael Double[14], Jennifer Jackson[15]*

# Primary Investigators of the IWC-SORP funded project
*IWC Science Committee intersessional working group co-conveners

*1. Department of Mathematics and Applied Mathematics, University of Cape Town, South Africa*
*2. Centre for Ecosystem Management Studies, Germany*
*3. Centre for Marine Science and Technology, Curtin University, Western Australia, Australia*
*4. Mammal Research Institute Whale Unit, Department of Zoology and Entomology, University of Pretoria, South Africa*
*5. Instituto Australis, Brazil*
*6. International Fund for Animal Welfare*
*7. University of Otago, New Zealand*
*8. Ocean Alliance, University of Utah, USA*
*9. Instituto de Conservación de Ballenas, Argentina*
*10. Department of Environment, Land, Water and Planning Victoria, Australia*
*11. School of Biological Sciences, University of Auckland, Private Bag 92019, Auckland, New Zealand*
*12 Institute of Marine and Antarctic Studies, University of Tasmania, Tasmania, Australia*
*13. Eubalaena Pty. Ltd.*
*14. Australian Antarctic Division, 203 Channel Highway, Kingston, Tasmania 7050, Australia*
*15. British Antarctic Survey, High Cross, Madingley Road, Cambridge, CB3 0ET, United Kingdom*

**Executive summary**

The work of the Intersessional Working Group (WG) "Multi-ocean assessment of southern right whale (SRW) demographic parameters and environmental correlates'" aims to compare SRW population demographics across the main southern hemisphere (SH) wintering grounds. This is to be achieved by applying a common demographic model to the populations in each region: Southwest (SW) Atlantic (Argentina/Brazil), Southeast (SE) Atlantic (South Africa), Australia and New Zealand, in order eventually to test hypotheses for the relationships between reproductive success and environmental variables. The project is a integral component of the International Whaling Commission Southern Ocean Research Program (IWC-SORP) Theme 6, *The right sentinel for climate change: linking foraging ground variability to population recovery in the SRW*. The IWC-SORP funding proposal related to this WG, submitted in January 2020 (SC/68b/O01), was successful.

Key progress made between April 2021 and March 2022 includes:

- The Southern Right Whale Consortium was established to facilitate multi-ocean collaboration and to develop data quality control standards – the related Memorandum of Understanding has initially been signed by 11 southern right whale researchers, and remains open to all those interested.

- At the time of the last report, the version of the common model applied to the SW Atlantic data incorporated an additional "unsuccessful mother" component. This explicitly modelled the number of females experiencing late abortions or early calf deaths, as this was found to be important for fitting to the data for the region. This component was not present in the version of the model applied to the South African data. Since then, this component has been included in the formal specification of the common model. The coding for this inclusion is almost complete, with model-fitting to commence soon. The model will first be fit to the South African data, then to the other available data sets.

- A global desk-top assessment of southern right whale sightings South of 40°S was completed by honours student Cuyler van Jaarsveld (University of Pretoria). Data were collected from multiple sources and used to produce maps in order to visualize where and when SRWs were sighted. A total of

357 sightings data points were collected from 13 separate sources, including SOWER cruises, CCAMLR, Happywhale, PROANTAR, ObsInt, IWC reports and the South Georgia Heritage Trust Database. A full report can be seen at SC/68d/SH03.

**Introduction**

The International Whaling Commission (IWC) Scientific Committee (SC) Southern Hemisphere (SH) intersessional working group (WG) for 'Multi-ocean assessment of southern right whale (SRW) demographic parameters and environmental correlates' (SC/67b/SHWP12 and SC/68a/SHWP19) was formed and endorsed during SC67b (2018). This work forms an integral part of IWC-SORP Theme 6, *The right sentinel for climate change: linking foraging ground variability to population recovery in the southern right whale (SRW).* An IWC-SORP funding proposal to advance the work of this WG, submitted in January 2020 (SC/68b/O01), was successful.

This multi-ocean collaborative project aims to compare population demographics across the main SH wintering grounds, by applying a common demographic model to the populations in each region in order eventually to test hypotheses for the relationships between demographic parameters (reproductive success, survival and population increase) and environmental variables. It involves 22 researchers from 7 countries and utilises 50+ years of data from SH wintering grounds to inform IWC-SH subcommittee priority species assessment for SRWs, and to address priority areas for IWC-SORP. The regional populations with available long-term photo identification (ID) databases which are available to be included are: (1) SE Atlantic (South Africa), (2) SW Atlantic (Argentina/Brazil), (3) Australia and (4) New Zealand.

**Objectives**

Specific objectives include:

1. To establish a SRW photo-ID consortium to develop data quality control standards, identify analytical biases, and facilitate multi-ocean collaboration.
2. To specify of a common demographic model to estimate life history parameters for the main breeding populations to include: calving interval, age of first parturition, mortality (of calves and non-calves) and population growth.
3. To obtain comparable estimates of the key parameters of the demographic model and of population growth rates for the populations from each of the major wintering grounds.
4. To collate published and available information in a desktop review of contemporary feeding grounds to inform the selection of environmental variables for further investigation of links between demographic parameters (especially reproductive success) and climate.

Progress towards achieving the specific objectives is summarised below.

**Results**

*Objective 1: Southern Right Whale Photo ID consortium*

A Memorandum of Understanding (MoU) was finalized for the formation of a SRW consortium, in which partners agree to collaborate with an ultimate goal to generate scientific data on the species on a circumpolar scale, which could not be achieved by individual research groups alone. The first, and most urgent, project undertaken by this consortium relates to the collation of long-term photo-identification and sightings datasets to allow for a comprehensive assessment of the global population status of southern right whales under a common statistical and biological model - the fundamental goal of this project. For more information, see SC/68c/SH07. The initial signatories to the SRWC MoU are listed below. They relate to IP holders of long-term sighting history data of individually identified southern right whales, data needed to be shared for the successful completion of this project. Obviously, the consortium remains open to include further interested partners who wish to collaborate towards a better understanding and conservation of the species. The number of projects that can be conducted under the consortium's umbrella is unlimited. The MoU is non-binding, and project-specific data sharing agreements will be established underneath the umbrella provided by the consortium.

Mandy Watson - Department of Environment, land, water and planning, AU
Mariano Sironi – ICB, ARG
Karina Groch – Instituto Australis, BR
Will Rayment – University of Otago, NZ
Kris Carlyon – Department of Primary Industries, Parks, Water and Environment, AU
Emma Carroll – University of Auckland, NZ
Alexandre Zerbini – University of Washington and NOAA, USA
Jennifer Jackson – British Antarctic Survey, UK
Victoria Rowntree – University of Utah, USA
Els Vermeulen – University of Pretoria, SA

A first virtual meeting of the SRWC is planned to be held just prior to the SC68d meetings to discuss ways forward, after which meetings may be held (bi-)annually.

*Objective 2: Common Demographic Model*

<u>Model structure</u>

Specification of the common SRW biological model (common model) is now complete, with a new feature added of explicitly modelling an "unsuccessful mother" component for females experiencing late abortions or early calf deaths. The model will allow various demographic parameters (e.g., true calving intervals and their changes over time, population growth rates) to be estimated for the different SRW populations. Major datasets have been provided for model input from Argentina/Brazil, Australia and South Africa. A New Zealand dataset will be requested once model runs are complete for datasets from the regions listed above.

This common model which accommodates the various aspects of the different SRW populations is shown schematically in Figure 1. Reproductive females are divided into (newly) Pregnant, Calving (lactating) (i.e., successful mothers), Unsuccessful mothers (females experiencing late abortions or early calf deaths) and Resting stages. The "normal" reproductive cycle is three years, consisting of one Austral winter season in each of the pregnant, calving and resting phases, with the calving phase disaggregated into successful mothers and unsuccessful mothers (Figure 1). However, there are various alternative paths that are each associated with a probability parameter which is to be estimated from each dataset (where possible). Some or all of these probability parameters may vary with time. It is these variations which this project hopes to relate to environmental factors (i.e., prey availability and climate variates) in future modelling (not covered under the IWC-SORP funded work scope SC/68b/O01). The probability parameters correspond to the following events:

**α:** a female becomes pregnant again after weaning its calf and skips the usual resting year (resulting in a 2-year calving interval if that pregnancy proceeds to term)
**β:** a resting female chooses to rest for a further year (resulting in a 4-year calving interval if followed by a normal cycle)
**γ:** a pregnant female loses its foetus too late to become pregnant again the same year, and reverts to the resting phase without having given birth (resulting in a 5-year calving interval if followed by a normal cycle)
**δ:** a pregnant female loses it foetus early and becomes pregnant again, thus spending a consecutive year in the pregnant phase (resulting in a 4-year calving interval if followed by a normal cycle).
**$\lambda$: a** pregnant female is an "unsuccessful mother", i.e., experiences a late abortion or an early calf death and rests the following year.
$\beta^*$: an unsuccessful mother (that rested a year after losing its calf in a late abortion or in an early calf death before it could be observed) rests an additional year.
(The probabilities of the paths are determined by the requirement that the transition and remaining probabilities for each state sum to the survival rate.)

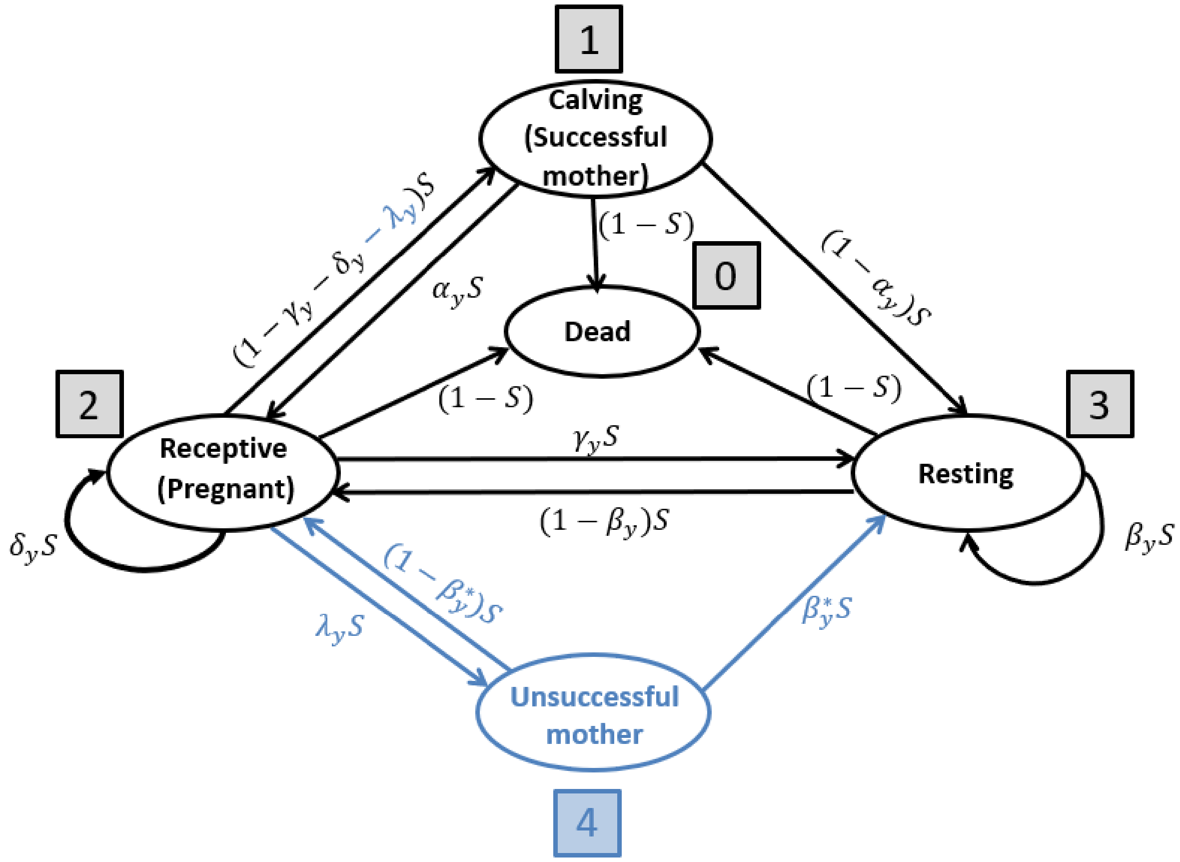



**Figure 1** Schematic outline of the common biological model. Text and arrows in black correspond to the Brandão *et al*. (2021) model and blue text and arrows to the additional component explicitly modelling the number of females experiencing late abortions or early calf deaths. This component has been added under the guidance of J. Cooke (*pers. comm.*) in accordance with the model previously applied to the SW Atlantic data.

The coding for the final common model is nearly complete. Runs to be undertaken will include the South African and the Argentina/Brazil SRW photo-ID sightings data because these data are familiar and available to the modelling team. The next steps after that are to include other datasets, including Australia and New Zealand, and to compare demographic parameters.
Exploratory fits will be required to determine which parameters can be reliably estimated for each data set. For example, the additional parameters required to fit the SW Atlantic situation (λ and β^*) may not be well estimated from the South African data. For its part, the SW Atlantic data set may lack sufficient inter-annual contrast to estimate the δ parameter, which was originally introduced to accommodate the South African data. If it is found that not all parameters are separately estimable for all data sets, then discussion will be required to determine suitable values or priors for the remaining parameters. The Australian dataset will be ready for exploratory fitting once the coding is finalised; this will be undertaken to identify any further issues that may not be apparent in the SW Atlantic and SE Atlantic (South African) datasets.

<u>Application to South African data</u>

Previous results reported here (and in Brandão et al. 2021) were based an application of an earlier draft of the common model which did not include the "unsuccessful mother" component. This model was an extension of the model of Brandão et al. (2019) to include the parameter, δ, to allow for a four-year calving cycle resulting from early abortions, so as to be able to account for recent increases in calving intervals indicated by the data. The results obtained previously indicated that inclusion of the "delta-loop" alone was not sufficient to eliminate the possibility of unrealistically low sighting probability estimates for some recent surveys. This necessitated the inclusion of a penalty term in the model fitting procedure to obtain results more consistent with the annual survey effort which has been quite stable over time. However, a coding error was recently discovered, and the corrected results now show that the "delta-loop" is able to account for nearly all of the very low number of sightings of cow-calf pairs (see Figure 2). The correction to the code has changed the estimates for other parameters only slightly.

Further work is ongoing to assist in drawing inferences about which environmental conditions may link to the delays in whale calving for this population of southern right whales (SC/68A/SH/12).

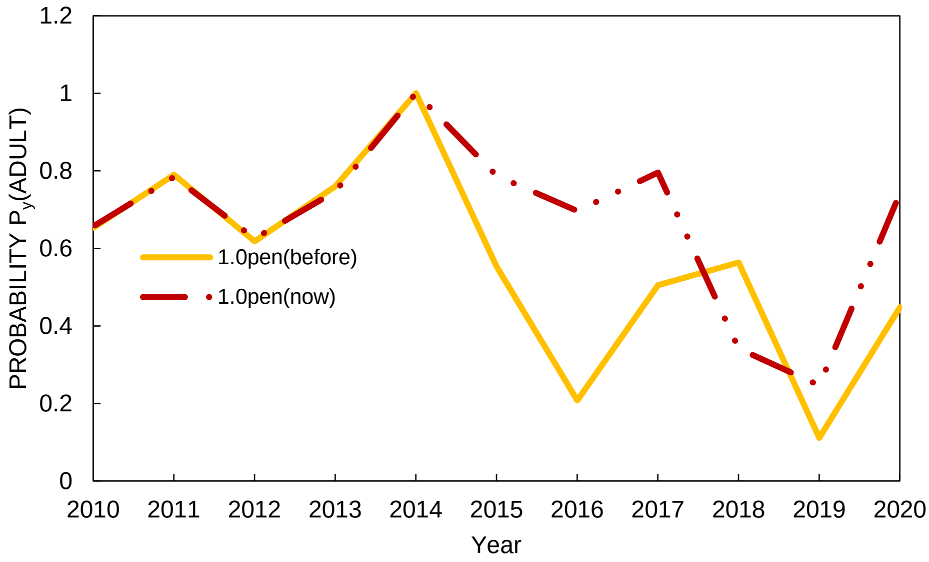



**Figure 2** Estimated probabilities of observing a cow-calf pair on South African aerial surveys for recent years under the draft common model before and after the coding correction.

<u>Application to the Argentina/Brazil data</u>

The collection of Photo-ID for this region was summarised in the previous report.

*<u>Demographic Model</u>*

The biological model for reproductive females, which is close to the current proposed common model, except that $\gamma$ is set to zero, is embedded into the demographic model for the entire population based on that developed by Cooke et al. (2015). This model is designed to be fit to the entire data set including whales without calves. However, for comparison with earlier implementations of the model for Argentina (e.g., SC/55/O23) and with the implementation used for South Africa (see above), the model will also be fit to cow-calf data only.
A further feature of the SW Atlantic data sets is a high degree of heterogeneity, and the exploratory fits found that large number of nuisance parameters were required to account for different sighting probabilities between the whales in various states and between individuals, where the relative probabilities also seem to vary over time. These additional parameters are required to fit the data, but do not require changes to the common biological model.

*<u>Exploratory model fitting</u>*

Some progress has been made in fitting the model to the SW Atlantic data, but as a result of unforeseen circumstances, updated results are not yet available.

<u>Application to the Australian data</u>

The Australian data have been made available to analysts, and have been pre-processed for input to the common model. Once the model coding has been completed and the model has been fit to the South African data, it will be fit to these Australian data. The Australian dataset is somewhat smaller than the South African dataset, so difficulties in estimating certain parameters may be experienced, but the extent of this will only be known once the fitting process commences.

*Objective 3: Obtain comparable estimates of the key parameters of the demographic model and of population growth rates for the populations from each of the major wintering grounds*

This will be addressed after the final development of the common model.

*Objective 4: Identification of foraging grounds to inform selection of environmental correlates*

A desktop study was conducted by Cuyler van Jaarsveld in the scope of his BSc Hons project at the University of Pretoria, under supervision of Drs Vermeulen and Carroll. The aim was to collate all published and unpublished data, grey literature, and other readily available information on the global occurrence SRWs, offshore and south of 40°S into a comprehensive review over the period 1980-2020. The goal is to use these data to advance understanding on the location of offshore SRW foraging grounds, likely leading to the ability to select environmental variables which may be relevant for the future investigation of links to reproductive success, pertinent to objective 2 and 4 of the IWC-SORP Theme 6.

Sighting data points were gathered from various sources including published and unpublished data and other readily available sources. Data from published literature and other databases were collected by searching for relevant journal articles, maps, books and encyclopaedias via Google Scholar as well as recognized databases including Encyclopaedia Britannica, JSTOR, PANGEA, South Georgia Heritage Trust (SGHT) and Scopus. Data from unpublished data and other available sources were collected by searching through Google Scholar and most importantly by obtaining a letter endorsed by SORP (Appendix 1) which allowed for the sending of data requests to various organisations and research vessels including the SC-IWC, Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), Polarstern (research icebreaker from Alfred Wegener Institute for Polar and Marine Research), Brazilian Antarctic Program (PROANTAR), Southern Ocean Whale and Ecosystem Research Program (SOWER), Happywhale, Marine Mammals Research and Conservation Discussion (MARMAM), and Observation International (ObsInt). Furthermore, a data request was also posted on the IWC-SORP website to increase exposure for the study with the purpose of maximizing data collection.

A total of 357 sightings data points were collected from 13 separate sources, with the majority of the sightings data, 91.3%, collected from organisations and databases (n=326), while 8.7% was collected from published literature (n=31). The largest collections of data came from the South Georgia Heritage Trust database (n=109) comprising 30.5% of all data, and SOWER (n=95) contributing 26.6% of all data. Sightings data from CCAMLR (n=50) made up 14% of the data collected, with Happywhale data (n=32) comprising 9%. PROANTAR data (n=10) comprised 2.8%, while data from PANGEA (n=5) and Nijs and Rowntree (2017) (n=6) made up 1.4% and 1.7%, respectively. Furthermore, both ObsInt data (n=13) and data from IWC reports (n=13), comprised 3.6%, while data contributed by Moore et al. (1997) (n=11) and data provided by Dr. Marc Eléaume from the National Museum of Natural History in France (n=11), made up 3%. Polarstern data (n=1) and data from Moore et al. (1999) (n=1) both contributed 0.3%.

Progress was also made towards improving understanding of foraging grounds through satellite tagging, stable isotopes and historical catch data, which are outlined further in the IWC-SORP Theme 6 report (SC/68d/SH07).

**Conclusions**

Objectives 1 and 4 were finalised, and substantial progress was made towards fulfilling objective 2.

- A Southern Right Whale Consortium was established, and the related MoU has already signed by 11 researchers.
- A common demographic model has been agreed upon and the coding is almost complete. Application of this model to the South African data will commence shortly, followed by the other available data sets (SW Atlantic and Australia). Exploratory fits will be required to determine which parameters can be reliably estimated for each data set. If it is found that not all parameters are separately estimable for all data sets, then discussion will be required to determine suitable values or priors for the remaining parameters.

- A desktop review was completed to assess SRW offshore sightings South of 40°S, ultimately to inform the selection of environmental variables for further investigation of links between demographic parameters (i.e., reproductive success) and climate.

The collaborators of this IWC-SORP funded project would like to acknowledge the contribution of the long-term photo-ID sightings datasets and the considerable far-sighted efforts of key researchers from each region. In particular, Peter Best and John Bannister are acknowledged for establishing the South African and Australian programs and the long time series of data from these regions are critical for the investigation of the important issues which this project plans to address.

**Challenges**

Given the complexity and intricacies of the common model, the implementation of the changes to the code to incorporate the new aspects of the common model have not been straightforward. Further challenges are envisioned with the application of the common model to the various datasets. Each dataset has characteristics that are particular to that population, and therefore, as mentioned before, exploratory fits will be required to determine which parameters can be estimated reliably for each and some iterative process will probably be necessary before final results can be obtained. From previous experience in fitting models with fewer estimable parameters that took several hours to run, this exercise will likely prove very time-consuming.

**Outlook for the future**

The project workplan outlines that the next steps to fulfil project objectives (1-4) include:

- Continue collaborative efforts under the SRWC to develop data quality control standards and identify analytical biases
- Complete the coding of the common model and apply to the various data sets available;
- Determine which parameters are estimable for which data set and determine suitable values for priors for the remaining parameters.
- Compare demographic parameters across the different SRW wintering grounds
- Investigate suitable environmental variables for further assess the links between demographic parameters (i.e., reproductive success) and climate.

Resources are available and work scheduled to hopefully deliver outputs by October 2022 as specified in IWC-SORP contracts.

**Project outputs**

*IWC/SC papers*

Carroll E, Vermeulen E, Charlton C, Jackson J, Clarke P (2020) Roadmap to success for the International Whaling Commission - Southern Ocean Research Partnership (IWC-SORP) Theme 6 - the Right Sentinel for Climate Change: linking southern right whale foraging ecology to demographics, health and climate. IWC paper SC/68b/SH07.

Charlton C, Vermeulen E, Carroll EL, Butterworth D, Justin C, Ross-Gillespie A, Brandao A, Groch K, Leaper R, Rayment W, Rowntree V, Sironi M, Van den Berg G, Watson M, Double M, Jackson J (2020) Progress Report on the intersessional working group "Multi-ocean assessment of southern right whale demographic parameters and links to environmental correlates". IWC/SC paper SC/68b/SH15.

Butterworth D, Justin C, Charlton C, Vermeulen E, Ross-Gillespie A, Brandao A, Groch K, Leaper R, Rayment W, Rowntree V, Sironi M, Agrelo M, Watson M, Carroll EL, Carlyon K, Burnell S, Double M, Jackson J (2022) Intersessional working group report: Multi-ocean assessment of southern right whale demographic parameters and environmental correlates. IWC/SC paper SC/68d/SH06.

Vermeulen E, Van den Berg G, Wilkinson C (2020) Report of the 2019 South African southern right whale aerial surveys. IWC papers SC/68b/SH02. http://doi.org/10.13140/RG.2.2.29556.37766

Vermeulen E, Van den Berg G, Paarman S, Wilkinson C (2021) Report of the 2020 South African southern right whale aerial surveys. IWC/SC paper SC/68c/SH04.

Vermeulen E, Wilkinson C, Germishuizen M (2022) Report of the 2021 South African southern right whale aerial surveys. IWC/SC paper SC/68d/SH02.

*Presentations*

Presentation at WMMC Southern right whale workshop (SC/68b/SH/07)

**Scientific references cited in report**

Brandão A, Vermeulen E, Ross-Gillespie A, Findlay K, Butterworth DS (2018) Updated application of a photo-identification based assessment model to southern right whales in South African waters, focusing on interferences to be drawn from a series of appreciably lower counts of calving females over 2015 to 2017. International Whaling Commission document SC/67B/SH/22. pp. 19

Brandão A, Vermeulen E, Butterworth DS (2019) Updated application of a photo-identification based assessment model to southern right whales in South African waters to include data up to 2018. Report presented to the 68Ath IWC scientific committee (Southern Hemisphere Subcommittee), Nairobi, Kenya. SC/68A/SH/14.

Cooke JG, Rowntree V, Sironi M (2015) Southwest Atlantic right whales: interim updated population assessment from photo-ID collected at Península Valdéz, Argentina. Paper SC/66a/BRG/23 presented to the IWC Scientific Committee.

Moore M J et al. (1999) Relative abundance of large whales around South Georgia (1979-1998). Marine Mammal Science 15(4): 1287–1302. doi: 10.1111/j.1748-7692.1999.tb00891.x

Nijs G, Rowntree VJ (2017) Rare sightings of southern right whales (*Eubalaena australis*) on a feeding ground off the South Sandwich Islands, including a known individual from Península Valdés, Argentina. Marine Mammal Science 33(1): 342–349. doi: 10.1111/mms.12354

**INTERSESSIONAL FUNDING 2021 (Shabangu et al.). Passive acoustic monitoring of marine mammals around Marion Island, southern Indian Ocean**

*Fannie Shabangu*[1]

*1. Department of Forestry, Fisheries and the Environment/University of Pretoria, South Africa*

## Executive summary

The year-round acoustic occurrence and behaviour of marine mammals around Marion Island are currently unknown, mainly because of lack of research effort in this region. Marine mammals that occur around this Subantarctic Island include seals, dolphins, beaked whales, toothed whales and baleen whales. Currently available information about the occurrence and behaviour of marine mammals in that region are based on short, seasonal sighting research from shore or research vessels, which is insufficient at providing accurate and comprehensive picture of these animals' ecology. This study aimed to collect year-round passive acoustic data around Marion Island to establish the long-term acoustic occurrence and behaviour of marine mammals. An acoustic recorder was deployed on an oceanographic mooring as a cost-effective method of collecting passive acoustic data. Seasonal occurrence and behaviour of different marine mammal species will be determined acoustically, and the acoustic results will be used to determine the use and importance of this habitat to these marine mammals. This study is the first long-term passive acoustic monitoring study to be conducted off this island, and results will be important at informing us of the long-term use of this ecoregion by different marine mammals and assessing the current status of these marine mammals' populations- some of which were reduced to low population levels by historic whaling in the Southern Hemisphere.

## Objectives

1) Establish the occurrence and proportion of marine mammal species occurrence over different seasons of the year to determine if animals use this region year-round or seasonally for breeding, feeding, migration and/or overwintering to help understand their acoustic ecology.
2) Determine whether the behaviour of marine mammals vary between different seasons of the year and time of day, which might provide an indication of the number of animals in the region over time.
3) Determine which environmental variables influence the seasonal occurrence and behaviour of marine mammals using a suite of environmental variables (e.g. satellite-derived sea surface temperature, sea surface height and upwelling indices).
4) Describe the acoustic repertoire of other marine mammals that occur in this region, which will be very useful for future studies in this area given that there is no acoustic research currently taking place there.
5) Comparison of seasonal occurrence and behaviour of marine mammals at Marion Island to other Southern Hemisphere regions.

## Results and conclusions

The SoundTrap hydrophone was successfully deployed on 24 April 2021 at 46° 46.4'S, 37° 54.7' E in Marion Island, and will be retrieve and redeployed next month (April 2022) at the same location. This hydrophone was duty cycled to record the first 14 minutes of every hour of the day at a sampling rate of 96 kHz. Data of this project will be retrieved in April/May 2022, and results will be available two or so months thereafter.

## Outlook for the future

The SoundTrap hydrophone will be retrieved next month (April 2022) and redeployed for another year (until April 2023). It is hoped that the project will continue for the next 3-5 years or for as long as oceanographic moorings are deployed in Marion Island. Resources required includes batteries to replace depleted ones and SD cards to replace to full ones. Hard drive storage of acoustic data will be needed in the future.