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Sub-committees/working group name:

IWC-SORP Research Fund: 2023 progress reports from funded projects

Elanor M. Bell (Compiler)

IWC-SORP Research Fund: 2023 progress reports from funded projects

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IWC-SORP Research Fund: 2023 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. In addition, discretionary funding totalling £5078.46 GBP has been awarded to two projects. This paper summarises the progress of 12 projects that have received grant or discretionary funding and were ongoing in 2022-23.

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. Our 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 theme 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' theme; 4) A theme that investigates 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' theme; 6) 'The right sentinel for climate change: linking foraging ground variability to population recovery in the southern right whale' theme ; and 7) the 'Recovery status and ecology of Southern Hemisphere fin whales' theme. Further details of all the IWC-SORP themes can be found in the IWC-SORP Annual Report, SC/69a/SH04, and at https://iwc.int/sorp.

IWC-SORP CALLS FOR PROPOSALS

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, made it possible for three Calls for Proposals to be made in 2016/17, 2018/19 and 2019/20. These contributions are gratefully acknowledged.

Further contributions have been made by the Government of Belgium and, artist, Emma Abel; these will allow a fourth Call for Proposals to be announced in the near future.

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.

Discretionary funding

The IWC-SORP Scientific Steering Committee (SSC) is able to allocate discretionary funding of up to £15,000 GBP per budget period in order to ensure the smooth running of approved programmes (IWC/66/Rep01, 2016, Annex W).

In 2021, £1328.46 GBP were allocated intersessionally by the 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 was be deployed off Marion Island and Prince Edward Islands in June 2021, and is contributing data to both the IWC-SORP Acoustic Trends and Killer Whale Themes.

In 2023, £3750 GBP were allocated intersessionally by the IWC-SORP SSC to Dr Helena Herr leader of the *Recovery status and ecology of Southern Hemisphere fin whales theme*, to support the the participation of an expert tagger and facilitate the deployment of up to 19 transdermal SPOT tags on fin whales during the 2023 FINWAP research expedition (MSM115) aboard the RV *Maria S. Merian*.

Status of the IWC-SORP Research Fund

In 2022, a voluntary contribution of ca. £39,500 GBP (€45,000) was made by the Belgian Government. In 2023, a donation of £140 GBP was made by artist, Emma Abel. A financial report of the IWC-SORP Research Fund is detailed in the IWC Research Fund Financial Report (SC/69a/O03). Approximately, **£96,906 GBP** remain unassigned and unspent. This figure includes interest and bank fees.

IWC-SORP sincerely thanks the Governments of Australia, Belgium, France, the Netherlands, WWF-Australia, the International Fund Animal Welfare and Emma Abel 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) for 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	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**	Completed. 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**	Completed. Final report received SC68b
13	Branch, Trevor		Modelling somatic growth and sex ratios to predict population-level impacts of whaling on Antarctic blue whales	**32,594**	Completed final report received SC68d
14	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**	Completed. Final report received SC68d
15 pp. 10-15	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 SC69a
16 pp. 16-22	Constantine, Rochelle; Friedlaender, Ari	Alex Zerbini, Ben Weinstein, Ryan Reisinger	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**	Completed. Final report received SC69a
17	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**	Completed. Final report received SC68d
18 pp. 23-24	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**	Completed. Final report received SC69a
19	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**	Completed. Final report

					received SC68d
20	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**	Completed. Final report received SC68d
21 pp. 25-32	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 SC69a
22 pp. 33-39	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 SC69a
23 pp. 40-41	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 SC69a
24 pp. 42-46	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**	Completed Final report received SC69a
25 pp. 47-56	Iñíguez Bessega, Miguel	Simone Baumann-Pickering Marta Hevia John Hildebrand Alexander Marino Mariana Melcón Maria Vanesa Reyes Reyes Ana Širović 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**	Completed. Final report received SC69a
			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. 57-60	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. 61-63	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. 64-72	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**	Completed. Final report received SC69a
29	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**	Completed. Final report received SC68d
30 pp. 73-77	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 SC69a
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**	Completed. Final report received SC68c
			TOTAL	**129,955**	

Table 4: List of the projects that received intersessional discretionary funding from the IWC-SORP Research Fund. 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**
pp. 78-85	Shabangu, Fannie	Kathleen M. Stafford, Trevor Branch, Els Vermeulen, Marcel van den Berg, Tarron Lamont, Tessa Munoz, Lora van Uffelen	Passive acoustic monitoring of marine mammals around Marion Island and Prince Edward Islands, southern Indian Ocean	**1328.46**	Ongoing Interim report received SC69a
	Herr, Helena		Research Cruise MSM115 'FINWAP' of RV Maria S.Merian - SR6701 Herr Recovery Status & Ecology SH Fin	**3,750**	Commenced March 2023 Report due SC69b
			TOTAL	**5078.46**	

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 either the reader is guided toward separate, more detailed, primary papers submitted to the IWC Scientific Committee for consideration.

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 fourth year of the project, the joint analysis of compiled fin whale data sets was finalised and published in *Frontiers in Marine Science*. Furthermore, the results of tagging efforts from the previous year, providing first insights into migratory movements of fin whales feeding at the Antarctic Peninsula, were published in *Marine Mammal Science*. Preparations for voyage MSM115 FINWAP, a dedicated fin whale research voyage in March 2023, dominated the remainder of the project year. Remaining project funds, plus £3,750 GBP awarded intersessionally, were dedicated to research voyage MSM115. At the time of writing, the voyage was still underway but 11 tags had been deployed on fin whales off Elephant Island; 20 biopsy and 4 faecal samples collected; visual surveys conducted; acoustic recordings collected and drone flights made; and 51 krill stations (net trawls) sampled.

Introduction

During the commercial whaling period, Southern Hemisphere fin whales (SHFW) were the most numerously exploited whale species in the Southern Ocean and were reduced to approximately 2% of their pre-whaling population size (Clapham & 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 cessation 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 in waters off the Western Antarctic Peninsula (WAP) suggest a return of fin whales to this area and provide an indication of population recovery (Herr, Viquerat, et al., 2022). 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 better understand distribution, abundance and seasonal movements. Furthermore, we aim to collect genetic samples from the fin whales feeding at the Antarctic Peninsula to gain insights on population structure; and using satellite tag deployment we want to track their movements at and after leaving the feeding area.

Objectives

The specific objectives of the project are:

1. 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.
2. Dedicated abundance estimation of fin whales in the WAP and Scotia Sea.
3. 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.
4. 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).
5. Collection of photo-ID to provide the foundation for a SHFW photo-ID catalogue.
6. Analyses of short-term and long-term movement patterns to assess habitat use, to describe migratory patterns and to deduce migratory destinations.
7. Creation of a collaborative network of fin whale researchers for future projects and continued efforts to investigate the recovery status of SHFWs.

Results (Status as of 22 March 2023)

1. Work towards objective 1) was reported during previous years and has now been completed and published in Viquerat et al. (2022). Fin whale sighting records from the Antarctic Peninsula and Scotia Sea from multiple sources and across 40 years were compiled and used in a novel approach combining ensemble learning and a maximum entropy model, to estimate abundance and distribution of fin whales in this region. The results show a seasonal distribution pattern with pronounced centres of distribution from January to March along the shelf edge of the West Antarctic Peninsula.

2. Abundance of fin whales along the Antarctic Peninsula was estimated based on an aerial survey in 2018 and published in Herr, Viquerat, et al. (2022). However, this abundance estimate has yet to be reviewed by the Abundance Steering Group (ASG).

3. Data for Objective 3 is being collected during the ongoing voyage, MSM115 FINWAP, where a dedicated krill survey is being conducted concurrent with a sighting survey.

4. Biopsy samples for work towards Objective 4 are being collected during the ongoing voyage MSM115 FINWAP.

5. Photo-ID data for work towards Objective 5 are being collected during the ongoing voyage MSM115 FINWAP.

6. Movement patterns of fin whales at the feeding grounds off Elephant Island have been analysed based on four satellite transmitters deployed in 2021. This work was reported last year (SC/68d/SH07) and has now been published in Herr, Hickmott, et al. (2022). Since the transmissions of tags ended a maximum of 30 days after deployment, long-term transdermal tags are to be deployed during research voyage MSM115 FINWAP. IWC-SORP discretionary funding of £3,750 GBP was obtained in 2023 to assist with securing tagging expertise.

7. The collaborative network of fin whale researchers has been successfully established.

Research voyages/expeditions

At the time of writing, research voyage MSM115 FINWAP (25 February – 30 March 2023) was underway. The voyage is covering the northern shelf edge area along the western Antarctic Peninsula, from the South Shetland Islands to the South Orkney Islands, 60-63°S, spanning a longitudinal range from 44° to 65°W (Figure 1). A sighting survey will be conducted along a set of track lines zig-zagging over the shelf-edge (Figure 1), the area where most fin whales are expected based on previous results (Herr, Viquerat, et al., 2022; Viquerat et al., 2022). A CCAMLR-standardised krill net trawl survey will be conducted along the same transects, for later comparison of whale and krill distribution. The surveys will be interrupted for small boat work when fin whale groups are encountered, in order to collect biopsy samples, photo-ID data and to deploy satellite transmitters.

By 22 March 2023, eleven tags had been deployed on fin whales off Elephant Island: six Standard Mk10; one Fast-Loc Mk10; two SPOT tags and two Stingray Camera Tags. Furthermore, 20 fin whale biopsy samples and 4 faecal samples had been collected. Visual surveys had been successfully conducted, acoustic recordings made and drone flights carried out. In addition, 51 krill stations (net trawls) had been sampled. Detailed analyses of these data will be presented next year.

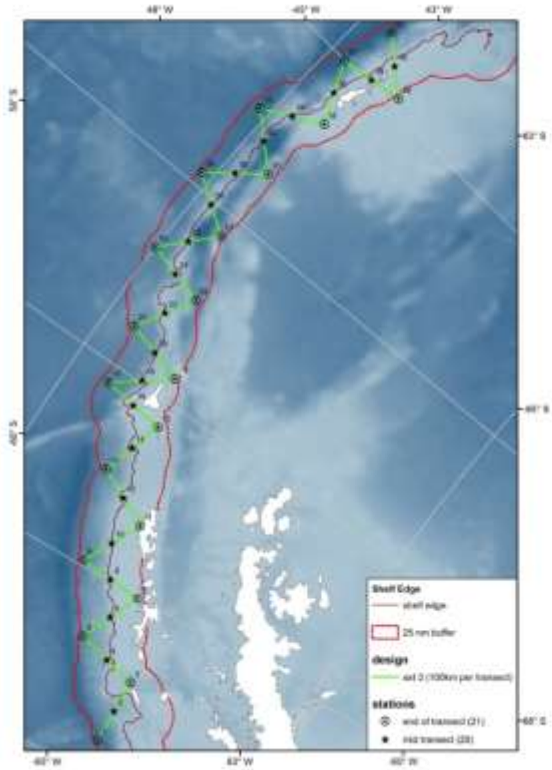

Figure 1 Cruise track and survey design for research cruise MSM115 FINWAP.

Conclusions

This project is composed of two major parts, 1) the compilation and analysis of existing data, and 2) collection and analyses of new data. Part 1 of this project has already been successfully achieved and completed. Data collection for Part 2 is still ongoing. A major contribution of data is expected from research voyage MSM115, with data becoming available for analyses in April 2023, soon after the return of the voyage.

Challenges

Weather conditions during research voyage MSM115 pose the main challenge for this project since how many tags will be deployed, how many biopsy samples may be taken and how good the coverage of the visual survey will be, will depend on conditions in the field.

Outlook for the future

Once data from research voyage MSM115 FINWAP becomes available, the project will be able to work on all remaining objectives and, hopefully, achieve the anticipated results within the expected time frame.

Project outputs

Students and theses

One student conducted an analysis of video imagery collected within the framework of this project for a semester project. The results of this work have been compiled in a report (Rychwalski 2023) and are currently being prepared for submission as a manuscript to a scientific journal: **Alexander N. Rychwalski**. Laterality analysis of southern fin whales (*Balaenoptera physalus quoyi*) during surface lunge feeding aggregations in the Antarctic. Semester project report, University of Hamburg, Germany, 2023.

Peer-reviewed papers – 5 new since 2022

Bamford C, Kelly N, Herr H, Seyboth E, Jackson JA (2023) The recovery of Antarctica's giants – baleen whales. Antarctic Environments Portal. https://doi.org/10.48361/edgj-pp83

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, Hickmott L, Viquerat V, Panigada S (2022) First evidence for fin whale migration into the Pacific from Antarctic feeding grounds at Elephant Island. Royal Society Open Science 9(9): 22072. https://doi.org/10.1098/rsos.220721

Herr H, Viquerat V, Lees A, Wells L, Devas F, Gregory B, Meyer B (2022) Return of Large fin whale feeding aggregations to historical whaling grounds in the Southern Ocean. Scientific Reports 12(1), 9458. https://doi.org/10.1038/s41598-022-13798-7

Herr H, Viquerat S, Naujocks T, Gregory B, Lees A, Devas F (2023) Skin condition of fin whales at Antarctic feeding grounds reveals little evidence for anthropogenic impact and high prevalence of cookiecutter shark bite lesions. Marine Mammal Science 39(1): 299-310. https://doi.org/10.1111/mms.12966

Viquerat, S, Waluda CM, Kennedy A, Kelly N, Jackson J, Hevia M, Carroll E, Buss D, Thain S, Smith P, Secchi E, Santora J, Reiss C, Lindstrøm U, Krafft B, Gittens G, Dalla Rosa L, Biuw M, Herr, H (2022) 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. Frontiers in Marine Science. https://doi.org/10.3389/fmars.2022.1040512

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

Rychwalski AN (2023) Laterality analysis of southern fin whales (Balaenoptera physalus quoyi) during surface lunge feeding aggregations in the Antarctic. Semester project report, University of Hamburg, Germany.

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.

Herr H (2022) Invited talk: Return of the fin whales. Evidence for population recovery 35 years after the end of

commercial whaling in the Southern Ocean. 28th International Polar Conference, 1-5 May, Potsdam, Germany.

Media interest

The paper 'Return of large fin whale feeding aggregations to historical whaling grounds in the Southern Ocean' received considerable media attention. Upon publication, Herr gave 21 interviews with the following news outlets, which all produced articles or news features:

- The New York Times (USA)
- The Wall Street Journal (USA)
- The Times (UK)
- Agence France Press (AFP) (France)
- Les Temps (Switzerland)
- The New Scientist (USA)
- Inside Climate News (USA)
- The World (US Radio News)
- iTV (UK)
- ZDFheute (Germany)
- BR Nachrichten (Germany)
- BR Wissen (Germany)
- WDR Quarks (Germany)
- Deutschlandfunk (Germany)
- Publico (Portugal)
- Japanese Daily News (Japan)
- NewsOmatic (USA)
- Republik.ch (Switzerland)
- Worlds Best News DK (Denmark)
- 2050 (Germany)
- Current Affairs Times (USA)

In addition, the study was also featured in e.g., Die Zeit, Der Spiegel, The Guardian, NBC News, N-TV, National Geographic, Bangkok Post, ElPeriodico, Newsweek, Brisbane Times, Der Tagesspiegel, JapanToday, Geo, Hamburger Abendblatt, Bildzeitung, etc.

As of 11 March 2023, altimetric (https://nature.altmetric.com/details/130806825) counts 182 stories appeared in 137 different news outlets (yet not counting most of the non-English language features)

The paper 'Return of large fin whale feeding aggregations to historical whaling grounds in the Southern Ocean' was featured as a Research Highlight in NATURE: https://www.nature.com/articles/d41586-022-01910-w

Other

Herr was guest in a German radio talk show speaking about fin whales. WDR Quarks – Wissenschaft und mehr, 12.10.2022, Germany

Herr was guest in a live talk show and talked about fin whales. 'Wahnsinn trifft Methode', 31.10.2022, Ernst Deutsch Theater, Hamburg, Germany

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PROJECT 16 (Constantine, Friedlaender, Reisinger 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

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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 understanding regional variation in the habitat selection of humpback whales. Using a large, circumpolar dataset of humpback whale tracking data, we found subtle but significant variation in the habitat use of humpback whales among regions. 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

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, totalling 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.

Hierarchical Generalised Additive Models (Reisinger et al. in revision) revealed significant regional variation in the movement behaviour of whales in response to 12 environmental variables. Multivariate analyses showed small but significant environmental differences in the environments encountered by the whales and, using a novel cross-prediction approach, we show that behavioural similarity among whales in different regions is related to environmental similarity, but does not correspond completely with geographic patterns. The behavioural and environmental distinctness of some populations accords with genetic differentiation. The heterogeneous distribution of humpback whales' prey, Antarctic krill, likely influences habitat-use variation. Regional variation in environmental change could result in different post-whaling recovery among humpback whale populations and region-specific impacts of future climate change. More broadly, we show the importance of considering regional-variation in large-scale studies of animal habitat-use and of using analytical approaches that can incorporate such variation, specifically considering both environmental availability and behavioural variation.

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) 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) 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

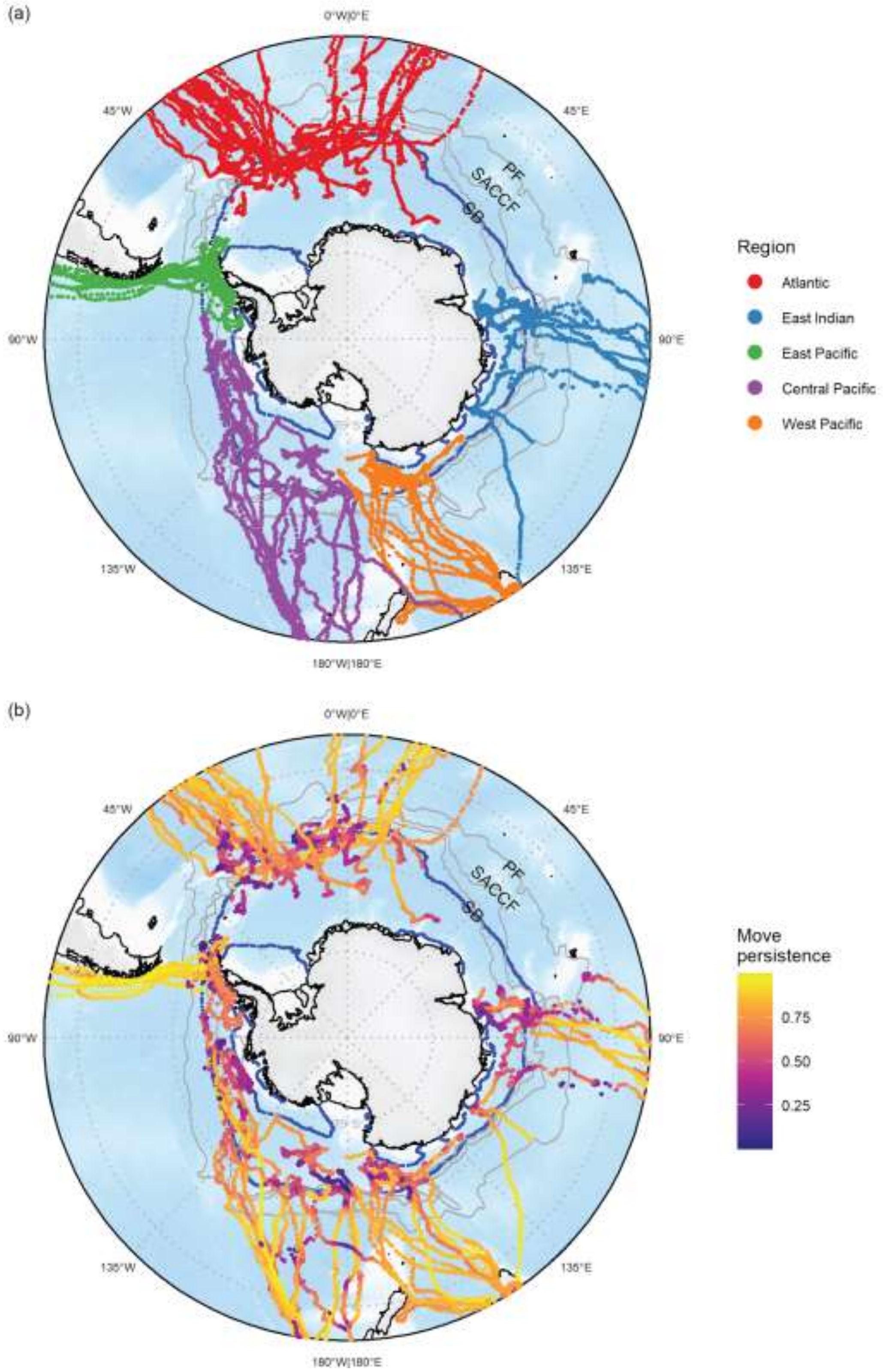

Figure 1 Humpback whale tracks (n = 162) in the Southern Ocean. A) Shows how we assigned tracks to five regions. B) Shows estimated move persistence along the tracks. Blue lines indicate the monthly median sea ice edge (1981-2010) in February (minimum extent) and September (maximum extent) (Fetterer et al. 2017). Grey lines indicate oceanographic fronts associated with the Antarctic Circumpolar Current; from north to south: Antarctic Polar Front (PF), southern Antarctic Circumpolar Current front (SACCF), southern boundary of the Antarctic Circumpolar Current (SB) (Park et al. 2019).

Conclusions

We demonstrate subtle but significant regional variation in humpback whales' use of available environments. This, coupled with regional variation in environmental change could result in different post-whaling recovery among humpback whale populations and region-specific impacts of future climate change. More broadly, we show the importance of considering regional-variation in large-scale studies of animal habitat-use and of using analytical approaches that can incorporate such variation, specifically considering both environmental availability and behavioural variation.

Challenges

Reisinger's transition to a full-time lectureship at the University of Southampton after completing his IWC-SORP-funded contract at University of California Santa Cruz has meant he is able to dedicate much less time to revisions of the project's second manuscript.

Outlook for the future

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

Students and theses

University of Southampton, under supervision of Reisinger:

2022-2023 academic year:
- **Amanda Madrigano Furlani** (third year independent project)

2023-2024 academic year:
- **Joseph Simons** (MSci independent project)
- **Freya Burleigh** (MSci independent project)

Peer-reviewed papers

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.

Popular articles

Reisinger RR, Friedlaender AS, Palacios DM (2022) Whale migrations: how new UN treaty aims to protect species on the high seas. The Conversation. https://theconversation.com/whale-migrations-how-new-un-treaty-aims-to-protect-species-on-the-high-seas-178805

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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

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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 high-throughput sequencing to generate 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 between 1990 and 2013 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

Sample selection - We selected 48 plates from each species for use in this project. Plate selection was based on providing relatively even geographic coverage of the area in which the catches were made, including similar numbers of plates from each of the two whaling seasons (1946-47 and 1947-48), and including similar numbers of whales of each sex. Each baleen plate was subsampled, with one subsample remaining at NMNH and the other shipped to SWFSC.

Library prep and sequencing – In the SWFSC lab, DNA extraction followed the protocol outlined in Höss and Pääbo (1993), with modifications as described in Hofreiter et al. (2004) and employed in Morin et al. (2006). Mitogenomic libraries for high-throughput sequencing (HTS) were prepared using a modified version of the capture array method detailed in Hancock-Hanser et al. (2013). Once hybridization was complete, an Agilent Bioanalyzer was used to assess the size and quality of DNA present in the post-hybridization product. The run did not identify any product in the appropriate size range (150-300bps), suggesting the hybridization step may have been unsuccessful. A second hybridization capture round was then conducted; this has been shown to improve the enrichment rate (e.g., Templeton et al., 2013). However, a second Bioanalyzer run again did not identify any product in the appropriate size range. Subsequent to this, a set of eight samples (four of each species) were shotgun sequenced to determine what was present in the post-hybridization library. Sequencing was performed on a MiSeq system using a MiSeq Reagent Nano Kit v2 (Illumina, Inc.).

In the NMNH laboratory, DNA was extracted using a standard phenol-chloroform extraction method. DNA libraries were prepared using the NEBNext Ultra II DNA Library Prep kit for Illumina (NEB) according to the manufacturer's protocol. An in-solution hybridization capture method using a custom myBaits CustomDNA-Seq Kit (Arbor Biosciences) previously designed based on the humpback whale mitogenome was used to enrich for the mitogenome. Enrichments were carried out using the standard protocol in myBaits_v5.02_Manual (Arbor Biosciences). Enriched and indexed libraries were quantified and pooled to equimolar concentrations and were then paired-end sequenced using two lanes of Illumina HiSeq 4000. Following sequencing, the reads were demultiplexed and trimmed before mapping them to the appropriate mitochondrial genome (blue or fin) in Geneious Prime using default parameters. Geneious Prime was also used to construct consensus sequences for each sample.

Results

Using the NMNH protocol, full mitogenome sequences were recovered from 44 of the 48 blue whale and 39 of the 48 fin whale samples, most of which had >20,000x coverage. One of the blue whale sequences had a single 'N', while one of the fin whale sequences had four ambiguous bases. There were no ambiguous sites in the remaining samples.

The mitogenome sequences that will be used to represent the contemporary strata were generated as part of previously published or ongoing projects to evaluate the subspecies taxonomy of blue and fin whales. For blue whales, this data set includes mitogenome sequences generated from samples collected from blue whales in Antarctic waters between 1990 and 2013 (n=68). For fin whales, the contemporary strata will be comprised of the mitogenome sequences analysed in Archer et al. (2013), which included 32 fin whales sampled in the Southern Ocean between 2003 and 2008. Analyses of these sequences is underway.

Challenges

We were unable to make progress on this project between February 2020 and February 2022 due to COVID-19-related laboratory closures.

Outlook for the future

We anticipate presenting a draft manuscript(s) summarising the results at SC/69b (2024).

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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

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Executive summary

In the past year, further 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 Wildlife Image Survey—Detection and Mapping (WISDAM) software 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 years' work. MAD is currently being tested using naïve labelled images and is integrated with the WISDAM 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.

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 algorithm). 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

Wildlife Image Survey—Detection and Mapping (WISDAM) software is a toolbox that allows users to analyse images collected from aerial platforms (Figure 1). (This application was previously known as the Dugong Detector, but was renamed given it now handles a number of other large marine taxa and has a broader range of capabilities and applications.) WISDAM software has been developed using in-kind support via Google.org and the Australian Marine Mammal Centre at the Australian Antarctic Division.

The current version of the software allows the user to conduct a range of image processing tasks where the identification of sightings in the images is done manually, but now also encompasses an AI detector. Specifically, the software is a fully integrated user interface that provides the following functions:

- Georeference and map imported aerial images (according to the specific make and model of the drone and format of the imagery and telemetry data)
- Manually label animal sightings and record associated data (Figure 2)
    - Labelled sightings are projected to overlapping images
    - 'Walk through' feature allows standardised magnified viewing of large images
- Manually assess environmental conditions in the images (Figure 2)
    - Scores/categories are propagated to successive images until changed
- Automatically detect and verify animal sightings using our latest AI detector which is now trained to find cetaceans, dolphins, dugongs and turtles (now dubbed the Marine Animal Detector, or MAD)
    - Sightings are then manually verified within the GUI
- Automatically detect individual animals that have appeared in multiple images based on location within images and label them to avoid counting the same animal multiple times (Figure 3)
- Compare sightings from (matching sightings are automatically detected and manually verified):
    - multiple reviewers (i.e., to assess perception bias via double-observer mark-recapture methods), or
    - manual and automated detections.
- View images and sightings spatially
- View and filter a grid of thumbnails of sightings
- Export all data in multiple GIS formats (e.g., as shapefiles, etc)

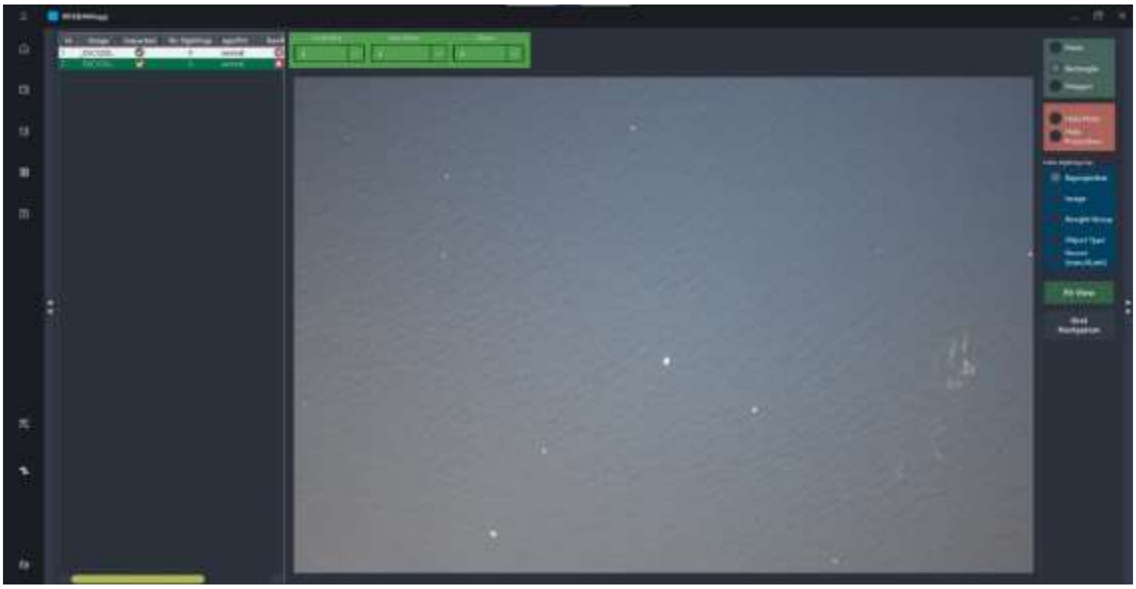

Figure 1 *WISDAM* GIU, displaying aerial image of Antarctic minke whales, where you can see the aerial image in full, including several cetaceans.

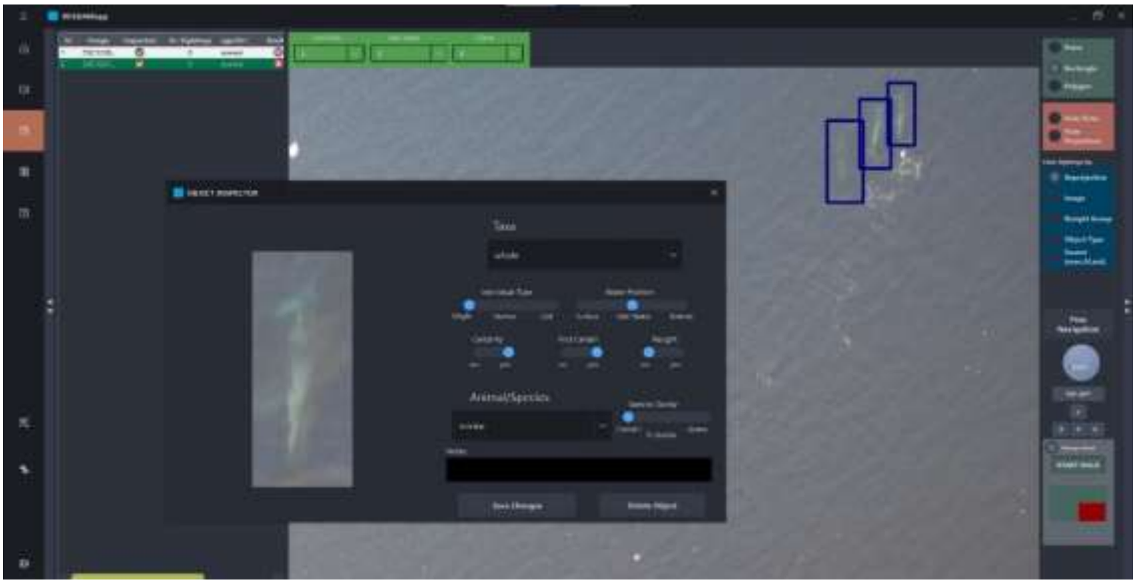

Figure 2 Labelling of the animal detections in *WISDAM*, which includes applying a bounding polygon around the animal, and tagging that polygon object with a range of information, including species, position relative to the water surface, certainty and environmental covariates related to sightability.

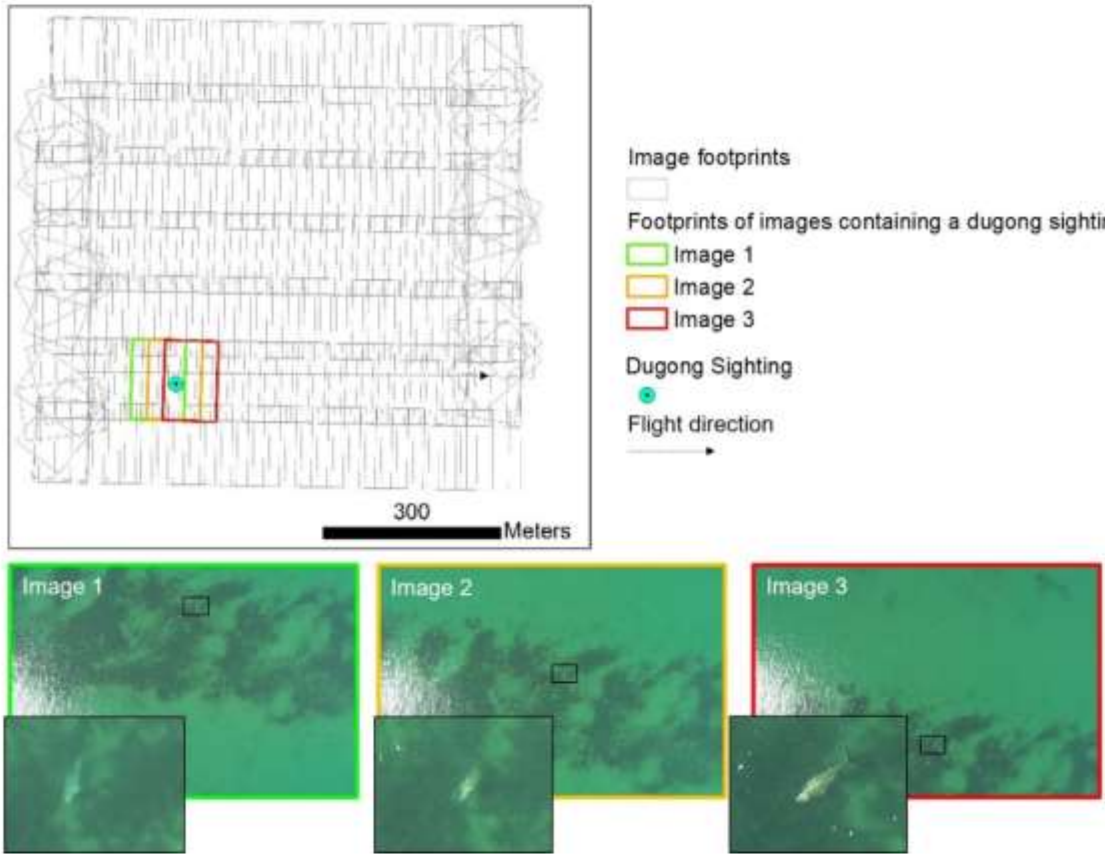

Figure 3 Representation of georeferenced image footprint, i.e., upon the water surface (image taken from Cleguer et al. (2021; Figure 2)). For interest, this is an example of a series of three consecutive images taken at 3 second intervals along a transect line. Each image contains the same individual dugong but its identification becomes certain only in the third image.

Deep neural network

The key deliverable of this IWC-SORP project was a computer application for the detection of cetaceans in images collected in aerial surveys. We have developed an application that includes interfaces for both manual and automated detection and labelling, with that latter based on deep neural networks to detect multiple species of animals from aerial images. The Marine Animal Detector (MAD) is an AI detector designed to find large marine animals in aerial imagery, and is the culmination of many year's work. The architecture of the MAD, which was originally trained to detect dugongs, has been updated a number of times to include the latest object detection frameworks available. The latest version of the MAD uses the updated version of Tensor-Flow's object detection framework. The backbone neural network used in our current detector is EfficientDet-B0. The most recent version of the MAD was trained with a new set of over 350 labelled drone images of dugongs. In addition, the dugong model was extended to the following marine animal categories: whales, dolphins, turtles, sharks, rays and belugas using images contributed by various collaborators. This list of species reflects the contents of the training images we have access to. However, the MAD architecture was designed so that it will be easy to add other taxa categories in the future, where there is sufficient training data (labelled images) to do so. The current model is trained with over 8,800 labelled images, representing many more labelled individual animals therein.

Several points of improvements have been identified for the MAD and its integration into WISDAM (and these tasks are ongoing throughout the 2023 calendar year):

<u>A. Ability to work more efficiently with a wider range of image resolution.</u>

A revision and extension of the existing code is proposed so that it can work with any model of the EfficientDet family, with the benefit being the ability to work more efficiently with a wider range of image resolutions. The general user (i.e., marine biologist) will specify some information on the new images to be processed (expected diameter range of the animals in pixels). The system will automatically choose the most appropriate neural network.

<u>B. Reducing processing speed per image</u>

The speed of the processed is currently 29 sec for a 6016 x 4000 pixel (~10mb) sized jpg image. Some images that require processing are larger than this, and therefore take longer to process. Ideally, work on the architecture will continue to minimise processing time. Other options, such as cloud-based or super-computing assets are also being considered, particularly for aerial imagery collections (i.e., > one million images).

<u>C. Allow integration of results from user verifications of detections by MAD, to be used to retrain the system</u>

At present, the project is receiving datasets from all around the world that have been labelled using various methods. A script to verify the labelling in a dataset has been written. Data entry errors were discovered while analysing the performance of our trained neural network. This script will be adapted to augment the original dataset with verified detections on new images.

<u>D. Automatic classification of environmental conditions</u>

This work is now being conducted by Murdoch University PhD student, Daniel Axford, as part of his PhD project, who, to date, has focussed on the application of convolutional neural networks (CNN - deep learning models) for classifying environmental conditions that are known to affect marine wildlife detection in drone and aerial imagery (water turbidity, sun glare, and sea state). To aid both Daniel's work, and WISDAM/MAD project more broadly, a wider range of labelled images are now available (i.e., images from multiple locations with a greater variety of water colour and turbidity, sea floor types, and other environmental conditions).

Finally, to aid in the classification of images containing potential seagrass (i.e., as part of the concurrent project on non-cetacean aerial imagery surveys), and to allow us to map those areas, semantic segmentation methods are being explored for labelling a training image dataset. There is potential to use similar methods to classify different sighting conditions in the Southern Ocean (e.g., different sea ice concentrations and types).

E. Real-world trials of WISDAM/MAD

The *WISDAM* user interface was used to manually label and cross-validate a large image dataset from a dugong aerial image survey in the Northern Territory and by colleagues at James Cook University, to process survey images from a range of locations in Australia and New Caledonia. In addition, the *WISDAM*/*MAD* combination was used to process images from dugong aerial imagery surveys of the southern Great Barrier Reef (Queensland) in November 2022, and will be used for surveys of Shark Bay (Western Australia) and the northern Great Barrier Reef in 2023. WISDAM has also been supplied to five NGOs in the Philippines, Indonesia, Malaysia and Thailand to allow them to conduct dugong surveys, as well as groups in Saudi Arabia (dugongs), the Seychelles (dugongs) and Florida (manatees – to trial the switch in species).

F. Retraining MAD with all available verified detections to improve recall rates

The latest version of the *WISDAM*/*MAD* has not been rigorously tested and there are a number of image datasets available for further training of the detector. For dugongs, for example, the *MAD* has been trained using labelled data from north-west Australia, but there are now labelled images from the Northern Territory where the water visibility and conditions were more varied. Many new labelled datasets are also available for turtles, whales, dolphins and rays. Work is currently underway to assess and further train our deep learning model to capitalise on all the available training data and to maximise the recall and precision of the system. The following steps will be undertaken within the next six months:

i. Curate and catalogue training and testing image datasets

The current iteration of the *MAD* has been trained using a range of images provided by colleagues around the world, and these need to be curated and catalogued to create a transparent record of the images available and which images are to be used for training, testing or validation. Dr Krista Nicholson of Murdoch University has been progressing curation of the whole image catalogue, and plans to complete this task in the first half of 2023[1].

ii. Process naïve images using the *MAD* and manually validate the output

Some testing of the current version of the *MAD* has been undertaken, but further tests are required to determine the efficacy of the model for various species in various habitats and survey conditions. Once the images have been catalogued, a subset of naïve images will be processed, and the output will be manually validated using the *WISDAM* software (GUI) to determine whether the detections are true or false positives.

iii. Evaluate the performance of the *MAD*

The output from the manual validation process will be cross-checked with the label records for each image dataset using this automated process within the *WISDAM* software to determine whether the automated detections match the manual detections. This process will allow us to evaluate the performance of the *MAD* by determining the true detection rate (recall) and precision (proportion of true positives as a fraction of the total detections).

iv. Further train the *MAD*

Depending on the outcome of iii, catalogued images earmarked for training will be used to further train the model with the aim of maximising the recall rate.

G. WISDAM/MAD dedicated website is designed and docker file is available to be downloaded

A dedicated website has not yet been developed for the *WISDAM* software. The aim is to start developing a website in 2023. The software has been under a phase of significant development after being used to process a large dataset of images and some essential new functions have been added. These functions need to be tested by a limited set of users over the coming year to ensure stability and that they are working as anticipated. The aim

[1] Funded by the Australian Antarctic Division under Australian Antarctic Project 4600 'Conservation and management of Australian and Antarctic whales – post-exploitation status, distribution, foraging ecology and their role in the Southern Ocean ecosystem'

is to make the software available after some international collaborators have field tested the software as these users are less familiar with our standard survey protocols will be new to these image processing methods.

Image catalogue

As previously reported, the project has collected and labelled >8,000 aerial images of cetaceans; a further 30,000 aerial images of cetaceans have also been offered to the project. During 2022, a further batch of aerial images of cetaceans (i.e., images known to contain detections) were also labelled by Dr Kym Reeve, with 3,215 images containing 23,070 labelled objects (including animal bodies, blows and footprints on the water surface) . This is in addition to the existing labels for >8,000 aerial images.

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 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. 2022).

Conclusions

Previous work to grow (and label) the image catalogue has led to the development of the MAD software, which is currently being tested and has been integrated into the WISDAM. This software will soon be available to download. 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

In 2022 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, and navigating options for fast processing of large image datasets. Regardless, we remain confident that we have the resources to complete all stated aims.

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

Students and theses

Daniel Axford of the Aquatic Megafauna Research Unit, Harry Butler Institute, Murdoch University, PhD candidate (supervisor: Dr Amanda Hodgson). Thesis title: Enhancing the feasibility of imaging surveys of sea turtles and other marine wildlife: Integrating drones and deep learning.

Peer-reviewed papers – 1 new since last year

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 (2022) Using Unoccupied Aerial Vehicles (UAVs) to estimate availability and group size error for aerial surveys of coastal dolphins. Remote Sensing in Ecology and Conservation. DOI: 10.1002/rse2.313

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)

Cleguer C, Hodgson AJ, Swaine M, Kelly N, Rankin R (*In prep.*) Transition Strategy and implementation plan for the monitoring of dugongs using aerial imagery surveys.

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

Cleguer C, Kelly N, Tyne J, Wieser M, Peel D, Hodgson A (2021) A Novel Method for Using Small Unoccupied Aerial Vehicles to Survey Wildlife Species and Model Their Density Distribution. Front. Mar. Sci. 8:640338. doi: 10.3389/fmars.2021.640338

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

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6. Centre d'Etudes Biologiques de Chizé (CEBC), UMR 7372, Université de la Rochelle-CNRS, Villiers en Bois 79360, France
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Executive summary

The project integrates data on habitat use, feeding ecology, population connectivity, historical population dynamics and regional patterns of diversity in killer whales (*Orcinus orca*). 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. The work 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 most recently investigated the relationships among killer whale survival, reproductive effort, social network structure, prey abundance, environmental proxies and fisheries effort. Indices of social structure had the strongest correlation with survival, with higher sociality associated with increased survival probability. Survival was also positively correlated to Patagonian toothfish fishing effort during the previous year, suggesting that fishery-linked resource availability is an important determinant of survival. No correlation between survival and environmental proxies of prey abundance were found. At-island prey availability influenced the social structure of Marion Island killer whales, but none of the variables explained variability in reproduction. We are collating updated information on the distribution and hunting behaviour of killer whales in South African waters – this includes ecologically significant interactions with large shark species. We are presently analysing four genomes from southern African killer whales in the context of eight 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.

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.

However, there is a significant gap in our understanding of the structure, movement and distribution of killer whale populations in the Sub-Antarctic and how their movements, dietary specialisation 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. 2014a, b; 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

From 2008 to date, 2,456 shore-based observation sessions, totalling 13,688 search hours, have been conducted at Marion Island. These sessions have yielded 3,411 killer whale sightings and more than 116,000 images. Additionally, more than 43,000 images have been taken during ~2,938 opportunistic sightings since 2008. A total of 40 tags have been successfully deployed and 82 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-present. *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**	**2022-2023 (to date)**	**TOTAL**
Observation sessions													
Number	481	210	273	231	216	170	196	165	181	23	168	142	2456
Hours	2511	1145	1846	1380	1247	916	951	918	979	82	918	795	13688
Sightings													
Dedicated	406	413	466	399	402	217	149	216	255	27	231	203	3411
Opportunistic	670	270	265	153	273	123	108	209	156	175	291	245	2938
Images													
Dedicated	9160	5354	7833	6288	8313	6453	6224	9413	12412	898	29520	>15000	>116848
Opportunistic	6420	5803	2346	876	4639	1918	1177	7575	4180	1559	6628	Not yet reported	>43121
Tagging													

Attempts	-	25	7	10	6	0	2	6	5	0	2	2	65
Successful	-	10	6	6	2	-	2	6	5	-	1	2	40
Tags lost (without transmitting)	-	6	1	4	0	-	0	0	0	-	1	0	12
Duration (average days)	-	7.5	26.6	8.2	5.9	-	30	12.7	20	-	15	17	Not yet reported
Biopsy													
Attempts	-	63	9	18	15	9	14	14	8	0	13	8	171
Samples	-	24	5	6	6	7	8	10	4	-	7	5	82

Jordaan et al. (submitted) tested whether the survival of killer whales observed at Marion Island correlated with social structure and prey variables (direct measures of prey abundance, Patagonian toothfish fishery effort and environmental proxies) using multistate models of capture recapture data spanning 12 years (2006 to 2018). We also tested the effect of these same variables on killer whale social structure and reproduction measured over the same period. Indices of social structure had the strongest correlation with survival, with higher sociality associated with increased survival probability (Figure 1). Survival was also positively correlated to Patagonian toothfish fishing effort during the previous year, suggesting that fishery-linked resource availability is an important determinant of survival. No correlation between survival and environmental proxies of prey abundance were found. At-island prey availability influenced the social structure of Marion Island killer whales, but none of the variables explained variability in reproduction. Future increases in legal fishing activity may benefit this population of killer whales through the artificial provisioning of resources they provide.

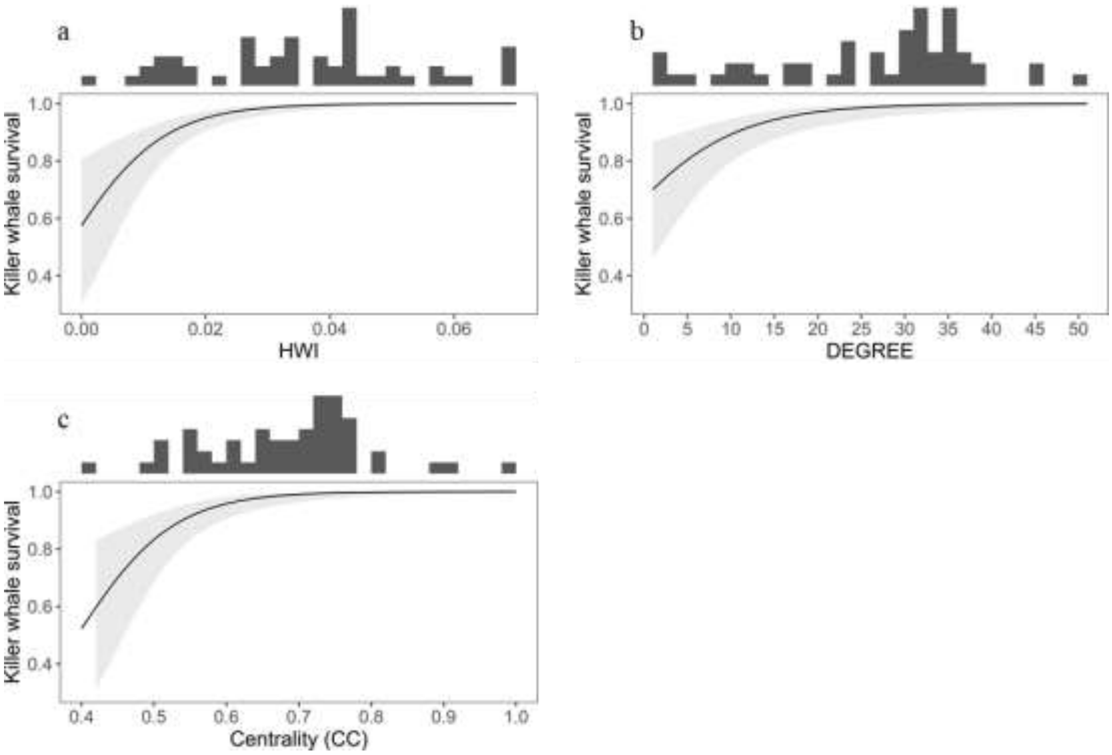

Figure 1 Marion Island killer whale survival as a function of social structure individual covariates a) half-weight-index (HWI), b) the degree and c) centrality in the same year. The shaded area represents the 95% confidence interval. The distributions of observed values of social structure are indicated by the histograms

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 voyages, 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 work was summarised in SC/68d/SH08 (2021).

Since then, Elwen et al. have collated 47 sightings records for 2022, of which 19 were two unusual and highly distinctive killer whales known to target inshore sharks. Both animals have completely bent over dorsal fins and are known locally as "Port" and "Starboard".

Elwen contributed to Towner et al. (2022a), which documented the emigration of white sharks Carcharodon carcharias in response to the presence Port and Starboard at a large white shark aggregation site in South Africa. Between February and June in 2017, five white shark carcasses washed up on beaches in Gansbaai, Western Cape Province, four of which had missing livers. Sightings and telemetry data demonstrated that white sharks emigrated from Gansbaai following these predation events, and in response to further sightings of this pair and other killer whale pods in the vicinity. Shark sightings dropped throughout the following 2.5 years; change-point analysis on both datasets confirmed these departures coincided with killer whale presence and shark carcasses washing up. These findings suggest that white sharks respond rapidly to risk from a novel predator. Elwen also contributed to Towner et al. (2023), describing direct observations of killer whales (including Starboard) preying on white sharks.

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, that is, the morphotype most similar to that observed at 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). Since June 2020, there were 328 additional encounters with photo-identification data, including 294 encounters of the “regular” morphotype (including 36 from Possession Island, 250 from fishing vessels and 8 from a documentary film vessel) and 34 encounters of the Type D morphotype. An additional 73,974 photographs were taken.

Three additional biopsy samples were collected from Crozet killer whales, from a fishing vessel in February 2023. In January 2022, a biopsy was also collected, for the first time, from one individual from the St. Paul/Amsterdam killer whale population. One tag was deployed on a killer whale there in January 2022.

Genetics

Material from the two South African killer whales Port and Starboard was shotgun sequenced material using the Illumina PCR-free True-seq method, and achieved ~20x coverage for each genome. Also sequenced by the same method were two killer whales, one from a stranding in Namibia, and the other a young male that spent several weeks in False Bay, Western Cape Province. These achieved ~65X coverage each, and will allow further analysis based on annotation and comparative exomic analyses. These four additional genomes are being analysed in the context of eight 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 of the genomes for Port & Starboard have revealed that they are half siblings (same mother, different father) and studies of the Y-chromosomes show that their fathers are likely from distinct geographic regions. Studies of historical demography based on the genomes show that Port & Starboard have profiles more similar to a local killer whale thought to eat fish than to another thought to take marine mammals. At the same time, profiles of diversity look more similar between Port & Starboard and the killer whale thought to take marine mammals. Based on nuclear genomes, all four South African killer whales cluster together, but the sample from Namibia clusters separately with a killer whale from Norway.

Research voyages/expeditions

Overwinter work at Marion Island as described above. Work off longline fishing vessels in the French Sub-Antarctic Territories, as described above. Opportunistic, inshore research along the South African coast, as described above.

Conclusions

Analysis of photographic identification data from the Sub-Antarctic 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

In the past year it has again been challenging to deploy satellite tags in South African waters and no additional biopsy samples were collected. A more dedicated effort, which is more feasible now that travel restrictions have eased, is required to tag killer whales, since the responsive mode we have used to date has been unsuccessful for tagging.

Outlook for the future

Biopsy sampling and satellite tagging of killer whales in South African waters remains challenging – a more dedicated effort will be attempted when additional funding is secured through other sources. At Crozet, the long-term photo-identification monitoring of killer whales will continue from the fishing vessels (conducted by fishery observers) and from Possession Island (conducted by fieldworkers). In addition, field activities including biopsy sampling, satellite tag deployment and behavioural tests will be conducted through dedicated trips on both fishing vessels and Possession Island in 2023 as part of a new project funded by the French Agence Nationale de la Recherche (ANR) for 2022-2025. This funding includes a PhD project that started in 2022 (the candidate is co-supervised by Tixier at MARBEC and by Guinet at CEBC). It aims at investigating behavioural heterogeneity across killer whale individuals and social groups of the Crozet population in regard to interactions with fisheries and its effects of the demography of the population. Concomitantly, biopsy sampling on killer whales of St. Paul and Amsterdam Islands will be attempted in 2023-2024 from a fishing vessel.

Tixier will spend a month in South Africa in 2023 to facilitate data sharing and build/strengthen the collaborative work on killer whale throughout the southwest Indian Ocean, with Elwen, de Bruyn and Reisinger. This includes the goal of a PhD student starting in 2024.

Project outputs

Students and theses

Rowan Jordaan completed his PhD at the University of Pretoria (lead supervisor: de Bruyn): Jordaan RK (2021) *The demography and sociality of killer whales* Orcinus orca *at subantarctic Marion Island*. PhD thesis. University of Pretoria, Pretoria.

A third-year project student under Reisinger's supervision at the University of Southampton is analysing killer whale movements in relation to fishing activity in the region.

Peer-reviewed papers – 5 new since 2022

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.

Jordaan R, Oosthuizen WC, Reisinger RR, de Bruyn PJN (Submitted) The effect of prey abundance and fisheries on the survival, reproduction and social structure of killer whales (*Orcinus orca*) at subantarctic Marion Island.

Loubiere M, Tixier P, Barbraud C, Authier M, Gasco N, Guinet C (Submitted). The effects of behavioural heterogeneity in interactions with fisheries on killer whale survival. Biological Conservation.

Richard G, Bonnel J, Beesau J, Calvo E, Cassiano F, Dramet M, Glaziou A, Korycka K, Guinet C, Samaran F (2022) Passive acoustic monitoring reveals feeding attempts at close range from soaking demersal longlines by two killer whale ecotypes. Marine Mammal Science 38: 304-325. https://doi.org/10.1111/mms.12860

Towner A, Watson R, Kock A, Papastamatiou Y, Sturup M, Gennari E, Baker K, Booth T, Dicken M, Chivell W, Elwen S, Kaschke T, Edwards D, Smale M (2022) Fear at the top: killer whale predation drives white shark absence at South Africa’s largest aggregation site. African Journal of Marine Science 44:139–152.

Towner AV, Kock AA, Stopforth C, Hurwitz D, Elwen SH (2023) Direct observation of killer whales preying on white sharks and evidence of a flight response. Ecology 104:e3875.

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).

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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.

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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

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.

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

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Towner AV, Kock AA, Stopforth C, Hurwitz D, Elwen SH (2023) Direct observation of killer whales preying on white sharks and evidence of a flight response. Ecology 104:e3875.

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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

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Executive summary

The Southern Ocean Observing System (SOOS), recently endorsed implementation of southern hemisphere humpback whales as a sentinel species for long-term, circum-polar surveillance of the Antarctic sea-ice ecosystem. This initiative was the outcome of 10 years of monitoring of the E1 breeding stock conducted under CI Bengtson Nash's Southern Ocean Persistent Organic Pollutants Program (SOPOPP), combined with in-house development of non-lethal, chemical/biochemical markers for the measurement of humpback whale adiposity and diet. Inclusion of further breeding stocks into monitoring translates to greater visibility of the circum-polar region in response to intense climatic variability. Annual population assessment is conducted at the height of winter migration, in the respective population's breeding ground, to ensure comparable stages of migration/fasting. In 2017, breeding stock D was incorporated into monitoring via collaboration with PI Christiansen, who is responsible for parallel developments in baleen whale energy reserve assessments with Uncrewed Aerial Vehicles (UAVs). As yet, breeding stock G, which represents the commercially important Western Antarctic Peninsula (WAP) region, is not included in the program. The long-term efforts of PI Friedlaender and PI Johnston working with this breeding stock in the WAP, however, have utilised UAV measurements of body condition for the investigation of humpback whale feeding ecology. PI Friedlaender's ongoing core IWC-SORP project holds significant potential to inform efforts regarding the proximate ecosystem drivers of inter-annual change in humpback whale diet and adiposity. This project therefore seeks to integrate the findings and ongoing efforts of the respective monitoring programs, targeting humpback whale foraging ecology in relation to the dynamics of their principal prey item, Antarctic krill. We propose facilitating program integration via, a) Fundamental method comparison and validation, and b) Same-year feeding vs breeding ground population comparisons (diet and energetic reserves). The anticipated outcome of this 2-year effort is 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.

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 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 of all samples finally completed in 2022, following pandemic-related delays.
- 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 commenced his PhD on the project in September, 2022, and is currently writing up the UAV measurements manuscript with the investigative team.

Conclusions

Field components of the project have been successfully completed. Sample transfers have been completed. Sample analysis and data interpretation is underway. Findings are yet to be published.

Challenges

The COVID-19 pandemic created lengthy delays for sample transfers and the PhD commencement. Planned research outputs are, however, 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

Students and theses

PhD student **Alexandre Bernie-Graveline**.

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

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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. The project resulted in a publication in the Proceedings of the National Academy of Sciences (PNAS), available as (Derville et al., IWC/SC69a/ForInfo36). The abstract, significance statement and figures showing foraging ground locations inferred from isotopic signatures in whale skin are displayed below.

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

The project has resulted in a publication in the Proceedings of the National Academy of Sciences (PNAS), available as Derville et al., IWC/SC69a/ForInfo36. The abstract, significance statement and figures showing foraging ground locations inferred from isotopic signatures in whale skin are displayed below.

Abstract
Assessing environmental changes in Southern Ocean ecosystems is difficult due to its remoteness and data sparsity. Monitoring marine predators that respond rapidly to environmental variation may enable us to track anthropogenic effects on ecosystems. Yet many long-term datasets of marine predators are incomplete because they are spatially constrained and/or track ecosystems already modified by industrial fishing and whaling in the latter half of the 20th century. Here we assess the contemporary, offshore distribution of a wide-ranging marine predator, the southern right whale (SRW, *Eubalaena australis*), that forages on copepods and krill from ~30°S to the Antarctic ice edge (>60°S). We analysed carbon and nitrogen isotope values of 1,002 skin samples from six genetically distinct SRW populations using a customized assignment approach that accounts for temporal and spatial variation in the Southern Ocean phytoplankton isoscape. Over the past three decades, SRW increased their use of mid-latitude foraging grounds in the south Atlantic and southwest Indian oceans in the late austral summer and autumn, and slightly increased their use of high-latitude (>60°S) foraging grounds in the southwest Pacific, coincident with observed changes in prey distribution and abundance on a circumpolar scale. Comparing foraging assignments with whaling records since the 18th century showed remarkable stability in use of mid-latitude foraging areas. We attribute this consistency across four centuries to the physical stability of

ocean fronts and resulting productivity in mid-latitude ecosystems of the Southern Ocean compared with polar regions that may be more influenced by recent climate change.

Significance Statement

Assessing change in Southern Ocean ecosystems is challenging due to its remoteness. Large-scale datasets that allow comparison between present-day conditions and those prior to large-scale ecosystem disturbances caused by humans (e.g., fishing/whaling) are rare. We infer the contemporary offshore foraging distribution of a marine predator, southern right whales (n=1002), using a novel, customized stable-isotope based assignment approach based on biogeochemical models of the Southern Ocean. We then compare the contemporary distributions to whaling catch data representing historical austral summer and autumn distributions. We show remarkable consistency of mid-latitude distribution across four centuries, but shifts in foraging grounds in the past 30 years, particularly in the high latitudes that are likely driven by climate-associated alterations in prey availability.

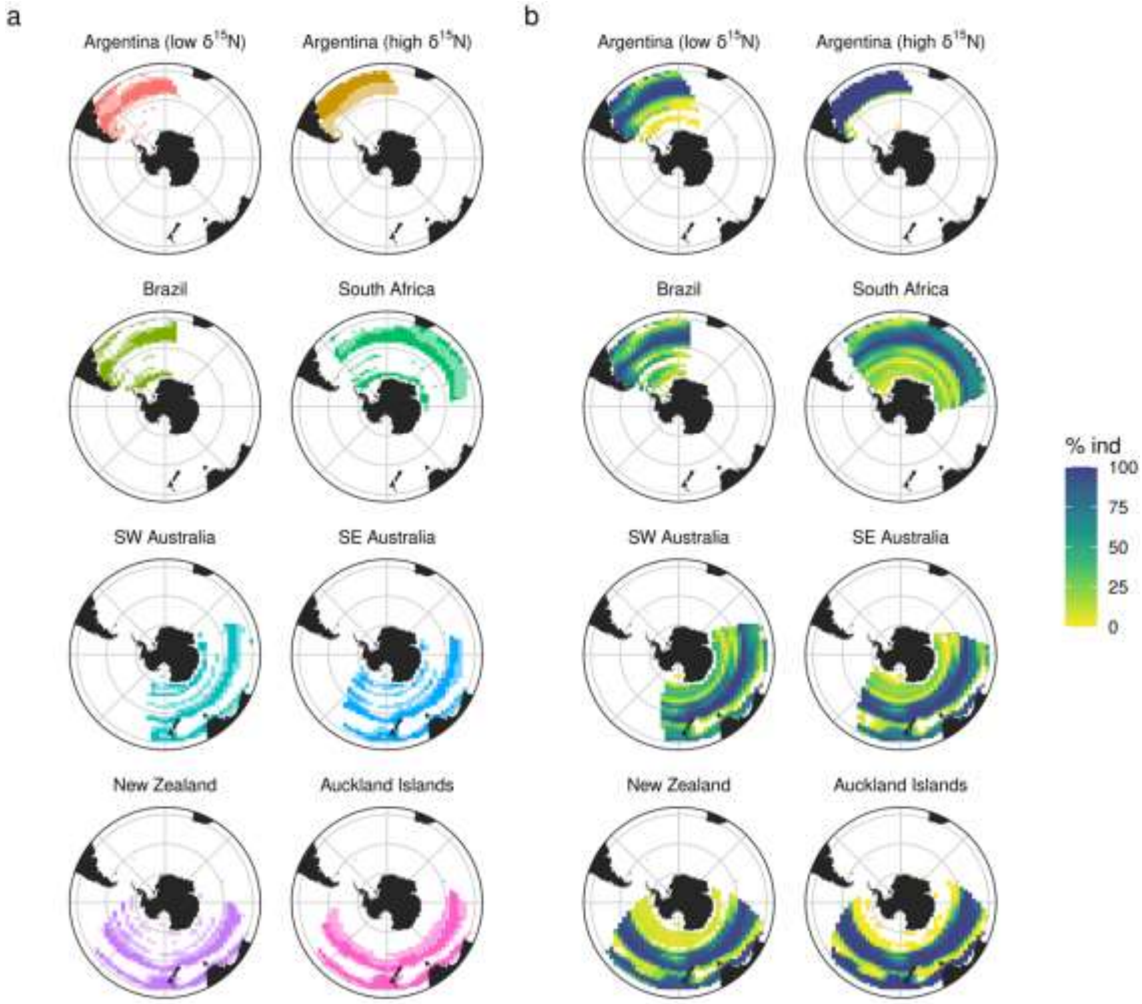

Figure 1 Isotopically assigned foraging grounds for each southern right whale wintering ground across all years (see Table S1 for sample sizes). (a) Population-level average core and general foraging areas in dark and light colors representing highest 25% and 50% probability pixels, respectively. (b) Individual-level summary of foraging grounds shown with a color scale representing the percent of sampled individuals that were assigned to each grid cell based on binary transformation of the 50% highest probability pixels. Note Australia wintering grounds are divided in southwest (SW) and southeast (SE). Parallels of latitude represented in grey in each map mark 30°S, 50°S, and 70°S.

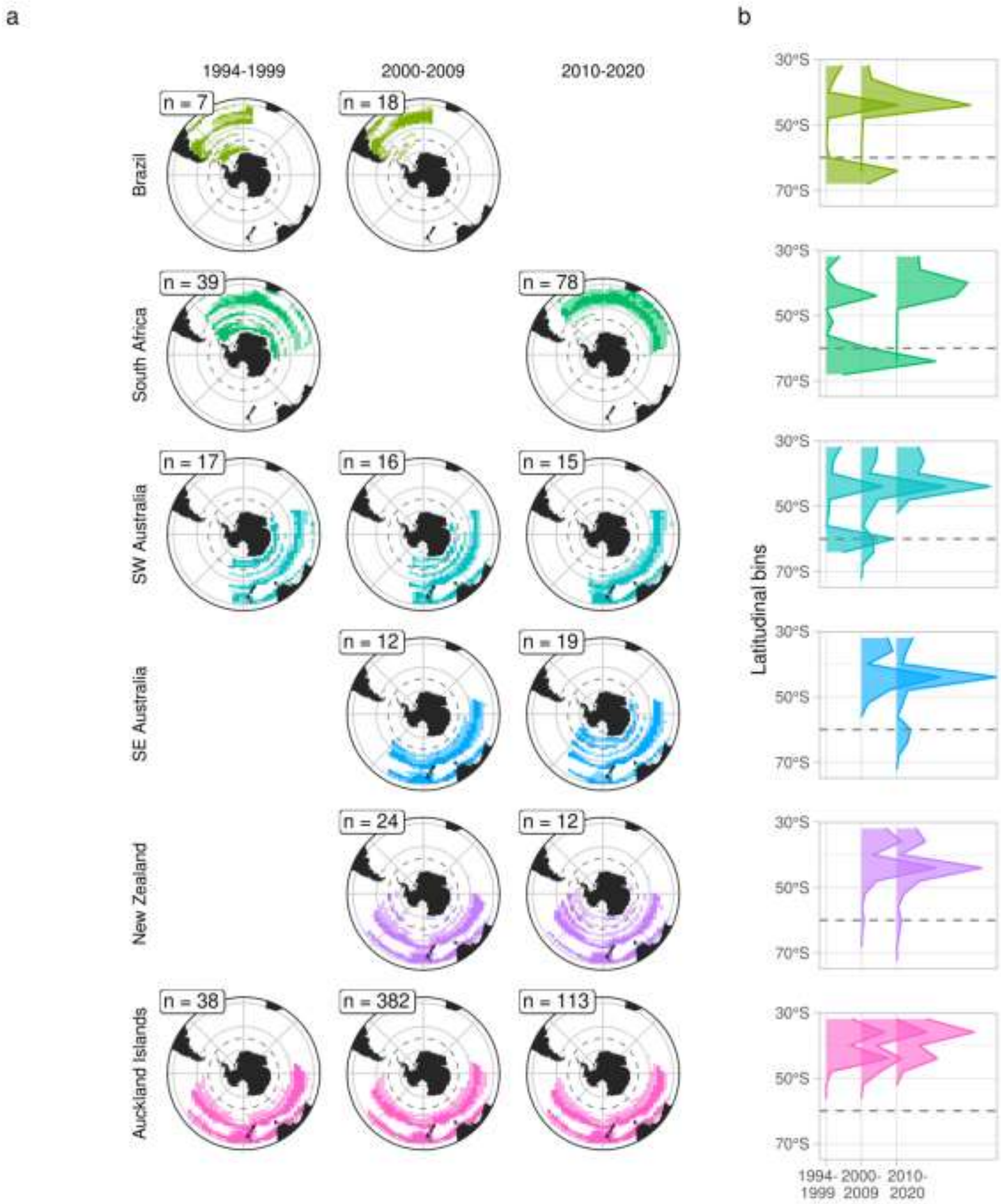

Figure 2 Southern right whale foraging grounds assignments by wintering ground and decade. (a) Maps of assigned general and core foraging areas. Sample size is indicated in each panel. Population-level average core and general foraging areas are represented for each decade by population combination in dark and light colours, respectively. (b) Distribution of the population-level foraging probabilities summed over all pixels (i.e., thresholds) in latitudinal bins of 4°, for each decade. Argentinian samples were collected over only one decade (2000-2009) and are therefore not represented in this figure. Note Australia wintering grounds are divided in southwest (SW) and

southeast (SE). Parallels of latitude represented in grey in each map mark 30°S, 50°S, and 70°S, and the dashed line delineates the 60°S latitude.

Outlook for the future

This project is now completed.

Project outputs

Derville S, Torres LG, Newsome SD, Somes C, Valenzuela LO, Vander Zanden HB, Baker CS,… , Carroll EL (2023) Long-term stability in the foraging range of a Southern Ocean predator between the eras of whaling and Anthropocene climate change. Proceedings of the National Academy of Sciences. https://doi.org/10.1073/pnas.2214035120

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. Period 2018-2022

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Abstract

This summary covers three years of fieldwork (2019, 2020 and 2022). During the year 2021, no Antarctic campaign was carried out due to the COVID-19 pandemic. Visual and acoustic surveys were conducted resulting in 368 encounters, with 780 cetaceans recorded. The project gathered unique data in this period that will help to support the creation of a Marine Protected Area in the Peninsula as proposed by the government of Argentina and Chile and has contributed to advances in six of the main themes of IWC-SORP. Reports were presented to the IWC (2019, 2020, 2022), the Argentine Government, Argentine Red List of Mammals and the United Nations.

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 Argentinean icebreaker ARA Almirante Irízar. These latter three voyages included the north-western and north-eastern parts of the Peninsula, Mar del Scotia/ Scotia Sea, Mar de Weddell/ Weddell Sea and Islas Orcadas del Sur/ South Orkney Islands, as well as the southern area of Mar de Weddell/ Weddell Sea.

Results and challenges

2019 survey
Visual and acoustic surveys of cetaceans were conducted aboard the Argentinean icebreaker, ARA Almirante Irízar, 22 February and 22 March, navigating along the North-Eastern Antarctic Peninsula in the Weddell Sea and through the Scotia Sea reaching Islas Orcadas del Sur/ South Orkney Islands (60°38.42'S 45°14.52'W). Visual surveys were conducted over a total of 48.5 h and 850 nm. On-effort cetacean sightings included four odontocete and three mysticete species, encompassing a total of 146 encounters. A total of 103 h of acoustic recordings were collected with a four-element towed hydrophone array. Recordings are being analysed in search for presence of odontocete acoustic signals. Additionally, photographs were taken of humpback, minke, fin and killer whales which are currently being reviewed. Those suitable for photo- identification will be classified and shared with other catalogues. A preliminary photo-identification catalogue of Antarctic fin whales was compiled using photographs taken from 2013 to 2019, and nine individual whales were catalogued.

2020 survey
Between 11 January and 9 February, visual and acoustic surveys were conducted on-board the Argentinean Icebreaker, ARA Almirante Irízar, along the Drake Passage, the Islas Shetland del Sur/ South Shetland Islands, the north-eastern Antarctic Peninsula, Islas Orcadas del Sur/ South Orkney Islands and into the Mar de Weddell/

Weddell Sea, reaching its southernmost location in the surroundings of the Argentinean base Belgrano II at 77°52’S 34°37’W. Visual surveys collected 222 records of cetaceans including fin, Antarctic minke, humpback, Antarctic killer and southern bottlenose whales. Preliminary analysis of data gathered during the acoustic survey using a four-element towed array resulted in the detection of Antarctic killer whale whistles and burst pulses. There were 8 deployments of towed acoustic equipment, (Elephant Island/ South Shetland Islands, South Orkney Islands), capturing 216 hours of data. Opportunistic acoustic recordings using a manually deployed Soundtrap hydrophone were taken at Potter Cove and Scotia Bay. Data analysis is ongoing. Two tissue samples were collected from humpback whales. Photographs were obtained from all species registered, some of which are suitable for photo-ID or suggestive of anthropic interaction. A new area to the project was sampled, the southern Weddell Sea, opening an opportunity for assessment of a rarely studied area. In addition to this voyage, fin whale visual records from previous years were shared as part of an IWC-SORP collaborative effort to analyse combined data. Reports were presented to the International Whaling Committee (x3), the Argentine Government (x4), Argentine Red List of Mammals (x8) with a UN report in preparation (x1).

2022 survey: 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 Irízar 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.

Results

Description and schedule of achievements for 2019-2022

Three survey voyages

(i) 22/02/2019–22/03/2019**;** 11/01/2020–09/02/2020 and 24/03/2022-3/04/2022 on board the Argentinean icebreaker “ARA Almirante Irízar”.
(ii) 2019 course: depart Ushuaia, Argentina–Drake Passage–the Mar de Weddell/ Weddell Sea east of the Antarctic Peninsula– the Mar del Scotia/ Scotia Sea– Islas Orcadas del Sur/ South Orkney Islands– Ushuaia.
(iii) 2020 course: depart Ushuaia–Drake Passage–Islas Shetland del Sur/ South Shetland Islands–the north-eastern Antarctic Peninsula–Islas Orcadas del Sur/ South Orkney Islands–Mar de Weddell/ Weddell Sea–Argentinean base Belgrano II–Ushuaia.
(iv) 2022 course: Drake Passage, Islas Shetland del Sur/ South Shetland Islands, northeastern and northwestern Antarctic Peninsula, and Mar de la Flota/ Bransfield Strait

Daylight visual surveys

(i) Surveys were concentrated near the Islas Orcadas del Sur/South Orkney Islands, Islas Shetland del Sur/South Shetland Islands, the Antarctic Peninsula and Mar de Wedell/ Wedell Sea. Species, group size and GPS position were recorded for all sightings.
(ii) Photographs were taken for all species encountered.
(iii) Preliminary data on species, number and location of sightings for all voyages have been analysed. Revision and analysis is on-going.

Mobile Acoustic Surveys

(i) Audio recordings were made from a hydrophone array towed between 3 and 18 knots. Data from four audio channels were recorded on to a computer hard-disk drive. An acoustic technician monitored incoming signals visually and on headphones. Signal start and end times, GPS position and ship track were logged for all acoustic encounters on the same database as sightings, to aid correlation.

(ii) Towed array and Soundtrap recordings were inspected using the MATLAB-based software Triton. Long-term spectral averages were calculated for visual inspection for odontocete (toothed whale) signals; descriptions and classification were made of toothed whale vocalisations in the study area.
(iii) Further analysis was made to verify species and locations of acoustic recordings.

Autonomous Acoustic Surveys

(iv) 2019: no data was able to be recovered from the moored HARP hydrophone as the HARP, along with its data had slipped its mooring and were lost.
(v) 2020: opportunistic acoustic recordings were taken of cetaceans using a Soundtrap hydrophone manually deployed from a small boat at Caleta Potter/ Potter Cove and Bahía Scotia/ Scotia Bay.
(vi) 2022: opportunistic acoustic recordings were taken of cetaceans using a Soundtrap hydrophone manually deployed from a small boat at Argentinean base Petrel.
(vii) HARP data continues to be analysed using Triton software and MATLAB routines and two papers will be published before SC 69B.

Conservation and Dissemination of Results

(i) Three reports, one per survey, were presented to IWC Scientific Committee meetings (SC/68A/SH/10; SC768B/SH/04; SC/68D/SH/07 Rev)
(ii) For the period April 2019 to December 2022: Four reports were presented to the Argentinean government. Eight contributions were made to the Argentinean Red List of Mammals (see item 12.2). A contribution to a United Nations second and *third cycle of the Regular Process for Global Reporting and Assessment of the State of the Marine Environment,including Socioeconomic Aspects.*
(iii) Project results were presented at an Underwater Acoustics seminar at the Universidad Nacional de Tres de Febrero (UNTREF), Argentina, in 2019, 2020, 2021 and 2022.

Individual cetaceans added to photo-ID catalogues

(i) Preliminary analysis resulted in pictures of 4 humpback whales, 3 fin whales, 1 Antarctic blue whale, 2 Antarctic minke whales, 7 Antarctic type B killer whales and 1 southern bottlenose whale suitable for photo-identification and addition to ID catalogues.
(ii) The blue whale has been shared with the Antarctic Blue Whale catalogue to search for a match with known individuals.
(iii) At least three individuals showed marks or scars suggestive of prior anthropic interaction: two possible entanglements and one ship strike. These will be shared to the IWC ship strike database for inclusion if confirmed.

Total number of species and encounters identified through visual survey

(i) Total number of encounters: 449, comprising 1043 individual cetaceans (see Table 1)

Reports presented to IWC and Argentine government on visual survey activities

(i) One report to the Scientific Committee of the International Whaling Commission Scientific Committee in May 2019 (SC/68A/SH/10, SC/68B/SH/10 and SC/68D/SH/07 Rev.)
(ii) Four reports to the Argentinean government.
(iii) Additions made to the Argentinean Red List of Mammals (see item 12.2) on eight endangered (EN) or data-deficient (DD) species.
(iv) Information gathered during the two surveys is contributing to the United Nations report: “World Ocean Assessment II” and the ongoing “World Ocean Assessment III”.

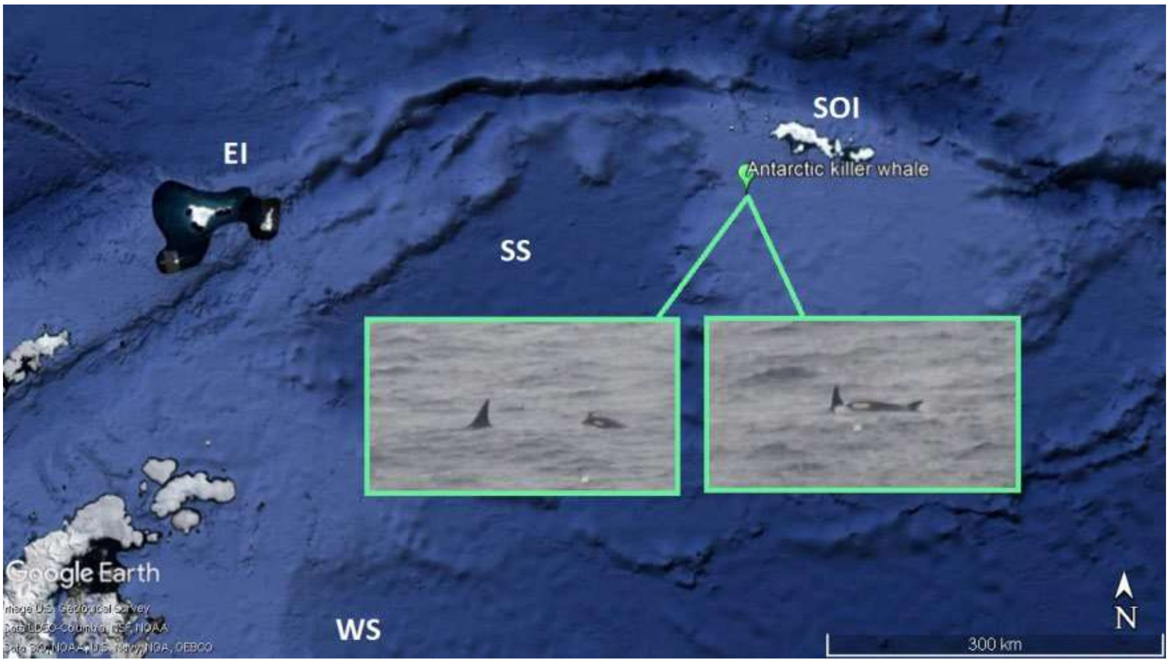

Figure 1 Geographic position (76°17.6'S 29°43.7'W) and photo confirmation of off-effort encounter with Antarctic killer whale type B acoustic detection (SS: Mar del Scotia/ Scotia Sea; SOI: Islas Orcadas del Sur/ South Orkney Islands; EI: Isla Elefante/ Elephant Island; WS: Mar de Weddell/ Weddell Sea) (photos: R. Genoves / Ecopelagos-FURG).

Total number of species identified through acoustic detections

(i) Towed array: 2019. Whistles and clicks from either long-finned pilot whales or orcas were recorded
(ii) 2020. Whistles and burst pulses were recorded which matched an off-effort sighting of 4 Antarctic killer whales type B.
(iii) 2022. Sperm whales clicks were recorded.
(iv) Static hydrophones: Humpback whale low frequency tonal soundswere opportunistically registered on two occasions: at Caleta Potter/ Potter Cove and at Bahía Scotia/ Scotia Bay.These recordings were shared with researchers of the Universidade Federal do Rio Grande do Norte Laboratory of Bioacoustics, Brazil and are currently being analysed for suitability for a broader comparison of songs between calving grounds and feeding grounds.

Reports presented to IWC and Argentine government on towed acoustic survey activities

(i) One report to theInternational Whaling Commission Scientific Committee (SC/68a/SH10, SC/68b/SH04 and SC/68d/SH07 Rev)
(ii) Four reports to the Argentinean government.

Characterisation of unknown acoustic signalsfrom toothed whales

(i) The whistles mentioned above were added to our data base and will be analysed once more samples are gathered or a visual match is obtained.
(ii) Killer whale type B calls will be added to an internal acoustic signals catalogue, and compared with both previous and future recordings to assess any new information about the species' acoustic repertoire.

Papers/Articles published on HARP data

(i) Acoustic data collected from the HARP in previous years is being analysed with Scripps Institute of Oceanography, UCSD. Preliminary results are shown in Trickey *et al*. (2019) and twopeer-reviewed publications are expected for 2023.

(ii) Researchers are still investigating potential southern right whale signals collected with the HARP in previousyears, and report results to the IWC/SC69b meeting.

Seasonality estimatesfor identified cetaceanspecies.

(i) Analysis is currently being conducted with IWC-SORP participating researchers. Estimates will be presented at IWC/SC69b.

Correlations made between species presence and remotely sensed environmental data

(i) Sea ice dynamics are being researched as a driver for shifts in seasonal relative abundance of cetaceans in this region.

(ii) Proximity to the Southern Antarctic Circumpolar Current Front (SACCF)will be examined to evaluate differences in habitat use across sites.

(iii) Fin whale information has been shared with the IWC-SORP fin whale project led by Dr. Herr from Germany. A paper including our data was published in 2022 by Viquerat et al., 2022.

Number of peer reviewed papers

Wood, M. and Sirovic, A. 2022. Characterization of fin whale song off the Western Antarctic Peninsula. *PLoS One* 17(3). https://doi.org/10.1371/journal.pone.0264214. Used data collected in the HARP deployed during previous years of this project.

Viquerat S, Waluda CM, Kennedy AS, Jackson JA, Hevia M, Carroll EL, Buss DL, Burkhardt E, Thain S, Smith P, Secchi ER, Santora JA, Reiss C, Lindstrøm U, Krafft BA, Gittins G, Dalla Rosa L, Biuw M and Herr H (2022) Identifying seasonal distribution patterns of fin whales across the Scotia Sea and the Antarctic Peninsula region using a novel approach combining habitat suitability models and ensemble learning methods. Front. Mar. Sci. 9:1040512. doi: 10.3389/fmars.2022.1040512

Two papers on acoustic of odotocetes and misticetes are being prepared to publish in peer reviewed journals in conjunction with the Scripps Acoustic Ecology Lab, Scripps Institution of Oceanography, University of California, San Diego.

Number of scientific documents presented to IWC Scientific Committee

(i) Three reports (May 2019, May 2020 and May 2022).

Identify the consequences and impact of the project vis-à-vis the beneficiaries

Visual and acoustic data gathered is adding evidence to the need for protecting the area proposed by Argentina and Chile as an MPA in Antarctic waters. Additionally, these data are adding to our understanding Antarctic habitat use by different species and, over time, can indicate whether there are changes of habitat preference. Re-sighting of individuals through photo-identification helps us understand individuals' movements and thus understand better those areas important for conservation. The addition onto international databases of photos of cetaceans detected with signs of ship strikes or entanglement help to better understand the magnitude and location of these issues which, in turn, helps to achieve better prevention and/or remedial actions. International cooperation, such as that undertaken under IWC-SORP, enhances knowledge of cetaceans in the Antarctic region which could not possibly be undertaken by a single group alone and collectively adds great input into assessment of conservation needs and helps to inform decision makers on the creation and implementation of protection measures. The contribution to the Categorization of Mammals of Argentina (Argentinean Red List of Mammals) resulted in the retention of the 2012 classification, with blue and sei whales being included into the Endangered category and the Antarctic minke whale, Southern bottlenose whale, Cuvier's beaked whale, Straptoothed beaked whale, Arnoux's beaked whale and Hourglass dolphin remaining as Data Deficient, providing evidence of the need to collect more data.

Scientific partners (in the field)

14 researchers from 4 countries participated in this project: Argentina (n=7), Brazil (n=2), Chile (n=2) and USA (n=3)

List of Researchers participating in this project (2019-2022)

Argentina
Melcón, M (Fundación Cethus, Argentina)
Hevia, M. (Fundación Cethus, Argentina)
Reyes Reyes, V. (Fundación Cethus, Argentina)
Marino, A. (Fundación Cethus, Argentina)
Valese, N. (Fundación Cethus, Argentina)
Zuazquita, E. (Fundación Cethus, Argentina)
Albalat, A. (Fundación Cethus, Argentina)
Miguel Iñíguez Bessega (IWC Delegate of Argentina)

Brazil
Genoves, R. (Ecopelagos – Universidade Federal do Rio Grande - FURG, Rio Grande, Brazil)
Barreto, J. (Amigos da Jubarte, Brazil)

Chile
Bedriñana-Romano, L. (Centro Ballena Azul, Chile)
Gaete, R. (Centro Ballena Azul, Chile)

USA
Baumman-Pickering, S. (Scripps Acoustic Ecology Lab, Scripps Institution of Oceanography, University of California San Diego, USA)
Hildebrand, J. (Scripps Acoustic Ecology Lab, Scripps Institution of Oceanography, University of California San Diego, USA)
Sirovic, A. (Department of Marine Biology, Texas A&M University at Galveston, Galveston, TX, United States of America, Biology Department, Norwegian University of Science and Technology, Trondheim, Norway)

Communication strategies carried out

(i) Reports and articles for Government representatives. Reports and articles for scientists involved in cetacean and Antarctic conservation. Navy staff (articles in its own magazine). General public (Video on WDC and Fundacion Cethus, facebook and Instagram profiles)

(ii) A 7´ video on the 2020 Antarctic campaign was featured on Fundación Cethus' Facebook (https://www.facebook.com/FundacionCethus/) and Instagram (https://www.instagram.com/fundacion_cethus/?hl=en) profiles and WDC's English language website.

Conclusions

Most objectives were achieved, with data gathered on 15 species of cetaceans: 5 baleen whales, sperm whales, 5 beaked whales, 2 ecotypes of killer whales and 3 small dolphins, and advancing our knowledge of their distribution and acoustic signals. The inconveniences we experienced -designation of a new route, changes in travel dates and non-timely reception of some equipment- did not affect our ability to research the region of the proposed Antarctic Peninsula and Scotia Sea arc MPA. The icebreaker was an opportunity to survey the less-monitored Mar de Wedell/Weddell Sea. We have been able to produce several reports to contribute baseline data needed to support cetacean conservation in the Southern Ocean.

This project has gathered unique data that helps support the creation of a Marine Protected Area in the Antarctic Peninsula as proposed by the government of Argentina and Chile. We have helped to advance six main themes of the IWC-SORP: 1) blue whales, 2) killer whales, 3) humpback connectivity, 4) blue and fin whale acoustics, 5) southern right whales, 6) fin whales. We have 18 photos across 6 species suitable for photo-identification which will make a significant increase to Southern Ocean cetacean identification catalogues, either as new individuals or matches. The sighting of two endangered Antarctic blue whale individuals east of the Antarctic Peninsula in 2020 is a very important outcome considering that only 1% of the original population remains and is a strong argument for further research in this very rarely surveyed area. The three individual whales showing prior entanglement or ship strike markings will make a contribution to the IWC ship strike database. The Antarctic killer whale type B acoustic signals added to our database are vocalisations from an ecotype not yet described by the scientific community. If we can build on this result and increase the size of the collected data in future surveys, we could contribute significantly to knowledge of their acoustic repertoire, enabling further passive acoustic research into the importance of this habitat for this species. If humpback whales' songs are identified and can be compared to the songs produced in calving grounds in the Atlantic and Pacific Oceans, we could identify possible cultural exchange in feeding grounds. The project's contribution to updating the Red List of Mammals of Argentina will support cetacean conservation in Argentina.

Challenges

(i) Due to COVID-19, our programmed 2020-21 fieldwork had to be suspended. This meant that we had to extend the project for another year.
(ii) Due to measures adopted by the Argentine government and logistical issues, researchers from other countries could not participate in the 2022 campaign.
(iii) The original route chosen for the 2022 Antarctic campaign as part of the project was modified. Instead of not carrying out a campaign, it was decided to use the slots granted by the Argentine Antarctic Institute for March/April 2022.

Table 1 Year of surveys, date, routes, numbers of encounters, numbers of animals watched during the Antarctic campaign 2018, 2019, 2020 and 2022. Keynotes: Ushuaia (USH), Drake Passage (DP)– Islas Shetland del Sur/South Shetland Islands (ISS/SSI), the north-eastern Antarctic Peninsula (NEAP), Islas Orcadas del Sur/South Orkney Islands (IOS/SOI), Mar de Weddell/Weddell Sea (MW/WS), Argentinean Belgrano II base (BII), Petrel base (PE), Gerlache Strait (GS), Mar de la Flota/ Bransfield Strait (MF/BS).

Dates	Route	Vessel	No encounters	No cetaceans
22 Feb - 22 Mar 2019	USH, DP, ISS/SSI, NEAP, IOS/SOI, MW/WS, BII, USH	ARA Almirante Irízar	146	315
11 Jan - 9 Feb 2020	USH, DP, ISS/SSI, NEAP, IOS/SOI, MW/WS, BII, USH	ARA Almirante Irízar	222	465
24 Feb - 3 Mar, 3-10 Ap 2022	DP, USH, DP, GS, MF/BS, ISS/SSI, NEAP.	ARA Almirante Irízar	81	263
			449	**1043**

Project outputs

Peer-reviewed papers

Wood M, Sirovic A (2022) Characterization of fin whale song off the Western Antarctic Peninsula. *PLoS One* 17(3). https://doi.org/10.1371/journal.pone.0264214. Used data collected in the HARP deployed during previous years of this project.

Viquerat S, Waluda CM, Kennedy AS, Jackson JA, Hevia M, Carroll EL, Buss DL, Burkhardt E, Thain S, Smith P, Secchi ER, Santora JA, Reiss C, Lindstrøm U, Krafft BA, Gittins G, Dalla Rosa L, Biuw M and Herr H (2022) Identifying seasonal distribution patterns of fin whales across the Scotia Sea and the Antarctic Peninsula region using a novel approach combining habitat suitability models and ensemble learning methods. Front. Mar. Sci. 9:1040512. doi: 10.3389/fmars.2022.1040512

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

Conference presentations

Trickey JS, Rice A, Solsona Berga A, Bartlett A, Jones JM, Thayre B, Hurwitz J, Baumann-Pickering S, Sirovic A, Hildebrand J, Reyes Reyes MV, Hevia M, Marino A, Melcón ML, Iñíguez M (2019) Cetacean occurrence near the South Shetland Islands based on long-term passive acoustic monitoring. The Journal of the Acoustical Society of America 146, 2806 (2019); https://doi.org/10.1121/1.5136720

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

Argentine Red List of Mammals

Iñíguez Bessega, Miguel A.; García, Néstor A. (2019). *Balaenoptera musculus*. En: SAyDS–SAREM (eds.) Categorización 2019 de los mamíferos de Argentina según su riesgo de extinción. Lista Roja de los mamíferos de Argentina. Versión digital: https://cma.sarem.org.ar/es/especie-nativa/balaenoptera-musculus

Hevia, Marta; Gribaudo, César A.; Dellabianca, Natalia A.; Mandiola, Agustina (2019). *Balaenoptera borealis*. En: SAyDS–SAREM (eds.) Categorización 2019 de los mamíferos de Argentina según su riesgo de extinción. Lista Roja de los mamíferos de Argentina. Versión digital: http://cma.sarem.org.ar. https://cma.sarem.org.ar/index.php/es/especie-nativa/balaenoptera-borealis

Cáceres-Saez, Iris; Gribaudo, César A.; Gribaudo, Fabio A.; Negrete, Javier; Hevia, Marta; García, Néstor A.; Dellabianca, Natalia A. (2019). *Balaenoptera bonaerensis*. En: SAyDS–SAREM (eds.) Categorización 2019 de los mamíferos de Argentina según su riesgo de extinción. Lista Roja de los mamíferos de Argentina. Versión digital:https://cma.sarem.org.ar/es/especie-nativa/balaenoptera-bonaerensis

Hevia, Marta; García, Néstor A. (2019). *Hyperoodon planifrons.* En: SAyDS–SAREM (eds.) Categorización 2019 de los mamíferos de Argentina según su riesgo deextinción. ListaRoja de los mamíferos de Argentina. Versión digital:https://cma.sarem.org.ar/es/especie-nativa/hyperoodon-planifrons

Iñíguez Bessega, Miguel A.; Hevia, Marta; García, Néstor A. (2019). *Berardius arnuxii*. En:SAyDS–SAREM (eds.)Categorización 2019 de los mamíferos de Argentina según su riesgo de extinción. Lista Roja de los mamíferos de Argentina. Versión digital:https://cma.sarem.org.ar/es/especie-nativa/berardius-arnuxii

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IñíguezBessega, Miguel A.; Hevia, Marta; García, Néstor A. (2019).*Mesoplodon layardii*. En: SAyDS–SAREM (eds.) Categorización 2019 de los mamíferos de Argentina según su riesgo de extinción. Lista Roja de los mamíferos de Argentina. Versión digital:http://cma.sarem.org.ar.

Dellabianca, Natalia A.; Hevia, Marta (2019).*Lagenorhynchus cruciger*. En: SAyDS–SAREM (eds.) Categorización 2019 de los mamíferos de Argentina según su riesgo deextinción. Lista. Versión digital:http://cma.sarem.org.ar

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.

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

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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 uncrewed 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. This project was initiated to explore the potential of developing an ethically and legally sound drone-based system intended as a safer method to generate satellite telemetry, biopsy and photogrammetry data streams. 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 (IWC-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 uncrewed 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 Antarctic blue whale ENRICH voyage led by the Australian Antarctic Division. During this 49-day Antarctic voyage, 134 flights were undertaken from a 94 m 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 aimed to take initial steps 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. Specifically we aimed to:

i) 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) Assess the specifications of commercially available quadcopters (maximum payloads, flight times and thrust) and their suitability for biopsy or tag deployment.

c) Undertake an ethical assessment and legal review.

ii) Approach suitable engineering consultants in order to generate projectile design solutions given our current needs.

iii) 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

As reported in previous years, we successfully completed ballistics testing and derived the mean speed of projectiles as they leave the firearm and as they hit the target as well as overall mean flight speed (SC/68d/SH08). We 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. To brief these engineers, we prepared a specifications document providing detailed information and requirements regarding operating conditions related to biopsy sampling and satellite tagging large whales in the Southern Ocean.

In the last year, we have generated and tested a pneumatic design solution that is able to deploy our current biopsy dart design at the required speed. The system has been incorporated onto a drone and a retrieval mechanism for the biopsy dart is partially complete. We are in the process of extending this project for another two years in order to develop a safety mechanism, test the drone incorporated deployment system, develop AI technology to assist with drone placement and determine if the current design can be used to deploy small satellite tags (LIMPETs).

Conclusions

This project has successfully completed initial steps towards generating a pneumatic based design solution to deploy biopsy darts from a drone. We have another two years of work scheduled in order to make this system field deployable.

Challenges

The ethical and legal component of this project continues to be delayed. Whilst initial discussions have occurred, much of the ethical and legal work needs to be informed by the final design and operating parameters.

Outlook for the future

This system is yet to be tested in the field. We will undertake a body of work to ensure reliable and safe operation using a whale proxy. Options for funding and continuing this work have been secured with another two years of development planned in collaboration with engineers based jointly at the Swiss Materials, Science and Technology Institute and Imperial College of London.

Project outputs

Media interest

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

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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

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6. Fundación Macuáticos Colombia, Calle 27 Nº 79-167, Medellin, Antioquia, Colombia

Executive summary

The Humpback Whale Sentinel Program (HWSP) implements southern hemisphere humpback whales as sentinels for long-term, circum-polar surveillance of the Antarctic sea-ice ecosystem. This initiative is the culmination of 12 years of monitoring of the E1 breeding stock conducted under CI Bengtson Nash's Southern Ocean Persistent Organic Pollutants Program (SOPOPP), combined with in-house development of non-lethal, chemical/biochemical markers for the measurement of humpback whale adiposity, diet and fecundity. Inclusion of further breeding stocks into monitoring for greater visibility of the circum-polar region, in response to intense climatic variability, commenced in 2017. Between 2016-2019, the number of targeted breeding stocks under the HWSP grew from 1-5, in part due to Southern Ocean Research Partnership (IWC-SORP) funding support which facilitated the inclusion of breeding stock G. Inaugural HWSP biopsy sampling of breeding stock G took place in 2019 via Co-I Botero-Acosta and Co-I Friedlaender, and in support of research IWC-SORP Theme 3 *Interactions between baleen whales and krill*. August 2019 similarly saw successful winter breeding round sampling of populations A, D, EI and EII via the other named project Co-Is. The 2019 HWSP sample archive now represents an unprecedented opportunity for direct, within-year, population comparison of standardised sentinel parameters, reflective of ecosystem productivity. As boat-based sample acquisition has successfully been conducted, this proposal is entirely land-based, carrying increased feasibility and reduced risk. Funding for analysis of population G sentinel parameters has similarly been secured via prior IWC-SORP support. Project outcomes support both Themes 3 and 5, *Movement and mixing of humpback whales*. The anticipated outcome of this 2-year effort is the delivery of data from the largest simultaneous field campaign of the HWSP to date. Data will made openly accessible for downstream applications in the wider Antarctic and cetacean research community.

Introduction

The 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 Antarctic Blue Whale Voyage (2013), 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 SORP efforts for inter-population comparison.

2. Screen the blubber of female individuals, from all five populations, for steroid hormone markers of pregnancy via Liquid Chromatography tandem Mass Spectrometry methodology.

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 accepted for publication in Science of the Total Environment.

- PhD students for adiposity measures and steroid homorne analysis have been appointed (Alexandre Bernier-Graveline and Ella Hearne).

Conclusions

Sample analysis is underway, and complete for dietary components. Analyses related to energetic parameters are underway, and Ella Hearne, has been recruited to work with fecundity aspects of the project.

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

Students and theses

Jasmine Gross
Alexandre Bernier-Graveline
Ella Hearne

Peer-reviewed papers

Gross J et al. (*In Press*) No local cuisines for humpback whales: a population comparison in the Southern Hemisphere. Science of the Total Environment (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

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Executive summary

We examined a key question for the IWC's upcoming in-depth assessment of Antarctic blue whales: is this subspecies comprised of a single population or multiple populations separated? We examined data from Discovery mark data collected from the 1930s to the 1960s, estimating the amount of longitudinal movement within the Antarctic across years. Similarly, we analysed more recent photo-ID catalogue data and limited available satellite tag tracks, to look for evidence of movement around the Antarctic. Based on songs, morphometrics, and seasonal timing, Antarctic blue whales disperse widely throughout temperate waters of the Southern Hemisphere in winter, but we uncovered no confirmatory evidence of this from photo-ID, satellite tags, or Discovery marks. Within the Antarctic waters in summer months, blue whales can travel vast distances, but most were recaptured in the same ocean basin across years. Given patterns of movement, Antarctic blue whales starting in any individual ocean basin would end up freely mixed within a few years, but these conclusions are based on relatively small sample sizes. Additionally, there is no evidence for movement across the Antarctic Peninsula, which may represent somewhat of a barrier to completely free dispersion.

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 across ocean basins (Indian, Pacific, Atlantic) using Discovery marks that takes into account marks, recaptures, mark losses, imperfect detection of marks, and whaling effort (catches) across space and time.

2) 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.

3) 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

Only two satellite tags have been deployed on Antarctic blue whales that yielded useful information. Both were tagged in 2013 (Figure 1). As part of this project, we published the entire dataset for anyone to use or incorporate into their own projects (Andrews-Goff et al. 2022, SC/69a/ForInfo48). One whale, PTT 123223 (tagged 320 km from the ice edge), initially travelled north and then west for a minimum of 6107 km across 74 days. The other whale, PTT 121205 (tagged 200 km from the ice edge), covered 1287 km 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.

No mark-recapture data for movements between Antarctic and temperate regions

No evidence was uncovered from the mark-recapture and satellite tag datasets for migratory movement between the Antarctic and lower latitude regions. Despite new photo-ID data from temperate regions, no matches have yet been made to the Antarctic Blue Whale Catalogue, nor were there any captures of Discovery marked Antarctic blue whales in any mid-latitude whaling stations. However, Antarctic blue whale song is widely heard across the Southern Hemisphere at all latitudes, especially with extensions in mid-winter (June-August) to equatorial regions (e.g., Branch et al. 2021, Shabangu et al. 2019). Our working assumption remains that Antarctic blue whales migrate to mid-latitude regions (particularly the west coast of southern Africa), based on seasonal timing, morphometrics, and song detections, but this assumption has yet to be confirmed by any direct photo-ID, satellite tag, or Discovery mark data.

Mark-recapture movement model

We created a spatially-explicit Bayesian mark-recovery model that combines population dynamics, whale movement, and catches, and was fitted to abundance estimates and inter-annual Discovery mark-recovery data (Table 1). Within-season recoveries are not included in the model. 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), and the intrinsic growth rate (r). (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 from each area into each 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 K. (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) Absolute estimates of abundance for ocean basins were derived from estimates for IWC areas (1978/9-2003/4, Branch 2007), that were then allocated to basins in proportion to the longitudinal range within each basin. (7) Relative indices of abundance for ocean basins were derived from abundance estimates for IWC areas IV and V (periods during 1989/90-2013/14) obtained from Hamabe et al. (2023).

The model of Discovery marks uses the same ocean basins and predict recoveries for each basin and year of the data. 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). Recoveries are a function of mark loss, reporting rates, harvest rates, and mark abundance in each basin. Given the small number of data points, we assumed a fixed natural survival of 0.96 in all years and basins (Branch et al. 2004), and parameterized the model so both the population model and the mark recovery assumed the same value of natural survival. We also combined mark loss and reporting rate into a single estimated parameter ("mark loss"), under the assumption that mark loss largely occurs soon after deployment, while reporting rate affects values only once (at capture). The model was fit with Bayesian methods in Stan.

We tested the estimation power of the model to distinguish between high and low movement scenarios by simulating datasets under these two scenarios and fitting the model these simulated datasets. The model estimated close to the true values of the parameters for both the high-movement and low-movement simulated datasets, except in the low movement scenario where the probability of remaining in the Atlantic which was underestimated in all simulations (Figure 4). We found that 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 (Table 2, Figure 5). Additionally, carrying capacity in the Pacific basin was estimated to be higher than in the Indian or Atlantic (Figure 6). 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

Table 2 Estimates of parameters from the Bayesian model fitted to the Discovery mark data, for inter-season movement rates within the Antarctic among the three ocean basins south of the Indian, Pacific, and Atlantic Oceans. The medians and 95% credible intervals are given from the posterior distributions from the model.

Parameter	Description	Median	2.5%	97.5%
r	Intrinsic growth	0.086	0.068	0.104
K	Carrying capacity (total)	187,175	172,456	204,579
K_{Atl}	Carrying capacity (Atlantic)	40,162	29,942	52,928
K_{Ind}	Carrying capacity (Indian)	63,890	52,166	77,825
K_{Pac}	Carrying capacity (Pacific)	82,336	68,360	99,439
$m_{Atl \rightarrow Atl}$	Movement	0.619	0.393	0.785
$m_{Ind \rightarrow Atl}$	Movement	0.102	0.022	0.262
$m_{Pac \rightarrow Atl}$	Movement	0.097	0.033	0.205
$m_{Atl \rightarrow Ind}$	Movement	0.149	0.009	0.326
$m_{Ind \rightarrow Ind}$	Movement	0.635	0.481	0.768
$m_{Pac \rightarrow Ind}$	Movement	0.207	0.112	0.323
$m_{Atl \rightarrow Pac}$	Movement	0.249	0.074	0.335
$m_{Ind \rightarrow Pac}$	Movement	0.261	0.141	0.334
$m_{Pac \rightarrow Pac}$	Movement	0.691	0.570	0.782
l	Mark loss	0.956	0.920	0.972
θ	Overdispersion	0.569	0.257	1.964

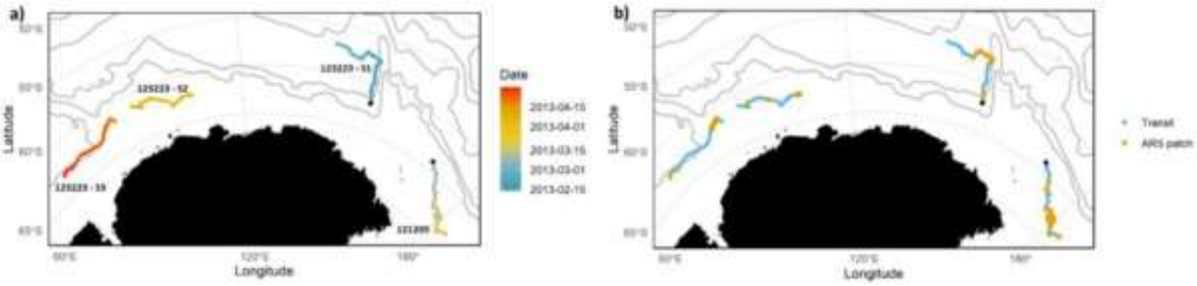

Figure 1 Satellite tag derived movements of two Antarctic blue whales, with colours coding move persistence: redder colours (close to zero) indicate area-restricted search (possible feeding areas), while bluer values (approaching one) indicate transit from one region to another. Source: Andrews-Goff et al. (2022).

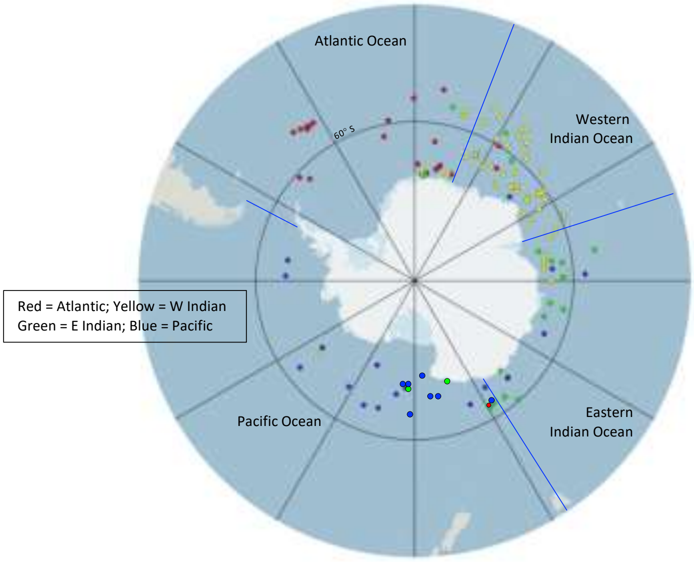

Figure 2 Locations of inter-annually recaptured Antarctic blue whales marked by Discovery tags and photo-ID. Point colors represent the ocean basin in which the whale was marked.

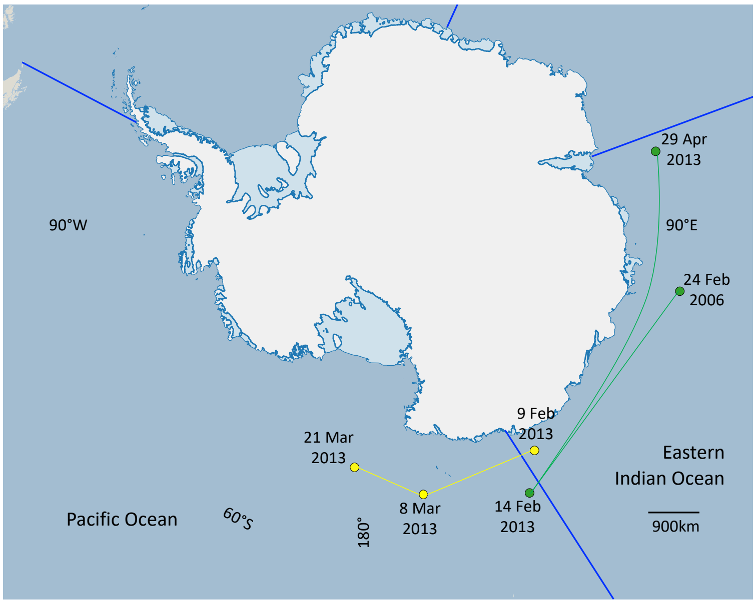

Figure 3 Locations of two individual Antarctic blue whales that were satellite tagged and were also marked and recaptured (photo-ID) either inter- or intra-seasonally. The whale represented in yellow (PTT121205) was marked on 9 February 2013 prior to being recaptured and tagged on 8 March. The last tag transmission occurred

on 21 March. The whale represented in green (PTT 123223) was marked in 2006, then recaptured and tagged on 14 February 2013. The last tag transmission occurred on 29 April 2013. Lines connect the points and do not represent whale movement.

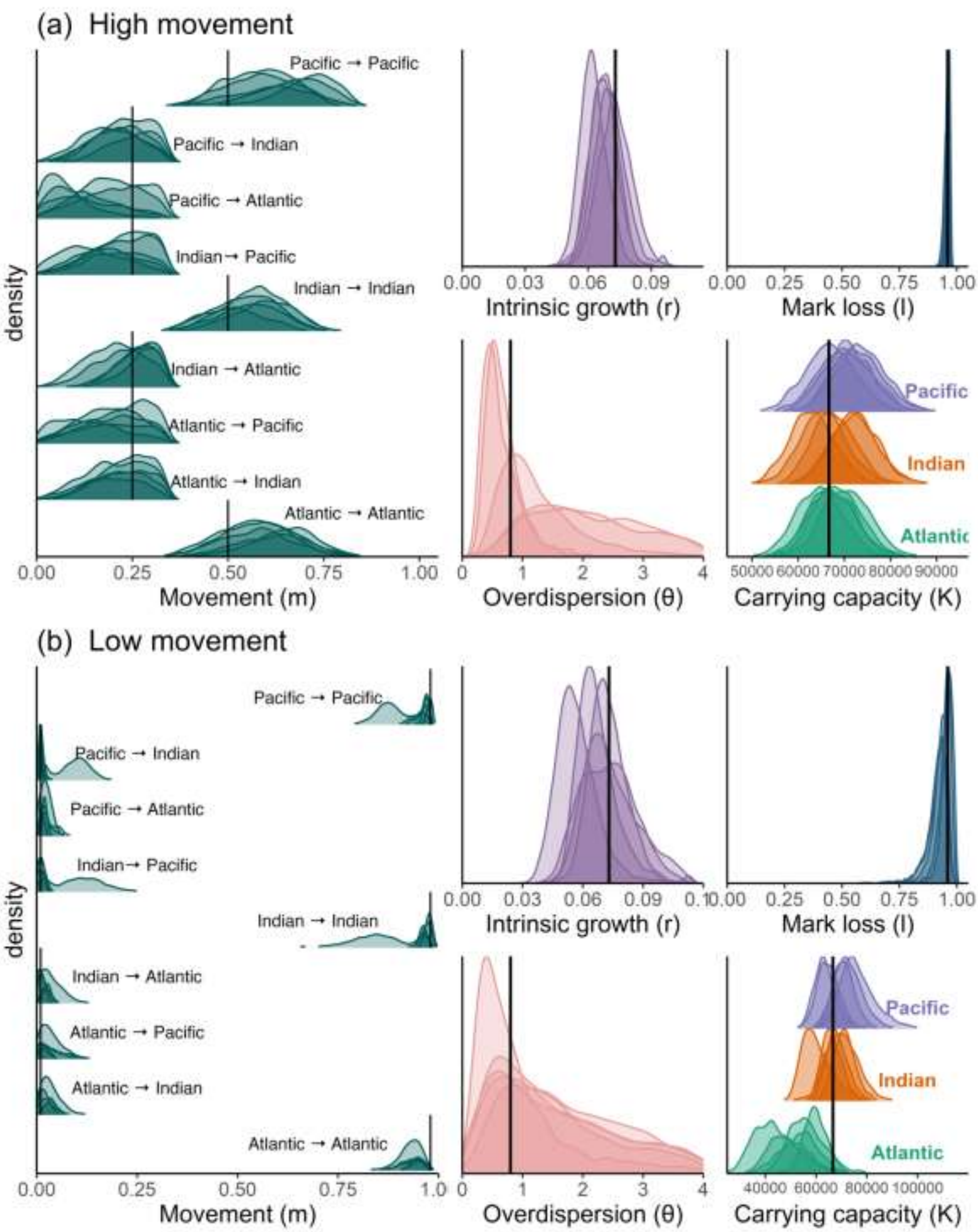

Figure 4 Posterior distributions of parameters from models fit with five simulated datasets under high movement (a, 25% move, 50% stay) and low movement (b, 1% move, 98% stay) scenarios. Values used in simulating data are represented by vertical lines.

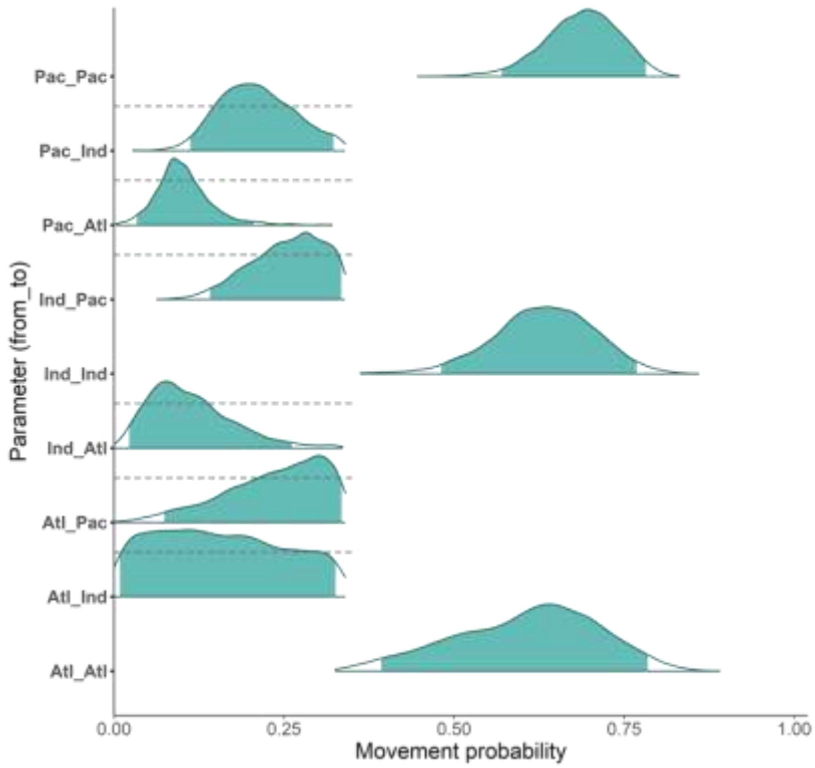

Figure 5 Estimated movement rates among ocean basins from the Bayesian model fitted to Discovery mark data. Prior (dashed line) and posterior (solid line) distributions and 95% credible intervals (shaded) are given for movement probabilities among basins (listed as from_to). The probability of remaining in a basin from season to season was calculated by subtraction.

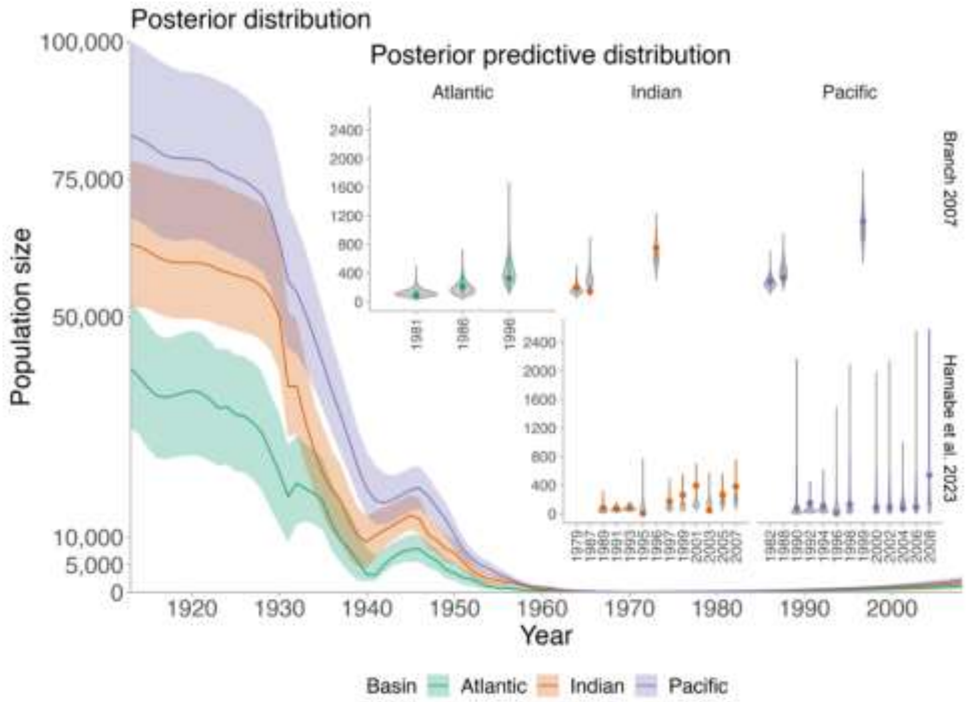

Figure 6 Estimated population size over time in each of the ocean basins, from the Bayesian model fitted to Discovery mark data. The main plot shows the posterior medians (solid line) and 95% intervals (shading), while the inset plots show model fits to the data with posterior predictive distributions (violins) to each abundance estimate (points with lines).

Conclusions

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. From one year to the next, most are recaptured in the same region that they were first encountered, but over the course of several years, the high movement rates estimated from the Discovery marks suggest mixing among all basins. However, completely free movement in all directions 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. Overall, the data support a single population for Antarctic blue whales, although the sparse nature of the Discovery marks, photo-ID, and satellite tag data, allow for surprises in the future.

Challenges

In the past year, the challenges previously posed by COVID-19, and the personnel change required to our original plan, have been overcome. The satellite tag data are now fully published and openly available (Andrews-Goff et al. 2022). Preliminary analysis of Discovery marks has been submitted to the SC (Rand et al. 2022), and is ready for submission to a scientific journal (Rand et al. in prep.) and the SC of the IWC in 2023. Finally an overview synthesis of the satellite tags, photo-ID, and Discovery marks has been presented to the SC of the IWC (Olson et al. 2022). This manuscript is also in preparation for submission to a scientific journal.

Outlook for the future

The project is completed, with papers either published or being readied for submission to peer-reviewed journals.

Project outputs

Peer-reviewed papers – 2 new in past year

Andrews-Goff V, Bell EM, Miller BS, Wotherspoon SJ, Double MC (2022) Satellite tag derived data from two Antarctic blue whales (Balaenoptera musculus intermedia) tagged in the east Antarctic sector of the Southern Ocean. Biodiversity Data Journal 10:e94228

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, Hucke-Gaete R, Staniland L (2022) Presence of Southeast Pacific blue whales (*Balaenoptera musculus*) off South Georgia in the South Atlantic Ocean. Marine Mammal Science, 38 (4). 1425-1441. https://doi.org/10.1111/mms.12946

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.

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.

Galletti Vernazzani B, Olson PA, Salgado-Kent C (2022) Progress report on Southern Hemisphere Blue Whale Catalogue: Period April 2021-March 2022. IWC paper SC/68D/SH/04.

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.

Olson P, Galletti Vernazzani B, Español-Jiménez S (2020) Using photo-identification to investigate the identity of blue whales at South Georgia: a comparison of photographs with Chile. IWC paper SC/68B/SH/13.

Olson PA, Double MC, Matsuoka K, Pastene LA, Findlay K (2020) The Antarctic Blue Whale Catalogue: new data from 2015-2019. IWC paper SC/68B/PH/04.

Olson PA, Kinzey D, Double MC, Matsuoka K, Findlay K (2021) Capture-recapture estimates of abundance of Antarctic blue whales. IWC paper SC/68C/ASI/15.

Olson PA, Boyd C, Miller E, Irvine L, Kavanagh AS, Donnelly D, Reyes MV, Smith J, Leaper R, Calderan S, Miller BS, Double MC (2021) Photo-identification of Antarctic blue whales during the ENRICH Voyage 2019. IWC paper SC/68C/PH/01.

Olson PA, Andrews-Goff V, Double MC, Matsuoka K, Pastene LA (2022) Movements of Antarctic blue whales derived from Discovery tag, photo-ID, and satellite tag data. IWC paper SC/68D/SH/09.

Rand ZR, Branch TA, Jackson JA (2022) Movement rates of Antarctic blue whales from Discovery marks. IWC paper SC/68D/SH/13.

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 24 tweets per month, and over the course of the project so far (May 2019-present) these tweets have been viewed 1.09 million times.

Scientific references cited in report

Andrews-Goff V, Bell EM, Miller BS, Wotherspoon SJ, Double MC (2022) Satellite tag derived data from two Antarctic blue whales (Balaenoptera musculus intermedia) tagged in the east Antarctic sector of the Southern Ocean. Biodiversity Data Journal 10:e94228

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.

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

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

Hamabe K, Matsuoka K, Kitakado T (2023) Estimation of abundance and population dynamics of the Antarctic blue whale in the Antarctic Ocean south of 60°S, from 70°E to 170°W. Marine Mammal Science doi: 10.1111/mms.13006

Olson PA, Andrews-Goff V, Double MC, Matsuoka K, Pastene LA (2022) Movements of Antarctic blue whales derived from Discovery tag, photo-ID, and satellite tag data. IWC paper SC/68D/SH/09

Rand ZR, Branch TA, Jackson JA (2022) Movement rates of Antarctic blue whales from Discovery marks. IWC paper SC/68D/SH/13.

Shabangu FW, Findlay KP, Yemane D, Stafford KM, van den Berg M, Blows B, Andrew RK (2019) Seasonal occurrence and diel calling behaviour of Antarctic blue whales and fin whales in relation to environmental conditions off the west coast of South Africa. Journal of Marine Systems 190: 25-39.

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

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Primary Investigators of the IWC-SORP funded project
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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 an integral component of the International Whaling Commission's Southern Ocean Research Program (IWC-SORP) Theme 6, *The right sentinel for climate change: linking foraging ground variability to population recovery in the SRW*.
Progress made in 2022/2023 includes: 1) The Southern Right Whale Consortium becoming fully active; 2) Advancements on the development of a common demographic model; 3) Further development of a MARAM model to incorporate an additional δ parameter to allow for the possibility of an early abortion and used to fit the South African photo-ID data; 4) The collation of published and available information regarding confirmed SRW offshore sightings south of 40°S. A full report on the, *Multi-ocean assessment of southern right whale demographic parameters and environmental correlates* and Theme 6, is presented in SC/69a/SH04.

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* was formed and endorsed during SC/67b (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.

Results

A common demographic population model is in development with funding support from IWC-SORP. The aim is to compare population demographics across the main Southern Hemisphere (SH) wintering grounds, by applying a common demographic model to the populations in each region, in order to eventually investigate correlations between reproductive success and environmental variables. The regional populations with available long-term photo identification (ID) databases to be included are: (1) SW Atlantic (Brazil/Argentina): (2) SE Atlantic (South Africa); (3) Australia; (4) New Zealand. This project directly contributes to the IWC-SORP Theme 6 objective 2, to update our knowledge on southern right whale population dynamics in a comparative framework.

Progress made in 2022/2023 includes:

- The Southern Right Whale Consortium is fully active, with a Memorandum of Understanding signed by 18 SRW scientific researchers of 9 countries. The consortium meets twice per year online to share knowledge, enhance collaboration and information sharing. In such meetings, presentations on progress made for each region have been shared by key researchers. At the moment, a website is in development for encouraging collaboration and outreach.

- Development of a Common demographic model is well advanced, and various intersessional (online) meetings have been held and work completed. Regular communications were maintained between key project investigators (Butterworth, Brandão, Ross-Gillespie, Charlton, Vermeulen) to discuss and progress with the Common model framework. However, application to the SW Atlantic was limited by the team member availability and specialist expertise offered by key team members.

- A MARAM model developed from Brandão et al. (2018) and based on the model from Cooke et al. (2001) was developed further to incorporate an additional δ parameter to allow for the possibility of an early abortion and used to fit the South African photo-ID data. This “Delta-loop” model will be published in Brandão et al. (In press). Model outputs using the Delta-loop and Common model for the South African right whale dataset show slight differences over the most recent years, the reasons for which have still to be fully investigated. The Common model has not yet been applied to the Australian dataset.

- The collation of published and available information regarding confirmed SRW offshore sightings south of 40°S was finalised in 2022 to inform the selection of environmental variables for further investigation of links between demographic parameters (i.e., reproductive success) and climate. For more info, see SC/68d/SH/03.

A full report of related work on Theme 6 can be found in SC/69a/SH04.

Conclusions

Objectives 1 and 4 have been completed, and substantial progress was made towards fulfilling objective 2. 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.

Project outputs

Peer-reviewed papers produced by consortium

Brandão A, Ross-Gillespie A, Vermeulen E, Butterworth D (*In press*) A photo-identification based assessment model of southern right whales (*Eubalaena australis*) surveyed in South African waters, with a focus on some recent low counts of mothers with calves. African Journal of Marine Science.

Carroll EL, Riekkola L, Andrews-Goff V, Baker CS, Constantine R, Cole R, Goetz K, Harcourt R, Lundquist D, Meyer C, Ogle M, O'Rorke R, Stuck E, van der Reis AL, Zerbini AN, Childerhouse SJ (2022) New Zealand southern right whale (Tohorā nō Aotearoa) habitat use in Port Ross, Auckland Islands, over three decades. Polar Biology 45: 1441-1458. https://doi.org/10.1007/s00300-022-03076-7

Christiansen F, Bejder L, Burnell S, Ward R, Charlton C (2022) Estimating the cost of growth in southern right whales from drone photogrammetry data and long-term sighting histories. Marine Ecology Progress Series 687: 173-194.

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Derville S, Torres LG, Newsome SD, Somes C, Valenzuela LO, Vander Zanden HB, Baker CS,… , Carroll EL (2023) Long-term stability in the foraging range of a Southern Ocean predator between the eras of whaling and Anthropocene climate change. Proceedings of the National Academy of Sciences. https://doi.org/10.1073/pnas.2214035120

Johnston DR, Rayment W, Dawson SM (2022) Morphometrics and body condition of southern right whales on the calving grounds at Port Ross, Auckland Islands. Mammalian Biology. https://doi.org/10.1007/s42991-021-00175-6

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Salgado Kent C, Burton C, Giroud M, Elsdon B (2023) A photo-identification study of Southern Right Whales to update aggregation area classification in south-western Australia. Project 1.22 report to the National Environmental Science Program. https://www.nespmarinecoastal.edu.au/project-1-22-final-report-2/

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Vermeulen E, Jouve E, Best P, Cliff G, Dicken M, Kotze D, McCue S, Meyer M, Seakamela SM, Thompson G, Thornton M, Wilkinson C (2022) Mortalities of southern right whales (*Eubalaena australis*) and related anthropogenic factors in South African waters, 1999 – 2019. JCRM 23(1): 149-6. https://doi.org/10.47536/jcrm.v23i1.357

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.

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

Reports

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Presentations

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

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

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Executive summary

The year-round acoustic occurrence and behaviour of most baleen whales around the Prince Edward Islands in the Southern Ocean south of South Africa are currently unknown, mainly because of lack of research effort in this region. Currently available information about the occurrence and behaviour of baleen whales in that region are based on short, seasonal sighting research from shore or research vessels, which is insufficient at providing an accurate and comprehensive picture of these animals' ecology. This study collected year-round passive acoustic data between two Prince Edward Islands (Figure 1) 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 large whale species were determined acoustically, and these acoustic results were 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 these islands, and results will be important at informing on the long-term use of this ecoregion by different whales and assessing the status of these marine mammals' populations - some of which were reduced to very low population levels by historic whaling in the Southern Hemisphere.

Introduction

Baleen whales produce calls that are used for communication and are specific to a particular geographic region, sex, species or even to a subspecies level (e.g., Payne and McVay, 1971; Edds-Walton, 1997; Ljungblad et al. 1998; McDonald et al. 2006; Širović et al. 2009; Leroy et al. 2021). These calls can be produced in a song form when a single or multiple animals produce these in a rhythmic, repetitive and sometimes predictable or complex hierarchal manner (e.g. Payne and McVay, 1971; Guinee and Payne, 1988; Ljungblad et al. 1998; McDonald et al. 2006). Antarctic blue whales (*Balaenoptera musculus intermedia*) produce Z-calls (frequency range:18-26 Hz, duration: 18-26 s) specific to males (Ljungblad et al. 1998; Rankin et al. 2005), and D-calls (frequency range: 22-106 Hz; duration: ~2-6 s) which are produced by both sexes during foraging (Rankin et al. 2005; Oleson et al. 2007) and social interactions (Schall et al. 2020). Fin whales *(B. physalus*) produce 20 Hz pulses (frequency range: 15-28 Hz, duration: <1 s) with simultaneous high frequency pulses (peaking at 99 Hz for the Eastern Antarctica Peninsula acoustic population and at 89 Hz for the Western Antarctica Peninsula acoustic population) specific to males (Edds-Walton, 1997; Širović et al. 2009), and the 40 Hz pulses (frequency range: 30−75 Hz; duration: 0.3-1 s) likely produced by both sexes during feeding (Wiggins and Hildebrand, 2020; Romagosa et al. 2021). Humpback whales (*Megaptera novaeangliae*) sing rhythmic songs throughout the world's oceans that are thought to be produced only by males (Payne and McVay, 1971; Guinee and Payne, 1988) whereas non-songs are produced by both sexes including calves (e.g. Videsen et al. 2017). Antarctic minke whales (*B. bonaerensis*) produce rhythmic bioduck songs that vary geographically (Dominello and Širović, 2016; Shabangu et al. 2020; Rossi-Santos et al. 2022; Risch, 2022). Finally, sei whales (*B. borealis*) are known to produce downsweeps, upsweep, upsweep-downsweep calls, arch, low and mid-frequency calls (e.g.

Calderan et al. 2014; Cerchio and Weir 2022). This project uses these vocalizations (Figure 2) to characterize the occurrence, behaviour, and ecology of baleen whales around the Prince Edward Islands (PEIs).

Objectives

This project had four main objectives aimed at better understanding the seasonal and spatial occurrence of large whales around the PEIs:

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.

Results

Acoustic data were collected using a SoundTrap 500STD recorder (Ocean Instruments NZ, New Zealand) deployed on an oceanographic mooring of the South Atlantic Meridional Overturning Circulation (SAMOC) program. The recorder was deployed on 24 April 2021 at 46° 46.4' S, 37° 54.7' E between Marion Island and Prince Edward Island (Figure 1) and was recovered on 06 May 2022. The oceanographic mooring was deployed at a water depth of 167 m, and the recorder was positioned 5 m off the seafloor at 162 m. From this acoustic dataset, calls of Antarctic blue whales, Madagascan pygmy blue whales (*B. m. brevicauda*), fin whales, sei whales, Antarctic minke whales, and humpback whales were detected (Figure 2). Madagascan pygmy blue whale calls were detected from mid-summer through autumn (December through May) but not in winter through early summer (June through November) (Figure 3a). Blue whale D-calls were intermittently detected in all seasons of the year although not detected in July, August, and October (Figure 3b). Antarctic blue whale Z-calls were detected in autumn through mid-spring (April through early October) (Figure 3c). The 18-28 Hz blue and fin whale chorus was detected from autumn through early spring (May through early September) and overlaps with blue and fin whale presence although this chorus was sometimes not detected when blue whale Z-calls and fin whale 20 Hz pulses were detected (Figure 3d). Fin whale 20 Hz pulses were detected throughout the year although intermittently in spring and summer and with a peak in autumn and winter (Figure 3e). Similarly, the fin whale 40 Hz pulses were detected throughout the year, with a peak in winter and spring (Figure 3f). There was a temporal separation between the detection of 20 and 40 Hz fin whale pulses in certain instances (Figure 3e,f). Humpback whale songs were detected from May 2021 through March 2022, where songs were detected continuously from June through mid-September but intermittently from late September through mid-March (Figure 3g). Antarctic minke whale "bioduck" calls were detected intermittently from July through October (Figure 3h). Sei whale upsweeps were detected in May 2021, September 2021, March 2022, April 2022, and May 2022 (Figure 3i).

Transmission loss was estimated using a parabolic equation (PE) model, Peregrine/Seahawk, developed by Applied Ocean Sciences (AOS), based on the PE code written by Michael Collins (RAM), and the model indicated that whale call TL was low below 25 km from the recorder location, but calls could be detected to a maximum of 140 km (Figure 4).

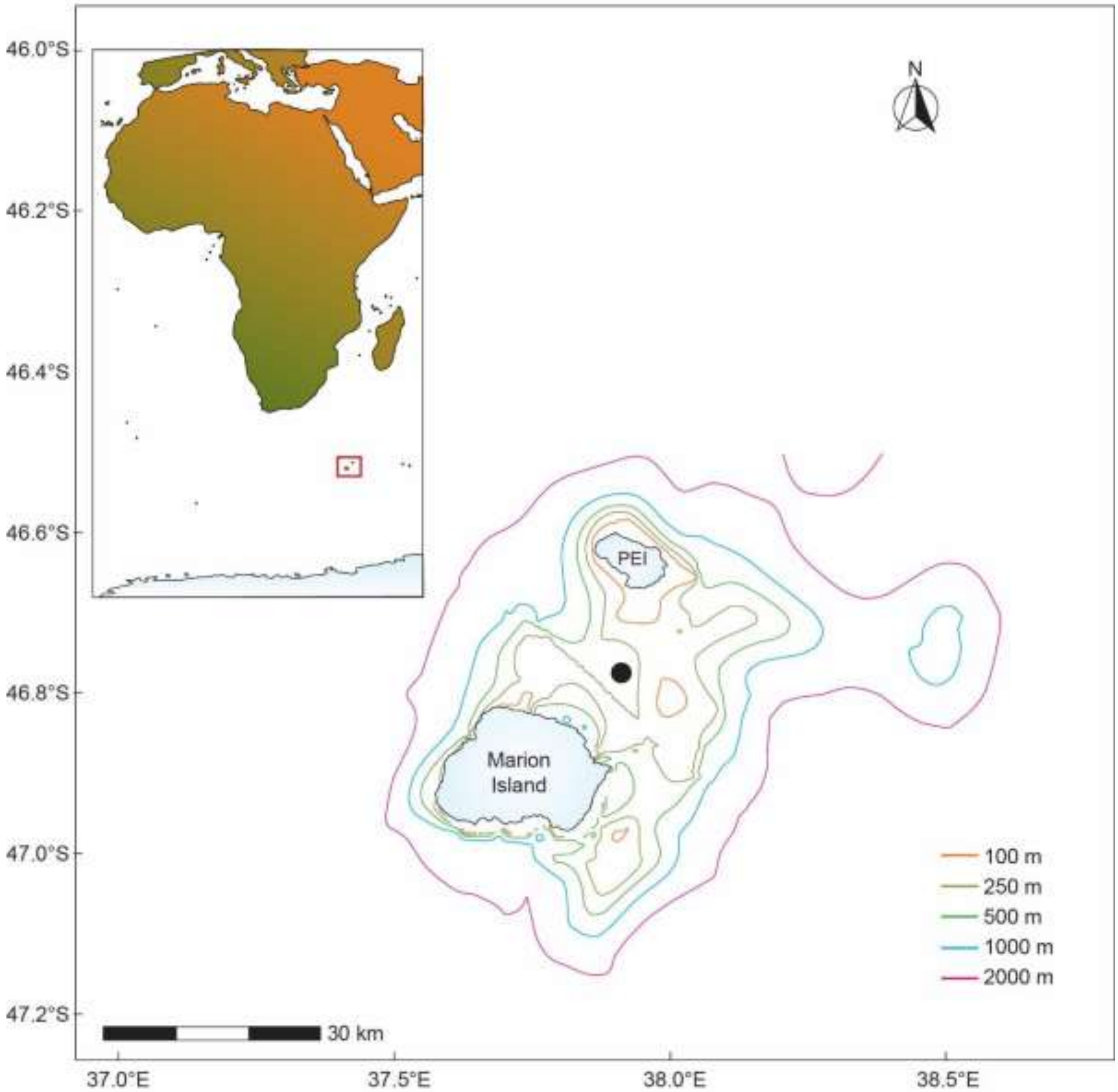

Figure 1 Map showing the location of Marion Island and Prince Edward Island (PEI) together with location of the oceanographic mooring containing the acoustic recorder (black circle) deployed between the two islands. Bathymetry around the islands is indicated by colour coded lines. The insert map shows the zoomed-out position of the Prince Edward Islands (small red box) relative to South Africa's mainland and Antarctica. Bathymetry data were obtained from 2022 GEBCO Compilation Group (https://doi.org/10.5285/e0f0bb80-ab44-2739-e053-6c86abc0289c). The sub-Antarctic Prince Edward Islands (PEIs) are located in the southern Indian part of the Southern Ocean and comprise of Marion Island (296 km2; 46.5°S, 37.5° E) and the smaller Prince Edward Island (45 km2; 46.2° S, 37.6° E) positioned to the north-east of Marion Island.

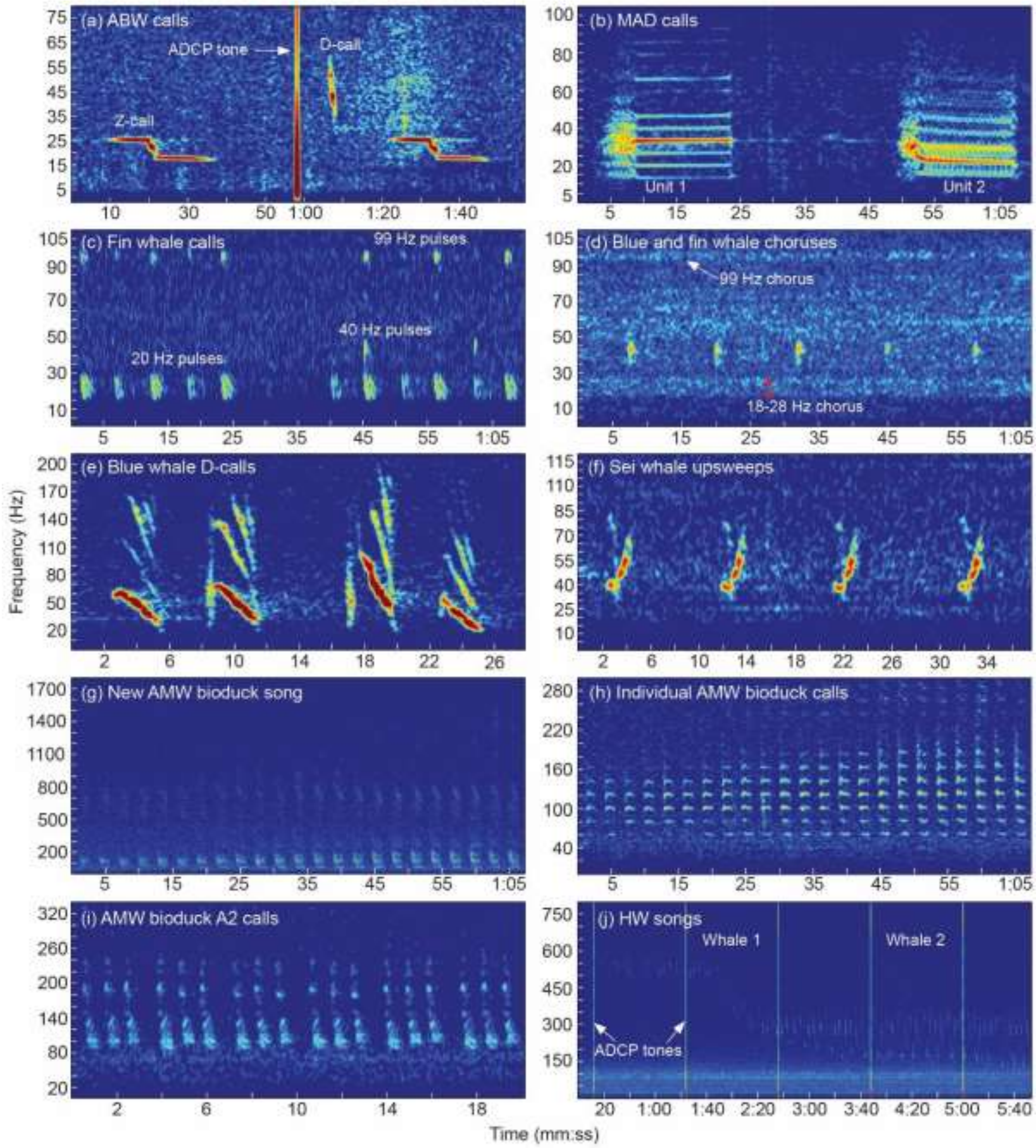

Figure 2 Spectrograms of detected (a) Antarctic blue whale (ABW) Z-calls, D-call and ADCP tone; (b) Madagascan (MAD) pygmy blue whale call units 1 and 2; (c) fin whale 20 Hz pulses, 40 Hz pulses and 99 Hz pulses; (d) blue and fin whale 18-28 Hz chorus, 99 Hz chorus and 40 Hz pulses; (e) D-calls with harmonics; (f) sei whale upsweep; (g) full frequency range including harmonics of Antarctic minke whale (AMW) “bioduck” calls produced in song form; (h) zoom in below 300 Hz range of (g) to show the spectral structure of the bioduck calls; (i) Antarctic minke whale bioduck A2 song; (j) humpback whale (HW) song from two whales together with regular Acoustic Doppler Current Profiler tones. Spectrogram parameters (Hann window and 90% overlap were used to produce all spectrograms): (a) frame size = 1.75 s and discrete Fourier transform (DFT) size = 32768 samples, (b) frame size = 1.24 s and DFT size = 16384 samples, (c) frame size = 0.52 s and DFT size = 8192 samples, (d) frame size = 0.93 s and DFT size = 16384 samples, (e) frame size = 0.56 s and DFT size = 8192 samples, (f) frame size = 0.60 s and DFT size = 8192 samples, (g) frame size = 0.34 s and DFT size = 4096 samples, (h) frame size = 0.70 s and DFT size = 8192 samples, (i) frame size = 0.27 s and DFT size = 4096 samples, and (j) frame size = 0.93 s and DFT size = 16384 samples.

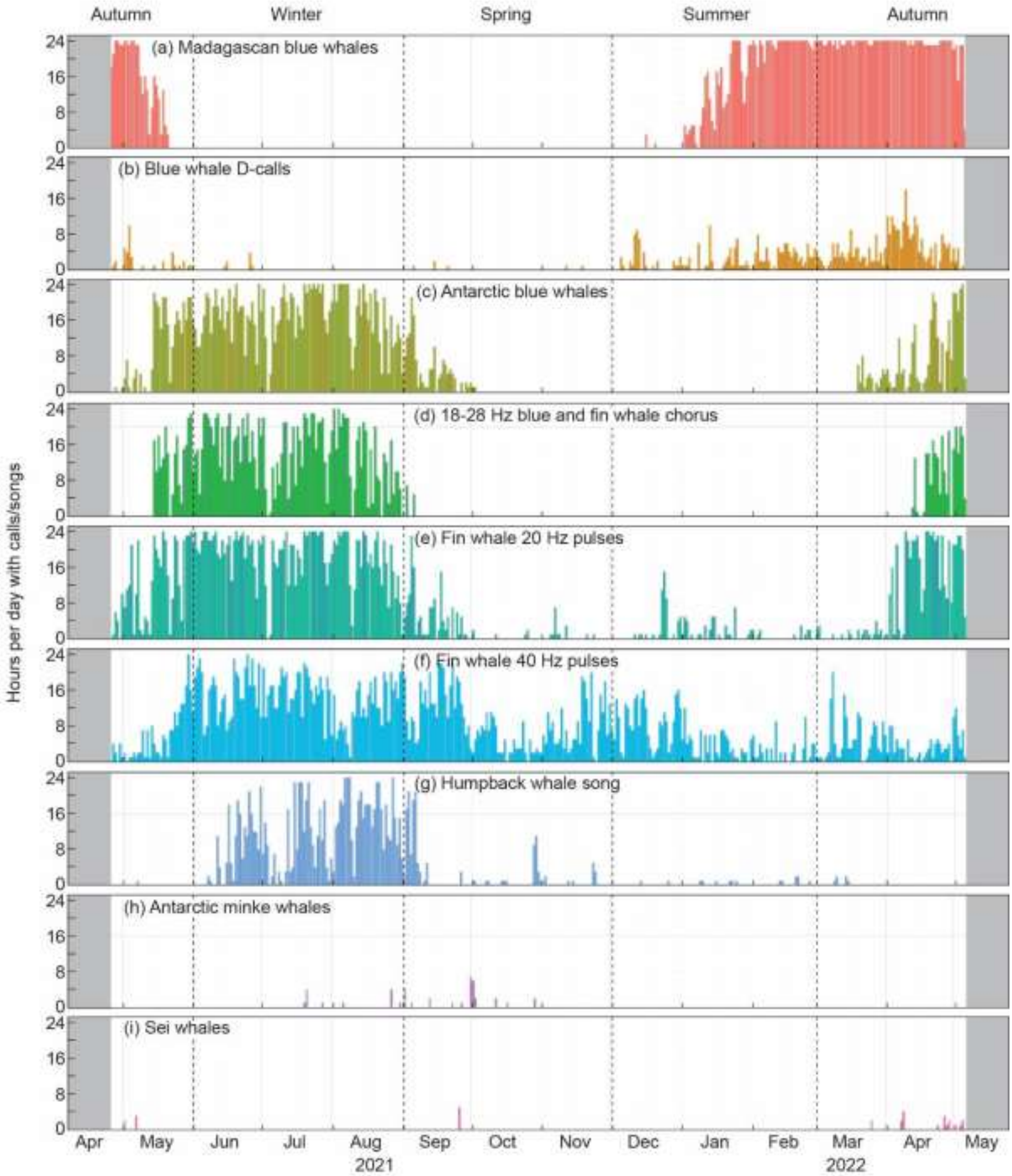

Figure 3 Daily acoustic occurrence pattern of all baleen whales: (a) Madagascan pygmy blue whales, (b) blue whale D-calls, (c) Antarctic blue whales, (d) 18-28 Hz blue and fin whale chorus, (e) fin whale 20 Hz pulse, (f) fin whale 40 Hz pulse, (g) humpback whales, (h) Antarctic minke whales, and (i) sei whales. Grey shadings indicate times without PAM effort.

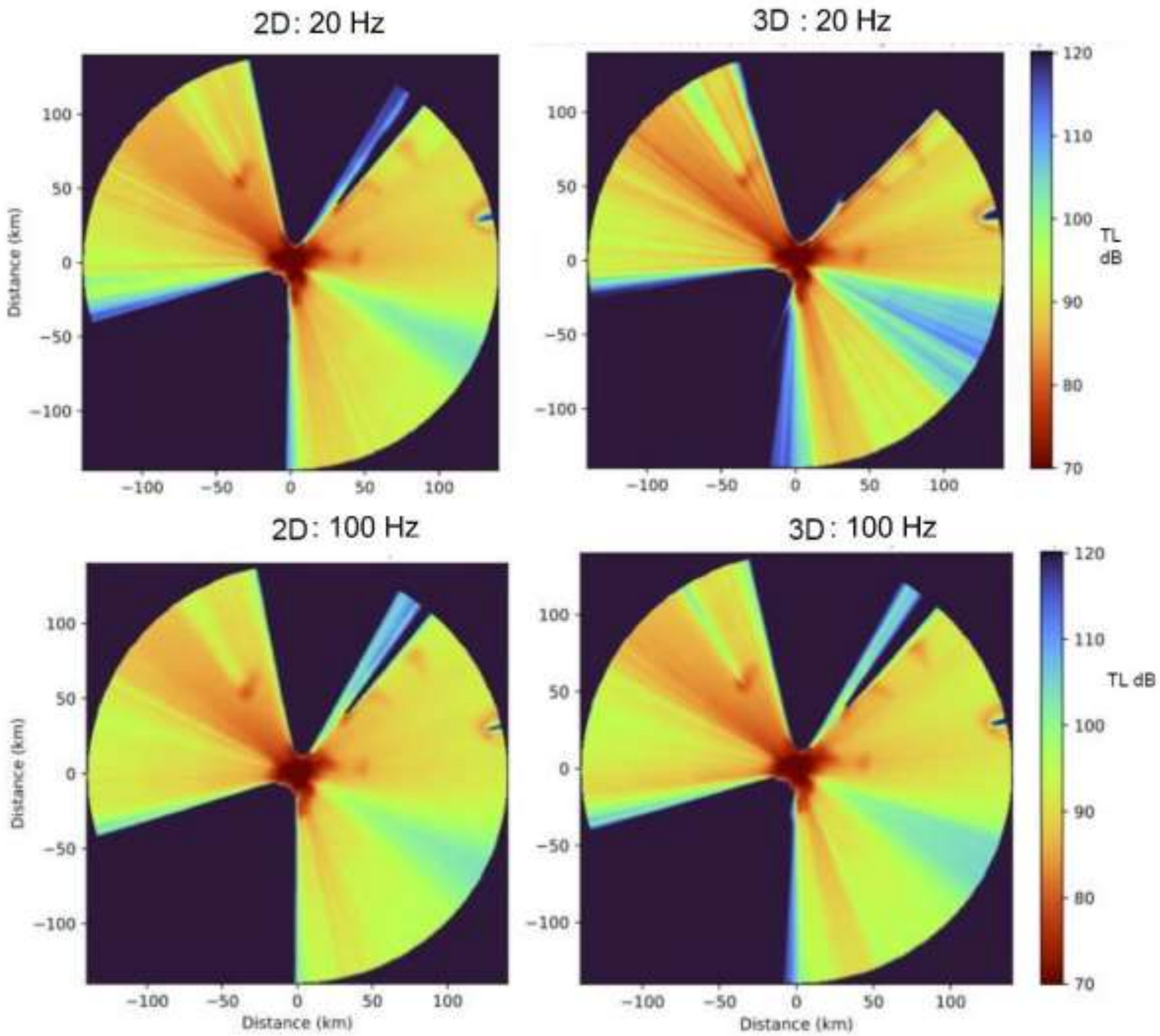

Figure 4 2D and 3D transmission loss (TL) in winter (June) for baleen whale calls simulated at 20 and 100 Hz for whales assumed to vocalize at 30 m depth.

Research voyages/expeditions

A total of 2099.77 hours of acoustic effort were conducted over 377 days between 2021 and 2022. April 2021 and May 2022 had the lowest acoustic effort (26.83 and 29.17 hours, respectively) since the acoustic recorder was deployed and recovered during those months, respectively. Nonetheless, May 2021 and April 2022 provide the full acoustic effort coverage for those months. More acoustic data have been collected between May 2022 and April 2023.

Conclusions

Fin whales appear to be resident, humpback whales are present almost year-around, while Antarctic blue whales, Madagascan blue whales, minke whales and sei whales are visitors using the PEIs as an overwintering ground, feeding ground, and/or stop over spot during migration. The observed high acoustic diversity of baleen whales qualifies the PEIs area as an important or hotspot habitat of these marine mammals. This is the first study of these baleen whale occurrence at this sub-Antarctic Island, continued monitoring at this area is warranted to inform future conservation and management strategies around sub-Antarctic islands.

Challenges

Noise caused by mooring vibration at high ocean current speeds masked some of the biological sounds in some instances, we are seeking ways to eliminate that noise.

Outlook for the future

There is potential for the project to continue for decades given that this project benefits from an existing long-term oceanographic project that is well established and will continue for the next decade or so. For the acoustic project to continue, there is a need for funds for purchasing batteries and SD cards to replace present ones during annual servicing of the instrument.

Project outputs

Students and theses

Robyn Daniels. Acoustic ecology and occurrence of killer whales at sub-Antarctic Marion Island. Honours Thesis University of Cape Town, South Africa. 2022.

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