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Annual Report of the Southern Ocean Research Partnership (IWC-SORP) 2021/22

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Revised

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ABSTRACT

The Southern Ocean Research Partnership (IWC-SORP) was established in 2009 with the aim of developing a multi-lateral, non-lethal scientific research programme that would improve the coordinated and cooperative delivery of science to the IWC. 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. This paper reports on the continued progress of IWC-SORP and its seven Commission-endorsed research themes[1] since the Scientific Committee meeting in 2021. This progress includes the production of at least 40 peer-reviewed scientific papers in 2021/22, bringing the total number of peer-reviewed publications related to IWC-SORP produced since the start of the initiative to ca. 248. Moreover, 190 IWC-SORP related papers have been submitted to the Scientific Committee, 22 of them this year. In addition, IWC-SORP has directly contributed to at least 11 Ph.D., 6 Masters and 5 honours theses.

The COVID-19 pandemic has caused major disruption to most of the IWC-SORP projects through the closure of laboratories, cancellation of voyages and disruption of fieldwork. Nevertheless, limited fieldwork was undertaken in the western Antarctic Peninsula and sub-Antarctic Marion Island. Southern right whale aerial surveys were conducted in South Africa and Australia. Images for photo-identification have been collected, satellite tags have been deployed on southern right and fin whales. Biopsy samples have been collected from southern right and humpback whales; long-term acoustic morrings have been deployed and hundreds of hours of cetacean acoustic recordings have been made and analysed. IWC-SORP funded projects have had extensions to their timelines approved to account for COVID-19 pandemic related disruptions.

KEYWORDS: SOUTHERN OCEAN RESEARCH PARTNERSHIP, IWC-SORP, ANTARCTICA, ABUNDANCE, ACOUSTICS, BIOPSY SAMPLING, PHOTO-IDENTIFICATION, SATELLITE TAGGING, MOVEMENT, CONNECTIVITY, RESEARCH VOYAGE, BLUE, KILLER, HUMPBACK, MINKE, SOUTHERN RIGHT, FIN, WHALE

INTRODUCTION

In 2008, the development of regional non-lethal cetacean research partnerships was proposed to the International Whaling Commission (IWC). These research partnerships would use modern, non-lethal, scientific methods to provide the information necessary to best conserve and manage cetacean species. The proposal was received very positively by IWC member nations. As as result, the Southern Ocean Research Partnership (IWC-SORP), a multi-lateral, non-lethal, scientific whale research program was established in March 2009 and has been supported by financial contributions from the Governments of Australia, the United States of America, Chile, the Netherlands, France, and the NGOs WWF-Australia and International Fund for Animal Welfare. The aim of IWC-SORP is to deliver coordinated and cooperative Southern Ocean science to the IWC. Partnership members include Argentina, Australia, Belgium, Brazil, Chile, France, Germany, Italy, Luxembourg, New Zealand, Norway, South Africa, the United States of America. IWC-SORP is an open Partnership that welcomes new members. Its ethos is one of open collaboration, communication and data sharing.

The objectives, research plan, and procedural framework for the Partnership were developed through a workshop held in Sydney, Australia in March, 2009. Subsequently, a framework and set of objectives for IWC-SORP were endorsed by the IWC at its Annual Meeting in June 2009. Project plans (SC/63/O13) were presented to the IWC in 2011 and 2012 and reports summarising the activities of IWC-SORP research themes (formally termed projects) have been presented annually to the Scientific Committee (SC/63/O12; SC/64/O13; SC/65a/O11; SC/65b/SH12; SC/66a/SH8; SC/66b/SH10; SC/67a/SH04; SC/67b/SH21; SC/68a/SH10; SC/68b/SH04; SC/68c/SH12; this paper).

This paper reports on the progress and results of the seven Commission endorsed research themes[1] since the last meeting of the Scientific Committee in 2020. Further details of all seven IWC-SORP themes can be found at https://iwc.int/sorp.

IWC-SORP RESEARCH FUND

In 2021/22, no funding allocations were made from the IWC-SORP Research Fund. Details of previous allocations and project progress reports are presented in SC/68a/SH11, SC/68b/SH05, SC/68c/SH13 and SC/68d/SH08.

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

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

VESSEL TIME

The following vessel time has been awarded to IWC-SORP researchers and either has taken place in the last reporting period or will when COVID-19 restrictions allow:

1. University of Auckland and Cawthron Institute led expedition to the Auckland Islands Maungahuka, June/July 2021
2. NSF-funded and opportunistic voyages to the Antarctic Peninsula – 2021/22 (Friedlaender, Pallin et al.)
3. Argentinean *ARA Almirante Irizar* voyage along Western Antarctic Peninsula – 24 February - 3 April 2022 (Iniguez et al.)
4. *RV Maria S. Merian* (*Rescheduled due to COVID-19*) to the shelf area from the South Orkney Islands/ Las islas Orcadas del Sur to the South Shetland Islands/ Las islas Shetland del Sur – 15 February- 17 March April 2023 (Herr et al.)
5. Argentinean *ARA Almirante Irizar* voyage along Western Antarctic Peninsula – early 2023 (Iniguez et al.)

[1]There are currently seven IWC-SORP Themes (formerly referred to as Projects) covering 1) blue whales, 2) killer whales, 3) baleen whale foraging, 4) humpback connectivity, 5) blue and fin whale acoustics, 6) southern right whales and 7) fin whales.

IWC-SORP THEME 1 PROGRESS REPORT – 2021/22. Antarctic Blue Whale Project (ABWP)

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Introduction

About a third of a million Antarctic blue whales (*Balaenoptera musculus intermedia*) were taken during commercial whaling in the Southern Hemisphere. In 1964 the International Whaling Commission banned the hunting of blue whales, although some were still caught illegally until 1973. The Antarctic blue whale is currently classified as critically endangered by the International Union for Conservation of Nature (IUCN) and is of global interest as one of the most at-risk species of baleen whale in the Southern Ocean.

Currently our understanding of Antarctic blue whale ecology, behaviour and post-exploitation recovery is very poor. Only two abundance estimates for Antarctic blue whales (ABW) have been derived since 1964, each with low precision. The Antarctic Blue Whale Project is a coordinated, international research programme, focused on applying a multi-disciplinary approach to understand both the recovery of Antarctic blue whales and their important role in the Southern Ocean ecosystem through an investigation of their foraging ecology, distribution, movements and habitat preferences. These data will ultimately contribute toward a precise estimation of Antarctic blue whale circumpolar abundance and their rate of recovery.

Overall objectives

The objectives of the Antarctic Blue Whale Project are to:

- Identify the most appropriate and efficient method to deliver a new circumpolar abundance estimate of Antarctic blue whales;

- Develop and refine methods to improve survey efficiency;
- Deliver a new circumpolar Antarctic blue whale abundance estimate;
- Improve understanding of Antarctic blue whale population structure;
- Improve understanding of linkages between Antarctic blue whale breeding and feeding grounds;
- Characterise the behaviour of Antarctic blue whale on the feeding grounds.

Project activities in 2021/22

Due to the ongoing COVID-19 pandemic, work on the Antarctic Blue Whale Project has largely focused on analyses of data collected during previous IWC-SORP voyages, analyses of movements of Antarctic blue whales from recent and historic data, and photo-identification of whales from research datasets and platforms of opportunity.

2019 ENRICH voyage to the Southern Ocean - update

The IWC-SORP *ENRICH* Voyage (**E**uphausiids and **N**utrient **R**ecycling in **C**etacean **H**otspots), was conducted from 19 January-05 March 2019, aboard the CSIRO Marine National Facility research vessel *RV Investigator*. The voyage departed from and returned to Hobart, Tasmania, Australia, and conducted most marine science operations in the area between 60°S – 67°S and 138°E – 152°E, covering 13,000 kilometres. The voyage was led by the Australian Antarctic Program and involved 28 international scientists. The voyage represented the first time that a survey of Antarctic blue whales has been conducted together with a structured survey of their prey, Antarctic krill. A full voyage report was presented last year in SC/68c/SH19. The data and samples collected on the voyage continue to be analysed and several peer-reviewed papers have already been published.

It is anticipated that the *ENRICH* voyage multidisciplinary research will contribute to the improvement of ecosystem-based management of the Antarctic krill fishery via the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) and the conservation of endangered Antarctic blue whales.

IWC-SORP sincerely thanks WWF-Australia for a contribution of $10,000 AUD toward participation of Paula Olson on the IWC-SORP ENRICH voyage. We gratefully acknowledge the CSIRO Marine National Facility staff and vessel crew for their incredible support before and during the voyage.

2021 TEMPO voyage to the Southern Ocean - update

The TEMPO Voyage (Trends in Euphausiids off Mawson, Predators and Oceanography) was conducted from 29 January-24 March 2021, aboard the CSIRO Marine National Facility research vessel *RV Investigator*. The voyage departed from and returned to Hobart, Tasmania, Australia, and conducted most marine science operations in the area between 62°S – 68°S and 55°E –80°E, covering 16,000 kilometres. The voyage was led by the Australian Antarctic Program and involved 20 scientists from only Australia and New Zealand due to COVID-19 travel restrictions.

The primary objective of the TEMPO voyage was to help ensure orderly development of the krill fishery by updating the biomass estimate to revise the catch limit for Antarctic krill in CCAMLR Division 58.4.2-East, in the IO sector. A number of Krill Observational Moorings for Benthic Investigation (KOMBI) system were deployed during the survey to further monitor seasonal dynamics of krill in the seasonally ice covered area. Furthermore, the survey was also designed to improve understanding of the connectivity of the krill population, and overlap between krill and predators, in addition to biological oceanographic processes. A team of marine mammal observers on board undertook line transect distance sampling and detected over 1,400 cetaceans throughout the entire voyage. Furthermore, several hundred sonobuoys were deployed regularly during the voyage, and blue and fin whales were commonly detected. A deeper understanding of all species and processes studied during the TEMPO voyage will support the design of a tractable and sustainable long-term monitoring plan and spatial management (small-scale management unit) of the krill fishery in East Antarctica (CCAMLR's Conservation Measure 51-03).

Results from the TEMPO voyage were presented to SC-CAMLR during 2021. Many of the data products and metadata are publically available on the CSIRO Marine National Facility data trawler (search IN2021_V01).

In addition, a Special Volume in Frontiers: *Antarctic krill and its ecosystem in the East Antarctic: population and environmental interactions*, is planned for 2023. This Special Volume will include data from both the IWC-SORP ENRICH and TEMPO voyages.

ARA Almirante Irizar *voyage 2022 - 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*

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

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

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

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

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

Photo-identification of Antarctic blue whales

One of the research objectives of the Antarctic Blue Whale Project is to collect identification photos of Antarctic blue whales at a number sufficient to contribute toward estimating abundance using mark-recapture methods. Obtaining a current estimate of abundance is considered fundamental for the assessment of the status of the Antarctic blue whale population and in monitoring its recovery (Bell, 2021).

Photo-identification of Antarctic blue whales was undertaken during the IWC-SORP 2019 ENRICH voyage, the 2015 and 2013 Antarctic Blue Whale Voyages, and during IWC IDCR/SOWER surveys. Photographs from these cruises, and from those collected from other sources, are compiled in the Antarctic Blue Whale Catalogue (e.g. Olson et al., 2016; Olson et al., 2020).

During 2021/2022, 10 new whale IDs (7 left sides, 4 right sides) were added to the Antarctic Blue Whale Catalogue from photographs collected opportunistically by fellow scientists working on other projects and by naturalists aboard tourist vessels. The current total number of identified blue whales in the catalogue is 562, represented by 421 left side and 413 right side photographs. This represents 25% of the most recent population estimate of 2,280 (Branch, 2007. These photo-ID data are being used in a new capture-recapture estimate of abundance (presented to the Scientific Committee during the 2020 SC/68c meeting). These data are also being used, in combination with Discovery tag data, in an investigation of intra- and inter-annual movement patterns of Antarctic blue whales (see also Project 28, SC/68d/SH08).

ABWP-related IWC-SORP Research Fund projects

Work also continues to model somatic growth and sex ratios to predict population-level impacts of whaling on Antarctic blue whales (Project 13, SC/68d/SH08); conduct a long-term, circumpolar comparison of call-densities of Antarctic blue and fin whales (Project 17, SC/68d/SH08); infer the demographic history of blue and fin whales in the Antarctic using mitogenomic sequences generated from historical baleen (Project 18, SC/68d/SH08); to develop statistical and technical methods to support the use of long-range UAVs to assess and monitor cetacean populations in the Southern Ocean (Project 21, SC/68d/SH08), to investigate the use of remote aerial deployment and sampling as a new sampling platform for large cetaceans (Project 26, SC/68d/SH08) and provide insights into Antarctic blue whale population structure and movements from photo-identification, Discovery marks and satellite tags (Project 28, SC/68d/SH08).

Platforms of opportunity

Partnerships with tourist ships, fishing vessels and naval vessels are essential for augmenting data for the circumpolar estimation of Antarctic blue whale abundance and other IWC-SORP projects. The COVID-19 pandemic has reduced such opportunities but it is anticipated that the use of platforms of opportunity by IWC-SORP researchers will increase again in coming years, once international travel resumes.

Project outputs

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Antarctic waters of the Scotia Sea and western Antarctic Peninsula: preliminary results. Poster presentation to the XVI Conference on Specialists on Aquatic Mammals from South America and 10th SOLAMAC Congress, December 2014, Cartagena de Indias, Colombia.

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Popular talks

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.

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.

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

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.

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

Popular articles

Cahalan S (2013) Protecting the icons of the deep. International Innovation: Environment April 2013.
Cahalan S (2013) Out of the Blue. Island, Issue 133.
Pyper W (2012) Listening to the blues. Australian Antarctic Magazine, Issue 23.
Pyper W (2013) Songs reveal elusive giants. Australian Antarctic Magazine, Issue 24.

Fundación Cethus´ blogs:
https://cethusnews.wordpress.com/2013/05/03/fundacion-cethus-in-antarctica/
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Media

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

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

Argentinean Navy's newspaper:
http://gacetamarinera.com.ar/el-trabajo-de-los-investigadores-a-bordo-del-irizar/
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

The successful 2015 Joint New Zealand-Australia Antarctic Ecosystems Voyage attracted considerable media attention. The voyage webpage including voyage sitreps and news items can be found here:
http://www.antarctica.gov.au/science/southern-ocean-ecosystems-environmental-change-and-conservation/wildlife-conservation/new-zealand-australia-antarctic-ecosystems-voyage-2015
and
http://www.niwa.co.nz/antarctic-ecosystems-voyage

ABWP scientists conducted a feature interview on the ABC Radio programme Off Track AMMC's Antarctic blue whale research and Antarctic blue whale song:
http://www.abc.net.au/radionational/programs/offtrack/the-biggest-underwater-choir-in-the-world/6914940
and
http://www.abc.net.au/radionational/programs/offtrack/antarctic-blue-whale-song-worlds-biggest-choir/6919222

The ABWP was represented at the sold-out panel discussion, Discovering the Deep, at the World Science Festival in Brisbane, Australia:
http://www.worldsciencefestival.com.au/program/events/discovering-the-deep/

Antarctic Circumnavigation Expedition (ACE):
http://www.antarctica.gov.au/news/2016/australian-scientists-to-join-international-colleagues-for-antarctic-circumnavigation-voyage
and
http://www.businessinsider.com.au/the-first-circumnavigation-of-antarctica-to-study-whales-and-ocean-plastics-2016-4

Social media

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

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IWC-SORP THEME 2 PROGRESS REPORT – 2021/22. Distribution, relative abundance, migration patterns and foraging ecology of three ecotypes of killer whales in the Southern Ocean

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Introduction

Five different ecotypes of killer whales have been described in Antarctic waters, any or all of which could eventually be recognized as separate species. Killer whales are large apex predators that are commonly found in Antarctic waters; although relatively little is known about the distribution, abundance, habitat and prey preferences of each of the different ecotypes, cumulatively they are expected to play a key role in the Antarctic marine ecosystem. This Theme is investigating the ecosystem impact the different ecotypes of killer whales that occur in Antarctic and adjacent waters, by focusing on their systematic relationships, abundance, demographics, distribution, movement patterns, health, and prey preferences.

Progress and results for 2021/22

Giancarlo Lauriano and Simone Panigada, Terra Nova Bay, Ross Sea, Antarctica

Introduction

Knowledge on the distribution, foraging habits and the abundance of Type B (both pack ice and Gerlache) and Type C (Ross Sea) killer whale ecotypes in the Antarctic is scant. Moreover, information on the species seasonal distribution and occurrence, as well as its and residency patterns in the region, are lacking. The impact of killer whales on the ecosystem depends on their movements, abundance, diet and prey requirements. A decrease in the prevalence of Type C individuals has been inferred following the depletion of Antarctic toothfish, *Dissostichus mawsoni*, as one of the main prey; this would force the species to compete more directly with other top predators.

Objectives

Assess the dynamics and role of killer whales in the highly local productive marine ecosystem of Terra Nova Bay, through the understanding of their fine and large scale movements (satellite tagging), prey-related distribution (photo-ID and behavioural sampling), dietary preferences (fatty acids and stable isotopes), toxicological status, and to estimate their abundance (mark recapture).

Results

No fieldwork was conducted during the 2021/222 austral summer.

Outlook for the future

Funding is sought to continue this work.

Luciano Dalla Rosa, West Antarctic Peninsula and Powell Basin.

Introduction

Luciano Dalla Rosa and colleagues (*Projeto Baleias*, Brazilian Antarctic Program) have been conducting cetacean research around the Antarctic Peninsula since 1997. Research on killer whales has included line transect surveys to investigate distribution and relative abundance, photo-identification, acoustics, and biopsy sampling for genetics, contaminant and stable isotope analyses.

Objectives

The specific objectives include investigating killer whale distribution and relative abundance around the Antarctic Peninsula; investigating the species-habitat relationships, and their acoustics; biopsy sampling for genetics, contaminant and stable isotope analyses; photo-identification. In addition, ongoing cetacean satellite tagging efforts, which have focused on fin whales, may opportunistically include killer whales depending on ecotype and area.

Results

No fieldwork was conducted in 2021/22 due to the COVID-19 pandemic.

Outlook for the future

Long term cetacean research is expected to continue in the northern Antarctic Peninsula. Additional funding and ship time is sought for 2022/23 and future seasons.

P.J.N. (Nico) de Bruyn and Ryan R. Reisinger, Marion Island, sub-Antarctic

Introduction

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

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

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

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

There is a significant gap in our understanding of the structure, movement and distribution of killer whale populations in the 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. 2014; A.R. Hoelzel, unpubl. data).

Objectives

- 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.

- 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), it is not yet understood if the key drivers are associated with resource use or ancestry or some other combination of factors.

- 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

Detailed results from 2021/22 work are provided in the IWC-SORP Research Fund: 2022 progress reports from funded projects, Project 22 (SC/68d/SH08).

Conclusions

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

Challenges

The COVID-19 pandemic has caused significant disruptions to the research project. Fieldwork in South Africa and on Marion Island faced disruptions and delays. Travel to South African has been difficult until recently, due to COVID-19-related travel restrictions. Genetics analyses were delayed due to university closures. In the past year it has been challenging to deploy satellite tags; in South African waters, a more dedicated effort, which is more feasible now that travel restrictions have eased, appears to be required to tag killer whales, since the responsive mode we have used to date has been unsuccessful for tagging.

Outlook for the future

Fieldwork at Marion Island resumed this year after COVID-19-related disruptions, and we hope that fieldwork will continue as normal from now onwards. South African fieldwork has also been impacted by COVID-19, but we expect to plan dedicated fieldwork there in the coming year, with the aim of collecting biopsy samples and deploying satellite tags. Due to the continued impact of COVID-19 on field- and lab-work in the last year, we request a further 1-year extension to the project.

The funds for the purchase of SPLASH10-292B tags and to assist with travel and fieldwork expenses were awarded from the IWC-SORP Research Fund (Project 22: SC/67b/SH18; SC/68a/SH11; SC/68b/SH05; SC/68c/SH13; SC/68d/SH08).

Project outputs

Peer-reviewed Papers

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IWC-SORP THEME 3 PROGRESS REPORT – 2021/22. Foraging ecology and predator-prey interactions between baleen whales and krill: a multi-scale comparative study across Antarctic regions

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Executive summary

Quantifying the linkages between predators and their prey are fundamental to understanding ecosystem function. The goals of our research program are to use tag technology and concurrent oceanographic and prey mapping methods to study the relationships between humpback and minke whales and their prey around the Antarctic Peninsula. We use short-term multi-sensor suction cup tags and long-term satellite-linked tags to study the foraging behaviours and movement patterns of baleen whales in relation to the distribution and abundance of krill and oceanographic variables.

To date we have deployed each type of tag on both humpback and minke whales and are completing comprehensive ecological analyses. From fine-scale tag and prey data, we have found that humpback whales feed in a manner consistent with optimal foraging theory: humpback whales feed when krill become available in the upper reaches of the water column in larger but less dense patches. However, within these patches, the deeper the whales feed the denser the krill density that they target.

We have also found that the feeding rates of minke whales are greater than those of any other baleen whale and that their foraging strategies, while similar to humpback whales in some respect, also include species-specific behaviours that indicate under sea-ice feeding. This information on the underwater behaviour of minke whales is the first of its kind for the species. From long-term satellite-linked tags, we have found that humpback whales range over broad spatial regions in the continental shelf waters of the Western Antarctic Peninsula. There is evidence that the size of their home ranges decreases throughout the feeding season in relation to the spatial distribution of krill. All of the humpback whales that have migrated while still carrying active tags have travelled up the western side of South America. Antarctic minke whales were tagged for the first time in 2013 and we continue to build a database from satellite tag deployments, including four LIMPET tag deployments in March 2016 as part of an Australian Antarctic Division and Oregon State University collaboration in the Western Antarctic Peninsula. The data are still being analysed but include a variety of movement patterns. While some animals remained in close proximity to nearshore bays for over 120 days, other whales moved from the Antarctic Peninsula into both the Weddell Sea to the north and east and the Bellingshausen Sea to the south and west. There is also evidence to support migration of some whales to tropical areas.

While the main analytical focus of this work is to understand ecological linkages, the practical focus has been to develop methodologies that can be transported in a manner so as to replicate this research with international collaborators in a variety of regions around Antarctica. International collaboration and regional research studies are at the core of the IWC's Southern Ocean Research Partnership and we continue to develop both our research methods and collaborative relationships towards this goal.

Introduction

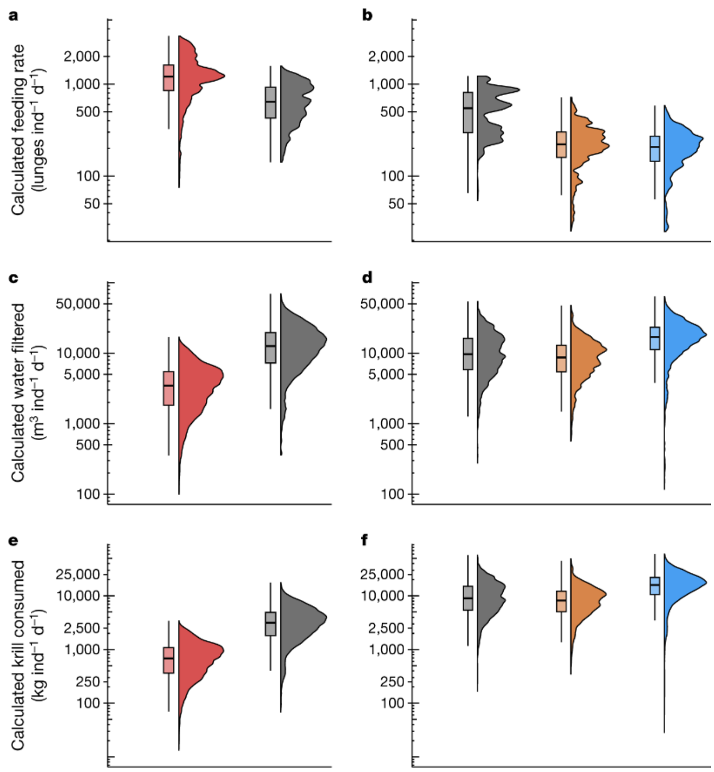
Recent technological advances in the miniaturisation of sensors have allowed for the development of tags that can measure, in fine detail, the underwater movement patterns and behaviours of marine mammals. Likewise, satellite-linked telemetry and analytical tools have advanced to allow for greater understanding of how the broad scale movement patterns and behaviours of marine mammals link to changes in the physical and biological seascape. Understanding both fine and broad scale behaviour of baleen whales in Antarctic waters is critical to understanding the ecological role of cetaceans and how these are being affected by climate-driven changes to their environment.

Objectives

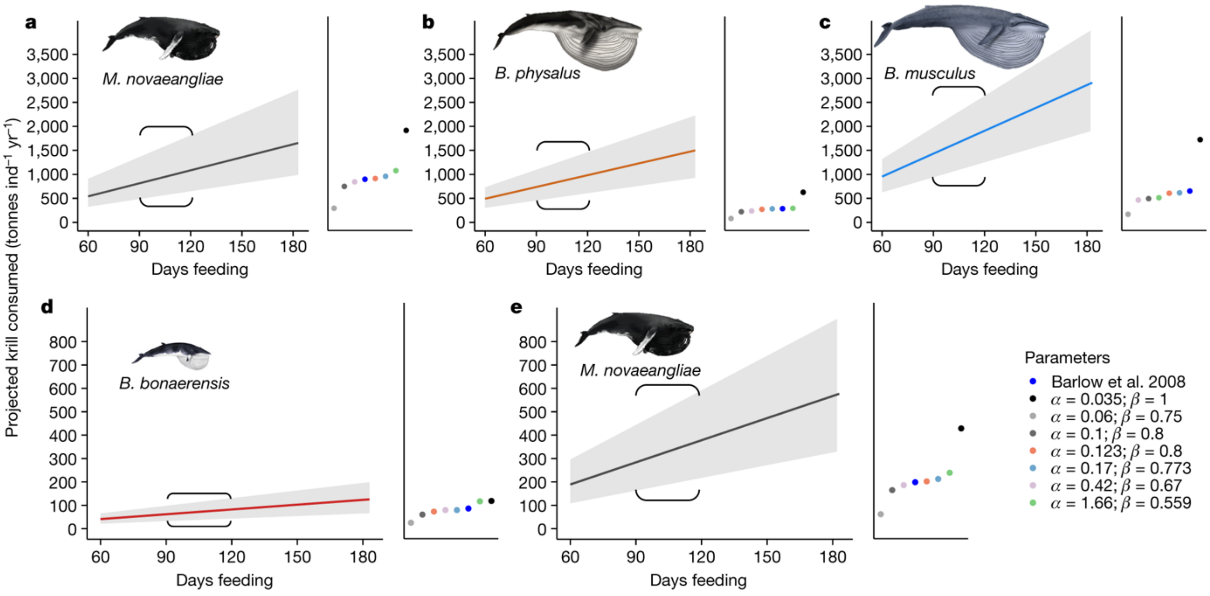
The objectives of our research program are to use technological advances in animal biotelemetry to elucidate the behaviour and ecological role of cetaceans in the nearshore waters around the Antarctic Peninsula, and to relate these to climate-driven changes that are currently occurring.

Results

Over the past year, we focused effort on publishing existing information on baleen whales and their relationship to the Antarctic environment. We have been significantly curtailed in our ability to return to field work in the Antarctic due to the COVID-19 pandemic but have made great strides in publishing our work and increasing the knowledge base of Antarctic baleen whale feeding ecology. It should be noted that the majority of the papers published in the most recent cycle were first-authored by graduate students and postdocs, speaking to the outstanding contributions of early career scientists to our efforts. Below are a selection of figures from recent publications, highlighting new findings:



Each column displays modelled daily feeding rates, filtration volumes and prey consumption on a log scale for the species depicted. **a**, **c**, **e**, The left column displays estimates from Antarctic minke (B. bonaerensis) and humpback whales (M. novaeangliae) from the West Antarctic Peninsula. **b**, **d**, **f**, The right column displays estimates from humpback, fin (B. physalus), and blue whales (B. musculus) from the eastern North Pacific. Density plots illustrate the full scope of all daily simulations with the height representing the relative probability of each output; the boxplots show the quartiles of these outputs with the thick line representing the median and the shaded region representing the Q1–Q3 range (25th−75th percentiles) of all modelled daily rates. From Savoca et al. 2021.



Dots represent prey consumption estimates from prior studies (see Extended Data Table 3 for references). The solid lines represent annual prey consumption estimates for an individual whale for a given number of days feeding (range, 60–182.5 days) using a conservative metric of prey consumption; solid line is the median; grey bars represent the Q1–Q3 range. Bracketed regions represent the most likely annual consumption per individual, represented by 90–120 feeding days. a–c, The coloured lines represent the projected annual krill consumption by an individual humpback (M. novaeangliae), fin (B. physalus) or blue whale (B. musculus) from the eastern North Pacific. c–e, The solid curved lines represent the median projected annual krill consumption by an individual Antarctic minke (B. bonaerensis) or humpback whale in the West Antarctic Peninsula. From Savoca et al. 2021

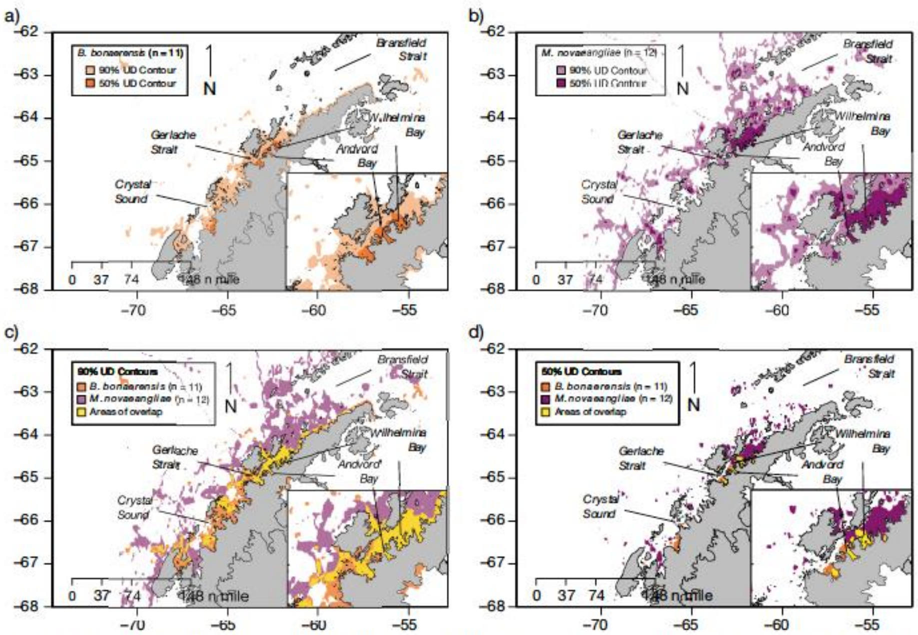
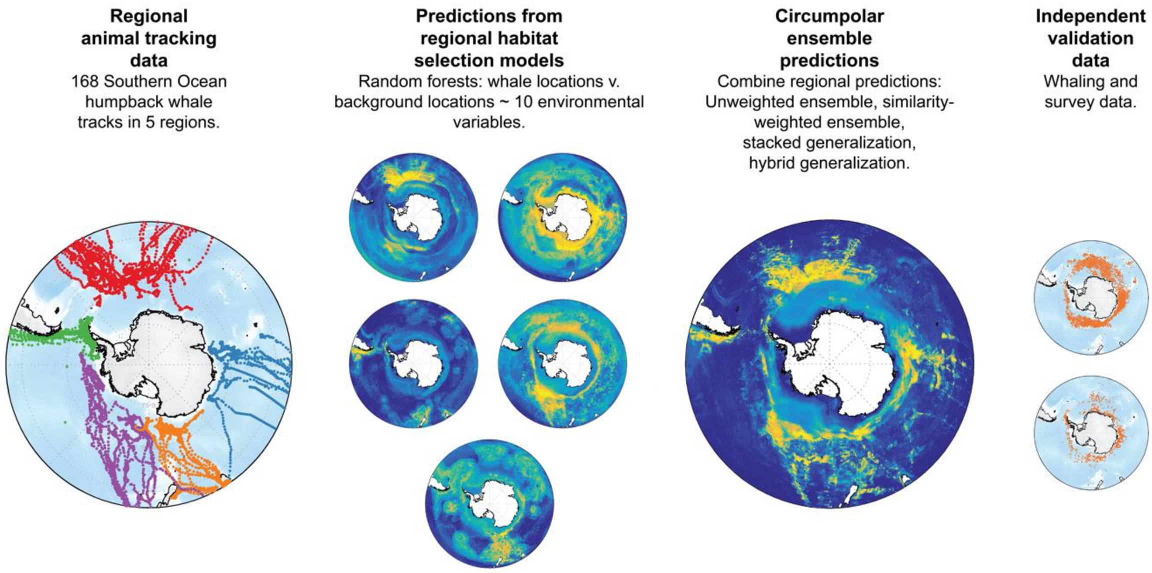


Fig. 6. Observed 50 and 90% habitat utilization distribution (UD) contours from (a) Antarctic minke whales (*B. bonaerensis*; n = 11) and (b) humpback whales (*M. novaeangliae*; n = 12) tracked off the west Antarctic Peninsula during the austral summer and fall of 2013. Also shown are areas of (c) 90% and (d) 50% UD contour overlap. UD estimates derive from n = 100 imputations drawn from continuous time correlated random walk models fitted using Argos location fixes. First transmission locations of each satellite transmitter in February 2013 are shown for each species, with tagging activity concentrated in protected bays (e.g. Wilhelmina, Andvord) along the Gerlache Strait

From Friedlaender et al. 2021.



From Reisinger et al. 2021.

IWC-SORP sincerely thanks WWF-Australia for their ongoing and invaluable support of this IWC-SORP Theme, as well as the Antarctic and Southern Ocean Coalition (ASOC), Hurtigurten and previous funders for research under this theme.

Project outputs

Peer-reviewed papers - New this calendar year

Bierlich KC, Schick RS, Hewitt J, Dale J, Goldbogen JA, Friedlaender AS, Johnston DW (2021) Bayesian approach for predicting photogrammetric uncertainty in morphometric measurements derived from drones. Marine Ecology Progress Series. https://doi.org/10.3354/meps13814

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Students and theses

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

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Social Media

Blog Stats
Direct links to our most popular blog posts:
Steady Hands
Welcome to Minke City

Tagging Days
The full blog can be accessed here: medium.com/in-search-of-minkes
It currently features eight published posts, and will continue to be updated with new content for the remainder of the trip, and periodically over the next year.
Since the beginning of the trip, the blog has received over 1,500 views.

Twitter
The main accounts generating original tweets from our content are:
@MarineUAS
@Goldbogenlab
@mlparkermedia
So far, over 100 tweets have been posted about the trip. Here are a few examples of our most impactful tweets/content:
On Feb 28, @MarineUAS posted this tweet including an aerial photo of humpback whales, which generated 38 retweets and 137 likes.
On March 1, @Goldbogenlab posted this tweet showing video of tagging a minke whale which generated 98 retweets, over 220 likes, and over 5,000 views of the video.
On March 7, @mlparkermedia posted this tweet highlighting a blog post about our field work, which generated 20 retweets, 61 likes, and 275 views of the blog.

@AntarcticReport (which has over 17,500 followers) has also tweeted some of our content.
On March 8, they tweeted our photo which generated 35 retweets and 87 likes.
On March 6, they tweeted our photo which generated 30 retweets and 88 likes.

It should also be noted that @MarineUAS won the #Tech4Wildlife challenge hosted by @WILDLABSNET by posting about our work in Antarctica.

Instagram
The main accounts generating original Instagram posts using our content are:
@insearchofminkes
@emmahattonlevy
@mlparkermedia
@marine_uas
The official Instagram account for the research group helps drive traffic to our blog site. The account currently has 150 followers and gains new followers each day. One of our most recent photos (of a tagged minke whale) received 50 likes. So far, the #insearchofminkes hashtag has 85 posts. The most popular post received 186 likes and 17 comments.

Media

National Geographic Channel Documentary Series: *Continent 7*
Antarctic Edge: 70° South

- Best in Festival, Princeton Environmental Film Festival 2015
- https://beyondtheice.rutgers.edu/
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IWC-SORP THEME 4 PROGRESS REPORT – 2021/22. What is the distribution and extent of mixing of Southern Hemisphere humpback whale populations around Antarctica? Phase 1: East Australia and Oceania

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4. Ecology and Evolutionary Biology, UC Santa Cruz, 115 McAllister Way, Santa Cruz, CA 95060, USA
5. Institute of Research for Development, Centre Nouméa, 101 av, Roger Laroque, Anse Vata, BP A5. 98848, Nouméa, New Caledonia
6. Center for Coastal Studies, 5 Holway Ave, Provincetown, MA 02657, USA.
7. Marine Mammal Laboratory, Alaska Fisheries Science Center, NOAA Fisheries, 7600 Sand Point Way NE, Seattle, WA 98115-649, USA, & Marine Ecology and Telemetry Research, 2468 Camp McKenzie Trail NW, Seabeck, WA 98380-4513, USA
*denotes Theme Leader: r.constantine@auckland.ac.nz; Authors ordered alphabetically.

Introduction

There were three research projects focused on humpback whale distribution and connectivity throughout the Oceania – east Australia region during the 2021/22 period, which continued the work encompassing South America, the West Antarctic Peninsula and also contributed to a circum-polar analysis. The research is focused on interchange, fecundity and movements of whales, areas that increasingly will add complexity to determining the recovery rates of different populations. The reason for the variation in the recovery of the Oceania (Eii – F) and East Australia (Ei) populations remains unknown but we know they have different migration paths (Reisinger et al., 2021), different feeding grounds (Andrews-Goff et al., 2018; Riekkola et al., 2019) and some of the whales migrating past East Australia forage en route (Owen et al., 2016). We do not yet understand the influence of climate change on the whales' feeding grounds, although some work has been done on the breeding grounds (Derville et al. 2019). With the east Australian Ei breeding stock at pre-whaling abundance, determining pregnancy rates of Oceania whales (Riekkola et al., 2018) and those from other Southern Ocean feeding grounds (Pallin et al., 2018) will contribute important information about recovery.

Here we briefly summarise the three research projects that shift the focus from within Oceania to understanding genetic connections to the genetically distinct breeding stock G (see Cypriano-Souza et al., 2017; Rosenbaum et al., 2017) of South America and to the feeding grounds of the Antarctic Peninsula (Project 11, SC/68d/SH08); understanding reproductive rates of humpback whales on different migration paths (Project 14, SC/68d/SH08); and the circum-polar analysis of humpback satellite tag data to determine feeding ground use of humpback whales (Project 16, SC/68d/SH08). This moves the humpback connectivity to other regions that require greater knowledge of connectivity between their populations and stock recovery.

Objectives

The focus of the 2021/22 research, which is the final year for these projects, was:

1) A circum-polar analysis of the foraging behaviour of humpback whales in Antarctica using satellite tag data spanning all ocean basins; led by Rochelle Constantine, Alex Zerbini, Ari Friedlaender and Ryan Reisinger. Reisinger et al., 2021, Reisinger et al., under review.

2) Determining whether there are changes in the migratory connectivity of humpback whales in the Central and Eastern Pacific using a decadal comparison of DNA profile data from Oceania, South America and the Wet Antarctic Peninsula; led by C. Scott Baker and Debbie Steel.

3) Understanding the reproductive rates of humpback whales from the Antarctic Peninsula, Oceania breeding grounds and migratory corridors and implications for population recovery across populations; led by Ari Friedlaender, Logan Pallin, C. Scott Baker, Claire Garrigue, Jooke Robbins and Rochelle Constantine.

Results

Circum-polar analysis of foraging behaviour of humpback whales in Antarctica (refer to IWC-SORP Project 16, SC/68d/SH08)

To understand the ecological role and environmental drivers influencing humpback whale behaviour on their Southern Ocean feeding grounds, we aggregated a circum-polar dataset of 378 humpback whale tracks from 11 different research programmes (2002 – 2019, Table 1). After filtering tracking data, fitting state-space models and move persistence models (Jonsen et al., 2019), there were 168 tracks, totalling 9,219 regularised location estimates (Figure 1). These were used to investigate regional difference in habitat use of whales by broad geographic region and assigned the putative IWC breeding stock (Figure 1). To estimate available habitat, we produced simulated tracks creating a dataset of 468,588 locations comprising 9,188 observed locations and 459.400 simulated locations. Using random forests, we made circum-polar predictions of humpback whale habitat selection and fitted five regional models. The multi-regional ensemble approaches resulted in models with higher predictive performance than the circumpolar naïve model (Reisinger et al., 2021).

There are differences in the southern extent of whale movement, with whales from some areas, e.g., Prydz Bay and Bellingshausen Sea regions, travelling over 15° further south than whales from the broader South Georgia, Scotia Sea region. Also, differences in potential environmental drivers of distribution (also see Riekkola et al., 2019). An ensemble modelling approach including regional predictions and environmental covariates resulted in better model outcomes (Reisinger et al., 2021). IWC catch and sightings data were used as an independent validation test of the approach to get more accurate habitat selection models. The circum-polar prediction of drivers of humpback whale habitat selection will be valuable for all species with variation in habitat. We are addressing the variations by population which will be valuable when considering population recovery under different environmental conditions throughout the Southern Ocean feeding grounds (Reisinger et al. under revision).

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

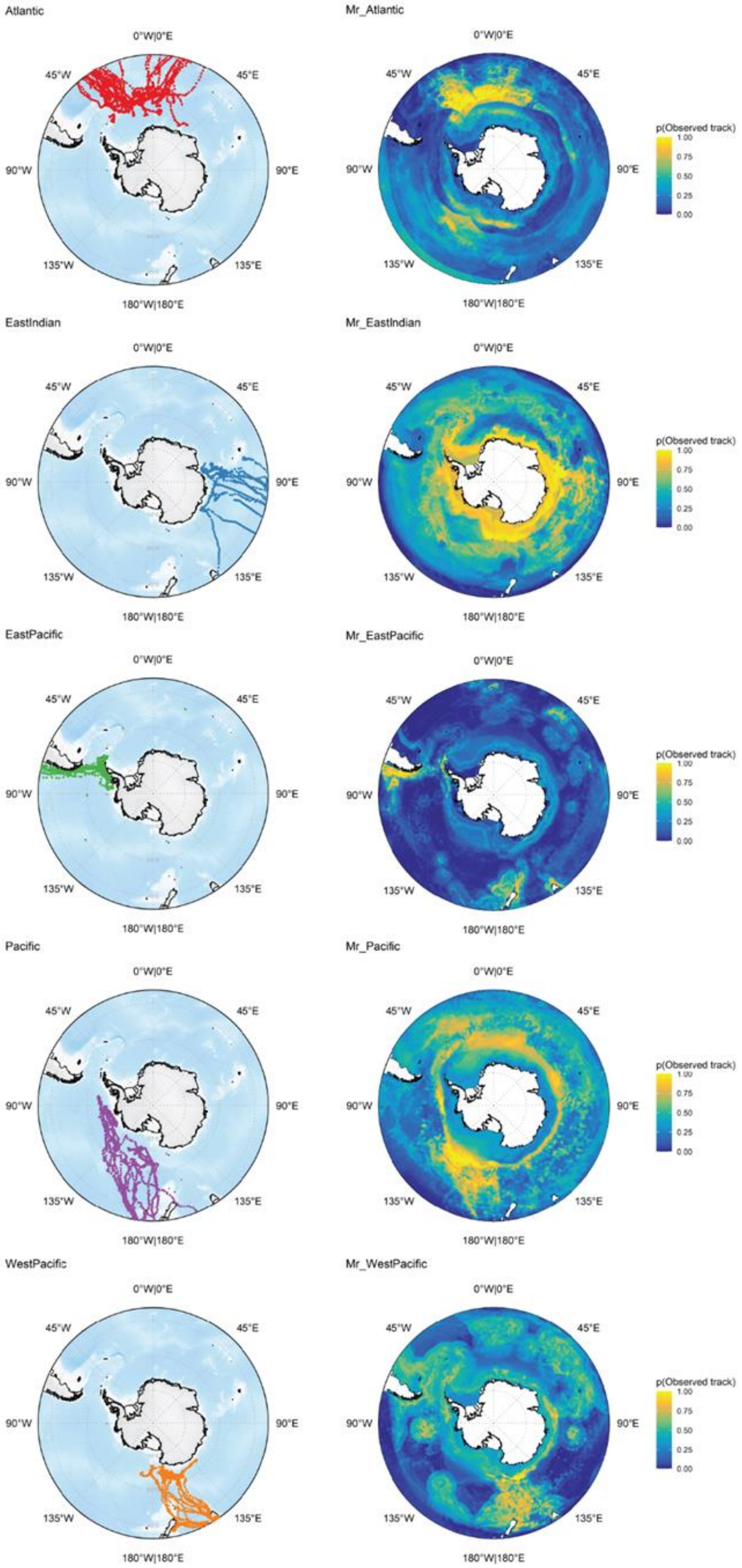
Atlantic
Mr_Atlantic
EastIndian
Mr_EastIndian
EastPacific
Mr_EastPacific
Pacific
Mr_Pacific
WestPacific
Mr_WestPacific
0°W|0°E
45°W
45°E
90°W
90°E
135°W
135°E
180°W|180°E
p(Observed track)

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

Is migratory connectivity of humpback whales in the Central and Eastern Pacific changing? A decadal comparison by DNA profiling (refer to IWC-SORP Project 11, SC/68d/SH08)

The DNA profiles of humpback whales from the South Pacific, spanning Breeding Stocks Ei – G, and Southern Ocean have been combined into a single, curated DNA register (Table 2). Of these, 806 individuals over two decades were used to investigate potential changes in connectivity with IWC Breeding Stock G. This includes samples from a range of Central and South America and Oceania breeding grounds and migratory corridors. This study reports 19 whales' records of migratory interchange between the Central and Eastern South Pacific region and the Antarctic Peninsula (Figure 2). No individual was located in more than two regions. There are no records of interchange with the inclusion of 130 individuals from Brazil, suggesting low likelihood of connectivity between the Atlantic and Pacific regions. We updated the Albertson et al. (2017) mixed-stock analysis of whales from the West Antarctic Peninsula comparing a larger sample size from six winter breeding grounds. There is still strong apportionment to Columbia/ Ecuador/ Panama in both decades, although in decade two there were small levels of apportionment (<2%) to New Caledonia and Brazil. There is temporal stability of genetic differentiation for the Breeding Stock G, despite over 25 years of growth in this, and other populations of humpback whales in the Southern Hemisphere. There is a small increase in the proportion of other breeding stocks mixing on the Antarctic Peninsula feeding grounds as revealed in earlier work (Albertson et al., 2017).

Table 2 The collection years, number of samples, number of unique genotypes (representing an individual identification) for humpback whales sampled in wintering grounds of the South Pacific and South Atlantic as well as over two decadal periods in the Antarctic Peninsula. The number of males, females and number of individuals with a mtDNA haplotype are also given.

Region	years	# QC samples	# unique genotypes	# male	# female	# unknown sex	# mtDNA haplotype
Great Barrier Reef [a]	2011-2017	92	78	52	26	-	77
Eastern Australia [b]	1996-2004	1,526	734	403	311	20	316
Combined East Australia			809				392
Oceania breeding grounds							
New Caledonia [a]	1995-2017	1,919	1,402	827	549	26	1,363
Tonga [c]	1991-2005	483	346	224	112	10	337
American Samoa/Samoa [c+]	2001-2019	232	214	155	58	1	206
French Polynesia [c+]	1997-2012	562	353	190	154	9	343
FP/AS/Sa	1997-2019	794	546	329	207	10	528
Eastern Pacific breeding grounds							
Colombia [c+]	1991-1999, 2015-2018	293	247	152	64	31	222
Ecuador [+]	2006-2010	52	49	33	7	9	46
Panama [+]	2016-2019	200	163	106	57	-	159
Co/Ec/Pan	1991-1999, 2006-2019	545	452	287	125	40	420
Brazil [d]	1999-2011		130				158
Antarctic Peninsula							
Decade 1 [c]	1990-2002	78	68	22	41	5	62
Decade 2 [e+]	2010-2017	847	742	333	402	7	719

[a] Garrigue et al. 2020, [b] Anderson et al. 2010, [c] Steel et al. 2018, [d] Cypriano-Souza et al. 2017, [e] Pallin et al. 2018, [+] indicates additional samples analysed as part of this study.

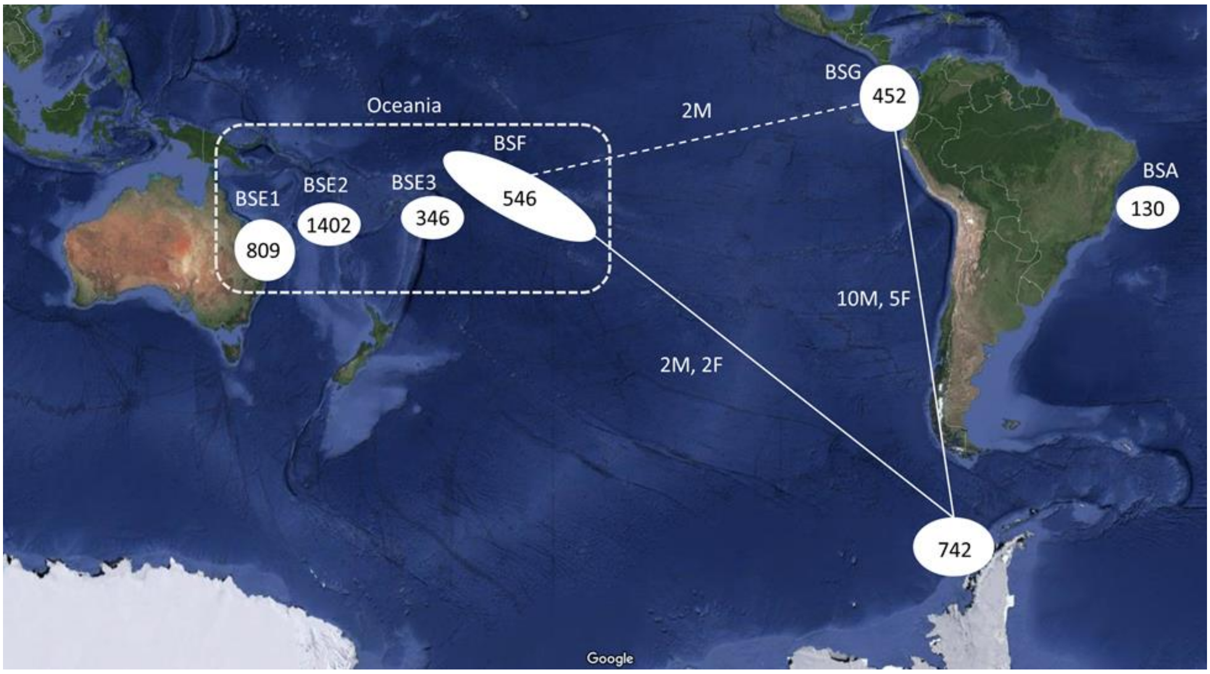

Figure 2 Individual recaptures identified through genotype matching. Wintering grounds from west to east are; East Australia (BSE1), New Caledonia (BSE2), Tonga (BSE3), American Samoa/Samoa/French Polynesia (BSF), Colombia/Ecuador/Panama (BSG) and Brazil (BSA). Numbers inside white circles represent number of individuals with a genotype suitable for matching, numbers alongside lines represent number of individuals recaptured between region. M = male, F = female. Dashed line indicates connection between two wintering areas that was presumably made via an intervening migration to a higher latitude feeding area. Individual recaptures within Oceania not shown.

Pregnancy rates in Southern Ocean humpback whales and the implications for population recovery across multiple populations (refer to IWC-SORP Project 14, SC/68d/SH08)

Progesterone analyses have been focused on samples from humpback whales on the breeding grounds (New Caledonia and American Samoa), migratory pathways (Kermadec Islands and mainland New Zealand) and feeding grounds (West Antarctic Peninsula (WAP) and Ross Sea). Feeding areas and migration pathways were characterised by a high proportion of pregnant females (Figure 3). Within the New Caledonia breeding ground, research to date has focused 199 samples from 2016-2019 that have been quantified and extracted. Preliminary analyses reveal patterns of progesterone, testosterone and oestradiol consistent with sex- and age-class (Figure 4). Additionally, we observed variation relative to basic oestrus cycles across the season (Figure 5). Specifically, we may be seeing follicular activity (high oestrogen) in the early season followed by corpus luteum activity (progesterone) increasing at least in the first month of sampling and then potentially a second phase of follicular activity at the end of the season. To our knowledge, this is the first documentation of these cycles in live baleen whales. However, more work and analyses are underway to better understand these temporal and population endocrine dynamics on the breeding ground which will better inform our interpretation of these hormone levels while they are on their Southern Ocean feeding grounds (see Pallin et al., 2018).

We have now characterised a nine-year temporal analysis of female humpback whales along the WAP (Figure 3 in blue). This feeding aggregation is still characterised by a high proportion of pregnant females (50%). Additional work is currently underway to explore the relationship between environmental cues and the observed pregnancy rates.

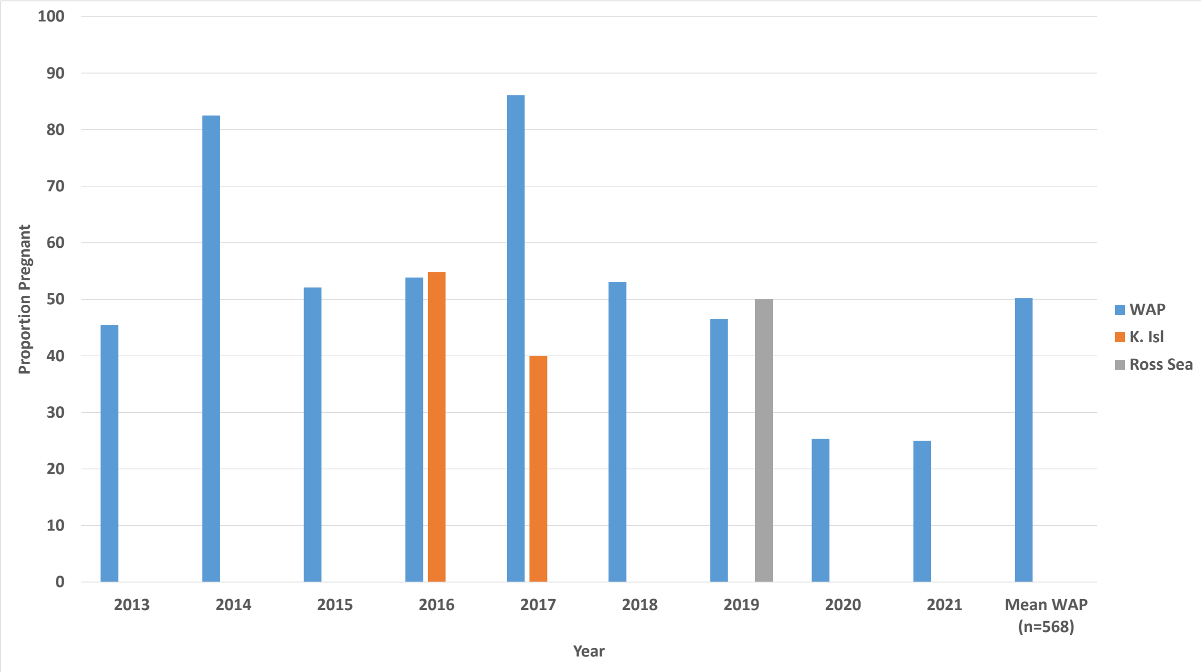

Figure 3 Inter-annual variation in the pregnancy rate of female humpback whales sampled along the Western Antarctic Peninsula (WAP), the Kermadec Islands, and in the Ross Sea.

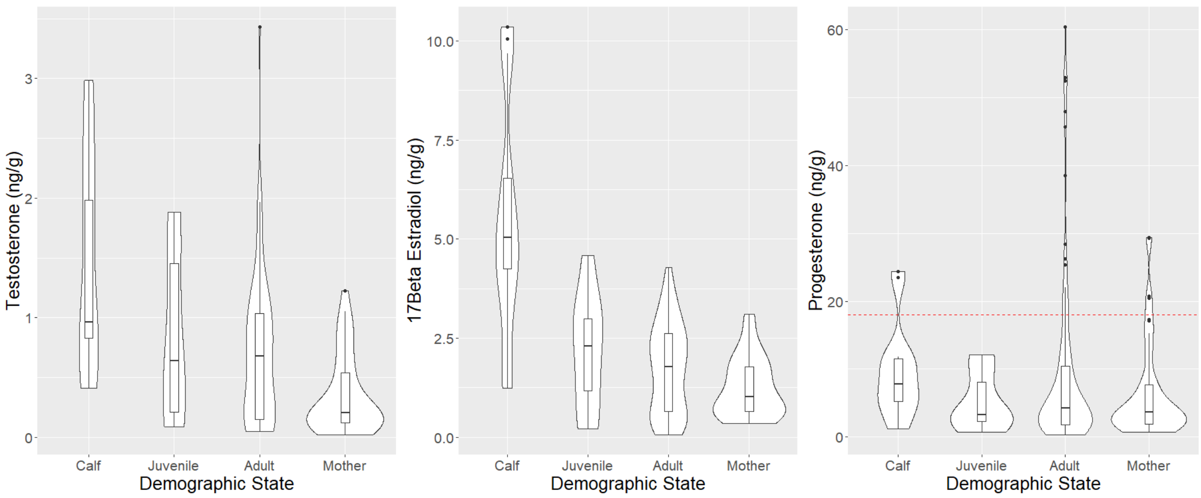

Figure 4 Demographic variation in testosterone (ng/g), 17β-oestradiol (ng/g) and, progesterone (ng/g) among female humpback whales sampled on the New Caledonia breeding ground. The red line in the progesterone plot designates levels indicative of pregnancy based on Pallin et al. (2018).

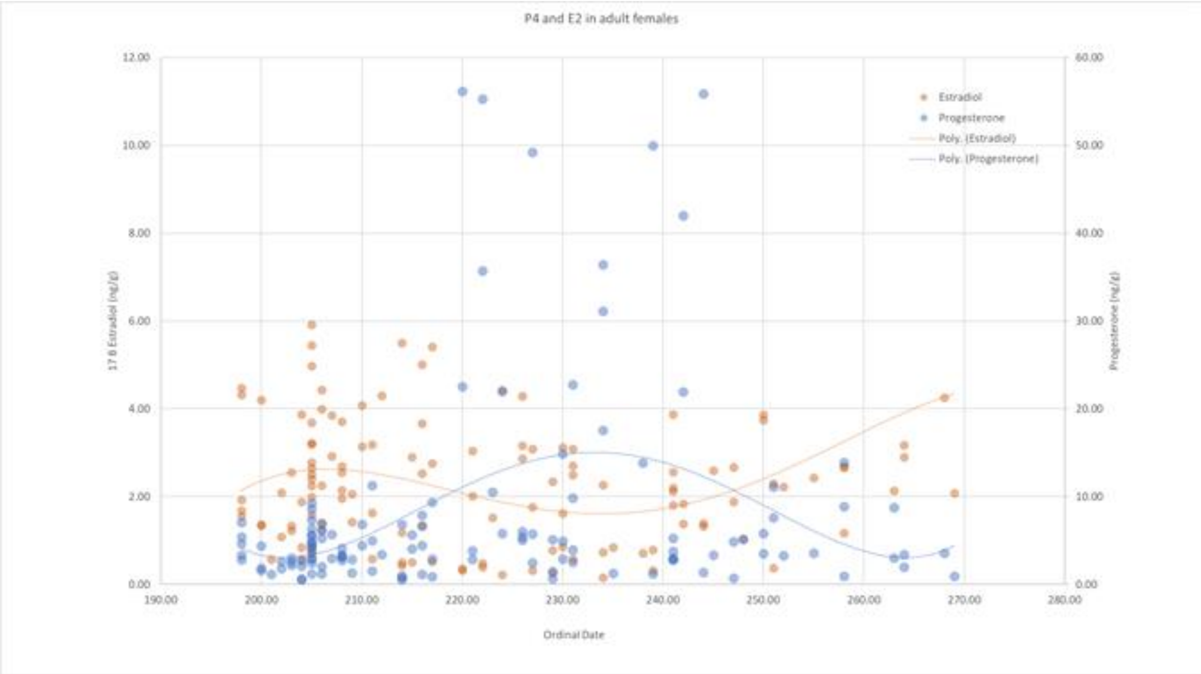

Figure 5 Temporal variation in 17β-oestradiol (ng/g) and progesterone (ng/g) across the New Caledonia breeding season.

Conclusions

The expansion of Phase 1 of the IWC-SORP project: Humpback Whale Connectivity has revealed the value of large-scale collaborative efforts to advance our understanding of whale distribution, behaviour, genetic connectivity and reproduction. In the case of Reisinger et al. (2022; Project 16, SC/68d/SH08) the work has expanded to other feeding grounds with some novel modelling approaches (Reisinger et al., 2021) providing greater resolution about the drivers of habitat choice. An approach that will be valuable for other species of whale in the Southern Ocean especially when understanding how variability in habitat choice will be affected by climate change, an important consideration for future research (see the recent 'Blue Corridors' report Johnson et al. 2022). The work by Steel et al. (2022; Project 11, SC/68d/SH08) confirms the lack of genetic differentiation between whales on the American Samoa, Samoa and French Polynesia breeding grounds, aggregating these as one stock (F). Similarly mtDNA tests showed no significant differentiation between Columbia, Ecuador and Panama breeding grounds so they are aggregated as one stock (G). Over two decades, there is still strong fidelity between humpback whales from breeding stock G and the Antarctic Peninsula with very few whales from other breeding grounds present. The recovery of the Southern Hemisphere humpback whale stocks is encouraging. There is an average 50% pregnancy rates of humpback whales in the West Antarctic Peninsula, and similar findings from whales in the Ross Sea and from the southern migratory corridor of the Kermadec Islands (Pallin et al. 2022; Project 14, SC/68d/SH08). The fluctuation is interesting and will be important in future work to map prey availability, habitat choice and reproductive success of these whales. The variation in hormone levels is an important finding for ascertaining research seasons in the future.

COVID-19 has slowed progress on all of these projects, but all three projects are producing valuable outputs for our understanding of humpback whales in the Southern Ocean.

Outlook for the future

We now have the opportunity for the humpback whale connectivity research to move to another ocean basin. The circum-polar analysis of tag data establishes a platform upon which we can use changes in Southern Ocean productivity to understand the future mixing of stocks and movements of whales. The large, collaborative partnerships formed by all of the three projects reported here, alongside well established regional collaborations in other regions mean there is a bright future for data sharing and open access arrangements to inform management of humpback whales into the future.

IWC-SORP gratefully acknowledges the South Pacific Whale Research Consortium (SPWRC) for their substantial and collaborative contribution to this project.

Project outputs

Peer-reviewed papers

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Meeting presentations

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SC/68d/SH07

IWC-SORP THEME 5 PROGRESS REPORT – 2021/22. Acoustic trends in abundance, distribution, and seasonal presence of Antarctic blue whales and fin whales in the Southern Ocean

The IWC-SORP acoustic trends steering group: Susannah Buchan[1], Ken Findlay[2], Danielle Harris[3], Brian Miller[4], Flore Samaran[5], Ana Širović[6], Fannie Shabangu[7], Kathleen Stafford[8], Ilse Van Opzeeland[9]

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Executive summary

Despite the global pandemic, 2021 continued to be another productive year for the Acoustic Trends Working Group (ATWG). The group conducted 10 intersessional meetings. In 2021, group members contributed 12 papers, including in-prep, and in-press manuscripts. The group has provisionally agreed on a 3-year work plan, but completion of this plan is contingent on securing additional funding. In 2021, group members retrieved 4 datasets of long-term recordings. The ATWG has revised and standardised new Terms of Reference and Mission statement. The group has broadened the spatial scope of its work to include the entire distribution range of Southern Hemisphere blue and fin whales. Previously the ATWG had restricted the scope of work to acoustic data south of 60°S. When taken together, the improved detection algorithms, development of a data analysis framework, continued long-term data collection, and other work of the group represent a step-change in the ATWG's ability to deliver on the promise of using passive acoustics to monitor trends in Antarctic blue and fin whales throughout the Southern Hemisphere.

Introduction

The Acoustic Trends Project and Acoustic Trends Working Group (ATWG) was one of the original five IWC-SORP projects that commenced in 2009. The focus of this project has been to deliver on the promise of using passive acoustics to monitor and discover trends in Antarctic blue and fin whales. Blue and fin whales are well-suited to passive acoustic studies because they frequently make distinctive, loud, low-frequency sounds that can be detected over large distances. Since conception, group members have built capacity for passive acoustics through supervision of 8 students, 1 postdoctoral researcher and development of novel analytical methods, and expansion of data collection efforts.

Objectives

In June 2020, the group reviewed previous objectives and the work plan that was developed at the 2017 Workshop in Bled, Slovenia. Broadly, the ATWG objectives fall into four output streams: generation of biological/ecological knowledge; development of methods and protocols; collection of data; and building capacity & strategic links for future work. Progress was made on all objectives (see Results section of this document for more details).

Also in 2020, the group developed a revised Mission Statement/Terms of Reference, and work plan, which we present in Appendix 1. In brief the group's overarching objective/mission statement remains to "address key knowledge gaps for Antarctic blue whales and southern hemisphere fin whales using passive acoustics." We have continued to use these guiding principles in 2021.

The group has identified four key knowledge gaps: 1) Distribution & occupancy; 2) Population structure; 3) Animal behaviour; 4) Abundance & density estimation.

Results

Generation of knowledge

Miller et al. (2021a) developed the largest dataset of source levels for blue and fin whale signals to date. Source levels are critical to understanding propagation of these signals in the water which is a key variable for density estimation.

During 2021, two studies (one funded by IWC-SORP and one by the IWC to Susannah Buchan PI) were initiated by the ATWG on the frequency and temporal characteristics of fin whale 20-Hz and Antarctic blue whale song calls off the coast of Chile. The same analyses were conducted for fin whales calls off Elephant Island, in the Southern Ocean and the Antarctic Peninsula by Victoria Field (Master student University of Bremen and Ilse Van Opzeeland), paralleling the just completed study (Wood and Širović 2022). These data will be pulled together during 2022 to compare frequency and temporal characteristics of fin whale 20-Hz calls in mid and high latitudes in the Southern Hemisphere. Analyses of Antarctic blue whale calls in the South Atlantic and Indian Oceans are being compared with data from Chile in order to ascertain if there is detectable geographic variation in Antarctic blue whale calls at low latitude wintering areas. These data come from disparate sources including moored hydrophones and Comprehensive Test Ban Treaty Organization data.

Method development

Annotated library

In 2020, the IWC-SORP funded Annotated Library of Blue and Fin Whale Sounds was completed, including both a publicly available dataset, and similarly titled peer reviewed publication (Miller et al. 2020, 2021b).

Standardised Framework

Dr Franciele Castro joined IWC-SORP Acoustic Trends Project (ATP) as a post-doctoral scholar in April 2019 (Primary supervisor Buchan; co-supervised by Harris and Miller). Her work was funded by IWC- SORP grant titled “A standardised analytical framework for robustly detecting trends in passive acoustic data: A long-term, circumpolar comparison of call-densities of Antarctic blue and fin whales” (see IWC-SORP grant report for details, Project 17, SC/68d/SH08). Her work tackled some of the long-standing shortcomings inherent in nearly all prior passive acoustic studies of ABW and fin whales, namely the challenges presented by incredibly variable noise levels and sound propagation that affect detectability of the blue and fin whale sounds and ultimately call density estimation.

Data were analysed from the South Kerguelen Plateau on the Southern Ocean Indian Sector between February 2014 and February 2015. The analysis estimated call densities by season at this site. Call density is a metric that standardizes acoustic detections to account for (1) false positive detections from automated detectors (2) recording effort and (3) factors affecting detectability such as sound propagation, noise levels and the performance of the recording and detection system. The method used here is based on Küsel et al. (2011). The results showed seasonal differences in false detection rates, recording effort and detectability at this site. The seasonal pattern of call detections did not correspond with the estimated call densities, highlighting the need to standardize acoustic datasets across time (and space in the case of multiple sites) to ensure that conclusions about patterns in animals’ calling activity are not affected by the factors listed above. This work is currently being prepared for publication (Castro et al., in prep). A natural extension to this project would be to expand the framework to more sites and years across the Southern Ocean. The annotated library was designed with this goal in mind, so would provide the basis for the extended analysis.

Improved detectors

Several group members have participated in projects with a goal of delivering improvements to detection algorithms. These include improvements to traditional or established signal processing techniques, and the implementation of newer machine learning algorithms.

Under the scope of the AI for Good research lab (Microsoft), Kate Stafford, and Maelle Torterotot of Flore Samaran's lab, worked with Microsoft engineer Ming Zhong on a deep learning approach to detect blue whale calls from the southern Indian Ocean for all four of the previously identified acoustic signals from that region. A manuscript based on this was published in the Journal of the Acoustical Society of America (Zhong et al. 2021).

A postdoctoral scholar, Dr Jeppe Rasmussen, working for Ana Širović, worked on the development of machine learning detection and classification approach for automated extraction of blue and fin whale social calls (D and 40 Hz calls, respectively). The manuscript describing the approach was published in 2021 in Journal of the Acoustical Society of America (Rasmussen and Širović 2021). While the initial development was not using the IWC-SORP annotated library, the testing of this new approach with that library can ultimately lead to efficient extraction of blue and fin whale social signals from various data sets from the southern hemisphere.

Dr Maelle Torterotot, of Flore Samaran's Lab, worked on the adaptation of detection algorithm based on dictionary learning and sparse representation (Socheleau et al., 2018) to detect non- stereotyped blue whale calls (D-Calls). This Sparse Representation based Detector is particularly well adapted for the detection of D-calls, using dictionaries that take D-calls' time-frequency variability into account. The algorithm was tested on the OHASISBIO long term data set in the southern Indian Ocean. The manuscript describing the approach and results is currently under review in the journal Marine Mammal Science. While the study area extends beyond Antarctic waters, results could help to understand the global picture of blue whale song and D-call occurrence and seasonal patterns in the southern hemisphere.

Automated methods are crucial to help processing long-term recordings of marine bioacoustics. To evaluate the efficiency of such methods, it is essential to develop large-scale annotated datasets in addition to the one developed by the ATWG. However, besides being laborious and resource intensive, recent studies have suggested that such a task could also be highly subjective with the generation of annotator specific errors. Paul Nguyen Hong Duc (PhD Student at Sorbonne University and Ensta Bretagne Flore Samaran's Lab) has investigated the question of inter-annotator agreement from a multi-annotator annotation campaign performed on a marine bioacoustics dataset. Results reveal that the acoustic event type, the Signal-to-Noise Ratio of the acoustic event and the annotator profile are three critical factors impacting the annotation results of a multi-annotator campaign. This study was published in Ecological Informatics in 2021 (Hong Duc et al. 2021).

Maximising the use of existing and new monitoring technologies

The ATWG is interested in maximising the use of opportunistic and existing monitoring technologies. The Comprehensive Nuclear Test Ban Treaty Organization International Monitoring System (CTBTO IMS) and Ocean Bottom Seismometers (OBS) also detect blue and fin whales and are a great potential source of opportunistic monitoring data (e.g., Harris et al., 2013; Dréo et al., 2019). ATWG members are actively engaged in continuing research into the use of OBS for monitoring blue and fin whales. In the last year, a collaboration involving Susannah Buchan and Dr. Matt Miller from the department of Geophysics at the University of Concepcion, and the University of Tokyo and JAMSTEC has been agreed upon, and analyses will be conducted during 2022. In addition, since 2021, Danielle Harris has been PI for the project CORTADO: Combining global OBS and CTBTO recordings to estimate abundance and density of fin and blue whales, co-funded by the US Navy's Office of Naval Research and Living Marine Resources Program. The project will run until 2025 and will produce open-source software tools to process CTBTO and OBS data to estimate call densities of blue and fin whales, working towards animal density and abundance estimates.

Data collection in 2021/22

Antarctic data collection (>60°S)/Southern Ocean Hydrophone Network: 2021/22

Analysis of the three moored recorderd recovered by the Australian Antarctic Division (AAD) in 2020 is on-going. The status of the AAD deployed AAD-Moored Acoustic Recorders at the South Kerguelen Plateau and Dumont d'Urville sites will be updated in next year's report.

One AAD recorder was recovered from near Dumont D'Urville (Area V). Data analysis is on-going and will be reported on in next year's report.

The Alfred Wegener Institute Antarctic instruments are on a 2-3 year deployment schedule. At the time of this report, the recovery redeployment voyage on the Polarstern was on-going so information on instrumentation deployed last year was unavailable.

The Department of Environment, Forestry and Fisheries, Fisheries Management Branch, Cape Town, deployed one Soundtrap recorder off Marion Island (Area III) in April 2021 and a Cornell Rockhopper was deployed on the Maud Rise, Antarctica (Area III) in January 2022.

Low-latitude data collection (<60°S) 2018/19

ENSTA Bretagne in collaboration with Institut Universitaire Européen de la Mer (IUEM) Géosciences Océan - UMR 6538 UBO-CNRS redeployed seven long term autonomous hydrophones in the Indian Ocean as part of OHASISBIO between 24° to 56° South and from 52° to 83° East in 2020/2021. At the time of this report, the recovery redeployment voyage was on-going so information on instrumentation deployed last year was unavailable. This network of hydrophones has been in place since 2009/2010. Four long term autonomous hydrophones were deployed in the Mozambique Channel in an array in October 2020. These were recovered in October 2021.

The Department of Environment, Forestry and Fisheries, Fisheries Management Branch, Cape Town, South Africa in collaboration with ENSTA Bretagne deployed a hydrophone off Durban, South Africa in February 2022 which will be recovered in 2023.

Data collection continues with bottom-mounted hydrophones off the coast of Chile in the Corcovado Gulf (43° South) by the University of Concepcion (since 2016); and off Northern Chile (29° South) by the Centro de Estudios Avanzados en Zonas Aridas (CEAZA) (since 2017).

Acousonde deployments on fin whale in Chilean waters

In 2021, the Centro de Estudios Avanzados en Zonas Aridas (CEAZA), Oregon State University, and ENSTA Bretagne continued investigating acoustic and foraging behaviour of blue and fin whale in Chile and the acoustic behavior of these species by deploying Acousonde and CATS loggers on whales. These tags provide acoustic recordings paired with accelerometer and time-depth data. In 2021 there were 28 deployments on fin whales and 1 on blue whales off northern Chile. These data are still being analysed and will be reported on next year. Additional field seasons are planned for March and April 2022. These deployments will be used to provide cue rates for foraging blue and fin whales to add to the database of acoustic behavior that can be used for ultimately determining blue and fin whale densities from acoustic data. They will also be used to determine calling depth for improving propagation modelling of hydrophone detection range for blue and fin whale calls.

Conclusions

The improved detection algorithms, standardised analysis framework, and continued long-term data collection, are each individually strong achievements. However, when taken together, they also represent a step-change in the ATWG's ability to deliver on the promise of using passive acoustics to monitor trends in Antarctic blue and fin whales throughout the Southern Hemisphere.

Challenges

While new detectors should improve the ability to obtain detection rates, the standardised framework for call density still requires an expert practitioner to operate. Thus, funding remains the major challenge for the ATWG and ATP. Participation in ATWG by most steering group members is conducted as an in-kind contribution. The group has increased capacity for acoustic analysis by training PhD students and employing post-doctoral fellows, however, additional funding is now required to fully leverage this increase in capacity for knowledge generation.

Outlook for the future

Provided that the group can obtain sufficient funding, the next steps will be to begin to apply the new detection algorithms, and the standardised framework for call-density to circumpolar datasets to investigate and quantify any spatio-temporal trends in call density of blue and fin whale sounds. We are looking forward to an in-person meeting either in 2022 or 2023 if we can find the funds to do so.

Given the central importance of the standardised analytical framework postdoctoral project carried out by Dr Franciele Castro, ATWG is currently actively seeking funds for this work to continue for a further two years to apply the framework to all acoustic datasets in the Southern Ocean.

Project outputs

Peer-reviewed papers

Buchan SJ, Hucke-Gaete R, Stafford KM, Clark CW (2018) Occasional acoustic presence of Antarctic blue whales on a feeding ground in southern Chile. Marine Mammal Science 34(1): 220-228.

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Students and theses

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Lisa Ganz (2018) Analysis of passive acoustic recordings from Elephant Island. Masters Thesis University of Bremen- Alfred-Wegener Institute Bremerhaven.

Maelle Torterotot (2020). Analysis of bioacoustic data recorded in the southern Indian Ocean. PhD Thesis, Institut Universitaire Européen de la Mer (IUEM) Géosciences – Océan, Plouzané, France.

Victoria Field (2021) Analysis of the geographic variation in fin whale (*Balaenoptera physalus*) calls reveals population identities. Master University of Bremen, Germany.

Constanza Alarcon (2022) Calling depth of fin whales (*Balaenoptera physalus*) in a feeding ground of Isla Chañaral, Northern Chile, using acoustic tags. Undergraduate in Marine Biology, University of Concepcion, Chile.

Meghan Aulich (2022) The soundscape ecology of the fin whale (*Balaenoptera physalus*) in Antarctic and Australian waters. Ph.D. candidate, Curtin University, Australia.

Paul Nguyen Hong Duc (2022) Ph.D. candidate, Sorbonne University, France.

Conference presentations

The global covid-19 pandemic caused many national and international conferences to be cancelled or move to virtual attendance therefore we had fewer presentations this year.

Bazin S, Dubost F, Torterotot M, Royer JY, Samaran F, Retailleau L (2021) Hydroacoustic observatory of Mayotte volcano: preliminary results Acoustics for studying marine geophysics Geological context.EMSO Time Series Conference.

Buchan S, Samaran F, Van Opzeeland I , Miller, B, Stafford K, Harris D, Findlay K, Sirovic A, Gedamke J (2017) Southern Ocean Research Partnership Blue and Fin Whale Acoustic Trends Working Group: current and future research challenges. Oral presentation during the Society for Marine Mammalogy Biennial Conference - PAM workshop, October 2017, Halifax, Canada.

Burkhardt, E., Boebel, O., Meister, M., Mattmüller, R., Spiesecke, S., Thomisch, K., Van Opzeeland, I (2018) Fin whale (*Balaenoptera physalus*) acoustic presence off Elephant Island (South Shetland Islands), Antarctica. Poster presented at the 32nd Annual Conference of the European Cetacean Society, 6-10 April 2018, La Spezia, Italy.

Burkhardt E, Boebel O, Ciesewski B, Mattmueller RM, Meister M, Schall E, Spiesecke S, Thomisch K, Van Opzeeland I (2018) The marine soundscape off Elephant Island: A Southern Ocean coastal habitat. Poster presented at Polar2018, 15-26 June 2018, Davos, Switzerland.

Le Cam K, Vanwynsberghe C, Samaran F, Lefort R (2018) Labeling method of the South Indian Ocean marine soundscape and associated database. Poster presented at the 8th DCLDE workshop, June 2018, Paris, France.

Leroy EC, Thomisch K, Van Opzeeland I (2017) Variability in ground-truth data sets and the performance of two automated detectors for Antarctic blue whale calls in different soundscape conditions. Oral presentation during the Third Joint Meeting of the Acoustical Society of America and the European Acoustics Association, 25-29 June 2017, Boston, Massachusetts, United States.

Leroy E, Socheleau FX, Carvallo Pecci A, Samaran F, Bonnel J, Royer J-Y. (2015) A new automatic detector for Antarctic blue whale calls. Oral presentation during the 7th International DCLDE Workshop, 13-16 July 13-16, La Jolla, United States.

Miller BS, Calderan S, Leaper R, Collins K, et al. (2015) Passive acoustic tracking of Antarctic blue whales during the 2015 NZ-Australia Antarctic Ecosystems Voyage: Preliminary results. Oral presentation during the 7th International DCLDE Workshop, 13-15 July, La Jolla, United States.

Miller BS, Gedamke J, Buchan S, Findlay K, Harris D, Samaran F, Širović A, Stafford K, Van Opzeeland I, Miller EJ, Double MC (2018) Overview of the deep water soundscape off East Antarctica. Oral Presentation at Marine Ecosystem Assessment of the Southern Ocean (MEASO), 9-13 April, Hobart Tasmania, Australia.

Samaran F, Leroy E, Miller B, Double M. (2015) Chatty Antarctic blue whales, tell me more about your calls. Abstract submitted for oral presentation at the 21st Biennial Conference on the Biology of Marine Mammals, 12-18 December, San Francisco, United States.

Schuster M, Miller B, Leaper R, Fischer M (2016) Airgun sounds in Antarctic waters: measurement and simulation. Oral presentation at the Fourth International Conference on The Effects of Noise on Aquatic Life, 10-15 July, Dublin, Ireland.

Shabangu F (2020). Acoustic occurrence and behaviour of marine mammals. Plenary talk. Second African Bioacoustics Community conference. Online.

Shabangu F, Findlay K, Best P, Ensor P, Stafford K (2015) We hear them in thousands: Acoustic distribution and behaviour of Antarctic blue whales, 21st Biennial Conference on the Biology of Marine Mammals, 13-18 December, San Francisco, United States.

Shabangu FW, Findlay KP (2016) Acoustic monitoring of the recovery of Antarctic blue and fin whales in the Benguela ecosystem. Benguela Symposium, University of Cape Town, 15-18 November, Cape Town, South Africa.

Shabangu FW, Findlay KP (2016) Sounds of Antarctic blue and fin whales off the west coast of South Africa. American Cetacean Society's 15th International Conference, 11-13 November, Monterey, United States.

Širović A, McDonald M, Balcazar-Cabrera N, Buchan S, Cerchio S, Clark CW, Davis G, Findlay K, Gagnon G, Kyo N, Leroy E , Miksis-Olds J, Miller B, Oleson E, Pangerc T, Rogers T, Samaran F, Simard Y, Stafford K, Stevenson D, Sugioka H, Thomisch K, Tripovich J, Truong G, Van Opzeeland I, Van Parijs SM, Yoshida R, Brownell Jr R (2017) Blue whale songs worldwide: an update. Poster presented at the 22nd Biennial Conference on the Biology of Marine Mammals, October 2017, Halifax, Canada.

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

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Thomisch, K, Boebel O, Clark CW, Hagen W, Spiesecke S, Zitterbart D, van Opzeeland I (2015) Spatio-temporal patterns of Antarctic blue whale vocal behaviour from a multi-year PAM array in the Southern Ocean, 21st Biennial Conference on the Biology of Marine Mammals, 13-18 December, San Francisco, United States.

Thomisch K, Boebel O, Burkhardt E, Clark CW, Hagen W, Kinderman, L, Spiesecke S, Van Parijs S, Zitterbart D, van Opzeeland I (2015) Pervasive acoustic presence of baleen whales in the Southern Ocean, 21st Biennial Conference on the Biology of Marine Mammals, Workshop "Baleen whale migration, revisited", 13 December, San Francisco, United States.

Thomisch K, Boebel O, Clark CW, Hagen W, Spiesecke S, Zitterbart D, van Opzeeland I (2015) Spatio-temporal patterns of Antarctic blue whale vocal behaviour in the Southern Ocean. Bioacoustics Days, IMARES, IJmuiden, Netherlands, 6 November 2015.

Thomisch K, van Opzeeland I, Spiesecke S, Zitterbart D, Boebel O (2015) Impacts of subsampling, detector performance and ambient noise levels on biological inferences. The 7th International DCLDE [Detection, Classification, Localization, and Density Estimation] Workshop, Scripps Institution of Oceanography, 13-16 July, La Jolla, United States.

Torterotot M, Socheleau F-X, Samaran F, Royer J-Y (2018) Automated detection of non-stereotyped whale calls using dictionary-based representations: application to blue whale D-calls. 8th DCLDE workshop, June 2018, Paris, France (Oral).

Torterotot M, Samaran F, Royer J-Y (2019). Detection strategy for long-term acoustic monitoring of blue whale stereotyped and non-stereotyped calls in the Southern Indian Ocean. OCEANS IEEE, June, Marseille, France (Oral).

Torterotot M, Cazau D, Nguyen Hong Duc P (2019). Some practical questions related to sound annotation in marine bioacoustics. Standards for Annotating & Storing Marine Passive Acoustic Data and Metadata workshop, November, Victoria, Canada (Oral).

Torterotot M, Samaran F, Royer J-Y, Stafford K (2019). Sounds from airguns and blue whales recorded from a long term hydrophone network in the Southern Indian Ocean. Acoustical Society of America winter meeting, December, San Diego, USA (Oral).

Torterotot M, Samaran F, Royer J-Y, Stafford K (2019). Seasonal and geographical occurrence of blue whale stereotyped and non-stereotyped calls in the Southern Indian Ocean. World Marine Mammal Conference, December, Barcelona, Spain (Oral).

Van Opzeeland I, Samaran F, Stafford KM, Findlay K, Gedamke J, Harris D, Miller BS (2013) Listen to the BLUE: Towards a pan-Antarctic monitoring system and blueprint of analysis methods to study fin and Antarctic blue whales in the Southern Ocean. Poster presented during the IWC-SORP special session at the Biennial Conference on Marine Mammals, 9-13 December, Dunedin, New Zealand.

Media interest

12 Jan 2022 article about the Miller et al. (2021) paper. https://www.antarctica.gov.au/news/2022/whale-scientists-pick-up-good-vibrations/

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Other

Miller BS, Stafford KM, Opzeeland I Van, Harris D, Samaran F, Širović A, Buchan S, Findlay K, Balcazar N, Nieukirk S, Leroy EC, Aulich M, Shabangu FW, Dziak RP, Lee W, Hong J (2020) An annotated library of underwater acoustic recordings for testing and training automated algorithms for detecting Antarctic blue and fin whale sounds. Dataset hosted by Australian Antarctic Data Center. https://data.aad.gov.au/metadata/records/AcousticTrends_BlueFinLibrary

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Socheleau F-X et al. (2015) Automated detection of Antarctic blue whale calls. The Journal of the Acoustical Society of America 138: 3105–3117.

Theme 5, Appendix 1
IWC-SORP Acoustic Trends Working Group Terms of Reference 2020

Mission statement
Address key knowledge gaps for Antarctic blue whales and southern hemisphere fin whales using passive acoustics.

Key ecological research topics for Antarctic blue and fin whale acoustics

1. Distribution & Occupancy
2. Population-structure
3. Animal behaviour
4. Abundance

Integrated & multidisciplinary approach

Engineering	Statistical survey methods	Data collection	International collaboration
• Instrument design & integration • Detection, classification, localisation of sounds • Acoustic measurements of signals and noise • Leverage emerging platforms (drifters, gliders, USVs, vector sensors, acoustic tags, etc)	• Maximising value of acoustic data • Density estimation • Long-term population trends • Integration of passive acoustics with complimentary data streams (e.g. remote sensed data, visual observations from voyages, telemetry tags, photo ID, genetics)	• Maintain long-term decade-scale focus • Expand moored hydrophone network towards circumpolar Antarctic coverage and throughout mid & low latitudes of the southern hemisphere • Collect supplementary passive acoustic data where possible (e.g. on voyages, from tags, USVs, OBSs)	• Research with global focus (entire southern hemisphere) • Develop standards for collection, collaboration, and analysis of acoustic data • Provide advice on best and emerging practices

Terms
1. Group members will follow IWC-SORP ethos to create an integrated, collaborative consortium for non-lethal whale research. Group membership and leadership will be open, inclusive, and equitable.
2. The ATWG will maintain an integrated and responsive relationship with the Scientific Committee of the International Whaling Commission (IWC).
3. Research conducted by the ATWG will acknowledge contributions of the ATWG, IWC-SORP, and co-authorship will be offered to individual group members who have made substantial contributions to that research. Provision of datasets is usually considered a substantial contribution.
4. Projects undertaken by the ATWG will focus on questions that have a global/southern hemisphere focus and that cannot be addressed practically by a single partner.

Implementation
Implementation of ATWG objectives will occur via three broad themes:

1. analysis and interpretation of acoustic datasets from the Southern Ocean and southern hemisphere,
2. the development and implementation of an ongoing network of long-term circumpolar underwater listening stations, and
3. development of novel and efficient methods for standardized analysis of acoustic data collected in the Antarctic and sub-Antarctic

Specifically, the group will:

- Provide advice and support for maintaining and expanding the Southern Ocean Hydrophone Network.
- Establish linkages with existing and emerging programs of relevance to this working group.
- Convene focussed sessions at national and international meetings, and facilitate synthesis products, to increase the awareness of the scientific community to the importance of the activities and outcomes of this working group.

- Provide practical recommendations to guide and support passive acoustic data collection in Antarctic waters.
- Develop standardized passive acoustic data from different areas for accurate and efficient analysis and interpretation.
- Develop capacity for passive acoustic research via training and supervision of students and early career researchers

Participation

- Most group business is conducted via email, and via ad-hoc communication amongst group members for specific projects.
- At a minimum, the group also aims to meet quarterly via teleconference, to discuss ATWG business and provide updates for the whole group.
- Contributions (of data, expertise, logistical support, analytical support, funding, etc.) are welcome. To-date, most contributions to the group have been voluntary and in-kind.
- Sharing of data is highly encouraged, and the expectation is that sharing of data will be reciprocal where possible.

Work plan 2020-2023

A. Virtual Workshop/Conference: Latest research and new directions for Antarctic blue and fin whale acoustic trends (working title)

B. ATWG terms of reference and work-plan 2020-2023 (this document) submitted to IWC-SC meeting 68C (virtual meeting)

C. IWC-SORP funded project: *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.*
   - Manuscripts describing the "Standardized analytical framework" will be written and submitted.
   - Seek funding to extend post-doc beyond Feb 2021

D. IWC-SORP funded project: *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*
   - Milestone 1 TBD
   - Milestone 2 TBD

E. IWC funded project: *Assessing regional variation in Antarctic blue whale regional song calls from mid-latitude sites in the Southern Hemisphere*.
   - Milestone 1 TBD
   - Milestone 2 TBD

F. Other work

Timeline

Milestone/output	Estimated Date
Virtual workshop: Latest research & new directions	June 2022
Standardised analytical framework manuscripts	May 2022
ATWG terms of reference and work-plan 2020-2023 (this document) submitted to IWC-SC meeting 68C (virtual meeting)	Apr 2021
Acoustic pop. ID for fin whales – milestone 1	Sep 2021
Acoustic pop. ID for fin whales – milestone 2	July 2022
ABW song variation in mid-lat – milestones	July2022

IWC-SORP THEME 6 PROGRESS REPORT – 2021/22. The right sentinel for climate change: linking foraging ground variability to population recovery in the southern right whale

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Executive summary

IWC67 endorsed the IWC-SORP research theme 6: *The right sentinel for climate change: linking foraging ground variability to population recovery in the southern right whale*.

The specific objectives of the theme are to:
1) Increase our understanding of southern right whale foraging habitats and ecology;
2) Update our knowledge on southern right whale population dynamics in a comparative framework;
3) Pursue integration of health assessment indicators with long-term monitoring data;
4) Investigate the impact of climate variation at foraging grounds on population recovery

The Theme is led by Emma Carroll and Els Vermeulen, in close collaboration with colleagues from Argentina, Australia, Brazil, New Zealand and South Africa. Work has been undertaken against all four objectives including:

1. Objective 1:
    a. Further analyses and collation of stable isotope data
    b. Deployment of satellite transmitters in Argentina, New Zealand and South Africa
    c. Exploration of the use of automated detection of SRW in multispectral satellite imagery to locate foraging sites
2. Objective 2
    a. Further progress towards the IWC-SORP funded project, *Multi-ocean assessment of southern right whale demographic parameters and environmental correlates*, including the formation of the Southern Right Whale Consortium, trials for a common demographic model and the collation of major datasets.
    b. Further collection of photo-ID data
3. Objective 3
    a. Further analyses and data collection on southern right whale body conditions
    b. Development of a new method to assess stress in reproductive females using stable isotope data from mother calf pairs
    c. Further assessments of endocrine data
    d. New information on the energetic cost of female reproduction
4. Objective 4
    a. Collation of southern right whale offshore sighting records South of 40°S to assess foraging locations
    b. New manuscript on the impact of El Niño events on female SRW survival
    c. Ongoing analyses of links between annual abundance and body condition with climatic timeseries datasets.

Introduction

The Southern Right Whale Theme was established in 2018 following endorsement at IWC67. It aims to provide an over-arching research programme linking southern right whale population dynamics and health with foraging ecology, and assessing these linkages on a global scale. Its main goal is to leverage the existing long-term datasets from the primary wintering grounds with new knowledge on the species' foraging ecology and linkages between migratory habitats, with the ultimate goal of investigating the impact of past and future climate variation on right whale recovery.

Objectives

1. Increase our understanding of southern right whale foraging ecology
2. Update our knowledge on southern right whale population dynamics in a comparative framework
3. Pursue integration of health assessment indicators with long-term monitoring data
4. Investigate the impact of past and future climate variation at foraging grounds on population recovery

Progress to date

Objective 1: Increase our understanding of southern right whale foraging ecology

Global

1.1. 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.

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This work is using modelled $\delta^{13}C$ and $\delta^{15}N$ isoscape of the Southern Hemisphere's oceans from 30°S to the ice edge, developed by Dr Chris Somes (Somes et al. 2017, 2021; Schmittner and Somes, 2016), in combination with bulk skin stable isotope data from 967 southern right whales (SRW) to identify foraging grounds on a circumpolar sale. This isoscape model provides an estimate of the stable isotope values at the base of the food chain (phytoplankton) for the oceans. Individual whale foraging locations were estimated using a modified version of the assignment model from Vander Zanden et al (2015) and this isoscape model. A challenge in identifying potential foraging grounds from the stable isotope data has been to identify a trophic enrichment factor or trophic discrimination factor (hereafter TDF) that provides a correction to apply to the isoscape that brings it to the trophic level of the SRW. This was addressed using mid to high-latitude SRW satellite track data provided by Dr Alex Zerbini and colleagues, and Dr Jen Jackson and colleagues, of whales tagged in the western South Atlantic (Zerbini et al 2018, J. Jackson, unpublished data) and by Dr Emma Carroll, Dr Alex Zerbini and Dr Simon Childerhouse and colleagues, of whales tagged in the Indo-Pacific (unpublished data). An analytical framework developed and implemented by Dr Solène Derville has optimized the TDF to maximise overlap between the area restricted search positions identified in the satellite track data and the isoscape assignments. This approach has proven effective at identifying a TDF that can be applied to the bulk skin isotope data. Initial results have shown the location of both the key foraging grounds for the New Zealand and Argentine wintering grounds, but also the wide distribution of foraging grounds inferred at a lower frequency in the population. Regular meetings are being conducted by the project steering committee (Carroll, Torres, Valenzuela, Newsome, Vander Zanden and Derville) to progress the project analyses and publications.

South Africa

1.2. Satellite transmitters were deployed on 4 adult female SRW in South Africa as a pilot study, to assess foraging locations. This research project is run in collaboration with Dr Els Vermeulen (MRI Whale Unit-UP), and Dr Alex Zerbini and Dr Amy Kennedy from the National Oceanic and Atmospheric Administration (NOAA), University of Washington's Cooperative Institute for Climate, Ocean and Ecosystem Studies (CICOES/UW), and the Marine Ecology and Telemetry Research (MarEcoTel). Funding is provided by Instituto Aqualie (Brazil) and the MRI Whale Unit. Updated locations of these whales can be seen at www.mammalresearchinstitute.science/whale-unit. The map below indicates the position (Figure 1) of 3 of the 4 whales in February 2022 (one tag stopped transmitting in December 2021). Up to date, all 4 females remained above 50°S.

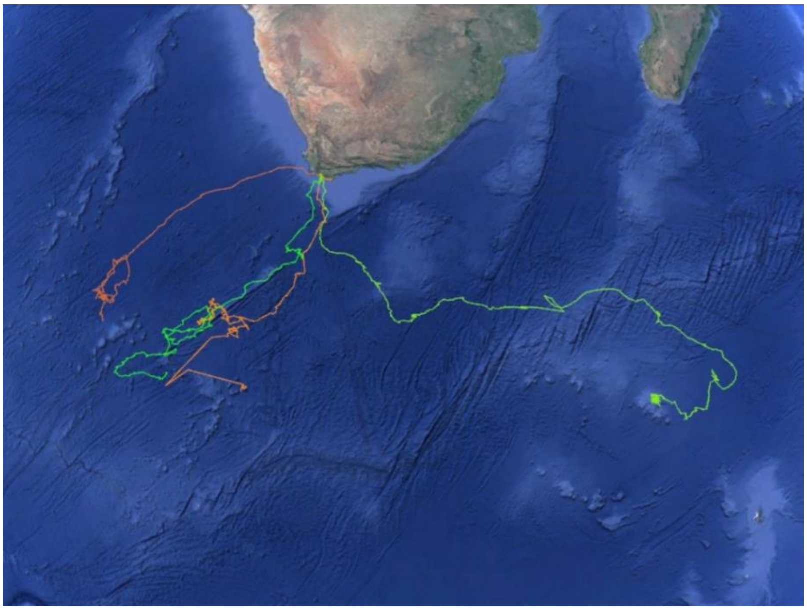

Figure 1 Tracks of the southern right whales instrumented with satellite transmitters off the South African coast in 2021.

1.3. Boat-based fieldwork in South African waters during 2020 allowed for the collection of 18 skin samples which will be processed for stable isotope and mtDNA. Additionally, skin samples used in van den Berg et al. (2021), for which stable isotope profiles exist, will have their mtDNA haplotype characterised in light of a project related to the investigation of maternally directed site-fidelity to foraging grounds in the South African population.

1.4. TheWhale Unit has been collaborating with researchers from the Polytechnic University of Catalonia in regards to the observation and automated detection of SRW in multispectral satellite imagery (see paper in review: Houegnigan et al.). The joint project, entitled *The Wildlife and Marine Mammal Spatial Observatory*, is a joint research effort for the census of wildlife and particularly of marine mammals in satellite imagery. In that context, Houegnigan et al. illustrates the development of a high accuracy algorithm for the detection of SRWs in sub-meter resolution multispectral satellite imagery with the constraint of a relatively small sample support of 580 SRW images. A significant space in the paper is devoted to exploratory data analysis to describe the statistical structure of right whale pixels and ocean surface pixels across multispectral bands.

Observations of SRWs in satellite imagery are divided into typical and atypical right whale forms and the first observations of right whale mother and calf pairs in satellite imagery are presented. Measurements of whales are furthermore automatically extracted from whale observations (major axis length, minor axis length, etc). A significant space is also devoted to statistical data exploration, a step frequently overlooked in machine learning solutions, yet one that offers interesting insight into the structure of animal detection in satellite imagery. The extracted statistics can readily be used by researchers to develop detection solutions even with low sample support. The adopted solution for detection consists of feature extraction with a convolutional neural network followed by classification with a support vector machine. Twenty different convolutional neural networks were tested for feature extraction. Biostatistics parameters (accuracy, sensitivity, specificity and precision) were measured for comparison. Most architectures generally achieved high performance with low false positive and false negative rates. 100% accuracy is achieved in the case of 2 convolutional neural networks, Nasnet Large and Inception V3, and only with a specific selection of multispectral bands. The full paper (still under review) can be seen at SC/68d/SH12.

1.5. Baleen plates of five adult females and three adult males that stranded along the South African coast between 1987 and 2020 were subsampled at 2cm intervals, and samples were used for stable isotope ($\delta^{15}N$ and $\delta^{13}C$). Preliminary analyses showed a larger range in both carbon and nitrogen values for the sampled males and that they seemed to occupy a broader niche space compared to the sampled females. When looking at the females alone, those with elevated progesterone levels occupied a marginally smaller niche space than those with normal progesterone levels. While most individuals showed clear cyclicity indicative of migration between foraging and breeding grounds, one individual did not. It is suspected that this individual did not migrate but remained on the west coast of South Africa.

Additionally, this coming year, radiocarbon profiles of a few adult baleen plates will be assessed to investigate the oceanic ^{14}C offset in the location of migrations, and assess possible temporal changes, in light of an honours project at the University of Pretoria.

Argentina

1.6. A study conducted to evaluate the potential impact of maternal nutrition on calf survival in the right whale population of Península Valdés (Marón et al. 2020) showed some results related to foraging ecology. For instance, fatty acid profiles and $\delta^{13}C$ and $\delta^{15}N$ stable isotopes did not differ between dead and living calves sampled in 2003-2011, indicating similar maternal diets between both groups. Likewise, similar isotopic values in living and dead calves imply that their mothers had similar foraging ranges and visited the same feeding areas: one potentially located south of the Polar Front and around Georgias del Sur/South Georgia (lowest isotope values), another at the Patagonian Sea and northerly waters (highest isotope values), while a third could be an unknown site or a combination of the previous two areas. Similar results were found by Valenzuela et al. (2009, 2018) when analysing $\delta^{13}C$ and $\delta^{15}N$ stable isotopes in reproductive females that were sampled at Península Valdés.

1.7. A long-term study to satellite track southern right whales wintering near Peninsula Valdés (Zerbini et al., 2015, 2016, 2018) has resumed after cancellation of the 2020 field season due to the COVID-19 pandemic. This study has been developed by research teams from Argentina (CENPAT/CONICET, Escuela Superior de

Ciências Marinas – U.N. Comahue, Instituto de Conservación de Ballenas, Wildlife Conservation Society – Argentina, Fundación Patagonia Natural), Brazil (Instituto Aqualie) and the United States (Cooperative Institute for Climate, Ocean and Ecosystem Studies-University of Washington, Marine Ecology and Telemetry Research, Marine Mammal Laboratory/AFSC-NOAA, and University of California, Davis). The goals of this research include determining migratory destinations of whales breeding off Argentina, assessing performance and effects of "transdermal" (type C, Andrews et al., 2019) satellite tags and developing minimally invasive ("blubber-only") implantable tags for right whales. Between 27 September and 9 October 2021, a total of 12 blubber-only tags and 6 transdermal tags were deployed on 13 females with calves, one mature male, one adult animal of unknown sex and three sub-adults of unknown sex. All whales were tagged in the area around Puerto Pirámides in Golfo Nuevo, Península Valdés. Biopsy samples were collected from all individuals and are being processed to determine the sex of tagged whales for which such information is not available. Average duration of blubber-only tags was 22.6 days and the 12 tags have now stopped transmitting. All transdermal tags were still transmitting at the time this report was prepared, indicating minimum transmission durations of 154-167 days. Follow-up of tagged whales to assess potential effects of transdermal and blubber tags was performed since tagging and until early December when the tagged whales left Golfo Nuevo. A total of 14 whales were resighted periodically over periods ranging from 10 to 68 days. Information from follow-up studies will be used to assess improvements in new satellite tags to minimize potential welfare issues associated with the use of invasive devices. Tracks of whales tagged with blubber-only and transdermal instruments are illustrated in Figure 2, 3 and 4. Long-term tracking of southern right whales from Argentina (65 tags deployed in 2014-2017, 2019 and 2021) indicates that these whales use the Patagonian shelf (including the Falkland Islands/Islas Malvinas), the Southwest Atlantic basin, areas around South Georgia/Georgias del Sur islands and the Weddell Sea as migratory destinations/foraging grounds. Interpretation of movement patterns depicted by tags deployed in 2021 will be presented to the IWC SC once all tags stop transmitting and data are fully analysed. Another field season of this project, which has been supported by the US Office of Naval Research, NOAA, and the governments of Argentina and of the Provinces of Chubut and Rio Negro, is expected to occur in the austral spring of 2022.

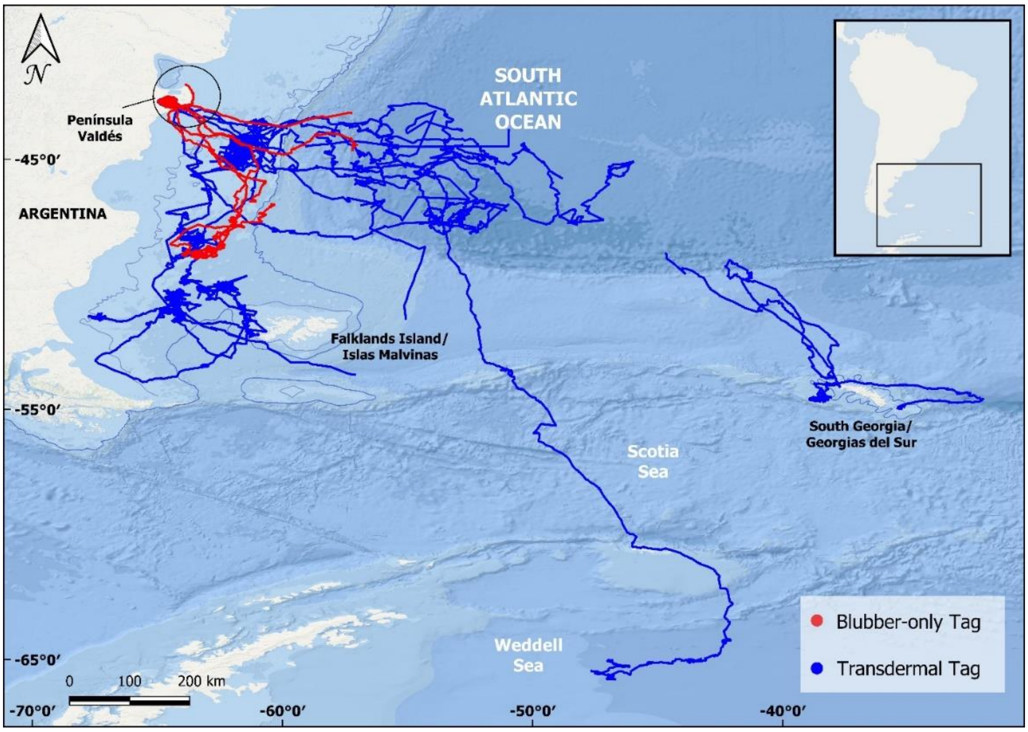

Figure 2 Tracks of southern right whales instrumented with "blubber-only" and "trandermal" tags off Peninsula Valdes, Argentina in 2021.

Figure 3 Track of right whales instrumented off Peninsula Valdes, Argentina, with "blubber-only" tags.

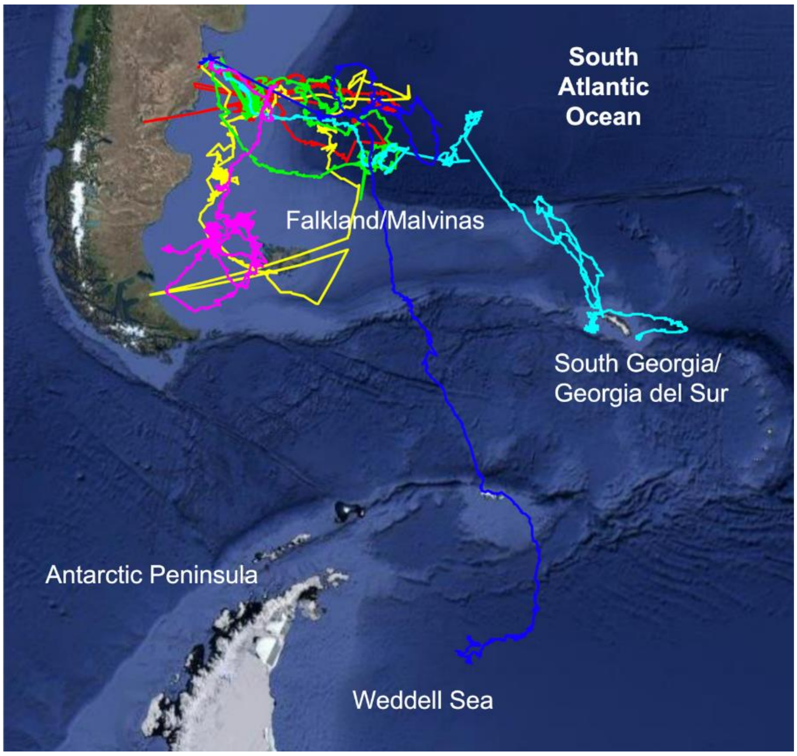

Figure 4 Tracks of right whales instrumented off Peninsula Valdes, Argentina, with "transdermal" tags.

Brazil

1.8. In 2020 and 2021 fifty-seven skin samples were collected for the analysis of stable isotopes of d13C and d15N to investigate the foraging patterns and intraspecific differences in the spatial and trophic ecology of E. australis that frequent the coast of southern Brazil. This is a new research project of ProFRANCA/Instituto Australis, funded by Petrobras, and is part of the Thaise Albernaz PhD study. The isotopic niche amplitude and overlap were calculated using the SIBER tool for each group of whales divided into years, solitary adult and females with offspring. Preliminary results indicated foraging areas at low latitudes, in waters such as the Patagonian platform. The species showed significant differences and partial segregation in the trophic niche between the two years and the groups of adults with and without offspring.

New Zealand

1.9. In August 2020 and June/July 2021, the University of Auckland and Cawthron Institute led expeditions to the Auckland Islands Maungahuka to investigate the recovery and foraging ecology of Tohorā nō Aotearoa - New Zealand SRWs. This is the continuation of genetic monitoring work on Aotearoa New Zealand SRW begun by the New Zealand Department of Conservation and the University of Auckland in 1995. Over two years the research programme collected 599 skin biopsy samples and deployed 18 satellite tags, in collaboration with the AAD and NOAA. One tag from the 2020 field season lasted 1 year and 17 days, and showed the complete migratory cycle of this male SRW. The combined tracks across the two years are shown in Figure 5 showing a general northwest migration pattern to a regional south of Australia in spring. The longest lasting tags in 2020 showed the whales were far west of the Auckland Islands wintering ground in the austral summer whereas the single tag transmitting in February 2021 was east of New Zealand. An update on this work is presented in SC/68d/SH08 (Project 24).

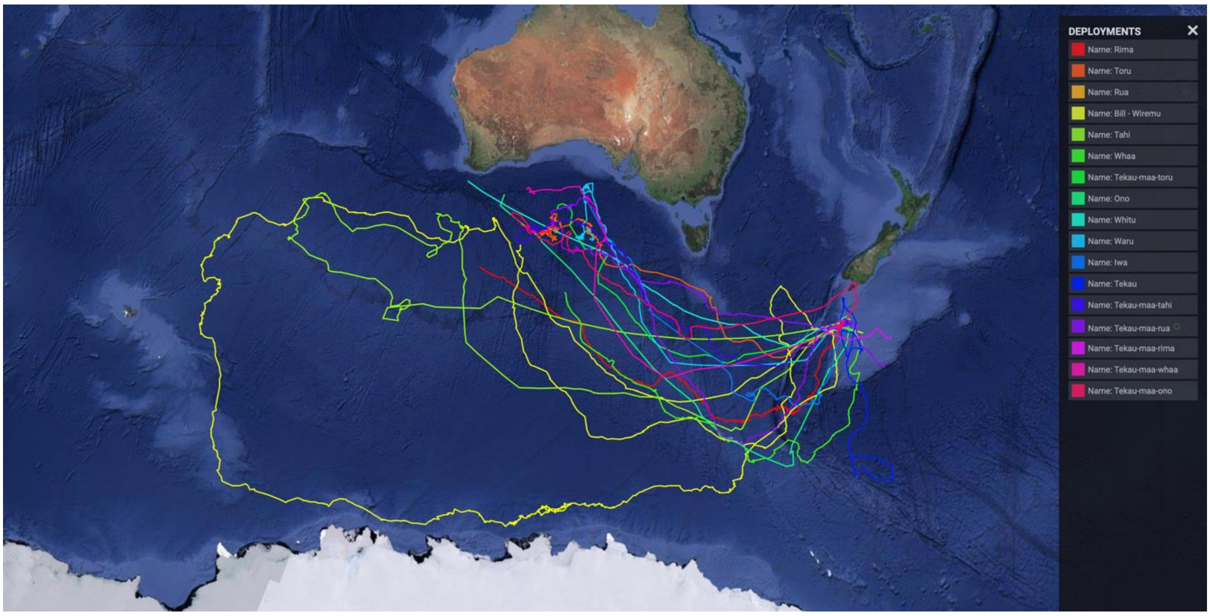

Figure 5 movement of SRW satellite tagged at the Auckland Islands wintering ground in August 2020 and July 2021.

1.10. The foraging ecology of New Zealand SRWs is being investigated using δ13C and δ15N isotope values from skin samples (n=739) with associated genetic profiles (individual identity, sex, age, reproductive status) collected between 1995 and 2020, with approximately 40 whales sampled in >1 year. The results, forming part of Annabelle Cranswick's MSc project, shows that there has been a steady contraction in the isotopic niche space of the population, which also show significant variation in isotopic profiles across decades (See Figure 6). Investigation of the stable isotope profile by demographic class of non-calf whales (n=591 individuals sampled up to three times) showed a change in nitrogen by reproductive state in females, on an individual and population level, that has also been found in compound specific analyses led by Dr Geraldine Busquest-Vass (see Busquets-Vass et al. 2022, SC68d/SH11).

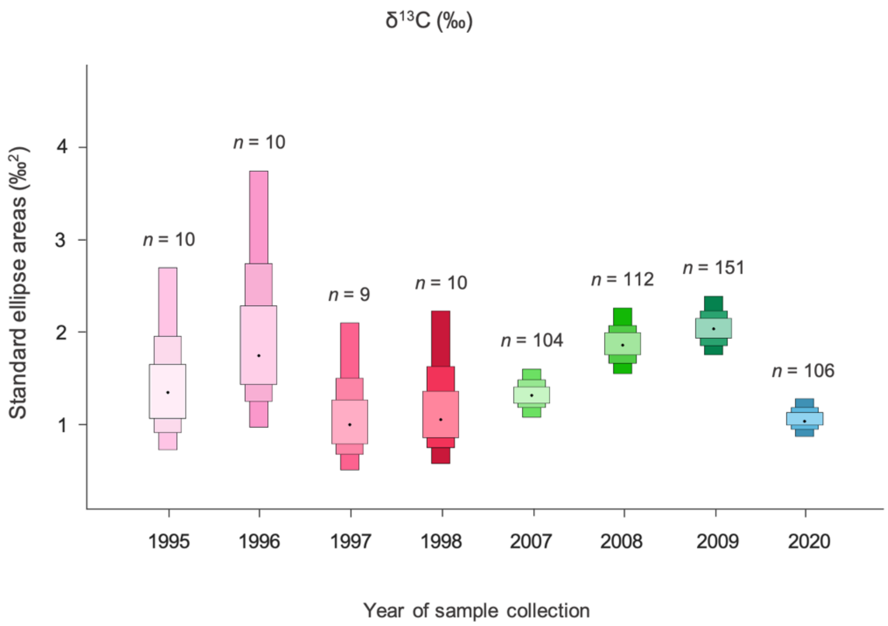

Figure 6 Variation in $\delta^{13}C$ and $\delta^{15}N$ values for Auckland Islands southern right whales (n = 591), grouped by year of sampling. The sample size is above each bar. Figure shows central tendency and measures of uncertainty (50%, 75%, and 95% credible intervals, where the black dot is the mode of each distribution) of Bayesian standard ellipse area, indicative of niche space for each year.

Objective 2: Update our knowledge on southern right whale population dynamics in a comparative Framework

Global

2.1. A funding application was submitted to the IWC-SORP to develop a common model for estimating SRW demographic parameters, which will contribute significantly to Objective 2: update our knowledge on SRW population dynamics in a comparative framework. With this application, it is aimed 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.

Progress on this project can be summarised as follows:

- A SRW Consortium was developed to facilitate multi-ocean collaboration, and form the basis for the exchange of long-term sighting history data to be included in the common model.
- Specification of the common SRW biological model (common model) is now complete, with a new feature added of explicitly modelling an “unsuccessful mother” component for females experiencing late abortions or early calf deaths. The model will allow various demographic parameters (e.g. true calving intervals and their changes over time, population growth rates) to be estimated for the different SRW populations. The coding for this inclusion is almost complete, with model-fitting to commence soon. Major datasets have been provided for model input from Argentina/Brazil, Australia and South Africa. A New Zealand dataset will be requested once model trials are complete for datasets from the regions listed above.

For more information, see IWC-SORP project progress reports related to, *Multi-ocean assessment of southern right whale demographic parameters and environmental correlates* (Project 30, SC/68d/SH08)

2.2. Wildme, NOAA and various international collaborators have advanced the Flukebook automated marine learning software for using artificial intelligence for photo identification cross matching of southern right whales. Data was contributed from South Africa, Argentina, Australia and New Zealand and software trained for southern right whales using hotspotter and deepsence.ai algorithm. The platform is up and running and available for photo id matching. Results are summarised in Kahn et al. (in review). Resources are required to trial the software for southern right whales and to contribute to software advancement and integration into existing photo identification databases used by the global research community.

South Africa

2.3. A manuscript was prepared regarding an updated photo-identification assessment model of SRW surveyed in South African waters, with a focus on some recent low counts of mothers with calves. This paper, authored by Brandão, Ross-Gillespie, Vermeulen and Butterworth, will soon be submitted for publication.

2.4. The 43rd annual SRW aerial survey was successfully conducted along the South African coast between 3 and 5 October 2021, during which 195 SRWs were photo-identified, of which 177 were cows. A full report is provided in SC/68d/SH02.

Brazil

2.5. The 2021 annual SRW aerial survey was conducted along 380 km of the Southern Brazilian coast (between Santa Catarina and Rio Grande do Sul States) on 4th September 2021, during which 120 SRWs were sighted (60 cow/calf pairs), 84 photo-identified, of which 60 cows and 24 calves.

New Zealand

2.6 Photo-ID data for the SRWs of the Auckland Islands, New Zealand, are held in two separate catalogues – one for lateral images and, more recently, one for aerial images collected via unmanned aerial vehicles (UAVs). Lateral data have been gathered during winter field seasons from 2006-2014 and 2016-2018 by teams from University of Otago, University of Auckland, Australian Antarctic Division, Department of Conservation and Cawthron Institute. The lateral catalogue currently contains 1,054 uniquely identifiable individual whales: 549 females, two males and 503 of unknown sex. All whales encountered in years 2006 – 2016 have been entered into the lateral catalogue. Mothers only for years 2017 and 2018 are also entered. The aerial catalogue, created in 2016, currently contains 638 unique whales: 305 females and 333 of unknown sex. All whales photographed by UAVs in 2016 – 2018 have been entered into this catalogue.

2.7. The production of annual abundance estimates of right whales at Port Ross, Auckland Islands, is currently underway using lateral images. Capture histories have been created and estimates are being derived via Huggins closed population estimation. This is part of the PhD project of David Johnston from the University of Otago, New Zealand. Annual estimates are expected to be available before the end of March 2022.

2.8. The advent of Flukebook, an open online platform for AI-driven photo-ID matching, has provided an opportunity to speed up the process of photo-ID, while simultaneously training newly developed algorithms that can be applied across populations. To date, all whales from both aerial and lateral catalogues have been entered into Flukebook. Additionally, lateral images of non-mothers in 2017 and 2018 are also entered into Flukebook, though have not yet been matched against the catalogue. Inter-regional matching between catalogues from New Zealand and Australia is currently being discussed and is expected to begin sometime in 2022, with the aid of Flukebook.

2.9. The recent Auckland Islands surveys by the University of Auckland and Cawthron Institute collected 599 skin biopsy samples over the austral winters of 2020 and 20201 (see ForInfo: Carroll et al.). DNA extraction and DNA profile construction of the 2020 samples was completed and reported by Carroll et al (2021) and this work is ongoing for the 379 samples collected in 2021, but delayed due to covid related lockdowns. These data will be the basis for a revised estimate of total abundance for the population, using the previously published POPAN-lambda model (Carroll et al 2013), and will be compared with the close kin mark recapture method of Bravington et al (2016).

Australia

2.10. Long term monitoring of southern right whale distribution, abundance and life histories in south-western Australia through count and photo identification were successfully completed in 2021. The annual aerial survey run by Murdoch University and in collaboration with Curtin University, and funded through the Australian Government National Environment Science Program (NESP), was undertaken between Cape Leeuwin, Western Australia and Ceduna, South Australia, 12-17 August 2021. A total maximum count from each survey leg recorded 634 whales, consisting of 267 mother-calf groups and 100 unaccompanied whales. The number of mother-calf pairs is substantially higher than last year (2020; N = 156), although the number of unaccompanied whales is the lowest recorded in the past 18 years (since 2003) and the current population estimate (N = 2,537) is similar to last year. The long-term population trend calculated as a linear rate of annual increase shows females with calves increasing at approx. 5.4%, however, southern right whales continue to exhibit highly fluctuating annual variation in abundance evident in recent years (2007-2021). The report from the 2021 survey will be made available on the NESP Marine and Coastal Hub website with reports from previous surveys from surveys available on the NESP Marine Biodiversity Hub website (https://www.nespmarine.edu.au/reports). Sightings from these surveys will be incorporated into the Australasian Right Whale Photo-Identification Catalogue (ARWPIC), managed by the Australian Government Department of Agriculture, Water and the Environment's Australian Antarctic Division.

The 32nd consecutive year of annual land-based population surveys at major aggregation ground at the Head of the Great Australian Bight South Australia were achieved between July 15 and August 30, managed by Curtin University (and 9th year of surveys at adjacent aggregation area at Fowlers Bay, SA). 2021 represented the largest cohort of breeding females and a total of 100 females with calves and 56 unaccompanied adults were successfully identified across both sites. Majority of females that calves at Head of Bight in 2021 were returning females with 85% positive matches to existing photo ID catalogues. Average calving rates for 2021 was four years, followed by five year intervals, which supports that mean calving intervals have increased since 2015 (Charlton et al. 2021). Lower than expected number of unaccompanied adults were recorded during aerial and cliff based surveys in 2021, which may indicate lower migration rates of this population class or a shift in distribution and requires further investigation. See also SC/68d/ForInfo35.

2.11. Complimentary research (not formally part of the IWC-SORP research theme) published in Evans et al. (2021) detail the final results of a three year national collaborative effort funded through the NESP Marine Biodiversity Hub to migrate a number of individual datasets into the ARWPIC for wider availability and utility for establishing resight information on animals in both the western and eastern Australian populations. Using mark-recapture data from ARWPIC, the project updated estimations of a number of population parameters and trends undertook spatial analyses of mixing of southern right whales in the Australian regions. The final report from the project is available on the NESP Marine Biodiversity Hub website (https://www.nespmarine.edu.au/reports).

2.12. Kemper et al. 2022 published findings on southern right whale distribution, relative abundance, residency and site fidelity at Encounter Bay, South Australia using historical sightings (n = 1071, 1970–2013) and photo-identified individuals (n = 191, 2006–2019). Results show that whale numbers have increased at this historical whaling station and nationally recognised Biologically Important Area, particularly since 2013. Encounter Bay is a critical habitat for nursing, breeding mating and resting female and calf pairs, and unaccompanied adults and also serves as an important coastal migration pathway. Mean residency periods were 51 days for cow calf pairs and 13 days for unaccompanied adults. Calving site fidelity was observed for returning mothers. Systematic land based surveys and opportunistic photo ID and behavioural studies were achieved in 2021 through citizen science program and Flinders University honours student.

2.13. Annual opportunistic photo identification including UAV and citizen science managed by M. Watson of the Victorian Department of Environment, Land, Water and Planning was completed for the South-Eastern population of SRW 2021. Watson et al 2021 published the assessment of calving intervals, long-range movements and site fidelity of southern right whales in south-eastern Australia in the J. Cetacean. Res. Manage. 22, 2021. At least 93 calves were born at Logans Beach between 1980 and 2018 (an average of 2.6 per year) with a mean calving interval of 3.5 ± 0.2 years (± SE, n = 34). The mean calving interval between 2007 and 2018 was 3.9 ± 0.2 years (± SE, n = 23). We also provide the first report of an Australian southern right whale female belonging to one subpopulation relocating long-term to a calving area in another.

2.14. Surveys have been underway by C. Burton since the 1990's in south-western Australia and continue with a range of researcher, volunteer and student contributors. With funding through NESP in 2022, C. Salgado Kent and C. Burton have progressed reporting on photo ID processing photo identification data and matching in the SouWEST (South Western Whale Ecology Study) catalogue. This project has processed 3000 whale photographs taken between 1994 and 2020. A total of 151 unique individuals were identified in Geographe Bay (GB) and 83 in Flinders Bay (FB) over this period. Residency varied among years, with a maximum recorded mother-calf stay in Geographe Bay over two month period. Matches between GB and FB are underway, as is uploading of photos to the National repository (ARWPIC). This work is ongoing into the future.

Objective 3: Pursue integration of health assessment indicators with long-term monitoring data

Substantial progress was also made toward Objective 3 of IWC-SORP Theme 6, related to the integration of health assessment indicators with long-term monitoring data.

Global

3.1. Carroll et al (2021) published a new method to assess stress in reproductive females using stable isotope data from mother calf pairs, building on work by Valenzuela et al (2010). Published in Marine Mammal Science, the study compared offsets in carbon and nitrogen isotope values of mothers and their offspring ($\Delta^{13}C_{calf\text{-}cow}$ and $\Delta^{15}N_{calf\text{-}cow}$) among three SRW populations. SRW from Aotearoa New Zealand, with high population growth rates and body conditions scores, have negative $\Delta^{13}C_{calf\text{-}cow}$ suggesting calves are utilizing ^{13}C-depleted lipid carbon in milk to fuel the synthesis of nonessential amino acids used to build new tissues and rapidly grow. In contrast, a significantly positive $\Delta^{13}C_{calf\text{-}cow}$ offset previously reported for SRW from Argentina during a high calf mortality period was hypothesized to be due to calves consuming milk with low lipid content. Patterns in $\Delta^{15}N_{calf\text{-}cow}$ were more difficult to interpret and highlight the complexity in nitrogen transfer between mother and offspring. When combined with similar data collected from Brazil and during a low calf mortality year in Argentina, we hypothesize this approach provides a way to retrospectively compare nutritional condition of breeding adult female SRW across nursery areas.

3.2. IWC Global standardized protocol for visual health assessment is in preparation for publication.

South Africa

3.3. The body condition of 47 lactating females was assessed using the methods of Christiansen et el. (2018, 2019), of which 20 were photographed in 1988/89 and 27 in 2019 and 2021. Temporal comparison showed a 23% reduction of the body condition of these lactating females. A manuscript is being finalised in which these results are detailed.

3.4. A preliminary assessment revealed a positive relationship between blubber glucocorticoid levels and body condition in lactating female SRWs in South African waters, indicating lactating females in a worse body condition had lower levels of blubber glucocorticoids. Interestingly, relative calf-length did not seem to be related to blubber glucocorticoid concentrations of related lactating females, suggesting that the duration of lactation (and thus the time lag from late pregnancy and the birthing process) was not a confounding factor. Although based on a small sample size, these results could point towards a decreased lipid mobilisation from the mother's adipose tissue to the milk when in poor body condition, and warrants further in-depth investigation.

3.5. Baleen plates of five adult females and three adult males that stranded along the South African coast between 1987 and 2020 were subsampled at 2cm intervals, and samples were used for stable isotope ($\delta^{15}N$ and $\delta^{13}C$) and reproductive hormones. Progesterone profiles clearly showed individual pregnancies and inter-calving intervals for the sampled adult females. Early, as well as late, abortions or the death of a neonatal calf could also be identified from progesterone profiles. Most interestingly, progesterone, as well as testosterone peaks, coincided with periods of low carbon isotope values suggesting that conception may take place in the Southern Ocean foraging grounds, with the duration of the progesterone profiles being suggestive of a gestation period well over 12 months and probably closer to 14-15 months. Further analyses of oestrogen, cortisol and glucocorticoid profiles are underway to gain a better understanding of the reproductive cycle of adult female SRWs.

3.6. Species distribution models of SRWs in southern Africa (see Purdon et al. 2020) will be used in the scope of an honours project over the course of 2022, to assess continued habitat suitability of coastal South Africa for southern right whales in light of increasing SSTs.

Southwest Atlantic

3.7. Body condition sampling of SRWs using drone photogrammetry (following the approach of Christiansen et al. 2018, 2019) continued in Península Valdés in 2019 and 2021, with 783 whales (247 calves, 202 juveniles, 79 adults and 255 lactating females) being sampled in 2019. The 2021 data is still being processed, but the approximate number of sampled whales is ~650. The project now has three years of data (2018, 2019, 2021) of approximately 2,500 individuals, and has secured funding to continue sampling in 2022 and 2023.

3.8. Data of SRW mothers and calves in Península Valdés from 2018-2019, combined with data from Australia (Head of Bight) from 2016-2019, was used to investigate the birth size of newborn calves, which was found to be ~35% of the maternal length. Combined with Soviet whaling records, this data was used to estimate the foetal growth rates of SRWs. The foetal growth curves were converted to tissue energy content using published tissue mass data (blubber, muscle, viscera and bones) from North Pacific right whales and published estimates of tissue energy content from fin, sei and minke whales. The energetic cost of foetal growth, as well as placental growth and heat of gestation (foetus maintenance) was calculated. The findings show that 95% of the total gestation cost is incurred during the 3rd trimester. The findings are currently in press in the Journal of Physiology (Christiansen et al. 2022a)

Argentina

3.9. A comparison between body fat condition of dead and living calves at Península Valdés, Argentina in 2003-2016 was conducted to evaluate whether lipid reserves were depleted in dead calves indicating signs of malnutrition. Neither total lipid content (Marón et al. 2021) nor fatty acid profiles (Marón et al. 2020) in the outer blubber layer differed significantly between dead and living calves. Furthermore, a comparison between blubber thickness of calves that died during seasons of high calf mortality (2003, 2005, 2007-2013) and low calf mortality (2004, 2006, 2014-2019) (Marón et al. 2021) indicated no evident changes in the patterns of fattening suggesting that individuals were not undernourished. For this study, blubber thickness was measured at nine body locations in a total of 350 newborn to 4–6-month-old calves.

New Zealand

3.10. The Auckland Islands survey undertaken in the austral winters of 2020 and 2021 spanned the peak period of use and indicate that the phenology of SRW using the area resembles that observed in the 1990s. In contrast, the proportion of groups containing cow-calf pairs has increased from 20% in the 1998 survey to 50% in 2020/21. These findings are consistent with a growing population undergoing strong recruitment, suggesting that either New Zealand SRW prey resources are stable or the population is adapting to changing prey resources. The continued use of Port Ross by all SRW demographic classes confirms that this is a key habitat for this species in New Zealand waters. This work is currently in review in Polar Biology, presented as SC/68d/ForInfo25.

3.11. The field work in 2020 and 2021 collected over 80 skin samples and matched photogrammetry data from Auckland Island SRWs, including from several satellite tagged individuals. Multiple data sources will be integrated including genetic, stable isotope, hormone and body condition, to understand the relationship between foraging ground and health in a future study using these data.

3.12. As part of the PhD project of David Johnston, assessment of the morphometrics of right whales at the Auckland Islands, New Zealand, has been conducted using UAV data collected in 2016 – 2018. Absolute measurements of total lengths were obtained for 337 whales across the three expeditions, as well as 134 calves (results summarised in Figure 7). Additionally, principal component analyses of length and width data indicated that body sites between 30% - 80% along total length were the most important for describing changes in relative width (Johnston et al. 2022, in press). Driven by these results, individual body condition indices have been produced for 522 whales encountered in 2016 - 2018, including calves.

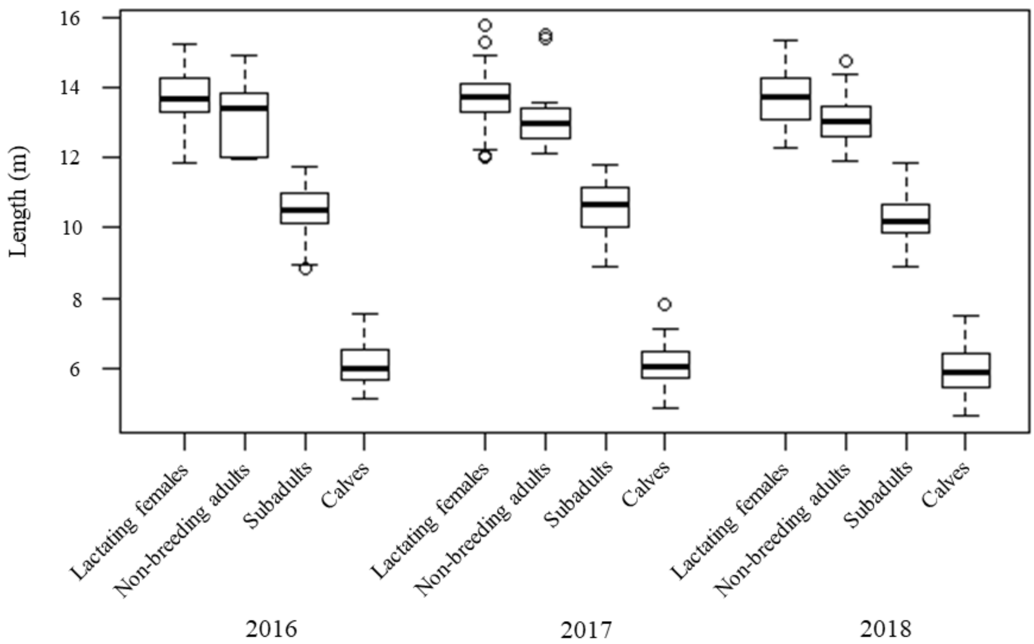

Figure 7 Box and whisker plots for lengths of southern right whales measured at the Auckland Islands during expeditions in 2016 – 2018 (n for lactating females 2016 = 32; 2017 = 61; 2018 = 88, apparent non-breeding adults in 2016 = 9; 2017 = 19; 2018 = 27, subadults in 2016 = 28; 2017 = 28; 2018 = 45 and calves in 2016 = 29; 2017 = 27; 2018 = 78). For each demographic, the median, upper and lower quartiles and greatest and lowest values are displayed. Outliers have not been removed as measurements are biologically plausible.

Australia

3.13. Body condition sampling of SRWs using drone photogrammetry (following the approach of Christiansen et al. 2018, 2019) continued at the Head of Bight in 2019 and 2021, with 162 whales (67 calves, 14 juveniles, 14 adults and 67 lactating females) being sampled in 2019. The 2021 data are still being processed, but the approximate number of sampled whales is ~150 individuals. The project now has five years of data (2016-2019, 2021) of approximately 1,000 individuals, and additional sampling is planned for 2022 if sufficient funding can be secured.

3.14. The cost of gestation of SRWs was estimated using data from Head of Bight and Península Valdés (see point above).

3.15. The cost of somatic growth was estimated for SRWs at the Head of Bight, using drone photogrammetry data (to estimate body length) and long-term photo ID data (to estimate age). Length-at-age curves were fitted and converted to mass-at-age curves using published estimates of tissue mass from North Pacific right whales. The cost of somatic growth was estimated by converting the tissue mass into energy content, using published tissue energy data from fin, sei and minke whales. The findings are currently in press in Marine Ecology Progress Series (Christiansen et al. 2022b).

3.16. A visual health assessment of southern right whales in south-east Australia utilising the long-term south-east Australian photo-ID data-set managed by Mandy Watson of the Victorian Department of Environment, Land, Water and Planning is underway by a Deakin University Honours Student.

Objective 4: Investigate the impact of past and future climate variation at foraging grounds on population recovery

Global

4.1. A global desk-top assessment of SRW sightings South of 40°S was completed by honour student Cuyler van Jaarsveld. Data were collected from multiple sources and used to produce maps in order to visualize where and when SRWs were sighted. A total of 357 sightings data points were collected from 13 separate sources, including SOWER cruises, CCAMLR, Happywhale, PROANTAR, ObsInt, IWC reports and the South Georgia Heritage Trust Database. A full report can be seen at SC/68d/SH03.

Argentina

4.2. Comprehensive analyses of the long-term data on SRW individual sighting records from the Instituto de Conservación de Ballenas and Ocean Alliance were undertaken by PhD student and ICB Researcher Macarena Agrelo and collaborators to assess how El Niño events affects female survival. By analysing a five-decade (1971-2017) data series of 1,380 individual SRWs photo-identified at Península Valdés, Argentina, researchers discovered a marked increase in whale mortality rates following strong El Niño events. By modelling how the population responds to changes in the frequency and intensity of El Niño events, it was found that predicted climate change events are likely to delay or even impede SRW population recovery. Such outcomes have the potential to disrupt food-web interactions in the SO, weakening that ecosystem's contribution to the mitigation of climate change at a global scale. These findings were published in Science Advances (Argelo et al. 2021). For more information, see SC/68d/ForInfo18.

Australia

4.3. A publication is in progress to assess drivers of increased calving intervals observed in recent years for the Australian southern right whale population through assessment of correlation between calf production and ENSO, SAM, Antarctic Oscillation and sea ice extent.

Project outputs

Peer-reviewed papers

Agrelo M, Daura-Jorge FG, Rowntree VJ, Sironi M, Hammond PS, Ingram SN, Marón CF, Vilches FO, Seger J, Payne R, Simões-Lopes PC (2021) Ocean warming threatens southern right whale population recovery. Science Advances, 7(42). https://doi.org/10.1126/sciadv.abh2823

Carroll EL, Dunshea G, Ott PH, Valenzuela LO, Baker CS, Childerhouse SJ, Gaggiotti OE, Flores PAC, Groch K, Gröcke DR, Hindell MA, Lundquist D, Oliviera LR, Rowntree V, Sironi M, Newsome SD (2021) Variation in δ13C and δ15N values of mothers and their calves across southern right whale nursery grounds: the effects of nutritional stress? Marine Mammal Science. https://onlinelibrary.wiley.com/doi/10.1111/mms.12871

Charlton C, McCauley RD, Brownell RL Jr., Ward R, Bannister JL, Salgado Kent C (2022) Southern right whale (*Eubalaena australis*) population demographics at major calving ground Head of Bight, South Australia, 1991–2016. Aquatic Conservation: Marine and Freshwater Ecosystems, 1–16. https://doi.org/10.1002/aqc.3771

Christiansen F, Uhart MM, Bejder L, Clapham P, Ivashchenko Y, Tormosov D, Lewin N, Sironi M (2022a, *In Press*). Foetal growth, birth size and energetic cost of gestation in southern right whales. Journal of Physiology.

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

Christiansen F, Dawson SM, Durban JW, Fearnbach H and others (2020) Population comparison of right whale body condition reveals poor state of the North Atlantic right whale. Marine Ecology Progress Series 640: 1-16. https://doi.org/10.3354/meps13299

Evans K, Charlton C, Townsend A, Watson M, Carroll E, Double M, Upston J, Carlyon K, Alderman R (2021) Estimation of population abundance and mixing of southern right whales in Australian and New Zealand regions. Report to the National Environmental Science Program, Marine Biodiversity Hub and CSIRO Oceans and Atmosphere.

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

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Marón CF, Lábaque MC, Beltramino L, Di Martino M, Alzugaray L, Ricciardi M, Fernández Ajó AA, Adler FR, Seger J, Sironi M, Rowntree VJ, Uhart MM (2021) Patterns of blubber fat deposition and evaluation of body condition in growing southern right whale calves (*Eubalaena australis*). Marine Mammal Science. https://doi.org/10.1111/mms.12818

Marón CF, Budge SM, Ward RE, Valenzuela LO, Di Martino M, Ricciardi M, Sironi M, Uhart M, Seger J, Rowntree VJ (2020) Evaluation of fatty acids and stable isotopes (δ13C, δ15N) in southern right whale calves (*Eubalaena australis*) in relation to age and mortality at Península Valdés, Argentina Marine Ecology Progress Series Vol. 646: 189–200.

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Watson M, Stamation K, Charlton C, Bannister J (*In press*) Calving rates, long-range movements and site fidelity of southern right whales (*Eubalaena australis*) in south-eastern Australia. Journal of Cetacean Research and Management.

Relevant articles in submission/review

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, Patenaude N, Russ R, Stuck E, van der Reis A, Zerbini A, Childerhouse SJ (*In Review*) NewZealand southern right whale (Tohorā nō Aotearoa) habitat use in Port Ross, Auckland Islands over three decades: 1998-2021. Polar Biology.

Houegnigan L, Merino ER, Vermeulen E, Block J, Safari P, Moreno-Noguer F, Nadeu C (*In Review)* Wildlife and Marine Mammal Spatial Observatory: Observation and automated detection of Southern Right Whales in multispectral satellite imagery. bioRxiv 2022.01.20.477141; doi: https://doi.org/10.1101/2022.01.20.477141

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Neveceralova P, Carroll EL, Steel D, Vermeulen E, Elwen S, Zidek J, Stafford JK, Chivell W, Hulva P (*Submitted*) Citizen science noninvasive genetics reveals population changes in a whale breeding ground. Diversity and Distributions.

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Vermeulen E, Jouve E, Best P, Cliff G, Dicken M, Kotze D, Mc Cue S, Meyer M, Seakamela M, Thompson G, Wilkinson C (*Submitted*). Moralities of southern right whales (*Eubalaena australis*) and related anthropogenic factors in South African waters, 1999 – 2019. Journal of Cetacean Research and Management.

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IWC papers

Agrelo M, Sironi M, Groch K, Vilches F, Marón C, Rowntree V, Cooke J. (2021). Working plan for assessing movement rates between breeding grounds of southwest Atlantic southern right whales applying multi-state analysis. Report presented to the 68c IWC scientific committee (Southern Hemisphere subcommittee). SC/68C/SH16.

Butterworth D, Cooke J, Charlton C, Vermeulen E, Ross-Gillespie A, Brandão A, Groch K, Meaper R, Rayment W, Rowntree V, Sironi M, Agrelo M, van den Berg G, Watson M, Carroll EL, Carlyon K, Burnell S, Double M, Jackson J. (2021) Progress report: Multi-ocean assessment of southern right whale demographic parameters and environmental correlates. Report presented to the 68c IWC scientific committee (Southern Hemisphere subcommittee). SC/68C/SH06.

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Charlton C, Vermeulen EL, Hoerbst, Gregory, Christiansen F, Findlay K, Moore M, Leslie, Minton G, Hamilton P, Pettis H (2021) Global, standardised southern right whale qualitative visual health assessment protocol. Report presented to the 68c IWC scientific committee (Southern Hemisphere Subcommittee). SC/68C/SH21.

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Riekkola L, Childerhouse S, Zerbini AN, Andrews-Goff V, Constantine R, Cole R, Stuck E, Carroll EL. (2021) An unexpected journey: tracking southern right whales from New Zealand subantarctic wintering grounds. Report presented to the 68c IWC scientific committee (Southern Hemisphere subcommittee). SC/68C/SH02.

Vermeulen E, Charlton C, Burnell S, Carlyon K, Double M, Groch K, Rayment W Rowntree V, Sironi M, Watson M (2021) Towards a southern right whale consortium. Report presented to the 68c IWC scientific committee (Photo-identification subcommittee). SC/68C/PHXX.

Vermeulen E, Jouve E, Cliff G, Dicken M, Meyer M, Saekamela M, Thompson G, Wilkinson C, Best P (2021) Mortalities of southern right whales and related anthropogenic factors in South African waters, 1999 – 2019. IWC/SC/68c committee (Southern Hemisphere subcommittee). SC/68C/SH14.

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

Vermeulen E, Wilkinson C, van den Berg G, Paarman S (2021) Report of the southern right whale aerial surveys 2020. IWC/SC/68c (Southern Hemisphere subcommittee). SC/68C/SH04.

Weir CR (2021) Southern right whale (*Eubalaena australis*) surveys in the Falkland Islands during winter 2019 and 2020: preliminary results. IWC/SC/68c (Southern Hemisphere subcommittee). SC/68C/CMP09.

Related theses finalised in 2021

Terriann Thavar - Southern right whale (*Eubalaena* australis) body condition and glucocorticoid levels at the South Africa breeding ground - Master of Science in Zoology and Entomology, Mammal Research Institute - University of Pretoria (under main supervision of Prof. A. Ganswindt)

Gideon Van den Berg - Foraging ecology of South Africa's southern right whales (*Eubalaena australis*) in relation to calving success and global climate variability - Master of Science in Zoology and Entomology, Mammal Research Institute - University of Pretoria (under main supervision of Prof. A. Ganswindt)

Meghan Van Zyl - Southern right whale baleen male hormone profiles – Honours - University of Pretoria (under main supervision of Prof. A. Ganswindt)

Cuyler Van Jaarsveld – Contemporary southern right whale sightings South of 40°S – a global database - Honours - University of Pretoria (under main supervision of Prof. A. Ganswindt)

Other students

Thaise Albenaz - Ph.D. candidate, ProFRANCA/INstituto Australis, Brazil.

David Johnson – Ph.D. candidate, University of Otago, New Zealand.

Macarena Agrelo – Ph.D. candidate, Federal University of Santa Catarina, Brazil.

Conference presentations in 2021

Cranswick A, Newsome S, Baker CS, Busquets-Vass G, Childerhouse SJ, Dunshea G, Carroll EL (2021) Foraging flexibly or consuming conservatively? Foraging ecology of New Zealand southern right whales over three decades using stable carbon δ13C and nitrogen δ15N isotopes. Oral presentation to the Stable Isotope Network for New Zealand Hui, December 2021.

Media interest - South Africa

Date	Journal	
14/08/2021	eNCA	Count survey
20/08/2021	The Village News	Whale season in full swing - Do not fear, the whales are here
17/09/2021	RSG radio	Live inverview Dr Vermeulen
17/09/2021	Daily Maverick	Researchers cite climate crisis as possible reason behind decreased southern right whale migration to SA
17/09/2021	Radio 786	Live inverview Dr Vermeulen
2/10/2021	Maritime Review Africa	Whale watching in the 21st century
2/10/2021	Business Tech Africa	Drones making waves
3/10/2021	RapportW esternCape	Hommeltuie help met walvisnavorsing
1/10/2021	EWN	UP whale unit to start world`s longest aerial survey of southern right whales
5/10/2021	Beeld, Daily	Groot walvis-tellery het begin
4/10/2021	Cape Times	The first stretch of the MRI Whale Unit aerial survey is complete
5/10/2021	Die Burger	Jaarlikse opname van walvisse langs Kaapse kusgebied begin
5/10/2021	Volksblad	Groot walvis-tellery het begin
14/10/2021	AM	Live interview with John Matham
29/10/2021	The Village News	Following our whales via satellite
1/11/2021	Gansbaai Courant	Aerial survey of southern right whales completed
09/07/2020	Cape Argus	Experts warn of ongoing threat to marine species
09/05/2020	The Saturday Star	Expert's letter calls for action to save cetaceans
09/07/2020	Independent online	Expert's letter calls for action to save cetaceans
09/14/2020	PDBY	UP Whale Institute researcher organises open statement against marine life extinction
09/23/2020	Conservation Magazine	Protecting Whales and Dolphins from Extinction: Call for Global Action
09/29/2020	Cape Times	Surveying SRW in SA
29/09/2020	Yiba	UP Whale Unot to gather data on dwindling southern right whale populations
02/10/2020	RSG radio	Live interview with Gideon Van den Berg
02/10/2020	Times Live	Whale numbers off SA down again as scientists warn of ecosystem turmoil
07/10/2020	The Village News	Whale survey findings published
07/10/2020	Hermanus times	Whale numbers down by half
14/10/2020	Amazonanws (Pril)	Whales are washing up along Cape coast
14/10/2020	Netwerk 24	Minder walvisse langs SA kus weens klimaat - opname
19/10/2020	JuniorTukkie	2020 Annual Aerial Survey of southern right whales

19/10/2020	Science at One	Interview - South African southern right whales
09/12/2020	Cape Talk	Decline in whale migration is due to less calving and lack of energy, say UP researchers
09/12/2020	Cape Times	Alarm over slump in number of visiting southern right whales
09/12/2020	Amazonaws	Study tackles the decline in the migration of whales to South Africa
10/12/2020	eNCA	TV interview - South Africa's southern right whales

Media interest – New Zealand

Guardian article: https://www.theguardian.com/world/2021/aug/27/bill-and-tags-excellent-adventure-a-year-in-the-life-of-one-southern-right-whale
New Zealand Geographic Articles
https://www.nzgeo.com/stories/the-whales-are-back/
https://www.nzgeo.com/stories/double-bill/?state=requireSubscription
https://www.nzgeo.com/stories/revisiting-tohora/
https://www.nzgeo.com/stories/tracks-of-the-tohora/
Radio New Zealand - Kim Hill Interview:
https://www.rnz.co.nz/national/programmes/saturday/audio/2018814769/dr-emma-carroll-following-the-whale-that-crossed-three-oceans
ABC article: https://www.abc.net.au/news/2021-11-23/tracking-southern-right-whales/100630866
BBC video: https://www.bbc.com/news/av/world-australia-59646562

Media interest – Argentina

New Scientist: https://www.newscientist.com/article/2293979-climate-change-could-slow-recovery-of-southern-right-whales/
Popular Science: https://www.popsci.com/animals/climate-change-threatens-whale-populations/
Mongabay: https://news.mongabay.com/2021/12/el-nino-takes-a-toll-on-southern-right-whales-in-the-atlantic-ocean/
Ocean care: https://www.oceancare.org/en/whale-recovery-threat-from-climate-change-the-antarctic-evidence/

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SC/68d/SH07

IWC-SORP THEME 7 PROGRESS REPORT – 2021/22. Recovery status and ecology of Southern Hemisphere fin whales

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Executive summary

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

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

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

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

Introduction

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

Objectives

The specific objectives of the project are:

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

The project is composed of two major parts:

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

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

B. New data collections

New data have been collected as part of this project:

RV Polarstern cruise PS119 (March-May 2019) - During cruise PS119, *RV Polarstern* was used as a platform of opportunity for an ad hoc helicopter survey collecting line transect distance sampling data on fin whales in the Scotia Arc region around South Georgia and the South Sandwich Islands.

Pelagic Australis cruise 'FinEphant' (March/April 2021) - Wildstar Media provided us with one berth on their *Pelagic Australis* expedition to Elephant Island. One scientist joint the cruise as a dedicated tagger to deploy satellite tags.

RV Maria S. Merian cruise MSM90 – FINWAP (March/April 2020) - A dedicated fin whale research cruise was to be conducted around the tip of the Western Antarctic Peninsula in 2020. A suite of non-lethal research methods was to be employed to analyse distribution, population structure, movement and migration, habitat use, behaviour and feeding ecology. The outbreak of the COVID-19 pandemic caused a last minute cancellation of the cruise in March 2020. The cruise has now been rescheduled to take place from 15 February to 17 March 2023.

Results

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

The data collection and analysis detailed in the previous report were completed this project year. A manuscript entitled 'Identifying seasonal distribution patterns of Southern Hemisphere fin whales from multiple data sources using a novel approach combining habitat suitability models and ensemble learning methods' has been drafted and circulated among all contributors and is in a near-final stage. It will be submitted to the journal Frontiers in Marine Science before the end of April 2022. The current draft manuscript represents the most complete and comprehensive description of the joint data analysis and its results and is provided in Appendix 1 of this report.

New data collections

Pelagic Australis cruise – project FinEphant

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

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

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

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

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

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

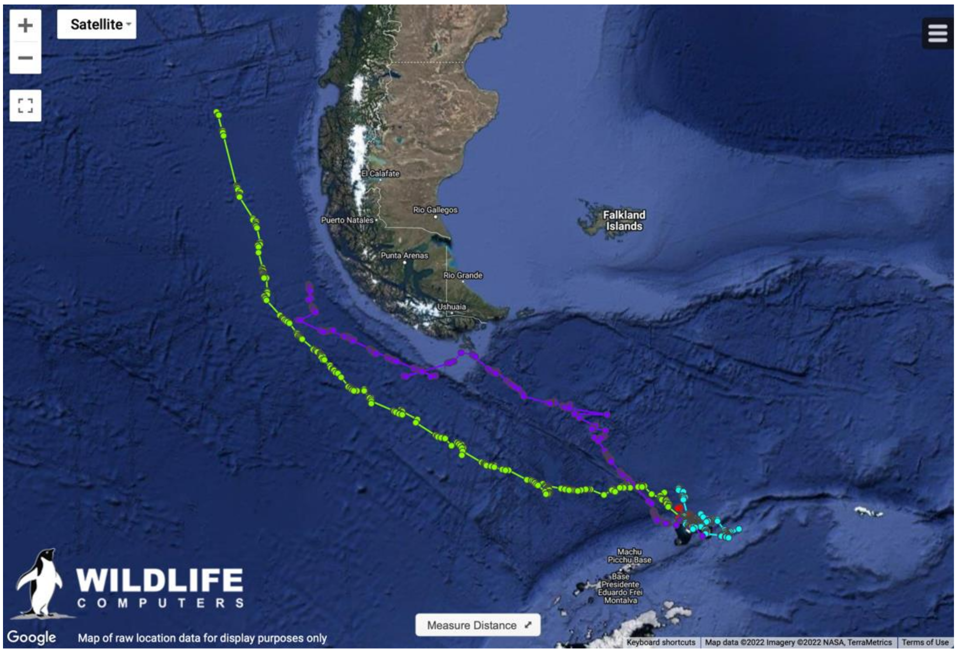

Figure 1 Tracks of four fin whales tagged at the northern coast of Elephant Island in the first half of April 2022. Figure 1: Display of all tracks: Red = PTT198904, Green=PTT198905, light blue=PTT198909, purple=PTT198915.

<u>*RV Maria S. Merian* cruise MSM90-FINWAP</u>

Cruise MSM90 – FINWAP, originally planned for March / April 2020 and cancelled due to the Covid19 pandemic (see previous report), has now been rescheduled by the German research fleet coordination and will be carried out from 15 February - 17 March 2023 as MSM115 – FINWAP.

Conclusions

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

Challenges

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

Outlook for the future

The manuscript *'Identifying seasonal distribution patterns of Southern Hemisphere fin whales from multiple data sources using a novel approach combining habitat suitability models and ensemble learning methods'* will be submitted to Frontiers in Marine Science by the end of April (Appendix 1).

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

Project outputs

Peer-reviewed papers

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

Herr H, Viquerat S, Naujocks T, Gregory B, Lees A, Devas F (*Submitted*) Life-history features of Antarctic fin whales documented by high-resolution aerial footage. Mammalian Biology.

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

Reports

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

Conference presentations

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

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

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

Theme 7: Recovery status and ecology of Southern Hemisphere fin whales
Appendix 1 – draft manuscript

Identifying seasonal distribution patterns of Southern Hemisphere fin whales from multiple data sources using a novel approach combining habitat suitability models and ensemble learning methods

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INTRODUCTION

Southern Hemisphere fin whales (*Balaenoptera physalus quoyi*, SHFW) were the most numerously exploited whale species in the Southern Ocean during the era of industrial whaling, with over 700,000 individuals killed (Clapham & Baker, 2002). Today, their recovery status is unknown, knowledge about current distribution and habitat use are limited (Edwards, Hall, Moore, Sheredy, & Redfern, 2015; Leaper & Miller, 2011). In their world-wide assessment of fin whale distribution, (Edwards et al., 2015) identified the Southern Hemisphere as a data gap. SHFW are assumed to be extensively distributed in latitudes between 40°S and 60°S, and rare to absent in equatorial waters north of 20°S and in the ice-covered waters south of 60°S (Cooke, 2018; Edwards et al., 2015). Like most balaenopterids, their general migratory pattern presumably is a movement between poleward feeding areas in the summer months and lower latitudes in the winter months (Mackintosh, 1966; Mizroch, Rice, & Breiwick, 1984). However, foraging areas have also been identified in low latitudes (Pérez et al., 2006; Sepúlveda et al., 2018; Toro, Vilina, Capella, & Gibbons, 2016). Migratory routes and the locations of Southern Hemisphere breeding grounds have not yet been identified (Cooke, 2018; Edwards et al., 2015; Mizroch et al., 1984) and the population structure is not fully understood (Archer et al., 2019, 2013; Cabrera et al., 2019; Pérez-Alvarez et al., 2021).

Today, much of the understanding of circumpolar post-whaling distribution and abundance of whales is based on the International Whaling Commission's (IWC) International Decade of Cetacean Research (IDCR) and Southern Ocean Whale Ecosystem Research (SOWER) cruise programmes, carried out in three circumpolar sets of surveys between 1978 and 2004, and localised 'experimental' voyages until 2010. Based on IDCR/SOWER data from surveys between 1991 and 1998, circumpolar fin whale abundance south of 60°S was last estimated at 5,445 (95 % CI 2,000–14,500) individuals (Branch & Butterworth, 2001). However, since some uncertain, but potentially substantial proportion of the population may range north of 60°S during the summer months and surveyed areas therefore did not represent their complete summer distribution, this estimate under-represents the total population size. For the Scotia Arc and Antarctic Peninsula region, fin whale abundance has last been estimated at 4,672 (CV 42.37) based on data from the dedicated CCAMLR/SOWER 2000 survey conducted in February and March 2000 (Reilly et al., 2004).

Since then, high densities and large feeding aggregations of fin whales have been reported from the Western Antarctic Peninsula (WAP) (Herr et al., 2021, 2016; J. A. Santora, Schroeder, & Loeb, 2014; J. Santora, Reiss, Loeb, & Veit, 2010; Viquerat & Herr, 2017), suggesting that some level of post-whaling population recovery has begun (Herr et al. submitted). Dedicated surveys to estimate abundance have been carried out for small discreet regions around the Antarctic Peninsula (Herr et al., 2021, 2016; Viquerat & Herr, 2017). Systematic surveys targeting fin whale distribution in the Atlantic sector of the Southern Ocean including areas north of 60°S are not yet available. However, in addition to smaller scale dedicated surveys, data on fin whale occurrences have been collected opportunistically during both research and commercial expeditions over the past few decades, incorporating both polar and sub-polar latitudes. Spread out and held by a variety of different organisations and data holders, combined, these sightings datasets represent a source of information on the seasonality and distribution of SHFWs.

Here, we (i) compile sighting records of fin whales from the Antarctic Peninsula and Scotia Sea region from multiple sources and research groups; (ii) use an ensemble learning and a maximum entropy approach to develop a workflow to estimate abundance from non-standardised opportunistically collected datasets; and (iii) provide insight into the environmental correlates that may be associated with the seasonality and distribution of fin whales across the Antarctic Peninsula and Scotia Sea region across a 40-year period.

MATERIAL & METHODS

Data integration and preparation

We compiled fin whale sighting records from datasets of ten different data holders (Table 1). In addition, we sourced two mass online repositories (GBIF.org and OBIS.org; accessed on the 6th of April 2021) for all fin whale records. Data were restricted to records south of 50°S and between 90°W and 10°W. In order to deal with the potential redundancy within mass online data repositories, we excluded all duplicates within these data sets based on location (geographic coordinates rounded to 2 digits), year and month. We only used definite fin whale sightings and excluded fin like type of sightings and any uncertain identifications. These definite fin whale records were considered confirmed presences. Data sets in this study originated from dedicated surveys for marine mammals and from opportunistic collection of sightings. Only dedicated survey data sets provided additional information on search effort. We used stretches of survey effort without fin whale detections from dedicated surveys as pseudo absence records ('pseudo', because absences in marine mammal surveys can never be considered ‘true’ absences (availability bias, see e.g. (Barlow, 2015; Hammond et al., 2021)). All geographic information was projected to IBCSO projection (EPSG: 9345; https://epsg.org/crs_9354/WGS-84-IBCSO-Polar-Stereographic.html). The pooled dataset contained the geographic position, estimated group size (including information on number of groups detected and the number of animals; for pseudo absences: 0), the year and the month for each presence / absence record.

We only considered data recorded after the introduction of the IWC’s New Management Procedure in 1975 (International Whaling Commision, 1976) and the classification of all SHFWs as Protection Stocks in 1976 setting the quota in the Southern Hemisphere to zero (International Whaling Commision, 1978), i.e., marking the end of commercial whaling on fin whales. Therefore, the dataset starts with the first dedicated large whale survey in the Southern Ocean (SOWER) in 1977 and concludes with the PHAROS surveys in January 2021. We pooled data across years into seasonal quarters (regular three-month intervals, i.e. Q1: January – March, Q2: April – June, Q3: July – September and Q4: October – December).

Table 1 Summary of data sources and number of provided records. Source: data holder / data source (in case of online data repositories); Type of data: short description of original data type; N: Number of sightings (presence records); I: Number of individual fin whales; A: indicates whether pseudo absences were available for the analysis.

Source	Type of data	N	I	A

AWI	Bridge observation by nautical officers collected during Polarstern cruises	73	233	-
BAS	Collection of dedicated marine mammal surveys along western Antarctic Peninsula	158	532	y
CCAMLR SURVEY	Joint krill, marine mammal and seabird survey 2019	355	672	y
Fundación Cethus	Photo ID and opportunistic data from Fundación Cethus surveys	245	507	y
GBIF	Global Biodiversity Information Facility (www.gbif.org, accessed on 01.08.2021)	6	6	-
GERMAN SURVEYS	Records from dedicated distance sampling surveys and opportunistic sightings during Antarctic expeditions	272	569	y
happywhale.org	Crowd sourced online repository mainly of photographic evidence (happywhale.org)	18	18	-
IWC IDCR / SOWER	Collection of dedicated visual survey data from IWC IDCR / SOWER cruises	187	830	-
OBIS	Ocean Biodiversity Information System (www.obis.org, accessed on 01.08.2021)	1	1	-
PHAROS	Collection of opportunistic records from around South Georgia / Islas Georgias del Sur	152	430	-
PROANTAR FURG	Sighting surveys, Photo Id and opportunistic data from the Brazilian Antarctic Program PROANTAR / FURG surveys	382	1,148	-
SGHT	Opportunistic sightings data reported to the South Georgia Heritage Trust	92	566	-
US AMLR	Collection of dedicated visual survey data from US AMLR cruises survey data from US AMLR cruises **2,439**	498 **6,511**	999	y
TOTAL		2439	6511	

Creation of sample grids

We based the boundary of our analysis on the buffered (100 km) convex hull around all presence records of the data set. The Antarctic Sound and the waters surrounding the Weddell Sea were manually excluded from the analysis due to data sparsity. The spatial extent of our study area comprised data within 80°W to 17°W and 50°S to 70°S, respectively, covering an area of app. 5.2 x 106 km² (Fehler! Verweisquelle konnte nicht gefunden werden.).

We gathered static (i.e. fixed values across all quarters) and environmental covariates (i.e. changing with each quarter) that were available across the extent of the survey area (Table 2). The majority of static covariates used in this analysis originates from depth data, for which we used the International Bathymetric Chart of the Southern Ocean, version 2 (IBCSO v2 (Dorschel et al., 2022)). Slope, aspect (the direction that the slope is facing), topographic position index (tpi; a measure used to classify the structure of an area surrounding a point) and terrain ruggedness index (tri; quantifying the variability of elevation (Riley, DeGloria, & Elliot, 1999)) were calculated using the terrain function from the raster package (Hijmans, 2017) in R (R Core Team, 2018). The implementation of tpi and tri is according to (Wilson, O'Connell, Brown, Guinan, & Grehan, 2007). These seafloor features describe physical properties that in turn may impact the ecological value of an area of ocean and are therefore prime candidates for species distribution studies in the Southern Ocean (El-Gabbas, Van Opzeeland, Burkhardt, & Boebel, 2021a, 2021b; Reisinger et al., 2021) and elsewhere (Claro, Pérez-Jorge, & Frey, 2020; Díaz López & Methion, 2019). We calculated the absolute distance from the continental shelf break as defined in (Herr et al., 2019) using spatial samples at a regular 5km interval via spsample in R (R Core Team, 2018) and produced a regular grid with each cell containing the distance to the nearest shelf edge line. For the set of dynamic covariates, we extracted monthly averages of sea surface temperature (sst) and chlorophyll-α (chla) for each year (starting from 2002) from https://neo.sci.gsfc.nasa.gov/archive/geotiff.float/MY1DMM_CHLORA/ (chla) and https://neo.sci.gsfc.nasa.gov/archive/geotiff.float/MYD28M/ (sst) and used these as environmental covariates. For data before 2002, we used monthly averages from latter years as approximation for sst and chla, respectively. All covariates were resampled to a regular grid of 5x5km resolution and projected to IBCSO (EPSG: 9354) to facilitate the analysis.

Table 2 Description of variables used in the analysis. Abbreviation: column name as used in the data; Comment: short description of data; Unit: unit of data; Source: data origin / data source.

Abbreviation	**Comment**	**Unit**	**Source**
Static covariates			
DIST2SHELF	distance from each cell midpoint to closest shelf edge	m	(Herr et al., 2019)
aspect	aspect of depth	rad	Extracted from IBCSO v2 (Dorschel et al., 2022)
depth	depth	m	
roughness	roughness index of seafloor	**-**	
slope	slope of seafloor	rad	
tpi	topographic position index	-	
tri	terrain ruggedness index	-	
Environmental covariates (per quarter)			
chla	satellite based chlorophyll-α concentration	mg/m^3	(Hu, Lee, & Franz, 2012)
sst	satellite based sea surface temperature	°C	https://neo.sci.gsfc.nasa.gov/view.php?datasetId=MYD28M

We subdivided our study area into regular hexagonal polygon cells with a grid spacing of 20 km, leading to a regular and equidistant grid. We joined static and environmental covariates to each grid cell based on the median of respective covariate grid for each cell and separately for each quarter, discarding NA values when calculating the median.

All fin whale records (both presence and pseudo - absences) were aggregated to the grid cells for each seasonal quarter, respectively, resulting in four seasonal sample grids containing all covariates and a summary of fin whale records and pseudo absences from 1977 – 2021 (see XXXX). Each seasonal sample grid contained information on the grid centroid (i.e. the midpoint coordinates of the hex cell), the observed number of fin whales, the number of fin whale groups and the average group size per grid cell (where available) for the respective seasonal quarter. We assigned presence and pseudo-absence per sample grid cell based on the observed number of fin whale groups, adhering to the following rules:

- **Presence within a seasonal quarter and cell supersedes pseudo absence** – Since absences in marine mammals can never be considered 'true' absences with certainty (hence the term 'pseudo absence'), any confirmed presence superseded pseudo absence. All pseudo absences from a seasonal quarter that were assigned to a cell that was also associated with a presence record for the given seasonal quarter were therefore discarded for this analysis.

- **Multiple pseudo absence records within a seasonal quarter and cell were treated as a single record of pseudo absence** – During dedicated surveys, effort is recorded at discrete intervals. Any number of pseudo absence records within a cell was therefore treated as a single record of absence.

Stratification of survey area

In order to quantify fin whale numbers, we selected four sub areas within the study area that provided a robust sample size (i.e. good coverage across at least some quarters). We centred these on four distinct island groups within the study area (Figure 3).

Analysis

We checked for the spatial auto correlation of our sample grid data using Moran's I (Moran, 1950) in ape (Paradis et al., 2018), noting any covariates that were spatially auto correlated. In addition, we ran separate correlation tests per quarter based on Spearman's ρ, ρ^2 and a hierarchical clustering on variables (using Spearman's ρ^2 as distance metric) in Hmisc (Harrell Jr., 2018). We used a threshold of $\rho^2 = 0.5$ in order to decide which covariates to keep. Feasible covariate combinations for each quarter were saved for the analysis. We conducted an analysis of the data set comprising (1) a species distribution model (SDM) to obtain the spatial distribution of presence probabilities, (2) a random forest model using generalized least squares (RF-GLS) to predict the spatial distribution of fin whale group sizes and (3) a final step combining the results of the SDM and RF-GLS step to produce abundance estimates for each of the Island Groups.

Species Distribution Model (SDM)

We estimated the probability of presence of fin whales within the survey area per quarter with a maximum entropy approach (Phillips, Dudík, & Schapire, 2020) as implemented in maxent version 3.4.0 (http://biodiversityinformatics.amnh.org/open_source/maxent) via the dismo package (Hijmans, Phillips, Leathwick, & Elith, 2017) in R (R Core Team, 2018). Each model ran 100 replicates using bootstrapping for sample selection in each replicate. We used the sample grid as input data for the modelling step, with each presence cell entering the model as an occurrence point (using cell midpoint as location) and each pseudo absence cell as a background point (if available). For each seasonal quarter, we tested the same set of models. No data on sst and chla were available in sufficient quality for Q2 (April – June) and Q3 (July – September), models including these as terms were skipped for respective quarters. Therefore, models containing environmental covariates were only run for Q1 (January - March) and Q4 (October - December). All models containing covariates that were discarded either due to spatial autocorrelation or correlation with other model terms were skipped. Model diagnostics for each replicate were extracted using the evaluate function in dismo (Hijmans et al., 2017).

Due to the high number of diagnostic measures and model replicates, we chose a dimension reduction approach, condensing the number of diagnostic measures for each model and quarters onto two principal component axis (each therefore giving the relative importance of its loadings). This allowed for visual model comparison, including the variability between replicates of a model and variability between models. The final selection of the best model for each season was based on the area under the curve (AUC) and Cohen's Kappa (Liu, White, & Newell, 2011). The selected model for each quarter was re-run with the same data, number of replicates and maxent settings (this was necessary due to computational limitations as we could not store all model replicates for each model per quarter).

We used the original covariate raster sets as input data for the prediction step, leading to 100 replicate predictions at 5x5 km cell size resolution per quarter. We used these replicate predictions to create summary statistics (mean, 25th and 75th percentile of predicted probabilities per raster cell) based on the selected model for each quarter at 5x5 km resolution.

As a last step, we ran a threshold model on each replicate as implemented by the threshold function in dismo (Hijmans et al., 2017) with a sensitivity of 90% using the combined sensitivity (true positive rate) and specificity (true negative rate) as criterion (Liu et al., 2011; Liu, White, & Newell, 2013). In order to condense the threshold values (discrete values of either 0 - absence and 1 - presence) across all replicates, we chose to use a hard max (favouring the most abundant threshold value per cell) to obtain a binary masks of presence / absence predictions across the survey area based (pthreshold).

Abundance estimation (RF-GLS)

We estimated the number of fin whales for each island group in an independent step. Estimating abundance from opportunistically collected data is challenging due to the lack of information on search effort involved. We interpreted the number of observed fin whales as a spatial stochastic process, i.e. driven by an unknown functional link between the observed number of fin whales and the observed covariate space. We also assume this functional link to generate highly auto correlated data across all spatial scales (i.e. we assume an underlying neighbourhood effect). Therefore, we decided to investigate the number of observed fin whales using a random forest approach based on our candidate explanatory variables (our covariate space). As an ensemble learning approach, traditional random forest models work best with discrete classes and usually provide class probabilities analogous to their traditional classification model counterparts (Tin Kam Ho, 1995). However, a recent study shows that it is possible to include the spatial structure of a data set (spatial lag, autocorrelation and adjacency of data) into ensemble learning models even for continuous responses (Saha, Basu, & Datta, 2021).

We therefore applied a random forest approach using generalized least squares in conjunction with a spatial dependency structure (RF-GLS) to model group sizes (yi) from the presence only data of the sample grid following:

$$y_i = m \cdot x_i + w(s_i) + \varepsilon_i$$

With $\varepsilon \sim (0, \tau^2 I)$ denoting the underlying Gaussian noise process and $w \sim C(\varphi, \nu, \sigma^2)$ the spatial Matérn Covariance for each observation i. We used the BRISC estimator for model estimation (Saha & Datta, 2018) via the RandomForestGLS package (Saha et al., 2021) in R (R Core Team, 2018).

The forest for each seasonal quarter was set up to contain 1,000 classification trees, with each tree including three variables randomly selected from the set of available static and dynamic variables, excluding x and y location (since these are included in the model in a separate spatial neighbourhood matrix). The latent spatial random surface (based on the cell midpoint coordinates) considered 18 neighbours for the spatial correlation effects and a maximum number of 20 leaf nodes were allowed per tree. We scaled and centred the response variable and the covariate matrix that was supplied to the RF-GLS model between 0 and 1. We then used the BRISC estimator to predict the estimated number of fin whales on the stack of 5x5 km covariate raster for each seasonal quarter rounded to the nearest integer (NRFGLS). For this step, we used the same covariate stack for each quarter as in the SDM step, cropped to each individual island group. We used a buffer around the island groups to prevent edge effects, which was removed for the next step.

Combination of SDM and RF-GLS

We multiplied the binary threshold mask for fin whale presence from the SDM (pthreshold) with the predicted fin whale numbers from the RF-GLS (NRFGLS) to obtain adjusted abundance estimates for each island group. Local densities of fin whales per cell for each island group and quarter (Di) were estimated using the (adjusted) number of predicted fin whales per cell i (N_i) divided by the cell size (5 x 5 km):

$$D_i = \frac{N_i}{25km^2}$$

We used the set of D_i per quarter and island group to estimate the average density $D_{adjusted}$ and its 95% confidence intervals for each island group and seasonal quarter. In the final step, we multiplied $D_{adjusted}$ with the total area of the respective island group to obtain an estimate of the number of fin whales we expect to observe in a given seasonal quarter if all cells in a given island region were observed ($N_{adjusted}$).

RESULTS

Data distribution

A total of 2,428 sighting records comprising 6,473 fin whales was used as the data basis for further analysis after filtering. All these records provided the required minimum information, i.e. geographic position, estimate of group size, year and month of the record. The distribution of data revealed an increase in sighting records since 2000 (Figure 1) The majority of presence data were recorded during Q1 (Jan – Mar; Figure 2, Figure 3).

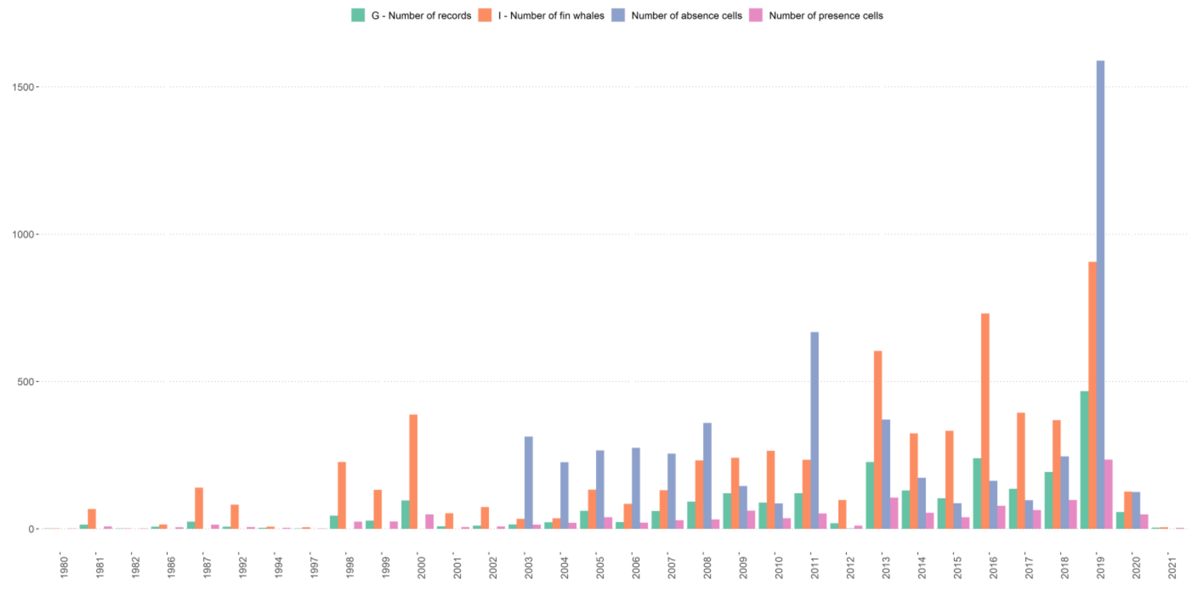

Figure 1 Number of fin whale groups G (green bar); individuals I (orange bar), Number of absence cells $C_{absence}$ (blue bar); Number of presence cells $C_{presence}$ (pink bar) per year.

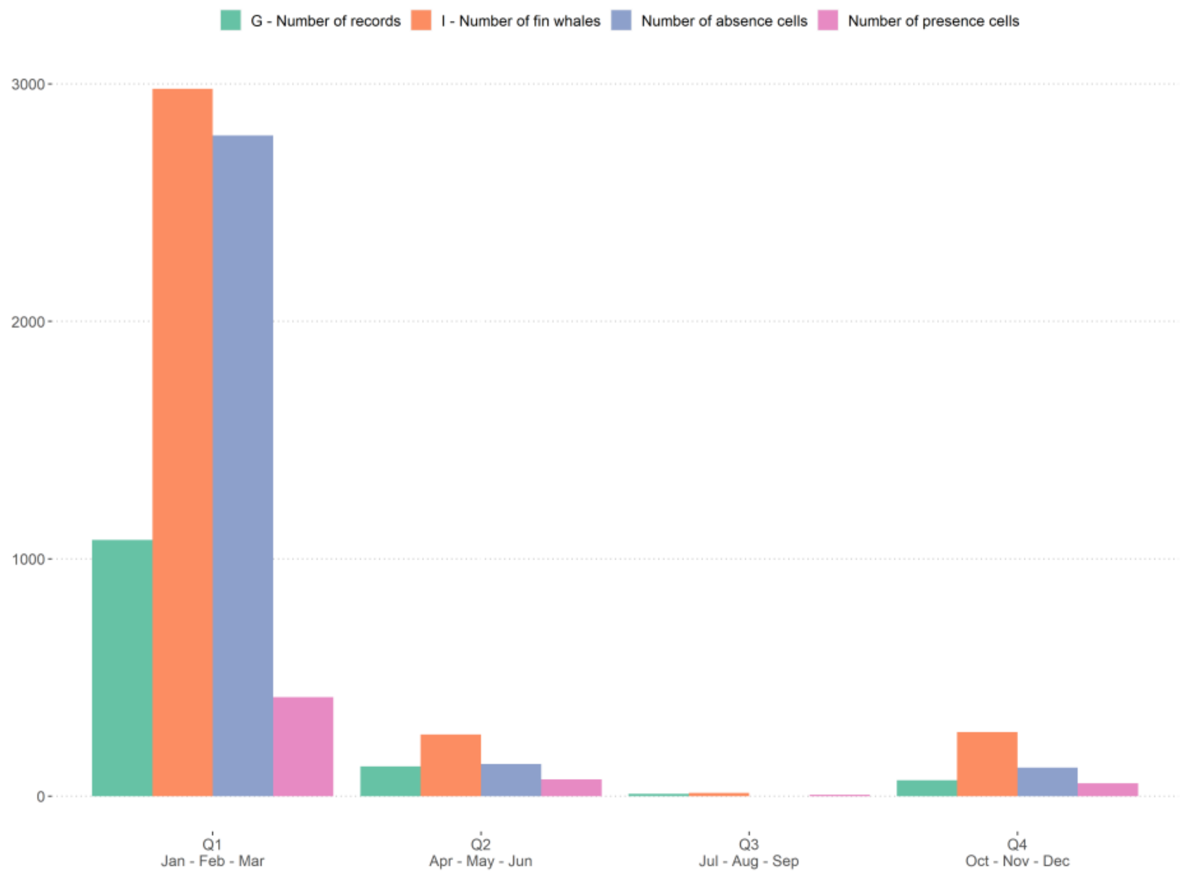

Figure 2 Number of fin whale groups G (green bar); individuals I (orange bar), Number of absence cells $C_{absence}$ (blue bar); Number of presence cells $C_{presence}$ (pink bar) per quarter. Q1: Jan – Mar; Q2: Apr – Jun; Q3: Jul – Sep; Q4: Oct – Dec.

Presences were recorded in 1,193 sample grid cells and pseudo absences in 5,445 cells (Table 3). The spatial distribution of sighting records showed a strong positive bias towards South Georgia / Islas Georgias del Sur and the Antarctic Peninsula (Figure 3).

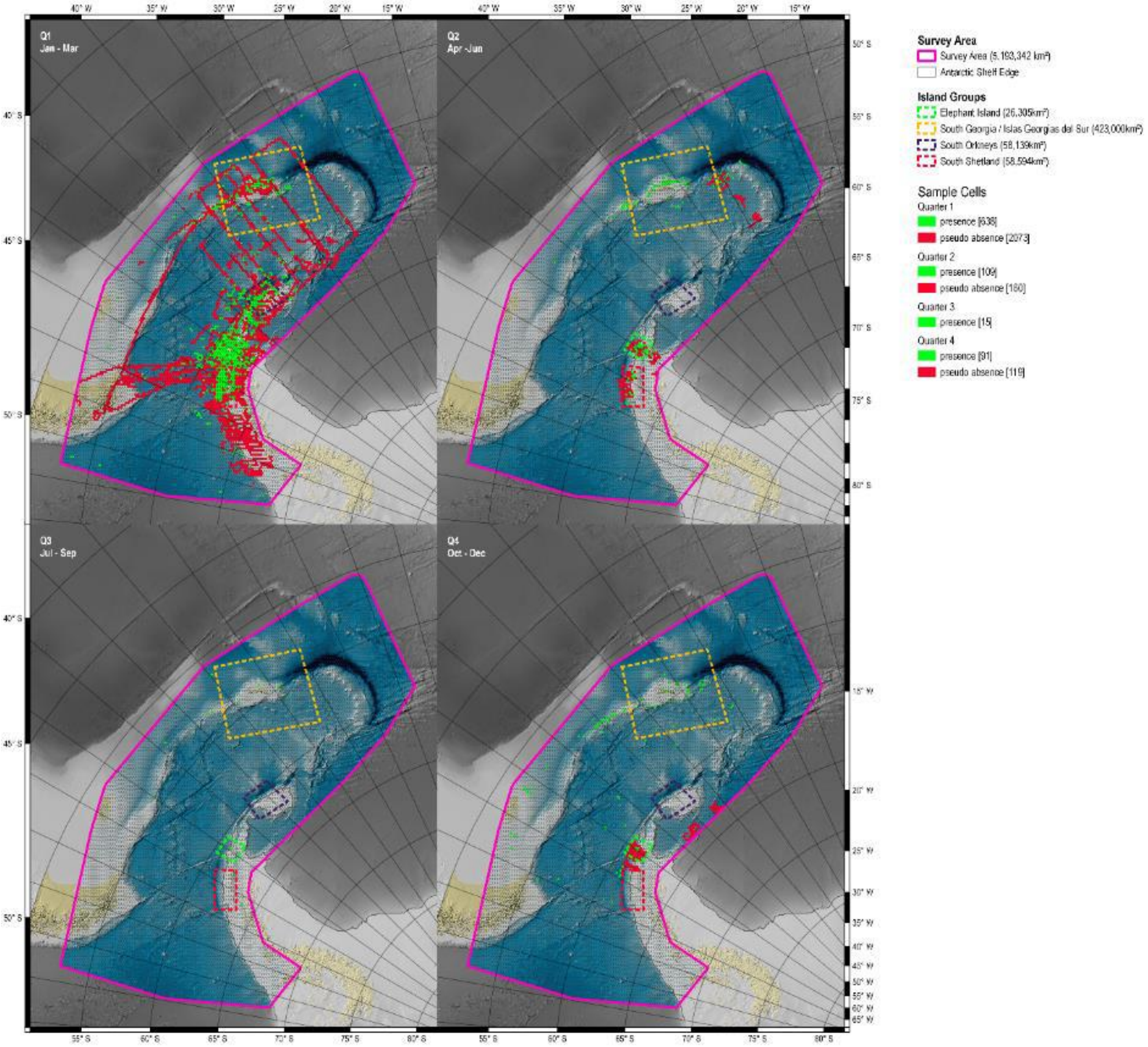

Figure 3 Sample grid as used in the SDM and RFGLS modelling step. Green cells: cells with confirmed presence of fin whales; red cells: cells with pseudo absence; transparent cells: cells not covered by data in the respective quarter. Background bathymetry based on IBCSO v2 (Dorschel et al., 2022). Q1: Jan – Mar, Q2: Apr – Jun, Q4: Oct – Dec.

Table 3 Summary of records and number of sighted individuals and across months, aggregated on sample grid cells. Month: month / total across all months; G: number of fin whale groups; Ind: number of individual fin whales aggregated in all cells; gs: average group size per month; $C_{presence}$: number of cells containing presence data; $C_{absence}$: number of cells containing pseudo absence data.

Quarter	**Month**	**G**	**Ind**	**gs**	$C_{presence}$	$C_{absence}$
Q1	Jan	666	1,479	2.22	367	2,783
	Feb	1,079	2,979	2.76	417	1,715
	Mar	380	1,129	2.97	184	648
Q2	Apr	125	260	2.08	71	136
	May	38	74	1.95	35	43

	Jun	6	63	10.5	6	0
Q3	Jul	6	14	2.33	6	0
	Aug	10	10	1	6	0
	Sep	4	7	1.75	3	0
Q4	Oct	17	44	2.59	16	0
	Nov	30	144	4.8	28	0
	Dec	67	270	4.03	54	120
	Total	**2,428**	**6,473**	**2.67**	**1,193**	**5,445**

Species Distribution Model (SDM)

We tested 20 models with different covariate combinations for each quarter using the covariates available for each quarter (Table 4).

Table 4 model definition for the SDM model of fin whale presence / pseudo absence records. Model: model name as used throughout rest of document (Model names marked with * indicate models that could not be run for all seasonal quarters due to lack of data on SST and chl-α); Predictors: covariate terms considered for this model (for a short description of the covariate and all other abbreviations, see Table 2).

Model	Predictors
m01*	sst
m02*	chla
m03*	sst + chla
m04	depth
m05*	depth + chla
m06*	depth + sst
m07	depth + DIST2_SHELF
m08*	depth + sst + chla
m09	depth + slope
m10*	depth + slope + sst
m10*	depth + slope + sst + DIST2_SHELF
m12*	depth + slope + chla
m13*	depth + slope + chla + DIST2_SHELF
m14*	depth + slope + chla + sst
m15*	aspect + depth + tpi + chla + sst + DIST2_SHELF
m16*	aspect + tri + chla + sst + DIST2_SHELF
m17	aspect + tri + DIST2_SHELF
m18	aspect + slope + DIST2_SHELF
m19	aspect + slope
m20	slope

We focussed on AUC and Cohen's Kappa for model selection (Figure 4, Figure 5). The high overall number and good coverage in Q1 (Jan – Mar) was reflected in consistent ROC AUC values around 0.7, whereas the widest range in AUC values were found for models for the spring quarter D (Oct – Dec). For quarter B (Apr – Jun), we recorded very few successful model runs due to the severe lack on sst and chla data for that season. Similarly, Cohen's Kappa followed a similar trend, with high values in Quarter Q1 and a wide range in Q4. Data sparsity (presence cells n= 17, Table 3) led us to remove quarter C from all subsequent analysis.

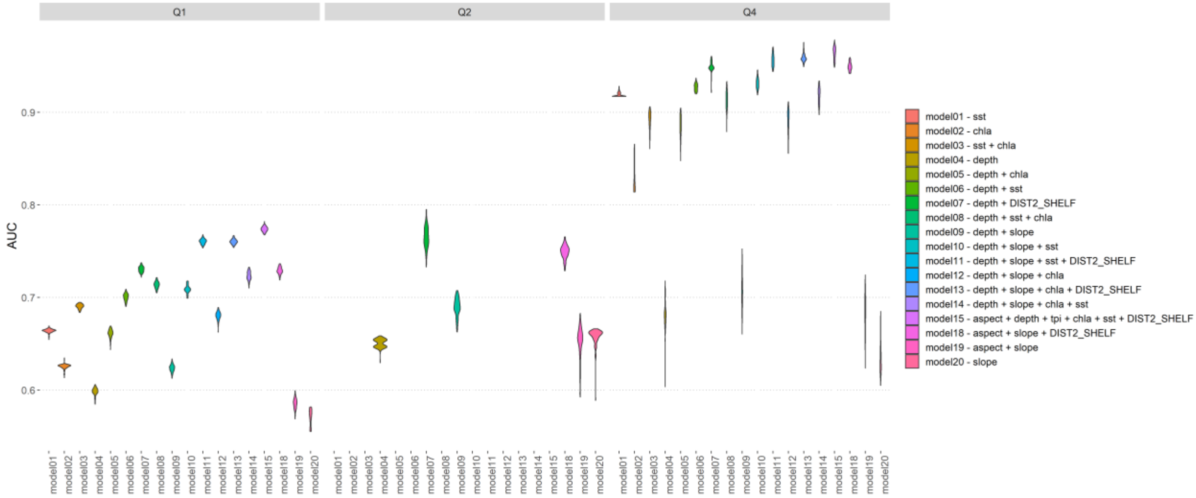

Figure 4 Summary of AUC (area under curve) for all maxent models in all quarters. Violins based on kernel density of 100 replicate AUC values.

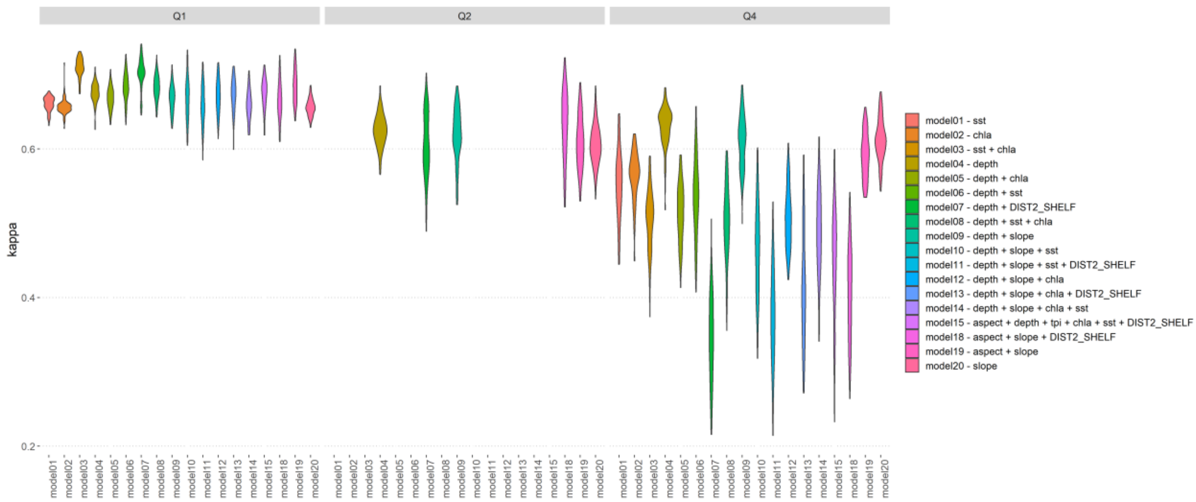

Figure 5 Summary of Cohen's kappa for all maxent models in all quarters. Violins based on kernel density of 100 replicate Cohen's kappa.

The best model for each seasonal quarter is given in Table 5.

Table 5 model parameters for the selected maxent models. covar: covars used in the model; O: number of sample grid cells providing observations (presence points); A: number of sample grid cells providing pseudo absences; AUC: ROC area under curve (see Figure 6a-c) including 25% - 75% confidence interval in brackets (based on 100 replicates); Cohen's κ: Cohen's Kappa including 25% - 75% confidence interval in brackets (based on 100 replicates).

	model	**covar**	**O**	**A**	**AUC**	**Cohen's κ**
Q1	m07	depth + DIST2_SHELF	630	2,032	0.7297 (0.7271 - 0.732)	0.7004 (0.6932 - 0.7096)
Q2	m18	aspect + slope + DIST2_SHELF	109	155	0.7495 (0.7448 - 0.7538)	0.6298 (0.6006 - 0.6715)
Q4	m10	depth + slope + sst + DIST2_SHELF	90	115	0.9316 (0.9276 - 0.9353)	0.4745 (0.4301 - 0.5076)

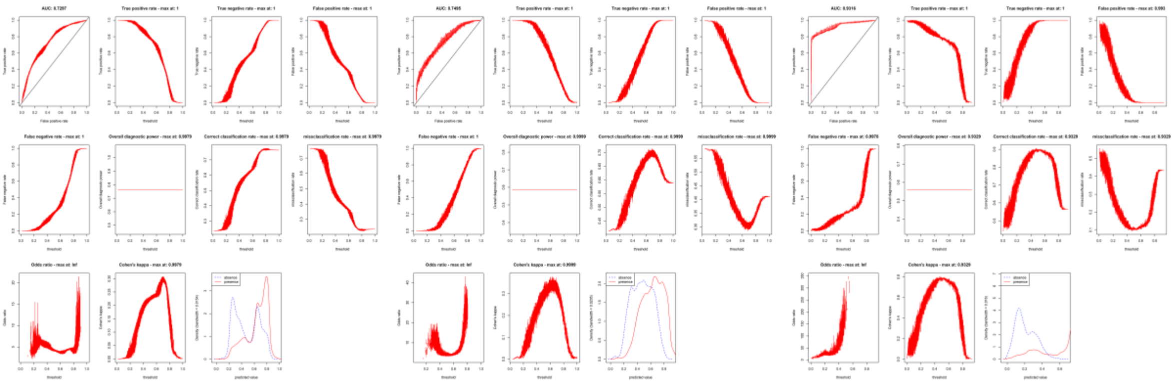

Figure 6 Model diagnostics for the selected model for each quarter. a) Model diagnostics for Quarter Q1; b) Model diagnostics for Quarter Q2; b) Model diagnostics for Quarter Q4. Based on 100 replicates per model. Q1: Jan – Mar, Q2: Apr – Jun, Q4: Oct – Dec.

Using the selected models (Table 5), we predicted the probability of fin whale presence (ppresence) for each seasonal quarter (Figure 7) and the threshold mask based on the combined sensitivity (true positive rate) and specificity (true negative rate) (Figure 8). In Q1 (Jan - Mar), high fin whale presences were predicted on the shelf along the Antarctic Peninsula. In Q2 (Apr - Jun), no apparent pattern in the distribution of ppresence could be observed. For Q4 (Oct - Dec), we predicted highest probabilities of presence further offshore, beyond the shelf.

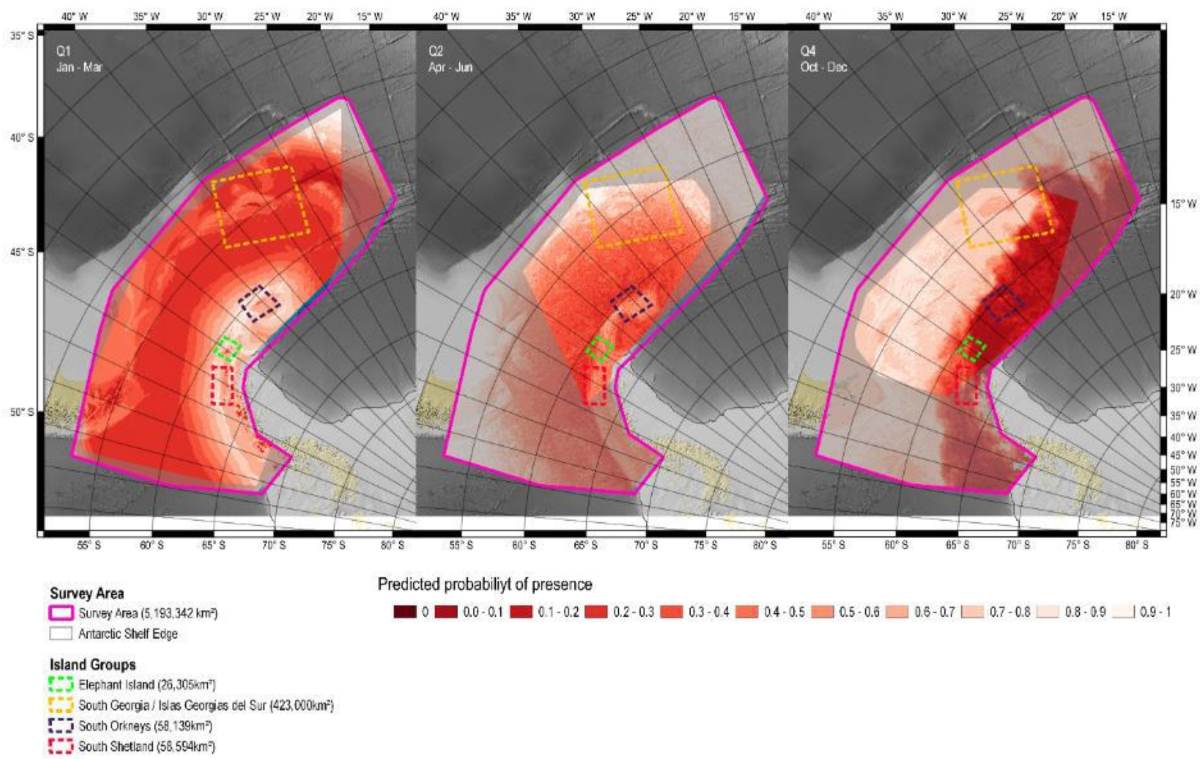

Figure 7 Predicted probability of fin whale presence per seasonal quarter (ppresence). Parts of the study area that did not provide presence records for a given seasonal quarter are dimmed. Quarter Q3 (July – September) was excluded due to lack of data. Q1: Jan – Mar, Q2: Apr – Jun, Q4: Oct – Dec.

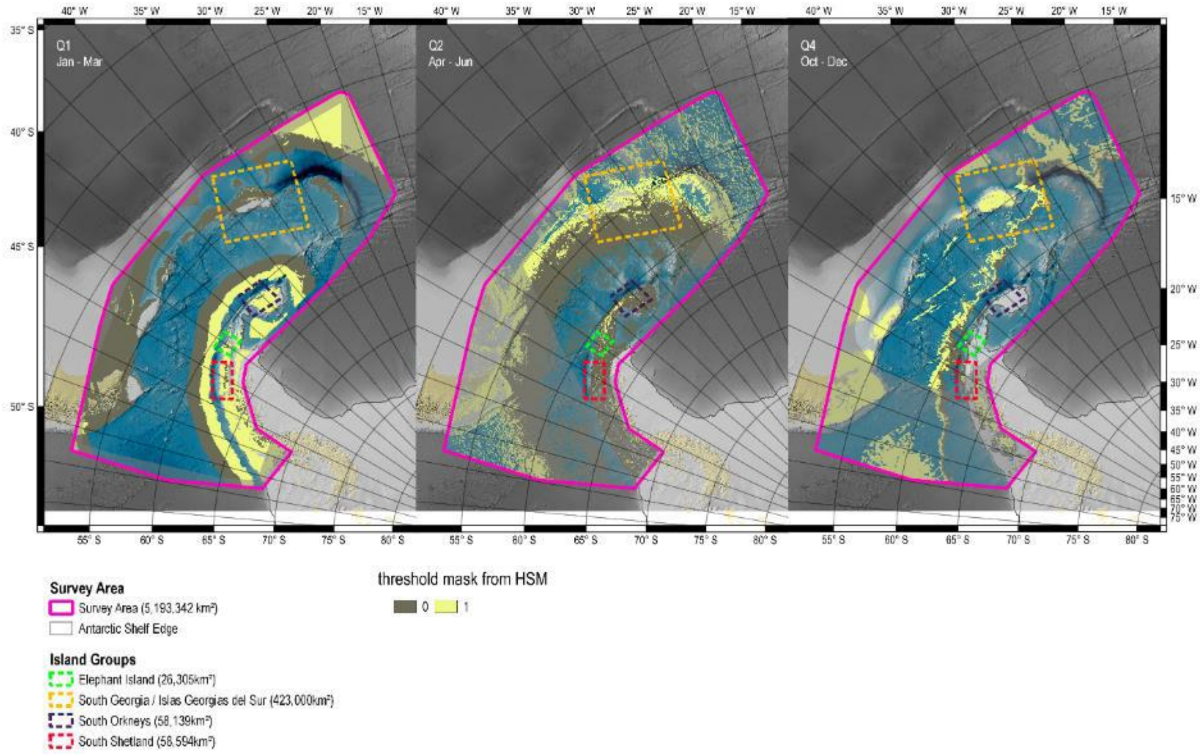

Figure 8 Predicted threshold mask of fin whale presence per seasonal quarter (pthreshold). Parts of the study area that did not provide presence records for a given seasonal quarter are dimmed. Quarter Q3 (July – September) was excluded due to lack of data. Q1: Jan – Mar, Q2: Apr – Jun, Q4: Oct – Dec.

Abundance estimation

We assessed the predictive capabilities of the RF-GLS using the set of input data for each seasonal quarter and comparing it to the prediction. For each input observation, we calculated the summary statistics for the 1,000 classification tree estimates to assess model accuracy. We used the ratio of prediction accuracy (Number of predicted fin whales / Number of observed fin whales) as model quality metric (Table 6). Predictive model accuracy was highest for Q4, with a median accuracy of 0.6332 (95%CI: 0.3426 - 0.9916), followed by Q1 with 0.5834 (95%CI: 0.2767 - 1.2015) and Q2 with 0.535 (95%CI: 0.3186 - 0.8789). The widest margin was observed for model predictions in Q1, with an interquartile range of 0.9247 compared to Q2 (0.6490) and Q4 (0.5603).

Table 6 Diagnostics for the RF-GLS model using the set of input data as test set. Nobs: Number of fin whale observations used in the RF-GLS model per quarter; ΣI_{obs}: Sum of all observed fin whales across all observations in quarter; ΣI_{pred}: Sum of all observed fin whales across all observations in quarter; accuracy: median accuracy of predicted number of fin whales across all classification trees (95% CI in brackets); IQR: range of the 95%CI.

Quarter	Nobs	ΣI_{obs}	ΣI_{pred}	accuracy	IQR
Q1	615	5466	5471	0.5834 (0.2767 - 1.2015)	0.9247
Q2	35	211	224	0.5345 (0.3186 - 0.8789)	0.6490
Q4	89	454	479	0.6332 (0.3426 - 0.9916)	0.5603

We used the RF-GLS model to predict abundances for each quarter and each of the island groups to obtain island group specific predictions of fin whale groups per raster cell. To avoid edge effects, we buffered each island group by 100 km and cropped the predicted surface to the actual extent of the area. In Q1, the RF-GLS predicted high numbers of fin whales within the island groups of Elephant Island, South Orkneys and South Shetland and a heterogeneous pattern around South Georgia. In Q2, very few animals were predicted along the Antarctic Peninsula and South Georgia remains an area with some high numbers of predicted fin whales. Q4 shows a distinct increase in numbers around Elephant Island and South Georgia (Figure 9).

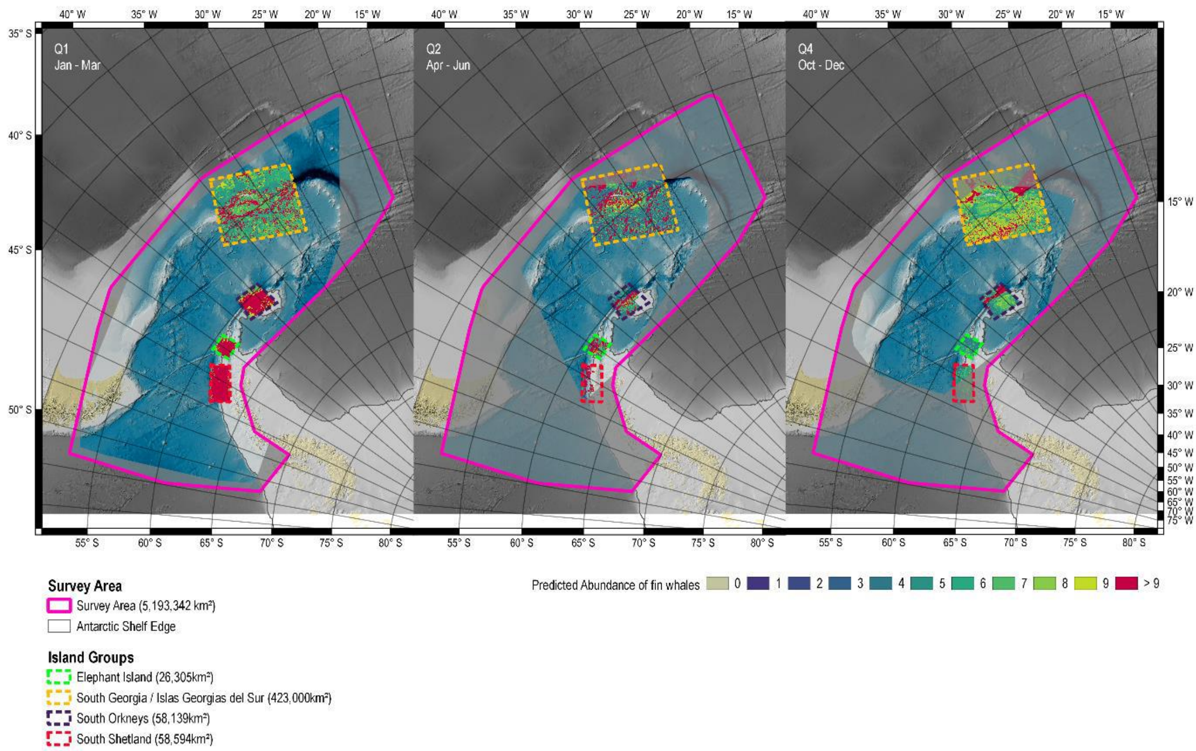

Figure 9 Number of fin whales per cell and seasonal quarter as predicted by the RF-GLS mode (NRFGLS). Parts of the study area that did not provide presence records for a given seasonal quarter are dimmed. Quarter Q3 (July – September) was excluded due to lack of data. Q1: Jan – Mar, Q2: Apr – Jun, Q4: Oct – Dec. Combination of SDM and RF-GLS

We multiplied the binary threshold mask from the SDM (Figure 8) with the RF-GLS results (Figure 9). Based on low probabilities for ppresence from the SDM, many areas for which fin whales were predicted by the RF-GLS were subsequently set to zero. After filtering, most of the areas associated with high abundances in Q1 (Jan – Mar) were located near the Antarctic Peninsula, while Q4 (Oct – Dec) featured South Georgia as an apparent centre of abundance (Figure 10). Q2 featured a heterogeneous distribution with no visible areas of high fin whale numbers. Abundance and density estimates for all sub-areas are shown in Table 7. The highest density across all quarters and island groups was predicted for Elephant Island (0.5366 ind. / km^2) followed by South Shetlands (0.5054 ind. / km^2) in quarter Q1. South Georgia / Islas Georgias del Sur showed an increase of densities between quarters Q1 to Q4. Some areas were stripped of all predicted fin whales due to low estimates of ppresence (and therefore a pthreshold of 0) within these areas.

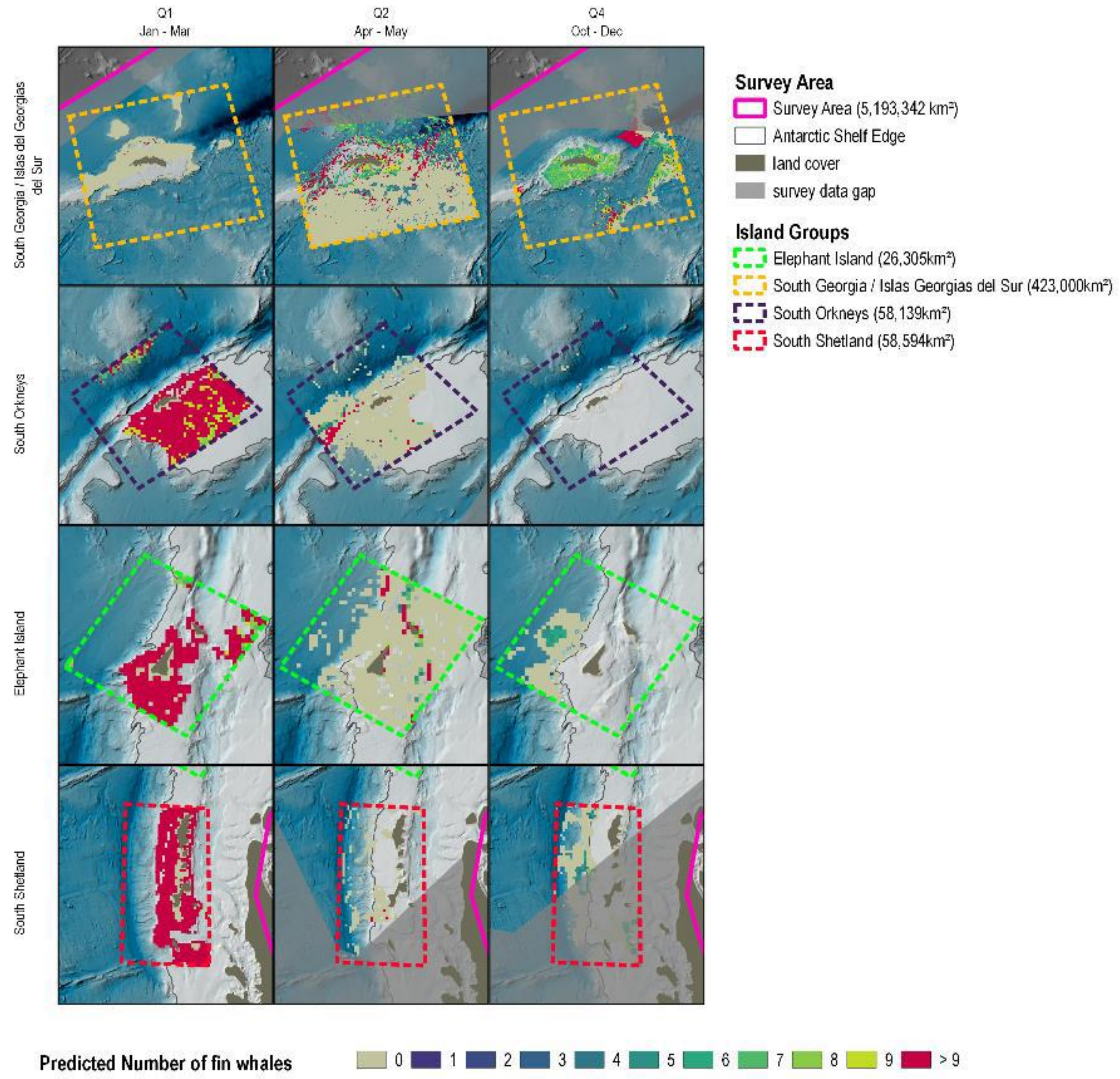

Figure 10 Number of fin whales per cell and seasonal quarter (N_{adj}; after filtering NRFGLS) based on combined results from the SDM and RF-GLS. From top to bottom: South Georgia / Islas Georgias del Sur, South Orkneys, Elephant Island, South Shetland. Parts of the study area that did not provide presence records for a given seasonal quarter are dimmed. Quarter Q3 (July – September) was excluded due to lack of data. Q1: Jan – Mar, Q2: Apr – Jun, Q4: Oct – Dec.

Table 7 Summary for each sub-area. Name: Name of the island group; Area: area of island region in km²; Quarter: seasonal quarter (Q1: Jan-Mar; Q2: Apr-Jun; Q4: Oct – Dec). $N_{adjusted}$: Total number of fin whales across all grid cells of sub-area (including 95% CI in brackets); $D_{adjusted}$: density estimate of fin whales / km² (including 95% CI in brackets).

Name	Area	Quarter	Nadjusted (95% CI)	Dadjusted (95% CI)
Elephant Island 2,630		Q1	1,412 (1,341 - 1,483)	0.5368 (0.5097 - 0.5639)
		Q2	76 (72 - 79)	0.0287 (0.0273 - 0.0301)
		Q4	63 (59 - 67)	0.024 (0.0225 - 0.0255)

South Georgia / Islas Georgias del Sur 42,044	Q1	358 (331 - 385)	0.0085 (0.0079 - 0.0092)
	Q2	4,596 (4,332 - 4,859)	0.1093 (0.103 - 0.1156)
	Q4	8,939 (8,429 - 9,450)	0.2126 (0.2005 - 0.2248)
South Orkneys 5,801	Q1	2,570 (2,460 - 2,680)	0.443 (0.424 - 0.462)
	Q2	171 (162 - 180)	0.0295 (0.028 - 0.031)
	Q4	0 (0 - 0)	0 (0 - 0)
South Shetland 5,852	Q1	2,959 (2,829 - 3,089)	0.5056 (0.4834 - 0.5278)
	Q2	50 (47 - 52)	0.0085 (0.0081 - 0.0089)
	Q4	197 (185 - 210)	0.0337 (0.0316 - 0.0359)

ACKNOWLEDGEMENT

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IWC-SORP PUBLICATIONS

Overall, IWC-SORP themes have produced at least 40 peer-reviewed papers in 2021/22, bringing the total number of peer-reviewed publications related to IWC-SORP produced since the start of the initiative to ca. 248. Moreover, 190 IWC-SORP related papers have been submitted to the Scientific Committee, 13 of which will be considered by the IWC Scientific Committee this year. In addition, IWC-SORP has directly contributed to at least 11 Ph.D., 6 Masters and 5 honours theses.

List of IWC-SORP related papers submitted to SC/68d for consideration[2]

SC/68d/ForInfo18 Agrelo M, Daura-Jorge FG, Rowntree VJ, Sironi M, Hammond PS, Ingram SN, Maron CF, Vilches FO, Seger J, Payne R, Simoes-Lopes PC (2022) Ocean warming threatens southern right whale population recovery.

SC/68d/ForInfo54 Aulich MG, McCauley RD, Miller BS, Samaran F, Giorlu G, Saunders BJ, Erbe C (2022) Seasonal distribution of the fin whale (*Balaenoptera physalus*) in Antarctic and Australian waters based on passive acoustics

SC/68d/SH07 Bell E (2022) Annual Report of the Southern Ocean Research Partnership 2021/22.

SC/68d/SH08 Bell E (2022) IWC-SORP Research Fund: progress reports.

SC/68d/ForInfo57 Burkhardt E, Van Opzeeland I, Cisewski B, Mattmuller R, Meister M, Schall E, Spiesecke S, Thomisch K, Zwicker S, Boebel O (2022) Seasonal and diel cycles of fin whale acoustic occurrence near Elephant Island, Antarctica.

SC/68d/SH11 Busquets-Vass G, Carroll L, Lübcker N, Constantine R, Childerhouse S, Baker CS, Dunshea G, Hindell M, Newsome SD (2022) A promising tool to infer the protein balance and reproductive status of the capital breeding southern right whale.

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

SC/68d/ForInfo25 Carroll EL (2022) New Zealand southern right whale (Tohorā nō Aotearoa) habitat use in Port Ross, Auckland Islands over three decades: 1998-2021.

SC/68d/EM03 de la Mare W (2022) An age-structured emulator for the individual based energetics model.

SC/68d/EM04 de la Mare (2022) The potential of individual-based energetics modelling for research on the ecology of whales.

SC/68d/EM01 El-Gabbas A, Van Opzeeland I, Burkhardt E, Boebel O (2021) Static species distribution models in the marine realm: the case of baleen whales in the Southern Ocean. Diversity and Distributions.

SC/68d/SH01 Field VR, Burkhardt E, van Opzeeland I (2022) Geographic variation in fin whale (*Balaenoptera physalus*) calls in the Weddell Sea, Antarctica.

SC/68d/SH04 Galletti Vernazzani B, Olson PA, Salgado-Kent Chandra (2022) Progress report on the Southern Hemisphere Blue Whale Catalogue: Period April 2021-March 2022.

SC/68d/SH10 Galletti Vernazzani B, Cabrera E, Olson PA et al. (2022) Blue whale photo-identifications reveal strong site fidelity to feeding areas from the Southeast Pacific and connectivity between southern Chile and Eastern Tropical Pacific.

SC/68d/SH12 Höschle C, Macleod K, Mahjoub AB, Kosarev V, Humphries G, Voss J, Carroll EL, Constantine R, Childerhouse S, Lundquist D, Riekkola L, Nehls G (2022) Satellite surveys prove a reliable monitoring method for high latitude southern right wahle habitat.

SC/68d/O04 IWC Secretariat (2022) Report on the Research Fund Financial Position.

SC/68d/SH09 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

SC/68d/SH13 Rand ZR, Branch TA, Jackson JA Movement rates of Antarctic blue whales from Discovery marks.

SC/68d/ForInfo55 Thums M, Ferreira LC, Jenner C, Jenner M, Harris D, Davenport A, Andrews-Goff A,

[2] *The COVID-19 pandemic has meant that a number of IWC-SORP related papers that would have been presented at IWC/SC/68d (a virtual meeting with strictly prioritised agenda) have been deferred until the next face-to-face meeting of the Scientific Committee.*

	Double M, Möller L, Attard CRM, Bilgmann K, Thomson PG, McCauley R (2022) Pygmy blue whale movement, distribution and important areas in the Eastern Indian Ocean.
SC/68d/SH02	Vermeulen E, Wilkinson C, Germishuizen M (2022) Report of the southern right whale aerial surveys – 2021.
SC/68d/SH03	Vermeulen E, van Jaarsveld C, Carroll E (2022) Desktop review of southern right whale (*Eubalaena australis*) offshore sightings south of 40°S (1980-2020).
SC/68d/ForInfo56	Wood M, Sirovic A (2022) Characterization of fin whale song off the West Antarctic Peninsula.

IWC-SORP related papers submitted to the SC in previous years

SC/61/SH17	Gales N, Double M, Robinson S, Jenner C, Jenner M, King E, Gedamke J, Paton D, Raymond, B. (2009) Satellite tracking of southbound East Australian humpback whales (*Megaptera novaeangliae*): challenging the feast or famine model for migrating whales.
SC/62/SH3	Garrigue C, Peltier H, Ridoux V, Franklin T, Charrassin J-B (2010) CETA: a new cetacean observation program in East Antarctica.
SC/63/O12	Childerhouse S (2011) Annual Report of the Southern Ocean Research Partnership 2011.
SC/63/O13	Childerhouse S (2011) Southern Ocean Research Partnership Revised project plans.
SC/63/SH16	Constantine R *et al.* (2011) Comprehensive photo-identification matching of Antarctic Area V humpback whales.
SC/63/SH10	Steel D et al. (2011) Initial genotype matching of humpback whales from the 2010 Australia/New Zealand Antarctic Whale Expedition (Area V) to Australia and the South Pacific.
SC/64/O13	Bell E (2012) Annual Report of the Southern Ocean Research Partnership 2011/12.
SC/64/O14	Baker CS, Galletti B, Childerhouse S, Brownell RL Jr, Friedlaender A, Gales N, Hall A, Jackson J, Leaper R, Perryman W, Steel D, Valenzuela L and Zerbini A (2012) Report of the Living Whales Symposium: Advances in non-lethal research techniques for whales in the Southern Hemisphere.
SC/64/SM06	Chambellant M, Garrigue C, Peltier H, Charrassin JB, Ridoux V (2014) First photo-ID catalogue of killer whales (*Orcinus orca*) in East Antarctica.
SC/64/IA10	Kelly N, Murase H, Kitakado T, Kock K-H, Williams R, Feindt-Herr H and Walløe L (2012) Estimating abundance and distribution of Antarctic minke whales within sea ice areas: data requirements and analysis methods.
SC/64/SH10	Kelly N, Miller B, Peel D, Double MC, de la Mare W and Gales N (2012) Strategies to obtain a new circumpolar abundance estimate for Antarctic Blue Whales: survey design and sampling protocols.
SC/64/SH11	Miller BS, Kelly N, Double MC, Childerhouse SJ, Laverick S and Gales N (2012) Development of acoustic methods: cruise report on SORP 2012 Antarctic Blue Whale voyages.
SC/64/SH12	Miller BS (2012) Real-time tracking of Blue Whales using DIFAR sonobuoys.
SC/64/SH13	Wadley V, Lindsay M, Kelly N, Miller N, Gales N, de la Mare W and Double MC (2012) Abundance estimation of Antarctic Blue Whales: preliminary voyage plan for SORP in March 2013.
SC/64/SH14	de la Mare WK (2012) Estimating relative abundance from historic Antarctic whaling records.
SC/64/SH15	Schmitt NT, Double MC, Baker CS, Steel D, Jenner KCS, Jenner M-NM, Paton D, Gales R, Jarman SN, Gales N, Marthick JR, Polanowski AM and Peakall R (2012) Low levels of genetic differentiation characterize Australian humpback whale (*Megaptera novaeangliae*) populations.
SC/64/SH26	Peel D and Kelly N (2012) Exploratory analyses of potential encounter rates for an acoustic tracking survey method for blue whales.
SC/65a/SH03	Andrews-Goff V, Olson PA, Gales NJ and Double MC (2013) Satellite telemetry derived summer movements of Antarctic blue whales.
SC/65a/O11	Bell (2013) Annual report of the Southern Ocean Research Partnership (SORP) 2012/13
SC/65a/SH25	Bell (2013) Report of the Southern Ocean Research Partnership Conference, 31 May - 2 June, 2013.
SC/65a/O10	Best PB, Findlay K, Thornton M and Stafford K (2013) SORP research report: the South African Blue Whale Project.

SC/65a/SH21 Double (2013) Cruise report of the 2013 Antarctic blue whale voyage of the Southern Ocean Research Partnership.
SC/65a/IA12 Gales N, Bowers M, Durban JW, Friedlaender AS, Nowacek DP, Pitman RL, Read AJ and Tyson RB (2013) Advances in non-lethal research on Antarctic minke whales: biotelemetry, photo-identification and biopsy sampling.
SC/65a/Forinfo08 Kelly N (2013) A new circumpolar abundance estimate for Antarctic blue whales: potential survey methods.
SC/65a/SH18 Miller BS, Barlow J, Calderan S, Collins K, Leaper R, Kelly N, Peel D, Olson P, Ensor and Double MC (2013a) Long-range acoustic tracking of Antarctic blue whales.
SC/65a/SH19 Miller BS, Barlow J, Calderan S, Leaper R, McDonald M, Ensor P, Olson P, Olavarria C and Double MC (2013b) Blue whale songs recorded around South Island, New Zealand.
SC/65a/SH11 Olson PA, Ensor P, Schmitt N, Olavarria C and Double MC (2013a) Photo-identification of Antarctic blue whales during the SORP Antarctic Blue Whale Voyage 2013.
SC/65a/SH12 Olson PA, Ensor P, Olavarria C, Schmitt N, Childerhouse S, Constantine R, Miller BS and Double MC (2013b) New Zealand blue whales: initial photo-identification of a little-known population.
SC/65a/Forinfro09 Peel D (2013) Examination of an acoustic-assisted mark recapture survey method for whales.
SC/65a/SH10 Reyes MV, Iñíguez M. (2013) Occurrence of cetaceans in the Scotia Sea during February-March 2013.
SC/65a/SH05 Robbins J, Zerbini AN, Gales N, Gulland FMD, Double M, Clapham PJ, Andrews-Goff V, Kennedy AS, Landry S, Mattila DK and Tackaberry J (2013) Satellite tag effectiveness and impacts on large whales: preliminary results of a case study with Gulf of Maine humpback whales.
SC/65b/SH12 Bell (2014) Annual report of the Southern Ocean Research Partnership (IWC-SORP) 2013/14.
SC/65b/SH17 Bravington MV, Jarman S, Skaug H (2014) Antarctic Blue Whale surveys: augmenting via genetics for close-kin and ordinal age.
SC/65b/Forinfo15 Double MC, Andrews-Goff V, Jenner CS, Jenner M-N, Laverick SM, Branch TA, Gales NJ. (2014) Migratory Movements of Pygmy Blue Whales (*Balaenoptera musculus brevicauda*) between Australia and Indonesia as Revealed by Satellite Telemetry. PLoS One10.1371/journal.pone.0093578
SC/65b/IA16 Feindt-Herr H, Kelly N, Kock K-H, Viquerat S, Scheidat M, Williams R, Lehnert LS, Siebert U (2014) German helicopter surveys provide insights in temporal and spatial variability of minke whale densities in ice.
SC/65b/SH01 Findlay K, Thornton M, Shabangu F, Venter K, Thompson I, Fabriciussen O (2014) Report of the 2013/14 South African Antarctic blue whale survey, 000° - 020°E.
SC/65b/Forinfo12 Friedlaender AS, Tyson RB, Stimpert AK, Read AG, Nowacek DP (2013) Extreme diel variation in the feeding behaviour of humpback whales along the Western Antarctic Peninsula in autumn. Marine Ecology Progress Series 494: 281-289.
SC/65b/Forinfo51 Friedlaender AS et al. *In press*. First records of feeding behaviour and diving kinematics of Antarctic minke whales, the smallest baleen whale. Journal of Experimental Biology.
SC/65b/SH05 Garrigue C, Peltier H, Chambellant M, Dodemont R, Perard V, Ridoux V, Charrassin J-B (2014) An update of the CETA project: cetacean observation program in East Antarctica 2010-2014.
SC/65b/IA15 Kelly N, Peel D, Bravington MV (2014) Distribution and abundance of Antarctic minke whales in sea ice regions of East Antarctica: a summary of results.
SC/65b/SH13 Kelly N, Bravington MV, Peel D (2014) Precision of a future mark-recapture study of Antarctic blue whales.
SC/65b/Forinfo26 Miller BS, Collins K, Barlow J, Calderan S, Leaper R, McDonald M, Ensor P, *et al.* (2014) Blue whale vocalizations recorded around New Zealand: 1964–2013. Journal of the Acoustical Society of America 135: 1616–1623.
SC/65b/Forinfo07 Miller BS, Leaper R, Calderan S, Gedamke J (*In review*) Red shift, blue shift: Doppler shifts and seasonal variation in the tonality of Antarctic blue whale song. PLoS One.
SC/65b/SH08 Miller BS, Gedamke J, Calderan S, Collins K, Johnson C, Miller E, Samaran F, Smith J, Double MC (2014) Accuracy and precision of DIFAR sonobuoys for acoustic localisation: Calibration and comparative measurements from three SORP voyages.
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SC/65b/SH14 Peel D, Bravington MV, Kelly N, Double MC (2014) Exploration of a future mark-recapture study of Antarctic Blue Whales.
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